# The Ocean Cleanup
# Final S03 Environmental Impact Assessment

August 2023


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**THE OCEAN CLEANUP**
**FINAL S03 ENVIRONMENTAL IMPACT ASSESSMENT**

DOCUMENT NO. CSA-THEOCEANCLEANUP-FL-23-3919-CO1_003-REP-01-FIN-REV01

Suggested citation: CSA Ocean Sciences Inc. (CSA). 2023. The ocean cleanup Final S03 environmental impact assessment. Prepared for The Ocean Cleanup. 250 pp. + app.

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| Internal review process | | | | | |
|---|---|---|---|---|---|
| Version | Date | Description | Prepared by: | Reviewed by: | Approved by: |
| INT-01 | 05/11/2023 | Initial updated draft for science review | K. Olsen/ A. McMahon | R. Cady | K. Olsen |
| INT-02 | 08/09/2023 | TE review | K. Olsen | K. Gifford/ R. Cady | K. Olsen |

| Client deliverable | | | |
|---|---|---|---|
| Version | Date | Description | Project Manager Approval |
| 01 | 05/15/2023 | Client deliverable | K. Olsen |
| FIN | 08/11/2023 | Final | K. Olsen |
| FIN-REV01 | 8/25/2023 | Revised Final | K. Olsen |
| | | | |
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## BACKGROUND

The Ocean Cleanup has developed an updated Ocean Retention System (S03) to collect buoyant plastic debris from within the North Pacific Subtropical Gyre (NPSG) to expand the size of the previous System (S002) components to their full-scale design. The Ocean Cleanup slowly implemented design changes and mitigation measures during Campaigns 10 through 12, implementing Systems S002A and S002B, that were evaluated in an Environmental Impact Assessment (EIA) Addendum (**Appendix A**). Campaigns have continued in 2023 implementing System S002C as it transitions to the full-scale S03. The Ocean Cleanup is focusing on the area known as the Great Pacific Garbage Patch, located roughly midway between California and Hawaii (**Figure ES-1**) and approximately 2,250 km from The Ocean Cleanup mobilization port of Victoria, British Columbia. The S03 Retention System (RS) still comprises two tow lines, two wings with a submerged net, and a retention zone (RZ) that is towed by two vessels (**Image ES-1**). The two wings are each 1,125 m in length and are designed to guide plastics into the RZ. The wings of the RS can be adjusted for standard plastics collection operations to provide the optimum plastics collection, but the nominal operational mode is anticipated to be a span of approximately 1,460 m.

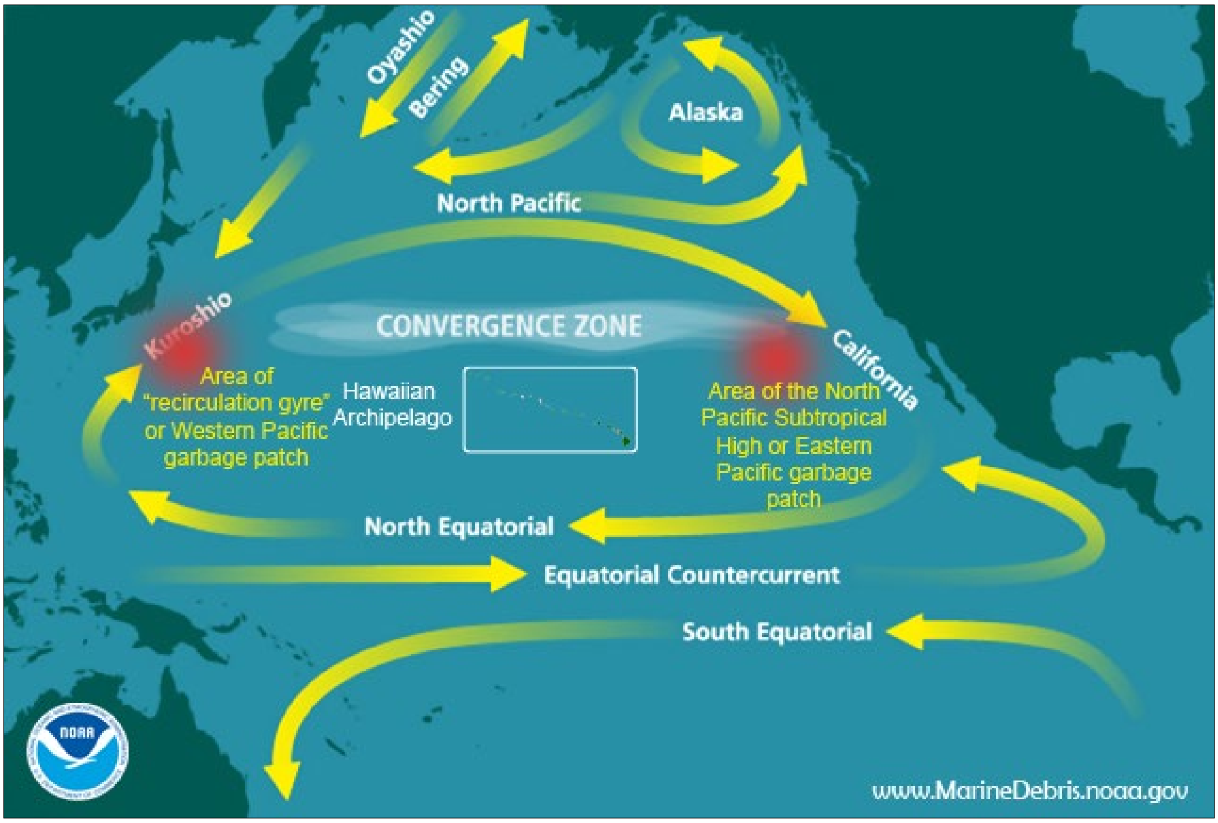


Figure ES-1. Map showing the major oceanic currents and zones in the North Pacific and the locations of Western and Eastern Pacific Garbage Patches.

Image ES-1. S03 towing lines (connected to each ship), Retention System (white wings and submerged net), and retention zone (blue and yellow net attached to the back of the Retention System).

The Ocean Cleanup has completed fifteen 6-week campaigns in the NPSG, with the S002. The Ocean Cleanup has used adaptive management to further advance the System design and operations to further reduce potential impacts to the environment. It is from this adaptive management approach and applying the data and information collected from the completed campaigns of S002 that design and operational changes were implemented to increase plastic collection and to further reduce environmental impacts in the current S03 System. These changes have been implemented in a stepwise fashion to be able to document the results of new design features and to document the effectiveness of the changes. Two initial sets of design changes were made to the S002 (i.e., larger RZ, deeper wings, longer wings) along with additional mitigation measures implemented which resulted in three System name changes, S002A, S002B, and S002C. S002A was first deployed in late August 2022, S002B was deployed in November 2022, and S002C was deployed in March 2023 as The Ocean Cleanup moves toward their full-scale System design, S03. The S03 incorporates design changes and additional mitigation measures along with some operational changes to increase efficiency and minimize impacts to marine life. For S03, most of the design components are the same as for S002 and S03 implements the design changes included in S002A (larger, 70 m RZ), S002B (deeper wings of 4 m), and S002C (longer wings and some modified mitigation measures) and continues to add wing modules to increase the wing length to a total of approximately 2,250 m (**Image ES-1**).

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## ENVIRONMENTAL IMPACT ASSESSMENT SUMMARY

This EIA evaluates the potential impacts from the single S03 in operation in the NPSG. The various components of the activities conducted by The Ocean Cleanup have been evaluated for potential impacts to the biological, physical, chemical, and social environment. A total of 17 resource areas were considered:

- Air quality
- Water quality
- Sediment quality
- Plankton
- Neuston
- Fish and fishery resources
- Benthic communities
- Marine mammals
- Sea turtles
- Coastal and oceanic birds
- Protected areas
- Biodiversity
- Archaeological resources
- Commercial and military vessels
- Human resources, land use, and economics
- Recreational resources and tourism
- Physical oceanography

A preliminary screening was conducted to identify resources at risk from the transit and deployment
A preliminary screening was conducted to identify resources at risk from the transit and deployment
of the S03 in the NPSG. In this preliminary analysis, the level of impact associated with each interaction was categorized as "potential impact for analysis" (i.e., a measurable impact to a resource is predicted) or "no impact expected" (i.e., no measurable impact to a resource is predicted). Several resources were identified as having no expected impacts from the project activities and were removed from further analysis, including air quality; water quality; sediment quality; benthic communities; archaeological resources; human resources, land use, and economics; recreational resources and tourism; and physical oceanography. The remaining resource areas were characterized based on review and summarization of pertinent data sources, including peer-reviewed literature, government publications, and applicable data sets including protected species observations and net sampling data collected during Campaigns 1 through 12.

Biodiversity was included in the screening process; however, it was determined that there is not enough information at this time to fully address biodiversity impacts from the S03; however, further discussions are ongoing about how to better address this complex topic. After the analysis of the data collected for plankton from the first three S002 campaigns and the review of potential Ecopath models (**Appendix E**), it has been determined that the potential for development of an Ecopath with Ecosim (EwE) model specific to the NPSG appears to be a viable means of assessing the potential effects of the removal of a portion of the neuston on ecosystem dynamics. A great deal of data has been obtained by The Ocean Cleanup (e.g., currents, plankton/neuston densities, water temperature, marine mammal sightings) that is being analyzed to determine how to use this data to better assess potential biodiversity impacts.

### Determination of Impact Consequence

Impact consequence and impact likelihood are two factors used to determine potential impact significance (**Figure ES-2**). Impact consequence reflects the assessment of an impact's characteristics on a specific resource (e.g., air quality and greenhouse gas contribution, benthic communities) arising from one or more impact-producing factors (IPFs). Impact consequence is determined regardless of impact likelihood. Impact consequence classifications include Positive (Beneficial), Negligible, Minor, Moderate, and Severe.

For negative impacts, where the change to the current situation of the resource is generally considered adverse or undesirable, the determination of impact consequence is based on the integration of three criteria (discussed below): intensity, extent, and duration. When appropriate, calculations were made to quantitatively characterize the intensity and extent of the impact. These calculations are explained for each of the resources concerned. Positive impacts, where the change to the current situation of the resource is generally considered better or desirable, are noted, but their consequence is not qualified.

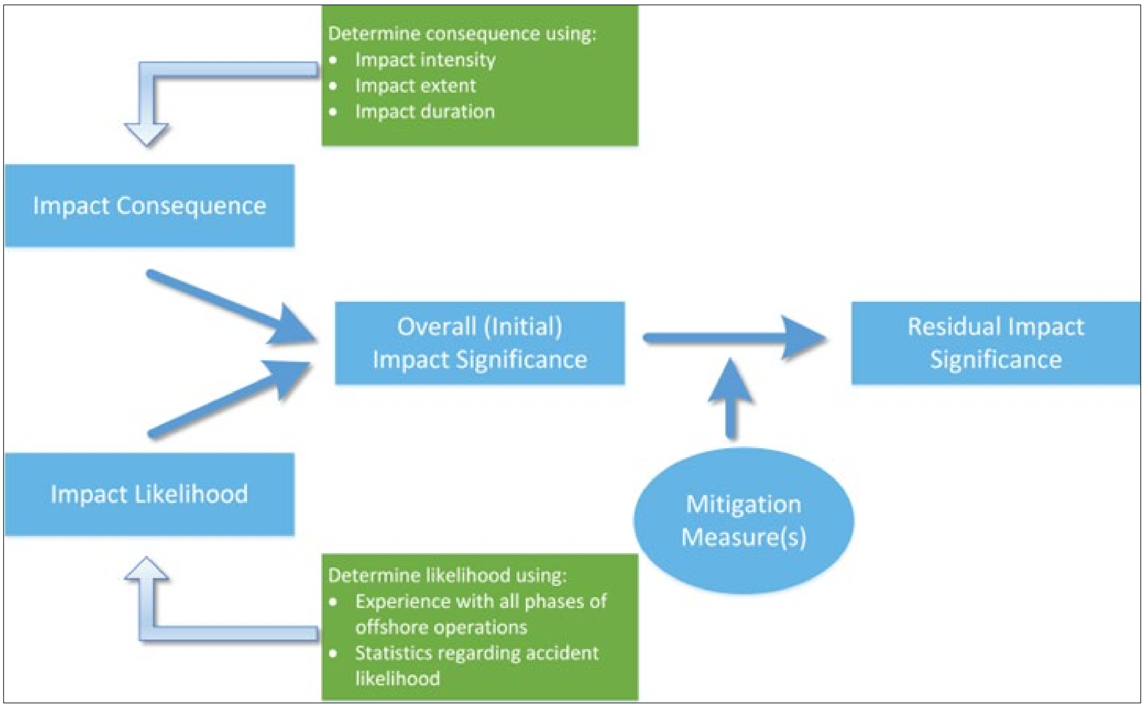


Figure ES-2. Impact assessment flow chart.

***Impact Intensity***

Impact intensity relates to the degree of disturbance associated with the impact and the alteration of the current state of the host environment. There are three levels of intensity[1]:

- **Low**: Small adverse changes unlikely to be noticed or measurable against background activities. For example, in the social environment, changes may be noticed only by a few individuals.
- **Moderate**: Adverse changes that can be monitored or noticed but are within the scope of existing variability without affecting the resource's integrity or use in the environment. For example, in the social environment, an adverse change that affects several people but not the entire community.
- **High**: For the physical environment, extensive or frequent violation of applicable air or water quality standards/guidelines, or widespread contamination of sediments with hydrocarbons, toxic metals, or other toxic substances. For the biological environment, extensive damage to habitats to the extent that ecosystem functions and ecological relationships would be altered, or numerous mortalities or injuries of a protected species or continual disruption of their critical activities. For the social environment, extensive adverse change that is far-reaching and widely recognized; it significantly limits the use of a resource by a community or a regional population, or its functional and safe use is seriously compromised. An impact potentially resulting in the mortality of one or more community members is also considered of high intensity.

[1] The definitions presented here are general descriptions of the levels for each criterion. Not all resources have been included as examples, but specific explanations are provided in the assessment when needed.

***Impact Extent***

The geographic extent of an impact expresses how widespread the impact is expected to be. It represents the area that will be affected, directly or indirectly. Impact extent is classified by the following levels:

- **Immediate vicinity**: Limited to a confined space within the area of interest, generally within 2 km of the project activities.
- **Local**: The impact has an influence that goes beyond the area of interest but stays within a relatively small geographic area (i.e., generally 5 to 20 km from the source of impact).
- **Regional**: The impact affects a large geographical area, generally more than 20 km from the source of impact.

In general, the extent of all impacts to resources from the current The Ocean Cleanup S03 project would be limited to the immediate vicinity, except for potential behavior modifications in marine mammals due to noise, which would be local, and in neuston, which would range from local to regional.

***Impact Duration***

The duration of an impact describes the length of time over which the effects of an impact occur. It is not necessarily the same as the length of time of an activity or an IPF because an impact can sometimes continue after the source of impact has stopped or the impact can be shorter if there is an adaptation. Therefore, the impact duration can include the recovery period or the adaptation period of the affected resource. Impact duration can be:

- **Short term**: The impacts are felt continuously or discontinuously over a limited period, generally during the project period of activity, or when the recovery or adaptation period is less than a year.
- **Long term**: The impacts are felt continuously or discontinuously beyond the life of the project.

The duration for all impacts associated with The Ocean Cleanup project for this evaluation is expected to be short term, although the potential for long-term impacts for certain resources are continuing to be assessed (e.g., plankton, neuston, biodiversity).

**Table ES-1** lists the combinations of criteria used to describe impact consequence.

Table ES-1. Matrix of consequence determination for negative impacts.

| Intensity | Extent | Duration | Consequence Criteria | | | |
|---|---|---|---|---|---|---|
| | | | Negligible | Minor | Moderate | Severe |
| Low | Immediate vicinity | Short term | ● | - | - | - |
| | Local | Short term | ● | - | - | - |
| | Regional | Short term | ● | - | - | - |
| | Immediate vicinity | Long term | ● | - | - | - |
| | Local | Long term | - | ● | - | - |
| | Regional | Long term | - | ● | - | - |
| Moderate | Immediate vicinity | Short term | - | ● | - | - |
| | Local | Short term | - | ● | - | - |
| | Regional | Short term | - | ● | - | - |
| | Immediate vicinity | Long term | - | ● | - | - |
| | Local | Long term | - | - | ● | - |
| | Regional | Long term | - | - | ● | - |
| High | Immediate vicinity | Short term | - | - | ● | - |
| | Local | Short term | - | - | ● | - |
| | Regional | Short term | - | - | ● | - |
| | Immediate vicinity | Long term | - | - | ● | - |
| | Local | Long term | - | - | - | ● |
| | Regional | Long term | - | - | - | ● |

- = not applicable.

**Determination of Impact Likelihood**

The likelihood of an impact describes the probability that an impact will occur. The likelihood of impact occurrence was rated using the following categories:

- Likely (>50% likelihood)
- Occasional (10% to 49% likelihood)
- Rare (1% to 9% likelihood)
- Remote (<1% likelihood)

Impacts are evaluated or predicted prior to and following implementation of mitigation measures. Mitigation measures are identified based on industry best practice, international standards (e.g., International Convention for the Prevention of Pollution from Ships [MARPOL] requirements), or measures deemed applicable and practicable by The Ocean Cleanup. Impacts that remain after implementation of mitigation measures are described as residual impacts. To summarize the overall significance of each impact, impact consequence and likelihood were combined using professional judgment and a risk matrix (**Table ES-2**). According to this matrix, the overall impact significance for biological and social negative impacts using a numeric, descriptive, and color-coded approach is rated as follows:

- 1 – Negligible
- 2 – Low
- 3 – Medium
- 4 – High

Table ES-2. Matrix combining impact consequence and likelihood to determine overall impact significance.

<table>
<tr><th colspan="2" rowspan="2">Likelihood vs. Consequence</th><th colspan="5">← Decreasing Impact Consequence</th></tr>
<tr><th>Positive</th><th>Negligible</th><th>Minor</th><th>Moderate</th><th>Severe</th></tr>
<tr><td rowspan="4">Decreasing Impact Likelihood ↓</td><td>Likely</td><td rowspan="4">Beneficial (no numeric rating applied)</td><td>1 – Negligible</td><td>2 – Low</td><td>3 – Medium</td><td>4 – High</td></tr>
<tr><td>Occasional</td><td>1 – Negligible</td><td>2 – Low</td><td>3 – Medium</td><td>4 – High</td></tr>
<tr><td>Rare</td><td>1 – Negligible</td><td>1 – Negligible</td><td>2 – Low</td><td>4 – High</td></tr>
<tr><td>Remote</td><td>1 – Negligible</td><td>1 – Negligible</td><td>2 – Low</td><td>3 – Medium</td></tr>
</table>

Impacts from routine operations resulting from the project activities are expected to occur based on a series of IPFs, including:

- S03 – entanglement/entrapment
- S03 – attraction/ingestion of plastics
- Vessel – physical presence/strikes
- Noise and lights
- Loss of debris

Resources potentially affected by each IPF were subsequently evaluated. The impact assessment process involved 1) an initial determination of impact, without any mitigation (i.e., potential impact); 2) an identification and implementation of appropriate mitigation measures; and 3) a determination of impact after mitigation was applied (i.e., residual impact).

Impacts rated Medium or High were considered primary candidates for mitigation, while those rated Negligible or Low were of secondary importance from a mitigation perspective. In application, mitigation measures were considered for all impacts, regardless of impact level. The initial analysis of routine operations (i.e., prior to implementation of mitigation measures) produced impact determinations that were predominantly in the Negligible or Low categories, with several identified as Medium or High for plankton and neuston and Medium for fish and fisheries. A comprehensive discussion of the mitigation measures and corporate/subcontractor policies. The Ocean Cleanup will follow during project activities is presented in a separate Environmental Management Plan.

This EIA also addressed potential impacts associated with an accidental fuel spill. Impacts from an accidental fuel spill were identified based on the accidental release of diesel fuel. Diesel fuel released into the marine environment undergoes rapid weathering, including evaporation and dissolution. Given the relatively small potential spill volume and weathering factors, the impacts to various resources from a fuel spill release were routinely rated Negligible or Low. Impacts from an accidental diesel fuel spill are expected to be localized and relatively short term (due to its high volatility and dispersibility).

A tabular summary of impacts from routine operations and an accidental fuel spill is presented in **Table ES-3**. When proper mitigation measures, maritime regulations, and industry best practices are applied, the significance of potential impacts of the project activities will generally be Negligible or Low. Moreover, The Ocean Cleanup has removed approximately 214 tons (193,832 kg) of plastics during the first 12 campaigns in the NPSG, which will have long-term positive (beneficial) impacts to biological resources in the area.

Table ES-3. Summary of impacts from routine operations and an accidental fuel spill from the project activities.

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| **Long-Term Impacts** | | | | | |
| ***Plastic Removal by S03*** | | | | | |
| All Resources Except Plankton and Neuston | Reduction in entanglements, ingestion, and contamination of biological and social resources by means of plastic debris removal from the North Pacific Subtropical Gyre (NPSG) | Beneficial | Not applicable. | Not applicable | Beneficial |
| **Routine Operations** | | | | | |
| ***S03 – Entanglement/Entrapment*** | | | | | |
| Plankton/Neuston | Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Intensity: Low to Moderate<br>Extent: Local to Regional<br>Duration: Short Term<br>Consequence: Negligible to Minor<br>Likelihood: Likely<br>Significance: 1 – Negligible to<br>Significance: 2 – Low | • **Mesh size** – Use of netting with 16 mm × 16mm mesh size, when possible, to allow smaller marine animals to exit the System. | Reduces likelihood | 1 – Negligible to<br>2 – Low |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Fish and Fishery Resources | Entanglement in the S03 or accumulated debris resulting in injury or mortality | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Likely<br>Significance: 2 – Low | • **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green light-emitting diode (LED) lights on the wings and RZ to enhance detectability of the system.<br>• **Vessel operations** – Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots).<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for fish.<br>• **Visual monitoring** – Two camera skiffs each with eight underwater cameras with integrated lights installed inside the RZ for visual observation by the Environmental Observers (EOs). | Reduces intensity and likelihood | Plastics Collection 2 – Low<br><br>Plastics Extraction 1 – Negligible |
| Marine Mammals | Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Intensity: High<br>Extent: Immediate Vicinity Regional (Protected Species)<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Remote<br>Significance: 2 – Low | • **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera Systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels. | Reduces intensity and likelihood | Plastics Collection 1 – Negligible |

Table ES-3. (Continued).

<table>
<tr><th>Resource Affected</th><th>Description of Potential Impact</th><th>Impact Determination Prior to Mitigation</th><th>Mitigation Measure(s)</th><th>Component of Impact Consequence Affected by Mitigation</th><th>Residual Impact</th></tr>
<tr><td rowspan="3">Marine Mammals (cont’d)</td><td rowspan="3">Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations (cont’d)</td><td rowspan="3">Intensity: High<br>Extent: Immediate Vicinity Regional (Protected Species)<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Remote<br>Significance: 2 – Low<br>(cont’d)</td><td>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Acoustic deterrent** – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for small marine mammals.<br>• **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.</td><td>Reduces intensity and likelihood (cont’d)</td><td>Plastics Extraction<br>1 – Negligible</td></tr>
<tr><td>• **Routine debris extraction** - Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.</td><td rowspan="2">Reduces likelihood (protected species)</td><td>Plastics Collection<br>2 – Low<br>For protected species</td></tr>
<tr><td>• **Rescue of animals** – Rescue attempts of entangled marine mammals in distress are performed according to the project procedures.</td><td>Plastics Extraction<br>1 – Negligible<br>For Protected Species</td></tr>
</table>

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Sea Turtles | Entanglement or entrapment within the S03 or accumulated debris | Collection Operations<br>Intensity: High<br>Extent: Regional<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Occasional<br>Significance: 3 – Medium<br><br>Extraction Operations<br>Likelihood: Remote | • **Visual monitoring** – Monitoring during the project identifies sea turtles that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera Systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for sea turtles.<br>• **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled sea turtles may be performed according to the project procedures. | Reduces intensity | Plastics Collection<br>2 – Low |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Sea Turtles (cont'd) | Entanglement or entrapment within the S03 or accumulated debris (cont'd) | Extraction Operations<br>Likelihood: Remote (cont'd) | • **Turtle zone steering strategy** – avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region. | Reduces intensity | Plastics Extraction<br>1 – Negligible |
| Coastal and Oceanic Birds | Entanglement in the S03 or accumulated debris resulting in injury or mortality | Intensity: High<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Rare<br>Significance: 2 – Low | • **Visual monitoring** – Monitoring during the project identifies seabirds that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera Systems; and<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for diving birds.<br>• **Breathing rings/hatches** – Area of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled birds may be performed according to the project procedures. | Reduces intensity and likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| ***S03 – Attraction/Ingestion of Plastics*** | | | | | |
| Plankton/Neuston | Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Occasional<br>Significance: 1 – Negligible | • None recommended. | Not applicable | 1 – Negligible |
| Fish and Fishery Resources | Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Likely<br>Significance: 2 – Low | • **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System. | Reduces likelihood | 2 – Low |
| Marine Mammals | Attraction to the S03; Ingestion of congregated plastics resulting in injury or mortality | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera Systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Acoustic deterrent** – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System. | Reduces likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Sea Turtles | Attraction to the S03; Ingestion of congregated plastics resulting in injury or mortality | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Occasional<br>Significance: 2 – Low | • **Visual monitoring** – Monitoring during the project identifies sea turtles that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera Systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for sea turtles.<br>• **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled sea turtles are performed according to the project procedures. | Reduces likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Coastal and Oceanic Birds | Attraction to the S03; Ingestion of congregated plastics resulting in injury or mortality | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Rare<br>Significance: 1 – Negligible | • **Visual monitoring** – Monitoring during the project identifies birds that may be near the tow vessels with:<br>○ EOs; and<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled birds may be performed according to the project procedures. | Reduces intensity and likelihood | 1 – Negligible |
| ***Vessel – Physical Presence/Strikes*** | | | | | |
| Fish and Fishery Resources | Attraction to vessels and strike resulting in injury or mortality | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • None recommended. | None | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Marine Mammals | Exposure to vessel strike resulting in injury or mortality | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• Vessel operations –<br>○ Between shore and the NPSG, transit vessels travel at slow speeds (<14 knots);<br>○ Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots);<br>○ Minimal Environmental Impact Operation (MEIO) mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 1 knot, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the event of a protected species observed in the vicinity; and.<br>○ Change in vessel direction to implement vessel strike avoidance. | Reduces intensity and likelihood | 1 – Negligible |
| | | Protected Species<br>Intensity: High<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Remote<br>Significance: 2 – Low | | | Protected Species<br>1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Sea Turtles | Injury or mortality resulting from a vessel collision | Intensity: High<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Rare<br>Significance: 2 – Low | • Vessel operations –<br>○ Between shore and the NPSG, transit vessels travel at slow speeds (<14 knots);<br>○ Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots);<br>○ MEIO mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 1 knot, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the event of a protected species observed in the vicinity; and.<br>○ Change in vessel direction to implement vessel strike avoidance.<br>• **Visual monitoring** – Monitoring during the project identifies sea turtles that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observation by the EOs; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Turtle zone steering strategy** – avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region. | Reduces intensity and likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Protected Areas | Disturbance of wildlife in marine protected areas from vessel transit | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Rare<br>Significance: 1 – Negligible | • **Strategic routing** – Vessels avoid protected areas when practicable.<br>• **Vessel operations** – Vessel speeds are kept to a minimum for transit. Between shore and the NPSG, vessels travel at slow speeds (<14 knots) and obey all separation scheme restrictions. | Reduces likelihood | 1 – Negligible |
| Commercial and Military Vessels | Temporary increase of vessel traffic | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Likely<br>Significance: 1 – Negligible | • **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:<br>○ Between shore and the NPSG, transit vessels travel at slow speeds (<14 knots); and<br>○ Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots).<br>• **Monitor notifications** – Vessels monitor NOTSHIP notifications prior to and during transit from port. | Not applicable | 1 – Negligible |
| ***Noise and Lights*** | | | | | |
| Plankton/Neuston | Behavioral modifications (e.g., suppress diel migration, attraction to System) from light exposure | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Occasional<br>Significance: 1 – Negligible | • **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces likelihood | 1 – Negligible |
| Fish and Fishery Resources | Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels) | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Occasional<br>Significance: 1 – Negligible | • **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable. The sound generated by banana pingers is localized and well above the hearing ranges of fish. | Reduces intensity and likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| | Attraction to tow vessels and lights | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Likely<br>Significance: 2 – Low | • **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces likelihood | 2 – Low |
| Marine Mammals | Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels) | Intensity: Low<br>Extent: Local<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Occasional<br>Significance: 1 – Negligible | • **Elimination of unnecessary acoustic energy** – Levels of anthropogenic noise are kept as low as reasonably practicable.<br>• **Acoustic deterren**t – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System. | Reduces intensity and likelihood | 1 – Negligible |
| Sea Turtles | Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels); attraction to light | Intensity: Low<br>Extent: Local<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Occasional<br>Significance: 1 – Negligible | • **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable. Sound generated by banana pingers is localized and well above the hearing ranges of sea turtles.<br>• **Visual cues** – Use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Coastal and Oceanic Birds | Behavioral modifications (e.g., disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels) | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Occasional<br>Significance: 1 – Negligible | • **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable. | Reduces intensity and likelihood | 1 – Negligible |
| Coastal and Oceanic Birds (cont'd) | Injury or mortality resulting from a collision with a vessel due to attraction to lights | Intensity: High<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Moderate<br>Likelihood: Rare<br>Significance: 2 – Low | • **Limit lighting** – Light level on board the vessels is kept as low as reasonably practicable to maintain a safe work environment at night, and the number of lights is limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces intensity and likelihood | 1 – Negligible |
| ***Accidental Events*** | | | | | |
| ***Loss of Debris*** | | | | | |
| Marine Mammals | Entanglement with or ingestion of debris accidentally lost | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Pollution prevention** – Compliance with International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence. | No change | 1 – Negligible |
| Sea Turtles | Entanglement with or ingestion of debris accidentally lost | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Pollution prevention** – Compliance MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence. | No change | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Coastal and Oceanic Birds | Entanglement with or ingestion of debris accidentally lost | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Pollution prevention** – Compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence. | No change | 1 – Negligible |
| ***Accidental Fuel Spill*** | | | | | |
| Plankton/Neuston | Diesel fuel exposure, including ingestion | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – A SOPEP is in place on towing, monitoring, and debris collection vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.<br>• **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses are equipped with dry-break couplings. Any re-fueling required is only undertaken in safe working weather conditions and good lighting.<br>• **No re-fueling at sea** – No re-fueling occurs at sea.<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces likelihood | 1 – Negligible |

Table ES-3. (Continued).

| Resource Affected | Description of Potential Impact | Impact Determination Prior to Mitigation | Mitigation Measure(s) | Component of Impact Consequence Affected by Mitigation | Residual Impact |
|---|---|---|---|---|---|
| Fish and Fishery Resources | Diesel fuel exposure, including ingestion | Intensity: Low<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Negligible<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Same as above** – SOPEP, spill equipment on board, fuel transfer protocols, no re-fueling at sea, and reporting procedures. | Reduces likelihood | 1 – Negligible |
| Marine Mammals | Diesel fuel exposure, including inhalation of vapors, ingestion, fouling of baleen | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Same as above** – SOPEP, spill equipment on board, fuel transfer protocols, no re-fueling at sea, and reporting procedures. | Reduces likelihood | 1 – Negligible |
| Sea Turtles | Diesel fuel exposure, including inhalation of vapors and ingestion | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Same as above** – SOPEP, spill equipment on board, fuel transfer protocols, no re-fueling at sea, and reporting procedures. | Reduces likelihood | 1 – Negligible |
| Coastal and Oceanic Birds | Diesel fuel exposure, including inhalation of vapors, ingestion, and fouling of plumage | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Same as above** – SOPEP, spill equipment on board, fuel transfer protocols, no re-fueling at sea, and reporting procedures. | Reduces likelihood | 1 – Negligible |
| Protected Areas | Diesel fuel exposure, fouling of habitat | Intensity: Moderate<br>Extent: Immediate Vicinity<br>Duration: Short Term<br>Consequence: Minor<br>Likelihood: Remote<br>Significance: 1 – Negligible | • **Same as above** – SOPEP, spill equipment on board, fuel transfer protocols, no re-fueling at sea, and reporting procedures. | Reduces likelihood | 1 – Negligible |

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# Acronyms and Abbreviations

| | |
|---|---|
| µPa | micropascal |
| ABNJ | area beyond national jurisdiction |
| CCS | California Current System |
| CEPA | Canadian Environmental Protection Act |
| $CO_2$ | carbon dioxide |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| CSA | CSA Ocean Sciences Inc. |
| dB | decibels |
| eDNA | environmental deoxyribonucleic acid |
| EEZ | exclusive economic zone |
| EIA | Environmental Impact Assessment |
| EMP | Environmental Management Plan |
| EOs | Environmental Observers |
| EwE | Ecopath with Ecosim |
| FAD | fish aggregating device |
| FRC | fast rescue craft |
| GPGP | Great Pacific Garbage Patch |
| GPS | global positioning system |
| HDPE | high-density polyethylene |
| IGC | intergovernmental conference |
| IPF | impact-producing factor |
| IUCN | International Union for Conservation of Nature |
| LED | light-emitting diode |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| MEIO | Minimal Environmental Impact Operation |
| MPA | marine protected area |
| NEBA | net environmental benefit analysis |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NOTSHIP | Notice to Shipping |
| NPP | net primary production |
| NPSG | North Pacific Subtropical Gyre |
| PM | particulate matter |
| PTS | permanent threshold shift |
| RES | Retention Extraction Section |
| RO | Retention Opening |
| RS | Retention System |
| RSS | Retention Safe Section |
| RZ | retention zone |
| SARA | Species at Risk Act |
| SOPEP | Shipboard Oil Pollution Emergency Plan |
| SPL | root-mean-square sound pressure level |
| TTS | temporary threshold shift |
| U.S. | United States |
| UNCLOS | United Nations Convention on the Law of the Sea |

# 1 Introduction

The Ocean Cleanup has developed an updated Ocean System (S03) to collect buoyant plastic debris from within the North Pacific Subtropical Gyre (NPSG) to expand the size of the previous System (S002) components to their full-scale design. The Ocean Cleanup slowly implemented design changes and mitigation measures during Campaigns 10 through 12, implementing Systems S002A and S002B, that were evaluated in an environmental impact assessment (EIA) Addendum (**Appendix A**). There are multiple areas where debris accumulates in the ocean, and The Ocean Cleanup is focusing on the area known as the Great Pacific Garbage Patch (GPGP), which is located roughly midway between California and Hawaii and approximately 2,250 km from The Ocean Cleanup mobilization port of Victoria, British Columbia (**Figures 1-1** and **1-2**).

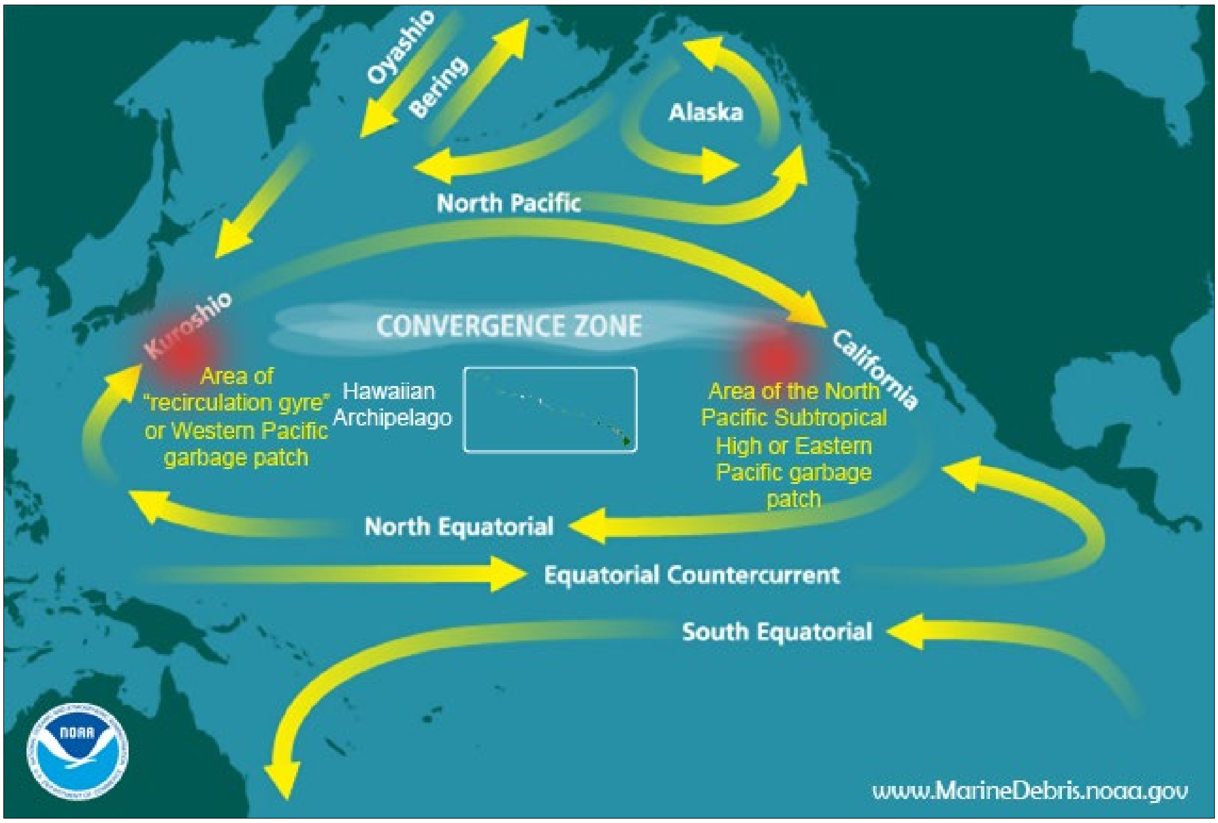



Figure 1-1. Map showing the major oceanic currents and zones in the North Pacific and the locations of Western and Eastern Pacific Garbage Patches (NOAA, 2017a).

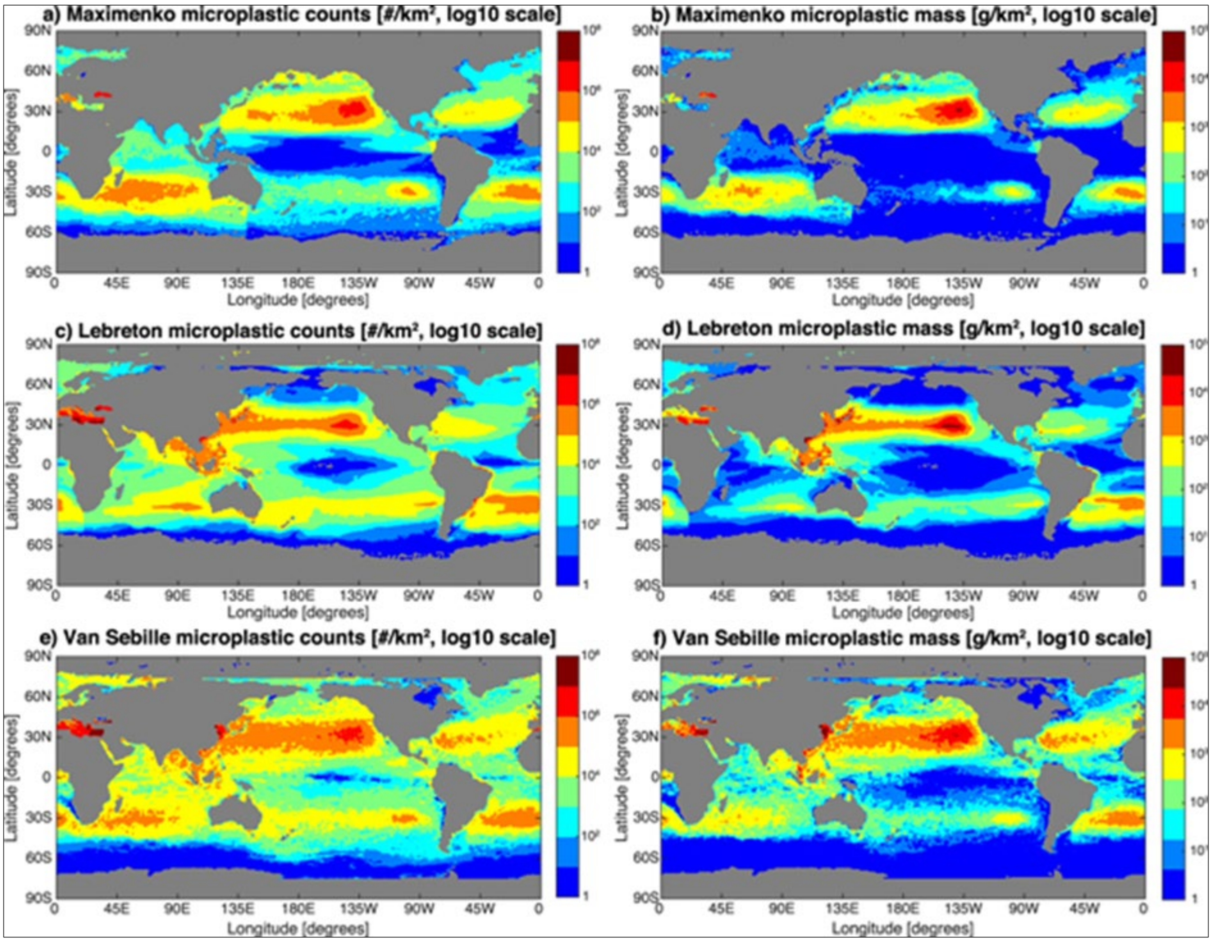



Figure 1-2. Results of computer modeling showing estimated density of microplastic contamination in the ocean (From: van Sebille et al., 2015).

The Ocean Cleanup has completed twelve 6-week campaigns in the NPSG that tested the S002 for proof of concept, evaluated the effectiveness of the mitigation measures implemented, and collected additional environmental data to characterize the baseline environment in the NPSG. Data, both operational and environmental, collected during the S002 campaigns provided valuable information for design and operational changes to increase plastic collection efficiency, increase effectiveness of the mitigation measures as well as provide additional baseline information for better characterization of the existing environment. This EIA presents the existing environmental conditions of the area that could be impacted by the project activities, including transiting from Victoria Harbour, British Columbia to the NPSG, followed by operations within the NPSG, and returning to Victoria Harbour, British Columbia for offloading. This EIA includes data and information collected from the first 12 campaigns. This EIA provides a description of the deployment and operational scenarios within the NPSG and an assessment of potential environmental impacts that may result from operations, together with the implemented actions to manage, mitigate, and monitor those impacts. This EIA is organized as follows:

- The **Executive Summary** is a condensed, non-technical summary of the project that briefly describes the background, purpose and need, resources at risk, impact methodology, and mitigation measures.
- **Chapter 1**, **Introduction**, briefly presents the project and discusses the purpose, scope, and organization of this EIA.

- **Chapter 2**, **Project Description**, provides a detailed narrative of the project activities, including mitigation measures implemented, location and schedule, vessels and equipment, waste and emissions that may be associated with the project, and alternatives to the project. Planned activities that may affect the environment are described in sufficient detail to support impact assessment.
- **Chapter 3**, **Legislative and Regulatory Environment**, identifies and describes the national and international laws, regulations, guidelines, protocols, and standards that were considered potentially applicable to the project. This chapter also summarizes specific permitting requirements that were considered in relation to the project.
- **Chapter 4**, **Description of Existing Environment**, characterizes the conditions of the project area environment in terms of the physical, chemical, and biological components and includes data collected during Campaigns 1 through 12. This chapter presents key information needed to understand the environmental setting, identify valued ecosystem components, and assess impacts. This chapter also provides a preliminary screening of resources to eliminate those with little or no potential for adverse or significant impact from the detailed analysis.
- **Chapter 5**, **Potential Environmental Impacts**, identifies and assesses the potential environmental impacts from this project, both beneficial and negative and includes data collected during Campaigns 1 through 12, as applicable. The chapter includes the basis for impact designation, impacts from routine operations, and impacts from potential accidents or upsets. Cumulative impacts are also discussed.
- **Chapter 6, Conclusions**, summarizes the findings of this EIA.
- The **Literature Cited**, lists all published and unpublished data sources referenced in this EIA.
- The **Appendices** present technical data used in support of this EIA.

## 1.1 PURPOSE AND NEED

Considering international law and in order to further fulfil its duty of care under the Agreement with the Dutch State (please refer to **Chapter 3.0**) as well as the Marine Biodiversity of Areas Beyond National Jurisdiction Treaty, The Ocean Cleanup has chosen to conduct an EIA to properly assess potential impacts and to ensure mitigation measures could be implemented to reduce or eliminate any substantial impacts. In the absence of specific regulatory requirements, this EIA was created to meet the 1999 International Association for Impact Assessment Principles of Environmental Impact Assessment Best Practices (IAIA, 1999) and has taken the draft text of the upcoming Marine Biodiversity of Areas Beyond National Jurisdiction Treaty into account.

# 2 Project Description

## 2.1 PROJECT HISTORY AND OVERVIEW

In 2018 and 2019, The Ocean Cleanup built and tested two passive drifting Systems (S001 and S001/B) that collected floating plastics in the top 3 m of the ocean surface. The S001 comprised a 600-m, U-shaped floating barrier with an attached screen. It was designed to be a passively drifting System driven by surface currents and wind; no engines or other propulsion Systems were present. The S001/B was very similar but smaller (140-m, U-shaped barrier) and featured the possibility to modify the System by adding a drift anchor or wind-capturing floating modules, in addition to having a fully detachable screen and plastic retention zone (RZ). The S001 and S001/B were mobilized out of California and British Columbia, respectively, for their sea trials. While the S001 and S001/B confirmed the concept's ability to concentrate and collect plastic debris, the S002 was created to incorporate the information obtained from the previous deployments and designs to improve upon the existing design. A small-scale prototype of the S002 was first tested in the North Sea in 2020.

After the initial test, the S002 (**Image 2-1, Section 2.1.1.1**) was first deployed in summer 2021 and continued throughout 2022 with some additional design modifications made throughout the 12 campaigns. The Ocean Cleanup used adaptive management to further advance the System design and operations to further reduce potential impacts to the environment. For example, based on field data, the original S002 retention zone was modified to add in an 8 m extension section to increase the distance between the camera skiff and the stern roller, avoiding potential damage to the camera skiff. It is from this adaptive management approach and application of the data and information collected from the completed campaigns of S002 that design and operational changes were implemented to increase plastic collection efficiency and to further reduce impacts to the environment in the current S03 System. These changes have been implemented in a stepwise fashion to be able to document the results of new design features and the effectiveness of the changes. Two initial sets of design changes were made to the S002 (i.e., larger RZ, deeper wings) along with additional mitigation measures implemented which resulted in three System name changes, S002A, S002B, and S002C (**Sections 2.1.1.2** through **2.1.1.4**). S002A was first deployed in late August 2022 and S002B was deployed in November 2022, and S002C was deployed in March 2023 as The Ocean Cleanup moved toward their full-scale System design, S03.

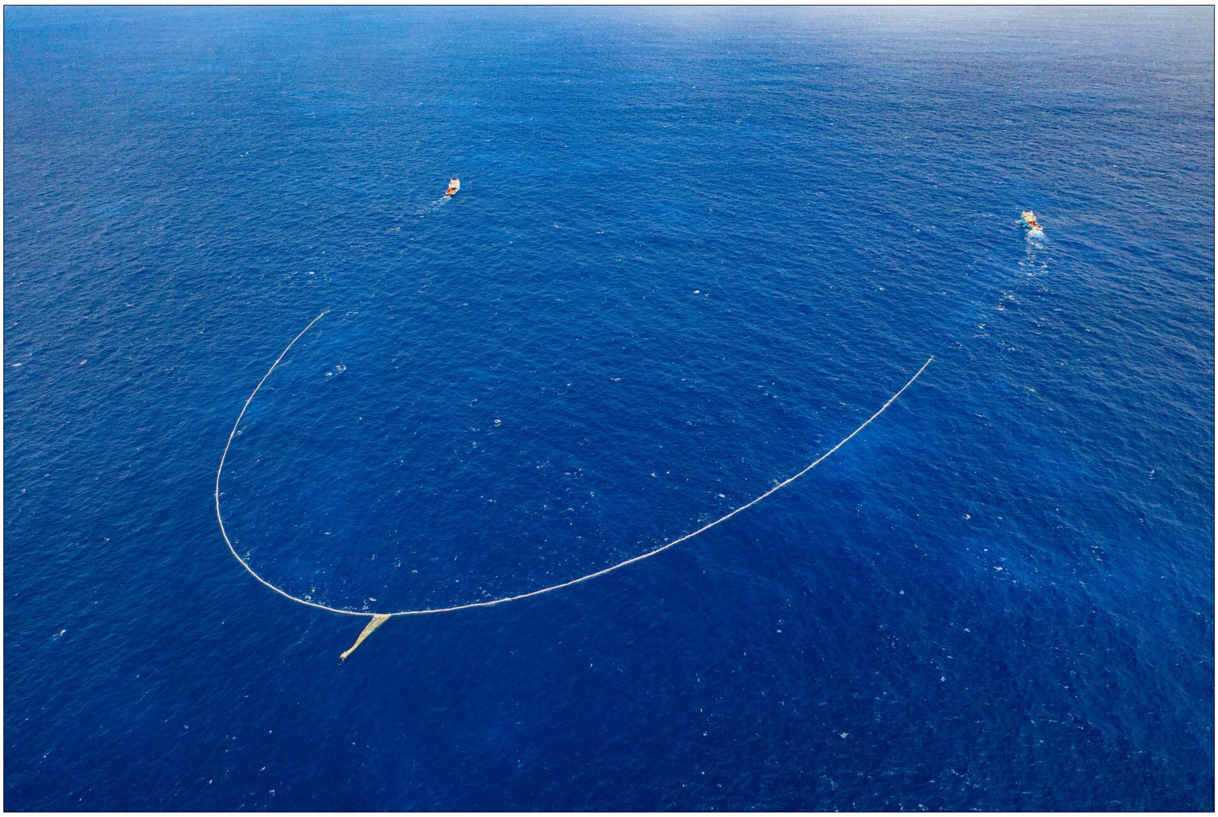


Image 2-1. S002 Retention System towing lines (connected to each ship), wings with submerged net), and retention zone (net attached to the back of the Retention System) (Image Credit: Toby Harriman).

### 2.1.1 The Ocean Cleanup System Designs

Below is a discussion of the S002 original design and the adaptive management and design modifications made in subsequent designs. However, many of the design and operational features of the S002 remain in the subsequent designs and operations. Only the differences are highlighted for each subsequent System design.

#### *2.1.1.1 System S002*

The Ocean Cleanup developed the S002 Retention System (RS) comprising towing lines, wings with submerged net, and RZ that are towed by two vessels (**Image 2-1**). The two wings were each 391 m in length. The wings of the RS span could be adjusted depending on the intended operation mode:

- **Gathering mode** allowed for a maximum span of 700 m to capture plastic between the wings and transport it along the wings to the RZ;
- **Nominal mode** had a span of 520 m, which is the standard operational mode and has the optimum factor of span to length; and
- **Minimum capturing mode** had a span of 195 m for vessel safety.

During operations, The Ocean Cleanup adjusts the span distance to allow for large quantities of plastics to travel to the RZ. The RS wings were designed to gather and guide plastics into the RZ (**Image 2-2**), minimize underflow, minimize overtopping, minimize bycatch, and limit drag. The wing design parameters are detailed in **Table 2-1**. The wings have a modular design, allowing them to fit onto one T-class vessel deck (the modules fit into 40-ft containers), and can be easily connected to the tow rigging. Each wing module was 23 m long, and 17 modules composed one wing.

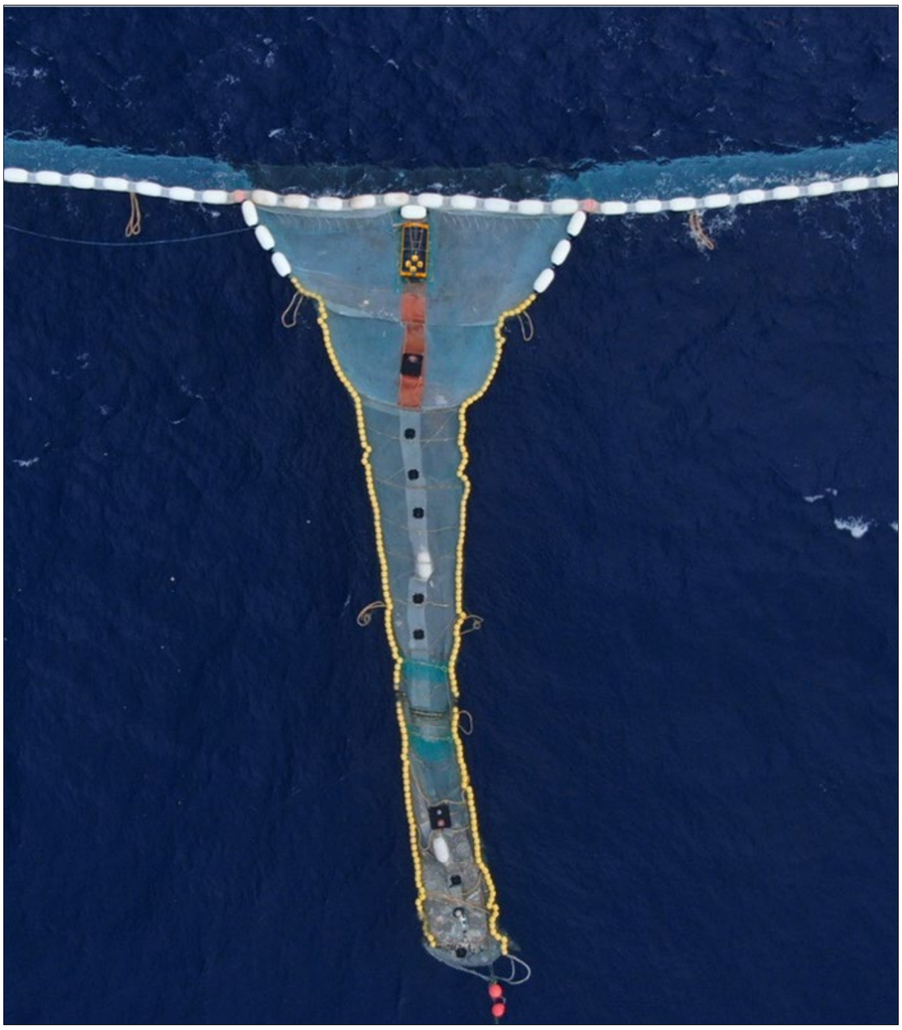


Image 2-2. S002 retention zone close-up.

Table 2-1. S002 Retention System wing design parameters.

| Defined Parameters | Inputs |
|---|---|
| Wing length | 391 m (per wing) |
| Wing depth | 3 m constant |
| Wing height above water | 0.4 m |
| Wing module length | 23 m (17 modules per wing) |
| Net mesh size | 10 mm (square) |
| Wing top section | Permeable screen |

The wings are comprised of a float line, ballast line, and screen attached between the float and ballast lines (**Figure 2-1**). The float line consists of heavy-duty inflatable fenders with a permeable cover at a height of 0.4 m above the water surface. Although the float line has a survivability of 5 years, its modular design means it can be replaced offshore in case of damage and can be easily stacked for storage in containers and on deck. The 10-mm × 10-mm Dyneema® netting composing the wings sits at a constant 3 m deep. The ballast line consists of chain wrapped in a fire hose and weighs 6 kg $m^{-1}$. It is used to keep the wings straight and reduce drag resistance. Like the float lines, the ballast lines are modular in design and can be replaced, modified, and removed, if needed.

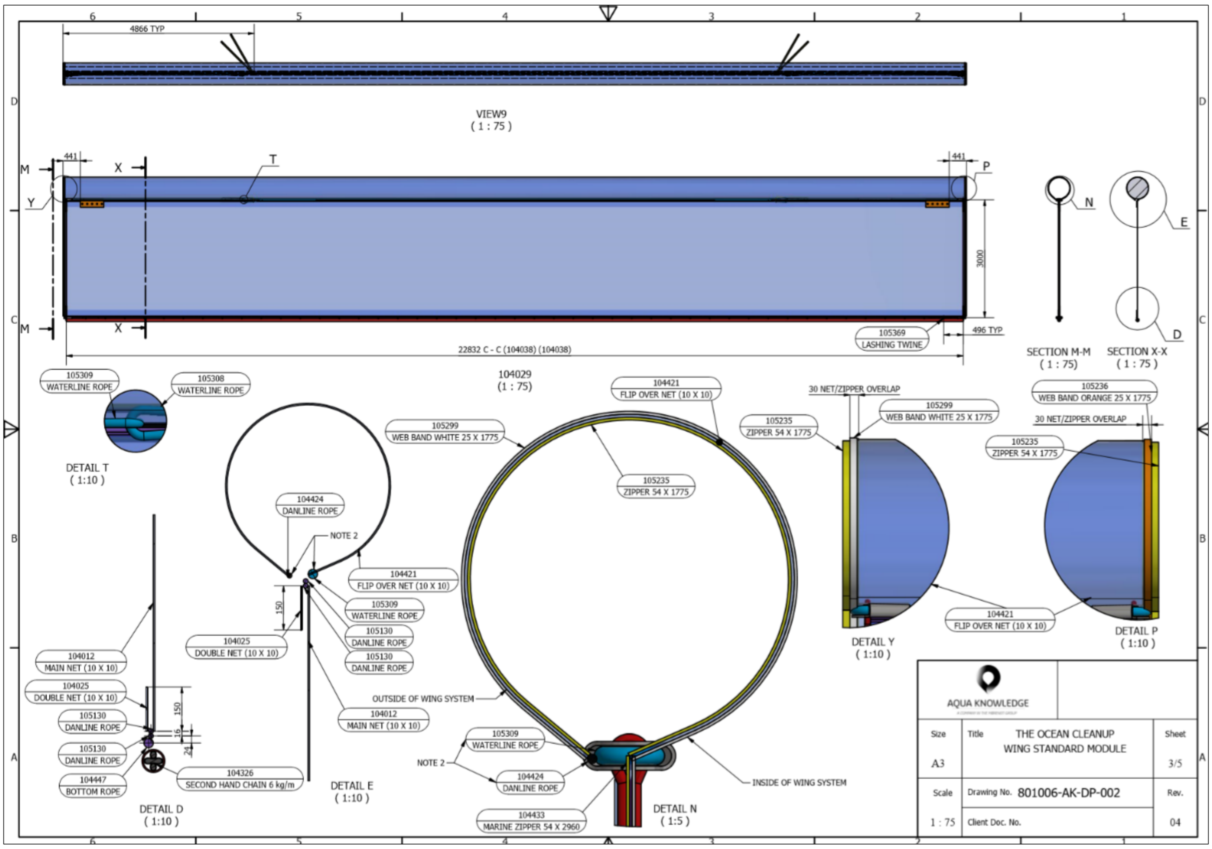



Figure 2-1. Wings and float line design.

The wing to RZ connection is a smooth transition, limiting plastic overtopping, underflowing, and from being pushed away. The connection is deployable via the vessel roller and is easily connected/disconnected on board the vessel. The assembled S002 is concave in shape, which is maintained with towing lines 500 m in length (**Image 2-1**). The wings are easily connected to tow rigging. The RS design allows for the integration of several design mitigation measures, global positioning system (GPS) trackers, motion reference units, lanterns, banana pingers (1 at the entrance of the RZ and 3 on each wing), and green light-emitting diode (LED) lights placed along the wings and at the entrance of the RZ. The banana pingers use randomized pings with harmonics to prevent habituation that operate between frequencies of 50 and 120 kHz at a sound level of 145 decibels (dB) ± 3 dB referenced to (re) 1 micropascal (µPa) m.

Located equidistant between the wings (at the back end of the RS) was a 39-m long, 5-m wide, and 2- to 3-m deep RZ where all captured plastics were collected and retained. The RZ design allowed for easy and rapid extraction of plastics on board a T-class vessel. The RZ modules are also made to be easily assembled on board the vessel. The RZ is made of a double layer of netting; the inner layer is a 5-mm × 5-mm Dyneema® netting, and the outer layer is a 50-mm × 50-mm layer of high-density polyethylene (HDPE) netting (**Image 2-3**). Only the bottom of the RZ entrance is composed of a single layer of 50-mm × 50-mm HDPE netting (**Image 2-3**).

The RZ is composed of three different areas: entrance, safe section, and extraction section (**Figures 2-2** and **2-3**). To minimize plastic debris overtopping the RZ, the entrance is initial height of 0.5 m above the water, which reduces to 0.2 m along the RZ sides. Due to its own weight, the top netting floats at the water surface for remaining portions of the RZ. In three locations (one for each section of the RZ) along the center line, the netting is raised 0.5 m from the water surface by using 1.5-m × 0.5-m heavy-duty floaters. This feature was added to the design to allow marine life to breathe in case of accidental entrapment. The safe section has an additional mitigation feature; as soon as the bottom of the RZ entrance terminates, a “fyke opening” was present. This opening was 0.4 m deep and 5 m wide and had no netting at the front, allowing a possible escape route for bigger animals. The entrance and safe section had a minimum length of 25 m necessary to prevent plastic from exiting the RZ in the case of no speed or during an extraction operation. The extraction section was 103.3 $m^3$ in volume and approximately 14 m long and 5 m wide for a 2-m deep RZ (**Figure 2-4**).

The extraction section was designed to allow for extraction of plastics up to every 2 weeks and could support a weight of 12.4 T of plastics (dry). The extraction section length could be increased in 8-m increments (one unit) to a maximum total RZ length of 48 m, which increased the maximum collectable volume to 183 $m^3$ (664.6 T). After the first several Campaigns, an additional 8-m extraction net extension was added to the RZ to increase the distance between the camera skiff and the stern roller, avoiding potential damage to the camera skiff (**Figure 2-5**). This net extension had several different configurations as adaptive management was applied. The first configuration was an additional 8-m continuous net, the second configuration included an additional fyke opening, and the final configuration has replaced the fyke opening with a bottom hole that is 3 m in length to facilitate animal escape.

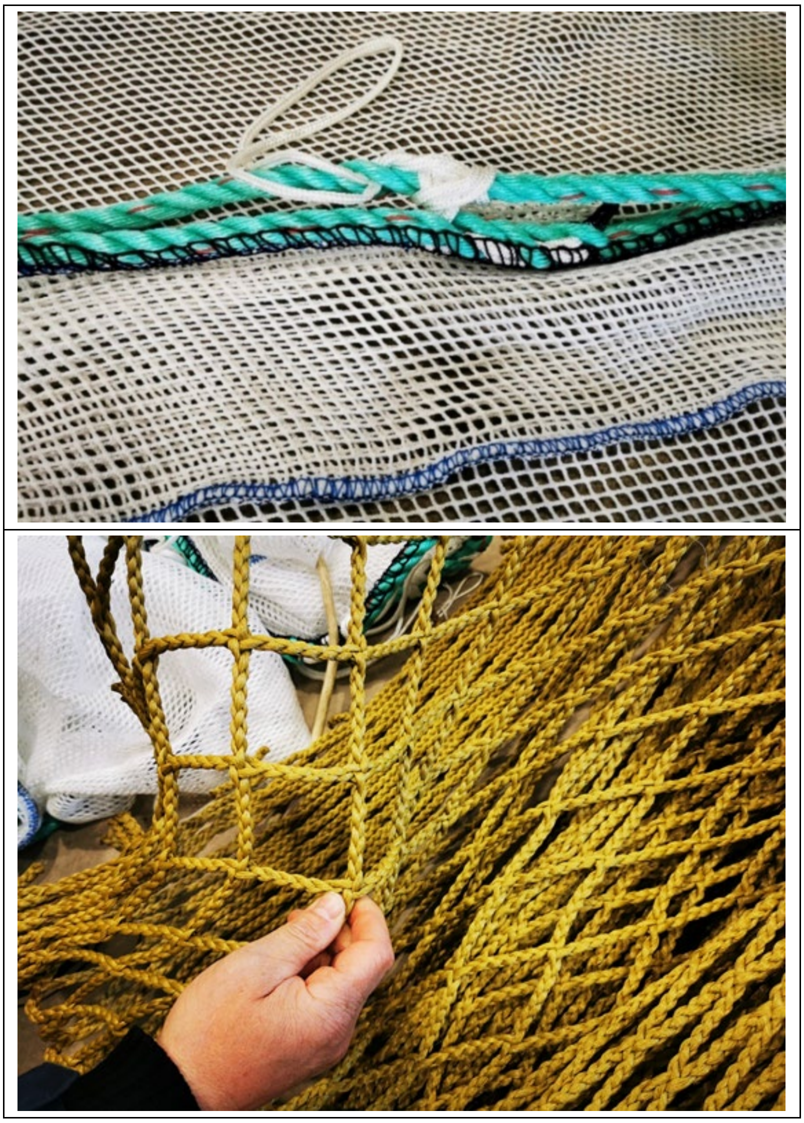


Image 2-3. Top: Retention System netting (5 mm × 5 mm); Bottom: retention zone entrance bottom netting with increased mesh size (50 mm × 50 mm).

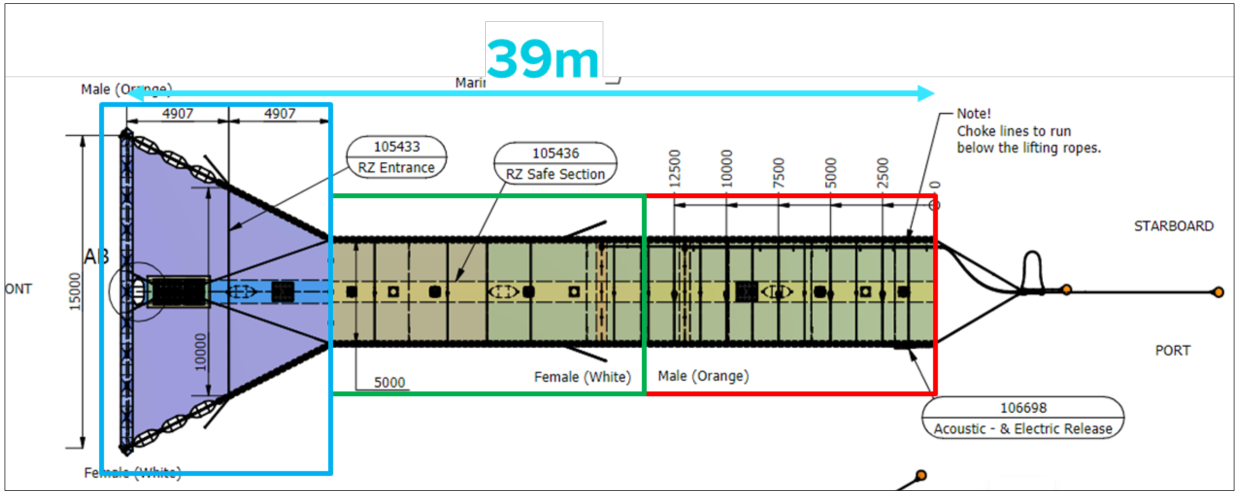



Figure 2-2. S002 retention zone (RZ) and respective sections. Blue outline area is the entrance, green outlined area is the safe section, and red outlined area is the extraction section.

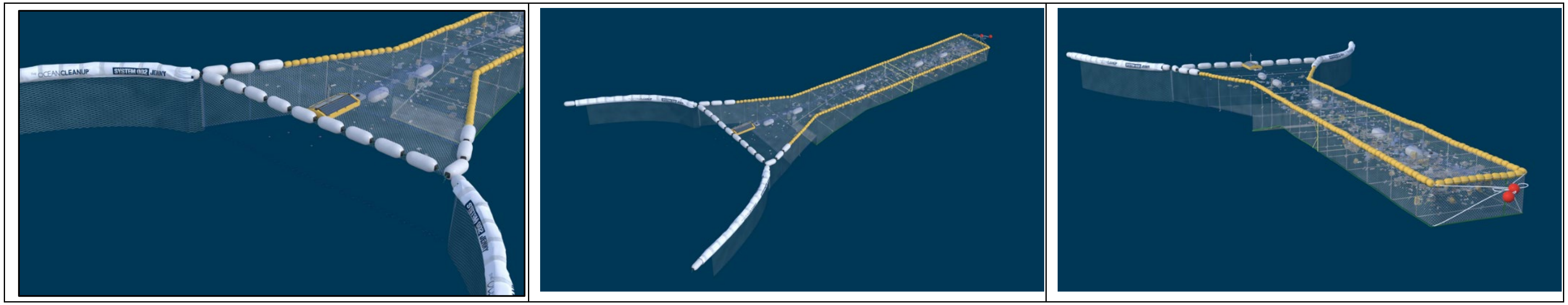


Figure 2-3. Rendering illustrating the details of the three areas of the retention zone.

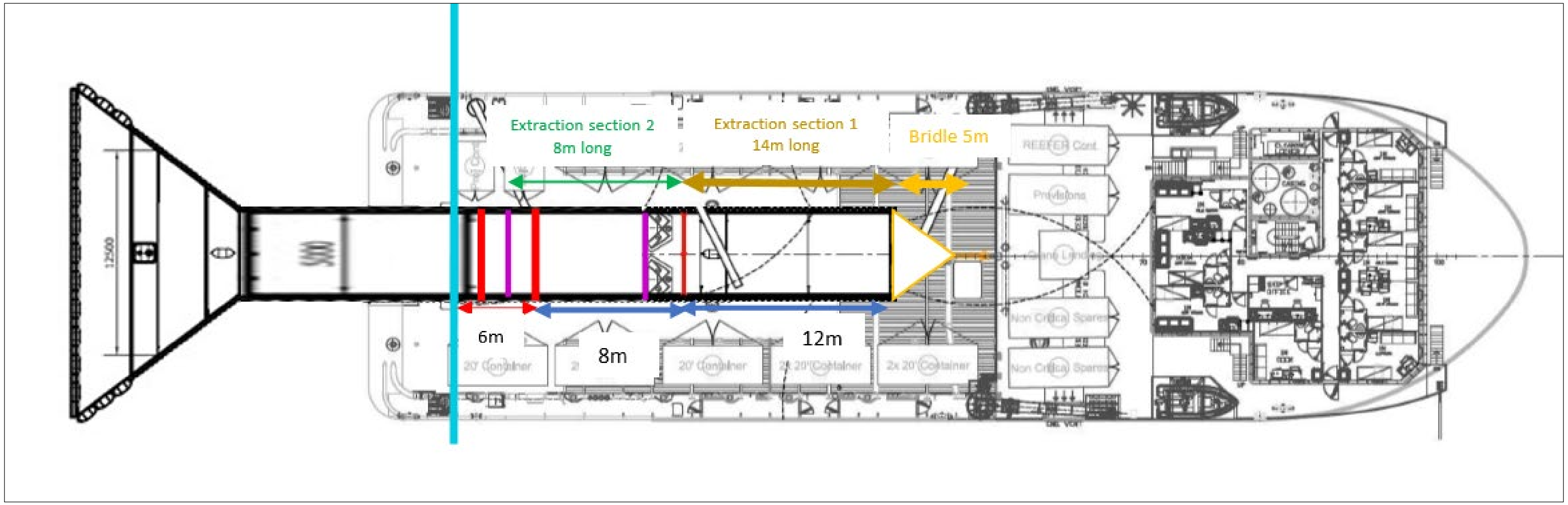



Figure 2-4. Schematic of the retention zone extraction section on vessel deck.

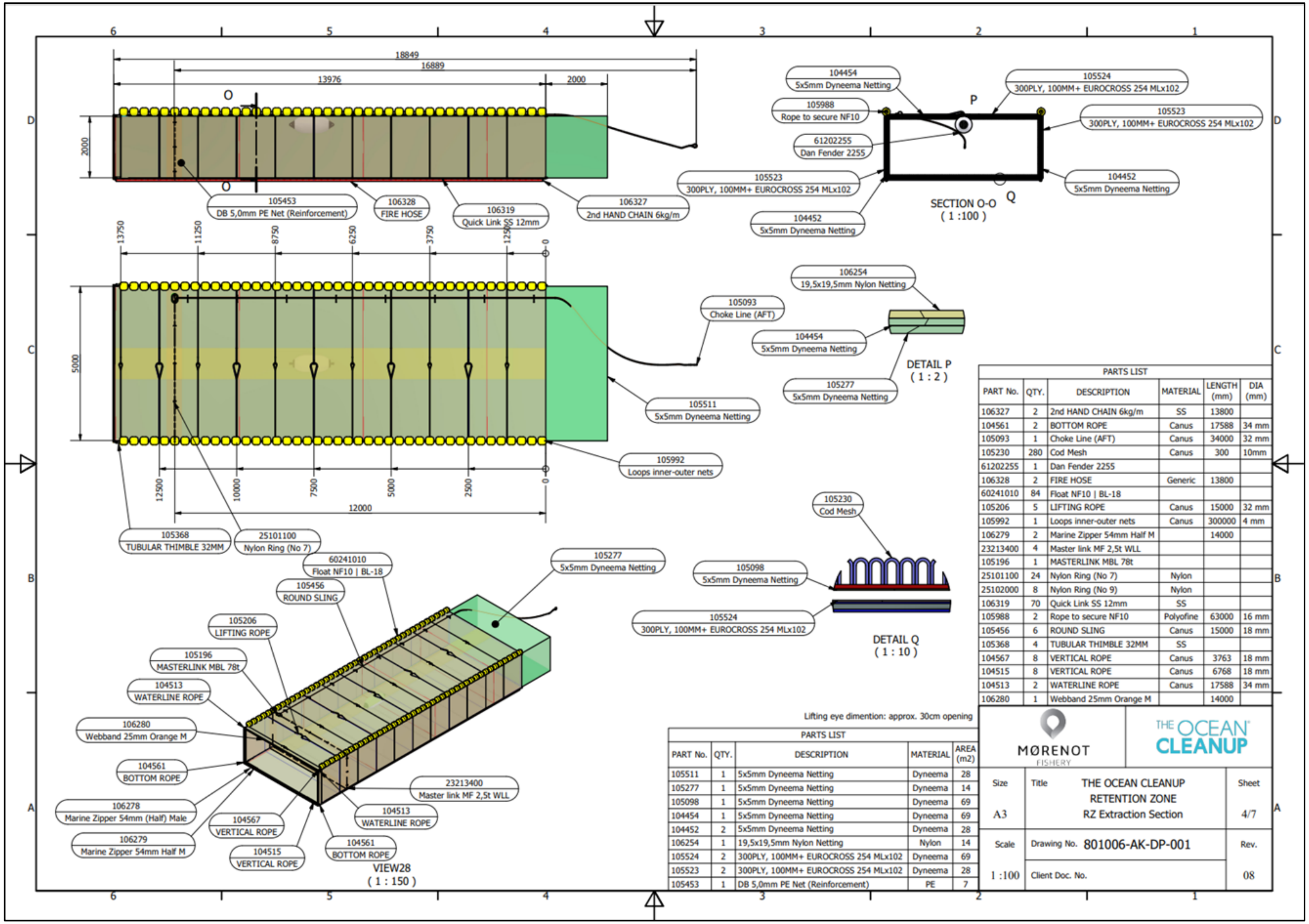


Figure 2-5.	S002 retention zone extension details.

A self-floating unit called a camera skiff (**Image 2-4**), developed specifically for the S002 project by Seiche Ltd., was mounted on top of the RZ entrance. This unit was solar powered (four 100 W solar panels), included a battery pack (four 90Ah lithium-ion batteries), had an integrated power management system, and was connected via WiFi to the vessel's monitoring station. In addition, the camera skiff had an Automatic Identification System AtoN transceiver and Echomax active radar reflector, plus a navigational light (**Figure 2-6**). The camera skiff powered and live-streamed footage from two above-water cameras mounted on the camera skiff unit itself (one forward-facing and one backward-facing) and three underwater cameras mounted inside the RZ (one forward-facing and two backward-facing) with lights. Based on recommendations by the Environmental Observers (EOs) monitoring the cameras on board the vessels during Campaigns 1 through 3, the camera configuration was modified to four underwater cameras (two forward- facing and two aft-facing) (**Image 2-5**) and has been functioning in that configuration on all subsequent campaigns. There are three LED lights also present; these lights are dimmable and can be operated by personnel from the control base station on the vessel. The camera skiff system was developed to allow constant monitoring from the vessel bridge outside and inside of the RZ and during nighttime and low-visibility conditions. Special focus for the cameras is on the marine life escape aids in the RZ entrance and safe section, as well as the areas where plastic accumulates, and where marine life may possibly be located if entrapped in the System.

Image 2-4. Camera skiff unit mounted on top of the S002 retention zone entrance.

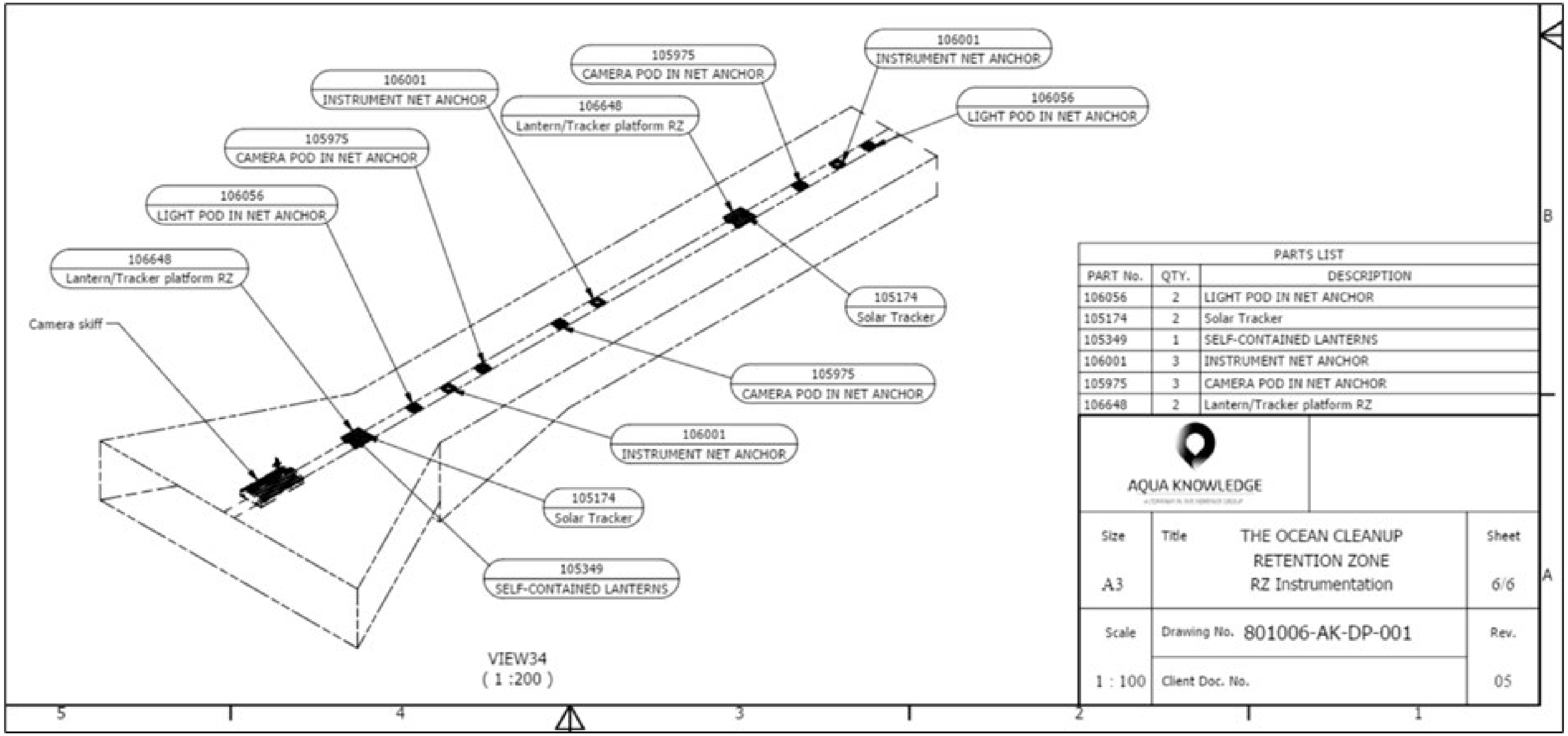



Figure 2-6. Schematic detailing the position of S002 retention zone instrumentation.

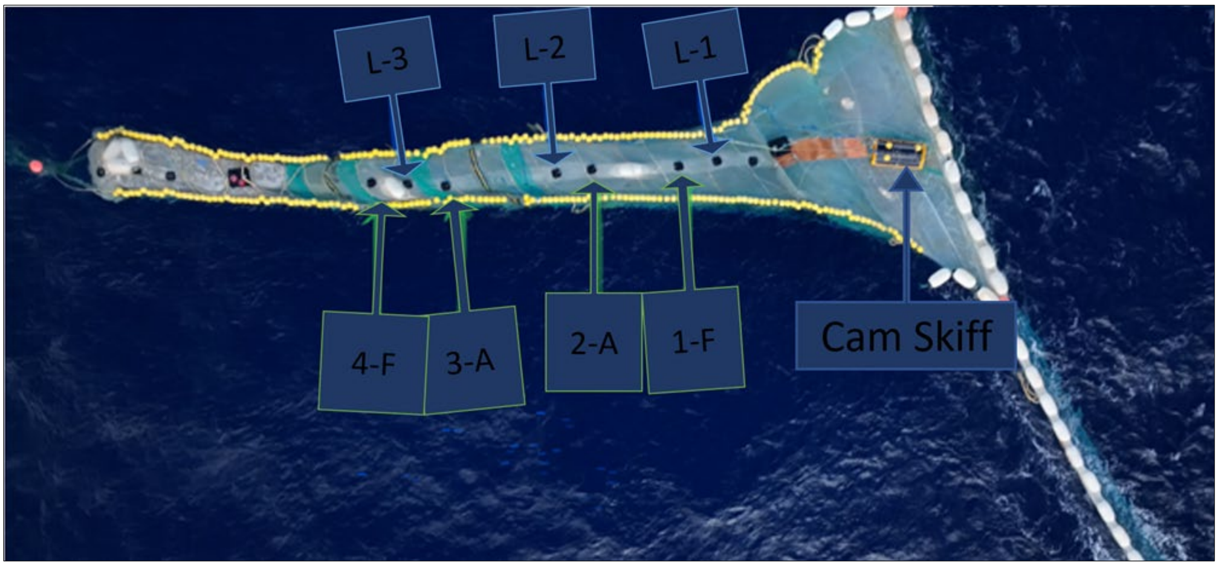



Image 2-5. Revised camera and light locations in the retention zone.
Blue outlined squares indicate light locations; green outlined squares indicate camera locations; A = aft-facing; F = forward-facing; L = light.

The RZ included another mission-specific mitigation measure, a remotely triggered electric release system for the back end of the of the extraction section (**Figure 2-7**). When activated, a weight is released in the water, pulling the line that keeps the end of the RZ extraction section closed, and opening the end of the RZ. Once fully open, water can flow through and flush all contents of the RZ back into open water (**Image 2-6**). The remotely triggered release is activated to mitigate the consequences of a possible event of a protected species accidentally entrapped captured during operation or in case visual observation and camera monitoring confirms concrete risk or high levels of marine life bycatch.

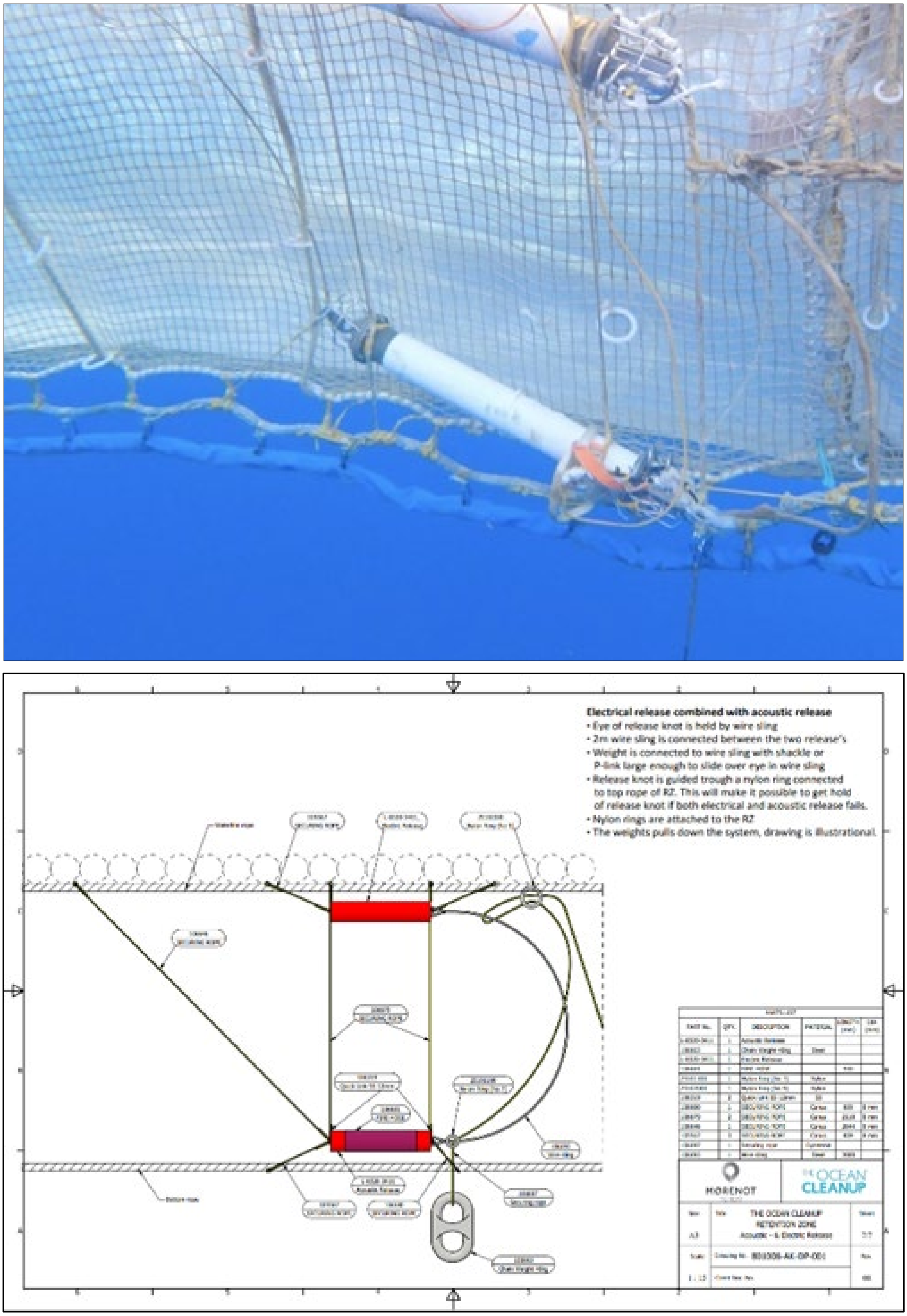



Figure 2-7. Remotely triggered electric release at the end of the retention zone.

Image 2-6. Plastics released from the retention zone after activation of the electric release.

#### 2.1.1.2 System S002A

The primary design change to S002 incorporated a larger RZ that measured 70 m in length, had an increased width and depth, and had a more streamlined shape to assist with plastic flow into the RZ and to avoid blocking cameras (**Figure 2-8**). In addition, the inner mesh of the larger RZ was changed to a 10 mm x 10 mm mesh. Each section of the RZ increased in size (**Image 2-7**). This larger RZ also allowed for longer extraction intervals (maximum of one week) resulting in more towing time per campaign. This System was called S002A and had all the other design features and mitigation measures included as part of S002.

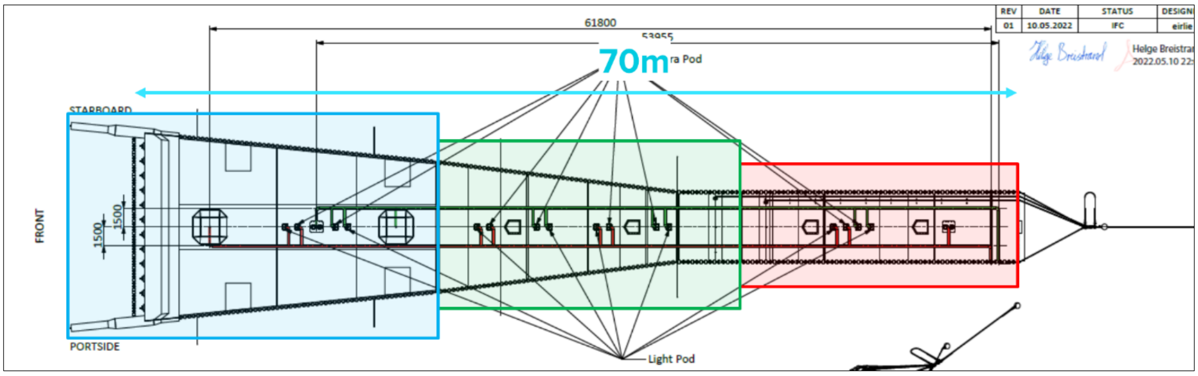



Figure 2-8. Larger retention zone, including three sections, included in S002A and subsequent designs. Blue area is entrance, green area is safe section, and red area is extraction section.

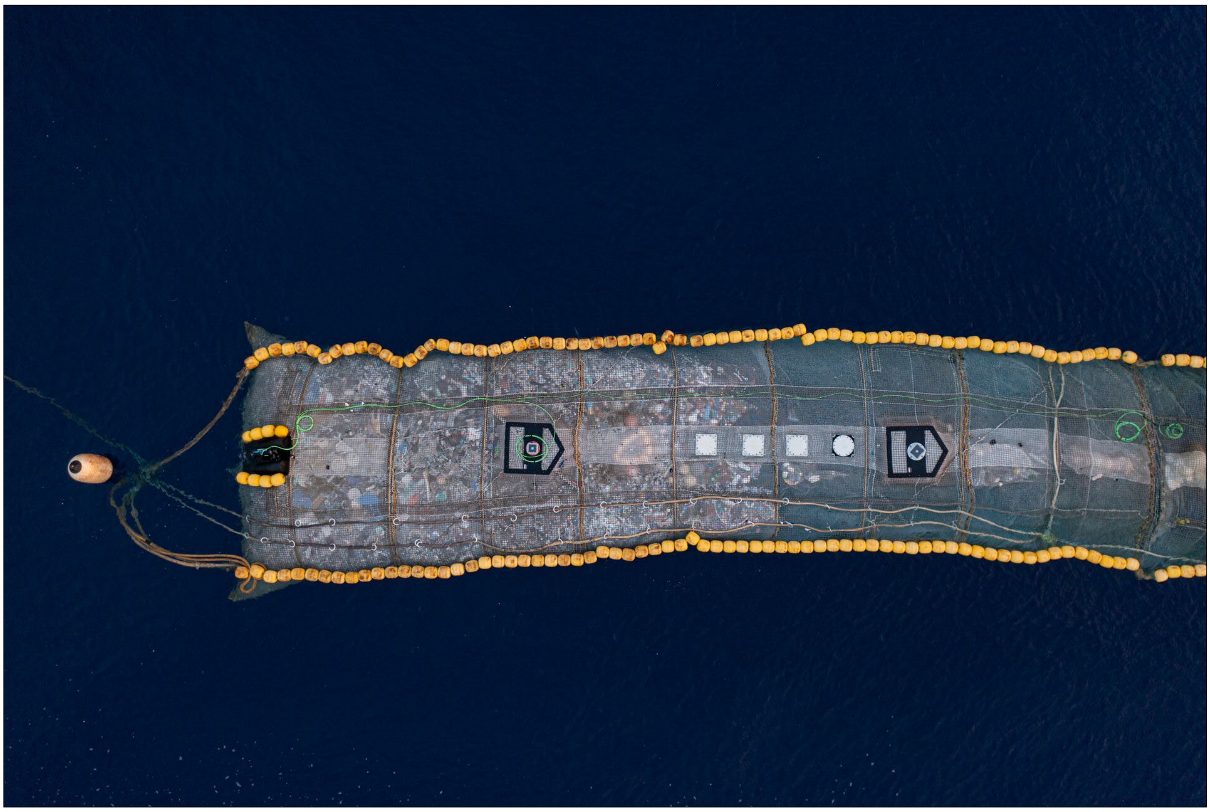


Image 2-7. Close-up of larger retention zone implemented in S002A and subsequent Systems.

#### *2.1.1.3 System S002B*

The next design change, S002B, consisted of adding new wing modules next to the larger RZ of S002A until the two 400-m wings were deployed. These new wings increased in depth to 4 m from the previous 3 m and the netting mesh size increased to 16 mm × 16 mm. In addition, several other design modifications were made to increase the floatation of the System by using larger fenders creating more freeboard, and increased ballast weight. This iteration of the System had all the other design features and mitigation measures included as part of S002A.

#### *2.1.1.4 System S002C*

The next design change (S002C) consisted of adding additional wing modules to the larger RZ and the new deeper wings of System S002B to reach 1,758 m to continue to scale-up the System. In addition, some mitigation measures were modified including replacing the fyke openings in the RZ with bottom holes, adding additional green LED lights, and re-design of the breathing rings/hatches.

#### *2.1.1.5 System S03*

The S03 is the full-scale design of the collection system and incorporates the information and data collected during deployments of the previous Systems, incorporates design changes and additional mitigation measures along with some operational changes to increase efficiency and minimize impacts to marine life. For S03, most of the design components are the same as for S002 and implement the design changes included in S002A (larger, 70 m RZ), S002B (deeper wings of 4 m, larger wing mesh size, additional floatation, and increased ballast weight), and S002C (longer wings) and adds wing modules to increase the wing length to a total of approximately 2,250 m (**Image 2-8**). **Table 2-2** provides a summary of the design parameters for S002, S002A, S002B, S002C, and S03. **Figure 2-8** shows the larger RS that includes a 16 mm square mesh along the wings and the initial portion of the RZ (**Figure 2-8** blue area), use of a 50 mm mesh on the bottom of the RZ for the initial 10 m of the RZ (**Figure 2-8**, blue area). In addition, the RZ length for S03 may also increase by adding an additional center section that is 30 m, which would increase the storage capacity for plastics; however, this is still being evaluated by The Ocean Cleanup. This potential additional RZ length increase will be evaluated in this EIA. Like the previous Systems, the wings have a modular design, allowing them to fit onto a T-class vessel deck (the modules fit into 40-ft containers), and can be easily connected to the tow rigging. Each wing module is either 22 or 23 m long depending on the floatation buoy size (**Table 2-2**), and 51 modules compose one wing. S03 also includes additional mitigation measures in the design which are discussed in detail in **Section 2.1.4**.

Image 2-8. S03 towing lines (connected to each ship), wings with submerged net, and retention zone.

Table 2-2. Summary of design parameters for S002, S002A, S002B, S002C, and S03.

| Defined Parameters | Original S002 | Updated S002 | S002A | S002B | S002C | S03 |
|---|---|---|---|---|---|---|
| RZ length | 39 m | 48 m | 70 m | 70 m | 70 m | 70–100 m |
| RZ width | 5 m | 5 m | 5.5 m | 5.5 m | 5.5 m | 5.5 m |
| RZ depth | 2 m | 2 m | 2.2 m | 2.2 m | 2.2 m | 2.2 m |
| RZ volume | 644.3 $m^3$ | 644.3 $m^3$ | 2,016.4 $m^3$ | 2,016.4 $m^3$ | 2,016.4 $m^3$ | 2,016.4–2,880.6 $m^3$ |
| RZ entrance length | 10 m | 10 m | 29 m | 29 m | 29 m | 29 m |
| RZ safe section length | 11.2 m | 18.7 | 19 m | 19m | 19m | 19–49 m |
| RZ extraction section length | 17.8 m | 17.8 m | 22 m | 22 m | 22 m | 22 m |
| RZ mesh size | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 10 mm × 10 mm inner layer, 50 mm × 50 mm outer layer | 10 mm × 10 mm inner layer, 50 mm × 50 mm outer layer | 10 mm × 10 mm inner layer, 50 mm × 50 mm outer layer | 10 mm × 10 mm inner layer, 50 mm × 50 mm outer layer |
| Wing length | 391 m (per wing) | 391 m (per wing) | 391 m (per wing) | 391–800 m (per wing) | 880 m (per wing) | 1,125 m (per wing) |
| Wing depth | 3 m constant | 3 m constant | 3 m constant | 4 m constant | 4 m constant | 4 m constant |
| Wing height above water | 0.4 m | 0.4 m | 0.4 m | 0.4–7 m[a] | 0.4–0.7 m[a] | 0.4–0.7 m[a] |
| Wing module length | 23 m (17 modules per wing) | 23 m (17 modules per wing) | 23 m (17 modules per wing) | 22 or 23 m[b] (17 modules per wing) | 22 or 23 m[b] (17 modules per wing) | 22 or 23 m[b] (52 modules per wing) |
| Net mesh size | 10 mm (square) | 10 mm (square) | 10 mm (square) | 16 mm (square) | 16 mm (square) | 16 mm (square) |
| Wing top section | Permeable screen | Permeable screen | Permeable screen | Permeable screen | Permeable screen | Permeable screen |

[a] = Larger fenders to increase the heigh above water are located near the RZ due to increased drag from the larger Retention System and minimize overtopping of plastics, [b] = Wing sections with smaller fenders for buoyancy are 23 m in length, whereas the wing sections with the larger fenders are 22 m in length. RZ = retention zone.

### 2.1.2 Plastics Collection Operations

Starting in 2021, the M/V *Maersk Tender* and M/V *Maersk Trader* traveled from Victoria Harbour, British Columbia, Canada to the deployment location within the NPSG for a series of twelve 6-week campaigns that lasted until December 2022. After Campaign 12, the field operations ceased while the weather was bad in the winter and allowed for continuation of design changes and enhanced mitigation measures to be completed for S03. In March 2023, Campaigns began again with S002B to begin the transition to S03 scheduled for completion during Campaign 16.

Transit time to and from the GPGP takes between 4 and 6 days each way for each campaign, depending on the chosen deployment location and weather conditions. When the vessels arrive on location for each campaign, the System modules are assembled on deck and deployed from a single vessel, and System towing operations begin when one of the tow lines is transferred from the single vessel to the other vessel ("handshake") and plastics collection begins. **Image 2-9** shows the System wings deployed as well as plastics collected on the wings being guided towards the RZ. The operations are supported by two smaller workboats (fast rescue craft [FRC]) for a variety of tasks, including monitoring activities (e.g., System inspections, assistance in releasing entangled sea turtles). For the S03, plastics will be extracted from the RZ approximately every 2.5 to 7 days, depending on weather and other operational factors.

Prior to the commencement of plastics collection operations, the area is inspected for potential presence of marine mammals, sea turtles, and other protected species. Observations are performed visually by EOs. System deployment operations do not begin until the area is free of marine mammals, sea turtles, and sharks. As soon as the area has been declared clear of protected animals, the System is fully deployed (after handshake), and operations commence. At select times, and only in case of necessity during the plastics collection operations, an acoustic deterrent device may be deployed to temporarily keep high frequency marine mammals out of the project area; however, during Campaigns 1 through 16, the acoustic deterrent device has not been needed.

During collection operations, a “wiggle” maneuver is performed to help free built-up plastic along the wings (build-up occurs typically on the wings closest to the RZ due to the U-shape of the system under tow). Wiggle operations currently consist of closing the vessel spacing to approximately 370 m and reducing the speed of one vessel from 1.5 knots to approximately 1 knot, causing offset of the vessels longitudinally by 150 m. This has the effect of “straightening” the wing of the vessel that is ahead, causing plastic to be pushed along the wing, and into the RZ. The vessels then realign, and the opposite vessel falls back to straighten their wing, again causing plastic to be pushed into the RZ.. During the “wiggle” maneuvers, much of plastic collected by the wings enters the RZ, which can obstruct the view of the cameras, making it difficult to observe animals that may be floating in the plastics along the wings and entering the RZ. However, based on data collected during Campaigns 1 to 12, the “wiggle” maneuvers need to be executed more frequently to reduce the amount of plastic entering the RZ at a given time to assist with reducing the camera obstruction.

During towing operations, if a living marine mammal, sea turtle, or other protected species is unexpectedly found entangled in a derelict net or other debris, a disentanglement and rescue procedure can be initiated while considering human safety, weather conditions, and the species involved.

The specific System deployment location is based on an expected area of high plastic density from predictive models used by The Ocean Cleanup. These models incorporate sea surface current, wind, wave, sea level anomalies, mixed layer depth, and Langmuir number data combined with daily plastic dispersal data to perform contour shape, hotspot detection, and target assessment analyses to determine the deployment location. The Senior Offshore Representative supported by The Ocean Cleanup’s engineering and environmental research teams evaluates all available data and makes a recommendation for each campaign prior to each deployment date. In addition, each campaign will move to different areas of the NPSG to follow the high- and low-density areas, which are shifting, to better understand the System performance in different scenarios as well as to work around poor weather conditions in the later (winter) campaigns.

Wings deployed in the ocean.


Plastics collection along starboard wing.


Plastics collection along port wing.

Image 2-9. System wings deployed and plastics collecting on wings moving towards the retention zone.

### 2.1.3 Plastics Extraction Operations

Prior to beginning plastics extraction operations from the extraction section of the RZ, the area is scanned for protected species and other marine life (marine mammals, sea turtles, large fish, and sharks). EOs look at the project area and the footage from the underwater camera systems mounted on the RZ to visually monitor the entrance and inside of the RZ. As soon as the area is cleared of visible marine mammals, sea turtles, large fish, and sharks, the extraction operations begin. Towing operations transfer from two vessels to one vessel, reducing the wingspan of the System to the width of the vessel stern, less than 5 m (**Figure 2-9**). The second vessel proceeds to the RZ end of the System, retrieves the buoy attached to the RZ bridle, and engages two chokes in the RZ to contain the plastics in the extraction section. The second vessel then recovers the RZ over the open stern and onto the main deck and secures the System (**Figure 2-10, Image 2-10**). After the RZ extraction section is detached and secured on deck, the remainder of the System is returned to the water and slowly towed behind a single vessel while deck crew perform plastics sorting from the extraction section. This operation is supported by a small excavator to segregate the larger items collected, such as ghost nets. The shortened RS (without the extraction section with the remotely triggered electric release) has the same design as the complete S03, including all mitigation measures (e.g., bottom openings, camera systems, deterrent lights), except for the remotely triggered electric release since it is located on the extraction section on deck, leaving the RZ being towed open by one vessel (**Image 2-11**).

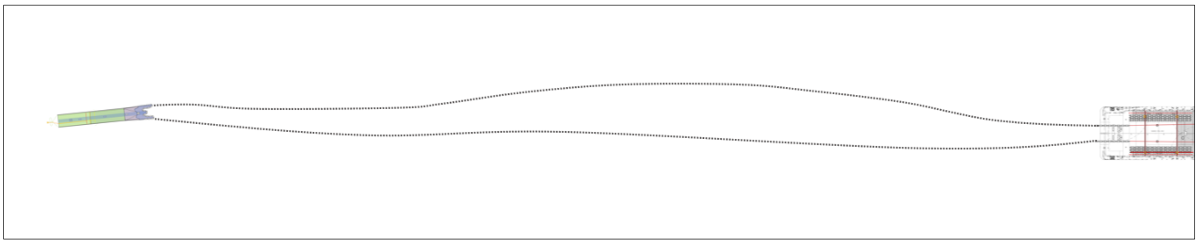


Figure 2-9. The System during extraction operations behind one vessel with reduced wingspan.

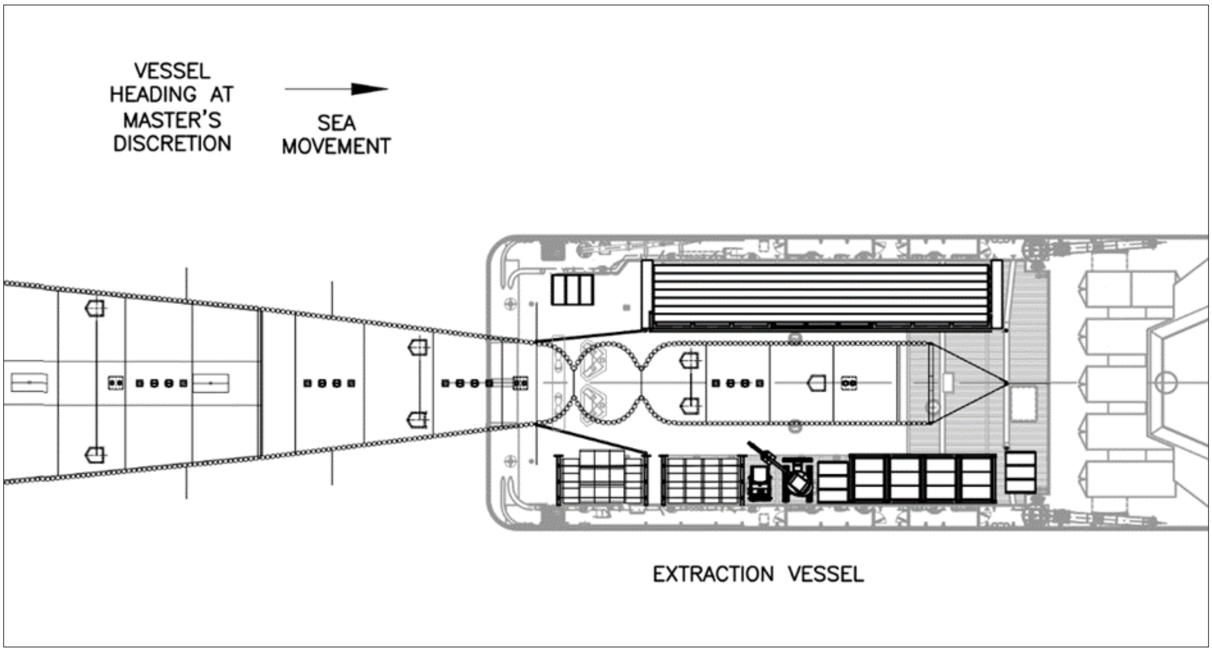



Figure 2-10. Retention zone with the two chokes on vessel deck.

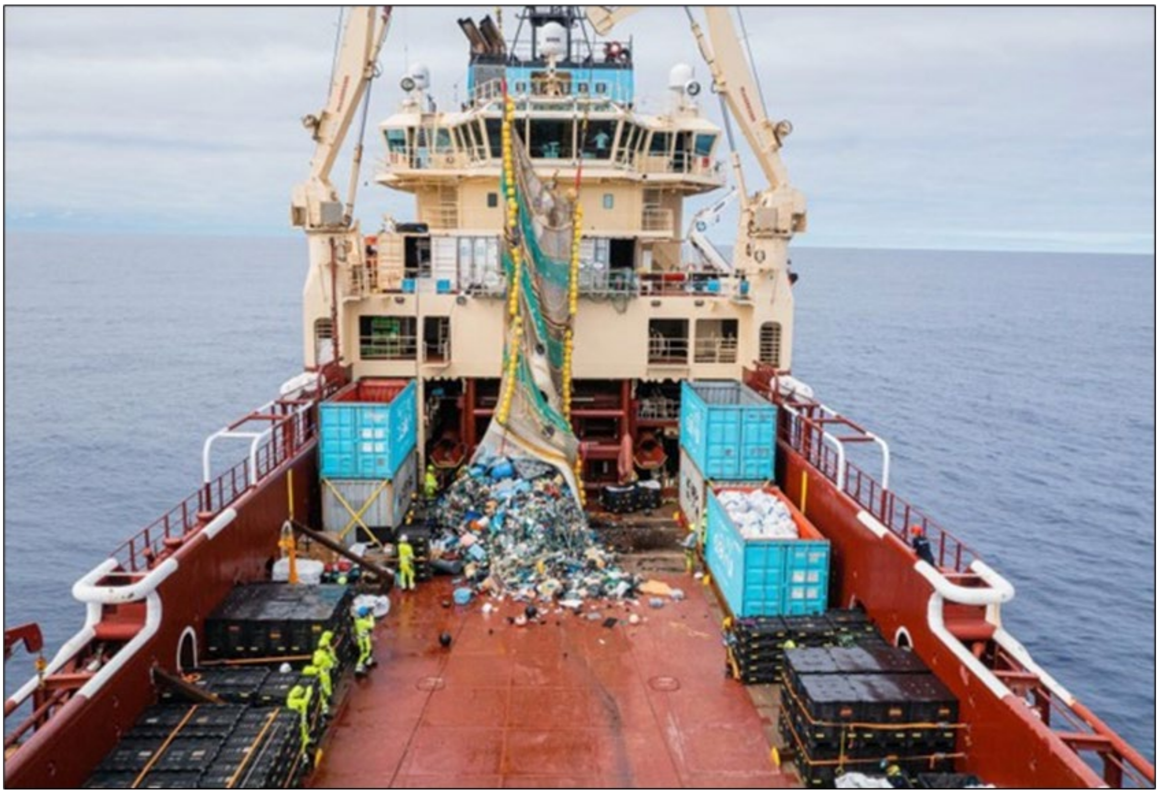


Image 2-10. Extraction operations (Image Credit: Toby Harriman).

Image 2-11. Shortened retention zone being towed by one vessel during plastics extraction operations.

The deck crew, including the EOs, sort through the plastics looking for live animals captured by the RS with the support of the small excavator to move the large items such as ghost nets. Once the search for live animals is complete, sorting of the plastics begins while moving the debris to one side of the deck, if possible, to create sufficient deck space for reattachment of the extraction section to the shortened RS. Once the reattachment occurs, the handshake takes place to pass one tow line to the second vessel (handshake), and towing operations resume for plastic collection operations (**Section 2.1.2**). Then the rest of the sorting continues by roughly separating the plastics by hand, with small hand tools, and with the small excavator which is used to lift the large ghost nets and other large items to separate them from other hard materials (**Image 2-12**). Water is allowed to drip off the plastic, which then is left to partially dry while being sorted and inspected for biofouling or any other marine life presence. The plastics are packed on board the vessel and weighed before being loaded into bales and bags according to the chain of custody guidelines. The sorted plastics are placed into on deck storage units. If live animals are found during sorting, they are documented (e.g., photograph, measured, identified), and returned to the water as quickly as possible or frozen for further analysis. This is done, in part, to understand the amount and type of bycatch, but also to assist in identifying additional mitigation measures for future System improvement.


Image 2-12. Small excavator separating ghost nets from other plastics.

The bales and bags are unloaded at Victoria Harbour and remain sealed. Weights are verified on shore, and the containers forwarded to The Ocean Cleanup's partner facility in the Netherlands for sorting and distribution to other facilities in the Netherlands and Denmark. After packaging on board, materials are in the custody of The Ocean Cleanup Catch Management project. Feasible options for further processing of the plastics continue to be assessed.

Due to the increased size of the RZ and associated increase in the amount of plastics to be collected per campaign, extraction of the RZ will occur on both vessels, M/V *Maersk Tender* and M/V *Maersk Trader*, to allow for the necessary storage space.

Any dead animals are also separated from the plastic, sorted by category (e.g., fish, barnacles, crabs) and classified as further discussed in **Section 2.1.7.1** as either primary bycatch, secondary bycatch, or previously deceased organisms based on the general condition of the organisms upon removal from the RZ.

Each group of bycatch is then further separated by species, if possible, photographed, weighed, and a subset of fish is frozen for further laboratory analysis, including stomach content analysis.

### 2.1.4 Mitigation Measures

During the development of S002, a variety of mitigation measures were researched for potential applicability to the project, their potential effectiveness evaluated, and then their potential for implementation determined in consultation with the System manufacturer, Mørenot, and from an operational perspective. Many of the mitigation measures developed and evaluated were emerging or new technologies used in different applications with some success (e.g., fyke openings, net coloring, pingers) while others were developed specifically for The Ocean Cleanup to reduce potential impacts from the operations (e.g., camera skiff, remotely triggered release, steering strategy to avoid sea turtle preference areas). Some mitigation measures were designed to prevent marine life from entering the System (e.g., EOs, cameras) while others were designed to minimize impacts if an animal was caught within the System (e.g., remotely triggered electric release, fyke openings, breathing hatches). Numerous mitigation measures were incorporated into the design of the S002 as well as additional monitoring tools implemented to reduce impacts to the environment and marine animals from System operations. These mitigation measures were evaluated during the previous campaigns and design modifications have been made and incorporated into S03 (e.g., bottom holes in lieu of fyke opening, redundant camera skiff with improved cameras and integrated lights, additional green LED lights). A summary of the mitigation measures developed for S002 design, and the results of the evaluations, is presented in **Section 2.5**. One operational tool, the drone and underwater inspections, used to perform System inspections was found to be a useful mitigation method for observing marine animals near or within the System that other mitigation measures may not see or to assist other methods with collecting additional data; therefore, it was added to the list of mitigation measures. Mitigation measures included in S03 are summarized as follows.

**Design Mitigation Measures**

- **Mesh size** – Use of netting with 16 mm × 16 mm mesh size, when possible, to allow smaller marine animals to exit the System.
- **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings replacing the fyke openings (**Figure 2-11**). These bottom openings can be closed if animals are observed entering the RS through them.

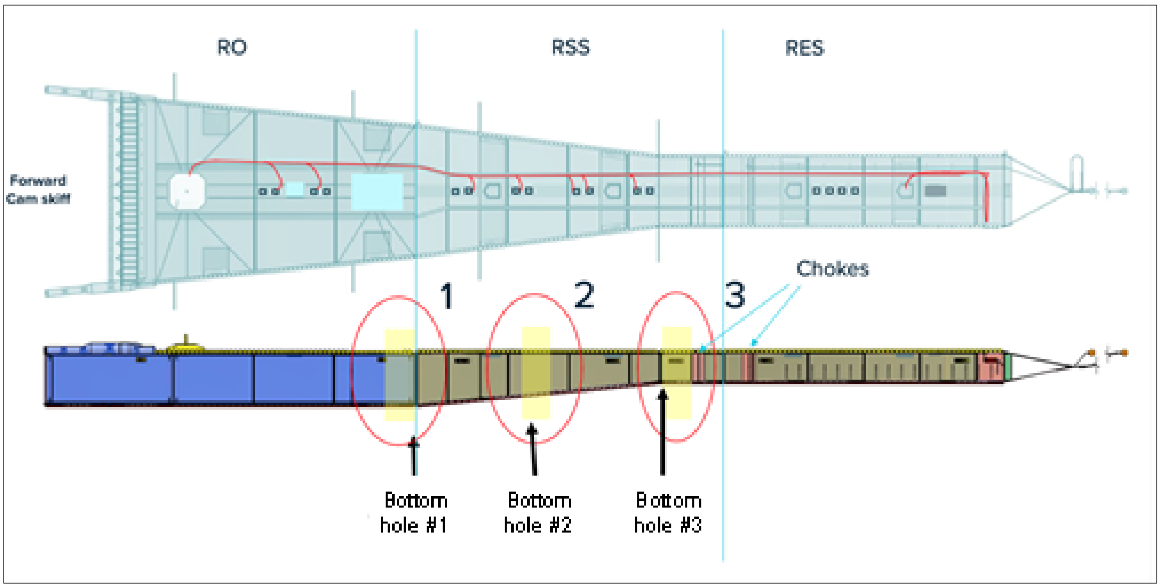



Figure 2-11. Location of bottom holes replacing the fyke opening in the S03 retention zone. RO = Retention Opening; RSS = Retention Safe Section; RES = Retention Extraction Section.

- **Visual monitoring** – Two camera skiffs each with eight underwater cameras (sixteen cameras in total) with integrated lights installed inside the RZ for visual observation by the EOs (**Figure 2-12**). Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations.

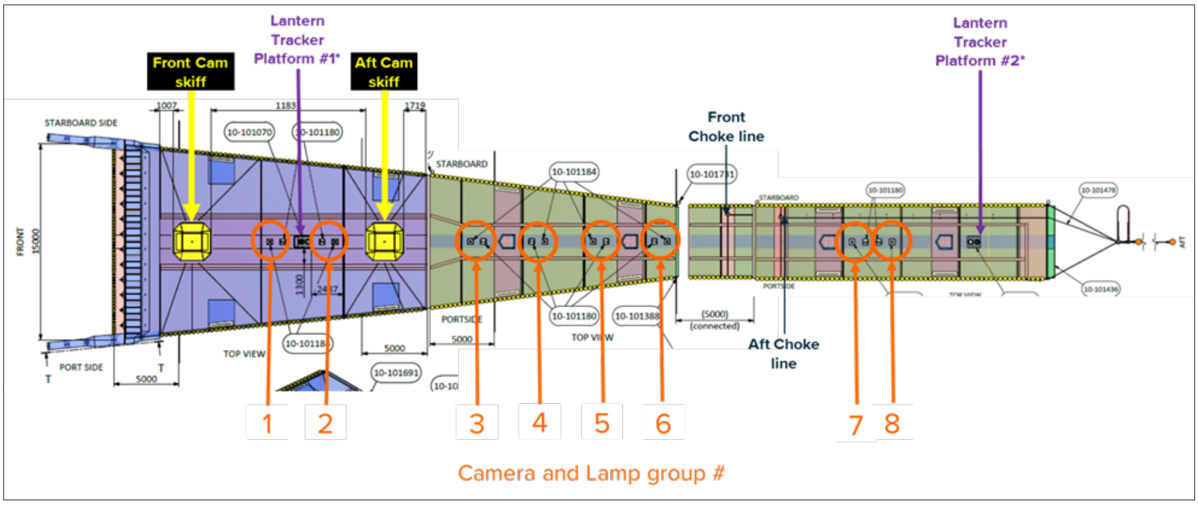



Figure 2-12. New camera skiffs and camera and light layout.

- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System. LED lights have reduced primary bycatch of small cetaceans, sea turtles, and seabirds on stationary nets (Ortiz et al., 2016; Kakai, 2019; Allman et al., 2020; Bielli et al., 2020).
- **Acoustic deterrent** – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System. Pingers may deter certain species of smaller cetaceans (Larsen et al., 2013; Mangel et al., 2013; Popov et al., 2020).
- **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals (**Figure 2-13**).

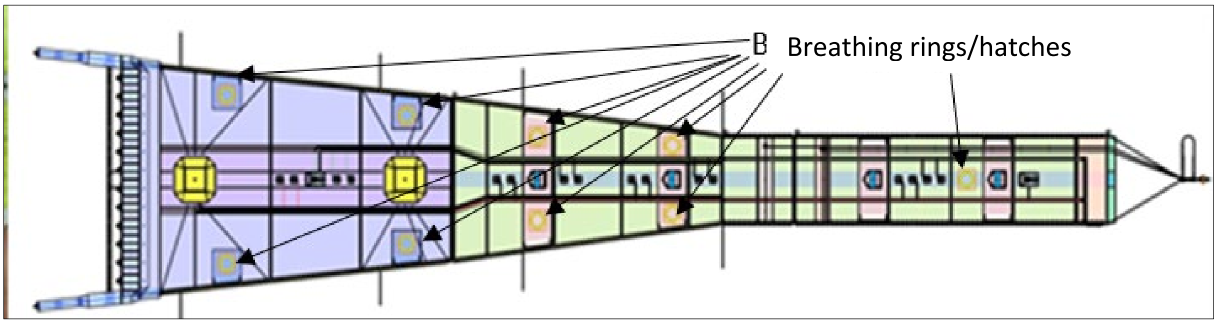



Figure 2-13. Location of breathing rings/hatches along the S03 retention zone.

**Operational Mitigation Measures**

- **Visual monitoring** – Continuous monitoring by EOs during transit and operations, and use of the thermal/RGB camera systems and the camera skiffs.
- **Visual monitoring** – Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:
    - During transit between shore and the NPSG, vessels travel at slow speeds (<14 knots);
    - During towing in the NPSG, vessels travel at extremely slow speeds (0.5 to 2.5 knots); and
    - Minimal Environmental Impact Operation (MEIO) mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 1 knot, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the following circumstances:
    - Protected species observed in the vicinity/risk of entanglement;
    - Equipment malfunction;
    - Camera skiff not operational and low visibility; or
    - Remotely triggered acoustic release not operational and low visibility.
- **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable.
- **Minimize nighttime lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.
- **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the S03 RZ.
- **Drone inspections** – Routinely (daily, weather permitting) perform inspections of the S03 and surrounding area by drone to identify System issues or damage and observe any protected species within or around the S03. EOs can request a drone inspection to assist with confirmation of protected species camera or visual observations.
- **Underwater inspections** – Perform a minimum of three underwater inspections of the System per trip to identify System issues or damage and observe any protected species within or around the S03.
- **Rescue of animals** – Rescue attempts of entangled marine mammals or sea turtles in distress are performed according to project procedures.
- **Turtle zone steering strategy** – Avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region.
- **Pollution prevention** – Compliance with International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 restrictions and implementation of vessel Waste Management Plans will reduce the likelihood of pollution.

- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the vessels (should one occur).
- **No re-fueling at sea** – No re-fueling will occur at sea.

#### 2.1.5 Adaptive Management

The Ocean Cleanup is committed to adaptively managing activities and data collection to better characterize the potential impacts to the environment from project operations. One means of adaptive management has been the implementation of active monitoring and using the data collected during campaigns with previous designs to modify the project mitigation measures, methodologies, and improve the design of S03. In addition to the adaptive management of monitoring and operational activities, adaptive management was applied to the design of the S03 and reflects the observations from the S002 to further reduce potential impacts to marine animals. It is from this adaptive management approach and applying the data and knowledge collected from the completed campaigns that the larger RZ with additional mitigation measures (S002A) and deeper wings (S002B) have been implemented in the S03 full-scale System design. Implementing the larger RZ allows for more room for the plastics to accumulate and reduce the potential for plastics blocking the view of the camera skiff system and the active monitoring for protected species within the RZ. Additional design changes and mitigation measures from data collected during previous campaigns include redundant camera skiffs, additional animal escape routes, improvement of the RZ remotely triggered release system, sealed ends on the double netting, and additional visual cues on the RZ, among other improvements.

In addition, as part of the adaptive management, additional mitigation measures are in development by The Ocean Cleanup to potentially further reduce impacts. The first additional measure is an actuated hatch that will be placed in the RZ. This hatch can be activated remotely when a protected species is unable to escape on its own, opening the final portion of the RZ while closing off the Extraction Section, helping the animal exit without losing any plastic. In addition, the placement of deterrent methods such as bubble barriers and acoustic devices at the RZ opening is being investigated to evaluate their potential to warn and deter animals from entering the RZ. These are examples of using the data collected in previous campaigns to continuously endeavor to minimize impacts to the environment from the Systems.

The Ocean Cleanup has prepared a Project Environmental Management Plan (EMP) that includes the strategy for implementing actionable mitigation measures (i.e., MEIO mode, rescue of animals, acoustic deterrent, drone and underwater inspections), an organizational chart with roles and responsibilities, and the monitoring plan. The EMP:

- Incorporates The Ocean Cleanup's corporate health, safety, and environmental policies;
- Provides a flowchart for implementing measures to mitigate potential environmental impacts that may occur as a result of The Ocean Cleanup's project activities;
- Provides the adaptive management process and response approach to environmental events;
- Identifies the monitoring protocols for the project activities to minimize potential environmental impacts;
- Identifies the organizational arrangements as well as roles and responsibilities; and
- Provides the monitoring plan and procedures for the implementation and monitoring of mitigation measures and the plastics research data collection activities.

During towing operations, some adaptive monitoring measures have been implemented to support visual monitoring. In some cases, some methods were more efficient than others, depending on weather and visibility. The following are examples of the adaptive management methods undertaken:

- **Requirement**: Remotely triggered acoustic release to be activated via a single electronic means. **Adaptive Management**: Changed configuration to an electric release and enable multiple electronic means (electronic, e-mail, manual) of triggering the release.
- **Requirement**: RZ monitoring cameras/skiff cameras: 24-hour/7-day cameras for bycatch observation at the RZ entrance and inside the cod-end. Parameters: 10 images per minute continuously. EOs monitored cameras for a period of 5 minutes out of 15 minutes or 20 minutes per hour to ensure screens remained clear of protected species. **Adaptive Management**: Relocation of RZ cameras and lights (**Image 2-6**) for better observations by the EOs based on how the RZ collected debris.
- **Requirement**: Seiche dual camera system: Detection of marine mammals through thermal camera system and high-definition cameras, one on each vessel. Distance estimation available under good weather conditions. **Adaptive Management**: EOs were moved to one vessel to facilitate better observations, and the second camera system was moved to the vessel with EOs and installed to facilitate better monitoring during transit.
- **Requirement**: The Ocean Cleanup and Maersk crew routinely inspected the System with underwater cameras, focusing on System repair and maintenance. **Adaptive Management**: Underwater cameras are also used to monitor for marine wildlife.
- **Requirement**: Drone pilots performed routine System inspections and alerted EOs of any possible sightings of protected species. **Adaptive Management**: EOs could request a drone inspection to assist with observations from the camera skiff, as needed.
- **Requirement**: Using a single camera skiff with four cameras and separate lights for underwater monitoring of the RZ. **Adaptive Management**: Designed new camera skiff with eight cameras with integrated lights and installed two camera skiffs within the RZ to provide redundancy.

### 2.1.6 Environmental Monitoring and Plastics Sampling

Environmental monitoring was performed during Campaigns 1 through 12 to better understand the existing plankton and neuston communities, relative abundance of neuston, and what species tend to co-accumulate with plastics. Whereas the plastics research is being performed to study the spatial heterogeneity of plastic accumulation in the GPGP and how/why plastic densities vary on the sub-mesoscale (i.e., within a few kilometers) and to establish baseline plastic densities to monitor the impact of the cleanup efforts on plastic accumulation in the North Pacific Ocean.

Different span widths of the wings were tested to gather data regarding the efficiency of plastics collection, vessel fuel consumption, environmental factors from the operations, and other operational data. In addition, observations by EOs and crew, implementation of monitoring and mitigation measures (e.g., above-water and underwater RZ camera systems, EOs, thermal/RGB camera system, marine life fyke openings, deterrent devices), and environmental research (e.g., bongo/plankton net sampling, conductivity-temperature-depth [CTD] data, manta trawl sampling) was performed and evaluated to monitor the environmental impacts of the operations. Results of this data collection are included in **Chapters 4** and **5** within each applicable resource discussion and provide additional data for baseline environmental conditions.

#### *2.1.6.1 Bycatch Analysis*

During the S002 campaigns, multiple operational/tow speeds (between 1 and 2.5 knots) and System configurations were implemented to collect data regarding the operations and performance of the System to determine the conditions for the highest efficiency of operations and make design and operational changes to the S03. After plastics extraction, additional tasks include documenting primary and secondary bycatch composition and quantity and evaluating the performance of the environmental mitigation and monitoring measures.

In addition, research continues to be conducted to assess the S03 bycatch composition and amount in different System operational configurations, to determine the amount of plastic recovered, and to document daily and seasonal variations and other possible variables. These data are being extrapolated to assess the ecological significance and impact of the bycatch for mission continuation. Bycatch is classified based on the general condition of the organisms upon removal from the RZ as the following:

- primary bycatch - when the organism is deemed to have been alive and fully free before being unintentionally caught during collection operations;
- secondary bycatch - when the organism is deemed to have been caught as a result of being entangled or otherwise not fully free (e.g., when the organisms are associated with the plastics, as is the case of barnacles, crabs); and
- previously deceased organisms (i.e., carcasses) - when the organism is deemed to have been already deceased in the environment when caught by the System.

The bycatch is categorized, separated by species, photographed, weighed, and either returned to the ocean or a subset of fish frozen for further laboratory analysis, including stomach content analysis. The Ocean Cleanup is also assessing health and safety related to bycatch accumulation in the RZ.

#### *2.1.6.2 Plankton and Bongo Net Sampling*

During S002 deployment, environmental research was conducted by Environmental Coordinators to increase baseline knowledge of the NPSG ecology, while allowing for comparison with marine life around the System in relation to bycatch assessment. The research consisted of bongo, manta, and plankton net (single ring) sampling focused on the plankton and neuston component at the surface (top 3 m) of the water column within the NPSG. All the net sampling gear has a mesh size of 500 µm to allow direct comparison of the data. The sampling schedule varied to accommodate poor weather conditions that created unsafe sampling conditions, but the goals are described below. Only the top 3 m of the water column were sampled to align with the maximum depth of the S002.

The monitoring purpose for the plankton and bongo net sampling devices was to understand the species presence and type at different depths from the surface to 3 m depth, in front of and behind the System as well as diurnal investigations (dawn, daytime, dusk, and nighttime). The data has provided additional information regarding the NPSG ecology, leading to a more accurate understanding of the real impact of the System in relation to other marine life bycatch.

A single bongo tow using a 0.6-m diameter bongo net (A net and B net) with a 500-µm mesh net was conducted during each diurnal investigation (4 times in a 24-hour period) for 10 minutes to a maximum depth of 3 m. The plankton net, which was a 0.6-m diameter single ring with a 500-µm mesh net, was towed twice during the day and dawn sampling periods for 10 minutes, as weather permitted.

The bongo tows were conducted in front of the S002 off the side of one of the tow vessels and were compared to the fully submerged plankton tows, which were conducted from the FRC behind the S002 to compare results in front of and behind the S002. The plankton net was used for the FRC sampling due to the limitations of handling the larger bongo net frame by hand from the FRC. The results and analysis of the data collected during campaigns 1 to 12 are included in **Chapters 4** and **5**. This sampling will be discontinued during the S03 campaigns since there is a total of 16 months of additional baseline data for supporting the characterization of these communities in the area.

#### *2.1.6.3 Manta Net Sampling*

Similar to the bongo and plankton net sampling gears, a 1-m manta net with a 500-µm mesh net was used to understand the species presence through diurnal investigations as well as in front of and behind the S002. The number of tows and timing were flexible based on the testing schedule and weather conditions. At minimum, a single manta tow at the surface was conducted during each diurnal investigation (4 times in a 24-hour period) for 10 minutes. The manta tows were conducted in front of the S002, off the side of one of the tow vessels. The results and analysis of the data collected during campaigns 1 to 12 are included in **Chapters 4** and **5**. This sampling has been discontinued during the S03 campaigns since there is a total of 16 months of additional baseline data for supporting the characterization of these communities in the area and the statistical analysis showed no significant differences in plankton abundance among the gear type.

#### *2.1.6.4 eDNA Sampling*

One surface water environmental deoxyribonucleic acid (eDNA) sampling was performed in conjunction with bongo net sampling to compare the eDNA present in the water to the physically identified organisms in the net sampling. The B net of the bongo samples were preserved for comparison with the eDNA sample results. A total of 12 eDNA samples were taken and the results and analysis of the eDNA data collected are included in **Chapters 4** and **5**.

#### *2.1.6.5 Plastics Research*

Plastic research sampling is being undertaken to understand the real impact of the System in relation to other marine life bycatch where there are high and low plastic concentrations as well as the operation of the System relative to sampling speed. The operations with the System provided a unique platform to conduct scientific research related to ocean plastic pollution and to further the understanding of ecosystem dynamics in the remote NPSG. Thirty-minute manta tows were performed with the tow vessels during transit as well as during operations in the NPSG. The samples were subsequently sent to The Ocean Cleanup's laboratory in Rotterdam for a detailed analysis of collected plastic debris and marine organisms. The analysis is still ongoing. Once completed, it will provide the first observational dataset to evaluate the seasonal relative distribution of plastic and neuston in the North Pacific Ocean. This complements additional observational data of marine megafauna collected by the EOs. This research is continuing during the S03 campaigns.

## 2.2 LOCATION AND SCHEDULE

### 2.2.1 Location

The mobilization point for the S03 is British Columbia, Canada, from Victoria Harbour, Ogden Point cruise terminal.

### 2.2.2 S03 Schedule

Currently six, 6-week Campaigns, 13 through 18, are planned for 2023 for the System with the full implementation of S03 starting on Campaign 17. During Campaigns 13 through 16, the System slowly increased in size and add the additional design and mitigation measures until the complete full-scale S03 is implemented. Additional campaigns will most likely continue into the future.

## 2.3 PROJECT VESSELS AND EQUIPMENT

For each campaign, the S03 is transported to the NPSG on board the M/V *Maersk Tender* or M/V *Maersk Trader*. The vessels are equipped with very high-frequency radio with digital selective calling, single side band radio, global maritime distress and safety system, Iridium Satellite phone, NavTex, radar with aft station display, chart navigation computer, GPS, depth sounder, Automatic Identification System, magnetic compass, autopilot, and dynamic positioning system gyro compasses.

In addition, two FRCs support project operations. The FRCs are deep V-bottom, aluminum-hulled vessels secured on board a Maersk vessel for transit and when not in use.

To support marine mammal visual observation, The Ocean Cleanup has used a camera monitoring system that assist the EOs in detecting the presence of marine mammals within the vicinity of the operation. The camera monitoring system is installed on both the M/V *Maersk Trader* and the M/V *Maersk Tender* and consists of two dual camera systems (high-definition RGB and thermal) able to continuously scan ahead of and beside the vessel in an arc of approximately 200° to 240°. The vessels are also equipped with a base monitoring station (computer and monitors) mounted on bridge of each vessel.

## 2.4 EMISSIONS AND DISCHARGES

### 2.4.1 Emissions

During the analysis of changing to a towed System, it was found that the carbon dioxide ($CO_2$) emissions from a towed System are similar to a passive System because support vessels were needed to service the passive Systems to extract the plastics and vessels are required to tow the new System to and from the GPGP. The analysis determined that approximately the same number of vessels are required for the towed operations and for supporting the passive Systems, though they are used in a different manner.

Activities from the project have produced and will continue to produce emissions from internal combustion engines, including greenhouse gases, and varying amounts of other pollutants such as carbon monoxide, additional oxides of nitrogen and sulfur, volatile organic compounds, and particulate matter (PM). The geographic location of operations ranges from the Victoria, BC area to the deployment location. The amount of air pollutants and greenhouse gases generated during The Ocean Cleanup activities will depend primarily on the number, design, and size of the vessels; the size of engines and generators on the vessels; the distance traversed under power; and overall duration of the activities. Fuel usage data provided by The Ocean Cleanup indicated an average of 9.05 metric tonnes (mt) of fuel has been consumed per day per vessel during Campaigns 1 through 12. The average combined total of $CO_2$ emissions per campaign was determined to be 2,473 mt. In addition, The Ocean Cleanup is using biofuels to improve emissions.

The Ocean Cleanup has compensated/offset all $CO_2$ emissions produced by the vessels' operation during the first two campaigns in 2021, using golden standards via South Pole, and will compensate/offset all future campaign $CO_2$ emissions. The Ocean Cleanup tracks the greenhouse gas emissions from the project and, where possible, will continue to consider mitigation measures to reduce the emissions footprint, including the use of biofuels.

### 2.4.2 Discharges

Discharges from project vessels may include sanitary and domestic wastes, deck drainage, cooling water, bilge water, and food wastes. All sanitary wastes are treated using a marine sanitation device, producing an effluent with low residual chlorine concentrations (i.e., 1.0 mg $L^{-1}$ or less), with no visible floating solids, oil, or grease. Treated black water discharges comply with MARPOL 73/78 requirements.

Domestic waste (also known as gray water) consists of the water generated from showers, sinks, laundries, galleys, safety showers, and eye wash stations. Domestic wastewater is typically screened to remove any floating solids, then discharged; domestic waste does not require treatment before discharge under MARPOL 73/78 requirements.

**Table 2-3** provides a summary of effluent discharges expected during the project, and **Table 2-4** provides estimated maximum volumes/weights for sanitary waste, domestic waste, and food waste expected to be generated during the project.

Table 2-3. Summary of effluent discharges expected during The Ocean Cleanup activities in the North Pacific Subtropical Gyre.

| Effluent | Expected Volumes; Treatment or Processing |
|---|---|
| Sanitary and Domestic Wastes | Sanitary waste: 132.5 L per person per day – macerate, chlorinate, discharge.<br>Domestic waste: 378.5 to 567.8 L per person per day – remove floating solids, discharge.<br>Sanitary waste is collected and treated, and domestic wastes are collected prior to discharge in compliance with MARPOL 73/78, Annex IV.<br>Total volumes of sanitary and domestic waste depend on number of personnel. |
| Deck Drainage | Deck drainage is monitored and treated to remove oil and grease; discharge not to exceed 29 mg $L^{-1}$ monthly average, or 42 mg $L^{-1}$ daily maximum for hydrocarbons. All discharges will be in compliance with MARPOL 73/78, Annex I. Total volume depends on rainfall. |
| Cooling Water | Effluent should result in a temperature increase of no more than 3°C at edge of the zone where initial mixing and dilution take place. Where the dilution zone is not defined, the dilution zone will be 100 m from point of discharge. |
| Bilge Water | Processed through an oil-water separator. Discharged in compliance with MARPOL 73/78, Annex I. Variable volumes, depending on vessels used. |
| Food Wastes | Food waste is ground and passed through 25-mm mesh screen prior to disposal overboard outside 22-km zone, as required by the MARPOL Convention (i.e., compliance with MARPOL 73/78, Annex V).<br>Total weight depends on number of personnel. |

°C = degrees Celsius; km = kilometer; L = liter; MARPOL = International Convention for the Prevention of Pollution from Ships; mg $L^{-1}$ = milligrams per liter; m = meter; mm = millimeter.
Generation rates: Per the Bureau of Ocean Energy Management (2012), a typical offshore facility will discharge 132.5 L (35 gallons) per person per day of treated sanitary wastes and 378.5 to 567.8 L (50 to 100 gallons) per person per day of domestic wastes, based on United States Environmental Protection Agency (1993) estimates. These estimates are considered conservative for sanitary and domestic waste discharges from oil and gas industry support operations, including seismic, guard, and supply vessels.

Table 2-4. Summary of estimated project discharges, reflecting volumes/weights for sanitary waste, domestic waste, and food waste from the 2023 campaigns.

| Vessels | Duration | Persons (max.) | Days (max.) | Sanitary Waste (L) | Domestic Waste (L) | Food Waste (kg) |
|---|---|---|---|---|---|---|
| *Maersk Tender* | 6 Campaigns (36 Weeks) | 66 | 252[a] | 2,203,704 | 6,295,212 | 16,632 |
| *Maersk Trader* | | 66 | 252[a] | 2,203,704 | 6,295,212 | 16,632 |
| | | | **Total (36 Weeks)** | **4,407,480** | **12,590,424** | **33,264** |

[a] Based on transit of 6 days each way.
kg = kilogram; L = liter.
Generation rates: Per Bureau of Ocean Energy Management (2012), a typical offshore facility will discharge 132.5 L (35 gallons) per person per day of treated sanitary wastes and 378.5 to 567.8 L (50 to 100 gallons) per person per day of domestic wastes, based on United States Environmental Protection Agency (1993) estimates. These estimates are considered conservative for sanitary and domestic waste discharges from offshore support operations. Estimated food waste is 1 kg/person/day.

### 2.4.3 Waste

Waste is managed in accordance with the vessels' Garbage Management Plans and associated bridging documentation/contractual conditions with The Ocean Cleanup as well as all applicable laws and regulations. The Ocean Cleanup reviewed the vessel Garbage Management Plans and conducted due diligence on the waste disposal subcontractors hired for the project.

## 2.5 ALTERNATIVES

The Ocean Cleanup project is, by its nature, evaluating different alternatives to their System as it has continued to use data collected during previous campaigns into the System design to develop S03. The Ocean Cleanup has implemented adaptive management from testing the previous System designs and it has been applied to the S03 design and will continue to try to use the data obtained from the field operations to continuously improve the plastic collection System design and operations. The only other alternative considered would be a No Action alternative of leaving the plastics in place. There are many potential impacts from the No Action alternative, including ingestion of plastics by marine organisms, sinking of plastic debris to the seafloor, entanglement with marine life, toxicity of marine plastics to marine organisms, attraction of marine animals leading to increased ingestion of plastics, and introduction of invasive species. **Appendix B** includes a summary of literature review on these key impacts from marine plastics.

In addition, as discussed in **Section 2.1.4**, numerous design and operational mitigation measures have been developed, evaluated, and implemented or deemed to be not practicable or useful and, therefore, not carried through for implementation. These mitigation measures were grouped into three categories: design, technological, or operational. Mitigation measures that were considered for implementation but not moved forward and the rationale for not moving forward are provided in **Table 2-5**.

In addition, two additional mitigation measures are in development by The Ocean Cleanup to further reduce impacts. The first additional measure is a bubble barrier that could be placed along the RZ opening to warn and deter animals from entering the RZ. The second additional measure is an actuate hatch to create a barrier and exit route in the event that a sea turtle is in the System and is unable to escape using the other escape aids. These potential additional mitigation measures are alternatives that will be evaluated later if it is determined that the technology can be developed.

Table 2-5. Summary of mitigation measures developed and evaluated for the System but not moved forward.

| Name | Mitigation Measure | Target Resource | Assessment of Effectiveness and Comments | Rational for Not Implementing |
|---|---|---|---|---|
| Design Measures | | | | |
| Marine life pre-warning line | Floating line inside the System, with or without corks | Marine Mammals<br>Sea Turtles<br>Fish/Sharks<br>Seabirds | +/- Vibration from pre-warning line likely will result in avoidance of the System, but placement 10 to 15 m before retention zone (RZ) may be too late for smaller biota to escape. Likely to make a difference for sharks, sunfish, and marine mammals.<br>- Weighted scare/herding lines would likely add entanglement risk for marine mammals, sea turtles, and seabirds. | Not implemented for operating reasons (not enough time to add to design before survey, limited deck space, would require additional handling). |
| Increased mesh size at the bottom of the wings netting – Option 1 | 40-mm × 40-mm square mesh (last 10 m of wings netting) | Sea Turtles<br>Fish/Sharks<br>Neuston | + Potential to reduce bycatch. | Not implemented due to potential to impact the plastic-capturing performance of the System. |
| Increased mesh size at the bottom of the wings netting – Option 2 | 80-mm × 80-mm square mesh (last 25 m of wings netting) | Sea Turtles<br>Fish/Sharks<br>Neuston | + Potential to reduce bycatch. | Not implemented due to potential to impact the plastic-capturing performance of the System. |
| Panels of increased netting mesh at cod-end bottom | Inside the last section of the cod-end, stripes of bigger mesh (options: 10-mm × 10-mm or 40-mm × 40-mm) would allow small fish to exit through the bottom while plastic is retained at the top. Mitigation is considered especially valuable for juvenile fish, the most likely component of bycatch. | Juvenile and Pre-juvenile Fish | + Potential for juvenile fish to actively exit through excluder openings if water flow is reduced. | Not implemented due to potential to impact the plastic-capturing performance of the System. |
| Increased netting mesh in the first 5 m of the RZ entrance bottom | 80-mm × 80-mm square mesh extending for 5 m inside the RZ. | Sea Turtles<br>Fish/Sharks<br>Neuston | + Potential to reduce bycatch. | Not implemented due to potential to impact the plastic-capturing performance of the System. |
| Modified turtle excluding device (TED) | Grid to exclude sharks, rays, sharks, and sea turtles built inside the RZ. | Sea Turtles<br>Fish/Sharks | + Potential to reduce bycatch. | Not implemented due to potential to impact the plastic-capturing performance of the System. |

Table 2-5. (Continued).

| Name | Mitigation Measure | Target Resource | Assessment of Effectiveness and Comments | Rational for Not Implementing |
|---|---|---|---|---|
| Use of bird-scaring lines, tori lines, and Rory lines | Line from the vessel to the RZ to reduce bycatch during tow (for albatross) and during retrieval (for smaller birds). | Seabirds | + Potential to reduce bycatch. | Not implemented due to potential impact to System operations. |
| Marine life – RZ side escape routes | Side opening to allow fish to escape before the cod-end. | Fish/Sharks | + Potential to reduce bycatch. | Too late in net design process to implement. |
| Weak links in RZ | Weak connection in key points of cod-end that break away if a marine mammal, sea turtle, or larger fish/shark gets trapped. | Marine Mammals<br>Sea Turtles<br>Fish/Sharks | + Used by commercial fishermen to reduce bycatch. | Too late in net design process to implement. |
| Technology Measures | | | | |
| Acoustic Sonar | Forward-looking sonar to identify marine mammals or other large objects in the project area. | Marine Mammals | + Useful in avoiding marine mammals during reduced visibility/nighttime when environmental observers (EOs) cannot. | Unable to evaluate use because not commonly equipped on Maersk vessels. Need to assess feasibility of the System on the vessel for mounting, cost, and monitoring. |
| Operational Measures | | | | |
| Varying tow speeds adjusted for specific time frames (adaptive towing) | Depending on time of day and weather/visibility conditions, implement different speeds (0.0, 0.5, 1.0, and 1.5 m $s^{-1}$). | Neuston | - Tow speeds not considered effective mitigation to avoid capturing neuston. However, a slack period prior to plastics collection or at set intervals (e.g., tow for 2 hours, slack for 10 minutes) may allow some captured species to escape. | Not implemented fully because at lower tow speeds, there is potential to impact the plastic-capturing performance of the System, fuel consumption, and ability to control the System in the water. |
| Adjust operations for specific time frames (adaptive towing) | Tow operations adjusted depending on time of day (daylight, nighttime, dawn, dusk), considering Great Pacific Garbage Patch ecology patterns. | Neuston | + Towing at night would reduce bycatch of seabirds. Also indicates limiting discharges (food waste) from the vessel to times when not towing to avoid attracting birds.<br>+/- Some neuston species (e.g., salps, copepods, several small fish species) are known to undergo diel vertical migration. | Not implemented due to potential to impact the plastic-capturing performance of the System. |

+ = positive effectiveness, - = negative effectiveness.

# 3 Legislative and Regulatory Environment

The Ocean Cleanup has its statutory seat in The Netherlands, and its activities are subject to Dutch law. States have a duty of care in relation to all operations, activities, and processes conducted under their jurisdiction or in areas where they exercise sovereign rights under the terms of various international conventions (e.g., on the basis of Article 194, paragraph 2 of United Nations Convention on the Law of the Sea [UNCLOS]). The Netherlands, therefore, has an obligation to ensure the activities undertaken by The Ocean Cleanup are in accordance with international standards in order to guarantee that the marine environment, maritime safety, and the rights of other users of the high seas are not put in jeopardy.

For this reason, and in view of the uniqueness of The Ocean Cleanup's System, the Dutch State and The Ocean Cleanup concluded the 2018 "Agreement between the State of the Netherlands and The Ocean Cleanup concerning the deployment of Systems designed to clean up plastic floating in the upper surface layer of the high seas" (the Agreement). The Agreement follows, to the extent possible, the legislation applicable to ships permitted under Dutch law to fly the Dutch flag. The Ocean Cleanup's Systems also bear national identification markings, so their origin and relationship to the Netherlands are clearly visible (Article 1.5 of the Agreement). Moreover, the Agreement was drawn up by analogy to the general principles applicable to marine scientific research, as set out in Part XIII of UNCLOS. UNCLOS requires the elaboration and design of the project be such as to guarantee that every System is sufficiently safe, does not endanger shipping, and complies with regulations for the protection and preservation of the marine environment. The Agreement, therefore, includes, among other things, arrangements with regard to maritime safety (Chapter 2), the protection of the marine environment (Chapter 3), and other uses of the high seas (Chapter 4). Although S03 will be towed by two Danish vessels during deployment, it is agreed between the Dutch State and The Ocean Cleanup that the Agreement continues to apply to The Ocean Cleanup's System.

The Ocean Cleanup is mobilized out of the Victoria, British Columbia area and will deploy the S03 within the NPSG. Under this mobilization and deployment scenario, The Ocean Cleanup transits through Canadian coastal waters and Canada's exclusive economic zone (EEZ) before reaching international waters. All deployment and testing of the System occurs in the NPSG, which is located on the high seas (**Section 3.1**). Consequently, and complementing Dutch law and the terms of the Agreement, legislative and regulatory requirements include all international norms applicable to The Ocean Cleanup's activities on the high seas. In absence of an obligation for The Ocean Cleanup to report incidental harassment of protected species on the high seas, The Ocean Cleanup will voluntarily report such incidental harassments (if any) caused by the deployment of S03 on the high seas to the Dutch ministry on an informal basis. The legislative and regulatory requirements also include Canadian regulations, which are applicable during the System's transit within Canadian maritime territory.

Brief descriptions of some of the main requirements and regulations involved are provided in the following subsections.

## 3.1 UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS) AND AREAS BEYOND NATIONAL JURISDICTION

Areas beyond national jurisdiction (ABNJs) are areas of ocean for which no single nation has sole responsibility for management. They are recognized as providing habitat for a significant marine biodiversity component, including unique species that have evolved to survive the extreme conditions present (e.g., heat, cold, salinity, pressure, darkness). ABNJs hold unique oceanographic and biological features and play a significant role in climate regulation (Premti, 2018).

UNCLOS provides that ABNJs include 1) the water column beyond the EEZ, or beyond the Territorial Sea where no EEZ has been declared, called the “high seas” (Article 86); and 2) the seabed that lies beyond the limits of the continental shelf, established in conformity with Article 76 of UNCLOS, designated as “the Area” (Article 1). Therefore, by definition, the upper portion of the water column within the NPSG is included in the high seas portion of ABNJs. This region is where The Ocean Cleanup will be testing the S03.

A comprehensive global framework for the conservation and sustainable use of ABNJs and to halt and prevent further degradation from human activities is currently under discussion. Until a new international instrument regulating ABNJs is agreed upon, the most relevant international legal regime governing those portions of the ocean outside of any specific State’s jurisdiction can be found under UNCLOS. Article 192 of UNCLOS requires signatories to protect and preserve the marine environment; however, there are no specific mechanisms or processes under UNCLOS for conserving marine biodiversity in ABNJs (Warner, 2014).

While existing regulations govern the exploration and exploitation of the seabed in ABNJs (under the auspices of the International Seabed Authority), there are no current regulations addressing such uses of the water column in ABNJs. Notwithstanding the absence of ABNJ regulations pertinent to the water column, there has been recent activity to protect marine biodiversity within ABNJs. The United Nations General Assembly adopted Resolution 72/249 in December 2017 to convene an intergovernmental conference (IGC) to develop an international, legally binding instrument on ABNJ marine biodiversity. The first three sessions of the IGC took place on 4 to 17 September 2018, 25 March to 5 April 2019, and 19 to 30 August 2019. The fourth IGC meeting, originally slated for 23 March to 3 April 2020, was postponed and convened from 7 to 18 March 2022. The IGC’s progress to date includes addressing four key ABNJ issues: 1) marine genetic resources, including questions on benefit-sharing; 2) EIAs; 3) area-based management tools, including marine protected areas (MPAs); and 4) capacity building and marine technology transfer.

Most relevant to The Ocean Cleanup and the testing of the S03 are the evolving requirements related to EIAs. The IGC recognizes the importance of EIAs as tools to integrate environmental considerations into decision-making. While definitive guidance regarding EIA content remains to be determined, the IGC has acknowledged that protection of ecologically or biologically significant or vulnerable areas is a priority, and that an EIA should be developed for planned activities under a State’s jurisdiction and control if those activities may result in pollution or an adverse change to the marine environment (Premti, 2018). As negotiations are ongoing, the S03 EIA is being prepared in line with the guiding environmental considerations as well as the draft provisions of the prospective treaty governing ABNJs.

## 3.2 UNITED NATIONS HIGH SEAS TREATY/BIODIVERSITY BEYOND NATIONAL JURISDICTION TREATY

On 4 March 2023, global negotiations concluded on the Treaty of the High Seas for the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction. The treaty is an agreement under UNCLOS and is also known as the Biodiversity Beyond National Jurisdiction treaty. The purpose of the treaty is to find solutions to issues related to biodiversity beyond national jurisdiction. The issues stem from the lack of environmental safeguards, under UNCLOS, with respect to the growing number of human activities conducted in international waters, and the related degrading condition of the high seas. The new treaty reflects an attempt by the international community to address these issues through the adoption of a set of new tools, including:

1. a regime for the exploitation of marine genetic resources and the sharing of benefits derived therefrom;
2. a requirement to conduct environmental impact assessments on planned activities that may lead to substantial pollution or harmful changes to the marine environment;
3. a framework for the establishment of a network of area-based management tools and MPAs; and
4. mechanisms for capacity-building and the transfer of marine technologies from developed to developing states.

Each of these tools shall enter into force in areas beyond national jurisdiction after the treaty is officially adopted by the United Nations and ratified by 60 member states; and this process is likely to take some time. The treaty also creates new international bodies that will oversee its implementation, including a conference of parties, a secretariat, a scientific and technical body and an implementation and compliance committee. At present, the tools of this treaty are not yet being enforced, but as The Ocean Cleanup moves towards full scale development, the tools will be taken into consideration.

## 3.3 INTERNATIONAL CONVENTIONS PREVENTING POLLUTION FROM SHIPS

The Ocean Cleanup endeavors to comply fully with all international norms regulating discharge from ships and prohibiting maritime pollution. A key legal instrument in this regard is the 1973 International Convention for the Prevention of Pollution from Ships, also known as MARPOL.

MARPOL was developed by the International Maritime Organization in an effort to reduce marine pollution from vessels. In 1978, MARPOL was updated to include five annexes on ocean dumping; the sixth annex, addressing vessel-based air pollution, was promulgated in 1997. By signing MARPOL, countries agree to enforce Annexes I and II (control of ship-based discharges of oil and noxious liquid substances) of the treaty. Annexes III (harmful substances), IV (sewage), V (prevention of pollution by garbage from ships), and VI (prevention of air pollution from ships) are optional. Both the Netherlands and Canada are signatories to all the optional MARPOL annexes.

Annex V is of particular importance to the maritime community, including shippers, oil platform personnel, fishers, and recreational boaters because it prohibits the disposal of plastic at sea and regulates the disposal of other types of garbage at sea. Pursuant to the main text of MARPOL, unlawful discharge does not include any release for purposes of legitimate scientific research into pollution abatement and control.

Prohibitions on the disposal of waste in the high seas are also found under the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its 1996 Protocol (London Protocol), the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention), the 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), as well as Article 210 of UNCLOS. All these legal instruments seek to combat the deliberate disposal of waste and harmful substances from a vessel and provide exemptions for purposes other than disposal or non-deliberate disposal of waste.

## 3.4 APPLICABLE CANADIAN ENVIRONMENTAL NORMS

The primary Canadian laws requiring an assessment of potential environmental impacts associated with major discretionary projects include the Canadian Environmental Protection Act (CEPA) and the Oceans Act, which is Canada's primary marine protection law.

The deployment location in the NPSG is in international waters, outside the permitting jurisdiction of Canadian agencies. Further, the activities being conducted by The Ocean Cleanup will not use Canadian-flagged vessels. Consequently, Canadian permits that might otherwise be required for a project of this nature are not required. Nevertheless, in the interest of transparency and to assess the project activities for potential environmental impacts and identify potential mitigation measures, this EIA was prepared to meet the International Association for Impact Assessment (1999) Principles of Environmental Impact Assessment Best Practices and current guidance (e.g., Brownlie and Treweek, 2018), including consideration of local environmental laws and regulations.

The Ocean Cleanup will comply with relevant regulations when transiting near shore and within the Canadian EEZ. As required, The Ocean Cleanup will issue a Notice to Mariners specifying anticipated transit dates from the Victoria area and deployment dates in the NPSG. Brief descriptions of relevant Canadian environmental laws are presented in the following subsections.

### 3.4.1 Canada Shipping Act (2001)

The Canada Shipping Act of 2001 is the Canadian law implementing MARPOL 73/78 (**Section 3.1**) in Canadian waters. Transport Canada is the enforcement agency for MARPOL 73/78 Annex V within the Canadian EEZ (within 370 km of the Canadian shore). Regulations primarily related to environmental matters under the Canada Shipping Act and applicable to The Ocean Cleanup vessel operations that are presently in force include the Regulations for the Prevention of Pollution from Ships and for Dangerous Chemicals (in force under the Canada Shipping Act as of 16 May 2007) and the Ballast Water Control and Management Regulations (in force under the Canada Shipping Act as of 8 June 2006) (Bird and Purcell, 2007).

Under MARPOL 73/78 Annex V, as implemented under the Canada Shipping Act, it is illegal to discard plastic waste off any vessel within the Canadian EEZ, except as part of scientific research into pollution control and abatement. It is also illegal to dispose of any other garbage (e.g., orange peels, paper plates, glass jars, monofilament fishing line) overboard while navigating inland waters or within 5 km of shore. The greater the distance from shore, the fewer restrictions apply to non-plastic garbage. However, in general, dumping plastics overboard in any Canadian waters is illegal at any time. Garbage must be brought ashore and properly disposed of in a trash can, dumpster, or recycling container. Docks and marinas are required to provide facilities to handle normal amounts of garbage from their paying customers.

### 3.4.2 Species at Risk Act (2002)

The Species at Risk Act (SARA) was enacted in 2002. The act was designed to 1) prevent wildlife species in Canada from becoming extirpated or extinct, 2) provide a strategy for recovery of species that became extirpated as a result of human activity, and 3) guide the management of species of concern to prevent them from becoming threatened or endangered. SARA is administered by the Minister of the Environment and Climate Change.

The S03 is being deployed in international waters using non-Canadian-flagged vessels and is not subject to SARA rules and regulations except while completing routine transit operations near shore and within the Canadian EEZ. When operating within the Canadian EEZ, it is highly unlikely that transit operations will result in the take of any SARA-listed species due to the extremely slow speeds used in nearshore shipping lanes.

### 3.4.3 Fisheries Act (2019)

The Fisheries Act of 2019 is a broad act that provides protection for fish and fish habitat, protects biodiversity, guides permitting for development project, and addresses habitat restoration and fish stock, among other guidance. The Fisheries Act was originally promulgated in 1868, with a series of subsequent revisions and updates occurring over the years. On 28 August 2019, provisions of the revised Fisheries Act came into force, including new protections for fish and fish habitat in the form of standards, codes of practice, and guidelines for projects near water. The Fisheries Act, which is administered by the Minister of the Environment and Climate Change on behalf of the Minister of Fisheries and Oceans, allows for the promulgation of specific regulations addressing marine mammals (**Section 3.3.4**), aquatic invasive species, province-specific fishing, and numerous others.

The Fisheries Act contains two key provisions relating to the conservation and protection of fish habitat essential to sustaining both freshwater and marine fish species. The Department of Fisheries and Oceans administers Section 35, the key habitat protection provision, prohibiting any project or activity that would cause the harmful alteration, disruption, or destruction of fish habitat. Environment and Climate Change Canada administers Section 36, the key pollution prevention provision, prohibiting the deposit of deleterious substances into waters frequented by fish, unless authorized by regulations under the Fisheries Act or other federal legislation (Government of Canada, 2020a).

The S03 is being deployed in international waters using non-Canadian-flagged vessels and is not subject to Fisheries Act rules and regulations except while completing routine transit operations near shore and within the Canadian EEZ. When operating within the Canadian EEZ, it is highly unlikely that transit operations will result in any negative impacts to fisheries, fish habitat, or biodiversity due to the routine nature of the transit activities.

### 3.4.4 Marine Mammal Regulations of the Fisheries Act (2018)

Promulgated under the Fisheries Act, the Marine Mammal Regulations were first enacted in 1993 as a consolidation of various regulations of individual species/taxa and were last amended in 2018. The Marine Mammal Regulations address conservation, management, and control of fishing of all marine mammals in Canadian waters. The Marine Mammal Regulations are administered by the Minister of the Environment and Climate Change on behalf of the Minister of Fisheries and Oceans.

The S03 is being deployed in international waters using non-Canadian-flagged vessels and is not subject to the Marine Mammal Regulations except while completing routine transit operations near shore and within the Canadian EEZ. When operating within the Canadian EEZ, it is highly unlikely that transit operations will result in any negative impacts to marine mammals due to the routine nature of the transit activities (MPANetwork, 2021).

### 3.4.5 Canadian Environmental Protection Act (1999)

The CEPA was promulgated in 2000. CEPA is aimed at preventing pollution and protecting the environment and human health. Notably, CEPA manages environmental impacts of marine pollution and disposal at sea.

The S03 is being deployed in international waters using non-Canadian-flagged vessels and is not subject to CEPA rules and regulations except while completing routine transit operations near shore and within the Canadian EEZ. When operating within the Canadian EEZ, it is highly unlikely that transit operations will result in any negative environmental impacts due to the routine nature of the transit activities.

### 3.4.6 Oceans Act (1996)

Administered by Fisheries and Oceans Canada, the Oceans Act is Canada's primary marine protection law and first came into force in 1997. Among other provisions, the Oceans Act outlined ocean management, MPAs, and marine environmental quality standards. The Oceans Act was updated with amendments in 2019.

There are several different terms used to describe MPAs in Canadian waters, depending on the legislation used to establish them. These include MPAs established under the Oceans Act, national marine conservation areas, national parks, marine wildlife areas, provincial parks, ecological reserves, conservancies, and various First Nations designations (MPANetwork, British Columbia Northern Shelf, 2021).

The S03 is being deployed in international waters using non-Canadian-flagged vessels and is not subject to the Oceans Act rules and regulations except while completing routine transit operations near shore and within the Canadian EEZ. When operating within the Canadian EEZ, it is highly unlikely that transit operations will result in any negative environmental impacts due to the routine nature of the transit activities. If possible, The Ocean Cleanup will avoid Canadian MPAs and other protected areas during transit from the Victoria area to the NPSG.

### 3.4.7 Migratory Birds Convention Act (2005)

The Migratory Birds Convention Act of 1917 (amended 1994 and 2005) is the primary legislation in Canada for the conservation of migratory birds. The Migratory Birds Convention Act allowed implementation of the Migratory Bird Convention, a treaty signed in 1916 with the United States (U.S.). Consequently, Canadian authorities passed the Migratory Birds Regulations (**Section 3.3.8**). The Minister of the Environment and Climate Change manages the Migratory Birds Convention Act.

### 3.4.8 Migratory Birds Regulations

Promulgated under the Migratory Birds Convention Act (2005), the Migratory Birds Regulations protect bird species that are included in the Migratory Bird Convention. This Act is similar to the U.S. Migratory Bird Treaty Act, although the list of protected species differs.

The S03 is being deployed in international waters using non-Canadian-flagged vessels and is not subject to the Migratory Bird Regulations except while completing routine transit operations near shore and within the Canadian EEZ. When operating within the Canadian EEZ, it is highly unlikely that transit operations will result in any negative impacts to migratory birds due to the routine nature of the transit activities.

### 3.4.9 International Union for Conservation of Nature

The International Union for Conservation of Nature (IUCN) is a membership union composed of government and civil society organizations. Created in 1948, the IUCN has evolved into the world's largest and most diverse environmental network. The IUCN is the global authority on the status of the natural world and the measures needed to safeguard it.

The IUCN Red List of Threatened Species (Red List) provides taxonomic, conservation status, and distribution information on plants, fungi, and animals that have been globally evaluated using the IUCN Red List Categories and Criteria. This system is designed to determine the relative risk of individual species' extinction. The main purpose of the IUCN Red List is to catalogue and highlight the plant and animal species facing a higher risk of global extinction (i.e., those listed as Critically Endangered, Endangered, and Vulnerable). The Red List is widely recognized as the most comprehensive, objective global approach for evaluating the conservation status of plant and animal species. In 1994, a scientifically rigorous approach to determine risks of extinction, applicable to all species, was introduced and has become a world standard. Far more than a list of species and their status, the IUCN Red List is a powerful tool to inform and catalyze action for biodiversity conservation and policy change (IUCN, 2021).

The IUCN Red List status of many of the resources that may be impacted from the deployment of the S03 are included in **Section 4.3**. Although most of the regulatory acts discussed only apply while transiting near shore and within the Canadian EEZ, the Red List provides an internationally recognized conservation status of these biological resources. The Ocean Cleanup's towing and deployment activities have been designed to minimize impacts to marine species, and the removal of plastic from the NPSG will result in a beneficial impact.

## 4.1 PRELIMINARY SCREENING OF ACTIVITIES AND AFFECTED RESOURCES

A preliminary screening was conducted to identify the resources at risk from the S03 deployment in the NPSG. Screening allows for completion of a focused impact analysis by eliminating (from detailed analysis) resources with little or no potential for adverse or significant impact. This approach focuses the analysis on the resources at greatest impact risk. A matrix was developed to list environmental resources in the vicinity of the transit and deployment as well as project activities that may impact resources (**Table 4-1**). In this preliminary analysis, the level of impact associated with each interaction was categorized as "potential impact for analysis" (i.e., a measurable impact to a resource is predicted) or "no impact expected" (i.e., no measurable impact to a resource is evident).

Several resources were identified as having no expected impacts from the project activities. Rationale for exclusion of these resources from further analysis are detailed in the following subsections.

Table 4-1. Preliminary screening of potential impacts.

| Resource | Impact-Producing Factor | | | | | |
|---|---|---|---|---|---|---|
| | S03 – Entanglement/ Entrapment | S03 – Attraction/ Ingestion of Plastics | Vessel – Physical Presence/ Strikes | Noise and Lights | Loss of Debris | Accidental Small Fuel Spill |
| Air Quality | -- | -- | -- | -- | -- | -- |
| Sediment Quality | -- | -- | -- | -- | -- | -- |
| Water Quality | -- | -- | -- | -- | -- | -- |
| Fish/Fishery Resources | ● | ● | -- | ● | ● | ● |
| Plankton | ● | ● | -- | ● | -- | ● |
| Neuston | ● | ● | -- | ● | -- | ● |
| Benthic Communities | -- | -- | -- | -- | -- | -- |
| Marine Mammals | ● | ● | ● | ● | ● | ● |
| Sea Turtles | ● | ● | ● | ● | ● | ● |
| Coastal and Oceanic Birds | ● | ● | ● | ● | ● | ● |
| Protected Areas | -- | -- | ● | -- | -- | ● |
| Biodiversity | U | U | U | U | U | U |
| Commercial and Military Vessels | -- | -- | ● | -- | -- | -- |
| Archaeological Resources | -- | -- | -- | -- | -- | -- |
| Human Resources, Land Use, and Economics | -- | -- | -- | -- | -- | -- |
| Recreational Resources and Tourism | -- | -- | -- | -- | -- | -- |
| Physical Oceanography | -- | -- | -- | -- | -- | -- |

● indicates a potential impact; - indicates no impact expected; U indicates there is not enough information at this time to assess.

### 4.1.1 Air Quality

Potential impacts from emissions on air quality are expected to be negligible. Vessels (transiting, monitoring, and debris collection), machinery, and equipment involved in The Ocean Cleanup's activities emit a variety of air pollutants, including nitrogen oxides, sulfur oxides, PM, volatile organic compounds, carbon monoxide, and greenhouse gases (e.g., $CO_2$), primarily from combustion of fossil fuels for propulsion and power generation. The amount of air pollutants and greenhouse gases generated during The Ocean Cleanup activities primarily depends on the number, design, and size of the vessels; the size of engines and generators on the vessels; the distance traversed under power; and overall duration of the activities. Based on the vessels used and actual fuel consumption, the fuel consumption has been less than anticipated. Further, the average combined total of $CO_2$ emissions per campaign was determined to be 2,473 mt.

Ambient air quality in the Vancouver area is generally deemed healthy, typically posing little to no risk to human health. While annual air quality averages rank Vancouver among the cleanest major cities in the world, unhealthy short-term pollution spikes are not uncommon. There were 30 incidents of short-term air pollution documented in 2019, based on one or more exceedances, including 1) 24-hr average $PM_{2.5}$ concentration >25 µg $m^{-3}$; 2) 1-hr average nitrogen dioxide concentration >200 µg $m^{-3}$; 3) 24-hr average sulfur dioxide concentration >20 µg $m^{-3}$; and 4) 8-hr ground-level ozone concentration >52 parts per billion (IQAir, 2021*)*.

Air emissions from The Ocean Cleanup vessels will contribute nominal amounts of pollutants to the emissions inventories attributed to other vessels in the waters offshore Vancouver. Project vessels will have a short-term, limited impact to ambient air quality in the Vancouver area, primarily due to the short duration of vessel presence while berthed (during mobilization) and during transit close to the Canadian coastline. In addition, The Ocean Cleanup has and will continue to compensate/offset all $CO_2$ emissions produced for the project execution and by the vessels' operation.

Air quality could also be temporarily affected by an accidental fuel spill in the immediate vicinity of vessel operations, but due to the small volume of a potential spill and the high volatility of refined fuels, any impacts on air quality are expected to be negligible (i.e., localized, short term). For these reasons, a more extensive analysis of air quality emissions associated with anticipated operations will not be performed as part of this EIA.

### 4.1.2 Sediment Quality

There are no project activities by The Ocean Cleanup that could have substantial impacts on sediment quality. No anchors or other bottom disturbing activities will occur during the transit or deployment. However, with the removal of plastics the potential of plastics deteriorating and sinking to the seafloor would provide a beneficial impact to sediment quality. Consequently, a more detailed analysis of potential impacts to sediment quality will not be performed as part of this EIA.

### 4.1.3 Water Quality

Potential impacts from vessel discharges on water quality are expected to be negligible. A summary of estimated project discharges, including sanitary waste, domestic waste, and food waste for the S03 campaigns is provided in **Table 2-4**. The project vessels will discharge treated sanitary and domestic wastes in compliance with MARPOL 73/78, Annex IV along with miscellaneous discharges (e.g., deck drainage, bilge water, machinery space drainage). Most discharges will occur in international waters beyond the Canadian EEZ and will quickly become diluted in seawater.

All vessels are subject to the regulations of MARPOL 73/78, as modified by the Protocol of 1978 (**Section 3.2**). MARPOL 73/78 includes six annexes that cover discharge of oil, noxious liquid substances, harmful packaged substances, sewage, garbage, and air pollution (International Maritime Organization, 2017). Annex V specifically prohibits plastic disposal anywhere at sea and severely restricts discharge of other garbage (International Maritime Organization, 2017). Adherence to these regulations minimizes or negates the likelihood of discharges of potentially harmful substances into the marine environment.

Water quality could be temporarily affected by an accidental fuel spill in the immediate vicinity of the spill. The extent and persistence of water quality impacts from a small diesel fuel spill would depend on the meteorologic and oceanographic conditions at the time and the effectiveness of spill response measures, but diesel fuel rapidly evaporates and is completely degraded by naturally occurring microbes (National Oceanic and Atmospheric Administration [NOAA], 2006). Impacts to water quality from an accidental fuel spill are not expected to be significant. For these reasons, more detailed analysis of water quality impacts associated with anticipated The Ocean Cleanup activities will not be performed as part of this EIA.

Water quality could be affected by the introduction of invasive species from ballast water used and discharged by the tow vessels; however, the potential for this is minimal and would not be different from other vessels traveling internationally. In addition, plastics are known to provide a vector for invasive species (**Section 5.2.1**).

### 4.1.4 Benthic Communities

There are no project activities that could have substantial impacts on benthic communities. No anchors or other seafloor-disturbing activities will occur during the transit or deployment. However, with the removal of plastics the potential of plastics deteriorating and sinking to the seafloor and potentially impacting benthic communities would provide a beneficial impact. Consequently, a more detailed analysis of impacts to benthic communities will not be performed as part of this EIA.

### 4.1.5 Archaeological Resources

No impacts to archaeological resources are anticipated from The Ocean Cleanup's activities. No seafloor-disturbing activities are being conducted that could impact shipwrecks or other submerged archaeological resources. Mobilization is expected to occur in the Victoria area in a developed, industrial area with no known archaeological resources nearby. The project does not involve any new land-based development. However, with the removal of plastics the potential of plastics deteriorating and sinking to the seafloor and potentially impacting archaeological resources would provide a beneficial impact. Consequently, a more detailed analysis of archaeological resources will not be performed as part of this EIA.

### 4.1.6 Human Resources, Land Use, and Economics

No substantial impacts to human resources, land use, or economics are expected from The Ocean Cleanup's activities. Project activities will result in a minor positive economic benefit from payments to federal, provincial, and/or local authorities and private parties for port fees, fuel, other miscellaneous purchases, potential employment opportunities during mobilization, and other incidental expenses incurred while in the Victoria area. No alteration to land use is being conducted, and no new ports or other infrastructure will be built. Collected plastics will be transported to the Victoria area in sealed containers before being forwarded to The Ocean Cleanup's facility in the Netherlands.

### 4.1.7 Recreational Resources and Tourism

Impacts to recreational resources and tourism from The Ocean Cleanup's activities are expected to be negligible. There are no known recreational or tourism resources in the NPSG as it is in a remote area of open ocean more than 1,800 km from land. Recreational or tourism boating activities may be briefly interrupted during the transit of the project vessels out of the Strait of Georgia and the Strait of Juan de Fuca. The Ocean Cleanup will coordinate with Transit Canada to issue any required Notice to Mariners to mitigate potential impacts. As a result of the temporary and negligible impacts expected, more detailed analysis of potential impacts to recreation resources and tourism will not be performed as part of this EIA.

### 4.1.8 Physical Oceanography

Physical oceanographic resources will not be affected by The Ocean Cleanup's activities and associated discharges; impacts to physical oceanography are expected to be negligible. Ocean current characteristics, water column density stratification, wave height, directional spectra, and vertical current structure, among other factors, will be considered during planning, deployment, and debris recovery operations. Consequently, a more detailed analysis of physical oceanography will not be performed as part of this EIA.

## 4.2 DATA SOURCES

Utilizing information provided by The Ocean Cleanup and the CSA Ocean Sciences Inc. (CSA) Research Library facility, CSA conducted a comprehensive review of literature, previously completed environmental studies, and EIAs concerning projects in the region as well as engaging independent subject matter experts on specific topics (e.g., neuston, plankton). Information specific to the project area is limited; as such, regional data were used to characterize the marine environment in the project area and have been updated to include actual data collected during Campaigns 1 through 12.

### 4.2.1 Analysis of Incomplete or Unavailable Information

When evaluating reasonably foreseeable significant adverse effects on the human environment in an EIA and when information is incomplete or unavailable, the technical experts shall make clear that such information is lacking. When incomplete or unavailable information was identified, the technical experts considered whether the information was relevant to the assessment of impacts and essential to its analysis of alternatives based upon the resource analyzed. The Ocean Cleanup technical experts then applied acceptable scientific methodologies to inform the analysis in light of this incomplete or unavailable information. For example, due to the remote nature of the project area, there is limited available data for several resources (i.e., neuston, plankton, air quality, sediment quality, water quality, benthic communities, archaeological resources). However, many of the resource areas that were identified as having limited data, were screened out in the EIA due to the project not impacting those resources. However, neuston and plankton may be impacted by the project; and therefore, The Ocean Cleanup has collected data to assist in filling this data gap. The neuston and plankton data collected is included in this EIA. In addition, subject matter experts have used the best available science and accepted scientific methodologies to evaluate impacts on the resources where incomplete or unavailable information was identified.

## 4.3 BIOLOGICAL ENVIRONMENT

The eastern region of the NPSG is a well-known open ocean ecosystem that contributes significantly to global primary production and export production. Primary production is the total amount of organic matter produced by phytoplankton in the surface layer, whereas export production is the fraction of primary production exported from the surface layer (Yoon et al., 2022). The physical characteristics of the water column and the biological productivity in the eastern NPSG can directly and indirectly affect variations in the two leading North Pacific climate modes: 1) the Pacific decadal oscillation, which is primarily associated with the changes in the strength of the Aleutian low-pressure system; and 2) the North Pacific gyre oscillation, which is directly connected to the variations in the north-south dipole pattern of sea level pressure (Yoon et al., 2022).

In oceanic systems, including the NPSG, photosynthesis is the primary source of organic carbon and energy, but the subsequent pathways and mechanisms for carbon cycling and energy dissipation are less well understood (Grabowski et al., 2019). The sinking and subsequent aging of PM in the NPSG can cause dramatic changes in the upper 500 m of the water column (Grabowski et al., 2019). Other studies have shown that deep carbon sequestration occurs in the eastern NPSG (Yoon et al., 2022).

### 4.3.1 Plankton

#### *4.3.1.1 Plankton in the North Pacific Subtropical Gyre*

The NPSG is a large system of circulating currents covering an area from approximately 15° to 35° N latitude and 135° E to 135° W longitude. With a surface area of approximately $2 \times 10^7$ $km^2$, the NPSG is the largest circulation feature on the planet (Karl, 1999). The NPSG includes a broad range of habitats that are temporally and spatially variable (Karl, 1999; Karl and Church, 2017).

Within the NPSG, there is limited information on the plankton community structure. However, what is known indicates picoplankton, or extremely small (between 0.2 and 2 µm) plankton, is the dominant group in terms of abundance (more than 50% of the total), while relative abundance of diatoms and dinoflagellates is <15% of the total (Uitz et al., 2006, 2010). *Prochlorococcus*, a cyanobacteria, accounts for >75% of the photoautotrophic biomass in the upper portion of the water column (Karl et al., 2001).

Zooplankton biomass peaks are observed during the summer months of highest primary productivity. Increased sea surface temperature, stratification, and nitrogen fixation occur during summer, which is reflected in peaks of primary production and zooplankton biomass. Many species of zooplankton undergo diel vertical migration where they move up to the epipelagic zone in the water column at night and return to the mesopelagic zone during the day.

Seasonality in phytoplankton has also been observed. During summer, surface species are found in the upper 75 m, whereas deep species found from 75 to 150 m bloomed in winter (Campbell et al., 1997; Batten and Freeland, 2007). Studies show low plankton abundance in winter associated with the North Pacific Current (Batten and Freeland, 2007), an eastward-flowing current that splits into the southward-flowing California Current and the northward-flowing Alaska Current within the southeastern Gulf of Alaska.

Studies related to other plankton groups, like diatoms, show low concentrations of diatom cells throughout the year, although distinct assemblages were observed in the mixed layer and in the deep chlorophyll maximum layer. However, a conspicuous increase in diatom concentration was observed, particularly in the mixed layer in July, mainly by *Hemiaulus hauckii* and *Mastogloia woodiana* (Scharek et al., 1999).

Summer plankton blooms are a common seasonal phenomenon in the NPSG. A high-frequency area of bloom occurrences in the NPSG is generally centered along 30° N, about 130° to 160° W (Dore et al., 2008). The largest historical blooms have covered more than 350,000 $km^2$ and lasted up to four months (Wilson, 2003). Blooms occur annually between June and October and generally coincide with sea surface temperatures >25°C and a mixed layer depth <70 m. Some blooms are dominated by *Richelia*-diatom symbioses, while others by *Trichodesmium*, a filamentous cyanobacteria (White et al., 2007).

#### *4.3.1.2 Gelatinous Macrozooplankton*

Gelatinous macrozooplankton (e.g., jellyfish, ctenophores) belong to the phyla Cnidaria. Little is known about the population abundance or dynamics of most species of jellyfish as many live in open ocean environments. **Table 4-2** lists species reported in the NPSG.

During deployment of S001/B in 2019, an estimated 500 colonies of *Velella velella* were collected in the System as bycatch, indicating their common presence in the NPSG during the collection period. One other species of gelatinous microzooplankton was identified during the 2019 campaign (violet sea snail; *Janthina janthina*); however, the degraded nature of the shells did not allow for an estimate of the number of individuals. During the S002 campaigns, limited numbers of *V. velella* have been collected as bycatch or within the net samples (**Section 4.3.1.7**) and have not been observed biofouling the S002. **Table 4-3** provides the seasonality of the S002 campaign net sampling. The design of the S03 is very different from the previous designs, including using a mesh net system rather than a solid HDPE curtain. Based on observations made during the current campaigns, there was overtopping of the S002 wings by waves and water, which was not completely expected (**Image 4-1**). This overtopping may be contributing to these and other plankton species being able to escape the S002 prior to being captured in the RZ. In addition, there may be a seasonality to the higher presence of *V. velella* captured in the bycatch with the previous System designs. However, some of the design changes for S03 are to reduce the overtopping of the wings. During Campaign 13, which includes the larger RZ and deeper wings, there still was only limited numbers of *V. velella* observed in the RZ.

Image 4-1. Overtopping of the S002 wings.

Table 4-2. Cnidarian species reported in the vicinity of the various Systems deployed in the North Pacific Subtropical Gyre (Data from: Wrobel and Mills, 1998).

| Class | Species | Climate Region or Geographic Range | Dominant Occurrence | Buoyancy (Positive/Neutral) | Feeding |
|---|---|---|---|---|---|
| Hydrozoa | *Aglantha digitale* | North Pacific 40° N to Arctic waters | Arctic water and open ocean | Neutral | At night at surface |
| | *Velella velella* | Tropical and temperate waters | Open ocean | Positive | At surface |
| | *Pegantha* spp. | 40° N to 40° S | Open ocean | Neutral | -- |
| | *Liriope tetraphylla* | 40° N to 40° S | Open ocean and near coast | Neutral | -- |
| | *Physalia utriculus* | North Pacific and Hawaiian waters | Open ocean | Positive | At surface |
| | *Physophora hydrostatica* | Tropical and temperate waters | Deep midwaters | Neutral | Deep waters |
| | *Porpita porpita* | Tropical and sub-tropical waters | Open ocean and near coast | Positive | At surface |
| Scyphozoa | *Aurelia aurita* | 70° N to 40° S | Mostly inshore; can be found in open water | Neutral | Water column |
| | *Aurelia labiata* | North Pacific from California to Japan | Mostly inshore; can be found in open water | Neutral | Water column |
| | *Phacellophora camtschatica* | Temperate waters from Gulf of Alaska to Chile | Open ocean | Neutral | Water column |

-- = Feeding method unknown.

Table 4-3. S002 campaign net sampling seasonality.

| Campaign Number | Start Month | End Month |
|---|---|---|
| 1 | August 2021 | August 2021 |
| 2 | September 2021 | October 2021 |
| 3 | November 2021 | November 2021 |
| 4 | December 2021 | December 2021 |
| 5 | February 2022 | February 2022 |
| 6 | March 2022 | March 2022 |
| 7 | April 2022 | May 2022 |
| 8 | May 2022 | June 2022 |
| 9 | July 2022 | July 2022 |
| 10 | August 2022 | September 2022 |
| 11 | September 2022 | October 2022 |
| 12 | November 2022 | November 2022 |

#### 4.3.1.3 Ichthyoplankton

Data regarding ichthyoplankton in the project area are sparse, but it is likely that many of the pelagic fish species discussed in **Section 4.3.3** may be present in larval form as well. Loeb (1979) described larval fish assemblages in the NPSG. Ichthyoplankton collected from six campaigns resulted in approximately 30,000 individual larvae from over 150 species, primarily mesopelagic species. However, it should be noted that Loeb (1979) reported that fish larvae constituted <2% of the total macrozooplankton collected in the NPSG. While overall fish larvae abundance was not found to differ by season, ichthyoplankton species composition did vary by season. Prominent families included lanternfishes (Myctophidae), bristlemouths (Gonostomatidae), and hatchetfishes (Sternoptychidae), constituting >84% of the larval specimens collected in the NPSG. Ichthyoplankton contributions, by family and for these three predominant families, exhibited similar patterns in the eastern tropical Pacific Ocean, within the California Current offshore area, and in the Indian Ocean (Loeb, 1979).

#### 4.3.1.4 Plankton in the California Current

The California Current is a Pacific Ocean current that flows southward from approximately 50° N latitude (roughly parallel to Vancouver Island) to offshore Baja California, approximately 15° to 25° N latitude. The current is largely driven by atmospheric pressure gradients and winds offshore the west coast of North America (Checkley and Barth, 2009), which are predominantly from the northwest, especially during summer.

The California Current System (CCS) upwelling is generally lowest during the winter and increases to peak levels during the late spring and summer months (Black et al., 2011). From October to March, conditions in the eastern North Pacific, along the western coast of North America, are predominantly downwelling; the water column is well-stratified, the standing stock of primary producers is low, and productivity is generally light or nutrient limited (White et al., 2014).

In the CCS, abrupt changes in zooplankton biomass and community structure on interannual scales are strongly linked to fluctuations of the El Niño Southern Oscillation (Valencia et al., 2016). During El Niño events, a deepening of the nutricline (a zone where nutrient levels decline rapidly with water depth) is expected. Consequently, primary productivity and macrozooplankton biomass decrease. However, individual taxa responses can vary. For example, the biomass of copepods and euphausiids (krill; Euphausiacea) underwent only a minor decrease during the El Niño of 1958 to 1959 (Lavaniegos et al., 2002).

Studies related to zooplankton variations during El Niño/La Niña events show that monthly averaged copepod species richness was anomalously high throughout most of 1996 to 1998 and low from winter 1999 to autumn 2002. The proportion of euphausiids was similar during the period analyzed, but the proportions of copepods and salps changed. Copepods were more abundant during the El Niño Southern Oscillation peak, and salps more abundant in the transition phases between peaks (Lavaniegos et al., 2002).

Seasonality in regional coastal phytoplankton offshore California has also been reported, with concentrations of nano- and microphytoplankton lowest during the winter and highest during the summer (Trujillo et al., 2001). Kahru and Mitchel (2022) showed phytoplankton net primary production (NPP) in the CCS has a strong annual periodicity correlated with El Niño/La Niña events. During El Niño events, NPP was reported to have a 30% reduction 100 to 300 km off southern California, while a 40% increase was observed off Baja California. During its peak, NPP decreased during El Niño by 10% to 15% in the 1,000-km band off Southern California but increased 20% to 30% off northern and southern Baja California. The total annual NPP was lowest during the El Niño years of 1997 to 1998 and peaked in 2000. Trends of increasing NPP and zooplankton volume were observed off Central and Southern California with the onset of La Niña (Kahru and Mitchell, 2002).

The current El Niño/La Niña forecast for 2023, according to NOAA (2023a), indicates a 62% chance for El Niño conditions to develop sometime between May and July.

Shifts in phytoplankton community composition have been observed over the upwelling/downwelling seasonal progression. During upwelling events, diatoms numbers increase due to high nutrient levels, while dinoflagellate concentrations increase during the nutrient-depleted, stratified summer periods and during the phases that interrupt upwelling events.

#### *4.3.1.5 Plankton in the Straits of Georgia and Juan de Fuca*

Plankton communities in the Strait of Georgia and the Strait of Juan de Fuca in the Vancouver area are critical habitats for plankton because they serve as important feeding grounds and migration corridors for several of Canada's Pacific salmon stocks and as spawning areas for herring (Costalago et al., 2020). Historically, plankton in the Strait of Juan de Fuca and surrounding waters have not been well studied. Chester et al. (1980) prepared a report for the U.S. Environmental Protection Agency characterizing the composition of phytoplankton, zooplankton, and ichthyoplankton in the Strait of Juan de Fuca. Results indicated that phytoplankton were primarily composed of flagellates during the fall and winter months, with diatoms blooming in the spring and summer. Zooplankton were dominated by copepods, specifically calanoid and cyclopoid taxa. Ichthyoplankton and fish eggs were most common in late winter and early spring. The most common group identified were smelt (Osmeridae). Other common taxa included Pacific sand lance (*Ammodytes hexapterus*), rockfishes (*Sebastes* spp.), Irish lords (*Hemilepidotus* spp.), sculpins (Cottidae), cods (Gadidae), and lumpfishes (Cyclopteridae) (Chester et al., 1980).

More recent studies have confirmed the findings by Chester et al. (1980) that the plankton food web is largely driven by diatoms and flagellates (Costalago et al., 2020). Moreover, Costalago et al. (2020) showed that, based on analyzed fatty acid composition of zooplankton (e.g., copepods, decapods, euphausiids), the dominant plankton organisms shift seasonally, with diatoms dominant during the spring bloom and flagellates dominant during the summer. This shift is important because it supplies more nutritious food for critical fish stocks in the Straits. A recent 4-year study using liquid chromatography to analyze phytoplankton pigments also identified diatoms as the dominant contributor to annual phytoplankton biomass during spring blooms (Del Bel Belluz et al., 2021). In the summer, other significant phytoplankton in the Strait of Georgia included prasinophytes and cryptophytes (Del Bel Belluz et al., 2021).

Springtime ichthyoplankton taxa were characterized during three field surveys from 2007 to 2010 in the Strait of Georgia by Guan et al. (2017). A total of 49 taxa from 23 families were identified. Species dominance varied by year, but the most common taxa identified were Pacific herring (*Clupea pallasii*), Alaska pollock (*Gadus chalcogrammus*), North Pacific hake (*Merluccius productus*), northern smoothtongue (*Leuroglossus schmidti*), slender sole (*Lyopsetta exilis*), and rockfishes (Guan et al., 2017).

#### *4.3.1.6 Plankton in the Kuroshio Current*

The Kuroshio Current is a subtropical gyre that forms the northwestern boundary of the Pacific Ocean Convergent Zone (Limsakul, 2003). The Kuroshio Current flows north from the Philippines to Japan and then eastward into the North Pacific. The Kuroshio Current consists of warm subtropical and highly saline water (Kawai, 1972; Masuzawa, 1972). The water column of the Kuroshio Current is well stratified, with higher temperatures persisting at the surface and lower temperatures in deeper layers (Kawai, 1972; Masuzawa, 1972). This stratification impedes vertical mixing of nutrients essential for phytoplankton growth (Limsakul, 2003) and results in low phytoplankton and zooplankton abundance with slight seasonal variability (e.g., Reid, 1962; Aruga and Ichimura, 1968; Takahashi et al., 1985; Ondrusek et al., 1991; Ayukai and Hattori, 1992; Furuya et al., 1995;

Sugimoto et al., 1995; Odate and Furuya, 1998). This condition of low abundance is typical of plankton dynamics found in low-latitude seas (Hayward et al., 1983; Hayward and McGowan, 1985; Yoder et al., 1993; Winn et al., 1995).

Wang et al. (2021) sampled along the Kuroshio Current Extension, which operates like a conveyance of warm hypersaline water to help stimulate plankton blooms in higher latitudes of the convergence zone. Collections of phytoplankton resulted in the identification of 81 phytoplankton taxa belonging to 45 genera of 4 phyla. Dominant taxa in both abundance and occurrence included the diatoms *Chaetoceros radicans*, *C. curvisetus*, *C. convolutus*, *C. debilis*, *C. peruvianus*, *Pseudonitzchia delicatissima*, *Coscinodiscus asteromphalus*, *Thalassionema nitzschioides*, *T. frauenfeldii*, and *Thalassiothrix longissimi*; the dinoflagellate *Protoperidinium subpyriforme*; and the cyanobacterium *Trichodesmium thiebautii* (Wang et al., 2021). Wang et al. (2021) found that nutrient limitations, rather than light impedance, influenced phytoplankton during the spring blooms.

#### *4.3.1.7 Plankton Environmental Sampling Results*

As discussed in **Section 2.1.6**, environmental sampling occurred during Campaigns 1 through 12, with a focus on plankton and neuston communities. Sampling included bongo and manta net sampling in front of the System to characterize the existing communities prior to the System passing through the water and plankton net sampling behind the System to see if the species composition differed between the sampling devices. All the sampling nets had 500-µm mesh, and the tows were performed for 10 minutes during different times throughout a 24-hour period (dawn, noon/midday, dusk, and midnight). The bongo and manta net sampling are performed off the side of the M/V *Maersk Tender* or M/V *Maersk Trader*, while the plankton net sampling is performed off the FRC due to the limitations of sampling by hand from the FRC. A total of 399 net tows (194 bongo tows, 143 manta tows, and 62 plankton tows) were performed during Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**). A taxonomic breakdown of the collections by gear type and Campaign is provided in **Appendix C**. The samples were taken to provide additional baseline characterization data for the plankton and neuston communities within the NPSG. Additionally, the samples will be used for comparative purposes of the organisms collected in front of the System with those collected behind the System to compare organisms potentially removed by the System. Comparisons between catches made both in front of and behind the System are presented in **Section 5.2.2.2**.

Catches from the bongo, neuston, and plankton nets are used in this section to characterize zooplankton, neuston, and ichthyoplankton assemblages found in the study area. Although these data are presented by gear type, the emphasis is on structure and taxonomic composition of these assemblages. Analysis of the samples from Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) has been completed and indicate that the three net types collected similar densities of organisms, including crustaceans, tunicates, chaetognaths (arrow worms), mollusks, cnidarians, insects (a single genus), and fishes (**Table 4-4**). The crustaceans accounted for the highest portion (53%) of individuals in all three gear types, followed by tunicates (18.7%) and chaetognaths (9%) (**Table 4-4**). Zooplankton accounted for >99% of all organisms collected in the plankton samples, with fish eggs and larvae contributing <1%.

Table 4-4. Total densities (number m$^{-3}$) of major taxonomic groups collected during Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) using bongo, manta, and plankton nets.

| Habitat | Family | taxon | Mean | pct |
|---|---|---|---|---|
| Mesopelagic | Lanternfishes | *Lampadena urophaos* | 0.0137 | 11.16267 |
| Mesopelagic | Lanternfishes | *Ceratoscopelus townsendi* | 0.0092 | 7.06268 |
| Mesopelagic | Lanternfishes | Myctophidae | 0.0071 | 6.602254 |
| Epipelagic | Sauries | *Cololabis saira* | 0.0138 | 5.297044 |
| Mesopelagic | Lanternfishes | *Taaningichthys minimus* | 0.0113 | 4.858166 |
| Mesopelagic | Lanternfishes | *Diaphus theta* | 0.0038 | 1.808144 |
| Mesopelagic | Dreamers | *Oneirodes* spp. | 0.0029 | 1.788336 |
| Mesopelagic | Lanternfishes | *Triphoturus mexicanus* | 0.0079 | 1.709249 |
| Mesopelagic | Lanternfishes | *Cyclothone* spp. | 0.0026 | 1.591547 |
| Epipelagic | Flyingfishes | *Hirundichthys* spp. | 0.0046 | 1.528962 |
| Coastal | Jacks | Carangidae | 0.0135 | 1.29518 |
| Epipelagic | Flyingfishes | Exocoetidae | 0.0031 | 1.194171 |
| Mesopelagic | Dragonfishes | *Aristostomias scintillans* | 0.0024 | 0.693785 |
| Mesopelagic | Lightfishes | *Vinciguerria lucetia* | 0.0040 | 0.670544 |
| Mesopelagic | Fanfin anglerfishes | *Caulophryne* spp. | 0.0022 | 0.568752 |
| Mesopelagic | Lanternfishes | *Nannobrachium* spp. | 0.0029 | 0.485104 |
| Mesopelagic | Anglerfishes | Lophiiformes | 0.0018 | 0.441149 |
| Epipelagic | Flyingfishes | *Cheilopogon* spp. | 0.0041 | 0.392326 |
| Coastal | Jacks | *Seriola lalandi* | 0.0020 | 0.389178 |
| Epipelagic | Dolphinfishes | *Coryphaena* spp. | 0.0019 | 0.317891 |

*Zooplankton*

The zooplankton were composed of 11 phyla, 16 classes, 39 orders, and 59 families. Crustaceans, primarily copepods (Calanoida and Cyclopoida), amphipods (Amphipoda), Isopods (Isopoda), shrimps, crabs, and lobsters (Decapoda) numerically dominated the catches. Other abundant zooplankton taxa included tunicates (Tunicata), arrow worms (Chaetognatha), and mollusks (Pteropoda, Gastropoda, and Heteropoda). **Table 4-4** shows the numbers of individuals from the major taxonomic groups for each gear type. **Figure 4-1** shows the densities of zooplankton based on the net used for collection, for each Campaign (plankton net samples were not collected during Campaigns 3 and 12 [November 2021 and 2022]) (**Figure 4-1**). A multivariate analysis of samples from Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) was conducted to examine similarity in taxonomic composition of zooplankton samples among gear types and campaigns. Raw data were fourth-root transformed to reduce the influence of high and low abundance values when calculating the similarity indices. The resulting similarity matrix was then analyzed using group average cluster analysis to define potential groupings based on taxonomic composition. The cluster analysis produced a dendrogram displaying samples based on similarity of taxonomic composition. To examine how individual taxa are distributed among the samples a second similarity matrix, the inverse of the sample similarity matrix, was constructed for taxa using the Bray-Curtis index. Only the 30 most abundant taxa were used in constructing this inverse matrix which was clustered in the same way as the sample similarity matrix. Results of sample and taxa-level clustering were used to order the raw data matrix into a two-way shade plot (**Figure 4-2**) that helps visualize patterns and identify taxa responsible for sample clusters (Clarke et al, 2014).

The two-way shade plot of the same matrix, interfacing the taxa and the samples, shows that calanoid copepods dominate the samples across gear types (**Figure 4-2**). Mysid shrimps (Mysidacea) were most abundant in the manta samples and hyperiid amphipods (Hyperiidea) were most abundant in the bongo samples.

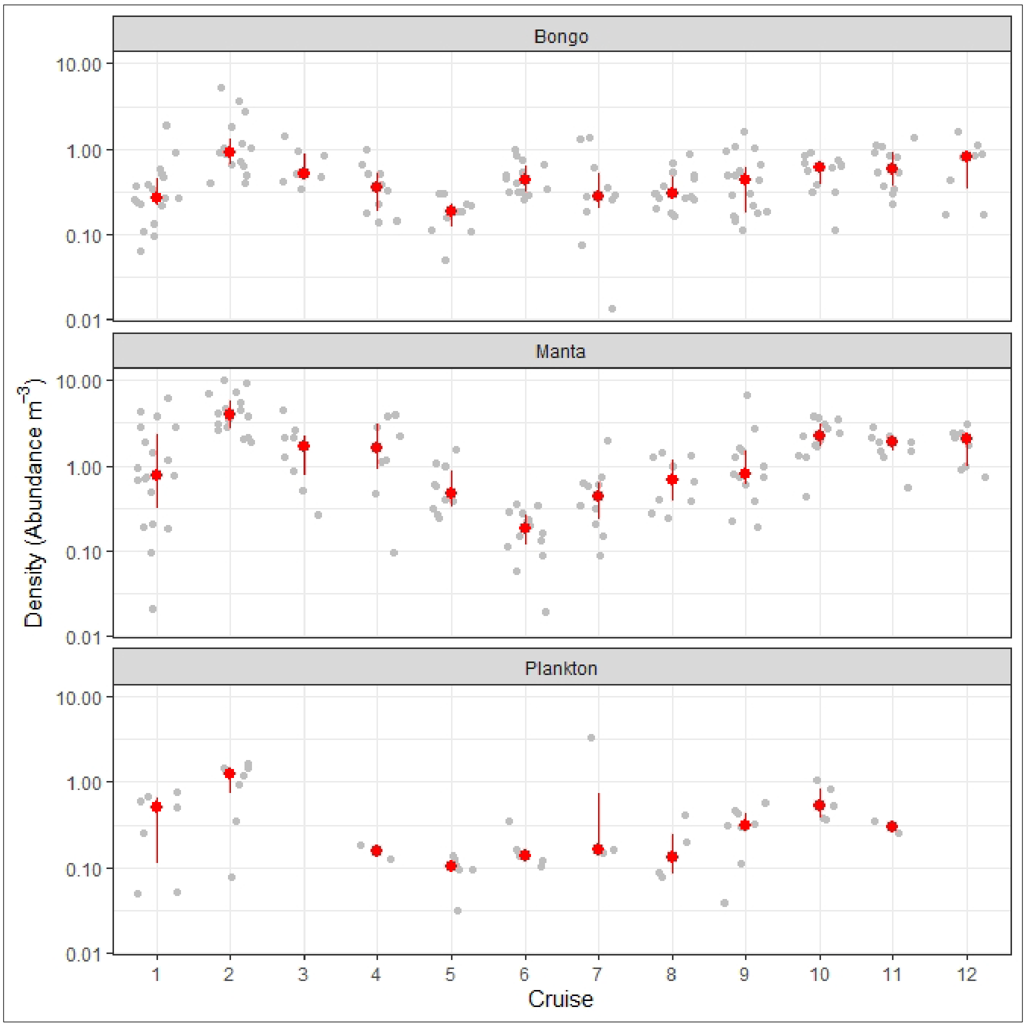



Figure 4-1. Zooplankton densities by Campaign and gear type. Gray symbols represent densities for individual tows, red points are medians and error bars are 50% confidence intervals which covers the interquartile range of the data. Plankton net samples were not collected during Campaigns 3 and 12 (November 2021 and November 2022; **Table 4-3**).

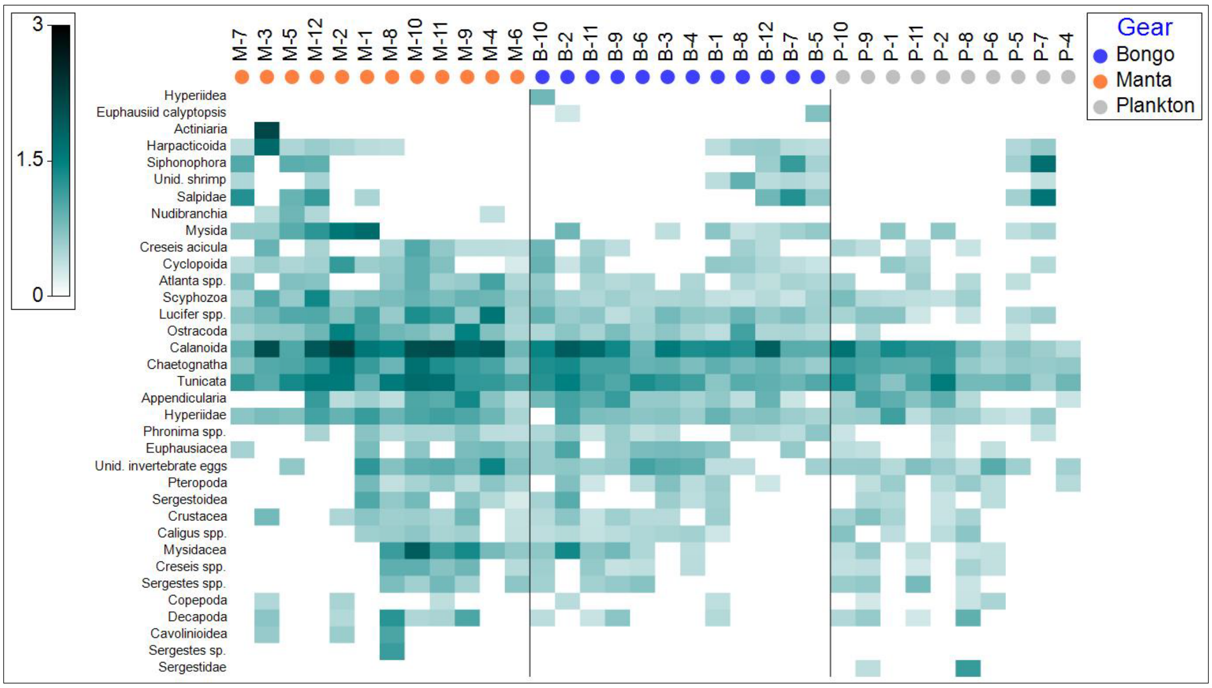



Figure 4-2. Two-way shade plot interfacing the 35 most abundant zooplankton taxa from Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) with gear type. The color gradient is 4th root transformed density. Samples (cruises within gear type) were ordered by group average cluster analysis.

*Ichthyoplankton (Fish Eggs and Larvae)*

Ichthyoplankton collected in the project area over the 12 campaigns (July 2021 to December 2022) consisted of 23 families from 11 orders of teleost fishes. Ichthyoplankton contributed less than 1% of the catches for all gear types combined (**Figure 4-3**).

The shade plot (**Figure 4-4**) depicts the distribution of taxa across gear types and cruises. The most abundant and frequently occurring component of the ichthyoplankton assemblage was unidentified fish eggs. Lanternfishes including unidentified Myctophidae, *Lampadena urophaos*, and *Ceratoscopelus townsendi* were also frequent and abundant in the samples.

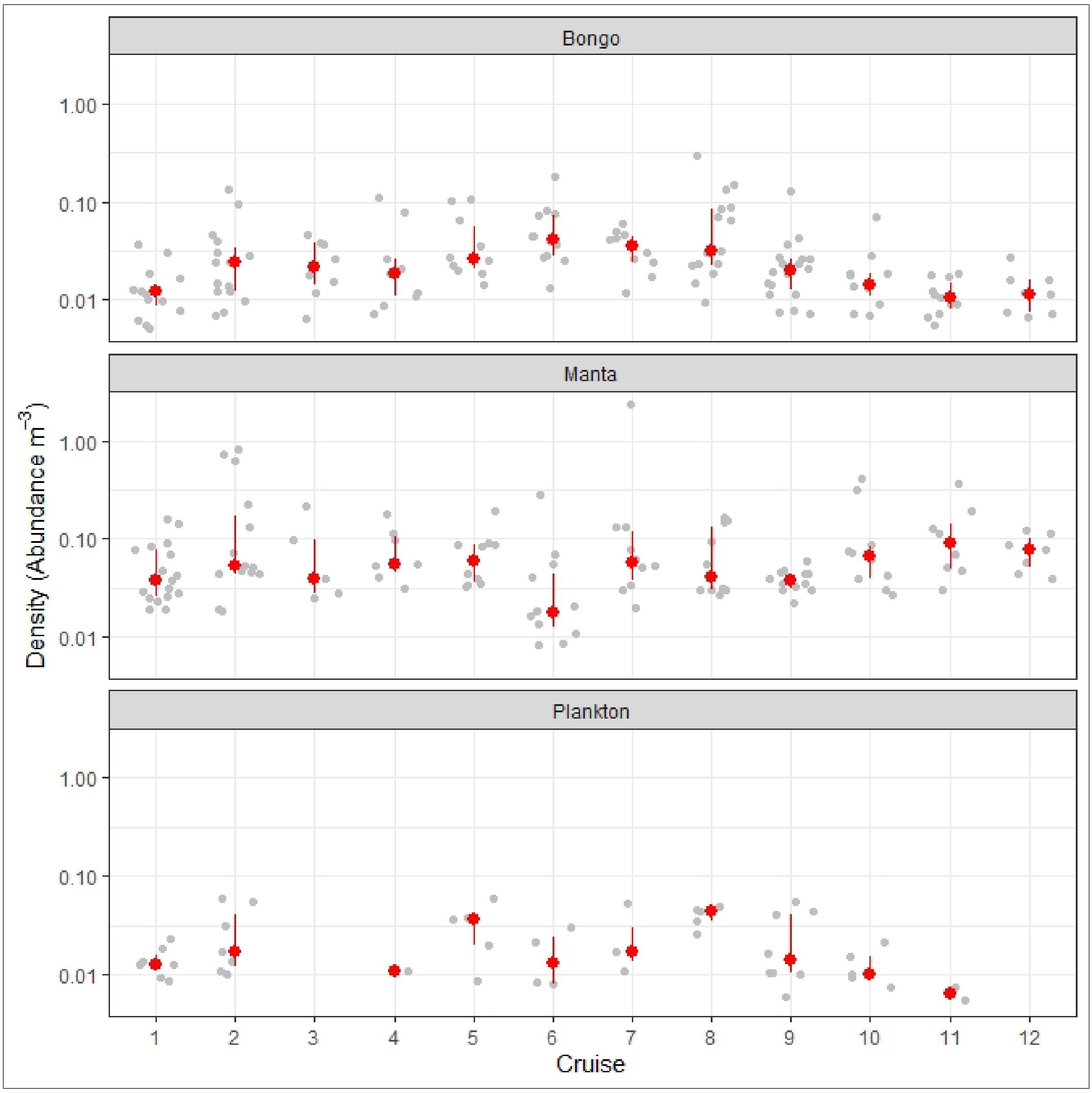



Figure 4-3. Ichthyoplankton densities by Campaign and gear type. Gray symbols represent densities for individual tows, red points are medians and error bars are 50% confidence intervals which covers the interquartile range of the data. Plankton net samples were not collected during Campaigns 3 and 12 (November 2021 – November 2022; **Table 4-3**).

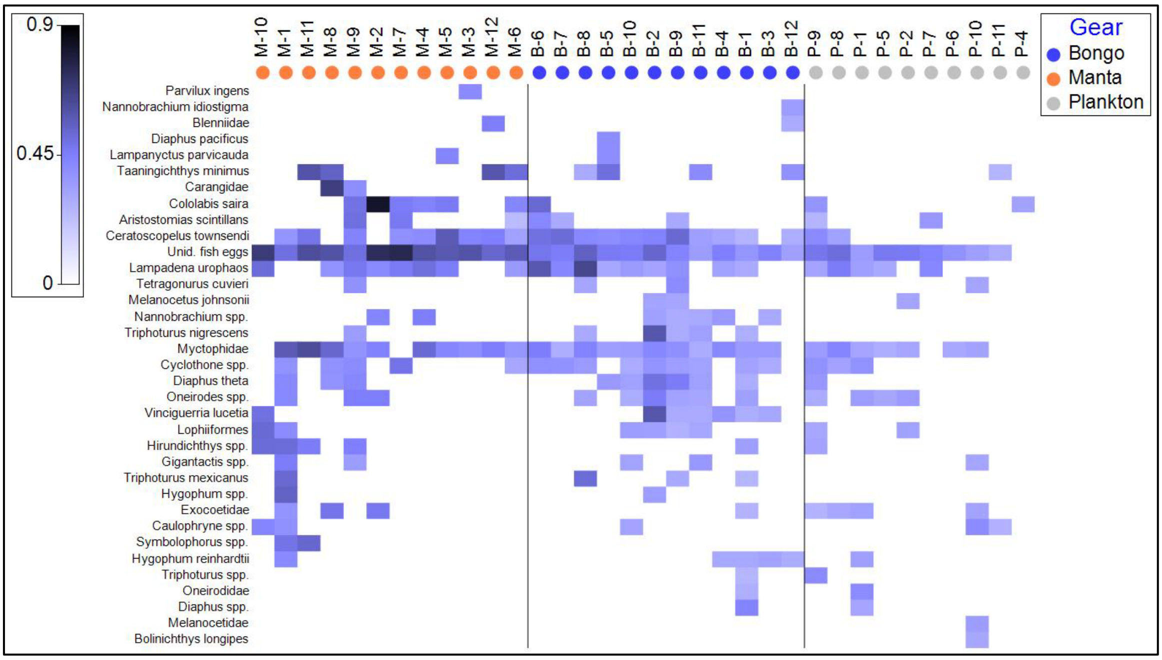



Figure 4-4. Two-way shade plot interfacing the 35 most abundant ichthyoplankton taxa from Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) with gear type. The color gradient is 4th root transformed density.

Samples from Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) yielded 1,385 individuals, with densities ranging from 0.004 to 2.322, across all gear types. There was a total of 31 larval fish collected among all gear types and across all campaigns. **Table 4-5** provides the most abundant fish taxa collected during Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**). Most of the taxa collected were larvae of mesopelagic taxa such as lanternfishes (Myctophidae), dragonfishes (Stomiidae), dreamers (Oneirodidae), and lightfishes (Phosichthyidae). Epipelagic fishes were represented by Pacific sauries (*Cololabis saira*), flyingfishes (Exocoetidae), and dolphinfishes (*Coryphaena* spp.). Larvae of coastal species were represented primarily by the jack family.

Table 4-5. Twenty most abundant fish taxa (>0.05%) collected during Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**) across gear types.

| Habitat | Family | Taxon | Mean (n m$^{-3}$) | Percent |
|---|---|---|---|---|
| Coastal | Jacks | Carangidae | 0.0135 | 6.5 |
| Mesopelagic | Lanternfishes | *Lampadena urophaos* | 0.0108 | 5.2 |
| Mesopelagic | Lanternfishes | *Taaningichthys minimus* | 0.0105 | 5.0 |
| Epipelagic | Sauries | *Cololabis saira* | 0.0082 | 3.9 |
| Mesopelagic | Lanternfishes | *Triphoturus mexicanus* | 0.0074 | 3.6 |
| Mesopelagic | Lanternfishes | *Ceratoscopelus townsendi* | 0.0072 | 3.5 |
| Mesopelagic | Lanternfishes | Myctophidae | 0.0063 | 3.0 |
| Mesopelagic | Lanternfishes | *Symbolophorus* spp. | 0.0058 | 2.8 |
| Mesopelagic | Lightfishes | *Vinciguerria lucetia* | 0.0045 | 2.2 |
| Mesopelagic | Lanternfishes | *Hygophum* spp. | 0.0043 | 2.1 |
| Mesopelagic | Lanternfishes | *Symbolophorus californiensis* | 0.0042 | 2.0 |
| Epipelagic | Flyingfishes | *Cheilopogon* spp. | 0.0041 | 2.0 |
| Mesopelagic | Sea devils | *Melanocetus johnsoni* | 0.0040 | 1.9 |
| Mesopelagic | Lanternfishes | *Nannobrachium* spp. | 0.0039 | 1.9 |
| Coastal | Blennies | Blenniidae | 0.0037 | 1.8 |

Table 4-5. (Continued).

| Habitat | Family | Taxon | Mean (n m$^{-3}$) | Percent |
|---|---|---|---|---|
| Epipelagic | Halfbeaks and sauries | Beloniformes | 0.0036 | 1.7 |
| Mesopelagic | Lanternfishes | *Myctophum* spp | 0.0034 | 1.7 |
| Mesopelagic | Lanternfishes | *Lampanyctus parvicauda* | 0.0032 | 1.5 |
| Epipelagic | Dolphinfishes | *Coryphaena equiselis* | 0.0031 | 1.5 |
| Coastal | Blennies | *Petroscirtes breviceps* | 0.0029 | 1.4 |

### 4.3.2 Neuston

The marine neuston community is a specialized subset of the pelagic community associated with the air-sea interface. A review by Marshall and Burchardt (2005), including determinations and contributions from earlier researchers (e.g., David, 1967; Zaitsev, 1971; Hempel and Weikert, 1972; Banse, 1975), further defined the community that composes the neuston. Goldstein (2012) summarized the neuston communities based on location in the water column (1 to 3) and life stage (4 to 6):

1. Epineuston, organisms that live on the water's surface and are exposed to air;
2. Hyponeuston, organisms that live on the underside of the surface layer;
3. Metaneuston or exopleuston, organisms that occupy space both above and below the water;
4. Euhyponeuston, organisms that are associated with the surface film for their entire life cycle;
5. Planktohyponeuston, organisms that vertically migrate; and
6. Merohyponeuston or endopleuston, organisms that inhabit this space for only a portion of their lives.

Some researchers refer to the entire upper water column community as epineuston and differentiate the surface-associated portion of the upper water column as the pleustal zone and the biota that live there as the pleuston (Banse, 1975; Cheng, 1975). For the purposes of this characterization, the approach of Goldstein (2012) has been applied, where the neuston encompasses both the surface habitat and its associated biota.

Definition of the neuston layer depth also varies among researchers. Hardy (1997) and Champalbert et al. (2003), among others, considered the upper 1 m of the ocean as the sea surface layer, while Zaitsev (1971) and Zaitsev et al. (1997), per Marshall and Burchardt (2005), considered the uppermost 5 cm of the ocean as the neuston. The physical, chemical, and biological conditions found within the uppermost 5 cm of the water column differ greatly from those found below. For the purposes of this baseline characterization, the neuston layer follows the convention of Zaitsev (1971), occupying the sea surface and the upper 5 cm of the water column.

The following discussion summarizes important data regarding neuston present in the NPSG, including free-floating biota (invertebrates and vertebrates) and taxa found in direct association with floating debris (i.e., the rafting assemblage).

#### *4.3.2.1 Free-Floating Neuston*

Goldstein (2012) observed that the oceanic neuston assemblage is distinct from the biota found lower in the water column only within tropical and subtropical waters (between 40° N and 40° S). In this region, sea surface temperature rarely falls below 10°C (Savilov, 1968, as cited in Cheng, 1975). The neustonic zooplankton community exhibits a vibrant blue and purple coloration, including cnidarians, pontellid copepods, and gastropods (Goldstein, 2012).

According to Goldstein (2012), the neustonic zooplankton community is dominated by a relatively small number of conspicuous, drifting organisms. Obligate sea surface-associated cnidarians include the siphonophore *Physalia physalis* and the chondrophores *V. velella* and *Porpita porpita*. These three drifting hydrozoan cnidarians are important prey items for the nudibranchs *Glaucus atlanticus* and *Glaucilla* spp. (Lalli and Gilmer, 1989). *V. velella* and *P. porpita* are also prey for the prosobranch gastropod *Janthina* spp. (Bieri, 1966). The gerrid insect *Halobates* spp. and pontellid copepods are also an abundant component of the neuston (Herring, 1967; Cheng, 1975; Goldstein et al., 2012). Other cnidarians found in the vicinity of the NPSG include *Aglantha digitale*, *Liriope tetraphylla*, *Pegantha* spp., *Physalia utriculus*, and *Physophora hydrostatica* (Wrobel and Mills, 1998).

*V. velella* is a cosmopolitan, holoplanktonic, free-floating marine hydrozoan living in open waters at tropical and temperate latitudes (Pires et al., 2018; Betti et al., 2019). The floating *Velella* hydranth stages are known to frequently form enormous congregations offshore, often composed of hundreds of thousands of colonial polyps (Purcell et al., 2012). Large occurrences of *V. velella* have a significant effect on the planktonic trophic web, with *V. velella* being an active predator of zooplankton, including fish eggs and juveniles (Purcell et al., 2015). In turn, *V. velella* is preyed upon by several pleustonic gastropods belonging to the genus *Janthina*, several different nudibranch taxa (e.g., *G. atlanticus*, *Fiona pinnata*), loggerhead sea turtles (*Caretta caretta*), and the ocean sunfish (*Mola mola*) (Betti et al., 2017, 2019).

Salps found within the NPSG include *Cyclosalpa pinnata*, *Iasis cylindrica*, *Salpa aspera*, *Cyclosalpa bakeri*, *Salpa fusiformis*, and *Ihlea punctata* (Brandon et al., 2019). In general, salps are an important component of open ocean and coastal ecosystems, serving as a significant pathway for oceanic carbon flux (i.e., providing fast-sinking fecal pellets and dead tunics to the benthos) (Bruland and Silver, 1981; Smith et al., 2014), exhibiting the highest filtration rates of all marine zooplankton filter feeders (Alldredge and Madin, 1982), having rapid growth rates (Alldredge and Madin, 1982), and occasionally forming large swarms in coastal waters under optimal conditions (Henschke et al., 2014), that can persist for up to six months (Smith et al., 2014). Salps are non-selective filter feeders, and their size range of prey overlaps with microplastic in the ocean (Chan and Witting 2012, Goldstein et al. 2013). Salps in the NPSG are often caught in nets or found in fish stomachs as empty barrels, lacking their internal organs, after hyperiid amphipods such as *Phronima sedentaria* have eaten their organs and used their barrels as brood pouches (Portner et al., 2017). The plankton sampling that was performed during Campaigns 1 through 12 as well as the S002 primary bycatch included some members of the Salpidae family (not all taxonomic identifications were to the species level). Salpidae individuals were observed in 94 of the 399 total net samples and were found in all net types.

Recent observational data from the NPSG are limited. The Ocean Cleanup tested the S001 in the NPSG in 2018 (Ferrari, 2019). More than 200 inspections were performed over the 115-day campaign, with no recurring accumulations of pelagic or neuston species. On one occasion, a limited aggregation (<250 individuals) of *V. velella* was observed; no other species of buoyant or neutrally buoyant zooplankton were observed accumulating in the vicinity of the System. During Campaigns 1 through 12 for the S002, there were no observations of large aggregations or accumulations of pelagic or neuston species within the areas transited. A total of 1,732 *V. velella* individuals were identified from the 399 total net samples collected and were identified in all three net samples; but most were found in manta net samples. Most individuals (1,639) were identified from 69 of the 143 manta net samples. Most often (58 of the 69 samples), less than 10 individuals were found with a high of 349 individuals. A total of 579 *Janthina* spp. individuals were identified from 67 of the 143 manta samples. **Table 4-3** provides a summary of plankton species identified in the net sampling.

#### 4.3.2.2 *Ichthyoplankton Neuston*

Chen et al. (2018), assessing the level of pollutants in plastics present within the NPSG, provided peripheral data regarding the relative proportion of plastics to neuston and summarized the neuston species collected. Chen et al. (2018) estimated that in the NPSG surface waters, the dry mass of buoyant plastics >0.5 mm was found to be approximately 180 times higher than the dry mass of biota >0.5 mm (i.e., plastic/biomass ratio average = 180.7, maximum = 448.5, minimum = 15.0, standard deviation = 127.7). These findings corroborate earlier findings by Moore et al. (2001).

Biota collected by Chen et al. (2018) during the neuston sampling effort included copepods, the marine insect *Halobates* spp., flyingfish, lanternfish, jellyfish, salps, *Velella* spp., *Janthina* spp., and eggs. When only the 0.5 to 5 mm-sized material was considered, Chen et al. (2018) estimated the dry mass of buoyant microplastics was 40 times higher than that of neustonic plankton (i.e., microplastic/plankton ratio average = 39.7, maximum = 143.0, minimum = 4.6, standard deviation = 38.3). Chen et al. (2018) also expressed caution regarding these preliminary results (i.e., the microplastic to plankton ratio), as some plankton groups are quite fragile and neuston biomass could have been underestimated.

Doyle (1992) characterized the neustonic ichthyoplankton collected off Washington, Oregon, and northern California during the 1980s, within the northern region of the CCS. While this summary is not directly applicable to the NPSG, a review of the data does provide insight into the potential presence of neustonic ichthyoplankton in the NPSG. Doyle (1992) described a neuston assemblage of fish eggs, larvae, and juveniles, with highest species diversity evident over the continental shelf and slope. Diel variation in the occurrence and abundance of certain species of fish larvae in the neuston samples was also evident. Three categories were apparent among the neustonic ichthyoplankton:

- Obligate members: larvae and early juveniles of nine species that occurred permanently and almost exclusively in the neuston but were scarce or absent in subsurface samples.
- Facultative members: other taxa of larvae and juveniles abundant at the surface only at night.
- Stray members: several taxa of fish eggs that accumulate at the surface because of positive buoyancy.

Fish larvae in the neuston were larger overall than those deeper in the water column; this is advantageous in terms of seeking prey and avoiding predators. Juveniles were also common in the neuston, but recently hatched larvae were largely absent (Doyle, 1992).

#### 4.3.2.3 *Rafting Neuston*

The neuston of the NPSG region, while lacking a distinct pelagic algae component evident in other oceans (e.g., North Atlantic), does exhibit species found in association with floating debris. Termed the rafting assemblage, this community may have originated in association with naturally occurring substrates such as terrestrial floating debris (e.g., logs), volcanically derived pumice, and marine megafauna (e.g., sea turtles) (Thiel and Gutow, 2005a,b). Goldstein (2012) cited several examples of these fauna, including the epipelagic crab *Planes* spp., commonly found on flotsam and as an epibiont of olive ridley sea turtles (*Lepidochelys olivacea*; Frick et al., 2011). Lepadomorph barnacles have also been found in association with abiotic and biotic flotsam (Cheng and Lewin, 1976).

Recent research indicates that floating plastic debris plays an important role in the transport and persistence of coastal rafting taxa in the open ocean Haram et al. (2023). Debris samples from the NPSG indicated that pelagic species were present on >94% of debris items, while coastal species were present on >70%. Haram et al. (2023) collected a total of 484 specimens of invertebrate biofouling taxa representing 46 taxa from six phyla, of which coastal taxa constituted 80% of the total taxa identified (i.e., 37 of 46 taxa). The most prevalent debris-associated coastal taxa included Bryozoa (14 taxa) and Arthropoda (Crustacea and Chelicerata; 11 and 10 taxa total, respectively).

Coastal taxa were more diverse than pelagic phyla present on plastic debris. Crustaceans represented three of the five most common taxa for both coastal and pelagic taxa found in association with floating plastic debris. Per Haram et al. (2023), the mean coastal taxa richness per debris item was slightly higher (3.1 ± 0.2) than the mean pelagic taxa richness (2.6 ± 0.1), with taxa community (coastal versus pelagic) having a significant effect on taxa richness (generalized linear model, GLM: $F_{1,171} = 4.811$, $P = 0.023$). Representative rafting species from Goldstein (2012) are summarized in **Table 4-6**. Rafting data from Haram et al. (2023) are presented in **Table 4-7**. Co-occurring taxa identified by both Goldstein (2012) and Haram et al. (2023) include arthropods (*Elasmopus rapax*, *Lepas* spp., *Planes* spp., *Caprella andreae*, *Plagusia* sp.), cnidarians (*Clytia hemisphaerica*, several *Anthopleura* species, *Obelia griffin*), molluscs (*Crassostrea gigas*, *Fiona pinnata*), and annelids (*Amphinome rostrata*).

While floating algae are absent in the NPSG, the presence of photosynthetic epibionts has been noted in association with floating debris. Bryant et al. (2016) documented elevated chlorophyll *a* concentrations on the surface of floating debris in the NPSG. Chlorophyll *a* measurements, combined with oxygen production and respiration measurements, demonstrated that metabolically active photosynthetic and heterotrophic organisms were attached to plastic debris. Chlorophyll *a* concentrations measured on the plastic debris ranged from approximately 0.03 to 0.42 mg $m^{-2}$, while chlorophyll *a* concentrations in the surrounding seawater ranged from 0.04 to 0.10 mg $m^{-3}$. Similarly, the microbial communities present on the surface of microplastics are genetically unique from those in the surrounding water column (Amaral-Zettler et al., 2015).

Rafting materials are frequently dominated by three lepadomorph barnacle species: *Lepas anatifera*, *L. pacifica*, and *L. (Dosima) fascicularis*, although others can be present. *L. (Dosima) fascicularis* must settle onto a floating object but is able to form its own float at the end of the juvenile stage and drift independently thereafter (Newman and Abbott, 1980). Many barnacles were observed in the bycatch from Campaigns 1 through 12 and were considered secondary bycatch because they were associated with the plastics collected.

Lepadomorph barnacles are omnivorous, feeding opportunistically on neustonic zooplankton. Bieri (1966) noted that *L. anserifera* has a multitude of food sources unlike any other found within the neuston. Lepadomorph barnacles are also prey for omnivorous epipelagic crabs (*Planes* spp.) and the rafting nudibranch *F. pinnata* (Bieri, 1966; Davenport, 1992). In the NPSG, Goldstein and Goodwin (2013) documented the presence of microplastics (<5 mm) in the gastrointestinal tract of *Lepas* spp., where more than one third of the analyzed specimens contained microplastics. Other conspicuous inhabitants of the rafting community are the cheilostome bryozoans (Order Cheilostomatida; Winston et al., 1997), the barnacle-associated parasitic polychaete *Hipponoe gaudichaudi* (Cheng, 1975), and the isopod *Idothea* sp. (Herring, 1969; Gutow et al., 2006).

Table 4-6. Rafting taxa found in association with floating plastics in the North Pacific (Adapted from: Goldstein, 2012).

| Phylum | Class | Order | Lowest Practical Taxonomic Level | Year(s) Observed | Previously Documented as Rafting |
|---|---|---|---|---|---|
| Annelida | Polychaeta | Aciculata | *Eunice* spp. | c | [1] |
| | | Amphinomida | *Amphinome rostrata* | c | [1] |
| | | | *Hipponoe gaudichaudi* | a,b | [1] |
| | | Phyllodocida | *Halosydna* spp. | b | N |
| | | | Nereididae | c | [1] |
| | | | *Nereis* spp. | c | [1] |
| | | | Phyllodocidae | c | [1] |
| | | Sabellida | *Salmacina* spp. | c | N |
| | | | Serpulinae | c | [1] |
| | | | Spirorbinae | a,c | [1] |
| Arthropoda | Malacostraca | Amphipoda | *Caprella* spp. | a,c | [1] |
| | | | *Elasmopus* spp. | a | [1] |
| | | | Hyalidae | a | [1] |
| | | | Isaeidae | b | N |
| | | | Pleustidae | c | N |
| | | | Sphaeromatidae | a | [1] |
| | | | Stenothoidae | a | [1] |
| | | | Gammaridea | c | [1] |
| | | Decapoda | *Chorilia* spp. | c | N |
| | | | *Herbstia* spp. | c | N |
| | | | Megalopae | b | [1] |
| | | | *Palaemon affinis* | c | [1] |
| | | | *Pilumnus* spp. | c | N |
| | | | *Plagusia* spp. | c | [1] |
| | | | *Plagusia squamosa* | a | [1] |
| | | | *Planes cyaneus* | a,c | [1] |
| | | | *Planes minutus* | a | [1] |
| | | | *Planes* spp. | b,c | [1] |
| | | Isopoda | Cirolanidae | a | [1] |
| | | | *Idotea* spp. | a,b,c | [1] |

Table 4-6. (Continued).

| Phylum | Class | Order | Lowest Practical Taxonomic Level | Year(s) Observed | Previously Documented as Rafting |
|---|---|---|---|---|---|
| Arthropoda | Hexanauplia | Harpacticoida | Harpacticoida | a | [1] |
| | | Kentrogonida (Rhizocephala) | *Heterosaccus* spp. | c | N |
| | | Lepadiformes | Barnacle cyprids | a | [1] |
| | | | *Lepas anatifera* | a, c | [1] |
| | | | *Lepas pacifica* | a | [1] |
| | | | *Lepas* spp. | a, b, c | [1] |
| | | Sessilia | *Amphibalanus amphitrite* | b | [1] |
| | | | *Chthamalus* spp. | c | N |
| | | | *Megabalanus rosa* | c | N |
| | | Siphonostomatoida | *Chlamys* (*Perissopus*) spp. | c | [1] |
| | Pycnogonida | Pantopoda | *Phoxichilidium quadradentatum* | a | N, may encyst in hydroids[2] |
| | | Unknown | Unknown | c | [1] |
| Bryozoa | Gymnolaemata | Cheilostomatida | *Bugula* spp. | a ,b, c | [1] |
| | | | *Jellyella eburnean* | a | [1] |
| | | | *Jellyella tuberculate* | a | [1] |
| | | | *Jellyella*/*Membranipora* | b, c | [1] |
| | | | *Membranipora* (*Arbopercula*) *tenella* | a | [1] |
| | | Ctenostomatida | *Bowerbankia* (*Amanthia*) spp. | a | [1] |
| | | | *Victorella* spp. | a | N, may disperse through fragmentation of substrate[3] |
| | Stenolaemata | Cyclostomatida | *Filicrisia* spp. | a | N |
| | | | *Stomatopora* spp. | a | N |
| | | | *Tubulipora* spp. | a | [1] |

Table 4-6. (Continued).

| Phylum | Class | Order | Lowest Practical Taxonomic Level | Year(s) Observed | Previously Documented as Rafting |
|---|---|---|---|---|---|
| Chordata | Actinopterygii | Perciformes | *Abudefduf* spp. *(vaigiensis?)* | b, c | N/A |
| | | | *Canthidermis maculata* | c | N/A |
| | | | *Chirolophis* spp. | c | N/A |
| | | | *Coryphaena hippurus* | b | N/A |
| | | | *Elagatis bipinnulata* | b | N/A |
| | | | *Histrio histrio* | c | N/A |
| | | | *Kyphosus* spp. *(vaigiensis?)* | b, c | N/A |
| | | | *Meiacanthus* spp. | c | N/A |
| | | | *Seriola rivoliana* | c | N/A |
| | Unknown | Unknown | Beige fish eggs | c | [1] |
| | | | Blue fish eggs | c | [1] |
| | | | Fish eggs | a, b | [1] |
| Ciliophora | Heterotrichea | Heterotrichida | *Halofolliculina* spp. | c | N on plastic, documented on wood[4] |
| Cnidaria | Anthozoa | Actiniaria | Actiniidae | b | [1] |
| | | | *Anthopleura* spp. | a, b | N, may disperse through detachment[5] |
| | | | *Calliactis* sp. | c | N |
| | | | *Metridium* spp. | a | N, may disperse through detachment[5] |
| | | | Hormathiidae | c | [1] |
| | | Scleractinia | Stony coral | b | [1] |
| | Hydrozoa | Leptothecata | *Clytia gregaria* | a | N, though nine other *Clytia* species documented as rafting[1] |
| | | | *Obelia* spp. | a | [1] |
| | | | *Plumularia setacea* | a | [1] |
| | | Unknown | Hydroid | b, c | [1] |
| Echinodermata | Ophiuroidea | N/A | Ophiuroidea sp. 1 | c | Not determined |
| | | | Ophiuroidea sp. 2 | c | Not determined |
| | | | Ophiuroidea sp. 3 | c | Not determined |
| Foraminifera | Globothalamea | Rotaliida | *Planulina ornata* | a | N |

Table 4-6. (Continued).

| Phylum | Class | Order | Lowest Practical Taxonomic Level | Year(s) Observed | Previously Documented as Rafting |
|---|---|---|---|---|---|
| Mollusca | Bivalvia | Arcida | Arcidae | c | N |
| | | Myida | *Teredo* spp. | c | [1] |
| | | | *Zirfaea* spp. *(pilsbryi?)* | b | N |
| | | Mytilida | *Mytilus galloprovincialis* | a, c | [1] |
| | | Ostreida | *Crassostrea* (*Magallana*) *gigas* | b, c | [1] |
| | | | *Pinctada* spp. | c | [1] |
| | | Unknown | Lower valve of oyster | c | [1] |
| | Gastropoda | Caenogastropoda | *Litiopa melanostoma* | c | [1] |
| | | Littorinimorpha | *Erronea* spp. | c | N, may have widespread larval transport[6] |
| | | Nudibranchia | *Fiona pinnata* | a, b, c | [1] |
| | | | *Fiona pinnata* eggs | a | [1] |
| | | Pleurobranchida | *Berthella* spp. | c | N |
| | | Superfamily Pyramidelloidea | *Odostomia (Evalea) tenuisculpta* | a | N |
| Platyhelminthes | Rhabditophora | Polycladida | Rhabditophora (Polycladida) | c | [1] |
| | | Rhabdocoela | Rhabdocoela | c | [1] |
| | Turbellaria (Platyhelminthes) | Unknown | Flatworm | a, b | [1] |
| | | | Flatworm | b | [1] |
| Porifera | Calcarea | Leucosolenida | *Sycon* spp. | b, c | N |
| | Demospongiae | Suberitida | *Halichondria panicea* | a | N |

Key:
a Eastern Pacific, 2009.
b Eastern Pacific, 2011.
c Western Pacific, 2012.
N – Not listed as rafting in scientific literature.
[1] Thiel and Gutow, 2005a,b.
[2] Lovely, 2005.
[3] Carter et al., 2010.
[4] Matthews, 1963.
[5] Riemann-Zürneck, 1998.
[6] Emerson and Chaney, 1995.
Note: Taxonomic nomenclature updated to 2021; revised per World Register of Marine Species (www.marinespecies.org).

Table 4-7. Frequency of occurrence and select and life history characteristics of observed coastal and pelagic taxa found associated with floating plastic debris (Adapted from Haram et al., 2023).

| Phylum | Taxon | Frequency (%) | Adult Mobility | Larval Development | Trophic Position | Feeding Mechanism | References |
|---|---|---|---|---|---|---|---|
| **Coastal Taxa** | | | | | | | |
| Arthropoda | *Stenothoe gallensis* | 36.9 | Mobile | Direct | Omnivore | Grazer | Nelson et al., 2016; Ambrose and Anderson, 1990 |
| Cnidaria | *Aglaophenia* aff. *pluma* | 25.2 | Sessile | Planktonic | Omnivore | Suspension feeder | Svoboda and Cornelius, 1991; Choong et al., 2018 |
| Arthropoda | *Ianiropsis serricaudis* | 24.3 | Mobile | Direct | Omnivore | Grazer | Nelson et al., 2016 |
| Arthropoda | *Calliopius pacificus* | 19.4 | Mobile | Direct | Carnivore | Predator | Macdonald et al., 2010; Nelson et al., 2016; Bock, 1982 |
| Bryozoa | *Aetea* sp. A | 17.5 | Sessile | Planktonic | Omnivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |
| Arthropoda | *Elasmopus rapax* | 14.6 | Mobile | Direct | Detritivore | Grazer | Ambrose and Anderson, 1990; Ferreira et al., 2019 |
| Cnidaria | *Anthopleura* sp. A | 12.6 | Sessile | Planktonic | Carnivore | Suspension feeder/Predator | Bocharova and Kozevich, 2011 |
| Cnidaria | *Anthopleura* sp. B | 8.7 | Sessile | Planktonic | Carnivore | Suspension feeder/Predator | Bocharova and Kozevich, 2011 |
| Cnidaria | *Diadumene lineata* | 7.8 | Sessile | Planktonic | Carnivore | Suspension feeder/Predator | Nelson et al., 2016 |
| Annelida | Spirorbidae sp. | 7.8 | Sessile | Planktonic | Omnivore | Suspension feeder | Terlizzi et al., 2000 |
| Cnidaria | *Anemonia erythraea* | 5.8 | Sessile | Planktonic | Carnivore | Suspension feeder/Predator | Bocharova and Kozevich, 2011 |
| Bryozoa | *Scruparia ambigua* | 3.9 | Sessile | Planktonic | Omnivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |
| Cnidaria | *Clytia hemisphaerica* | 2.9 | Sessile | Planktonic | Omnivore | Suspension feeder | Cornelius, 1982; Choong et al., 2018; Takeda et al., 2018 |
| Arthropoda | *Endeis nodosa* | 2.9 | Sessile | Benthic | Carnivore | Predator | Nelson et al., 2016 |
| Porifera | *?Haliclona* sp. | 2.9 | Sessile | Planktonic | Omnivore | Filter feeder | Maldodano and Riesgo, 2008 |
| Annelida | *Hydroides* sp. cf. *ezoensis* | 2.9 | Sessile | Planktonic | Omnivore | Suspension feeder | Nelson et al., 2016 |
| Cnidaria | *Anthopleura* sp. D | 1.9 | Sessile | Planktonic | Carnivore | Suspension feeder/Predator | Bocharova and Kozevich, 2011 |
| Bryozoa | *Catenicella* sp. | 1.9 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |
| Bryozoa | *Crisia* sp. | 1.9 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |
| Bryozoa | *Disporella* sp. | 1.9 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |
| Arthropoda | *Jassa marmorata* | 1.9 | Mobile | Direct | Omnivore | Suspension feeder/Predator | Nelson et al., 2016 |

Table 4-7. (Continued).

| Phylum | Taxon | Frequency (%) | Adult Mobility | Larval Development | Trophic Position | Feeding Mechanism | References |
|---|---|---|---|---|---|---|---|
| Cnidaria | *Plumularia strictocarpa* | 1.9 | Sessile | Planktonic | Omnivore | Suspension feeder/Predator | Hirohito, 1995; Kolzoff, 1990; Nelson et al., 2016 |
| Annelida | Nereididae sp. | 1.9 | Mobile | Planktonic | Omnivore | Grazer/Predator | Nelson et al., 2016 |
| Bryozoa | *?Tubulipora* sp. | 1.9 | Sessile | Planktonic | Omnivore | Suspension feeder | Nelson et al., 2016; Bock, 1982; Weaver et al., 2018 |
| Bryozoa | *Aetea anguina* ? | 1.0 | Sessile | Planktonic | Omnivore | Suspension feeder | Nelson et al., 2016 |
| Bryozoa | *Aetea* sp. B | 1.0 | Sessile | Planktonic | Omnivore | Suspension feeder | Nelson et al., 2016 |
| Bryozoa | *Amathia gracilis* | 1.0 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock, 1982; Weaver et al., 2018; Reed, 1988 |
| Arthropoda | Amphilochidae sp. | 1.0 | Mobile | Direct | Omnivore | Grazer/Predator | Guerra-García et al., 2014 |
| Cnidaria | *Antennella secundaria* | 1.0 | Sessile | Direct | Omnivore | Suspension feeder | Hirohito, 1995 |
| Bryozoa | *Bugula tsunamiensis* | 1.0 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |
| Bryozoa | *Callaetea* sp. | 1.0 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock 1982, Weaver et al., 2018 |
| Mollusca | *Crassostrea gigas* | 1.0 | Sessile | Planktonic | Omnivore | Filter feeder | Nelson et al., 2016 |
| Bryozoa | *Cryptosula pallasiana* | 1.0 | Sessile | Planktonic | Omnivore | Suspension feeder | Nelson et al., 2016 |
| Mollusca | *Musculus cupreus* | 1.0 | Sessile | Direct | Omnivore | Filter feeder | Nelson et al., 2016 |
| Porifera | *?Leucosolenia* sp. | 1.0 | Sessile | Planktonic | Omnivore | Filter feeder | Maldodano and Riesgo, 2008 |
| Porifera | *?Sycon* sp. | 1.0 | Sessile | Planktonic | Omnivore | Filter feeder | Maldodano and Riesgo, 2008 |
| Porifera | *?Halichondria* sp. | 1.0 | Sessile | Planktonic | Omnivore | Filter feeder | Maldodano and Riesgo, 2008 |
| **Pelagic Taxa** | | | | | | | |
| Bryozoa | *Jellyella* spp. | 75.7 | Sessile | Planktonic | Omnivore | Suspension feeder | Bock, 1982; Weaver et al., 2018; Taylor and Monks, 1997 |
| Arthropoda | *Lepas* spp. | 65.0 | Sessile | Planktonic | Omnivore | Suspension feeder/Predator | Howard and Scott, 1959; Patel, 1959; Bieri, 1966; Moyse, 1987 |
| Arthropoda | *Planes* spp. | 40.8 | Mobile | Planktonic | Omnivore | Grazer/Predator | Frick et al., 2011 |
| Arthropoda | *Caprella andreae* | 25.2 | Mobile | Direct | Omnivore | Grazer/Predator | Nelson et al., 2016 |
| Cnidaria | *Obelia griffini* | 25.2 | Sessile | Planktonic | Omnivore | Suspension feeder | Nelson et al., 2016 |
| Arthropoda | *Plagusia* sp. | 7.8 | Mobile | Planktonic | Omnivore | Grazer/Predator | Frick et al., 2011 |
| Annelida | *Amphinome rostrata* | 2.9 | Mobile | Planktonic | Carnivore | Predator | Donlan and Nelson, 2003 |
| Mollusca | *Fiona pinnata* | 1.9 | Mobile | Planktonic | Carnivore | Predator | Bieri, 1966; Holleman, 1972; Trickey, 2013 |
| Bryozoa | *Arbopercula angulata* | 1.0 | Sessile | Planktonic | Herbivore | Suspension feeder | Bock, 1982; Weaver et al., 2018 |

#### *4.3.2.4 Spatial and Temporal Distribution Patterns of Neuston*

Thibault (2021) notes that dispersal drives the exchange of genetic material among marine populations, with diverse ecological and evolutionary consequences including species range limits, connectivity, and the potential for local adaptation. Population genetic connectivity can be maintained by the exchange of very few larvae (Strathmann et al., 2002; Swearer et al., 2002; Burgess et al., 2015), rendering it extremely sensitive to disruptions in larval dispersal. Furthermore, larval supply is an important factor affecting population dynamics, interaction strengths, and community resilience (Menge et al., 1997; Navarrete et al., 2005; Palardy and Witman, 2014; Bashevkin et al., 2020). However, the fate and survivability of pelagic larvae is uncertain, as they contend with strong currents, patchy food supplies, predators, and environmental variation before finding a suitable nursery or adult habitat (Morgan, 1995; Llopiz et al., 2014). In addition, larvae are generally more sensitive to stressors than adults (Byrne, 2011; Harvey et al., 2013; Kroeker et al., 2013; Przeslawski et al., 2014; Pandori and Sorte, 2019), making them especially vulnerable to environmental change. Recent research conducted by Haram et al. (2023) indicates that coastal species formerly thought to be limited in their distribution by physiological or ecological constraints may have been restricted by the absence of available substrate, limiting their potential colonization of open ocean environments. The transport of plastic debris, and its associated taxa, from coastal waters to open ocean has provided the mechanism for species normally associated with coastal environments to successfully establish themselves in an open ocean environment.

A comprehensive characterization of the spatial and temporal distribution patterns of neuston in the NPSG is lacking, although the results of recent collection efforts (e.g., Egger et al., 2021; The Ocean Cleanup Campaigns 1 through 12) are helping to fill these data gaps. For rafting neuston species found in association with marine debris, including both natural materials and plastics, distribution patterns follow those exhibited by the debris itself. Important rafting species include lepadomorph barnacle species, epipelagic crabs (*Planes* spp.), the rafting nudibranch *F. pinnata*, cheilostome bryozoans, the barnacle-associated parasitic polychaete *H. gaudichaudi*, and the isopod *Idothea* spp. Distribution patterns for the free-floating neuston are less well known. Drifting neuston include the siphonophore *P. physalis*, chondrophores *V. velella* and *P. porpita*, nudibranchs *G. atlanticus* and *Glaucilla* spp., the prosobranch gastropod *Janthina* sp., the gerrid insect *Halobates* sp. (although their eggs are deposited on rafting substrates, and thus would follow the distribution of those floating materials; Goldstein et al., 2012), and pontellid copepods, as well as various ichthyoplankton taxa. *G. atlanticus* has a cosmopolitan subtropical distribution. Cryptid species of *Glaucus* spp. have recently been differentiated; *Glaucus mcfarlenei* and *Glaucus thompsoni* are only currently known in the North Pacific (Churchill et al., 2014). Diel vertical migration is also exhibited by various species. In general, there is a significant increase in neuston diversity at night (David, 1967; Harbison and Campenot, 1979; Hobbs and Botsford, 1992). One such diel vertically migrating species is the abundant neon flying squid (*Ommastrephes bartramii*) which migrates from between 36° N and 46° N latitude in the summer and fall to between 25° N and 35° N in the winter when spawning occurs (Ichii et al., 2009).

Egger et al. (2021) summarized observational data acquired in 2015 and 2019, reporting on the relative spatial and temporal distribution patterns for both floating plastic debris (i.e., 0.05 to 5 cm in size) and neuston present in the NPSG. The data provide an indication of how the neuston community is distributed relative to plastic pollution in the study area, further supplementing data acquired between 2015 and 2019 (Egger et al., 2020a,b). Summary results for important neuston species are provided in **Table 4-8**. No individuals of *V. velella* were observed in the outer boundaries of the NPSG by Egger et al. (2021), although this species was observed both inside and outside the NPSG. The dominant fish species observed were Pacific saury and lanternfishes.

Table 4-8. Summary of neuston species density within and outside the North Pacific Subtropical Gyre (Adapted from: Egger et al., 2021).

| Species/Taxa | Abundance (number of individuals) | | Density (number of individuals km$^{-2}$) | |
|---|---|---|---|---|
| | Outside the NPSG | Inside the NPSG | Outside the NPSG | Inside the NPSG |
| *Velella velella* | 110,962 | 639 | 61,541–133,935 | 557–855 |
| *Halobates* spp. | 15,033 | 16,650 | 11,227–25,493 | 9,429–32,655 |
| *Janthina janthina* | 3,315 | 1,897 | 2,124–9,363 | 542–4,566 |
| *Porpita porpita* | Not observed | 95 | Not observed | 91–678 |
| *Glaucus* spp. | 1 | <1,000 | 1 | <1,000 |
| *Physalia physalis* | 1 | Not observed | Not observed | Not observed |
| Copepods | 1,230 | 397,079 | Not reported | 43,545–1,731,593 |
| Amphipods | 740–3,818 | | 643–6,939 | |
| Pteropods, isopods, heteropods | Not observed | 561–659 | Not observed | 187–4,654 |
| Crabs | 1,255 | 959–1,550 | 1,785 | 604–3,501 |
| Squid | 908 | 747–1,069 | 555 | 371–588 |
| Euphausiacea | 1,840 | 592–1,975 | 9,991 | 570–25,320 |
| Fish | 1,171–2,105 | | 622–4,949 | |

NPSG = North Pacific Subtropical Gyre.

#### *4.3.2.5 Other Relevant Studies*

Moore et al. (2001) summarized the results of 11 neuston tows completed during August 1999 in the NPSG. A total of 152,244 planktonic organisms, weighing approximately 70 g, were collected from the surface waters near the central pressure cell of the North Subtropical High in the gyre, with a mean abundance of 1,837,342 organisms km$^{-2}$ and mean mass of 841 g km$^{-2}$ (dry weight). Abundance estimates were quite variable, ranging from 54,003 organisms km$^{-2}$ to 5,076,403 organisms km$^{-2}$; estimated weights were also highly variable, ranging from 74 to 1,618 g km$^{-2}$. Plankton abundance was higher than plastic abundance in 8 out of 11 samples, with the difference being much higher at night. Two filter-feeding salps (*Thetys vagina*) were also collected in this study.

Per Olivar et al. (2014), the vertical distribution of neustonic fish assemblages present in the Pacific, Atlantic, and Indian oceans is primarily controlled by light. Fish assemblages are routinely dominated by late-larvae and juvenile flyingfishes, halfbeaks (Hemiramphidae), and sauries (Scomberesocidae) during the day. At night, the vertical migration of mesopelagic species changes the dominance pattern in favor of lanternfishes and sauries.

Batten et al. (2010) published a compendium of physical, chemical, and biological data for the Pacific's oceanic region from 2003 to 2008, including data for the NPSG. The NPSG supports a diverse assemblage of apex predators, including tunas (Scombridae), billfishes (Istiophoridae, Xiphiidae), sharks (Carcharhinidae, Lamnidae, Rhincodontidae), marine mammals, and seabirds. While the data review provides a general synopsis of mesoscale trends within the North Pacific, it did not include specific information regarding the neuston of the region.

Though most of the abundance of plastic debris in the North Pacific is in the form of small fragments (Lebreton et al., 2018; Hidalgo-Ruz et al., 2012), these particles carry few large taxa, most of which are known subtropical rafters such as *Jellyella* or *Membranipora* bryozoans, but they carry a thriving community of bacteria and microbes (Zettler et al., 2013; Amaral-Zettler et al., 2015). Goldstein (2012) found most potentially invasive taxa (i.e., nonindigenous species), such as the majid crab *Herbstia*, on large items such as net balls, though the coral pathogen *Halofolliculina* spp. was found on medium-sized plastic fragments (0.03 to 0.1 m$^2$). Microplastics have since been found to be vectors of pathogens like *Vibrio* (Zettler et al., 2013; Kirstein et al., 2016) and *Aeromonas* *salmonicida* (Virsek et al., 2017). Recent collections of floating plastic-associated invertebrate assemblages in the NPSG summarized by Haram et al. (2023) highlight the transport mechanisms which have introduced nonindigenous coastal species into the open ocean environment via association with floating plastic debris. Selective removal of medium to large plastic debris objects may provide a degree of protection to coastal habitats where the potential invasion of nonindigenous species is of concern, but some pathogens may remain on microplastics. In another recent assessment of potential impacts of plastic removal on the open ocean ecosystem, Spencer et al. (2023) evaluated impacts to neuston within an ecosystem services context, accompanied by a characterization of the legal environment for Areas Beyond National Jurisdiction. Their results indicated that oceanic neuston may supply at least 28 ecosystem services (i.e., 20 directly linked services; 8 indirectly linked services) out of a total of 33 possible services. Spencer et al. (2023) concluded that the potential effects of plastic removal from the ocean surface on neuston populations are uncertain but potentially negative, further recommending that additional studies be conducted the acquire more data regarding the life history data for open-ocean neuston species.

#### *4.3.2.6 Energy Flow in the Pelagic Ecosystem and the Relative Contribution from Neuston*

Goldstein (2012) suggested plastic-associated rafting organisms may be affecting the pelagic ecosystem by reworking the particle size spectrum through ingestion and egestion (see also Mook, 1981). Suspension-feeding rafting organisms prey on a variety of particle sizes, from 3 to 5 µm for *Mytilus* mussels (Lesser et al., 1992), 10 to 20 µm for bryozoans (Pratt, 2008), 20 to 125 µm for caprellid amphipods (Caine, 1977), 0.5 to >1 mm for lepadomorph barnacles and hydroids (Evans, 1958; Boero et al., 2007), and the very wide range of <1 µm to 1 mm for salps (Madin, 1974; Vargas and Madin, 2004). This size range encompasses a significant portion of the nonmicrobial particle size spectrum of the oligotrophic North Pacific (Sheldon et al., 1972). Because particle size determines which energy pathway benefits—either the microbial loop or the metazoan food web—Karl et al. (2001) noted that any large-scale alterations in particle size could substantially influence the species composition of the NPSG. Size-related preferences for one component of the neuston, salps, was addressed by Brandon et al. (2019).

The ecological role of plastic-associated rafting assemblages on the open ocean ecosystem remains unclear. Increased concentrations of *Halobates* spp. have been noted (e.g., Majer et al., 2012; Goldstein, 2012). Goldstein (2012) noted that the most abundant large-bodied, plastic-associated rafting organisms, the lepadomorph barnacles, may not be sufficiently abundant to consume a significant portion of neustonic zooplankton biomass. Nevertheless, macroplastics floating on the ocean surface provide settling substrate and habitat for a diversity of coastal and open ocean organisms in the pelagic environment. Haram et al. (2021, 2023) noted that floating plastic debris has allowed the transport of coastal species to the open ocean where they persist and may disperse coastal species from one coast to others across waterbodies, introducing invasive species. In addition, with the increase in durable, buoyant plastic materials providing substrate for species previously only found in coastal waters, there appears to be a shift in the composition of the open ocean invertebrate community that could persist for years, particularly in the subtropical gyre systems (Haram et al., 2021, 2023).

#### *4.3.2.7 Neuston Environmental Sampling Results*

Neuston were predominantly captured in the manta net sampling although they were found in some bongo and plankton net samples (**Figure 4-5**). Only the five primary taxa (*Halobates* spp., *Velella velella*, *Janthina* spp., *Porpita* spp., and *Glaucous* sp.) were used to characterize neuston density and occurrence in these samples. **Figure 4-5** indicates some temporal patterns with lowest densities recorded during Campaigns 6 and 7 (March – May; **Table 4-3**). **Figure 4-6** shows the occurrence of the primary taxa across gear types and campaigns. Clearly, the manta net is most effective at sampling these taxa. A closer look at manta samples reveals total densities per tow ranged from

0.2 to 148.3 individuals m$^{-3}$ and averaged 32.2 individuals m$^{-3}$. **Table 4-9** ranks the top 20 taxa collected in 143 manta tows made during Campaigns 1 through 12 (August 2021 – November 2022) by total count. The samples were numerically dominated by calanoid copepods followed by tunicates, chaetognaths, *Lucifer* spp., mysid shrimps, invertebrate eggs, and hyperiid amphipods. This list includes three of the five primary neuston taxa: *Halobates* spp., *V. velella*, and *Janthina* spp. Temporal patterns in density of neuston taxa over Campaigns 1 to 12 (August 2021 – November 2022) are shown in **Figure 4-5.** Clearly the manta net is most effective at sampling the neuston. Plankton and bongo net samples were sparse and highly variable with respect to neuston densities and occurrence in the samples.

A shade plot for the primary neuston taxa is provided in **Figure 4-6**. The water strider, *Halobates* was most abundant and frequently occurring in the samples for all gear types. By-the-wind sailors (*V. velella*) were the next most abundant taxon followed by the gastropod, *Janthina* spp.

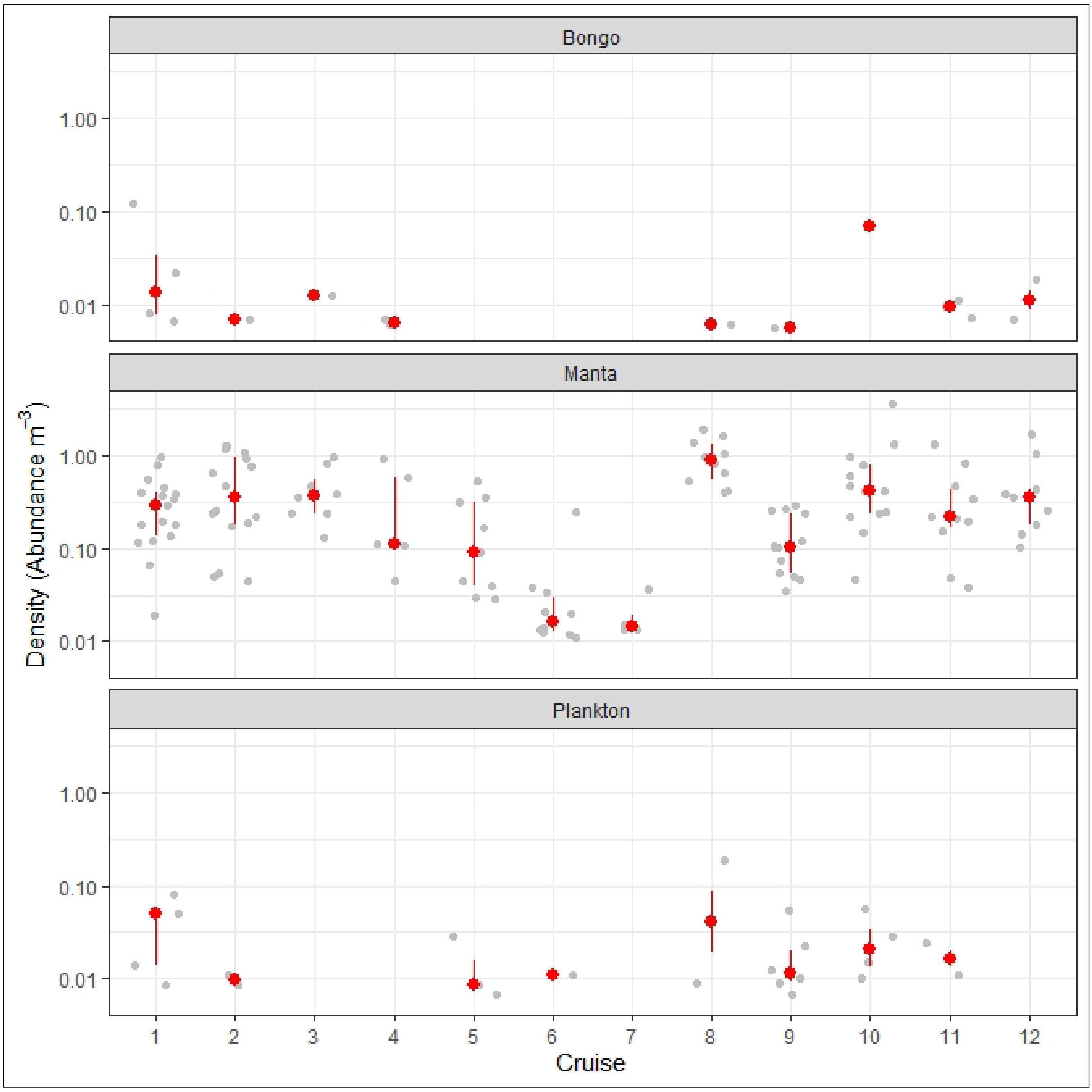



Figure 4-5. Temporal patterns of primary neuston taxa in samples from Bongo, Manta, and Plankton nets over Campaigns 1 to 12 (August 2021 – November 2022; **Table 4-3**).

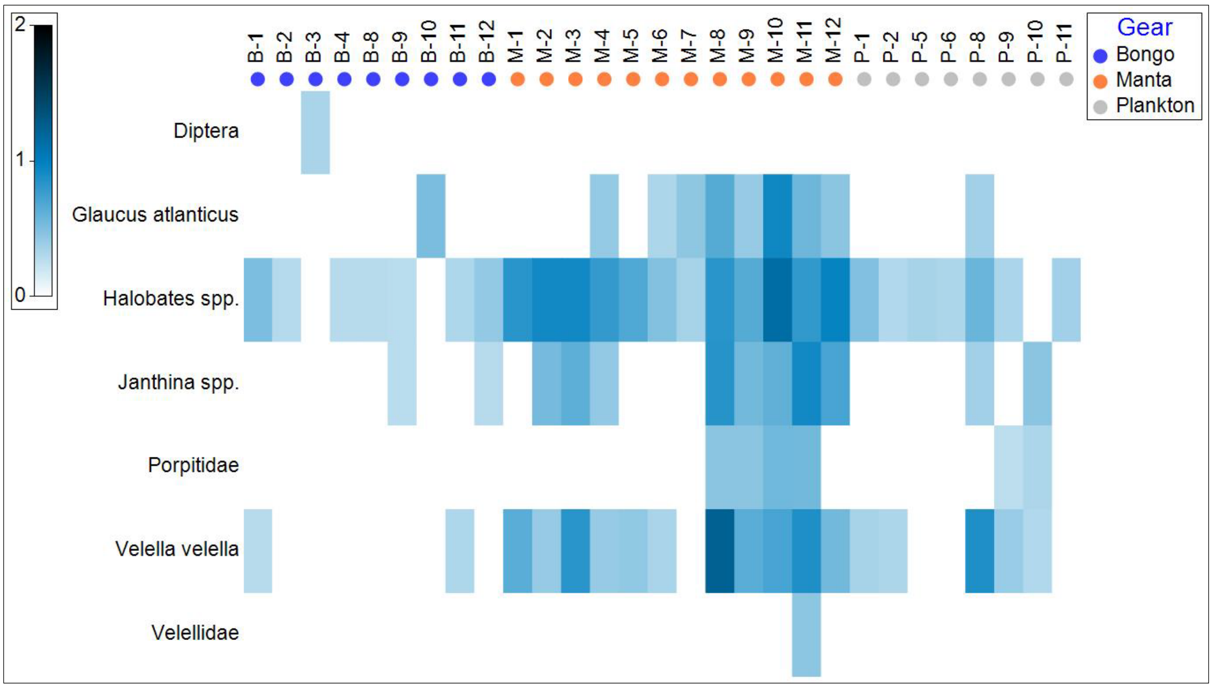



Figure 4-6. Shade plot comparing occurrence and density of primary neuston taxa with gear types and samples. Color range is 4th root transformed densities (n $m^{-3}$).

Table 4-9. Total counts, densities, and occurrence of taxa collected in 143 manta net tows made over Campaigns 1 through 12 (August 2021 – November 2022; **Table 4-3**).

| Group/Species | Mean Density (n $m^{-3}$) | Standard Deviation (n $m^{-3}$) | Total Count | Percent (%) | Occurrence |
|---|---|---|---|---|---|
| Calanoida | 831.8 | 9,191.8 | 105,218 | 38.5 | 136 |
| Tunicata | 297.9 | 3,298.1 | 37,754 | 13.8 | 129 |
| Chaetognatha | 170.4 | 1,874.4 | 21,456 | 7.9 | 129 |
| *Lucifer* spp. | 89.5 | 981.4 | 11,234 | 4.1 | 98 |
| Mysida | 88.6 | 972.2 | 11,128 | 4.1 | 52 |
| Mysidacea | 76.2 | 842.3 | 9,642 | 3.5 | 46 |
| Unid. Invertebrate eggs | 65.2 | 723.2 | 8,278 | 3.0 | 68 |
| Hyperiidae | 50.8 | 553.4 | 6,334 | 2.3 | 117 |
| Ostracoda | 49.2 | 539.2 | 6,172 | 2.3 | 63 |
| Scyphozoa | 46.0 | 501.3 | 5,738 | 2.1 | 87 |
| Appendicularia | 43.1 | 473.1 | 5,416 | 2.0 | 53 |
| Salpidae | 36.4 | 401.7 | 4,598 | 1.7 | 30 |
| *Halobates* spp. | 36.4 | 393.5 | 4,504 | 1.6 | 114 |
| Decapoda | 29.1 | 323.2 | 3,700 | 1.4 | 35 |
| *Velella velella* | 26.1 | 286.2 | 3,276 | 1.2 | 66 |
| Siphonophora | 14.6 | 159.7 | 1,828 | 0.7 | 27 |
| *Atlanta* spp. | 14.3 | 154.0 | 1,762 | 0.6 | 54 |
| Cyclopoida | 12.5 | 132.8 | 1,520 | 0.6 | 55 |
| Unid. fish eggs | 9.2 | 95.8 | 1,094 | 0.4 | 87 |
| *Janthina* spp. | 8.9 | 95.3 | 1,090 | 0.4 | 46 |

N/A = not applicable.

### 4.3.3 Fish/Fishery Resources

#### *4.3.3.1 Coastal and Estuarine Species*

Numerous species of fish use the Strait of Juan de Fuca and the Strait of Georgia as passageways from the open ocean to estuarine and inland waterways in Washington and Canada. Nearshore beach seine surveys, conducted over a 9-year period by Frick et al. (2018), identified 45 to 55 species of fish per year, with the catch numerically dominated by three species of forage fish: Pacific herring, Pacific sand lance, and surf smelt (*Hypomesus pretiosus*).

Pelagic trawl surveys conducted in 2016 and 2017 within the U.S. portion of the Strait of Juan de Fuca and its tributaries identified 96 different species of fish and invertebrates (Burger et al., 2020). However, like other studies, the catch was dominated by forage fish, with just nine species making up 96% of the individuals collected. Dominant species were Pacific herring, North Pacific hake, shiner perch (*Cymatogaster aggregata*), and market squid (*Doryteuthis opalescens*).

The only coastal fish species listed under Schedule I of SARA is the yelloweye rockfish (*Sebastes ruberrimus*), which is listed as Threatened. Fourteen species of sharks are known to occur in the waters of British Columbia (Fisheries and Oceans Canada, 2011), including the basking shark (*Cetorhinus maximus*), which is listed under Schedule I of SARA as Endangered. Fourteen species of skates and rays are also known to occur in British Columbian waters (Fisheries and Oceans Canada, 2012), but none are listed under Schedule I of SARA. **Table 4-10** describes some of the common species found in the coastal and estuarine habitat of the Vancouver area.

Table 4-10. Examples of species found within coastal and estuarine habitats in the Vancouver area.

| Common Name | Scientific Name | Species Details |
|---|---|---|
| Alaska pollock | *Gadus chalcogrammus* | • Widely distributed in the North Pacific Ocean, with the largest populations found in the Bering Sea<br>• Foraging species, but primary food sources consist of copepod plankton and krill<br>• Commercially important species |
| Chinook salmon | *Oncorhynchus tshawytscha* | • Migratory species<br>• Distributed in North America from the Monterey Bay area of California to the Chukchi Sea area of Alaska<br>• Hatch in freshwater streams and rivers, and migrate to the open ocean to feed<br>• After a few years feeding in the ocean, they return to the streams or rivers to spawn, generally in summer or early fall |
| Chum salmon | *Oncorhynchus keta* | • Migratory species<br>• Distributed in the North Pacific Ocean (i.e., Korea, Japan, Okhotsk, Arctic Alaska, south to San Diego, California)<br>• Spawns from late summer to March, with peak spawning in early winter when the river flows are high<br>• Hatch in freshwater streams and rivers, and migrate to the open ocean |
| Sockeye salmon | *Oncorhynchus nerka* | • Migratory species, although some populations live entire lives in fresh water<br>• Spawns in late summer or fall in British Columbia<br>• Distributed in the North Pacific Ocean and its tributaries<br>• Hatch in freshwater streams and rivers, and migrate to the open ocean to feed |
| Coho salmon | *Oncorhynchus kisutch* | • Migratory species<br>• Occurs in the North Pacific Ocean and in most coastal streams and rivers from Alaska to central California<br>• Spends 1 to 2 years feeding in the ocean, then returns to natal streams or rivers to spawn, generally in fall or early winter |

Table 4-10. (Continued).

| Common Name | Scientific Name | Species Details |
|---|---|---|
| Dover sole | *Microstomus pacificus* | • Found in the Pacific Ocean from the Bering Sea and western Aleutian Islands to southern Baja California<br>• Live near the ocean floor and prefer soft bottom habitat in waters up to 1,400 m deep<br>• Spawning seasons vary by location, and larvae usually settle to the bottom after a year of living in the upper water column |
| English sole | *Parophrys vetulus* | • Spawn from winter to early spring over soft, muddy ocean floors in water 50 to 70 m deep<br>• Travel north to summer feeding grounds after spawning and returns south in the fall |
| Flathead sole | *Hippoglossoides elassodon* | • Migrate in winter along the outer continental shelf to feeding grounds in shallower water in the spring<br>• Spawning occurs from February to April in deeper waters |
| North Pacific hake | *Merluccius productus* | • Found from the northern portion of Vancouver Island south to the northern portion of the Gulf of California<br>• Most abundant groundfish in the California Current System, with more hake caught than all other groundfish combined<br>• Populations also exist in major Pacific Ocean inlets, including the Strait of Georgia<br>• Commercially important species |
| Surf smelt | *Hypomesus pretiosus* | • Found from Prince William Sound in Alaska to Southern California<br>• Nighttime spawning occurs in summer and fall (May to October)<br>• Important part of the diet of several salmon species |
| Pacific herring | *Clupea pallasii* | • Found from the Bering Sea to Baja California<br>• Pacific fishery collapsed in the early 1990s but is slowly recovering to viability<br>• Considered a keystone species in the Pacific Northwest<br>• Spawns variably throughout the year, but usually in intertidal submerged vegetation habitats |
| Pacific mackerel | *Scomber japonicus* | • Found from southeastern Alaska to Mexico<br>• Perform inshore/offshore migration, with numbers increasing near the California coast from July to November<br>• Spawning timing varies depending on location, but often occurs from late April to September off California; spawning is year-round off central Baja California, peaking from June through October<br>• Commercially important species |
| Pacific sardine | *Sardinops sagax* | • Juveniles perform a northward return migration, taking advantage of the surface manifestation of the poleward flowing California Undercurrent to assist migration (Weber et al., 2015) |
| Yelloweye rockfish | *Sebastes ruberrimus* | • Found from Dutch Harbor, Alaska to Baja California<br>• Prized for their high-quality meat fillet, which has led to overfishing<br>• Extremely long-lived species, with estimated lifespans up to 120 years |
| Market squid | *Doryteuthis opalescens* | • Spawning occurs April through October in central California and October through April or May in southern California<br>• Spawning squid congregate in large schools near their spawning grounds, usually over sandy habitats<br>• The California market squid fishery is strongly affected by environmental and atmospheric conditions of the California Current System as well as El Niño/La Niña events<br>• Overall catches can decrease during El Niño then rebound with the increased upwelling of cooler La Niña phases (Jackson and Domeier, 2003; Pacific Fishery Management Council, 2017) |

#### *4.3.3.2 Oceanic Species*

Oceanic or epipelagic fishes generally inhabit the upper 200 m of the water column. The group is defined by sharks, billfishes, tunas, dolphinfishes, flyingfishes, halfbeaks (Beloniformes), opahs (Lampridae), oarfishes (Regalecidae), jacks (Carangidae), remoras (Echeneidae), pomfrets (Bramidae), driftfishes (Stromateidae), molas (Molidae) and triggerfishes (Balistidae) (e.g., Parin, 1968). Many of these species, such as dolphinfish (*Coryphaena* spp.), wahoo (*Acanthocybium solandri*), striped marlin (*Kajikia audax*), blue marlin (*Makaira nigricans*), and tunas (*Thunnus* spp.), are important to commercial and recreational fisheries. Many epipelagic species migrate great distances within or outside the central Pacific. For example, blue marlins will migrate across the entire Pacific Ocean in response to seasonal changes in sea surface temperature and productivity (Carlisle et al., 2016). Yellowfin tuna (*Thunnus albacares*) and albacore (*Thunnus alalunga*) migrate across the northern Pacific seeking preferred water temperatures and food resources (Collette and Graves, 2019). **Table 4-11** presents distribution, migration pattern, and spawning details for some of the common species found near the NPSG and the CCS.

Table 4-11. Distribution, migration pattern, and spawning details for some of the common species found near the North Pacific Subtropical Gyre and the California Current System.

| Common Name | Scientific Name | Species Details |
|---|---|---|
| Yellowfin tuna | *Thunnus albacares* | • Highly migratory species<br>• Spawning occurs in the southeastern Pacific, near Central America, during January and February<br>• Commercially important species |
| Skipjack tuna | *Katsuwonus pelamis* | • Found worldwide in waters warmer than 15°C<br>• Spawning occurs in the eastern Pacific in the summer months<br>• Commercially important species |
| Bigeye tuna | *Thunnus obesus* | • Highly migratory species<br>• Distributed across the Pacific Ocean, but the bulk of the catch is made toward the eastern and western ends of the basin<br>• Spawns in the equatorial South Pacific between April and September<br>• Commercially important species |
| Albacore | *Thunnus alalunga* | • Typically conducts an expansive annual migration that begins in spring or early summer in waters off Japan, continues throughout late summer into inshore waters off the United States Pacific coast, and ends late in the year in the western Pacific Ocean<br>• Spawning takes place in the mid-Pacific<br>• Large specimens caught northwest of the Hawaiian Islands in late summer carry nearly ripe eggs in their ovaries<br>• Fishing for albacore takes place in waters 37 to 185 km offshore central and southern California |
| Pacific bluefin tuna | *Thunnus orientalis* | • Juveniles migrate to eastern Pacific waters late in the first or second year of life<br>• Commercially important species |
| Wahoo | *Acanthocybium solandri* | • Found worldwide in tropical and subtropical waters<br>• Popular game fish |
| Striped marlin | *Kajikia audax* | • Highly migratory species<br>• Abundant off the coast of California from July to October |
| Swordfish | *Xiphias gladius* | • Highly migratory species<br>• Occur worldwide in tropical and temperate seas<br>• Most encountered between the mainland and the Channel Islands off southern California<br>• Spawning occurs offshore Hawaii from April until July |
| Yellowtail amberjack | *Seriola lalandi* | • Distributed from Chile to Canada<br>• Spawning occurs from June through October |

Table 4-11. (Continued).

| Common Name | Scientific Name | Species Details |
|---|---|---|
| Dolphinfish | *Coryphaena hippurus* *Coryphaena equiselis* | • Highly migratory species<br>• Distributed widely in all oceanic waters, including coastal and open ocean areas<br>• Commercially important species usually caught by tuna troll lines and occasionally by purse-seines and driftnets |
| Great white shark | *Carcharodon carcharias* | • Found along the Pacific coast most of the year<br>• In the spring, a migration pattern occurs, and the sharks move west into the open ocean and congregate approximately halfway between Hawaii and California (Jorgenson et al., 2009) within an area called “white shark café”, possibly for reproduction or feeding, from April to July. |
| Spinetail devil ray | *Mobula japanica* | • The southern Gulf of California serves as an important spring and summer mating/feeding ground for adults<br>• Pupping takes place around offshore islands or seamounts |
| Shortfin mako shark | *Isurus oxyrinchus* | • Rare in British Columbian waters<br>• Tends to follow movements of warm water poleward in the summer |
| Oceanic whitetip shark | *Carcharhinus longimanus* | • Common bycatch of longline, purse-seine, and hand line fisheries worldwide |
| Silky shark | *Carcharhinus falciformis* | • Common bycatch of longline, purse-seine, and hand line fisheries worldwide |
| Blue shark | *Prionace glauca* | • Caught in the North Pacific as bycatch in the giant flying squid fishery by becoming entangled while preying on squids<br>• Commonly caught with hook and lines, pelagic trawls, and bottom trawls |

*Flotsam-Associated Fishes*

Floating seaweed, jellyfishes, siphonophores, trees, logs, and artificial debris attract juvenile and adult epipelagic fishes (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967, 1968; Nelson, 2003; Thiel and Gutow, 2005a,b; Goldstein et al., 2014). The reasons for attraction to flotsam are not well known but likely involve shelter, feeding opportunities, and need for a reference point in an otherwise featureless ocean (Castro et al., 2002). Most common species are from the jack and triggerfish families. Other common families in the open ocean flotsam assemblage include halfbeaks, flyingfishes, chubs (Kyphosidae), tripletails (Lobotidae), damselfishes (Pomacentridae), frogfishes (Antennariidae), and filefishes (Monacanthidae). More than 300 species are documented to associate with living or dead flotsam in shelf waters worldwide (Castro et al., 2002). In open ocean waters of the Pacific, 29 species from 20 families were documented by Parin and Fedoryako (1999).

The spatial relationships and orientation of fishes with floating objects vary with fish size and life stage (Parin and Fedoryko, 1999; Castro et al., 2002). Parin and Fedoryako (1999) described three behavioral groups of flotsam-associated fishes, broadly defined by body size (small, intermediate, and large). Small individuals (<12 cm total length), including early life stages with limited swimming abilities, associate intimately with flotsam, staying within about 50 cm of objects. Examples include flyingfishes, sargassumfish (*Histrio histrio*), tripletail (*Lobotes surinamensis*), sergeant majors (*Abudefduf* spp.), and dolphinfishes. Most of these individuals are juveniles, often cryptically colored, and will seek interstitial spaces within natural or artificial floating objects. Also, flyingfishes will deposit eggs on floating plant material. This group highlights the fact that flotsam serves as a nursery area for many oceanic (and coastal) species.

Intermediate-sized fishes (3 to 12 cm total length) will remain within 2 to 3 m below the floating material but come closer at night or when frightened by potential predators. Juveniles and adults of this group are generally competent swimmers and exhibit countershading (light below, dark above) instead of cryptic coloration. Common members of this group include jacks (Carangidae*)*, amberjacks [*Seriola* spp.], and pilotfish [*Naucrates ductor*]), driftfishes (Stromateidae), subadult dolphinfishes, and chubs (Kyphosidae).

Larger (0.5 to >1.0 m total length), highly mobile predatory species such as sharks (silky shark [*Carcharhinus falciformis*], oceanic whitetip shark [*C. longimanus*]), dolphinfishes, rainbow runner (*Elagatis bipinnulata*), amberjacks, and tunas (yellowfin tuna, skipjack tuna [*Katsuwonus pelamis*]) may range from 2 to >10 m away from floating material. The propensity of tuna and dolphinfishes for floating material has affected the behavior of commercial fisheries in some regions (e.g., Caddy and Majkowski, 1996).

As described in **Section 2.1.1**, the System includes a camera skiff with multiple underwater cameras monitored by the EOs. Included in the observations of the RZ are many fish species swimming within the System. Many fish species are seen exiting the System via the fyke openings on S002 and the new bottom holes on the current RZ, and smaller fish swim freely through the System's larger netting. However, some fish are captured in the RZ, categorized as primary bycatch, and included with the plastics collected and brought on board for sorting. All RZ materials were sorted with the bycatch separated from the plastics, photographed, weighed, and documented. Live organisms are returned to the water as quickly as possible to facilitate their survival.

The fish taxa collected as primary bycatch included representatives of groups known to associate with flotsam or drifting algae, either as juveniles or during their entire lives. An example of the latter is the sargassumfish, well known as a resident of drifting sargassum assemblages worldwide (Florida Museum, 2021). Others such as jacks, spiny puffers (*Diodon holocanthus*), filefishes, flyingfishes, halfbeaks, and damselfishes have been well-documented associating with flotsam as juveniles. Two additional species in this category, the blackbanded blenny (*Petroscirtes breviceps*) and the knifejaw (*Oplegnathus* sp.), are less well known as flotsam associates but have been reported to associate with drifting sargassum or flotsam off Japan (Masuda et al., 1984). The presence of these two species, common around the Japanese archipelago and western Pacific, suggests a western origin for the recovered flotsam. One species group not considered an associate of flotsam are the kitefin sharks (Dalatiidae), including the cookiecutter shark (*Isistius brasiliensis*). Cookiecutter sharks are known to migrate vertically from as deep as 1,500 m to feed in the surface waters at night (Campagno et al., 2005; Carlise et al., 2021). Blennies were the most common fish caught during all deployment events.

Below the epipelagic zone of the water column is the mesopelagic zone (200 to 1,000 m). In the mesopelagic zone, fish assemblages are numerically dominated by lanternfishes, bristlemouths, and hatchetfishes (Sutton et al., 2017). Lanternfishes are small silvery fishes that can be extremely abundant, often responsible for the deep scattering layer in sonar images of the deep sea. Lanternfishes and other mesopelagic fishes spend the daytime in depths of 200 to 1,000 m, but migrate vertically at night into the food-rich upper water column. Some species will reach near-surface waters during their nocturnal forays. Mesopelagic fish, while less commonly known, are important ecologically because they transfer significant amounts of energy between the mesopelagic and epipelagic zones over each daily cycle. Lanternfishes are important prey for mesopelagic and epipelagic predators such as seabirds, tunas, swordfish, and marine mammals (Davison and Asch, 2011; Choy et al., 2015).

Fish observations were not quantified during The Ocean Cleanup's transit and deployment of the S001 in 2018, but numerous flyingfish, dolphinfish, sunfish, and yellowfin tuna were observed (Seiche, 2019). During The Ocean Cleanup's deployment of the S001/B in the NPSG in 2019, 11 species of fish were observed in proximity of the deployed System, including blue shark (*Prionace glauca*), dolphinfish, California flyingfish (*Cheilopogon pinnatibarbatus californicus*), blue marlin (**Image 4-2**), the protected ocean sunfish, pilotfish, striped marlin, Pacific sergeant major (*Abudefduf troschelii*), chubs (Kyphosidae), and yellowtail amberjack (*Seriola lalandi*) (The Ocean Cleanup, 2020). Additionally, unidentified tuna, sharks, pufferfishes, and other unidentified large and small fishes were observed. Similar fish species were observed during the S002 Campaigns

1 through 5 (**Image 4-3**). In addition, the EOs observed six ocean sunfish, the only IUCN fish species observed, that had surfaced either in front of or beside the vessels. Also, the remains of an unidentified shark were found entangled in ghost nets during plastic sorting. From observations, it appeared the animal was entangled in the ghost net before entering the System; therefore, it was considered a previously deceased organism.

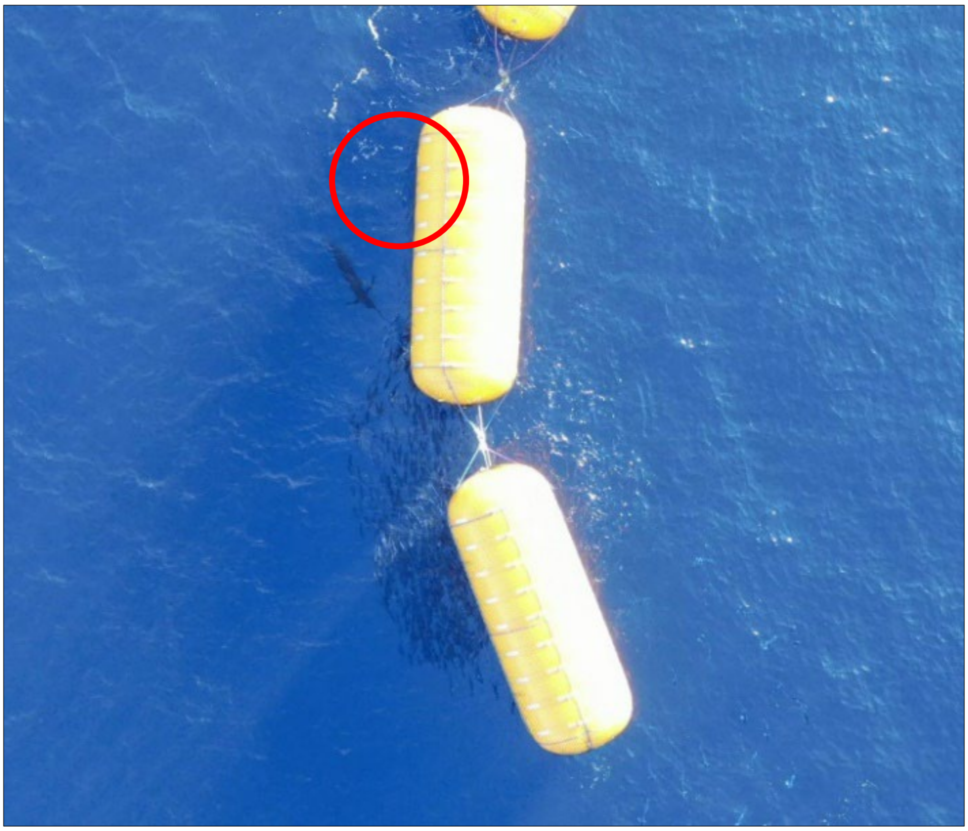


Image 4-2. Blue marlin swimming at depth (red circle) near The Ocean Cleanup's deployed S001/B in the North Pacific Subtropical Gyre in 2019 (From: The Ocean Cleanup, 2020).

Image 4-3. Yellowtail amberjacks swimming around The Ocean Cleanup's deployed S002 in the North Pacific Subtropical Gyre in 2021 (From: The Ocean Cleanup, 2021).

Numerous fish species that could occur in the area of deployment in the NPSG are classified by the IUCN (Red List), with the species of elevated concern listed as either Vulnerable, Endangered, or Critically Endangered. **Table 4-12** summarizes the Vulnerable and Endangered species that may be found in the vicinity of the S002 deployment.

Table 4-12. Species of pelagic fish classified as Vulnerable or Endangered that may be found in the vicinity of The Ocean Cleanup's S002 deployment in the North Pacific Subtropical Gyre (From: IUCN Red List, 2023).

| Family | Common Name | Scientific Name | IUCN Red List Status | Typical Depth Range | Reference |
|---|---|---|---|---|---|
| Sphyrnidae | Great hammerhead shark | *Sphyrna mokarran* | Critically Endangered | Surface to 80 m | Rigby et al. (2019a) |
| | Scalloped hammerhead shark | *Sphyrna lewini* | Critically Endangered | Surface to 275 m | Rigby et al. (2019b) |
| | Smooth hammerhead shark | *Sphyrna zygaena* | Vulnerable | Surface to 200 m | Rigby et al. (2019c) |
| Rhincodontidae | Whale shark | *Rhincodon typus* | Endangered | Surface to >1,900 m | Pierce and Norman (2016) |
| Lamnidae | Shortfin mako shark | *Isurus oxyrinchus* | Endangered | Surface to 500 m | Rigby et al. (2019d) |
| | Longfin mako shark | *Isurus paucus* | Endangered | Surface to 1,752 m | Rigby et al. (2019e) |
| | Great white shark | *Carcharodon carcharias* | Vulnerable | Surface to 250 m | Rigby et al. (2019f) |
| Molidae | Ocean sunfish | *Mola mola* | Vulnerable | Surface to 400 m | Liu et al. (2015) |
| Alopiidae | Pelagic thresher shark | *Alopias pelagicus* | Endangered | Surface to 150 m | Rigby et al. (2019g) |
| | Big eye thresher shark | *Alopias superciliosus* | Vulnerable | Surface to 725 m, mostly below 100 m | Rigby et al. (2019h) |
| | Common thresher shark | *Alopias vulpinus* | Vulnerable | Surface to 366 m | Rigby et al. (2019i) |
| Carcharhinidae | Oceanic whitetip shark | *Carcharhinus longimanus* | Critically Endangered | Surface to 150 m | Rigby et al. (2019j) |
| | Silky shark | *Carcharhinus falciformis* | Vulnerable | Surface to 500 m | Rigby et al. (2017) |
| Cetorhinidae | Basking shark | *Cetorhinus maximus* | Endangered | Surface to 1,000 m | Rigby et al. (2021) |
| Mobulidae | Giant manta ray | *Mobula birostris* | Endangered | Surface to 120 m | Marshall et al. (2020a) |
| | Spinetail devil ray | *Mobula mobular* | Endangered | Surface to 1,112 m | Marshall et al. (2020b) |
| | Sicklefin devil ray | *Mobula tarapacana* | Endangered | Surface to 1,896 m | Marshall et al. (2019a) |
| | Bentfin devil ray | *Mobula thurstoni* | Endangered | Surface to 100 m | Marshall et al. (2019b) |
| Scombridae | Bigeye tuna | *Thunnus obesus* | Vulnerable | Surface to 1,500 m | Collette et al. (2011a) |
| Istiophoridae | Blue marlin | *Makaira nigricans* | Vulnerable | Surface to 1,000 m | Collette et al. (2011b) |

IUCN = International Union for Conservation of Nature.

### 4.3.4 Marine Mammals

In the northeastern Pacific Ocean, there are 42 species of marine mammals representing two taxonomic orders that may be present: Cetacea (baleen whales, toothed whales, dolphins, and porpoises) and Carnivora (true seals and eared seals) (Jefferson et al., 2008).

All marine mammals within Canadian waters are protected under the Marine Mammal Regulations promulgated under the Fisheries Act (**Section 3.3.3**). Some species are further protected under SARA (**Section 3.3.2**). Under SARA, a species is considered endangered if it is "a wildlife species that is facing imminent extirpation or extinction." A species is considered threatened if it is "a wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction." The Marine Mammal Regulations (**Section 3.3.4**) prohibit, with certain exceptions, disturbing or killing any marine mammal.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is an advisory panel to the Minister of the Environment and Climate Change that assesses the status of wildlife species at risk of extinction. COSEWIC is the regulatory body that makes recommendations for species to be listed as endangered or threatened under SARA. Subsequent steps include COSEWIC reporting its results to the Canadian government and the public, and the Minister of the Environment and Climate Change providing an official response to the assessment results. Wildlife species designated by COSEWIC may then qualify for legal protection and recovery under SARA.

The IUCN Red List provides taxonomic, conservation status, and distribution information on plants, fungi, and animals that have been globally evaluated using the IUCN Red List categories and criteria. This system is designed to determine the relative risk of extinction. The main purpose of the IUCN Red List is to catalogue and highlight plants and animals facing a higher risk of global extinction (i.e., those listed as Critically Endangered, Endangered, and Vulnerable). The current IUCN, COSEWIC, and SARA status of each marine mammal species that may occur within the project area are provided in the following subsections.

#### *4.3.4.1 Whales, Dolphins, and Porpoises (Order Cetacea)*

Baleen Whales *(Suborder Mysticeti)*

Eight species of baleen (mysticete) whales are known to occur in the North Pacific Ocean (**Table 4-13**). Three species (sei whale [*Balaenoptera borealis borealis*], blue whale [*Balaenoptera musculus*], and North Pacific right whale [*Eubalaena japonica*]) are classified as Endangered, four species (minke whale [*Balaenoptera acutorostrata*], gray whale [*Eschrichtius robustus*], Bryde's whale [*Balaenoptera edeni*], and humpback whale) are classified as Least Concern, and one (fin whale [*Balaenoptera physalus physalus*]) is classified as Vulnerable in the IUCN Red List (**Table 4-11**).

Table 4-13. Mysticete whales present from southwestern Canadian coast to the North Pacific Ocean.

| Common Name | Scientific Name | Migratory | IUCN Red List Status | COSEWIC Status | SARA Status | Reference |
|---|---|---|---|---|---|---|
| Common minke whale (North Pacific subspecies) | *Balaenoptera acutorostrata scammoni* | Yes, but some are present year-round | Least Concern | Not at Risk | Not Listed | Cooke (2018a) |
| Sei whale (northern hemisphere subspecies) | *Balaenoptera borealis borealis* | Yes | Endangered | Endangered | Endangered | Cooke (2018b) |

Table 4-13. (Continued).

| Common Name | Scientific Name | Migratory | IUCN Red List Status | COSEWIC Status | SARA Status | Reference |
|---|---|---|---|---|---|---|
| Bryde's whale | *Balaenoptera edeni* | Yes | Least Concern | -- | -- | Cooke and Brownell (2018) |
| Blue whale (northern hemisphere subspecies) | *Balaenoptera musculus musculus* | Yes | Endangered | Endangered | Endangered | Cooke (2018c) |
| Fin whale (northern hemisphere subspecies) | *Balaenoptera physalus physalus* | Yes, but some have year-round residency | Vulnerable | Special Concern | Threatened | Cooke (2018d) |
| Gray whale | *Eschrichtius robustus* | Yes | Least Concern | Not at Risk | Not Listed* | Cooke (2018e) |
| North Pacific right whale | *Eubalaena japonica* | Yes | Endangered | Endangered | Endangered | Cooke and Clapham (2018) |
| Humpback whale (North Pacific subspecies) | *Megaptera novaeangliae kuzira* | Yes | Least Concern | Special Concern | Special Concern | Cooke (2018f) |

-- = not assessed; COSEWIC = Committee on the Status of Endangered Wildlife in Canada; IUCN = International Union for Conservation of Nature; SARA = Species at Risk Act.
*Northern Pacific migratory population.

### *Common Minke Whale (Balaenoptera acutorostrata)*

The common minke whale is a small mysticete that is divided into three subspecies. The subspecies *B. a. scammoni* occurs within the North Pacific (Committee on Taxonomy, 2017). Adult minke whales reach lengths of up to 10.7 m (Jefferson et al., 2008).

#### *Distribution*

The minke whale has a cosmopolitan distribution and occurs in polar, temperate, and tropical waters. In the Pacific Ocean, minke whales are usually seen over continental shelves (Brueggeman et al., 1990). The distribution of minke whales in the North Pacific within the extreme northern part of their range is believed to be migratory, but within the inland waters of Washington and central California, they appear to establish home ranges (Dorsey et al., 1990). Although minke whales are relatively common within their northern range (Bering and Chukchi seas and the Gulf of Alaska), they are not considered abundant in any other part of the eastern Pacific (Leatherwood et al., 1982; Brueggeman et al., 1990).

#### *Auditory and Vocalization Range*

Minke whale vocalizations are low frequency, ranging from 80 Hz to 20 kHz range (Winn and Perkins, 1976; Frankel, 2002). They are classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007, 2019).

### *Status*

Minke whales off the coasts of Washington, Oregon, and California are included within the California/Oregon/Washington stock. The IUCN Red List classifies minke whales as a species of Least Concern. Minke whales are listed as Not at Risk by COSEWIC and are not listed under SARA.

## *Sei Whale (Balaenoptera borealis)*

The sei whale is a large mysticete that is divided into two subspecies. The subspecies *B. b. borealis* occurs within the northern hemisphere (Committee on Taxonomy, 2017). Adult sei whales reach lengths of 12 to 18 m (Jefferson et al., 2008).

### *Distribution*

Sei whales have a cosmopolitan distribution and occur in subtropical, temperate, and subpolar waters around the world but appear to prefer temperate waters in the mid-latitudes. The entire distribution and movement patterns of this species is not well known. Sei whales are distributed in oceanic waters and do not appear to be associated with coastal features. This species may unpredictably and randomly occur in a specific area, sometimes in large numbers. Sei whales' summer distribution is known to be mainly north of 40° N latitude. While little is known about the species' winter distribution (Reilly et al., 2008a), animals migrate southward to lower latitudes. There have been no sightings of sei whales off Canada's Pacific coast since the moratorium on commercial whaling in 1976; however, the species prefers deeper offshore habitat, more so than other species (Government of Canada, 2021a).

### *Auditory and Vocalization Range*

Recorded vocalizations of sei whales range from 432 Hz to 3.5 kHz (Thompson et al., 1979; Knowlton et al., 1991; McDonald et al., 2005). While there are no direct hearing data available for this species (Ketten, 2000), sei whales are classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007, 2019).

### *Status*

The IUCN Red List classifies sei whales as Endangered. Sei whales are listed as Endangered by COSEWIC and under SARA.

## *Bryde's Whale (Balaenoptera edeni)*

The IUCN regards the Bryde's whale as a species whose taxonomy is "not yet settled"; there are at least two and maybe three Bryde's whale species (Reilly et al., 2008b). Currently, there are two recognized subspecies. The subspecies *B. e. brydei* occurs within the North Pacific (Committee on Taxonomy, 2017). Bryde's whales can reach lengths of 13 to 16.5 m.

### *Distribution*

Bryde's whales have a circumglobal distribution in tropical and subtropical waters and are distributed widely across the tropical and warm-temperate Pacific Ocean (Leatherwood et al., 1982). Bryde's whales are not found in Canada's Pacific waters.

### *Auditory and Vocalization Range*

Bryde's whale vocalizations are low frequency, ranging from 20 to 900 Hz (Cummings, 1985; Oleson et al., 2003). The species is classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007, 2019).

*Status*

The IUCN Red List classifies Bryde's whales as a Least Concern species. Bryde's whales have not been assessed by COSEWIC and are not listed under SARA.

### *Blue Whale (Balaenoptera musculus)*

The blue whale is the largest whale species and is divided into five subspecies. The subspecies *B. m. musculus* occurs within the northern hemisphere (Committee on Taxonomy, 2017). North Pacific blue whales were once thought to comprise five separate populations (Reeves et al., 1998). Recent acoustic evidence suggests only two populations, one each in the eastern and western North Pacific, respectively (Stafford et al., 2001; Stafford, 2003; McDonald et al., 2006; Monnahan et al., 2014). Adult blue whales reach lengths of up to 33 m (Jefferson et al., 2008).

*Distribution*

The blue whale is a cosmopolitan species, found in all oceans except the Arctic and some regional seas such as the Mediterranean, Okhotsk, and Bering seas (Reilly et al., 2008c). Blue whales commonly occur within offshore waters (Rice, 1998); however, individuals are occasionally sighted in relatively shallow water. In particular, there are a few locations in the world where blue whales are known to migrate through near-coastal, relatively shallow areas (Jefferson et al., 2008). In Canada, blue whales in the North Pacific migrate past Vancouver Island in the spring and fall. There are no current estimates of the population size offshore Canada, but given the rarity of sightings, the population is likely low (Government of Canada, 2021b).

*Auditory and Vocalization Range*

Blue whales produce a variety of low-frequency sounds in the 10 to 200 Hz band (Stafford et al., 1998, 1999a,b, 2001; Frankel, 2002). Short sequences of rapid-frequency modulated calls below 90 Hz are associated with animals in social groups (Moore and DeMaster, 1999; Mellinger and Clark, 2003). Most blue whale vocalizations are between 17 and 20 Hz. Sound intensity of blue whale vocalizations is the loudest of any animal (up to 188 dB re 1 µPa) (Sears, 2002).

While there are no direct hearing data available (Ketten, 2000), blue whales are classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007, 2019).

*Status*

The IUCN Red List classifies the blue whale as an Endangered species, although the worldwide population is increasing. In Canada, the Pacific population of the blue whale is listed as Endangered by COSEWIC and under SARA.

### *Fin Whale (Balaenoptera physalus)*

The fin whale is a large mysticete and is divided into three subspecies. The subspecies *B. p. physalus* occurs within the northern hemisphere (Committee on Taxonomy, 2017). Fin whales attain a maximum length of approximately 22 m in the northern hemisphere.

*Distribution*

Fin whales have a similar distribution to sei and blue whales; however, this species is known to be distributed farther north than the latter species. The northern hemisphere fin whale likely includes distinct Pacific and Atlantic subspecies (Archer et al., 2013). Fin whales migrate offshore British Columbia between their winter range offshore California and their summer range in the Arctic. Some fin whales have been noted spending the summer offshore British Columbia. In summer, they occur off the entire coast of western North America from California into the Gulf of Alaska. While there appears to be some migration of fin whales, acoustic data suggest there is no marked seasonality in distribution in the North Pacific (Watkins et al., 2000).

Fin whales occur year-round off southern and central California (Reilly et al., 2013), in the Gulf of California (Urbán et al*.,* 2005), and in Hawaiian waters (Angliss and Outlaw, 2005). Fin whales in the Gulf of California constitute a genetically isolated subpopulation (Bérubé et al., 2002). In summer, their distribution extends north to the region around the Gulf of Alaska and the Okhotsk Sea (Angliss and Outlaw, 2005; Reilly et al., 2013).

#### *Auditory and Vocalization Range*

Fin whale vocalizations are low frequency, generally below 70 Hz but ranging up to 750 Hz (Clark et al., 2002). While there are no direct hearing data available (Ketten, 2000), fin whales are classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007).

#### *Status*

The IUCN Red List classifies the fin whale as a Vulnerable species. The Pacific population of the fin whale is listed as a species of Special Concern by COSEWIC and Threatened under SARA. At the last status review by COSEWIC, the fin whale met the criterion for Threatened under A1d (actual but potential levels of exploitation), but the species of Special Concern status was retained due to noted abundance of the species in neighboring U.S. waters (Government of Canada, 2021c).

### ***Gray Whale (Eschrichtius robustus)***

The gray whale includes one species, although genetic comparisons indicate there are distinct eastern and western North Pacific population stocks (LeDuc et al*.,* 2002; Lang et al., 2011; Weller et al., 2013). Gray whales mostly feed on tube-dwelling amphipods and polychaete tubeworms on the seafloor, but can also prey on crabs, baitfish, crab larvae, amphipods, eggs, larvae, and cephalopods.

#### *Distribution*

Most gray whales in the eastern North Pacific population feed in the Chukchi, Beaufort, and northwestern Bering seas during summer and fall; however, there is a relatively small number of whales (approximately 200) that summer and feed along the Pacific coast between Kodiak Island, Alaska and northern California (Darling, 1984; Gosho et al., 2011; Calambokidis et al., 2012) and are referred to as the Pacific Coast feeding group. During winter, there are three primary wintering lagoons in Baja California, Mexico (Jones, 1990). While gray whales were once more widely distributed, they now only occur in the North Pacific and adjacent waters. The northern Pacific migratory population migrates from summer foraging grounds in the Chukchi, Beaufort, and Bering seas to winter breeding grounds off Baja California. Some (presumably a small number) also summer and forage between coastal Vancouver Island and central California.

#### *Auditory and Vocalization Range*

Gray whales have a limited call repertoire (six distinct calls) and produce low-frequency calls, generally ranging between 100 to 2,000 Hz. They are classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007, 2019).

The IUCN Red List classifies the gray whale as a species of Least Concern. The gray whale is not listed by COSEWIC or under SARA as numbers are well above mid-20$^{th}$ century populations and are considered stable (Government of Canada, 2021d).

### *North Pacific Right Whale (Eubalaena japonica)*

Right whales are large mysticetes. The North Pacific right whale is the largest of the three right whale species (Jefferson et al., 2008). Adults are generally 13.7 to 16.7 m in length.

#### *Distribution*

North Pacific right whales inhabit waters of the Pacific Ocean, particularly between 20° and 60° N latitude. Few sightings of right whales occur in the central North Pacific and Bering Sea. Sightings have been reported as far south as central Baja California and Hawaii, and as far north as the sub-Arctic waters of the Bering Sea and Sea of Okhotsk in the summer. They are considered vagrant in southwestern Canada (Reilly et al., 2008d). They primarily occur in coastal or shelf waters, although movements over deep waters are known. For much of the year, their distribution is strongly correlated to the distribution of their prey. Two areas within the Gulf of Alaska and within the Bering Sea are designated as critical habitat for the North Pacific right whale (73 Federal Register [*FR*] 19000).

#### *Auditory and Vocalization Range*

Morphometric analyses of inner ears from stranded North Atlantic right whales (*Eubalaena glacialis*), a congener to North Pacific right whales, were used for development of a preliminary model of the frequency range of hearing. From these results, the estimated hearing range of right whales is 10 Hz to 22 kHz (Parks et al., 2007). They are classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007).

#### *Status*

The IUCN Red List classifies the North Pacific right whale as Endangered. The North Pacific right whale is listed as Endangered by COSEWIC and under SARA (Government of Canada, 2021e).

### *Humpback Whale (Megaptera novaeangliae)*

The humpback whale is a large mysticete and is divided into three subspecies. The subspecies *M. n. kuzira* occurs within the North Pacific Ocean (Committee on Taxonomy, 2017). Humpback whales attain lengths of 18 to 22 m in the northern hemisphere.

#### *Distribution*

Humpback whales are a cosmopolitan species (Clapham and Mead, 1999), living in all major oceans from the equator to subpolar latitudes, including the NPSG. Nearly all populations, including the North Pacific, migrate from high latitude summer grounds to low latitude winter grounds where they breed (Clapham, 2002). Calving and mating generally occur in coastal waters. In summer, humpback whales range from southern California to the region around Alaska, the Bering Sea, and over to northeastern Japan. In winter, these humpback whales occur off islands from Hawaii to the northern Philippines and off the coast of Mexico and Central America. Canadian waters, especially productive waters offshore British Columbia, are largely used for feeding and as migration routes to far northern feeding areas (Government of Canada, 2021f).

#### *Auditory and Vocalization Range*

Humpback songs are known to range from 20 Hz to at least 8 kHz. This species is classified within the low-frequency cetacean functional marine mammal hearing group (7 Hz to 22 kHz) (Southall et al., 2007, 2019).

*Status*

The IUCN Red List classifies the humpback whale as a species of Least Concern. Currently, the humpback whale is listed as a species of Special Concern by COSEWIC and under SARA.

*Toothed (Odontocete) Whales, Dolphins, and Porpoises*

Twenty-five species of toothed (odontocete) whales and dolphins are known to occur in the North Pacific Ocean (**Table 4-14**). One odontocete species (sperm whale [*Physeter macrocephalus*]) is classified as Vulnerable under the IUCN Red List, while all other odontocete species are listed as Least Concern or Data Deficient.

Vocalization information for specific odontocetes/odontocete groups are presented in Erbe et al. (2017) and Southall et al. (2019). Given the lack of endangered species likely to be encountered in the NPSG and the limited auditory impacts associated with deployment of the S03, no species-specific vocalization information is presented here.

Table 4-14. Toothed whales (Suborder Odontoceti) present between the southwestern Canadian coast and the North Pacific Ocean.

| Common Name | Scientific Name | IUCN Red List Status | COSEWIC Status | SARA Status | Reference |
|---|---|---|---|---|---|
| Baird's beaked whale | *Berardius bairdii* | Least Concern | Not at Risk | Not Listed | Taylor and Brownwell (2020) |
| Eastern North Pacific long-beaked common dolphin | *Delphinus delphis bairdii* | Data Deficient | -- | -- | Hammond et al. (2008a) |
| Short-beaked common dolphin | *Delphinus delphis delphis* | Least Concern | Not at Risk | Not Listed | Braulik et al. (2021) |
| Pygmy killer whale | *Feresa attenuata* | Least Concern | -- | -- | Braulik (2018) |
| Short-finned pilot whale | *Globicephala macrorhynchus* | Least Concern | Not at Risk | Not Listed | Minton et al. (2018) |
| Risso's dolphin | *Grampus griseus* | Least Concern | Not at Risk | Not Listed | Kiszka and Braulik (2018a) |
| Pygmy sperm whale | *Kogia breviceps* | Least Concern | Not at Risk | Not Listed | Kiszka and Braulik (2020a) |
| Dwarf sperm whale | *Kogia sima* | Least Concern | Data Deficient | Not Listed | Kiszka and Braulik (2020b) |
| Pacific white-sided dolphin | *Lagenorhynchus obliquidens* | Least Concern | Not at Risk | Not Listed | Ashe and Braulik (2018) |
| Northern -right whale dolphin | *Lissodelphis borealis* | Least Concern | Not at Risk | Not Listed | Braulik and Jefferson (2018) |
| Hubbs' beaked whale | *Mesoplodon carlhubbsi* | Data Deficient | Not at Risk | Not Listed | Pitman and Brownell (2020a) |
| Blainville's beaked whale | *Mesoplodon densirostris* | Least Concern | Not at Risk | Not Listed | Pitman and Brownell (2020b) |
| Gingko-toothed beaked whale | *Mesoplodon ginkgodens* | Data Deficient | -- | -- | Pitman and Brownell (2020c) |
| Indo-Pacific beaked whale, or Longman's beaked whale | *Indopacetus pacificus* | Least Concern | -- | -- | Pitman and Brownell (2020d) |
| Killer whale, or Orca | *Orcinus orca* | Data Deficient | Threatened[1] | Threatened[1] | Reeves et al. (2017) |
| Harbor porpoise | *Phocoena phocoena* | Least Concern | Special Concern | Special Concern | Braulik et al. (2020) |
| Dall's porpoise | *Phocoenoides dalli* | Least Concern | Not at Risk | Not Listed | Jefferson and Braulik (2018) |
| Sperm whale | *Physeter macrocephalus* | Vulnerable | Not at Risk | Not Listed | Taylor et al. (2019) |

Table 4-14. (Continued).

| Common Name | Scientific Name | IUCN Red List Status | COSEWIC Status | SARA Status | Reference |
|---|---|---|---|---|---|
| False killer whale | *Pseudorca crassidens* | Near Threatened | Not at Risk | Not Listed | Baird (2018) |
| Pantropical spotted dolphin | *Stenella attenuata* | Least Concern | -- | -- | Kiszka and Braulik (2018b) |
| Striped dolphin | *Stenella coeruleoalba* | Least Concern | Not at Risk | Not Listed | Braulik (2019) |
| Spinner dolphin | *Stenella longirostris* | Least Concern | -- | -- | Braulik and Reeves (2018) |
| Rough-toothed dolphin | *Steno bredanensis* | Least Concern | -- | -- | Kiszka et al. (2019) |
| Common bottlenose dolphin | *Tursiops truncatus* | Least Concern | Not at Risk | Not Listed | Wells et al. (2019) |
| Cuvier's beaked whale | *Ziphius cavirostris* | Least Concern | Not at Risk | Not Listed | Baird et al. (2020) |

-- = not assessed; COSEWIC = Committee on the Status of Endangered Wildlife in Canada; IUCN = International Union for Conservation of Nature; SARA = Species at Risk Act.

[1] Status for the Northeast Pacific offshore population, which is the primary population expected to occur around the North Pacific Subtropical Gyre.

### *Baird's Beaked Whale (Berardius bairdii)*

The Baird's beaked whale (*Berardius bairdii*) is the largest member of the beaked whale family (Ziphiidae). Females reach lengths of about 13 m and can weigh approximately 12,000 kg (Jefferson et al., 2008). They feed on cods/hakes (Gadiformes), cephalopods, and crustaceans living near the seafloor as well as some pelagic fish such as mackerel, sardines, and saury (Balcomb, 1989; Kasuya, 2002). Observations of Baird's beaked whales are rare in Canadian waters (Government of Canada, 2021g).

#### *Distribution*

The Baird's beaked whale is distributed in the North Pacific Ocean and adjacent seas. They are known to occur from the southern range of the Gulf of California to Honshu, Japan; however, the limits of their range in oceanic waters are not well known (Balcomb, 1989; Kasuya, 2002). There are an estimated 1,100 Baird's beaked whales in the eastern North Pacific, and no information is available on trends for the species. Baird's beaked whales occur in deep oceanic waters and sometimes in waters closer to shore where deep water occurs near the coast. Baird's beaked whales generally are sighted near the continental slope and oceanic seamounts at depths of 1,000 to 3,000 m (Kasuya, 2002).

#### *Status*

The IUCN Red List classifies the North Pacific right whale as a Least Concern species. Currently, the Baird's beaked whale is listed as Not at Risk by COSEWIC and is not listed under SARA.

### *Eastern North Pacific Long-beaked Common Dolphin (Delphinus delphis bairdii)*

Eastern North Pacific long-beaked common dolphins (*Delphinus delphis bairdii*) are relatively small dolphins that may reach lengths of 1.9 to 2.6 m and weigh between 80 and 235 kg (Jefferson et al., 2008). They are commonly found within approximately 93 km of the coast, primarily inshore of the 250-m isobath, with very few sightings (<15%) in waters deeper than 500 m (Carretta et al., 2017).

*Distribution*

The distribution of eastern North Pacific long-beaked common dolphins is not well known. Generally, this species, if found, is observed in nearshore waters (Heyning and Perrin, 1994). Prior to 2005, long-beaked common dolphins were only known from British Columbia from a single stranding. However, Ford (2005) described specimen records and sightings from 1993 to 2005 and concluded the species may be found in Canadian Pacific waters during warm-water periods.

*Status*

The IUCN Red List classifies the long-beaked common dolphin as a Data Deficient species. Currently, the eastern North Pacific long-beaked common dolphin is sufficiently rare in Canadian waters that it has not been assessed by COSEWIC or under SARA.

### ***Common Dolphin (Delphinus delphis delphis)***

The common dolphin may reach approximately 2.7 m in length and weigh 200 kg (Jefferson et al., 2008). They prefer oceanic and offshore waters that are warm tropical to cool temperate (10°C to 28°C). They also prefer waters altered by underwater geologic features where upwelling occurs (Hammond et al., 2008b).

*Distribution*

The common dolphin is widely distributed in tropical and temperate waters, including within the Pacific Ocean (Perrin, 2002). Almost 3 million individuals have been estimated in the eastern tropical Pacific and approximately 352,000 individuals for the U.S. west coast (Gerrodette and Forcada, 2002). This species occurs in offshore and near-coastal waters. In some locations, common dolphins show seasonal changes in abundance (Forney and Barlow, 1998). Short-beaked common dolphins in the eastern tropical Pacific have been sighted in association with yellowfin tuna; they prey on schooling fish and squid (Perrin, 2002) and have been found to interact with tuna purse-seine fishing operations (Gerrodette, 2002). They often forage in upwelling areas with steep seafloor gradients (Reilly, 1990; Fiedler and Reilly, 1994). This species is only an occasional visitor to Pacific Canadian waters (Government of Canada, 2021h).

*Status*

The IUCN Red List classifies the common dolphin as a species of Least Concern. Currently, the common dolphin is listed as Not at Risk by COSEWIC and not listed under SARA.

### ***Pygmy Killer Whale (Feresa attenuata)***

The pygmy killer whale (*Feresa attenuata*) is a small member of the dolphin group. They can reach a length of 2.6 m and weigh up to 170 kg (Jefferson et al., 2008). Pygmy killer whales forage on fish and squid (Perryman and Foster, 1980). However, little additional information is known about their diet.

*Distribution*

The pygmy killer whale occurs in tropical and subtropical offshore oceanic waters around the world, and close to the coast where there are deep waters. There are 38,900 individuals of this species estimated in the eastern tropical Pacific (Wade and Gerrodette, 1993). The pygmy killer whale is not known to occur in Canadian waters.

*Status*

The IUCN Red List classifies the pygmy killer whale as a Least Concern species. The pygmy killer whale has not been assessed by COSEWIC or under SARA.

### *Short-finned Pilot Whale (Globicephala macrorhynchus)*

The short-finned pilot whale (*Globicephala macrorhynchus*) is a larger member of the dolphin group, reaching average lengths of 5.5 m and weighing 1,000 to 3,000 kg (Jefferson et al., 2008). The species is thought to mainly target squid but is also known to take fish in deep waters over the outer continental shelf or continental slope.

*Distribution*

Short-finned pilot whales are distributed in warm temperate to tropical waters around the world. The species generally has been sighted in deep offshore waters (Reilly and Shane, 1986; Olson and Reilly, 2002). The estimated abundance of the species in the eastern tropical Pacific is around 590,000 individuals (Gerrodette and Forcada, 2002). Off the west coast of North America, approximately 300 individuals are estimated, and off Hawaiian waters, around 8,800 individuals are estimated (Barlow, 2006). The species is not common in the Canadian Pacific Ocean (Government of Canada, 2021i).

*Status*

The IUCN Red List classifies the short-finned pilot whale as a Least Concern species. Currently, the short-finned pilot whale is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Risso's Dolphin (Grampus griseus)*

The Risso's dolphin (*Grampus griseus*) is a medium-sized cetacean that can reach lengths of 2.6 to 4 m and weigh 300 to 500 kg. It is found in temperate, subtropical, and tropical waters of 10°C to 30°C with depths generally >1,000 m (Jefferson et al., 2008). Prey targeted by Risso's dolphin include squid and crustaceans.

*Distribution*

Risso's dolphins are widely distributed in tropical to temperate waters (Kruse et al., 1999). The species occurs mostly in deep waters off the continental slope, outer shelf, and in oceanic areas beyond the shelf slope in the eastern tropical Pacific. Among many other locations, it also occurs in the Gulf of California. Abundance estimates of populations in the northwestern Pacific of North America are approximately 16,000 individuals (Barlow, 2003). Risso's dolphins are rare in Canadian waters (Government of Canada, 2021j). In Hawaiian waters, estimates are around 2,000 individuals. In the eastern tropical Pacific, around 175,000 individuals have been estimated (Wade and Gerrodette, 1993).

*Status*

The IUCN Red List classifies the Risso's dolphin as a species of Least Concern. Currently, the Risso's dolphin is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Pygmy Sperm Whale (Kogia breviceps)*

The pygmy sperm whale (*Kogia breviceps*) is a small cetacean that may reach lengths of 3.5 m and weigh between 315 and 450 kg (Jefferson et al., 2008). It prefers tropical, subtropical, and temperate waters in oceans and seas worldwide. Pygmy sperm whales are most common seaward of the continental shelf edge and slope; in most areas, they are thought to be more oceanic and "anti-tropical" than dwarf sperm whales (*Kogia sima*), the latter of which are discussed below (Jefferson et al., 2008). Pygmy sperm whales are known to feed on cephalopods, deepsea fishes, and shrimp (Aguiar-Dos Santos and Haimovici, 2001; McAlpine et al., 1997).

*Distribution*

Pygmy sperm whales are distributed in all tropical to warm temperate oceans (McAlpine, 2002). The species' range is poorly known, and no global abundance estimates available; however, estimates off California, Oregon, and Washington are around 250 individuals (Barlow, 2003). Estimates off Hawaii are higher at around 7,000 individuals (Barlow, 2006). Pygmy sperm whales are uncommon in Canadian waters.

*Status*

The IUCN Red List classifies the pygmy sperm whale as a Least Concern species. Currently, the pygmy sperm whale is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Dwarf Sperm Whale (Kogia sima)*

The dwarf sperm whale is a small cetacean that can reach lengths of 2.7 m and weigh between 135 and 270 kg. It prefers warm tropical, subtropical, and temperate waters worldwide and is most common along the waters of the continental shelf edge and slope. Dwarf sperm whales are thought to occur in shallower depths than pygmy sperm whales (Jefferson et al., 2008). Like pygmy sperm whales, dwarf sperm whales appear to feed on cephalopods in deep water, among other prey species (Aguiar-Dos Santos and Haimovici, 2001).

*Distribution*

The dwarf sperm whale appears to be distributed widely in offshore waters of tropical and warm temperate areas (Caldwell and Caldwell, 1989). Like the pygmy sperm whale, no global estimates of the population are available. Off Hawaii, estimates are around 19,000 individuals, and in the eastern tropical Pacific around 11,200 animals (Wade and Gerrodette, 1993). Off Hawaii, site fidelity has been recorded (Baird et al., 2006). The presence of dwarf sperm whales in Canada's waters is unknown.

*Status*

The IUCN Red List classifies the dwarf sperm whale as a Least Concern species. Currently, the dwarf sperm whale is listed as Data Deficient by COSEWIC and not listed under SARA.

### *Pacific White-sided Dolphin (Lagenorhynchus obliquidens)*

The Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) reaches lengths of 1.7 to 2.5 m and can weigh between 135 and 180 kg. They are extremely playful and highly social animals. Schools of thousands of Pacific white-sided dolphins are occasionally observed, but group size generally ranges from 10 to 100 animals. They inhabit waters from the continental shelf to the deep open ocean (Jefferson et al., 2008). The species feeds on cephalopods and small pelagic schooling fish such as lanternfish, anchovies, saury, horse mackerel (*Trachurus* spp.), and hake (Brownell et al., 1999).

*Distribution*

Pacific white-sided dolphins occur in temperate waters of the North Pacific and adjacent seas (Brownell et al., 1999; Van Waerebeek and Würsig, 2002). In the central North Pacific, abundance estimates range from 900,000 to 1 million (Buckland et al., 1993; Miyashita, 1993a); however, these are likely overestimated (Buckland et al., 1993). Abundance estimates off the U.S. west coast are between 13,000 and 122,000 individuals (Forney et al., 1995). Pacific white-sided dolphins occur in shelf and slope waters of continental margins (Carretta et al., 2006) and in some inland waterways such as off British Columbia (Heise, 1997). The species is an abundant, permanent resident of pelagic waters off the west coast of Canada (Government of Canada, 2021k).

*Status*

The IUCN Red List classifies the Pacific white-sided dolphin as a species of Least Concern. Currently, the Pacific white-sided dolphin is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Northern Right Whale Dolphin (Lissodelphis borealis)*

The northern right whale dolphin (*Lissodelphis borealis*) can reach lengths of 2 to 3 m and weigh between 60 and 115 kg. Northern right whale dolphins feed on cephalopods and mid-water fishes, among other species (such as market squid and lanternfishes off southern California).

*Distribution*

The northern right whale dolphin is generally found in waters over the outer continental shelf and slope that are colder than 19°C (Jefferson et al., 2008) and has been sighted in the North Pacific Ocean in deep, temperate waters. Estimates of abundance are available for some geographical regions. In the oceanic North Pacific, between 307,000 and 400,000 animals have been estimated (Buckland et al., 1993; Miyashita, 1993a; Hiramatsu, 1993). The distribution in the eastern North Pacific appears to vary seasonally (Forney and Barlow, 1998), though it is rare in Canadian waters (Government of Canada, 2021l). This species sometimes occurs closer to the coast in deep water areas (including in the CCS) (Jefferson et al., 1994).

*Status*

The IUCN Red List classifies the northern right whale dolphin as a species of Least Concern. Currently, the northern right whale dolphin is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Hubbs' Beaked Whale (Mesoplodon carlhubbsi)*

The Hubbs' beaked whale (*Mesoplodon carlhubbsi*) is a poorly known species, and few specimens (fewer than 60 records) have been examined. These specimens were up to 5.32 m in length. The species is oceanic, feeding on squid and deepwater fishes. Currently, there are no abundance estimates available for this species.

*Distribution*

Hubbs' beaked whale is only known to occur off central British Columbia down to southern California and off Japan (Mead, 1989; MacLeod et al., 2006). It is thought to occur across the North Pacific (MacLeod et al., 2006). Nothing is known about movements within their range and species distribution data from the high seas are unavailable.

*Status*

The IUCN Red List classifies the Hubbs' beaked whale as a Data Deficient species. Currently, the Hubbs' beaked whale is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Blainville's Beaked Whale (Mesoplodon densirostris)*

The Blainville's beaked whale (*Mesoplodon densirostris*) can reach lengths of 4.5 to 6 m and weigh 820 to 1,030 kg. They are generally found in deep, offshore waters of the continental shelf. This species is often associated with steep underwater geologic structures such as banks, submarine canyons, seamounts, and continental slopes (Jefferson et al., 2008). Blainville's beaked whales feed on squid and deepwater fish (Heyning and Mead, 1996).

*Distribution*

The distribution of Blainville's beaked whales is considered the most extensive of the *Mesoplodon* genus. They have a cosmopolitan distribution throughout the world's oceans and range from the Mediterranean Sea to England, Iceland, Nova Scotia, Brazil, and South Africa in the Atlantic to California, Chile, Japan, New Zealand, and Australia in the Pacific. They appear relatively common in tropical waters (Reeves et al., 2003). This species appears to occur mostly in deep offshore waters but can occur closer to shore in deep waters (MacLeod and Zuur, 2005). They are not regularly known to occur off the west coast of Canada.

*Status*

The IUCN Red List classifies Blainville's beaked whale as a Least Concern species (Pitman and Brownell, 2020b). Currently, Blainville's beaked whale is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Ginkgo-toothed Beaked Whale (Mesoplodon ginkgodens)*

Ginkgo-toothed beaked whales (*Mesoplodon ginkgodens*) are more robust than most *Mesoplodon* species, reaching lengths of 4.9 m. The species does not appear to be very common anywhere. This species is thought to primarily feed on squid and fish.

*Distribution*

The ginkgo-toothed beaked whale has been sighted in deep, oceanic temperate and tropical waters of the Indo-Pacific Ocean, among other locations (Mead, 1989; Pitman, 2002), and is thought to occur across the Pacific Ocean and into the eastern Indian Ocean (MacLeod et al., 2006). They are not known to occur in coastal Canadian waters.

*Status*

The IUCN Red List classifies the ginkgo-toothed beaked whale as a Data Deficient species. The ginkgo-toothed beaked whale has not been assessed by COSEWIC or under SARA.

### *Longman's Beaked Whale (Indopacetus pacificus)*

The Longman's beaked whale (*Indopacetus pacificus*) is considered one of the least known cetacean species. Compared to other *Mesoplodon* species, it is relatively large, reaching lengths of 6 to 9 m (Jefferson et al., 2008). They live in generally warm (21°C to 31°C) and deep (>1,000 m) waters. The species appears to primarily feed on cephalopods (Yamada, 2004).

*Distribution*

Longman's beaked whales do not appear to be common. Sightings have been from the tropical and subtropical Indo-Pacific, with abundance estimates off Hawaii of 1,007 individuals and 291 animals in the eastern North Pacific (Ferguson and Barlow, 2001; Barlow, 2006). They are not known to occur in coastal Canadian waters.

*Status*

The IUCN Red List classifies the Longman's beaked whale as a Least Concern species. The Longman's beaked whale has not been assessed by COSEWIC or under SARA.

### *Killer Whale (Orcinus orca)*

The killer whale (*Orcinus orca*) is a large cetacean, with males reaching up to 10 m in length and 10,000 kg in weight. Genetic studies and morphological evidence suggest the existence of multiple species or subspecies of killer whales worldwide. Killer whales are most abundant in colder waters but may be abundant in temperate waters. Killer whales also occur, though at lower densities, in tropical, subtropical, and offshore waters. Their diet is often geographic or population specific and may include fishes, marine mammals, and seabirds (Jefferson et al., 2008).

Killer whales within the project area may be members of several populations, as defined by Canadian regulators: the Northeast Pacific northern resident population (occurring mainly from Alaska to Washington state), Northeast Pacific southern resident population (occurring mainly from northern British Columbia to central California), Northeast Pacific offshore population (occurring across the northeast Pacific but generally farther from shore than other populations), or the Northeast Pacific transient population (widely distributed in coastal waters of the eastern North Pacific) (Government of Canada, 2021m).

#### *Distribution*

Killer whales are a cosmopolitan species, occurring worldwide (Forney and Wade, 2006). Killer whales tend to be more common along continental margins and in temperate and polar waters than tropical waters. Global abundance estimates have resulted in 50,000 killer whales; however, more accurate population-specific estimates have been made. Estimates of killer whales in the eastern tropical Pacific are around 8,500 animals (Wade and Gerrodette, 1993).

Of the populations found in nearshore Canadian waters, the Northeast Pacific northern resident population has been estimated at 290 individuals (as of 2014); the Northeast Pacific southern resident population has been estimated at 78 individuals (as of 2014); the Northeast Pacific offshore population has been estimated at 300 individuals (as of 2013); and the Northeast Pacific transient population has been estimated at 349 individuals (as of 2019) (Government of Canada, 2021m). Under SARA, critical habitat has been established in the Strait of Georgia and the Strait Juan de Fuca for the Northeast Pacific southern resident population (Port of Vancouver, 2020).

#### *Status*

The IUCN Red List classifies the killer whale (globally) as a Data Deficient species. Of the populations found in nearshore Canadian waters, the Northeast Pacific northern resident population is classified as Threatened by COSEWIC and under SARA; the Northeast Pacific southern resident population is classified as Endangered by COSEWIC and under SARA; the Northeast Pacific offshore population is classified as Threatened by COSEWIC and under SARA; and the Northeast Pacific transient population is classified as Threatened by COSEWIC and under SARA (Government of Canada, 2021m).

### *Harbor Porpoise (Phocoena phocoena)*

The harbor porpoise (*Phocoena phocoena*) is a small cetacean, reaching lengths of 1.5 to 1.7 m and weighing 61 to 77 kg. They are commonly found in bays, estuaries, harbors, and fjords <200 m deep (Jefferson et al., 2008). Harbor porpoises target a wide variety of fish and cephalopods (Smith and Gaskin, 1974; Recchia and Read, 1989; Fontaine et al., 1994; Gonzales et al., 1994; Aarefjord et al., 1995; Gannon et al., 1998; Read, 1999; Börjesson et al., 2003; Santos et al., 2004; Reeves and Notarbartolo di Sciara, 2006).

*Distribution*

Harbor porpoises occur in cold temperate and subpolar waters in the northern hemisphere (Gaskin, 1992; Read, 1999), in continental shelf waters, and sometimes in deeper offshore waters. In the eastern North Pacific, they range from central California to the Chukchi Sea.

*Status*

The IUCN Red List classifies the Pacific Ocean population of the harbor porpoise as a species of Least Concern. It is listed by COSEWIC and under SARA as a species of Special Concern.

### *Dall's Porpoise (Phocoenoides dalli)*

The Dall's porpoise (*Phocoenoides dalli*) can reach a maximum length of approximately 2.4 m and weigh up to 220 kg. They can be found in offshore, inshore, and nearshore oceanic waters (Jefferson et al., 2008). Dall's porpoises forage on a wide range of fish and squid, among other prey (e.g., krill, shrimps) (Houck and Jefferson, 1999; Jefferson, 2002a).

*Distribution*

Dall's porpoises occur only in the northern North Pacific Ocean and adjacent seas in deep waters (Jefferson, 1988; Houck and Jefferson, 1999), from the west coast of North America to Japan. Dall's porpoise occurs in deep offshore waters and in fjords and channels (Miyashita and Kasuya, 1988; Jefferson, 1988; Rice, 1998).

*Status*

The IUCN Red List classifies the Dall's porpoise as a species of Least Concern. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Sperm Whale (Physeter macrocephalus)*

The sperm whale is a large cetacean, with adult males reaching approximately 16 m and 40,823 kg in weight. Sperm whales commonly inhabit areas with a water depth of 600 m or more and are uncommon in waters <300 m deep. Sperm whales forage on cephalopods and fish, among other species (Jefferson et al., 2008).

*Distribution*

The sperm whale is widely distributed around the world (Rice, 1989). They generally occur along the continental slope and in deeper waters. Sperm whales are distributed across the entire North Pacific and into the southern Bering Sea in summer, but the majority are thought to be south of 40° N in winter. They are found year-round in British Columbia waters. Sperm whale population trend estimates indicate the pre-whaling global population may have been around 1.1 million animals and has been reduced approximately 67% (Whitehead, 2002).

*Status*

The IUCN Red List classifies sperm whales as a Vulnerable species. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

### *False Killer Whale (Pseudorca crassidens)*

The false killer whale is a large member of the dolphin family. Males reach lengths of almost 6 m and weigh approximately 700 kg. False killer whales mostly occur in relatively deep offshore waters (Stacey et al., 1994; Odell and McClune, 1999), but also occur in some partially enclosed seas and bays. False killer whales mostly forage on fish and cephalopods, but can attack small cetaceans (Baird et al., 2008).

*Distribution*

False killer whales are found in tropical to warm temperate waters in all oceans. No global estimates are available. However, abundance off Hawaii has been estimated to be 268 animals (Barlow, 2006), and in the eastern tropical Pacific, abundance has been estimated at 39,800 individuals (Wade and Gerrodette, 1993). False killer whales are rare in Canadian waters (Government of Canada, 2021n).

*Status*

The IUCN Red List classifies false killer whales as a Near Threatened species. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Pantropical Spotted Dolphin (Stenella attenuata)*

The pantropical spotted dolphin (*Stenella attenuata*) is a relatively small dolphin species, reaching lengths of 2 m and weighing approximately 114 kg at adulthood. They spend the majority of daylight hours in shallower water (usually between 90 to 300 m deep). At night, they dive into deeper waters to search for prey. Pantropical spotted dolphins prey on fish, squid, and crustaceans (Robertson and Chivers, 1997).

*Distribution*

The pantropical spotted dolphin occurs in all oceans between 40° N and 40° S. It is more abundant in lower latitudes. In the eastern Pacific, more than 220,000 coastal animals were estimated in 2000 (Gerrodette and Forcada, 2002), and in the eastern North Pacific offshore estimates were 737,000 animals in 2003 (Gerrodette et al., 2005), 24% of what they were estimated to be approximately 45 years earlier (Reilly et al., 2005). Within the eastern Pacific, pantropical spotted dolphins occur in greatest numbers north of the equator. The species is not known to occur in coastal Canadian waters.

*Status*

The IUCN Red List classifies the pantropical spotted dolphin as a species of Least Concern. The species has not been assessed by COSEWIC or under SARA.

### *Striped Dolphin (Stenella coeruleoalba)*

The striped dolphin (*Stenella coeruleoalba*) can reach lengths of approximately 2.7 m and weigh up to 160 kg for males. They prefer highly productive tropical to warm temperate oceanic waters (10°C to 26°C) and are often linked to upwelling areas and convergence zones (Jefferson et al., 2008). Striped dolphins forage on a wide variety of fish and squids in continental slope or oceanic regions (Wurtz and Marrale, 1993; Hassani et al., 1997; Archer, 2002).

*Distribution*

Striped dolphins are widely distributed in tropical and warm temperate oceans and seas. The striped dolphin abundance in the western North Pacific was estimated as 570,000 individuals (Miyashita, 1993b). In the eastern tropical Pacific, population estimates are >1.4 million individuals (Gerrodette et al., 2005). Off Hawaii, numbers are estimated at more than 13,000 individuals (Barlow, 2006). Striped dolphins in the North Pacific occur in oligotrophic waters of the Central North Pacific Gyre and in upwelling areas in the eastern tropical Pacific (Miyazaki et al., 1974; Reilly, 1990; Archer and Perrin, 1999; Balance et al., 2006). Striped dolphins have been observed offshore British Columbia but are rare due to water temperatures that are typically cooler than the species prefers.

*Status*

The IUCN Red List classifies striped dolphins as a species of Least Concern. The species is listed as Not at Risk by COSEWIC and is not listed under SARA.

### *Spinner Dolphin (Stenella longirostris)*

The spinner dolphin (*Stenella longirostris*) is relatively small, reaching lengths of 2 m and weighing 59 to 77 kg at adulthood. In most places, spinner dolphins are found in the deep ocean where they likely track prey (Jefferson et al., 2008). Six morphotypes within four subspecies of spinner dolphins have been described worldwide in tropical and warm-temperate waters (Perrin et al., 2007). The Gray's (or pantropical) spinner dolphin (*S. l. longirostris*) is the most widely distributed subspecies and is found in the Atlantic, Indian, and central and western Pacific oceans, including the project area (Perrin et al., 1991). Spinner dolphins forage on a variety of fish, squid, and shrimp (Perrin et al., 1973; Dolar et al., 2003).

*Distribution*

Spinner dolphins occur in tropical and subtropical zones in both hemispheres, mainly around oceanic islands (Rice, 1998). Spinner dolphins occur in pelagic waters over the continental shelf in the eastern tropical Pacific and off Baja California (Perrin, 1990). In 2000, approximately 801,000 individuals were estimated to be present in the eastern tropical Pacific (Gerrodette et al., 2005), where they can occur in very large numbers offshore. Spinner dolphins do not occur in Canadian waters.

*Status*

The IUCN Red List classifies the spinner dolphin as a Data Deficient species. The species has not been assessed by COSEWIC or under SARA.

### *Rough-toothed Dolphin (Steno bredanensis)*

The rough-toothed dolphin (*Steno bredanensis*) is a small member of the dolphin group that can grow up to 2.6 m long and weigh about 160 kg. They prefer deeper areas of tropical and warmer temperate waters where their prey is concentrated (Jefferson et al., 2008). Rough-toothed dolphins feed on cephalopods and fish (Pitman and Stinchcomb, 2002).

*Distribution*

The rough-toothed dolphin occurs in deep tropical and subtropical waters (Jefferson, 2002b). Approximately 145,000 rough-toothed dolphins have been estimated to occur in the eastern tropical Pacific (Wade and Gerrodette, 1993), and almost 20,000 individuals may be present off Hawaii (Carretta et al., 2006). The rough-toothed dolphin occurs mainly in waters beyond the continental shelf (Maigret, 1994), but can be seen closer to the coast in deep areas with a steep seafloor gradient (Ritter, 2002). Rough-toothed dolphins do not occur in Canadian waters.

*Status*

The IUCN Red List classifies the rough-toothed dolphin as a species of Least Concern. The species has not been assessed by COSEWIC or under SARA.

### *Common Bottlenose Dolphin (Tursiops truncatus)*

The common bottlenose dolphin (*Tursiops truncatus*) ranges in length from 1.8 to 3.8 m and can weigh 136 to 635 kg. They are found in temperate and tropical waters around the world. There are coastal populations that inhabit bays, estuaries, and river mouths as well as offshore populations that inhabit pelagic waters along the continental shelf and slope. Common bottlenose dolphins prey on a wide range of fish and squid (Barros and Odell, 1990; Barros and Wells, 1998; Blanco et al., 2001; Santos et al., 2001) and can prey on shrimp and other crustaceans.

#### *Distribution*

Common bottlenose dolphins are distributed worldwide in tropical and temperate waters. This species occurs in inshore, shelf, and oceanic waters (Leatherwood and Reeves, 1990; Wells and Scott, 1999; Reynolds et al., 2000). A minimum global abundance estimate may be on the order of 600,000 animals. In the eastern tropical Pacific, around 240,000 common bottlenose dolphins have been estimated (Wade and Gerrodette, 1993). Off Hawaii, abundance estimates exceed 3,000 animals (Barlow, 2006). In inshore waters near California, approximately 300 animals are estimated (Dudzik et al., 2006). Offshore California, Oregon, and Washington, around 2,000 animals have been estimated (Bearzi et al., 2012). Common bottlenose dolphins are occasional visitors to British Columbia waters but are not common (Government of Canada, 2021o).

#### *Status*

The IUCN Red List classifies the common bottlenose dolphin as a species of Least Concern. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

### *Cuvier's Beaked Whale (Ziphius cavirostris)*

The Cuvier's beaked whale (*Ziphius cavirostris*) can reach lengths of 4.5 to 7 m and weigh 1,845 to 3,090 kg. They can be found in temperate, subtropical, and tropical waters of the continental slope and edge (usually where water depth is >1,000 m) as well as around steep underwater geologic features like banks, seamounts, and submarine canyons. They feed mostly on squid, fish, and crustaceans (MacLeod et al., 2003). Cuvier's beaked whales that occur within the project area are members of the California/Oregon/Washington management stock.

#### *Distribution*

Cuvier's beaked whales are distributed in offshore waters from tropical to polar regions in both hemispheres (Heyning, 1989, 2002) and in some enclosed seas such as the Gulf of California. Cuvier's beaked whales appear to be common, with a possible worldwide abundance of approximately 100,000 animals. In the eastern tropical Pacific, abundance estimates are around 80,000 animals (Ferguson and Barlow, 2001). Off the United States west coast, estimated abundance was approximately 1,800 individuals (Barlow, 2003). Off Hawaii, abundance estimates were around 15,000 animals (Barlow, 2006). Cuvier's beaked whales are only rarely found in Canadian waters (Government of Canada, 2021p).

#### *Status*

The IUCN Red List classifies the Cuvier's beaked whale as a species of Least Concern. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

#### *4.3.4.2 Seals and Sea Lions*

The suborder Pinnipedia includes seals, sea lions, and walruses. Four eared seals (Otariidae) and two true seals (Phocidae) are known to occur in the waters between the west coast of Canada and the deployment area in the NPSG. These include four species classified by the IUCN as Least Concern (Guadalupe fur seal [*Arctocephalus townsendi*], California sea lion, northern elephant seal [*Mirounga angustirostris*], and harbor seal [*Phoca vitulina*]), one Vulnerable species (northern fur seal [*Callorhinus ursinus*]), and one Near Threatened species (Steller sea lion [*Eumetopias jubatus*]) (**Table 4-15**).

Seals and sea lions have specific core areas of distribution; however, vagrants are commonly sighted outside of the core areas. Two species are listed as migratory, the northern fur seal and the northern elephant seal. Migratory species generally migrate during particular seasons or life stages.

Vocalization information for specific pinnipeds/pinniped groups are presented in Erbe et al. (2017) and Southall et al. (2019). Given pinnipeds will likely be encountered only during vessel transit, the lack of Endangered species likely to be contacted, and the limited auditory impacts associated with vessel transit, no further species-specific vocalization information is presented here.

Table 4-15. Seals and sea lions present from the southwestern Canadian coast to the offshore area of the North Pacific Subtropical Gyre.

| Common Name | Scientific Name | Migratory | IUCN Red List Status | COSEWIC Status | SARA Status | Reference |
|---|---|---|---|---|---|---|
| Guadalupe fur seal | *Arctocephalus townsendi* | No | Least concern | -- | -- | Aurioles-Gamboa (2015) |
| Northern fur seal | *Callorhinus ursinus* | Yes | Vulnerable | Threatened | Not Listed | Gelatt et al. (2015) |
| Steller sea lion | *Eumetopias jubatus* | No | Near Threatened | Special Concern | Special Concern | Gelatt and Sweeney (2016); Committee on Taxonomy (2017) |
| California sea lion | *Zalophus californianus* | Yes | Least Concern | Not at Risk | Not Listed | Aurioles-Gamboa and Hernández-Camacho (2015) |
| Northern elephant seal | *Mirounga angustirostris* | Yes | Least Concern | Not at Risk | Not Listed | Hückstädt (2015) |
| Pacific harbor seal | *Phoca vitulina richardii* | No | Least Concern | Not at Risk | Not Listed | Lowry (2016) |

-- = not assessed; COSEWIC = Committee on the Status of Endangered Wildlife in Canada; IUCN = International Union for Conservation of Nature; SARA = Species at Risk Act.

Steller Sea Lion *(Eumetopias jubatus)*

The Steller sea lion is the largest otariid seal, with adult males reaching a length of approximately 3.3 m and average weight of 1,000 kg (Jefferson et al., 2008).

### *Distribution*

The Steller sea lion is distributed as far south as central California, north to the Gulf of Alaska, through the Aleutian Islands and Kamchatka Peninsula, across to Japan and the Sea of Japan (Loughlin, 2009). Vagrants have been reported in China and Herschel Island (Rice, 1998).

Core habitat used by Steller sea lions mainly includes coastal and continental shelf waters. However, Steller sea lions occur in deep ocean waters in some areas. Offshore waters are accessed during regular foraging trips where adult sea lions target pelagic fish and invertebrates and may dive more than 400 m in depth (Merrick and Loughlin, 1997; Fadely and Lander, 2012; Fadely et al., 2013; Gelatt and Sweeney, 2016). Steller sea lions often can be found in high numbers in areas of high prey concentrations and around fishing vessels (Gelatt and Sweeney, 2016). Steller sea lions breed in late spring and summer, pupping between May and July. During the non-breeding season (winter), females may engage in longer foraging trips (Merrick and Loughlin, 1997; Fadely and Lander, 2012; Fadely et al., 2013). In Canadian waters, there are three main breeding areas: Scott Island (off northern Vancouver Island), Cape St. James (off the southern Queen Charlotte Islands), and the Banks Islands. There also are numerous, well-known haul-out sites in the coastal areas of British Columbia (Government of Canada, 2021q).

### *Status*

The Steller sea lion is classified as Near Threatened by the IUCN Red List. It is listed as a species of Special Concern by COSEWIC and under SARA due to its restricted breeding range and sensitivity to human disturbance while on land.

Northern Fur Seal *(Callorhinus ursinus)*

The northern fur seal is an otariid seal that may grow to a length of 2.1 m and a weight of 270 kg. They primarily use two types of habitat, open ocean for foraging and rocky beaches for reproduction (National Marine Fisheries Service [NMFS], 2017).

Adult fur seals spend more than 300 days per year foraging at sea, and often concentrate around major oceanographic features such as seamounts, canyons, valleys, and along the continental shelf break, based on the availability of prey. Breeding seals normally haul out on rocky beaches, but colonies can also use broad sandy beaches.

### *Distribution*

The northern fur seal is distributed between the Bering Sea and California (Sterling et al., 2014), including areas offshore British Columbia. These seals spend most time during non-breeding periods in pelagic waters foraging in offshore areas and the edge of the continental shelf. Many migrate between the Bering Sea and California during non-breeding periods. During the breeding season, around June to August, northern fur seals spend around 1 to 1.5 months on land. Most of the northern fur seals found in Canadian waters breed either in Alaska or in California (Government of Canada, 2021r).

### *Status*

The IUCN Red List classifies the northern fur seal as Vulnerable. The species is listed by COSEWIC as Threatened and under SARA (review is pending for addition).

Guadalupe Fur Seal *(Arctocephalus townsendi)*

The Guadalupe fur seal is an otariid seal that may grow to a length of 2 m and a weight of 160 to 170 kg (Jefferson et al., 2008). They primarily use two types of habitat, open ocean for foraging and rocky beaches for reproduction (NMFS, 2017). Guadalupe fur seals are solitary, non-social animals.

### *Distribution*

Guadalupe fur seals are distributed mainly on islands along the coast of California, with vagrants reported as far as Washington state (Moss et al., 2006). Little is known about the breadth of their foraging activities and offshore distribution when at sea. However, evidence indicates that Guadalupe fur seals forage as far off the coast as several hundred kilometers. The breeding season is in summer, with the greatest number of pups being born on Guadalupe Island (around June; Wickens and York, 1997; Aurioles-Gamboa, 2015). Guadalupe fur seals are not found in Canadian waters.

### *Status*

The IUCN Red List classifies the Guadalupe fur seal as a Least Concern species. It has not been assessed by COSEWIC or under SARA.

California Sea Lion *(Zalophus californianus)*

The California sea lion is an otariid seal that may grow to a length of 2.4 m and a weight of more than 390 kg (Jefferson et al., 2008). California sea lions occur in shallow coastal and estuarine waters. Sandy beaches are preferred for haul-out sites.

### *Distribution*

California sea lions are distributed from Baja California to the Gulf of Alaska and the Aleutian Islands (Maniscalco et al., 2004; Aurioles-Gamboa and Hernández-Camacho, 2015). They forage on the continental shelf and slope on fish and cephalopods on the benthos as well as within the water column (García-Rodríguez and Aurioles-Gamboa, 2004; Weise et al., 2010; Villegas-Amtmann et al., 2011). Pups are born in the summer between May and July (García-Aguilar and Aurioles-Gamboa, 2003). In Canada, males occasionally migrate from California, but no breeding is known to occur (Government of Canada, 2021s).

### *Status*

The IUCN Red List classifies the California sea lion as Least Concern. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

Northern Elephant Seal *(Mirounga angustirostris)*

The northern elephant seal is the largest phocid seal in the northern hemisphere. Males can reach lengths >4 m and weigh nearly 2,000 kg. They spend about 9 months each year in the ocean (NMFS, 2017).

### *Distribution*

Northern elephant seals are distributed throughout a large area of the eastern Pacific Ocean, from Baja California north of 27° N latitude to the Gulf of Alaska and the Aleutian Islands (Le Boeuf et al., 2000; Robinson et al., 2012). Vagrants have been reported in the Midway Islands and Japan. Northern elephant seals forage as far offshore as 8,000 km and can dive to depths >1,700 m (Robinson et al., 2012). Pups are born on islands offshore Baja California and California, with some born as far north as British Columbia (Lowry et al., 2014).

### *Status*

The IUCN Red List classifies the northern elephant seal as Least Concern. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

Harbor Seal *(Phoca vitulina)*

The harbor seal is a phocid seal that can grow to 1.9 m and weigh 70 to 150 kg (Jefferson et al., 2008). Two subspecies of harbor seal exist in the Pacific: *P. v. stejnegeri* in the western North Pacific, near Japan, and *P. v. richardii* in the eastern North Pacific (Carretta et al., 2017). Harbor seals live in temperate coastal habitats and use rocks, reefs, beach, and drifting glacial ice as haul-out and pupping sites.

### *Distribution*

Harbor seals are distributed from temperate to polar regions in the North Pacific. Eastern Pacific harbor seals range from Baja California to the Aleutian Islands (Rice, 1998). These seals forage on a range of species of fish, cephalopods, and crustaceans in bays, estuaries, and coastal waters out to the continental shelf slope (Pitcher, 1980; Olesiuk et al., 1990; Lowry, 2016).

### *Status*

The IUCN Red List classifies the harbor seal as Least Concern. The species is listed as Not at Risk by COSEWIC and not listed under SARA.

#### *4.3.4.3 Marine Mammal Observations*

During the S001 transit and deployment in 2018/2019, a total of 62 marine mammals were observed including 10 humpback whales, three fin whales, two gray whales, sperm whales, and short-finned pilot whales each, and single sightings of a sei whale and a blue whale, and six common bottlenose dolphins. During transit and deployment of the S001/B in the NPSG in 2019, 17 sightings were made of marine mammals, including five sperm whale sightings, two humpback whale sightings, two groups of short-beaked common dolphins, one individual unidentified dolphin, one group of unidentified dolphins, one group of two unidentified whales, four groups of solitary unidentified whales, and one unidentified cetacean (The Ocean Cleanup, 2020). Observations were made between June and November 2019.

During transit and deployment of the S002 to the NPSG in 2021/2022, 1,511 marine mammal observations were made, including 1,498 sightings of cetaceans and 13 sightings of pinnipeds, for a total of 19 different identifiable species. Most marine mammals (1,454) were observed during towing or transit operations (i.e., the vessel moving to and from port) while only 57 were observed during towing operations. Summarized marine mammal observation data from the 2018 S001 and 2021/2022 S002 (Campaigns 1 through 12) during transit and deployments are presented in **Table 4-16**.

Table 4-16. Species or groups identified during transit and deployment of The Ocean Cleanup's S001, S001/B, and S002 in the North Pacific Subtropical Gyre in 2018 and 2021 (Campaigns 1 through 12) (Adapted from: Seiche, 2019; Marine Ventures International, Inc., 2022).

| Species or Group | S001 Number of Observations[a] | S001/B Number of Observations[b] | S002 Number of Observations[c] |
|---|---|---|---|
| Humpback whale (*Megaptera novaeangliae kuzira)* | 10 | 2 | 262 |
| Fin whale (*Balaenoptera physalus physalus)* | 3 | - | 17 |
| Gray whale (*Eschrichtius robustus)* | 2 | - | 1 |
| Sei whale (*Balaenoptera borealis borealis)* | 1 | - | 5 |
| Blue whale (*Balaenoptera musculus musculus)* | 1 | - | 4 |
| Sperm whale (*Physeter macrocephalus)* | 2 | 5 | 31 |
| Short-finned pilot whale (*Globicephala macrorhynchus)* | 2 | - | 29 |
| Northern right whale dolphin (*Lissodelphis borealis)* | - | - | 31 |
| Blainville's beaked whale (*Mesoplodon densirostris)* | - | - | 15 |
| Killer whale (*Orcinus orca)* | - | - | 20 |
| False killer whale (*Pseudorca crassidens)* | - | - | 12 |
| Common bottlenose dolphin (*Tursiops truncates)* | 6 | - | - |
| Risso's dolphin (*Grampus griseus)* | - | - | 19 |
| Pacific white-sided dolphin (*Lagenorhynchus obliquidens)* | - | - | 121 |
| Short-beaked common dolphin (*Delphinus delphis delphis)* | - | 2* | 606 |
| Dolphins (spinner [*Stenella longirostris*] and common dolphins [*Tursiops truncates*] mixed) | 1 | - | - |
| Dall's porpoise (*Phocoenoides dalli*) | 2 | - | 25 |
| Harbour porpoise (*Phocoena phocoena*) | - | - | 39 |
| Northern fur seal (*Callorhinus ursinus*) | 1 | - | 4 |
| Harbour seal (*Phoca vitulina richardii*) | 1 | - | - |
| Gray seal (*Halichoerus grypus*) | 1 | - | - |
| California sea lion (*Zalophus californianus*) | 5 | - | 4 |
| Stellar sea lion (*Eumetopias jubatus*) | - | - | 1 |
| Marine otter (*Lontra feline*) | 2 | - | - |
| Unidentified mysticete | 14 | 6 | 28 |
| Unidentified balaenopteridae | - | - | 47 |
| Unidentified odontocete | - | - | 26 |
| Unidentified odontocete/Phocoenidae | - | - | 12 |
| Unidentified Ziphiidae | - | - | 6 |
| Unidentified dolphin | 4 | 1(1*) | 142 |
| Unidentified beaked whale | 1 | - | - |
| Unidentified Otariidae | | | 2 |
| Unidentified seal/sea lion | | | 2 |
| Unknown | 1 | 1 | - |
| **Total** | **62** | **17** | **1,511** |

* A group of indetermined number.

[a] Observations from September 2018 to January 2019.

[b] Observations from June 2019 to October 2019.

[c] Observations from July 2021 to December 2022.

During all extraction and towing operations, experienced EOs conduct visual monitoring and initiate necessary mitigation measures on the vessel. Protected species observations are conducted from specific vantage points on the top deck of the vessel, 16.5 m above sea level, allowing for a 360-degree view around the vessel. The EOs are equipped with reticle binoculars, and DSLR cameras to assist with image identification of protected species observed. This type of visual monitoring takes place during transit to and from the NPSG. Based on data collected during the first several cruises, it was determined that the monitoring of the underwater skiff cameras was the most useful for observations; and therefore, the EOs have and will continue to focus on the monitoring of the underwater cameras.

The EOs documented their observations of protected marine mammals as well as fish, sea turtles, and birds. From August 2021 through mid-December 2022 the EO effort totaled just under 7,836 hours. There were 327 protected species sightings throughout Campaigns 1 through 12 (marine mammals and sea turtles), 36 of which, including 9 marine mammal sightings, mitigation measures were implemented.

At the beginning of Campaign 12, reduced transit monitoring was performed to focus primarily on vessel strike avoidance, which will continue for the S03 Campaigns.

#### 4.3.5 Sea Turtles

Five species of sea turtles may occur in the NPSG close to where the S03 will be deployed (**Table 4-17**). Globally, all five species are categorized as Vulnerable, Endangered, or Critically Endangered by the IUCN Red List. All sea turtles that occur in the North Pacific are part of a specific subpopulation as defined by the IUCN, COSEWIC, and SARA (**Table 4-17**). These subpopulations differ genetically from other populations, show different trends in occurrence, and many have separate status designations on the IUCN Red List.

During transit from California to the NPSG for deployment of the S001 in 2018, one unidentified sea turtle was observed (Seiche, 2019). During deployment of the S001/B in the NPSG in 2019, two sea turtles (one green sea turtle [*Chelonia mydas*] and one loggerhead sea turtle (*Caretta caretta*) were observed in the vicinity of the S001/B (The Ocean Cleanup, 2020). A total of 51 sea turtles (8 green sea turtle, 25 loggerhead sea turtles [**Image 4-4]**, 2 olive ridley, and 16 unidentified sea turtles from the Cheloniidae family) were observed during Campaigns 1 through 12 (**Table 4-18**).

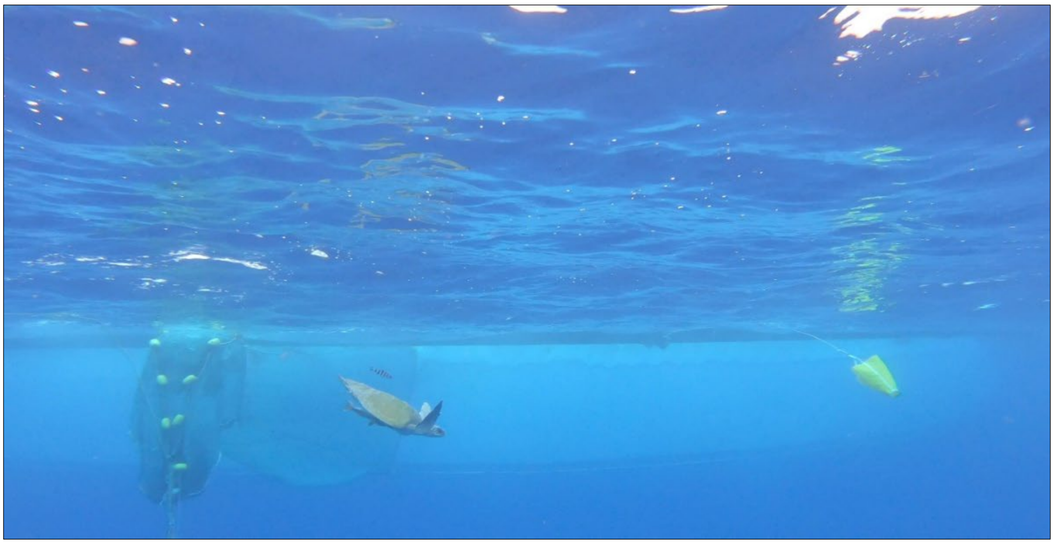


Image 4-4. A loggerhead sea turtle swimming near the surface in the vicinity of The Ocean Cleanup's S002 in the North Pacific Subtropical Gyre in 2022.

Table 4-17. Sea turtle species in the Pacific Ocean.

| Common Name | Scientific Name | Population | Habitat and Diet | IUCN Red List Status for the Global Population and (Regional Subpopulation) | COSEWIC Status | SARA Status |
|---|---|---|---|---|---|---|
| Loggerhead sea turtle | *Caretta caretta* | North Pacific subpopulation | Occupies three different habitats – oceanic, neritic, and terrestrial (nesting only), depending on life stage; omnivorous. | Vulnerable (Least Concern) | Endangered | Endangered |
| Olive ridley sea turtle | *Lepidochelys olivacea* | Pacific subpopulation | Primarily pelagic but may inhabit coastal areas, including bays and estuaries; most breed annually, with annual migration (pelagic foraging, to coastal breeding/nesting grounds, back to pelagic foraging); omnivorous, benthic feeder. Also forages in the midwater column and on surface-dwelling organisms. | Vulnerable (Vulnerable) | -- | -- |
| Leatherback sea turtle | *Dermochelys coriacea* | West Pacific subpopulation | Pelagic, living in the open ocean and occasionally entering shallower water (bays, estuaries); specialized diet on gelatinous prey (jellyfish; salps, etc.). | Vulnerable (Critically Endangered) | Endangered | Endangered |
| Green sea turtle | *Chelonia mydas* | Hawaiian and East Pacific subpopulations | Aquatic, but known to bask onshore rarely; generally, a coastal species; omnivorous. | Endangered (Least Concern) | -- | -- |
| Hawksbill sea turtle | *Eretmochelys imbricata* | Indo-Pacific/ East Pacific subpopulation | Coastal, inhabiting coral and rocky reefs and mangrove-lined estuaries; feeding changes from pelagic surface feeding to benthic, reef-associated feeding; opportunistic diet, but often specialize on sponges. | Critically Endangered (Critically Endangered) | -- | -- |

-- = not assessed; COSEWIC = Committee on the Status of Endangered Wildlife in Canada; IUCN = International Union for Conservation of Nature; SARA = Species at Risk Act.

Table 4-18. Sea turtle species and life stage observed during Campaigns 1 through 12.

| Common Name | Adults | Juveniles | Total |
|---|---|---|---|
| Green sea turtle | 0 | 8 | 8 |
| Loggerhead sea turtle | 9 | 16 | 25 |
| Olive ridley sea turtle | 1 | 1 | 2 |
| Unidentified sea turtle | 15 | 1 | 16 |
| Total | 25 | 26 | 51 |

#### *4.3.5.1 Migration and Nesting*

Many sea turtle nesting seasons start around June and extend through October/November, but nesting season varies by species and populations. During nesting, sea turtles are found close to the nesting areas or are migrating back and forth between nesting and foraging areas. Outside of the nesting periods, sea turtles occupy foraging habitats, which vary among species and can range in type from coastal benthic habitats to high-seas pelagic areas (**Table 4-19**).

Table 4-19. Sea turtle species found in the North Pacific Ocean, their nesting and foraging areas, and feeding behavior (From: National Oceanic and Atmospheric Administration 2014b,c, 2016a,b, 2017b; Polovina et al., 2004).

| Common Name | Primary Pacific Ocean Nesting Area | Nesting Season | Foraging/Migration Area | Feeding Behavior |
|---|---|---|---|---|
| Loggerhead sea turtle | Japanese coast | June to November | North Pacific to Baja California and Japan to central/eastern North Pacific | Opportunistic omnivorous. Feed on bottom-dwelling invertebrates such as horseshoe crabs, clams, and mussels. During migration, they feed on floating mollusks, jellyfish, sponges, and flyingfish. |
| Olive ridley sea turtle | Mexican west coast and west Pacific | Typically June to November; extends to January in some locations | Along the west coast, from Mexico to Oregon; within 1,931 km offshore but spotted in the center of the subtropical gyre (140° W) | Omnivorous; shallow prey feeders (crabs, jellyfish, fish, eggs, mollusks) |
| Leatherback sea turtle | Coast of Indonesia, Papua New Guinea, Solomon Islands | June to November | Indonesia to California and Mexico | Gelatinivorous, only soft animals like jellyfish; deep-diving species |
| Green sea turtle | Mexico, Hawaii, South Pacific islands | November to April for Mexico populations; June to October for others | Pacific areas with seagrass | Herbivorous (seagrass, algae) |
| Hawksbill sea turtle | Hawaii and Pacific islands | June to October | Tropical, found in mainly in areas with coral reefs; migration area extends to the North Pacific | Spongivorous (preferably sponges and animals in coral reefs) |

#### 4.3.5.2 Loggerhead Sea Turtle

Adult loggerhead sea turtles are primarily found in tropical and subtropical coastal waters, but they may be found in the open ocean during migration. Satellite tracking and modeling studies have shown that juvenile loggerhead sea turtles may use the NPSG during migration (Kobayashi et al., 2008; Abecassis et al., 2013; Briscoe et al., 2016a,b). However, most juvenile loggerheads tracked by satellite tags were more commonly found in the northwest Pacific and not in the NPSG (Abecassis et al., 2013).

Loggerhead sea turtles do not nest in coastal southwest Canada and are rarely found in coastal areas (Halpin et al., 2018). After the breeding season, some females go to pelagic zones for foraging while others feed on the continental shelf off the coast of southern California, Mexico, or in the South China Sea (Seminoff et al., 2014; Allen et al., 2013; Okuyama et al., 2022). Adults feed on a wide variety of benthic fauna such as clams, conch, crabs, sea urchins, sponges, and occasionally fish. Young loggerhead sea turtles feed on jellyfish, *Sargassum*, gastropods, and crustaceans while living in the high seas. The major threat to adult loggerheads is interactions with fisheries, including entanglement with longlines, driftnets, and set nets (Lewison et al., 2004; Peckham et al., 2008).

#### 4.3.5.3 Olive Ridley Sea Turtle

The Olive ridley sea turtle is a pantropical species that lives mainly in pelagic areas occupying warmer waters but has been sighted in coastal areas. Olive ridley sea turtles do not nest in coastal southwest Canada. This species nests on the west coast of Mexico but has been sighted as far north as Oregon. Olive ridley sea turtles are omnivorous and feed mainly on algae, lobster, tunicates, mollusks, shrimp, and fish (NOAA, 2014b).

#### 4.3.5.4 Leatherback Sea Turtle

The leatherback sea turtle is better suited to cold waters than other sea turtles. This sea turtle is a highly pelagic species that forages in offshore waters through the north Pacific as well as coastal waters of the U.S. west Coast and Canada. Leatherbacks occurring in the NPSG originate from nesting beached in Indonesia, Papua New Guinea, and the Solomon Islands. Several studies employing satellite tags indicate leatherbacks routinely conduct trans-Pacific migrations between their nesting and foraging areas (Benson et al., 2007, 2011). Consequently, it is likely that leatherbacks will be present in the project area during the S002 deployment and possibly during the transit between the Vancouver area and the NPSG; however, to date, no leatherback sea turtles have been identified during Campaigns 1 through 12.

The leatherback sea turtle does not nest in coastal southwest Canada and is rarely sighted in waters offshore British Columbia (Government of Canada, 2021t). The eastern Pacific subpopulation nests in Central America from Mexico to Ecuador (NOAA, 2016a). Leatherback sea turtles feed mainly on jellyfish, tunicates, and other epipelagic soft-bodied invertebrates.

#### 4.3.5.5 Green Sea Turtle

Green sea turtles are widely distributed in tropical and subtropical waters near continental coasts and islands. Green sea turtles do not nest in coastal southwest Canada and are most common south of Los Angeles where foraging grounds stretch from southern California to Chile (NOAA, 2016b). The primary nesting areas in the Pacific are in Mexico, the Hawaiian Islands, and many of the small islands in the South Pacific. Most green sea turtle populations are herbivorous, feeding mainly on algae and seagrasses, yet in the east Pacific they species is omnivorous and consumes seagrass, algae, and invertebrates (NOAA, 2016b; Jones and Seminoff, 2013).

#### *4.3.5.6 Hawksbill Sea Turtle*

The hawksbill sea turtle is the most tropical of all sea turtles and does not nest in coastal southwest Canada. Pacific nesting beaches are mainly on the Hawaiian Islands, South Pacific islands, and on beaches of Nicaragua and El Salvador in South America. The hawksbill sea turtle is carnivorous and feeds on a variety of organisms such as sponges and invertebrates (NOAA, 2014c). Individuals may occur in the central Pacific Ocean near the deployment of the S002; however, none have been identified during Campaigns 1 through 12, but hawksbill sea turtles will not be present in the Vancouver area.

#### *4.3.5.7 Sea Turtle Observations*

A total of 51 sea turtles of 3 different identified species had interactions with S002 or the support vessels during Campaigns 1 through 12. Interactions ranged from being caught in the RZ to being detected swimming up to 200 m from the vessel. Roughly half of the observed turtles were noted as being juveniles, especially the loggerhead (**Table 4-18**)**.** The majority of unidentified sea turtle observances occurred during transit to and from the GPGP or detected by a camera briefly and shortly after escaped S002. No sea turtle encounters or observations occurred on the first Campaign (**Table 4-20**). **Tables 4-18** and **4-20** provide a summary of all sea turtle encounters.

Table 4-20. Sea turtle species observed during each of the Campaigns 1 through 12.

| Common Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Green sea turtle | - | 1 | - | - | - | - | - | 1 | - | - | 3 | 3 | 8 |
| Loggerhead sea turtle | - | 1 | - | 2 | 4 | 2 | 3 | 3 | 8 | 1 | - | 1 | 25 |
| Olive ridley sea turtle | - | - | - | - | - | - | 1 | - | - | - | - | 1 | 2 |
| Unidentified sea turtle | - | 1 | 1 | 3 |  | 2 | 1 | - | 2 | 1 | 3 | 2 | 16 |
| Total | - | 3 | 1 | 5 | 4 | 4 | 5 | 4 | 10 | 2 | 6 | 7 | 51 |

- = no observations.

### 4.3.6 Coastal and Oceanic Birds

#### *4.3.6.1 Coastal Birds*

The Vancouver Island area and surrounding estuaries provide essential habitat for millions of birds on the Pacific Flyway, a bird migration corridor along the Pacific Coast that stretches from northern Canada and Alaska to the southern tip of South America (**Figure 4-7**). It is estimated that up to eight million waterfowl transit through coastal British Columbia during annual migrations (Ducks Unlimited, 2021).


Figure 4-7. The Pacific Flyway migration route in relation to Vancouver (From: Vancouver Bird Advisory Committee, 2015).

Coastal areas in British Columbia have a wide variety of habitats, including coniferous and deciduous forests, tidal flats and marshes, ponds, subtidal areas with eelgrass (*Marina zostera*), open ocean areas that support numerous waterbirds, and inland areas of grasslands (South Coast Conservation Program, nd). The estuaries of British Columbia are of vital importance to migrating and wintering waterfowl. The main river estuary near Vancouver is the Fraser River, which runs more than 1,300 km from the Rocky Mountains until it empties into the Strait of Georgia, just south of Vancouver. The estuary has more than 32,000 hectares of mud and sandflats. Mudflats on Roberts Bank have been recorded to have more than 500,000 Western Sandpipers (*Calidris mauri*) present on a single day (Western Hemisphere Shorebird Reserve Network, 2019). Some of the estuary is protected, with portions designated as Provincial Wildlife Management Areas. Additionally, the Alaskan National Wildlife Area is listed as a Ramsar Wetland of International Importance.

Common coastal species present in the estuary are a subset of waterbirds in the families Gaviidae (loons), Podicipedidae (grebes), Phalacrocoracidae (cormorants), Ardeidae (herons, bitterns, and allies), Rallidae (rails, gallinules, and coots), Gruidae (cranes), and Laridae (skuas, gulls, terns, and skimmers), among others. More than 75 species of waterbirds have been identified in British Columbia (Birds Canada, 2020), and more than 250 species of birds have been identified within the metropolitan Vancouver area (Vancouver Bird Advisory Committee, 2015). Stevens (1995) identified 356 bird species from the two climate zones around Vancouver Island, coastal Douglas fir and coastal Western Hemlock. Bird monitoring was not a priority during transit; the monitoring focus was on bird interaction with the S002 during operations.

There are four Important Bird Areas around Vancouver, British Columbia: Fraser River Estuary, English Bay and Burrard Inlet, Greater Vancouver Watershed, and Pacific Spirit Regional Park (Vancouver Bird Advisory Committee, 2015). An additional five Important Bird Areas have been designated in the marine waters around Vancouver: Snake Island, Porlier Pass, Active Pass, Sidney Channel, and Chain and Great Chain Islets (IBA Canada, 2001). **Table 4-21** lists the threatened and endangered birds found in the vicinity of Vancouver.

Table 4-21. Threatened and endangered birds potentially present in the Vancouver area. Data compiled from the International Union for Conservation of Nature (IUCN, 2021) and the Government of Canada's species at risk public registry (Government of Canada, 2021u).

| Common Name | Scientific Name | Presence in Coastal Canada | Foraging/ Migration Area | IUCN Red List Status | COSEWIC Status/SARA |
|---|---|---|---|---|---|
| Barn Swallow | *Hirundo rustica* | Year-round | Open fields | Least Concern | SC,T |
| Black Swift | *Cypseloides niger* | Year-round | Variable | Vulnerable | E,E |
| Common Nighthawk | *Chordeiles minor* | May to August | Variable | Least Concern | SC,T |
| Horned Lark | *Eremophila alpestris strigata* | Year-round | Open areas | Least Concern (for *E. alpestris*) | E,E |
| Lewis's Woodpecker | *Melanerpes lewis* | Year-round | Scrubland | Least Concern | T,T |
| Marbled Murrelet | *Brachyramphus marmoratus* | Year-round | Protected marine lagoons | Endangered | T,T |
| Northern Goshawk | *Accipiter gentilis laingi* | Year-round | Forests | Least Concern (for *A. gentilis*) | T,T |
| Northern Saw-whet Owl | *Aegolius acadicus brooksi* | Year-round | Open forests | Least Concern (for *A. acadicus*) | T,T |
| Olive-sided Flycatcher | *Contopus cooperi* | Year-round | Open areas | Near Threatened | SC,T |
| Pink-footed Shearwater | *Ardenna creatopus* | Year-round | Coastal ocean | Vulnerable | E,E |
| Red Knot | *Calidris canatus roselaari* | Fall | Sandflats | Near Threatened (for *C. canatus*) | T, NL |
| Short-tailed Albatross | *Phoebastria albatrus* | Year-round | Open ocean | Vulnerable | T,T |
| Spotted Owl | *Strix occidentalis caurina* | Year-round | Old growth forests | Near Threatened (for *S. occidentalis*) | E,E |
| Western Screech Owl | *Megascops kennicottii kennicottii* | Year-round | Coastal forests | Least Concern (for *M. kennicottii*) | T,T |
| | *Megascops kennicottii macfarlanei* | Year-round | Riparian forests | | T,T |

COSEWIC = Committee on the Status of Endangered Wildlife in Canada; IUCN = International Union for Conservation of Nature; SARA = Species at Risk Act.
E = Endangered; NL = Not Listed; SC = Special Concern; T = Threatened.

#### *4.3.6.2 Oceanic Birds*

Orders of seabirds relevant to the project area include Procellariiformes (albatrosses, petrels, shearwaters, storm-petrels, and diving petrels); Pelecaniformes (pelicans, cormorants, boobies, frigatebirds); Charadriiformes (gulls, terns, alcids); Gaviiformes (loons); and Podicipediformes (grebes). Seabirds can be highly pelagic, coastal, or, in some cases, spend part of the year away from the sea entirely.

In the open ocean waters of the NPSG, mainly pelagic seabirds are present (**Table 4-22**), especially during their migratory period. Pelagic seabirds present in the NPSG are known to nest along coastal areas or on islands in the Pacific Ocean. In the North Pacific, breeding generally occurs during spring and summer. When not breeding, these birds forage in coastal areas or the open ocean. The CCS is an attractive area for birds due to its high nutrient content and corresponding high prey availability (Sydeman et al., 2012). Species migrate great distances to feed within the CCS.

Table 4-22. Common birds in the North Pacific Ocean. Data compiled from the International Union for Conservation of Nature (2021), BirdLife International (2021), and the Government of Canada (2021u) species at risk public registry.

| Common Name | Scientific Name | Foraging/ Migration Season | Foraging/Migration Area | IUCN Red List Status | COSEWIC/SARA Status |
|---|---|---|---|---|---|
| Brown Booby | *Sula leucogaster* | Year-round | Pacific Ocean | Least Concern | NL, NL |
| Red-footed Booby | *Sula sula* | March to October | Open ocean, only in far south of northeastern Pacific and Hawaii | Least Concern | NL, NL |
| Masked Booby | *Sula dactylatra* | Year-round | Open ocean, only in southern portion of northeastern Pacific and Hawaii | Least Concern | NL, NL |
| Black-footed Albatross | *Phoebastria nigripes* | May to October | North Pacific Ocean | Near Threatened | NL, NL |
| Laysan Albatross | *Phoebastria immutabilis* | August to November | North Pacific Ocean; seen in northeastern Pacific but prefers western Pacific | Near Threatened | NL, NL |
| Short-tailed Albatross | *Phoebastria albatrus* | June to October | North Pacific, especially Alaska but spotted around Hawaii and California | Vulnerable | T, T |
| Ashy Storm-petrel | *Oceanodroma homochroa* | November to April | California Current System | Endangered | NL, NL |
| Black-vented Shearwater | *Puffinus opisthomelas* | July to February | California Current System and North Pacific | Near Threatened | NL, NL |
| Cassin’s Auklet | *Ptychoramphus aleuticus* | Year-round | Along North American west coast | Near Threatened | SC, SC |
| Murphy’s Petrel | *Pterodroma ultima* | November to April | Between Hawaii and California, at least 64 km offshore | Least Concern | NL, NL |
| Pink-footed Shearwater | *Puffinus creatopus* | April to October | Along continental shelf of U.S. and Canada west coast | Vulnerable | E, E |
| Wedge-tailed Shearwater | *Ardenna pacifica* | Year-round | Tropical oceans (35° N to 35° S) | Least Concern | NL, NL |
| Sooty Shearwater | *Ardenna grisea* | April to October | Circular migration; full Pacific Ocean | Near Threatened | NL, NL |
| Leach’s Storm-petrel | *Hydrobates leucorhoa* | November to April | Pacific Ocean | Vulnerable | NL, NL |

COSEWIC = Committee on the Status of Endangered Wildlife in Canada; IUCN = International Union for Conservation of Nature; SARA = Species at Risk Act.
E = Endangered; NL = Not Listed; SC = Special Concern; T = Threatened.

During transit from California and deployment of the S001 in the NPSG in 2018, 10 unique species of birds were observed. Observations were not enumerated, but taxa observed included Black-footed Albatross (*Phoebastria nigripes*), Laysan Albatross (*Phoebastria immutabilis*), Red-tailed Tropicbird (*Phaethon rubricauda*; **Image 4-5**), White-tailed Tropicbird (*Phaethon lepturus*), Blue-footed Booby (*Sula nebouxii*), Masked Booby (*S. dactylatra*), Brown Booby (*S. leucogaster*), Band-rumped Storm-petrel (*Hydrobates castro*), Osprey (*Pandion haliaetus*), and Sanderling (*Calidris alba*) (Seiche, 2019).

Image 4-5. A Red-tailed Tropicbird observed during The Ocean Cleanup's S001 deployment in the North Pacific Subtropical Gyre in 2018 (From: Seiche, 2019).

During transit from California and deployment of the S001/B in the NPSG in 2019, 106 bird observations were made over the course of 157 days. Most bird sightings were of two species: Black-footed Albatross (32 observations) and Masked Booby (26 observations; **Image 4-6**). Other observations included unidentified albatrosses (15 observations), Laysan Albatross (9 observations), Red-tailed Tropicbird (3 observations), Western Gull (*Larus occidentalis*; 2 observations), and unidentified boobies (2 observations). Fifteen observations of unidentified birds were also made (The Ocean Cleanup, 2020).

Image 4-6. A Masked Booby resting on a towhead of The Ocean Cleanup's S001/B in the North Pacific Subtropical Gyre in 2019 (From: The Ocean Cleanup, 2020).

During the transit from Vancouver and deployment of the S002 during all campaigns, bird observations were not a priority and were not documented the same way as marine mammals and sea turtles. However, 3,213 birds were observed on the M/V *Maersk Trader* and M/V *Tender* during Campaigns 1 through 12. These observations were dominated by Laysan Albatross, unidentified Gulls, and Red Phalarope (*Phalaropus fulicarius*), while Leach's Storm-petrel (*Hydrobates leucorhoa*), unidentified gulls, and Black-footed Albatross were also commonly observed. The birds were engaged in different activities when observed; 1,735 were observed flying, 156 were on the vessel deck, 3 were sitting on the S002, and 1,319 were sitting on the water. **Figure 4-8** shows the total number of bird individuals per species group observed during Campaigns 1 through 12, and **Table 4-23** provides a summary of the different activities the birds were engaged in.

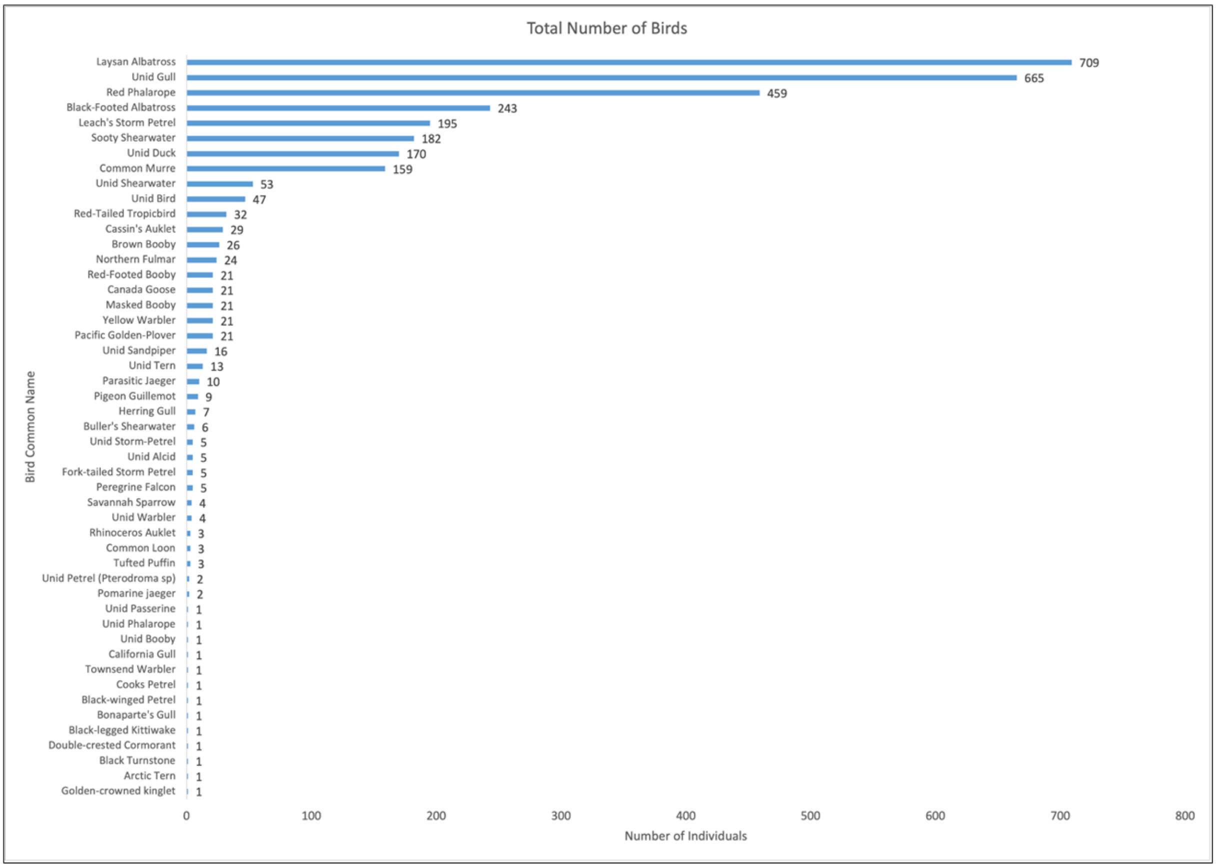



Figure 4-8. Total number of bird individuals per species group observed during Campaigns 1 through 12.
Bird numbers reflect the total number of bird individuals observed across different sightings.

Table 4-23. Total number of oceanic birds engaged in different activities.

| Activity | Total Number of Birds |
|---|---|
| Flying | 1,735 |
| On deck | 156 |
| On System | 3 |
| Sitting on water | 1,319 |
| **Total** | **3,213** |

### 4.3.7 Protected Areas

There are no protected areas in the vicinity of the S03 deployment location in the NPSG. However, the project vessels will transit past several coastal protected areas, including Race Rocks Ecological Reserve, Juan de Fuca Park, Pacific Rim National Park Reserve of Canada, and Olympic National Park in the U.S.

The Endeavour Hydrothermal Vents MPA is the only MPA in the vicinity of potential transit operations offshore Vancouver. Located approximately 260 km southwest of Vancouver Island, the vents are located in a narrow seafloor valley along the Juan de Fuca Ridge, approximately 14 km long and 1.5 km wide. There are as many as 572 vent chimneys spread over the region (Clague et al., 2020).

The Endeavour Hydrothermal Vents MPA is within a broad area known as the Canadian Offshore Pacific Area of Interest (**Figure 4-9**). The area is approximately 133,000 km$^2$ in size and is meant to protect and conserve unique seafloor features and the ecosystems they support (Government of Canada, 2020b).

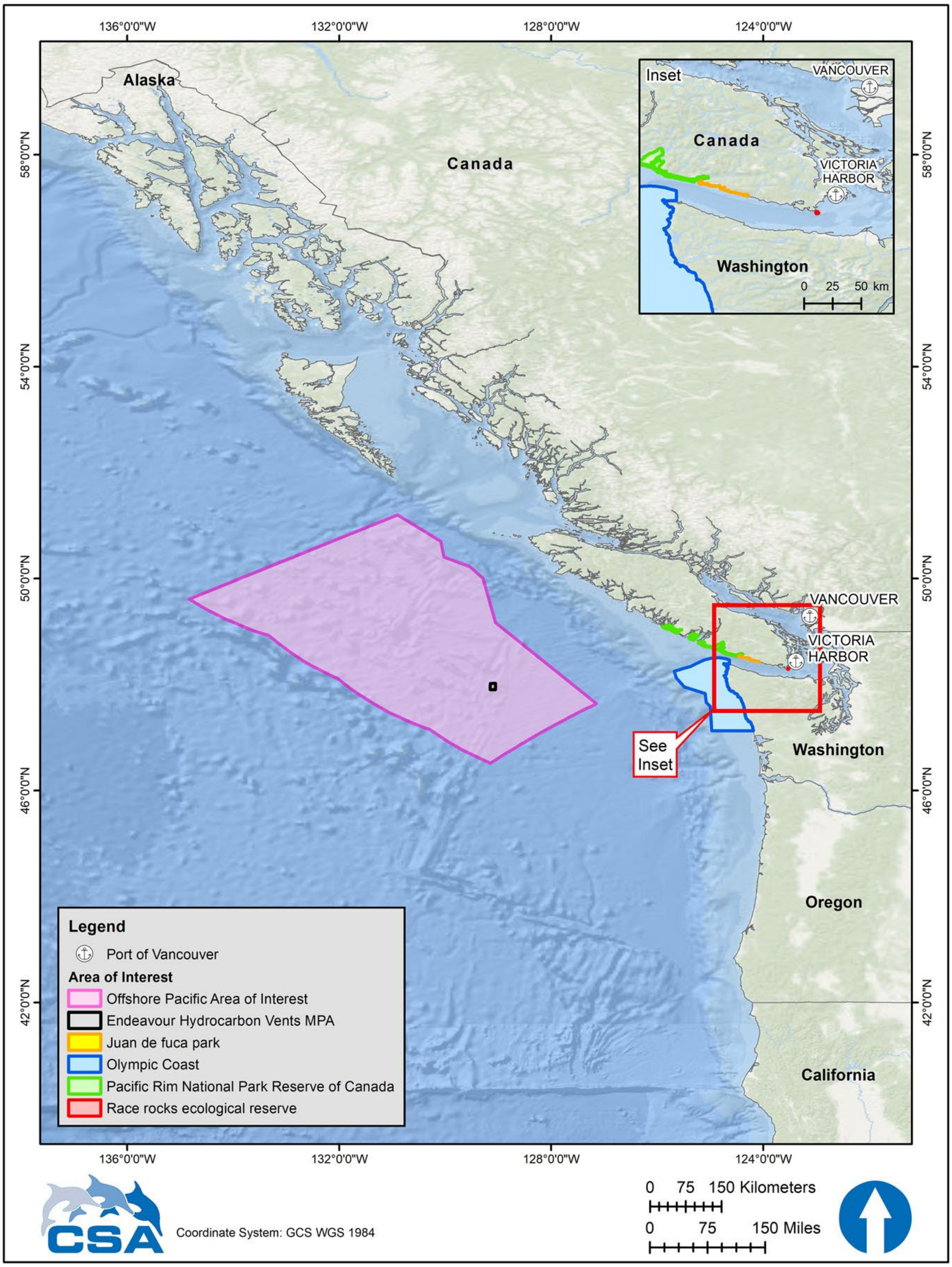



Figure 4-9. The Canadian Offshore Pacific Area of Interest and the Endeavour Hydrothermal Vents Marine Protected Area offshore Vancouver Island (Adapted from: Government of Canada, 2020b).

Depending on the exact transit route chosen, the project vessels may pass through or near the Canadian Offshore Pacific Area of Interest (**Figure 4-10**). Summary characteristics of the two protected areas described above are presented in **Table 4-24**.

Table 4-24. Summary characteristics of the Endeavour Hydrothermal Vents Marine Protected Area and Canadian Offshore Pacific Area of Interest offshore Vancouver Island in the vicinity of the transit routes for the Ocean Cleanup System.

| Name | Area ($km^2$) | Designated (Year) | Major Features |
| --- | --- | --- | --- |
| Endeavour Hydrothermal Vents Marine Protected Area | 97 | 2003 | The Endeavour segment of the Juan de Fuca Ridge is an active seafloor-spreading zone. Across five vent fields, black smokers, vent chimneys, and other vent structures emit water at up to 300°C. Fauna associated with the vents include numerous species of brittle stars, worms, and an incredibly diverse microbial community. |
| Canadian Offshore Pacific Area of Interest | 133,019 | 2017 | Composing more than 2.3% of Canada's maritime territory, this large marine area is designed to protect several interlinked ecosystems, including seamounts and hydrothermal vents. The area contains more than 90% of Canada's hydrothermal vents. |

°C = degrees Celsius; $km^2$ = square kilometers.

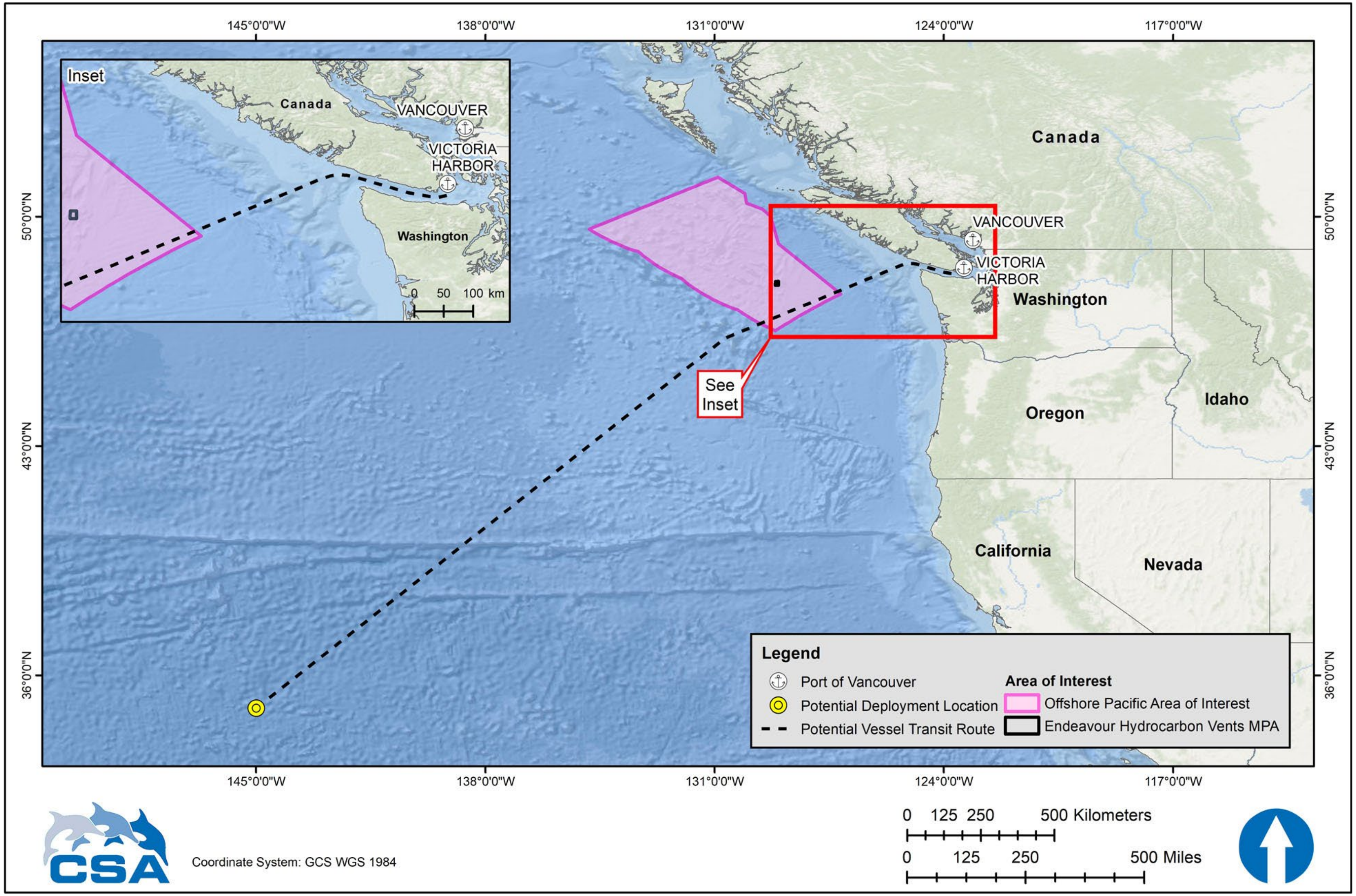



Figure 4-10. Canadian Offshore Pacific Area of Interest and the Endeavour Hydrothermal Vents Marine Protected Area (MPA) relative to a hypothetical transit route from the Vancouver area to the North Pacific Subtropical Gyre.

### 4.3.8 Biodiversity

No significant impacts to biodiversity are expected from The Ocean Cleanup's activities. While deployment of the S03 may have impacts on individuals of a variety of species (**Chapter 5**), it is not expected that any detrimental impacts will occur at a species level that would result in harm to overall biodiversity in the area.

Following issuance of the initial EIA for The Ocean Cleanup in 2018 (CSA, 2018), the issue of impacts to neuston were raised by members of the public, with some indicating they felt certain portions of the neuston community, especially *V. velella*, would be significantly impacted. The neuston community of the North Pacific Ocean has been studied, but only to a limited extent (e.g., Moore et al., 2001; Goldstein, 2012). Key references in this regard include recent publications from The Ocean Cleanup and professional affiliates (e.g., Egger et al., 2021), neuston-specific research (e.g., Moore et al., 2001, 2005), and peripheral data acquired during sampling and analysis of macro- and microplastics. **Appendix D** provides a limited review of existing ecosystem modeling review results for the North Pacific Ocean. The review was conducted to determine if the Ecopath with Ecosim (EwE)[2] modeling method is a suitable tool to better characterize the function of neuston in this open ocean ecosystem and, in doing so, address the potential for the System to impact the open ocean neuston community and overall ecosystem dynamics. The Ocean Cleanup is currently continuing its sampling efforts of the neuston in the region and will attempt to focus on determining the direct impact of operations on neuston abundance and diversity before and after the System passes through the water.

## 4.4 SOCIAL ENVIRONMENT

### 4.4.1 Commercial and Military Vessels

Commercial vessel activity is high through the Strait of Juan de Fuca, Salish Sea, and Strait of Georgia. Vancouver is Canada's busiest port, with more than 16,000 hectares of water serving approximately 3,200 commercial ship visits each year (Port of Vancouver, 2021).

The Canadian Coast Guard is responsible for issuing Notices to Shipping (NOTSHIP), a mechanism to inform commercial and recreational mariners about hazards to navigation and to share other important information. Verbal NOTSHIP alerts are broadcast via radio by Canada's Marine Communications and Traffic Services, while written NOTSHIP alerts are issued when the hazard location is beyond broadcast range or when the information remains in effect for an extended period of time (Port of Vancouver, 2020). The Ocean Cleanup vessels will monitor NOTSHIP notifications prior to and during transit from the Vancouver area.

Canadian Forces Base Esquimalt is Canada's Pacific naval base. Located on the southern end of Vancouver Island adjacent to the Strait of Juan de Fuca, it covers more than 12,000 acres. No impacts to the base are expected from transit activities, but military vessels may be present in the vicinity when project vessels are transiting.

Numerous commercial and recreational vessels were in the Salish Sea during transit of the project vessels to and from the Vancouver area during all campaigns. **Figure 4-11** presents established shipping lanes in the Vancouver area and a potential route for the project vessels.

[2] https://ecopath.org/

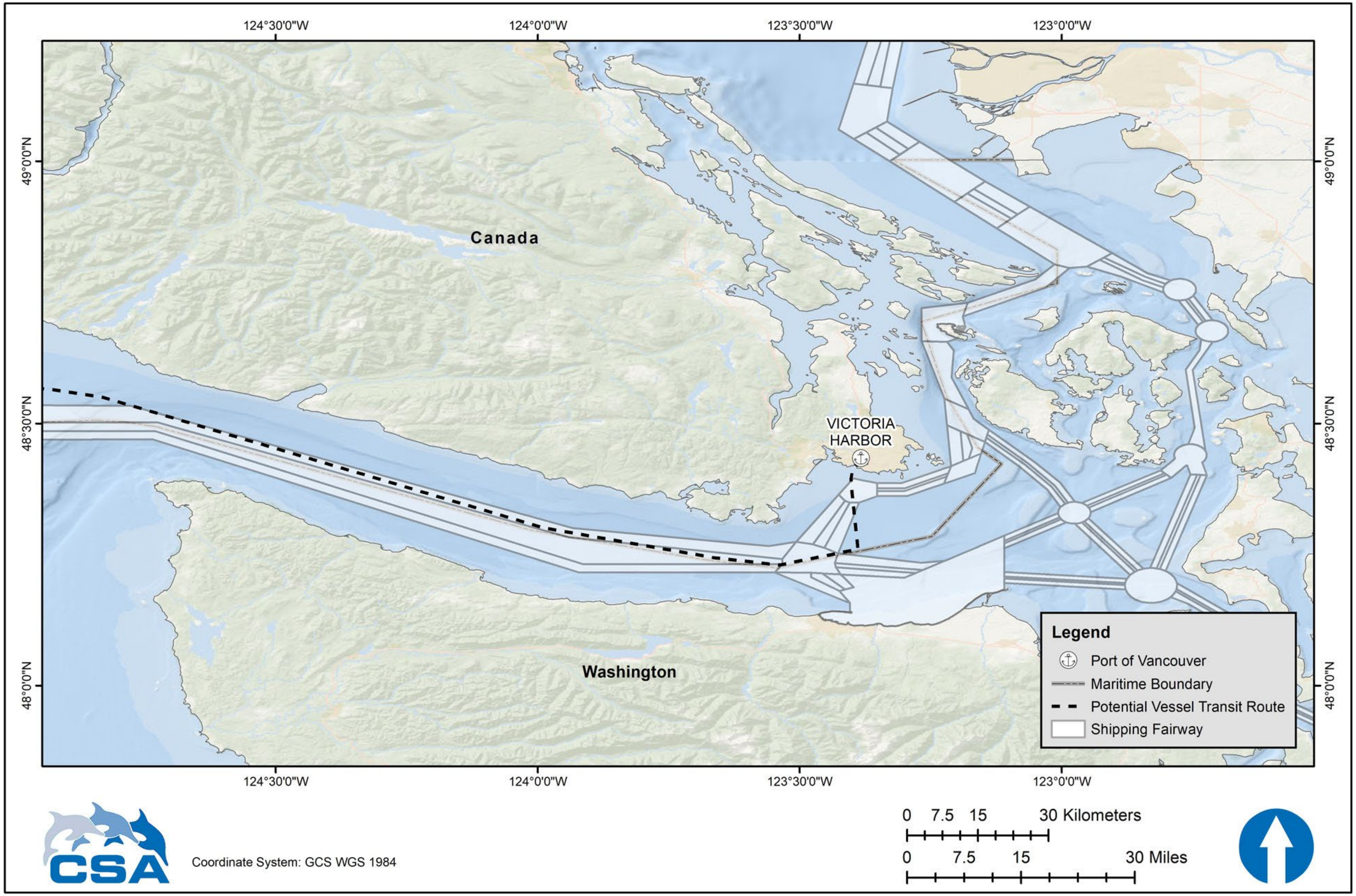



Figure 4-11. Shipping routes in the vicinity of Victoria, British Columbia.

## 5.1 IMPACT ASSESSMENT METHODOLOGY

Based on the project description (**Chapter 2**), impact-producing factors (IPFs) associated with the transit and deployment of the S03 have been identified for both routine operations and potential accidents/unplanned events. A preliminary screening exercise was completed (**Section 4.1**) to identify biological and social resources that will not be affected by The Ocean Cleanup activities or where impact consequence was deemed, *a priori*, to be negligible. Resources for which more extensive analysis will not be performed as part of this EIA include air quality; sediment quality; water quality; benthic communities; archaeological resources; human resources, land use, and economics; recreational resources and tourism; and physical oceanography.

**Table 5-1** identifies the potential sources of impact associated with the project activities and the biological and social resources that may be affected by project activities. Some IPFs that are expected to result in similar or identical impacts to a particular resource were combined to reduce redundancy in reporting.

Table 5-1. Matrix of potential impacts from The Ocean Cleanup transit and deployment activities for the S03.

| Project Activity/ Impact-Producing Factor (IPF) | Environmental Resource | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Biological | | | | | | | Social |
| | Plankton | Neuston | Fish/ Fishery Resources | Marine Mammals | Sea Turtles | Coastal and Oceanic Birds | Protected Areas | Commercial and Military Vessels |
| S03 – Entanglement/ Entrapment | ● | ● | ● | ● | ● | ● | -- | -- |
| S03 – Attraction/Ingestion of Plastics | ● | ● | ● | ● | ● | ● | -- | -- |
| Vessel – Physical Presence/ Strikes | -- | -- | ● | ● | ● | ● | ● | ● |
| Noise and Lights | ● | ● | ● | ● | ● | ● | -- | -- |
| Loss of Debris | -- | -- | -- | ● | ● | ● | -- | -- |
| Accidental Fuel Spill | ● | ● | ● | ● | ● | ● | ● | -- |

● indicates a potential impact to the resource; -- indicates no or negligible potential for impact.

The only accident evaluated in this EIA is a fuel spill, as there are no activities being conducted by The Ocean Cleanup that have a reasonable likelihood of resulting in a large spill of crude oil or other chemicals. Most small spills that occur during offshore operations are ≤1 barrel (bbl)[3] in volume. In the Gulf of Mexico, the median volume for spills of 1 to 10 bbl is 3 bbl (Anderson et al., 2012). The most likely cause of a small spill would be a rupture of a fuel hose resulting in the loss of contents (<3 bbl). Consequently, a spill size of 3 bbl is used as a hypothetical spill scenario for this EIA.

Other potential accidents involving the S03 could include: 1) breaking up at sea, 2) sinking, or 3) becoming entangled with the tow vessels while deployed. Such incidents are considered unlikely due to the engineering design of the S03, sensor and positioning system redundancy, and multi-layered safety precautions. Safety measures have been put in place during the design and fabrication phases to avoid or minimize potential impacts resulting from failure of the S03. If damage

[3] One barrel equals 42 U.S. gallons, 35 imperial gallons, or approximately 159 L.

is detected that could interfere with the safe operation of the S03, the System (or any broken parts) will be brought to shore immediately.

The S03 is constructed primarily of Dyneema® netting, buoys, a float line, a ballast line, and marine connectors. The System is composed of the RS (wings), with attached towing lines, and the RZ, with a bridle. As outlined in **Section 2.1.1**, the S03 RS is modular in design and composed of two 1,125-m wings designed to prevent underflow and overtopping and to limit drag effect. The RS is composed of 102 wing sections, each either 22 or 23 m long depending on the floatation buoy size for a total length of approximately 2,250 m, and includes a float line, ballast line, net attached between the float and ballast lines, and the RZ. The float line consists of heavy-duty fenders each with a permeable cover and either 215 or 720 kg of flotation. The wing segments with the greater buoyancy are placed closest to the RZ entrance. The RZ is constructed of Dyneema® netting, buoys, lines, a ballast chain, and marine connectors. It is composed of the RZ entrance, safe section, and extraction section with bridle.

The RS design allows the integration of, and provides stability for, a global training tracking system, which is composed of a series of trackers evenly distributed along the length of the S03. Other components of the RS include motion reference units, lanterns, banana pingers (currently five in the RZ and six on each wing, but final configuration is being evaluated through adaptive management from field data), two camera skiffs each with eight cameras with integrated lights to monitor the entire RZ (**Figure 2-12**), and green LED deterrent lights placed along the wings and RZ entrance and top (**Figure 2-13**). To the extent feasible, with due consideration to risks to human and marine health and safety, The Ocean Cleanup will recover the S03 parts and debris generated, should the System break apart. If the S03 separates at sea, the global training tracking system signals will show the separated parts farther apart than designed. In the unlikely event that such an accident was to occur, potential environmental impacts are anticipated to be negligible to minor, as all the major parts of the S03 are intended to remain floating and available for recovery.

Potential impacts of the S03 project activities are evaluated using the methodology described in the following subsections. Impact consequence and impact likelihood are two factors used to determine potential impact significance (**Figure 5-1**).

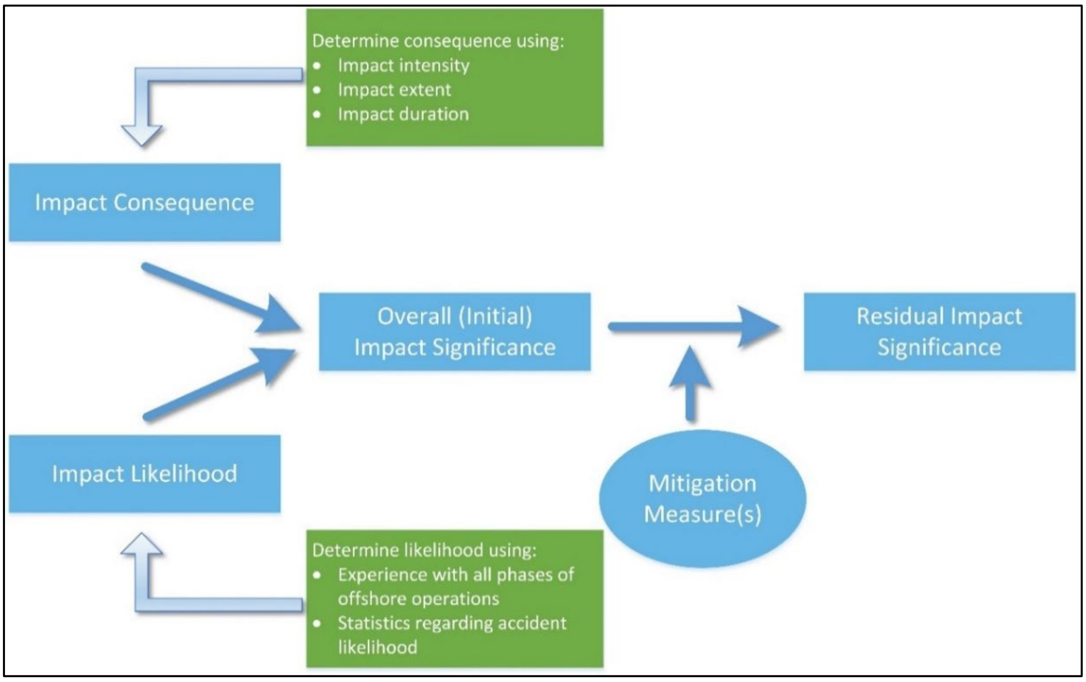



Figure 5-1. Impact assessment flow chart.

### 5.1.1 Determination of Impact Consequence

Impact consequence reflects an assessment of an impact's characteristics on a specific resource (e.g., fish/fishery resources, marine mammals) arising from one or more IPFs. Impact consequence is determined regardless of impact likelihood. Impact consequence classifications include Positive (Beneficial), Negligible, Minor, Moderate, and Severe.

For negative impacts, where the change to the current situation of the resource is generally considered adverse or undesirable, the determination of impact consequence is based on the integration of three criteria: intensity, extent, and duration. When appropriate, calculations were made to quantitatively characterize the intensity and extent of the impacts. These calculations are explained for each of the resources concerned. Positive impacts, where the change to the current situation of the resource is generally considered better or desirable, are noted, but their consequence is not qualified.

#### *5.1.1.1 Impact Intensity*

Impact intensity relates to the degree of disturbance associated with the impact and the alteration of the current state of the host environment. There are three levels of intensity[4]:

- **Low**: Small adverse changes unlikely to be noticed or measurable against background activities. For example, in the social environment, changes may be noticed only by a few individuals.
- **Moderate**: Adverse changes that can be monitored or noticed but are within the scope of existing variability without affecting the resource's integrity or use in the environment. For example, in the social environment, an adverse change that affects several people but not the entire community.
- **High**: For the physical environment, extensive or frequent violation of applicable air or water quality standards/guidelines, or widespread contamination of sediments with hydrocarbons, toxic metals, or other toxic substances. For the biological environment, extensive damage to habitats to the extent that ecosystem functions and ecological relationships would be altered, or numerous mortalities or injuries of a protected species or continual disruption of their critical activities. For the social environment, extensive adverse change that is far-reaching and widely recognized; it significantly limits the use of a resource by a community or a regional population, or its functional and safe use is seriously compromised. An impact potentially resulting in the mortality of one or more community members is also considered of high intensity.

#### *5.1.1.2 Impact Extent*

The geographic extent of an impact expresses how widespread the impact is expected to be. It represents the area that will be affected, directly or indirectly. Impact extent is classified by the following levels:

- **Immediate vicinity:** Limited to a confined space within the area of interest, generally within 2 km of project activities.
- **Local:** The impact has an influence that goes beyond the area of interest but stays within a relatively small geographic area (i.e., generally 5 to 20 km from the source of impact).
- **Regional:** The impact affects a large geographical area, generally more than 20 km from the source of impact.

[4] The definitions presented here are general descriptions of the levels for each criterion. Not all resources have been included as examples, but specific explanations are provided in the assessment when needed.

In general, the extent of all impacts to resources from The Ocean Cleanup project would be limited to the immediate vicinity, except for potential behavior modifications in marine mammals due to noise, which would be local, and in neuston, which would range from local to regional.

#### *5.1.1.3 Impact Duration*

The duration of an impact describes the length of time over which the effects of an impact occur. It is not necessarily the same as the length of time of an activity or an IPF because an impact can sometimes continue after the source of impact has stopped or the impact can be shorter if there is an adaptation. Therefore, the impact duration can include the recovery period or the adaptation period of the affected resource. Impact duration can be:

- **Short term**: The impacts are felt continuously or discontinuously over a limited period, generally during the project period of activity, or when the recovery or adaptation period is less than a year.
- **Long term**: The impacts are felt continuously or discontinuously beyond the life of the project.

The duration for all impacts associated with The Ocean Cleanup project for this evaluation is expected to be short term, although the potential for long-term impacts for certain resources are continuing to be assessed (e.g., plankton, neuston).

**Table 5-2** lists the combinations of criteria used to delineate impact consequence.

Table 5-2. Matrix of impact consequence determinations for negative impacts.

| Intensity | Extent | Duration | Consequence Criteria | | | |
|---|---|---|---|---|---|---|
| | | | Negligible | Minor | Moderate | Severe |
| Low | Immediate vicinity | Short term | ● | - | - | - |
| | Local | Short term | ● | - | - | - |
| | Regional | Short term | ● | - | - | - |
| | Immediate vicinity | Long term | ● | - | - | - |
| | Local | Long term | - | ● | - | - |
| | Regional | Long term | - | ● | - | - |
| Moderate | Immediate vicinity | Short term | - | ● | - | - |
| | Local | Short term | - | ● | - | - |
| | Regional | Short term | - | ● | - | - |
| | Immediate vicinity | Long term | - | ● | - | - |
| | Local | Long term | - | - | ● | - |
| | Regional | Long term | - | - | ● | - |
| High | Immediate vicinity | Short term | - | - | ● | - |
| | Local | Short term | - | - | ● | - |
| | Regional | Short term | - | - | ● | - |
| | Immediate vicinity | Long term | - | - | ● | - |
| | Local | Long term | - | - | - | ● |
| | Regional | Long term | - | - | - | ● |

- = not applicable.

### 5.1.2 Determination of Impact Likelihood

The likelihood of an impact describes the probability that an impact will occur. The likelihood of impact occurrence was rated using the following categories:

- Likely (>50% likelihood)
- Occasional (10% to 49% likelihood)
- Rare (1% to 9% likelihood)
- Remote (<1% likelihood)

Impacts are evaluated or predicted prior to and following implementation of mitigation measures. Mitigation measures are identified based on industry best practice, international standards (e.g., MARPOL 73/78 requirements), or measures deemed applicable and practicable by The Ocean Cleanup. Impacts that remain after implementation of mitigation measures are described as residual impacts. To summarize the overall significance of each impact, impact consequence and likelihood were combined using professional judgment and a risk matrix (**Table 5-3**). According to this matrix, the overall impact significance for biological and social negative impacts using a numeric, descriptive, and color-coded approach is rated as follows:

- 1 – Negligible
- 2 – Low
- 3 – Medium
- 4 – High

Table 5-3. Matrix combining impact consequence and likelihood to determine overall impact significance.

| Likelihood vs. Consequence | | ← Decreasing Impact Consequence | | | | |
|---|---|---|---|---|---|---|
| | | Positive | Negligible | Minor | Moderate | Severe |
| Decreasing Impact Likelihood ↓ | Likely | Beneficial (no numeric rating applied) | 1 – Negligible | 2 – Low | 3 – Medium | 4 – High |
| | Occasional | | 1 – Negligible | 2 – Low | 3 – Medium | 4 – High |
| | Rare | | 1 – Negligible | 1 – Negligible | 2 – Low | 4 – High |
| | Remote | | 1 – Negligible | 1 – Negligible | 2 – Low | 3 – Medium |

Impacts of Negligible consequence were assigned the lowest overall significance value (1 – Negligible), regardless of impact likelihood. Severe impacts were assigned the highest significance value (4 – High) if the impacts were Likely, Occasional, or Rare and assigned a lower value (3 – Medium) if the likelihood was Remote. The most significant impacts (those rated as 3 – Medium or 4 – High) were primary candidates for mitigation. Mitigation was also considered for lower significance levels (1 – Negligible and 2 – Low) to further reduce the likelihood or consequence of impacts. A comprehensive discussion of the mitigation measures and corporate/subcontractor policies that The Ocean Cleanup will follow during project activities is presented in a separate EMP.

## 5.2 POTENTIAL IMPACTS FROM PROJECT ACTIVITIES

The long-term beneficial impacts from The Ocean Cleanup project are discussed in **Section 5.2.1**, while the environmental consequences discussed in subsequent sections address the potential impacts that could be incurred as a result of the transiting and deployment/operation of the S03. For each resource, the IPFs identified in **Table 5-1** were further examined and refined to identify aspects of those factors specific to the resource under evaluation. The impact assessment for each resource includes a list of the relevant IPFs, a discussion concerning the effects of each IPF on the resource, and the significance of the impact on the resource from the IPFs. Summary tables are presented for the impact rating to determine impact significance prior to and following implementation of mitigation measures.

### 5.2.1 Long-Term Impacts from Project Plastics Removal

Plastics are manufactured from polymers retrieved from fossil fuels (gas, coal, or oil). Plastic gets its characteristics due to a blend of added chemicals called additives. Because of its light, cheap, strong, and durable characteristics, plastic is an ideal product for manufacturing everyday items (Thompson et al., 2009). The production of plastic has increased exponentially over the past 60 years and continues to increase, especially in areas with growing economies such as China and Southeast Asia (PlasticsEurope, 2016). Most consumer plastics are HDPE, low-density polyethylene, polypropylene, polyethylene terephthalate, or polyvinylchloride.

Because of their environmental persistence, plastics can stay in oceans for decades (Barnes et al., 2009). Studies estimated that in 2010, 4.8 to 12.7 million metric tons entered the ocean annually from coastal populations (Jambeck et al., 2015), while plastic input from inland rivers was estimated to add between 0.79 and 1.52 million tons to the world's oceans (Lebreton et al., 2017). Total worldwide plastics production reached 359 million tons in 2018 (PlasticsEurope, 2019), approximately 30% higher than the 265 million tons in 2010 (PlasticsEurope, 2011) and continued to increase to 367 million tons in 2020. Due to the COVID-19 pandemic, this was a similar figure to the quantity produced in 2019 (PlasticsEurope, 2021).

When macroplastics break down due to mechanical, biological, or ultraviolet degradation, microplastics can form. Microplastics, defined by NOAA as plastic pieces <5 mm in size, are difficult if not impossible to remove from the marine environment, and their numbers will increase exponentially over time as macroplastics present in the environment continue to break down (Thompson et al., 2004). Microplastic content in the North Pacific increased by two orders in terms of weight and number between 1972 to 1987 and 1999 to 2010 (Goldstein et al., 2012). A recent study performed by The Ocean Cleanup estimated 80 kilotons of plastic in an area of 1.6 million km$^2$. Approximately 6 kilotons were macroplastics, while the remaining 74 kilotons were considered microplastics; microplastics made up 94% of the abundance of plastic pieces, however. Microplastics in the marine environment will also continue to break down, creating small microparticles and nanoparticles (e.g., Gigault et al., 2018; Yee et al., 2021).

Microplastics and macroplastic fragments often are mistaken for food and ingested by biota in all trophic levels. Although ingestion of plastic is not directly lethal to the individual (only in 4% of cases), it does have negative effects such as reduced fitness, toxicity caused by absorption of toxins, a false feeling of satiation, and eventually starvation (Gall and Thompson, 2015). Birds are especially vulnerable to the effects of plastic ingestion due to their small gizzards and many species' inability to regurgitate indigestible items (Azzarello and van Vleet, 1987).

López-Martínez et al. (2021) reviewed various approaches and protocols used to assess macro- and microplastic ingestion in marine vertebrates (e.g., sea turtles, cetaceans, fish). The analysis of 112 studies indicated the highest plastic ingestion by organisms from the Mediterranean Sea and northeast Indian Ocean exhibited significant differences among plastic types, varying by animal group, color, and type of polymer. For example, in sea turtles, white plastics (66.6%), fibers (54.5%), and low-density polyethylene polymers (39.1%) were prevalent, compared to white macro- and microplastics (38.3%), fibers (80.0%), and polyamide polymers (49.6%) in cetaceans. In fish, transparent plastics (46.0%), fibers (66.7%), and polyester polymers (36.2%) predominated. Considering all study results, the authors determined clear fiber microplastics were the predominant type ingested by marine megafauna worldwide (López-Martínez et al., 2021).

Because of their increased surface area to volume ratio relative to macroplastics, microplastics release more chemical additives into the environment. Some of these additives are highly toxic or can increase the risk of disease. Examples of such additives are residual monomers, which are considered toxic to humans and ecosystems (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2016). These additives are released after ingestion and can accumulate in individuals (Wright et al., 2013). Additives are stored in body tissue, which may result in food chain pollution by bioaccumulation (Hammer et al., 2012). In addition, plastics in the ocean attract other chemicals because of their hydrophobic nature, increasing the overall toxicity of floating plastics (Andrady, 2011).

Plastic debris has become a serious problem affecting the marine environment due to a variety of reasons, including the aforementioned slow degradation and breakdown toxicity of plastics and toxic accumulation in the food web, the spread of invasive species by rafting of coastal species (e.g., barnacles, bryozoans, crabs, anemones, hydroids, amphipods) to the open ocean where they persist, ingestion of microplastics by marine organisms, entanglement with marine organisms, and the sinking of plastics to the seafloor where they are incorporated into sediment deposits (Thevenon et al., 2014; Haram et al., 2023). The short- and long-term fates of plastics in the ocean have been studied to determine their impacts. **Appendix B** provides a summary and analysis of literature primary findings on the following key topics: 1) short- and long-term fates of ocean plastics; 2) plastics toxicity; 3) floating macroplastics as fish aggregating devices (FADs); 4) changes in buoyancy resulting from colonization (and subsequent sinking through the water column); 5) plastic degradation (i.e., macroplastics to microplastics); 6) life cycle analysis of plastics; and 7) potential removal impacts, particularly impacts to neuston. The literature review provided the data necessary to reach conclusions using a net environmental benefit analysis (NEBA) approach for The Ocean Cleanup project. NEBA is a method for identifying and comparing net environmental benefits of alternative management options. Net environmental benefits are the gains in environmental services or other ecological properties attained by remediation or ecological restoration, minus the environmental injuries caused by those actions (e.g., Efroymson et al., 2003). The results of the data search and synthesis efforts were further evaluated within a NEBA-type evaluation, comparing relative impacts associated with plastic removal versus no action (i.e., leaving plastic debris in the ocean). Based on the NEBA approach, it was concluded that removal of ocean plastics by the System provides a greater environmental benefit for all marine resources impacted, including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston, compared to leaving the plastics in the ocean. The complete impact analysis using the NEBA approach is provided in **Appendix B**.

During the 12 Campaigns the System was towed for a total of 4,554 hours for plastic collection. During this time a total of 190,183 kg of plastic was collected and removed from the environment by the System. **Figure 5-2** summarizes the weight of plastic debris collected and the total towing time for Campaigns 1 through 12. The total towing time per Campaign ranged from 181 (Campaign 1) to 510 hours (Campaign 2), averaging 380 hours per Campaign. The weights of the plastic collected ranged from 4,340 to 30,984 kg, averaging 15,849 kg per Campaign. An additional 3,649 kg of ghost nets and other large plastics were removed from the NPSG that were not removed as part of the System extraction process but by the vessel crew separately which brings the total of extracted plastic debris to 193,832 kg from the 12 Campaigns.

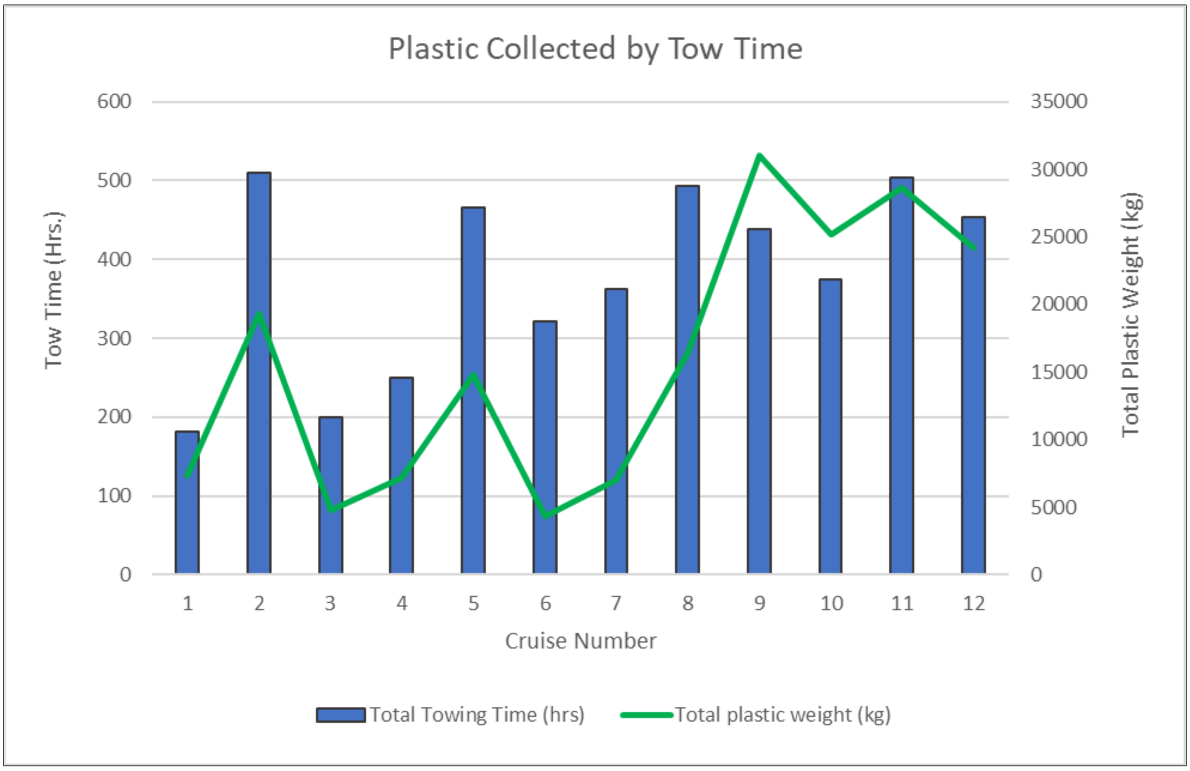



Figure 5-2. Summary by Campaign of total plastic debris collected and total towing time.

The long-term benefits of removing macroplastics and other marine debris (e.g., ghost nets) from the NPSG include reducing 1) the potential for entanglement of marine species; 2) the potential for ingestion or adsorption of plastics by marine species; 3) the potential impacts to marine species from the release of degradation byproducts (i.e., toxic chemicals); 4) the amount of microplastics produced via fragmentation of macroplastic debris and the associated impacts; and 5) the seafloor deposition of macroplastic debris due to biofouling (**Appendix B**). Consideration must also be given to the possible benefits these plastics have afforded to the same marine species such as creating new surfaces for colonization by organisms and use as nursery habitat. For example, some species (e.g., flyingfish, *Halobates* spp.) are known to lay eggs on floating items (both natural and anthropogenic), and floating plastics provide nursery habitat for many fish and sea turtle species. Additionally, rafting species are likely to be impacted more than other fish species as well as bryozoans, hydrozoans, and arthropods (e.g., barnacles, crabs), which use the plastics as habitat in the marine environment.

The Ocean Cleanup's ultimate goal is to remove plastic debris from the oceans. While the remainder of this chapter discusses the negative impacts to the biological and social environment resulting from S03 deployment, the potential long-term result of S03 deployment and future plastic-collection devices includes substantial beneficial impacts to numerous marine resources. While this EIA addresses the S03 deployment in the NPSG, The Ocean Cleanup's long-term goal is to deploy numerous collection Systems in various plastic-polluted ocean basins worldwide. The data collected, observations made, and lessons learned during the previous campaigns have been used to improve the scale-up S03 design, using an adaptive management approach. This EIA includes the data collected, findings, and observations from the 12 previous S002 campaigns.

For this EIA, several resources that were screened out of further analysis (**Section 4.1**) would likely benefit from the long-term reduction of floating plastics in the marine system, including water quality, by reducing chemical-leaching plastics into the water; benthic communities, by reducing the potential for plastics to sink and contaminate or otherwise adversely affect seafloor communities; archaeological resources, by reducing potential for contamination of archaeological sites or shipwrecks; biodiversity, by collectively reducing impacts on the NPSG ecosystem and its species; and recreational resources and tourism, by reducing costs associated with debris removal and negative public perception of coastal or offshore recreational areas contaminated by debris.

The presence of marine debris, including plastics, and the associated potential harm to the marine environment globally, is one of the major perceived threats to marine biodiversity (Gall and Thompson, 2015). Biodiversity was included in the screening process, and it was determined that there is not enough information at this time to fully address biodiversity impacts from the S03. After analyzing the data collected for plankton from the first S002 campaigns and reviewing potential Ecopath models, it was determined that development of an EwE model specific to the NPSG could be a viable means of assessing the potential effects of removing a portion of the neuston on ecosystem dynamics. The most appropriate EwE model candidate appears to be Godinot and Allain (2003), with further development of a simplified food web diagram. However, additional work is necessary to complete this effort (**Appendix E**).

Most biological resources discussed in the following subsections would likely realize some positive benefit from the reduction of plastics in the NPSG. However, the resources that would realize the greatest benefit would be sea turtles, marine mammals, and seabirds as these resources could be subjected to the highest level of potentially harmful effects from floating plastics. These three resources would likely reap the greatest benefits as a result of reduced marine plastics in the NPSG. In addition, selective removal of medium to large plastic debris objects may provide a limited degree of protection to coastal habitats where the potential invasion of nonindigenous species is of concern, acknowledging the relatively slow process this mechanism may entail.

#### *5.2.1.1 Marine Mammals*

According to NOAA (2014a), most cetaceans that become entangled in marine debris do so in actively fished gear. However, numerous examples have been documented of cetaceans becoming entangled in discarded or lost nets, monofilament line, or other abandoned gear. Mysticetes that have documented entanglements with a definitive cause as marine debris (as opposed to actively fished gear) include humpback, North Pacific right, minke, gray, and bowhead (*Balaena mysticetus*) whales (Laist, 1997; Baulch and Perry, 2012). All these species except the bowhead whale may occur in the NPSG.

It is not possible to estimate the number and species of marine mammals that may be prevented from becoming entangled in marine debris due to its removal by the S03. However, it is known that a significant number of marine mammals become entangled. For example, based on scars, Robbins and Mattila (2004) estimated 46% to 68% of humpback whales have been entangled at some point in their life. Additional discussion of entanglement potential is provided by Stelfox et al. (2016) and Gilman et al. (2021). Given the Endangered status of some marine mammal species found within the NPSG, if successful at removing plastics and other marine debris, the S03 will almost assuredly contribute to a **Beneficial** impact – reducing marine mammal entanglements and mortalities caused by discarded rope, nets, monofilament line, and other anthropogenic debris.

#### *5.2.1.2 Sea Turtles*

All species of sea turtles have been documented as entangled with marine debris. Of particular concern in places such as the NPSG, where large amounts of debris have accumulated, is the tendency of juvenile sea turtles to seek shelter under or within floating objects and based on the number of sea turtle encounters during the S002 campaigns, that seems to be the case as most sea turtles observed have been juveniles.

Of the seven extant sea turtle species, five can be found in the vicinity of S03 deployment in the NPSG. Due to trans-Pacific migratory pathways that transect the NPSG (Benson et al., 2011), leatherbacks may be the most likely sea turtle species to be present; however, to date, no leatherback sea turtles have been identified during Campaigns 1 through 12. However, juvenile loggerheads are also known to occur in the North Pacific (Abecassis et al., 2013). Primarily, green and loggerhead sea turtles were observed during the Campaigns 1 through 12; however, two olive ridley sea turtles were also observed. Leatherbacks and loggerheads have been commonly observed entangled in monofilament line. Other debris documented entangling sea turtles includes plastic six-pack rings, burlap bags, plastic bags, bottles, among other types (Miller et al., 1995). During Campaign 2, a juvenile green sea turtle was observed entangled in a ghost net alongside one of the vessels and was rescued, detangled, evaluated, and released safely by The Ocean Cleanup crew. In addition, one juvenile loggerhead sea turtle was captured alive in the RZ bycatch that had a piece of plastic netting inside its mouth all the way to the cloaca that was removed from the sea turtle and released safely back to the ocean.

Like marine mammals, it is not possible to estimate the number and species of sea turtles that may be prevented from becoming entangled in marine debris due to its removal by the S03. However, because sea turtles are relatively common (as compared with some species of marine mammals), it is likely that a substantial number have become entangled at some point in their life. A study by Bjorndal and Bolton (1995) documented more than 1,500 free-swimming sea turtles, reporting approximately 5% were entangled in some type of debris. Regional analyses of sea turtle entanglements in the north Atlantic Ocean and Mediterranean Sea by Darmon et al. (2017) suggested that sea turtles select areas where debris is more concentrated. This may occur because both debris and sea turtles drift to the same areas due to currents, sea turtles meet debris accidentally by selecting areas of high food concentration, or sea turtles actively seek out debris, confusing it for potential prey items. Sea turtles were among the first taxa recorded to ingest plastic debris, which occurs in every region of the world and in all sea turtle species. Globally, it is estimated that approximately 52% of all sea turtles have ingested plastic debris (Wilcox et al., 2018). As documented in the necropsies performed on dead sea turtles found in the S002, all but one sea turtle contained plastics in their intestinal tract. In addition, biofouled marine plastics produce dimethyl sulfide, which some species use as an olfactory cue to locate prey. Studies have shown that loggerhead turtles showed increased foraging behavior when dimethyl sulfide was present (Savoca et al., 2016; Pfaller et al., 2020). For these reasons, if successful at removing plastics and other marine debris, the S03 will almost assuredly contribute to a **Beneficial** impact by reducing entanglements as well as ingestion and mortalities of sea turtles.

#### *5.2.1.3 Coastal and Marine Birds*

Studies between 1962 and 2012 revealed that 59% of seabirds examined had ingested plastics and nearly one-third had plastics in their gut (Blastic, 2017). Seabirds, especially those belonging to the Order Procellariiformes (albatross, petrels, shearwaters, storm-petrels, and diving petrels), often mistake floating plastics for food (Blastic, 2017). The effects of plastic ingestion on seabirds have become a particular concern due to the frequency of occurrence and emerging evidence of impacts on seabird body condition and transmission of toxic chemicals, which could result in changes in mortality and reproduction (Wilcox et al., 2015). Ingested plastics have been reported to typically be between 0.5 and 51.5 mm, but up to 11.3 cm. Ingested plastics reduce gut storage volume resulting in smaller meal sizes and slower growth rates (Blastic, 2017).

It is not possible to estimate the number and species of seabirds that may be prevented from ingesting marine debris due to its removal by the S03. However, Wilcox et al. (2015) predicted through modeling that plastics ingestion is increasing in seabirds, estimating it will reach 99% of all species by 2050, but that effective waste management can reduce the threat. Given the Endangered status of some marine bird species found within the NPSG, if successful at removing plastics and other marine debris, the S03 will almost assuredly contribute to a **Beneficial** impact – reducing seabird ingestion and mortalities caused by the ingestion and buildup of toxic chemicals.

#### *5.2.1.4 Other Resources*

Other resources (e.g., fish and fishery resources, protected areas) may also benefit from the removal of plastics and marine debris from the NPSG. For example, massive amounts (estimated at 52 metric tons annually) of marine debris consisting mostly of fishing gear as well as other plastics washes up on the shores of the Papahānaumokuākea Marine National Monument, which is a protected area mostly uninhabited by people and located away from human populations in the Northern Hawaiian Islands (NOAA, 2023b). Removal of plastic debris will reduce the potential for entanglement, ingestion, or contamination of numerous species and ecosystems. Overall, if successful, The Ocean Cleanup project (including the current campaigns in the NPSG and future campaigns around the world) will result in plastic and debris removal as well as a reduction in the extent of negative impacts caused by plastic pollution, contributing to a **Beneficial** impact to biological and social resources in the NPSG and other oceans worldwide.

#### *5.2.1.5 Plankton and Neuston*

As marine debris collects on the sea surface, it can block sunlight from reaching phytoplankton and algae, which can affect the entire food web; therefore, removal of plastics could be beneficial for the plankton community in the NPSG (National Geographic, 2022). In addition, zooplankton have been shown to readily ingest microplastics, providing a route for microplastics and byproducts to transfer up the food chain (Cole et al., 2013; Botterel et al., 2019). Current literature shows that microplastic ingestion has been recorded in 39 zooplankton species from 28 taxonomic orders, including holo- and meroplanktonic species, which has been shown to result in negative effects on feeding behavior, reproduction, growth, development, and lifespan (Botterel et al., 2019). In addition, Katija et al. (2017) found that a particular species (*Bathochordaeus stygius)* of giant larvacean zooplankton, which is abundant in global zooplankton assemblages, ingests microplastics that are then present in its fecal pellets. Microplastics adhere to these fecal pellets as well as the mucus structures that filter PM from the surrounding waters, and sink quickly to the seafloor, resulting in the delivery of pulses of carbon to benthic ecosystems. Therefore, these giant larvaceans can contribute to the vertical flux of microplastics through the rapid sinking of fecal pellets and discarded houses (Katija et al., 2017). Uy and Johnson (2022) suggested that while the effects of microplastics on feeding rate during early larval phases of the California grunion (*Leuresthes tenuis*) may be minor, the trophic transfer of microplastics from zooplankton to larval fish may have significant effects on their growth and survival. Irigoien (2022) indicated plastic fragments are likely to enter the trophic chain at all levels of the planktonic community.

Plankton communities may benefit from the removal of macroplastics, which could otherwise break down into microplastics that can be ingested by plankton. In addition, the removal of macroplastics may help prevent the transfer of plastics and the associated breakdown chemicals through the food web. However, it could also have a counterproductive impact on the biodiversity and recruitment of several commercial meroplanktonic species. As discussed in **Sections 4.3.8** and **5.2.1**, data collected during deployment of the S002 are recommended to be used in an EwE model for further evaluation of this topic (**Appendix E**).

Currently, there is not enough data to determine if there may be benefits to neuston communities from plastic removal or if there could be a counterproductive impact on biodiversity in this community. Therefore, the overall impacts remain uncertain (**Appendix E**).

#### *5.2.1.6 Data Collection*

Direct collection of scientific data from survey vessels operating in remote areas of the ocean is rare due logistical limitations and cost. During the deployment of the S002 collection of primary data that may further scientific knowledge about how marine life is attracted to offshore debris and interacts with floating plastic was performed. Reports from EOs and the monitoring of camera systems on board project vessels has provided a database (i.e., presence/absence data) for marine mammals and sea turtles in the North Pacific. Furthermore, scientific equipment on the S002 collected a variety of meteorologic and hydrographic data, while sampling with bongo nets and manta trawls has acquired data regarding plankton and neuston present in the area (**Section 4.3.1.7**). Although difficult to quantify precisely, the collection of scientific data resulting from deployment of the S002 will have a **Beneficial** impact by contributing to the base of scientific knowledge about marine life in the North Pacific. Reporting by the Eos (including records of marine mammals, turtles, birds, sharks), monitoring cameras, meteorologic and hydrographic data collection will continue during the deployments of S03. In addition, plankton, neuston, bycatch, and plastic research (**Section 2.1.6.5**) is also continuing during S03 deployments.

#### *5.2.1.7 Plastics Collection and Associated Primary Bycatch*

During the 12 previous campaigns, the System was collectively towed for a total of 4,554 hours for plastic collection across a total of 37 deployment events or RZ extractions. This resulted in a total of 190,183 kg of plastic collected and removed from the GPGP from the RZ extractions. **Figure 5-2** provided a summary of the plastics collected per campaign with the associated towing time. The average total tow time per Campaign was 380 hrs. This corresponded to plastic collection amounts ranging from 4,340 (Campaign 4) to 30,984 kg (Campaign 9) per Campaign with an average of 15,849 kg. There were an additional 3,649 kg of plastics, primarily ghost nets and other large plastics, observed and collected opportunistically by the vessel crew but not as part of the System extraction process, which were added to the plastics collected during RZ extractions, resulting in a total of 193,832 kg of extracted plastic debris during the 12 campaigns. **Figure 5-3** shows the total weight of plastic collected for each Campaign and the cumulative amount of plastic collected at the end of each Campaign.

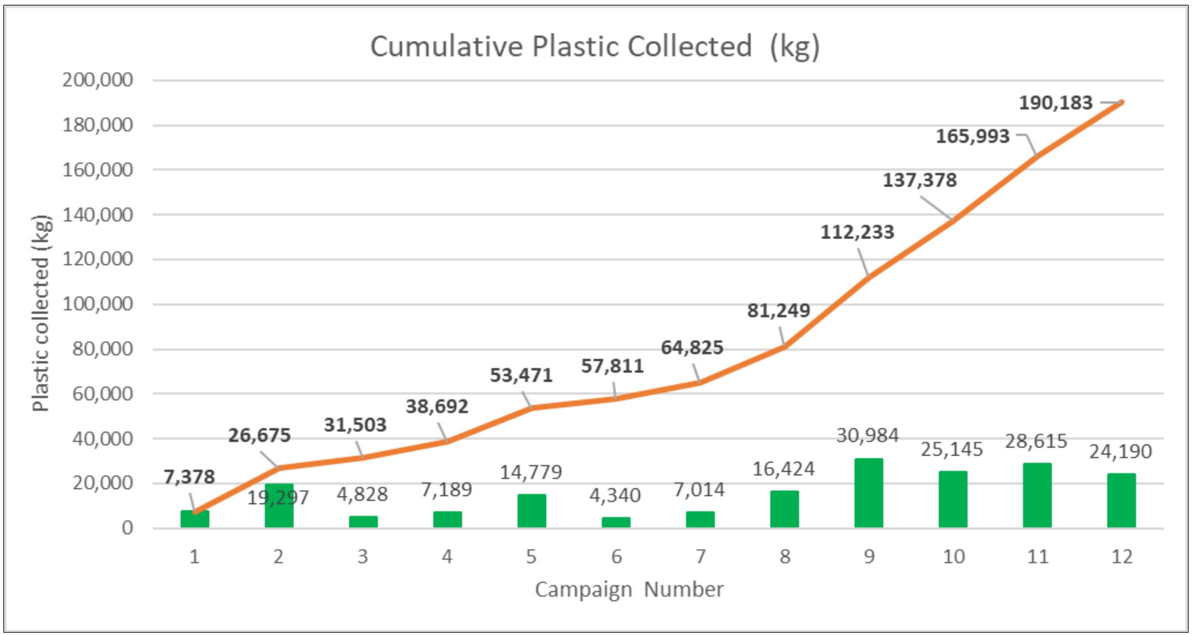



Figure 5-3. Summary of plastic collected by Campaign (green bars with values collected in that Campaign) and the cumulative total of plastic collected (kg) at the end of each Campaign (orange line with cumulative values [kg] above the line).

The early cruises had different primary goals such as testing the System in different operating conditions, ensuring that the System was operating properly, obtaining a better understanding of how the System performed, determining whether mitigation measures for protection of marine life were working, and performing operational tests to optimize the operations. Therefore, there were a different number of RZ extractions and towing times for the early cruises, whereas, once the operational factors were determined, the primary goals of the later cruises were to maximize the towing times and plastics collection whilst minimizing primary bycatch, which is reflected in the range of towing times and total plastic extracted between cruises. In addition, weather conditions and sea state also had an impact on the towing times.

The fish taxa collected as primary bycatch included representatives of groups known to associate with flotsam or drifting algae, either as juveniles or during their entire lives. Combtooth blennies (Blennidae) were the most common fish collected with sergeant major (*Abudefduf* sp.) being the second most common, with individuals of both collected during all 37 deployment events. The detailed breakout of the primary bycatch is discussed in detail in **Section 5.2.3.2**.

### 5.2.2 Potential Impacts on Plankton and Neuston

Because potential impacts to plankton and neuston are similar, they are discussed together to reduce redundancy.

#### *5.2.2.1 Impact-Producing Factors*

- S03 – Entanglement/Entrapment
- S03 – Attraction/Ingestion of Plastics
- Noise and Lights
- Accidental Fuel Spill

### *5.2.2.2 S03 – Entanglement/Entrapment*

*Potential Impacts*

Because the S03 is an actively towed System, it is likely that some zooplankton, phytoplankton, ichthyoplankton, and neuston with limited or no active mobility will become entrapped within the RZ during deployment in the NPSG. During plastic collection operations, the S03 collects plankton and neuston in the RS (two 1,125-m wings designed to guide plastics into the RZ). The wings extend 4 m below the water surface, have a mesh size of 10 mm × 10 mm, and the System opening between the wings is anticipated to be approximately1,460 m. Any plankton or neuston approximately 10 mm or larger that are within the area swept by the S03 will likely be retained in the RZ. During plastics extraction operations, the S03 is towed at a slower speed, and the opening between the wings is reduced to the width of one vessel, less than 5 m, which significantly reduces the area swept by the System, possibly also reducing the amount of plankton and neuston retained in the RZ.

Estimating potential losses of neuston from the System is difficult for several reasons. There is a paucity of data regarding the structure and function of neuston communities in most of the world's oceans, as evidenced by the scarcity of peer-reviewed and gray literature. There is also limited information regarding the regional distribution of neuston within the NPSG, although data from Campaigns 1 through 12 strongly suggest most neustonic taxa exhibit a patchy distribution with extremely variable densities. The spatial and temporal distribution of the neuston community in the NPSG largely depends on the species composition of the community, their different diel and ontogenic migrations, their different life cycles, and their lifespan (i.e., generation times). Spatial distribution of neuston tend to follow mesoscale circulation patterns, temperature, salinity, and wind patterns within the area of interest (Thibault, 2021, personal communication). Additional information regarding neuston density estimates, life history, and generation times is presented in **Appendix D**.

A recent effort to sample neuston in the North Pacific was summarized by Egger et al. (2021), based on neuston collections within and beyond the NPSG. Egger et al. (2021) reported rare observational data on the relative spatiotemporal distribution of floating plastic debris (0.05 to 5 cm in size) and members of the neuston community in the eastern North Pacific Ocean. The study was based on 54 manta trawl samples collected in the eastern North Pacific Ocean during two expeditions between July 2015 and December 2019 (Egger et al., 2021). Additionally, nine manta trawls were conducted during The Ocean Cleanup's Mega expedition (Lebreton et al., 2018) between July and September 2015, of which six were deployed during daytime and three during nighttime. The manta trawl, with an aperture of 90 cm × 15 cm and a square mesh net of 500 µm (333 µm mesh size cod-end), was deployed for 60 to 180 minutes at a tow speed of <3 knots. An additional 45 manta trawls were conducted for 30 minutes at a tow speed of <2.5 knots during The Ocean Cleanup's North Pacific Mission 3 research expedition on board the M/V *Maersk Transporter* in November/December 2019, including 39 daytime tows and 6 nighttime tows. The longer manta trawl deployments during the Mega expedition (as compared to the North Pacific Mission 3 expedition) resulted in a lower average detection limit: 114 individuals $km^{-2}$ (Mega) versus 611 individuals $km^{-2}$ (North Pacific Mission 3). Sampled water surfaces were estimated based on distance measurements from a mechanical flow meter multiplied by the width of the net mouth. Observed species and their relative densities within the NPSG, as determined by Egger et al. (2021) in association with floating plastics, are presented in **Table 5-4**. Results presented by Egger et al. (2021), while representing multi-year collections (2015 to 2019), are limited to a total of 54 tows, several of which were located outside the NPSG.

Table 5-4. Estimated density of neuston species in the North Pacific Subtropical Gyre (NPSG). Reported densities from Egger et al. (2021) reflect calculated densities found in association with floating plastics (i.e., within the NPSG).

| Species/Taxa | | Reported Densities from Egger et al. (2021) (individuals $km^{-2}$) | |
|---|---|---|---|
| | | Minimum | Maximum |
| Copepods | Arthropodaa | 43,545 | 1,731,593 |
| *Halobates* spp. | Arthropoda | 9,429 | 32,655 |
| *Glaucus* spp. | Mollusca | 1,000 | 1,000 |
| Amphipods | Arthropoda | 643 | 6,939 |
| Fish | Chordata | 622 | 4,949 |
| Crabs | Arthropoda | 604 | 3,501 |
| Euphausiacea | Arthropoda | 570 | 25,320 |
| *Velella velella* | Hydrozoa | 557 | 855 |
| *Janthina janthina* | Mollusca | 542 | 4,566 |
| Squid | Mollusca | 371 | 588 |
| Pteropods, isopods, heteropods | Mollusca/Arthropoda | 187 | 4,654 |
| *Porpita porpita* | Hydrozoa | 91 | 678 |
| *Physalia physalis* | Hydrozoa | 0 | 0 |

More recently, The Ocean Cleanup conducted a series of cruises in the NPSG (i.e., 12 campaigns between August 2021 and December 2022). While primarily designed to test and validate the S002 design, these cruises also acquired plankton and neuston data using several different plankton sampling devices: a plankton net, with full and partial submergence; a bongo net; and a manta net. All devices were equipped with 500-µm net at the cod-end, comparable to the mesh used by Egger et al. (2021). Sampling was conducted during four discrete periods – daytime (midday); dusk (evening); night (dark); and dawn (early morning). Manta and bongo net sampling was conducted in front of the S002; plankton net sampling, including sampling with half of the net out of the water to collect neuston, was conducted behind the S002.

In terms of neuston sampling conducted by The Ocean Cleanup, the most appropriate sampling device is the manta net, which samples the uppermost layer of the ocean surface, including the neuston community. Sampling using a plankton net also provides data on neuston. Further, concurrent sampling in front of and immediately behind the System can provide insight into the neuston taxa that escaped the System. Results of the manta net sampling during Campaigns 1 through 12 are presented in **Table 4-3**.

Results of the S002 campaigns net sampling (The Ocean Cleanup, unpublished) indicate the neuston community was dominated by several taxa including Calanoids, tunicates, chaetognaths, *Lucifer* spp., and Mysids. Other neuston such as *V. velella*, *Janthina* sp., and *Janthina* spp. occurred less frequently in manta tows, and in much lower quantities than the dominant species. Occurrence of each taxon within the sampling data was highly variable with many taxa occurring on a very limited basis, and most taxa collected being intermittently present (e.g., collected in limited numbers during one campaign, not present in the remaining campaigns). These observations highlight the extremely patchy nature of the neuston distribution within the NPSG.

In addition, rafting neuston, including species found in association with floating debris, may be at particular risk from entanglement and entrapment as the removal of floating debris is the primary purpose of the System. Given the relatively high density of plastics and floating debris within the NPSG, there is likely a substantial rafting neuston community where the S03 will be deployed. Rafting materials are frequently dominated by three lepadomorph barnacle species—*L. anatife*ra, *L. pacifica*, and *L. (Dosima) fascicularis*. If these or other rafting species are attached to debris collected by the RS or RZ, they will likely not survive while in the RZ or when they are removed from the water during plastics collection.

Previous studies quantifying neuston densities in the NPSG are scarce. The most complete effort is by Moore et al. (2001), whose study was based on 11 stations sampled along two transects measuring 322 and 157 km, although no information on the spatial variation along those transects was provided. Moore et al. (2001) reported abundance and dry weight of plankton samples. Details of the taxonomic composition of each sample were absent; only the filter-feeding salp (*T. vagina*) was identified. Zooneuston mean abundance was 1,837,342 organisms km$^{-2}$ with a mean mass of 841 g km$^{-2}$ (dry weight), and abundance values ranged from 54,003 to 5,076,403 organism km$^{-2}$. The authors also highlighted the strong day/night component in the neuston community, noting that zooneuston were at least three times more abundant at night. Other studies in the eastern Pacific were conducted outside the NPSG (e.g., Moore et al., 2002; Lattin et al., 2004) and mentioned only plastic to plankton ratios in term of biomass.

A comparison of Egger et al. (2021) and The Ocean Cleanup (unpublished) densities for several prevalent neuston taxa is presented in **Table 5-5**. While differences in taxonomic resolution between the two data sets prevent a comprehensive comparison, there are several trends and consistencies evident. For example, both Egger et al. (2021) and The Ocean Cleanup (unpublished) consistently identify key components of the neuston – copepods, *Halobates* spp., amphipods, *V. velella*, and *J. janthina*, with acknowledged differences in density estimates for prevalent taxa.

Table 5-5. Comparison of reported densities of key neuston species (Adapted from: Egger et al., 2021; The Ocean Cleanup, unpublished).

| Species/Taxa | | Reported Densities (individuals km$^{-2}$) | | | |
|---|---|---|---|---|---|
| | | Egger et al. (2021) | | The Ocean Cleanup (unpublished) | |
| | | Minimum | Maximum | Minimum | Maximum |
| Copepods | Arthropoda | 43,545 | 1,731,593 | 2,382 | 1,262,246 |
| *Halobates* spp. | Arthropoda | 9,429 | 32,655 | 2,111 | 657,010 |
| *Glaucus* spp. | Mollusca | 1,000 | 1,000 | 1,033 | 631,605 |
| Amphipods | Arthropoda | 643 | 6,939 | 2,087 | 145,617 |
| Fish | Chordata | 622 | 4,949 | 1,033 | 464,487 |
| Crabs | Arthropoda | 604 | 3,501 | 2,871 | 116,689 |
| Euphausiacea | Arthropoda | 570 | 25,320 | 2,678 | 196,069 |
| *Velella velella* | Hydrozoa | 557 | 855 | 1,333 | 1,262,246 |
| *Janthina janthina* | Mollusca | 542 | 4,566 | 2,128 | 6,315,470 |
| Squid | Mollusca | 371 | 588 | 11,696 | 12,563 |
| Pteropods, isopods, heteropods | Mollusca/ Arthropoda | 187 | 4,654 | 2,834 | 132,307 |
| *Porpita porpita* | Hydrozoa | 91 | 678 | 2,111 | 158,557 |
| *Physalia physalis* | Hydrozoa | 0 | 0 | NR | NR |

NR = not reported as separate taxa.

### *Effect of the S03 on Neuston Densities*

A total of 399 net tows (194 bongo tows [with 2 nets each], 143 manta tows, and 62 plankton tows) were performed during Campaigns 1 through 12. Neuston density from manta nets and plankton nets towed synoptically (The Ocean Cleanup, unpublished) were used to compare samples collected in front of the S002 using the bongo and manta net to those collected behind the S002 with the plankton net. As noted previously, the plankton net was towed at the surface. Total counts and densities for neuston organisms collected in the bongo and manta tows are shown in **Table 5-5**.

*Comparison of Zooplankton in Front of and Behind the S002*

Aggregate zooplankton densities in bongo and plankton net tows were used to compare samples collected in front of the S002 to those collected behind the S002. Zooplankton were sampled using bongo and plankton nets, with contents identified to the lowest practical taxonomic level. Bongo nets were used to collect plankton from in front of the System whereas plankton nets were used to collect samples behind the System.

In front of and behind the System differences in total densities of zooplankton were examined for each paired sample collected on particular dates during the campaigns. Tests were only conducted with zooplankton and ichthyoplankton as too few neuston taxa were collected to allow for meaningful analyses. On most cruises paired samples were collected twice daily – at midday and around dusk.

Density differences were calculated by subtracting the plankton sample densities from the bongo sample densities. These density differences were used to compare samples collected in front of the S002 to those collected behind the S002 after it passed. Paired t-tests were used to test for significant mean differences by position (i.e., in front or behind the System) separately for the two time periods, midday versus dusk. Data from different sampling dates were treated as replicates (e.g., Stewart-Oaten et al., 1986). Paired data were not available from midday samples for Cruises 3, 11, and 12, and dusk samples from Cruises 3, 10, and 12, resulting in the following in front of and behind the System comparisons based on samples from nine cruises. Paired t-test results were considered significant if $p \leq 0.05$. **Figure 5-4** shows the differences in zooplankton density estimated in front of and behind the S002 for sample dates across cruises for dusk and midday periods.

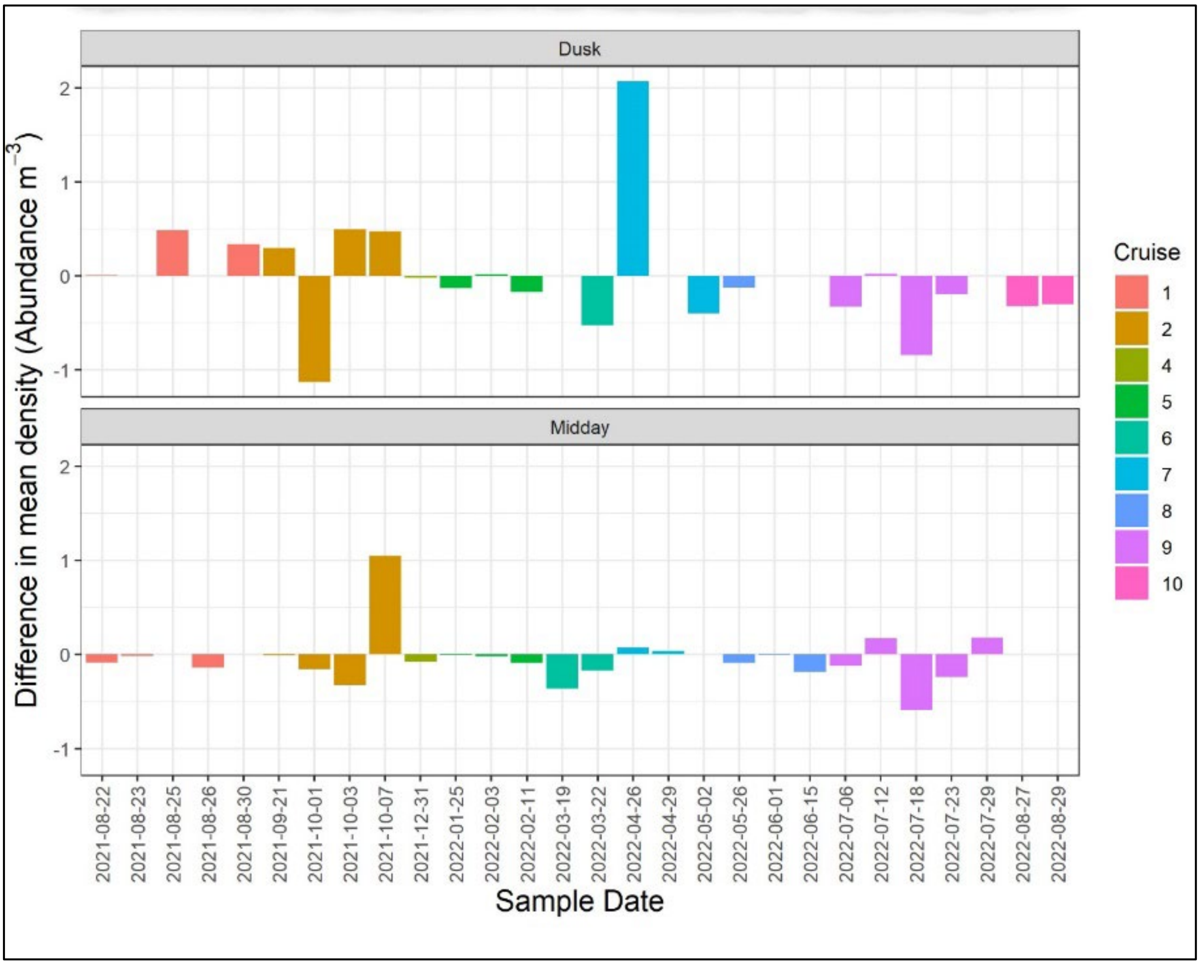



Figure 5-4. Differences in zooplankton density estimated in front of and behind the S002 for sample dates across cruises for dusk and midday periods. Negative differences indicate zooplankton density was lower in samples collected behind the System (plankton net) when compared with samples collected in front (Bongo net) of the System.

For dusk samples, differences varied in magnitude and direction over time as illustrated in **Figure 5-4** and the mean difference was -0.0116 n m$^{-3}$. However, the paired t-test results for the mean difference across all sample dates for dusk was not significant (t=-0.0843, degrees of freedom = 20, p=0.934).

Most of the midday samples exhibited small but negative values with a mean difference of -0.0502 n m$^{-3}$. However, the mean difference across dates for midday samples was not significant (t=-0.817, degrees of freedom=20, p=0.423).

Major zooplankton taxa collected in the in front of and behind the System samples, based on density, included calanoid copepods (Calanoida), arrow worms (Chaetognatha), tunicates (Tunicata), siphonophores (Siphonophora), salps (Salpidae), crabs (Decapoda), unidentified invertebrate eggs, and sergestid shrimp (*Lucifer* spp.).

Using different gear types for the in front of and behind the System sampling due to the challenges of towing a manta net behind the S002 is not ideal for this comparison but provides a relative comparison. The Ocean Cleanup is evaluating the potential to perform sampling with manta nets simultaneously in front of and behind the system to have more comparable results.

*Comparison of Ichthyoplankton in Front of and Behind the S002*

The sampling and analysis described above for zooplankton were also used to evaluate differences in ichthyoplankton density in bongo and plankton net tows were also used to compare samples collected in front of the S002 to those collected behind the S002 of ichthyoplankton as well.

In front of and behind the System differences in aggregate densities of ichthyoplankton were examined for each paired sample collected during the cruises and are shown in **Figure 5-5**.

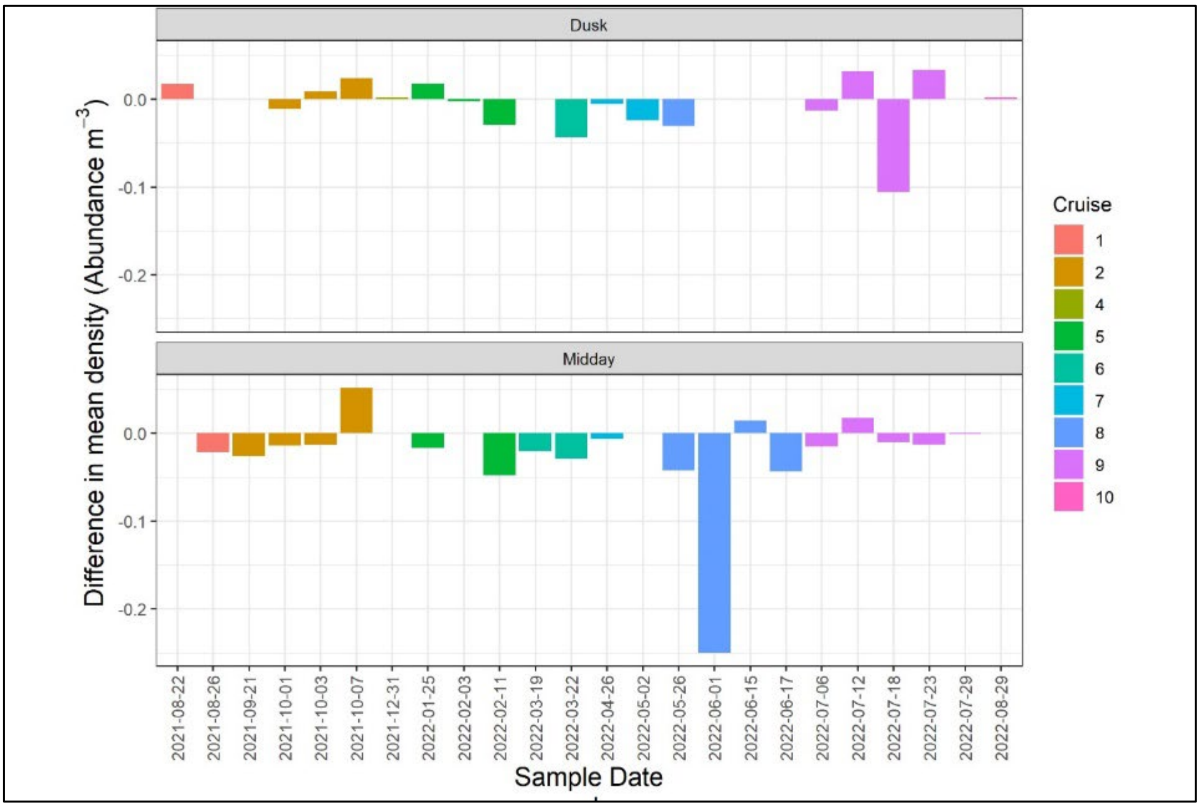



Figure 5-5. Differences in ichthyoplankton density estimated in front of and behind the S002 system for different sample dates across Campaigns for dusk and midday periods. Negative differences indicate ichthyoplankton density was lower in samples collected behind the system (plankton net) when compared with samples collected in front of the system (bongo net).

Differences among dusk samples averaged –0.0075 n $m^{-3}$ but this difference was not significant (t=--0.920, degrees of freedom=16, p=0.371). For midday samples the average difference between in front of and behind the System ichthyoplankton densities was –0.0256 n $m^{-3}$ and this was also not significant (t=-1.89, degrees of freedom=18, p=0.0752).

Major ichthyoplankton taxa collected in the in front of and behind the System samples, based on density, included sunbeam lanternfish (*L. urophaos*), dogtooth lampfish (*C. townsendi*), unidentified fish eggs, Mexican lampfish (*Triphoturus mexicanus*), lanternfishes (Myctophidae), California headlightfish (*Diaphus theta*), waistcoat lanternfish (*Taaningichthys minimus*), Pacific saury (*Cololabis saira*), jacks (Carangidae), and flyingfishes (*Hirundichthys* spp., Exocoetidae).

The initial results of the in front of and behind the System sampling suggest that neither zooplankton nor ichthyoplankton densities are being significantly reduced by the operation of the S002. This will be further confirmed with focused sampling efforts using manta trawling.

Based on average aggregate densities for zooplankton and ichthyoplankton, and considering sampling period, **Table 5-6** shows the estimated losses resulting from use of the System. These differences were very small for both taxonomic groups and although not statistically significant (Paired t-test, p>0.05) zooplankton densities decreased behind the whereas ichthyoplankton increased behind the S002.

Table 5-6. Summary of potential losses of zooplankton and ichthyoplankton from S002 use.

| Taxonomic Group | Sampling Period | Average Density Difference (%) |
|---|---|---|
| Zooplankton | Dusk | -0.08 |
| | Midday | -0.711 |
| Ichthyoplankton | Dusk | 1.19 |
| | Midday | 2.72 |

***Plankton Losses***

Per several sources (e.g., Goldstein et al., 2013; Helm, 2021), supplemented by data collected during the S002 campaigns using various gear types, (bongo, manta, and plankton nets) and different collection times (dawn, day, dusk, and night), neuston exhibit extremely patchy distribution. Neuston blooms/aggregations are common-. According to Brandon (2021, personal communication), the blooms or aggregations realized by some drifting neuston species may simply be the result of currents and winds accumulating them in one spot. In contrast, swarms, or blooms, of salps (which may occur in the neuston or deeper in the water column) are due to a life cycle that is highly adapted to patchy, unpredictable food sources. When there is little food available, their alternation of generations and hermaphroditism allows them to maintain genetic variability and to exist without reproducing (Alldredge and Madin, 1982). However, when they encounter abundant food sources, their high growth rate, short generation time, high fecundity, direct development, maternal nutrition of both the embryos and stolons, efficient morphology, and alternation of generations all combine to allow for population explosions (Alldredge and Madin, 1982). A portion of the neuston community is composed of a variety of species that are true drifters (**Section 4.3.2.1**; as opposed to rafting species, **Section 4.3.2.3**), with their spatial distribution determined by the wind and weather/storm events. For example, *V. velella* come in two forms – a right-handed and a left-handed orientation, based on which way their sail is oriented. *V. velella* orientations are thought to be equally mixed together in the center of the Pacific Ocean. By the time individual *V. velella* reach the coasts of Asia or North America on the edges of the NPSG, one orientation predominates as the wind has determined their distribution (Brandon, 2021, personal communication; Ferrer and González, 2021). Neuston are also found in association with drifting natural and anthropogenic debris (i.e., rafting assemblages), as described in **Section 4.3.2.3**; rafting neuston distribution patterns, while affected in a similar fashion as true drifters, are more closely linked to the transport of the floating plastic debris with which they associate.

It is necessary, when considering potential losses of plankton to the System, to account for the two different tow configurations used by the S002. It is anticipated that deployment of the S03 would last approximately 2.5 to 7 days for plastics collection operations (**Section 2.1.2**). This would be followed by a shorter period (typically < 12 hours) for plastics extraction operations (**Section 2.1.3**). During plastics collection, the wing span of the System is anticipated to be approximately1,460 m; during plastics extraction, the extraction section is removed and the remainder of the System is towed by behind the stern of one vessel with a mouth opening of less than 5 m.

Neuston densities from Egger et al. (2021) and The Ocean Cleanup (unpublished) were presented previously in **Table 5-4,** indicative of the prevalent species/taxa present. Based on the results of the in front of and behind the System sampling (**Table 5-6**), reductions in zooplankton densities may be expected to range from 0.08% to 0.711%, depending upon sampling period (i.e., density losses at dusk were lower than those evident at midday). Similarly, reductions in ichthyoplankton densities may be expected to range from 1.19% to 2.72%, again depending upon sampling period (i.e., density losses at midday were higher than those noted at dusk). However, system design changes, including the use of larger floats with more buoyancy along the top of the wings, may reduce the amount of overtopping of water and potentially of plankton and neuston over the wings. In addition, the mesh size of the wings has increased which may allow more plankton and neuston to flow through the wings.

In summary, estimates of plankton loss associated with System use vary between major plankton groups as well as by sampling period. Overall, losses to zooplankton are expected to be <1%, while ichthyoplankton losses are projected to range from <1% to <3%. Because the S002 is actively towed, any plankton or neuston that become trapped in the RZ are unlikely to be able to free themselves and will remain trapped until opening of the RZ during plastics collection approximately every 2.5 to 7 days. Based on the comparison of manta and plankton net samples, comparing neuston densities in front of and behind the S002, respectively, the majority of some neuston appear to escape the System as well as being displaced in the water column due to the “wake” created by S002, though precise quantification of this is not yet possible. Monitoring in front and behind the S03 will be continuing to obtain additional data for further analysis for impact analysis.

As discussed in **Section 4.3.2**, the marine neuston community is diverse. For the purposes of identifying impacts attributed to entanglement/entrapment, neuston defined by location (i.e., epineuston, hyponeuston, and metaneuston or exoneuston) or life stage (i.e., euhyponeuston, planktohyponeuston, and merohyponeuston or endohyponeuston) may all be impacted based on their (at least partial) interaction with surface or near-surface waters. Some groups (e.g., planktohyponeuston, which vertically migrate) may be impacted to a lesser degree by entanglement and entrapment than others because they will be present at the surface near the RS and RZ less often. Conversely, neuston that live solely near the surface or just beneath the surface (e.g., epineuston, hyponeuston) may be disproportionally impacted to a higher degree.

Based on the fragile, often gelatinous nature of much of the oceanic neuston, they are easily damaged. Any entrapment of these organisms will likely result in them being compacted or compressed against the mesh in the RS or RZ or damaged/abraded by the mesh, with subsequent mortality. Upon retrieval of the RZ, collected biota would likely be an amorphous biotic “soup” with only a negligible portion of live organisms and only the largest obvious ones, like *P. porpita* and *V. velella*, to be accounted for by visual observation (Ferrari, 2019). It was anticipated that biofouling of the RS and RZ mesh over time could increase clogging and reduce the filtering efficiency of the net, which would likely increase impacts to the smallest entrapped organisms; however, this has not been observed during Campaigns 1 through 16.

Use of the System might increase entanglement of neuston species, particularly crustaceans such as decapod larvae and copepods, which carry large spines, protruding growths, or complex feather-like structures easily caught in fibers (Kang et al., 2020). Data from the manta net samples from Campaigns 1 through 12 indicate decapod species were present in only 55 of the 143 samples (i.e., indicative of intermittent presence), while almost all (136 of 143) net samples contained copepods.

The environmental monitoring activity performed during The Ocean Cleanup’s deployment of the S001/B in the NPSG in 2019 reported an estimated 500 colonies of *V. velella* collected in the System as bycatch, confirming their presence in the NPSG during the collection period (Ferrari, 2019). In contrast, very few *V. velella* were observed during Campaigns 1 through 12 or collected in the net sampling. One other species of gelatinous macrozooplankton was identified during the 2019 campaign (*J. janthina*); however, the degraded nature of the shells did not allow for an estimate of the number of individuals. Due to their gelatinous nature, many organisms collected within the RS or RZ will likely be unable to escape. It is important to note that the S001/B, as tested in the NPSG in 2019, was a fundamentally different design that functioned by herding floating macroplastics using a barrier system, whereas the S002 uses a mesh net.

Data from the RZ processing of campaigns 1 through 12 indicate primary bycatch predominantly consists of fish (**Section 4.3.3.2**), with fewer small sharks, crustaceans (mostly crabs), barnacles, and mollusks (octopus, clam), and only a few cnidarians observed (e.g., *V. velella*). In addition, the anticipated biofouling of the RZ mesh was not observed by the Environmental Coordinators on board the M/V *Tender*.

Rafting neuston, including species found in association with floating debris, may be at particular risk from entanglement and entrapment as the removal of floating debris is the primary purpose of the S03. Given the relatively high density of plastics and floating debris within the NPSG, there is likely a substantial rafting neuston community where the S03 will be deployed. Rafting materials are frequently dominated by three lepadomorph barnacle species—*L. anatife*ra, *L. pacifica*, and *L. (Dosima) fascicularis*. If these or other rafting species are attached to debris collected by the RS or RZ, they will likely suffer mortality while in the RZ or when they are removed from the water during plastics collection. Observations and bycatch data from Campaigns 1 through 12 confirm barnacles have been associated with the collected plastics.

The long-term impacts of deploying the S03 should be **Beneficial** on plankton and neuston due to the removal of large amounts of plastics and other marine debris from the NPSG. The removal of macroplastics that would otherwise degrade into microplastics available for the potential ingestion by plankton will reduce potential impacts from the release of degradation byproducts (i.e., toxic chemicals) and transfer to higher levels of the food chain. There still are considerable knowledge gaps in the current understanding of how floating plastic debris accumulating in subtropical oceanic gyres may harm neuston. Removing floating plastic debris from the ocean surface can minimize potentially adverse effects of plastic pollution on neuston as well as prevent the formation of large quantities of secondary micro- and nanoplastics. However, due to the scarcity of observational data from remote and difficult-to-access offshore waters, neuston dynamics in subtropical oceanic gyres and thus the potential impacts of plastic pollution and cleanup activities on the neuston remain uncertain.

Based on the observations from S001/B trials, the short-term, and possibly long-term, impacts of the S002 on plankton and neuston were expected to be negative. However, based on observations and data collected during Campaigns 1 through 12, the anticipated mortality of plankton and neuston organisms from the S002 deployment within the area where floating plastics have been collected has not been realized. Although the area swept with the S03 will be larger than with the S002, the potential mortality of plankton and neuston included in the in front of and behind the System analyses has not been observed with S002; and is therefore, not anticipated for the S03. As described earlier, limited numbers of neuston were observed in the RZ as primary or secondary bycatch. Additional data are needed to understand why plankton and neuston is not being observed in the RZ; however, a contributing factor could be due to the overtopping of the wings by waves and water allowing some plankton and neuston species to escape the System prior to being captured in the RZ or it could be due, in part, to the patchy nature of plankton and neuston distribution within the NPSG. In addition, with the mesh size of the wings and RZ, some smaller plankton would be able to pass through the mesh openings. One purpose of the net sampling design was to evaluate those plankton and neuston species collected alongside the tow vessels (in front of the S002) by the bongo and manta nets and behind the S002 (plankton nets) to evaluate the differences in the species and quantity collected. This analysis has shown there were not significant differences in the species of copepods and fish eggs and larvae from the bongo samples taken in front of the S002 and the plankton samples taken after the S002 except for anglerfish larvae (**Section 4.3.1.7**). Based on the updated neuston densities obtained during Campaigns 1 through 12, the variable plankton densities present in the NPSG, and the in front of and behind the System comparisons of zooplankton and ichthyoplankton,- impact intensity is rated as low, though it is possible the impact intensity could be moderate. The extent of impact is expected to range from local to regional, with a short duration (based on relatively short generation times). Resulting impact consequence is deemed to range from negligible to minor. Due to the likely nature of this impact, the overall impact significance rating is expected to range from **1 – Negligible** to **2 – Low** during plastics collection operations prior to implementing mitigation measures.

During plastics extraction operations the S03 is towed behind one vessel, at a slower speed, and has a narrowed wingspan, which significantly reduces the area swept by the System. Plastics extraction operations are anticipated to typically take less than 12 hours for each extraction and occur between three and five times during each 6-week campaign. While the impact likelihood would remain the same, the impact intensity would be reduced due to a smaller area for capture, resulting in an overall impact significance of **1 – Negligible** during plastics extraction operations prior to implementation of mitigation measures.

<u>*Mitigation Measures*</u>

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to plankton and neuston from entrapment and entanglement:

- **Mesh size** – Use of netting with a 16mm × 16 mm mesh size, when possible, to allow smaller marine animals to exit the System.

Mitigation measure effectiveness will be affected if the wings or RZ becomes severely clogged; however, to date, no clogging of the System has been observed. Zooplankton could be entangled within the mesh system and have little to no ability to swim away from the net even if deployed at low speed. Waves have been observed overtopping the System wings, which may be allowing some neuston and plankton to not be captured within the RZ or wing mesh.

<u>*Residual Impacts*</u>

Implementing the mitigation measures during plastics collection operations should reduce the likelihood component of impact consequence. In addition, the operations of retrieving the RZ extraction area requires that the net rest in order for the extraction operations to occur. The 16 mm × 16 mm mesh size and this operational resting of the net may reduce impacts for some species, but generally the reduction in impacts is not significant enough to lower the impact significance and would remain **1 – Negligible** to **2 – Low** for plastics collection operations.

For entanglement and entrapment during plastics extraction operations, the, impact significance would remain **1 – Negligible**.

#### *5.2.2.3 S03 – Attraction/Ingestion of Plastics*

<u>*Potential Impacts*</u>

As detailed in **Section 4.3.2**, the neuston in the NPSG is composed of free-floating species, ichthyoplankton, and a rafting assemblage. While floating plastic debris naturally attracts rafting assemblage species, free-floating species and ichthyoplankton may or may not be found in association with macroplastics. Deployment of the S03, including collection and extraction operations (**Sections 2.1.2** and **2.1.3**), is not expected to attract neuston, primarily because the System will be constantly moving while under tow.

Moore et al. (2001) completed plankton tows in the NPSG and reported plankton abundance was five times higher than plastic abundance, but the mass of plastic was higher than the plankton mass in most samples, though this was skewed by a few large pieces of plastic. The large amount of plastic relative to plankton indicates the likelihood of filter-feeders ingesting plastic is common, particularly for microplastics. Due to their size relative to neuston, macroplastics are less likely to be ingested. Given the relatively high concentration of plastic particles in the NPSG, the deployment likely will result in an increased level of plastic ingestion or adsorption by plankton and neuston. Thibault (2021, pers. comm.) also noted that potential ingestion of macro- and microplastics by filter-feeding neuston needs to account for particle size distribution, which Moore et al. (2001) did not address.

Goldstein (2012) suggested plastic-associated rafting organisms may affect the pelagic ecosystem by reworking the particle size spectrum through ingestion and egestion (see also Mook, 1981). Suspension-feeding rafting organisms ingest a variety of particle sizes, from 3 to 5 µm for *Mytilus* mussels (Lesser et al., 1992), 10 to 20 µm for bryozoans (Pratt, 2008), 20 to 125 µm for caprellid amphipods (Caine, 1977), and 0.5 to >1 mm for lepadomorph barnacles and hydroids (Evans, 1958; Boero et al., 2007). This size range encompasses a significant portion of the nonmicrobial particle size spectrum in the oligotrophic North Pacific (Sheldon et al., 1972). Because particle size determines which energy pathway benefits, either the microbial loop or the metazoan food web, Karl et al. (2001) noted that any large-scale alterations in particle size could markedly influence species composition in the NPSG. The food web dynamics for neuston need to be clearly characterized (Thibault, 2021, pers. comm.). Copepods are omnivorous and will prey on ciliates and flagellates as part of the microbial loop. Euphausiids can also prey on members of the microbial food web. Salps and doliolids can feed on bacteria and cyanobacteria. Karl et al. (2001) did not account for gelatinous zooplankton, as this component of the neuston was not well defined and were not included in their food web characterization. The capacity for gelatinous zooplankton to feed on very small items (via filter feeding) or larger items will strongly modulate the transfer of energy through the food web (Thibault, 2021, pers. comm.).

Zooplankton readily ingest microplastics, providing a route for microplastics and byproducts to be transferred up the food chain (Cole et al., 2013; Botterel et al., 2019). Current literature shows microplastic ingestion has been recorded in 39 zooplankton species from 28 taxonomic orders, including holo- and meroplanktonic species. This ingestion of microplastics has shown to result in negative effects on feeding behavior, reproduction, growth, development, and lifespan (Botterel et al., 2019). A literature review by Irigoien (2022) indicated plastic fragments are likely to enter the trophic chain at all levels of the planktonic community. However, the microplastics that would be ingested by the planktonic community are not the target of the S03, which can only capture macroplastics due to the mesh size of the netting.

The potential increased ingestion of plastics by filter feeders as a result of deploying the S03 would be a localized, temporary impact, offset to a limited extent by the long-term **Beneficial** impact of the deployment and associated removal of macroplastics from the NPSG and prevention the breakdown of macroplastics to microplastics that could be available for filter-feeders to ingest. Ingestion of plastics or adsorption of plastic-linked chemicals by plankton and neuston as a result of S03 deployment is considered an occasional impact of minor consequence and severity. Overall impact significance is rated **1 – Negligible**. The likelihood and impact significance of ingested microplastics and chemical byproducts collected by the S002 being bioaccumulated through the food chain through the ingestion of these plankton organisms is difficult to quantify.

*Mitigation Measures*

No mitigation measures are recommended to avoid ingestion of plastic particles by plankton and neuston. The plastics ingested by plankton and neuston would be microplastics that are not captured by the S03, which can only capture macroplastics due to the mesh size of the netting.

*Residual Impacts*

The residual impact significance remains **1 – Negligible**.

#### *5.2.2.4 Noise and Lights*

*Potential Impacts*

Plankton and neuston that have limited active mobility may be attracted to the System due to lights on the vessel or the System itself. Conversely, there is some evidence that both natural and anthropogenic light pollution may suppress diel migration of zooplankton, which would reduce the number of organisms migrating into the surface layer (Ludvigsen et al., 2018). The S03 and its tow vessels will stand out in the project area as possibly the only artificial light sources.

Attraction of plankton and neuston to lighting on the System and tow vessels would be limited to the immediate vicinity and would primarily occur only when the vessels are traveling at extremely low speeds. However, it could result in increased predation by fishes or other predators similarly attracted to the noise and lights. Many plankton and neuston are free-floating, predominantly moving with currents and wind; therefore, impacts would mostly be applicable only to species able to actively move towards the System (e.g., planktohyponeuston, which vertically migrate) or free-floating plankton and neuston that happen to be in the vicinity.

Impacts on plankton and neuston from noise and lights is considered occasional, short term, and of low intensity, resulting in a negligible impact consequence. Overall impact significance is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measure to reduce potential impacts to plankton and neuston from noise and lights:

- **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.

*Residual Impacts*

While limiting lights will reduce the likelihood of impacts, the reduction is not significant enough to warrant a reduction in the impact significance. The residual impact significance remains **1 – Negligible**.

#### *5.2.2.5 Accidental Fuel Spill*

*Potential Impacts*

A diesel fuel spill could affect plankton and neuston because they do not have the ability to avoid contact. Many planktonic communities drift with water currents and recolonize from adjacent areas. Because of these attributes and their short life cycles, plankton usually recover rapidly to normal population levels following disturbances. Fish eggs and larvae will suffer mortality if exposed to certain toxic fractions of diesel fuel, but due to the wide dispersal of early life history stages of fishes, a diesel fuel release would not be expected to have significant impacts at the population level. Little is known about the impacts of a fuel spill on neuston groups, but in the event of a diesel spill, the area affected would be relatively small and the duration of impact would presumably be only a few days.

Due to the limited areal extent and short duration of water quality impacts, a small diesel fuel spill would be unlikely (remote) to produce significant impacts on plankton and neuston, and any impacts that do occur would be of negligible consequence. Overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to plankton and neuston from an accidental fuel spill:

- **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on the towing, monitoring, and debris collection vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.
- **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.
- **No re-fueling at sea** – No re-fueling occurs at sea.
- **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain-of-command to The Ocean Cleanup and regulatory bodies.

*Residual Impacts*

Based on the mitigation measures that The Ocean Cleanup implements and the short-term nature of the activities, the likelihood of impacts would be reduced. The residual impact significance would remain **1 – Negligible**.

#### 5.2.2.6 *Plankton and Neuston Impact Summary*

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Removal of plastics and debris from the environment | The plankton and neuston communities may benefit from removing macroplastics that can breakdown into microplastics and be ingested by plankton. In addition, the removal of plastics may help prevent the transfer of plastics and the associated breakdown chemicals through the food web, but could also have a counterproductive impact on biodiversity, food web structure, and recruitment of several commercial meroplanktonic species. Data collected during the deployment are recommended to be used in an Ecopath with Ecosim model for further evaluation of this topic (**Appendix E**). | | | | | |
| Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Low to Moderate | Local to Regional | Short Term | Negligible to Minor | Likely | 1 – Negligible to 2 – Low |
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | Low | Immediate Vicinity | Short Term | Minor | Occasional | 1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to System) from lights | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Diesel fuel exposure, including ingestion | Low | Immediate Vicinity | Short Term | Negligible | Remote | 1 – Negligible |

*Mitigation Measures*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
| --- | --- | --- | --- |
| Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • **Mesh size** – Use of netting with a 16 mm × 16 mm mesh size, when possible, to allow smaller marine animals to exit the System. | Reduces Likelihood | 1 – Negligible[1]<br>2 – Low |
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | • None recommended. | None | 1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to the System) from lights | • **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces Likelihood | 1 – Negligible |
| Diesel fuel exposure, including ingestion | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on towing, monitoring, and debris collection vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.<br>• **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses are equipped with dry-break couplings.<br>• **No re-fueling at sea** – No re-fueling occurs at sea.<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces Likelihood | 1 – Negligible |

MARPOL = International Convention for the Prevention of Pollution from Ships.
[1] The escape aids may reduce impacts to some species, but generally the reduction is not significant enough to warrant a reduction in the impact significance without additional research.

### 5.2.3 Potential Impacts on Fish and Fishery Resources

#### *5.2.3.1 Impact-Producing Factors*

- S03 – Entanglement/Entrapment
- S03 – Attraction/Ingestion of Plastics
- Vessel – Physical Presence/Strikes
- Noise and Lights
- Accidental Fuel Spill

For fish and fishery resources, the impacts of S03 entanglement/entrapment, attraction/ingestion of plastics, and vessel physical presence/strikes are interrelated. Therefore, potential impacts from these three IPFs are discussed together to avoid redundancy.

#### *5.2.3.2 S03 – Entanglement/Entrapment, Attraction/Ingestion of Plastics, and Vessel – Physical Presence/Strikes*

<u>*Potential Impacts*</u>

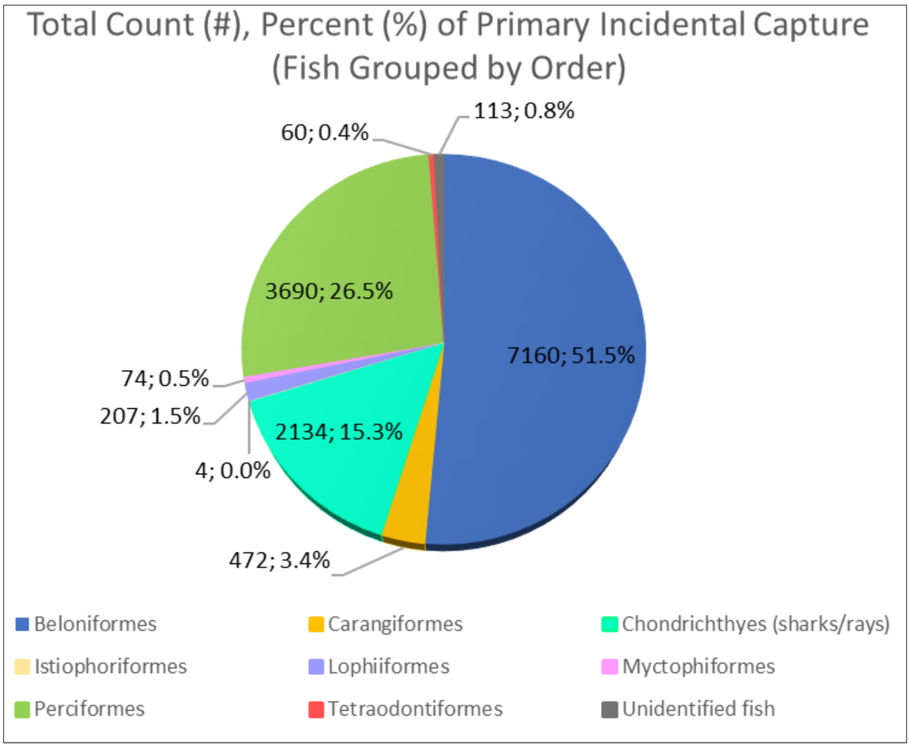
Fish species are attracted to offshore structures such as oil and gas platforms and various types of flotsam (Shomura and Matsumoto, 1982; Franks, 2000; Fabi et al., 2004). These structures can provide substrate habitat for invertebrates, protective habitat for finfish, and light attraction. Studies have shown that different fish species have different use patterns for offshore structures, which may be influenced by physical factors such as temporal variation in temperature and oceanographic conditions as well as biological factors such as prey availability, species-specific sedentary/migratory behavior, and life cycle stages (Stanley and Wilson, 1991; Schroeder and Love, 2004; Love et al., 2005, 2006; Page et al., 2007; Fujii, 2016; Fujii and Jamieson, 2016). The S03 and tow vessels, as floating structures in an open-ocean environment, likely act as FADs. In oceanic waters, the FAD effect is likely most pronounced for epipelagic fishes such as tunas, dolphin, billfishes, and jacks, which are commonly attracted to fixed and drifting surface structures (Holland, 1990; Higashi, 1994; Relini et al., 1994). The FAD effect also could enhance the feeding of epipelagic predators by attracting and concentrating smaller fish species.

Along with the plastic collected by the System, bycatch of biological organisms occurred during each RZ extraction which primarily included fish, shark, mollusks, crustaceans and sea turtles. Sea turtles will be addressed in **Section 5.2.5** and removed from the primary bycatch data shown below (**Table 5-7**). Captured marine organisms were separated by type, counted, photographed, weighed, and either returned to the water if alive or frozen for further analysis. The total bycatch was further divided into three categories: 1) primary bycatch, corresponding to the organisms that were alive and fully free before being unintentionally captured by the System; 2) secondary bycatch, corresponding to organisms that were caught as a result of being associated (not fully free) with the plastics collected, (e.g., attached or sessile fauna); and 3) previously deceased organisms, corresponding to organisms that were determined to have been already deceased when collected by the System. Secondary bycatch associated with the plastics consisted primarily of crabs and barnacles, although anemones, sea stars and other invertebrates have been observed on the plastics. Previously deceased organisms have included sharks, fish, and sea turtle carcasses. Overall, the weight ratio of primary bycatch to extracted plastics was 0.33%. As the main focus is the potential impacts from the System, primary bycatch will only be discussed in the following tables and figures.

Table 5-7. Summary of primary bycatch fish species from Campaigns 1 through 12.

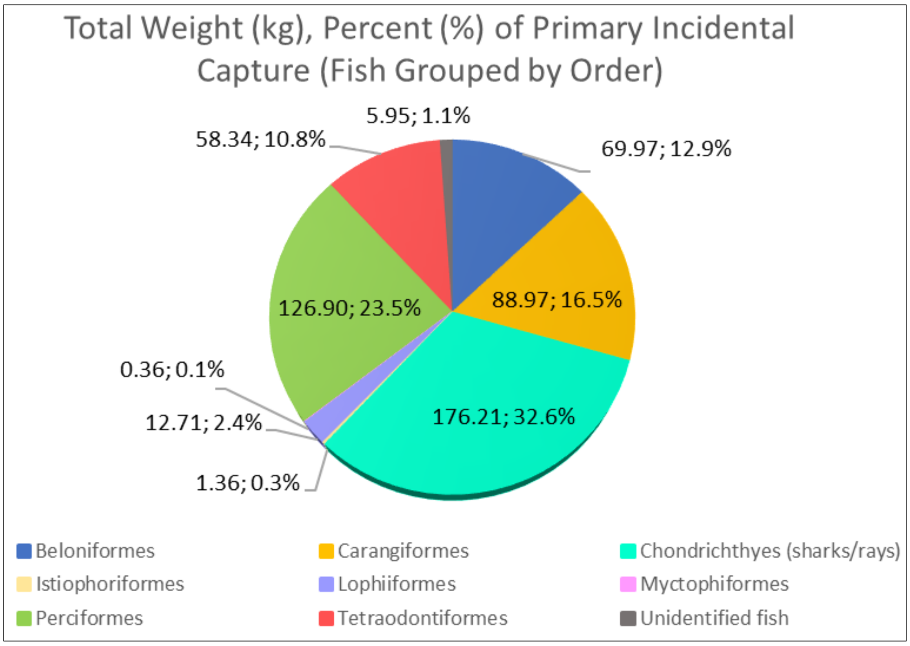
| Species | Order/Family (Lowest Taxonomic ID) | Number of Individuals Caught | Number of Cruises Present |
|---|---|---|---|
| Amberjacks (*Seriola* spp.) | Carangidae | 438 | 11 |
| Blennies (*Petroscirtes breviceps* and others) | Blenniidae | 6,272 | 12 |
| Blue shark (*Prionace glauca*) | Carcharhinidae | 11 | 3 |
| Dolphinfish (*Coryphaena* spp.) | Coryphaenidae | 28 | 3 |
| Filefish | Tetraodontiformes | 17 | 8 |
| Flyingfishes (*Cheilopogon* sp., *Hirundichthys* sp.) | Exocoetidae | 806 | 9 |
| Garfish | Beloniformes | 82 | 5 |
| Lanternfish | Myctophiformes | 74 | 1 |
| Pacific pomfret (*Brama japonica*) | Bramidae | 11 | 6 |
| Pelagic stingray (*Pteroplatytrygon violacea*) | Dasyatidae | 1 | 1 |
| Pilotfish (*Naucrates ductor*) | Carangidae | 6 | 2 |
| Porcupinefish | Diodontidae | 36 | 3 |
| Pygmy shark (*Euprotomicrusbispinatus*) | Dalatiidae | 2,122 | 12 |
| Rough triggerfish (*Canthidermis maculata*) | Balistidae | 4 | 2 |
| Sargassumfish (*Histrio histrio*) | Antennariidae | 207 | 9 |
| Sergeant major (*Abudefduf* spp.) | Pomacentridae | 3,652 | 12 |
| Spearfish | Istiophoridae | 4 | 1 |
| Spotted knifejaw (*Oplegnathus punctatus*) | Oplegnathidae | 13 | 8 |
| Striped beakfish (*Oplegnathus fasciatus*) | Oplegnathidae | 2 | 1 |
| Sunfish | Molidae | 1 | 1 |
| Unidentified fish | | 2 | 2 |

The fish taxa collected as primary bycatch from Campaigns 1 through 12 included representatives of groups known to associate with flotsam or drifting algae, either as juveniles or during their entire lives. Blennies (Beloniformes) were the most common fish collected with sergeant major (*Abudefduf* sp.) being the second most common, with individuals of both collected during all 12 campaigns. **Figures 5-6** and **5-7** provide the different fish Orders comprising the fish primary bycatch by Order. **Figure 5-6** shows the total count (individuals) and percent, while **Figure 5-7** shows the total weight (grouped as Order) and percent. Although fish were captured incidentally, numerous fish were observed on cameras swimming into and out of the System through the mesh and fyke openings, indicating that most of the fish that entered the System were not captured in the RZ.




*Note: Beloniformes includes: blenny, flying fish, and garfish; Carangiformes includes: amberjack, dolphinfish, Japanese amberjack, pilot fish, and yellowtail amberjack; Istiophoriformes includes: spearfish; Lophiiformes includes: sargassum fish; Myctophiformes includes: lanternfish; Perciformes includes: Pacific pomfret, sergeant major, spotted knifejaw, striped beakfish; and Tetraodontiformes, includes: filefish, porcupinefish, rough triggerfish, and sunfish.*

Figure 5-6. Total number of fish; with percent, comprising primary bycatch by Order from all 12 Campaigns.




*Note: Beloniformes includes: blenny, flying fish, and garfish; Carangiformes includes: amberjack, dolphinfish, Japanese amberjack, pilot fish, and yellowtail amberjack; Istiophoriformes includes: spearfish; Lophiiformes includes: sargassum fish; Myctophiformes includes: lanternfish; Perciformes includes: Pacific pomfret, sergeant major, spotted knifejaw, striped beakfish; and Tetraodontiformes, includes: filefish, porcupinefish, rough triggerfish, and sunfish.*

Figure 5-7. Total fish weight; with percent comprising primary bycatch by Order from all 12 Campaigns.

Plastic debris accumulating in the marine environment is known to fragment into smaller pieces, which increases the potential for ingestion by smaller marine organisms (Ryan et al., 2009; Alimba and Faggio, 2019). Additionally, the buoyancy of smaller pieces of plastic increases the likelihood for mixing with sea surface food sources. Once attracted to S03, fish and fishery resources will have a greater chance of ingesting plastics that have accumulated in the NPSG either through direct feeding on the plastic or by consuming lower trophic level organisms that have ingested plastics. Studies have shown a wide variety of fishes with plastics in their guts, including planktivorous fish and larger predatory species, migratory and nonmigratory species, and species inhabiting various depth ranges (Ryan et al., 2009; Boerger et al., 2010; Davison and Asch, 2011; Carson, 2013; Choy and Drazen, 2013; Choy et al., 2013; Gassel et al., 2013; Rochman et al., 2014). The ingestion of plastics can affect fish in a variety of ways (**Figure 5-8**), including impacts to the immune system, both chemically, through the absorption of toxic components, and physically, by obstructing the digestive system (Espinosa et al., 2016). **Appendix B** provides a Plastics Literature Summary White Paper that includes additional information regarding the impacts of floating plastic debris on fish and fish resources.

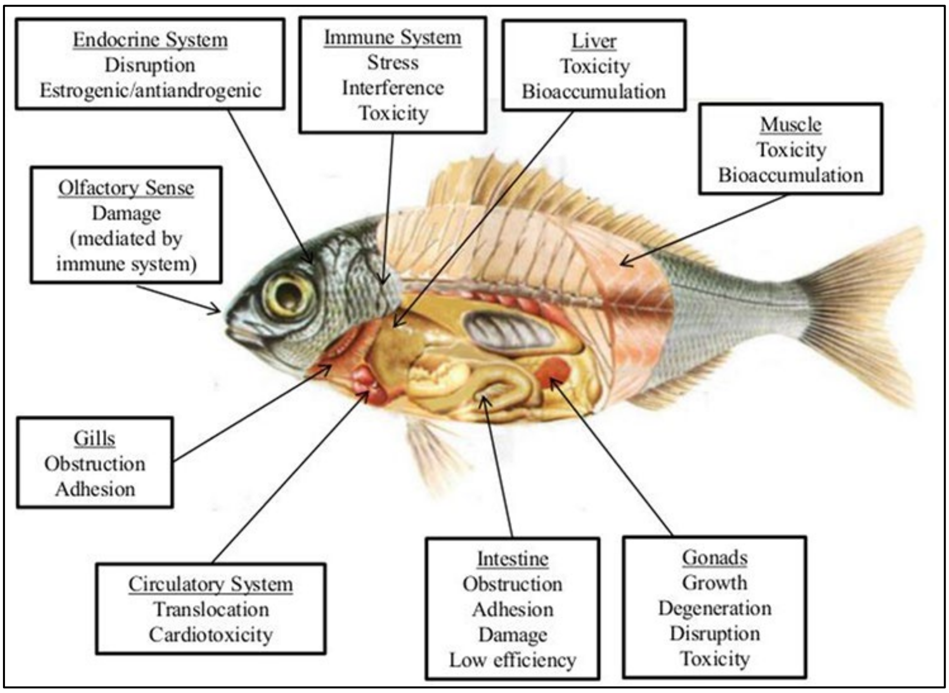



Figure 5-8. The principal effects of microplastics on fish (From: Espinosa et al., 2016).

Plastics collection and extraction operations were anticipated to result in the capture, injury, or mortality of substantial numbers of individual fishes. During Campaigns 1 through 12, there was a total of 0.69 tons of primary bycatch, while at the same time The Ocean Cleanup removed a total of 209.64 tons of plastic debris from the NPSG. This corresponds to 0.33% of primary bycatch weight per plastic debris weight removed.

This primary bycatch consisted of 20 identified fish groups, predominantly small blennies and sergeant majors (**Table 5-7**). The number of fish captured would not be significant on the regional or population level for any of those species. The long-term impacts of deploying the S03 should be **Beneficial** on fish and fishery resources due to the removal of large amounts of plastics and other marine debris from the NPSG (**Section 5.2.1**). This will reduce the potential for fish to ingest plastics and for impacts due to release of degradation byproducts (i.e., toxic chemicals) as well as reducing the potential from entanglement from debris, such as ghost nets, that makes up a large portion of the plastics collected.

Vessel strikes are not expected to occur to fish and fishery resources. Effects on fish and fishery resources from attraction/ingestion of plastics congregated by the S03 and from vessel physical presence are considered likely. The impacts are expected to be of moderate intensity, short term, and of minor consequence, resulting in an impact significance of **2 – Low** for plastic collection operations. No population-level effects on fish communities are expected. However, because of the high likelihood and moderate impact intensity of fish and fishery resources becoming entangled/entrapped in the RZ, as observed in the primary bycatch data (**Table 5-7**), impact consequence for this IPF is minor, resulting in an impact significance of **2 – Low** during plastics collection operations.

During plastics extraction operations, the S03 would be towed behind one vessel, at a slower speed, with a narrowed wingspan and the shortened open RZ, which significantly reduces the area swept by the System. Each plastics extraction operation is anticipated to take less than 12 hours and occurs between three and five times during the campaigns. In 2022 each campaign was 6-week long and had multiple extraction operations per campaign, totaling 47 extraction events. While the impact likelihood would remain the same, the impact intensity would be reduced due to a smaller area for capture, resulting in an overall impact significance of **1 – Negligible** during plastics extraction operations prior to implementation of mitigation measures.

*<u>Mitigation Measures</u>*

The Ocean Cleanup implements the following mitigation measures that have proven effective in reducing potential impacts to fish and fishery resources from entanglement/entrapment, attraction to the System and subsequent ingestion of plastics, and attraction to the tow vessels and will be carried forward for S03:

- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.
- **Vessel operations** – Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots).
- **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for fish.
- **Visual monitoring** – Two camera skiffs each with eight underwater cameras with integrated lights installed inside the RZ for visual observation by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations.

*<u>Residual Impacts</u>*

The mitigation measures for attraction to the System and the vessels will somewhat reduce the likelihood of impacts from these IPFs, but the residual impact significance will remain **2 – Low** for both plastics collection and extraction operations. For entanglement and entrapment, although fish were caught by the System as primary bycatch, observations made from the underwater cameras and System inspections showed many fish could readily swim into and out of the System, including the RZ using the bottom openings, by swimming under the wings, or by swimming through the mesh holes, indicating effective mitigation measures to reduce the primary bycatch. In addition, the operations of retrieving the RZ extraction area requires that the net rest in order for the extraction operations to occur allowing additional fish to potentially escape the RZ. Therefore, the mitigation measures somewhat reduce the likelihood of impact occurrence and the intensity; however, not enough to change the overall impact rating of **2 – Low** for plastics collection operations.

For entanglement and entrapment, all mitigation measures would still be in place during plastics extraction operations other than the remotely triggered electric release; however, the shortened RZ is open to allow free flow through the RZ. Therefore, the mitigation measures reduce the impact intensity from moderate to low and reduce the likelihood of impact occurrence, resulting in a reduction of impact significance to **1 – Negligible** for plastics extraction operations.

#### *5.2.3.3 Noise and Lights*

*Potential Impacts*

Fishes inhabiting or transiting the project area could be subjected to noise from support vessel traffic. Two support vessels will always be present during plastics collection and extraction operations. Vessels cause a path of physical disturbance in the water that could affect the behavior of certain fish species, depending on the type of vessel and ecology of the fish species.

Vessel noise is a combination of narrow-band (tonal) and broadband sound (Richardson et al., 1995). Tones typically dominate up to approximately 50 Hz, whereas broadband sounds may extend to 100 kHz. Usually, the larger the vessel or the faster the vessel is moving, the greater the noise it generates (Richardson et al., 1995). Depending on the vessel, source levels can range from less than 150 dB to more than 190 dB (Richardson et al., 1995). Noise levels from vessels and equipment are within the general hearing range of most fishes (Amoser et al., 2004). Engines from the vessels may radiate considerable levels of noise underwater, significantly contributing to the low-frequency spectrum. Machinery necessary to drive and operate a ship produces vibration within the frequency range of 10 Hz to 1.5 kHz, resulting in the radiation of pressure waves from the hull (Mitson and Knudsen, 2003). In addition to broadband propeller noise, there is a phenomenon known as "singing," when a discrete tone is produced by the propeller, resulting in very high tone levels within the frequency range of fish hearing.

Vessel noise may disturb pelagic fish and alter their behavior by inducing avoidance, potentially displacing some species from preferred habitat, altering swimming speed and direction, and altering schooling behavior (Sarà et al., 2007). Pressure waves from vessel hulls could displace fish near the surface and cause injury or mortality to non-swimming and weakly swimming fish life stages and fish prey. Cavitation of bubbles generated by vessel hull structures and vibrations from vessel pumps could result in barotraumatic injury and mortality of epipelagic non-swimming and weakly swimming fish life stages and fish prey (Hawkins and Popper, 2012). Additionally, vessel noise can mask sounds that affect communication between fishes (Purser and Radford, 2011).

Fish may exhibit avoidance behavior when subjected to loud noises from a vessel. Abnormal fish activity may continue for some time as the vessel travels away. However, vessel noise is inherently transient, rendering adverse impacts temporary resulting in a low impact intensity. Fish in the immediate vicinity of vessels may also exercise avoidance. Although vessel and equipment noise would increase in the project area, negative effects on fish behavior are considered occasional; however, they are expected to be short term and only within the immediate vicinity. For these reasons, the impacts of vessel noise on fish and fisheries resources are of negligible consequence and expected to have an impact significance of **1 – Negligible**.

The S03 will introduce new hard substrate that could provide habitat for some prey species, which subsequently could attract managed species in the upper water column (Fujii, 2015). Additionally, operational lights create small "halos" of light in the water at night that attract fish and predators (Barker, 2016). The System and its tow vessels will stand out in the project area as possibly the only artificial light sources. Lights will be used during evening and night hours on the S03 and tow vessels, although efforts will be made to reduce lighting as much as practicable. Fishes may be attracted by the System's nighttime light field. The light may also attract phototaxic prey and provide enhanced lighting conditions for predators to locate and capture prey while foraging within the light field surrounding the vessels. Fish foraging in the light field may also attract larger predators, rendering each in turn vulnerable to other predators and to entanglement and entrapment by the System itself. However, the light field produced by the S03 and its associated vessels is expected to cover a significantly smaller area than what is produced by a typical offshore structure such as an oil and gas platform. Additionally, the light field will move as the System is towed, so no one location will receive a steady light field. Therefore, the impacts from light are expected to be of moderate intensity, short term, and of minor consequence, resulting in an impact significance of **2 – Low**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to fish and fishery resources from noise and lights:

- **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise is kept as low as reasonably practicable. The sound generated by banana pingers will not propagate far and is well above hearing ranges of fish.
- **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.

*Residual Impacts*

The elimination of unnecessary acoustic energy mitigation measure will reduce both intensity and likelihood of impacts from noise, but not enough to lower the impact significance, which remains **1 – Negligible** for noise.

The mitigation measure of limiting lights to the extent practicable will reduce the likelihood of impacts to fish, but not enough to lower the impact significance, which will remain **2 – Low** for lights.

#### *5.2.3.4 Accidental Fuel Spill*

*Potential Impacts*

A small diesel fuel spill in offshore waters would produce a thin slick on the water surface and introduce concentrations of petroleum hydrocarbons and their degradation products. The extent and persistence of impacts would depend on the meteorologic and oceanographic conditions at the time and the effectiveness of spill response measures. Moreover, in the event of a diesel fuel spill, the area affected would be relatively small, and the duration of impact would presumably be only a few days. Adult and juvenile fishes may actively avoid an accidental fuel spill.

Due to the limited areal extent and short duration of water quality impacts, a small diesel fuel spill would be unlikely to produce significant impacts on fish and fishery resources. The likelihood of impacts to fish and fishery resource is considered remote and of negligible consequence. Overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to fish and fishery resources from an accidental fuel spill:

- **SOPEP** – The Ocean Cleanup ensures a SOPEP is in place on towing, monitoring, and debris collection vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.
- **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.
- **No re-fueling at sea** – No re-fueling occurs at sea.
- **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain-of-command to The Ocean Cleanup and regulatory bodies.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements the likelihood of impacts would be reduced. The residual impact significance would remain **1 – Negligible**.

#### 5.2.3.5 *Fish and Fisheries Impact Summary*

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Removal of plastics and debris from the environment | Removal of plastics and other marine debris (e.g., ghost nets) from the North Pacific Subtropical Gyre will reduce the potential for fish entanglement, ingestion of plastics, and impacts from the release of degradation byproducts (i.e., toxic chemicals). However, the beneficial aspect (**Section 5.2.1**) will be somewhat offset by the removal of nursery habitat for some fish species. | | | | | |
| Entanglement or entrapment with the deployed S03 | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |
| Attraction to the S03 and ingestion of plastics collected | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |
| Attraction to vessels and strike resulting in injury or mortality | Low | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure; avoidance of noise sources (e.g., tow vessels) | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to tow vessels and lights | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |
| Diesel fuel exposure, including ingestion | Low | Immediate Vicinity | Short Term | Negligible | Remote | 1 – Negligible |

*Mitigation Measures*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S03 | • **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Vessel operations** – Tow vessels in the North Pacific Subtropical Gyre travel at extremely slow speeds (0.5 to 2.5 knots).<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for fish.<br>• **Visual monitoring** – Two camera skiffs each with eight underwater cameras with associated lights installed inside the RZ for visual observation by the Environmental Observer. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations. | Reduces Intensity and Likelihood | Plastics Collection<br>2 – Low<br><br>Plastics Extraction<br>1 – Negligible |
| Attraction to the S03 and ingestion of plastics collected | • **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System. | Reduces Likelihood | 2 – Low |
| Attraction to vessels and strike resulting in injury or mortality | • None recommended. | None | 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure; avoidance of noise sources (e.g., tow vessels) | • **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable. The sound generated by banana pingers is localized and well above hearing ranges of fish. | Reduces Intensity and Likelihood | 1 – Negligible |
| Attraction to vessels and lights | • **Limit lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces Likelihood | 2 – Low |

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Diesel fuel exposure, including ingestion | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on towing, monitoring, and debris collection vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.<br>• **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses are equipped with dry-break couplings.<br>• **No re-fueling at sea** – No re-fueling occurs at sea.<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces Likelihood | 1 – Negligible |

MARPOL = International Convention for the Prevention of Pollution from Ships; RZ = retention zone.

### 5.2.4 Potential Impacts on Marine Mammals

#### *5.2.4.1 Impact-Producing Factors*

- S03 – Entanglement/Entrapment
- S03 – Attraction/Ingestion of Plastics
- Vessel – Physical Presence/Strikes
- Noise and Lights
- Loss of Debris
- Accidental Fuel Spill

#### *5.2.4.2 S03 – Entanglement/Entrapment*

<u>*Potential Impacts*</u>

There is a risk of entanglement any time gear, particularly lines and cables, are put in the water. Gall and Thompson (2015) reviewed previous literature and found 52 species of marine mammals have entanglement records with marine debris, primarily fishing gear or nets. Porpoise and other small cetacean mortality from gillnet entanglement has been documented by Tregenza et al. (1997). Allen and Angliss (2011) estimated at least 3.3 gray whale mortalities per year are attributed to fishing gear entanglement along the west coast of the U.S. In 2016, 71 separate cases of entangled whales were reported off the west coast of the U.S. Humpback whales were the predominant species reported as entangled (54 cases, NOAA, 2017c). Other identified entangled species included gray, blue, killer, and fin whales. Entanglement data for mysticetes may reflect a high interaction rate with active fishing gear rather than with discarded trash and debris (Laist, 1996). Entanglement records for odontocetes that are not clearly related to bycatch in active fisheries are almost absent (Laist, 1996). Entanglement cases were associated with specific fishing gear types from the Dungeness crab (*Cancer magister*) commercial and recreational trap fisheries, gillnet fisheries, spot prawn trap fishery, sablefish (*Anoplopoma fimbria*) trap fishery, and spiny lobster fishery (NOAA, 2017c).

Stelfox et al. (2016) conducted a literature review of the effect ghost gear entanglement has on marine megafauna, namely mammals, reptiles, and elasmobranchs. They reviewed 76 publications and other sources of gray literature that highlighted 40 species recorded as entangled in or associated with ghost gear from the Atlantic, Pacific, and Indian oceans. Overall, 27 marine mammal species, 7 reptile species, and 6 elasmobranch species were reported as entangled in ghost gear, with marine mammals making up 70% of entanglements. Ghost gear responsible for the entanglements included fishing nets, monofilament lines, ropes from traps and pots, unknown ropes, or a combination of net and line. Species recorded as entangled in the review by Stelfox et al. (2016) that could be present in the study area include the Guadalupe and northern fur seals, California sea lion, northern elephant seal, harbor seal, and gray, humpback, sei, and sperm whales.

The S03 consists of nets, lines, and chains that could entangle marine mammals; however, during Campaigns 1 through 12, a total of 57 marine mammals have been observed by EOs on board the vessels while towing the System in the NPSG. None of the marine mammals have been observed entangled in the System. The System moves slowly during deployment, making the likelihood of entanglement remote. Also, marine mammals may be able to visually identify the S03 and actively avoid contact. Entanglement in marine plastics or other debris concentrated within the S03 is more likely, though based on observations from S002 considered a remote occurrence, because marine mammals may become attracted to the structure and cover the S03 provides, and some may mistake congregated plastics as a food source.

By design, the S03 is expected to accumulate marine debris, which may include lines, nets, and other materials that could entangle marine mammals. However, during plastics collection operations the likelihood of a marine mammal becoming entangled is remote, partially due to the relatively small size of the S03 compared to the NPSG and the North Pacific as well as the relatively low density of marine mammals in the area. If a marine mammal did become entangled in lines or chains connected to the S03 or in marine debris, nets, or lines accumulated within the S03, the individual could be harmed or drown if it were unable to untangle itself; this would result in an impact of high intensity. In the case of mortality of an endangered marine mammal (e.g., North Pacific right whale), such an incident could be significant at the population level with a regional extent. However, while possible, the mortality of a marine mammal due to deployment of the S03 is considered remote. Overall, the long-term impacts of the S03 on marine mammals should be **Beneficial** due to the removal of large amounts of plastics and other marine debris from the NPSG (**Section 5.2.1**). Because of the possibility of harm or mortality of marine mammals due to the S03 deployment, the consequence severity is rated moderate. The remote likelihood and moderate consequence severity result in an overall impact significance rating of **2 – Low** during plastics collection operations prior to implementing mitigation measures**.**

During plastics extraction operations, the S03 is towed by one vessel, at a slower speed, and has a narrowed wingspan (less than 5 m), which significantly reduces the area swept by the System. Plastics extraction operations are anticipated to typically take less than 12 hours for each extraction and occur every 2.5 to 7 days. The impact likelihood would remain remote, the impact intensity would be reduced due to a smaller area for capture, and the impact consequence would remain moderate, resulting in an overall impact significance of **2 – Low** during plastics extraction operations prior to implementation of mitigation measures.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures that have proven effective to reduce potential impacts of marine mammal entanglement:

- **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:
  - EOs and the mounted thermal/RGB camera systems;
  - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously; and
  - Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.
- **Acoustic deterrent** – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System.
- **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings.
- **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.
- **Routine debris extraction** - Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.
- **Rescue of animals** – Rescue attempts of entangled marine mammals in distress may be performed according to project procedures.

*Residual Impacts*

Based on the observations during Campaigns 1 through 12, several marine mammals have been observed within the System wings but either on their own or with the implementation of mitigation measures (i.e., MEIO mode) swam out and away unharmed. The data collected during S002 campaigns has shown that the mitigation measures are successful in minimizing impacts with no marine mammal entanglements during the 12 campaigns; therefore, two components of impact consequence—intensity and likelihood—would be reduced, resulting in a residual impact significance of **1 – Negligible** for non-protected species. However, for protected species, even though an entanglement of a protected marine mammal is a remote possibility the residual impact significance for protected species would remain **2 – Low** for plastics collection operations as such an incident could be significant.

During S03 operations, the goal is to return the entire System to the water as quickly as possible (typically within 12 hours); and therefore, the extraction operations time where one vessel tows the System with the shortened RZ open will decrease. Although the remotely triggered electric release portion of the escape aids mitigation measure is not implemented during plastics extraction operations, all other mitigation measures are in effect, including towing the shortened RZ with the end open. Extraction operations will be performed during daylight hours, which will allow for the visual monitoring mitigation measures to be most effective. Based on implementation of the mitigation measures and additional operational actions that would be implemented, as necessary (e.g., further reduced vessel speed but ensure that the net does not collapse, holding the System wings in the current only), the likelihood of entanglement would remain remote (to date, there have been no marine mammals captured within the RZ) and the impact intensity would be reduced due to a smaller area for capture. Impact consequence would also be reduced due to the open shortened RZ, which would allow a marine mammal to swim through the System and reduce the potential for entanglement. Therefore, the overall impact significance would be reduced to **1 – Negligible** during plastics extraction operations with the implementation of mitigation measures.

#### *5.2.4.3 S03 – Attraction/Ingestion of Plastics*

*Potential Impacts*

Some marine mammals may be attracted to offshore structures, while others will avoid the floating S03. Marine mammals have been known to ingest trash and debris. Gall and Thompson (2015) noted 30 species of marine mammals have records of marine debris ingestion. Debris items may be mistaken for food and ingested, or the debris item may have been ingested accidentally with other food. Marine mammals that are attracted to the System or encounter it by chance may have a moderate probability of ingesting plastics due to the plastic-congregating nature of the system. If a marine mammal mistakes the congregated plastic for a food source, a substantial amount of plastic could be ingested by a single individual. Debris ingestion can lead to loss of nutrition, internal injury, intestinal blockage, starvation, and death (NOAA, 2015). However, records suggest entanglement is a far more likely cause of mortality to marine mammals than ingestion-related interactions (Laist et al., 1999). During Campaigns 1 through 12, a total of 57 marine mammals were observed by the EOs on board the vessels while towing the System. Most of the observed marine mammals were 500 to 2,000 m from the vessels and the System and did not interact with the System.

By design, the S03 is expected to accumulate marine debris, which may include lines, nets, and other materials that could be ingested by marine mammals and result in impact of moderate intensity. However, the marine debris captured by the wings of the System is guided into the RZ and regularly pushed into the RZ through operational “wiggle” maneuver. The RZ is a closed net that limits potential access by marine mammals to the accumulated marine debris. The long-term impacts of the S03 on marine mammals should be **Beneficial** due to the removal of large amounts of plastics and other marine debris from the NPSG (**Section 5.2.1**). Because the marine debris enters into the RZ from the wings regularly through operational maneuvers, the likelihood of harm or mortality of marine mammals resulting from plastic ingestion is remote, the consequence severity is considered minor. Overall, the impact significance is rated **1 – Negligible**.

<u>*Mitigation Measures*</u>

The Ocean Cleanup implements the following mitigation measures that have proven effective and have been enhanced based on data collected during S002 campaigns to reduce potential impacts of plastics ingestion by marine mammals:

- **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:
  - EOs and the mounted thermal/RGB camera systems;
  - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously; and
  - Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.
- **Acoustic deterrent** – Banana pingers attached to the System deter high-frequency hearing marine mammals from the System.

<u>*Residual Impacts*</u>

During Campaigns 1 through 12 during towing operations, most of the observed marine mammals were 500 to 2,000 m from the vessels and the System; however, several small groups of whales (Humpback, Pilot whales, Short-finned Pilot whales, False Killer whales) and some common bottlenose dolphins were observed approaching the vessels or System. One group of three Humpback whales were first observed approximately 1,600 m from the vessels and then approached the System and one was observed between the wings. Mitigation measures were applied including continual observation by the EO, reducing vessel speed, full stop of the vessels, underwater camera observations until the whales were seen leaving the area unharmed and did not interact directly with the System.

Based on the proven mitigation measures that The Ocean Cleanup implements, the likelihood component of impact consequence would be further reduced but remain remote. The residual impact significance would remain **1 – Negligible**.

#### *5.2.4.4 Vessel – Physical Presence/Strikes*

<u>*Potential Impacts*</u>

Some marine mammals may be attracted to offshore structures, while others will avoid the vessels. There is a remote possibility of the vessels striking a marine mammal during transit to the NPSG and during routine operations. Variables that contribute to the likelihood of a strike include vessel speed, vessel size and type, barriers to vessel detection by an animal (e.g., acoustic masking, heavy traffic, biologically focused activity), and, in some cases, mitigation measures. Collisions with whales and dolphins are highly unlikely; most dolphins are agile swimmers and unlikely to collide with vessels (Laist et al., 2001; Jensen and Silber, 2003; Glass et al., 2009; Van der Hoop et al., 2015). Most reports of collisions involve large whales, though collisions with smaller species have been reported as well (Laist et al., 2001; van Waerebeek et al., 2007; Douglas et al., 2008; Pace, 2011). Large whale species most frequently involved in vessel strikes include the fin whale, North Atlantic right whale, humpback whale, minke whale, sperm whale, sei whale, gray whale, and blue whale (Dolman et al., 2006). Laist et al. (2001) provided records of the vessel types associated with collisions with whales. From these records, most severe and lethal whale injuries involved ships longer than 80 m. Vessel speed was found to be a significant factor as well, with 89% of records involving vessels moving at 14 knots or more (Laist et al., 2001).

In the North Pacific, marine mammals at risk for possible vessel strikes include slow-moving species and deep-diving species while on the surface (e.g., Bryde's whales, sperm whales, pygmy/dwarf sperm whales, beaked whales). Of the large whale species present in the project area, blue, fin, humpback, and gray whales are considered the most at-risk for vessel strikes because they migrate in nearshore areas where vessel traffic is heaviest (NOAA, nd).

When considering the level of commercial traffic off the western Canadian and U.S. coast, the activities conducted by The Ocean Cleanup do not significantly contribute to overall vessel traffic. The likelihood of a collision between a project-related vessel and a marine mammal is considered remote. If a collision occurs, it could cause injury or mortality of the individual, resulting in a moderate impact intensity for non-protected species, but a high impact intensity for protected species. Potential collisions with marine mammals are considered remote resulting in a minor consequence for non-protected species but could have population-level effects for some protected species, thus resulting in moderate consequence. The overall impact on marine mammals from vessel collisions is expected to be **1 – Negligible** for non-protected species and **2 – Low** for protected species.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures that have proven effective to reduce potential impacts of collisions with marine mammals:

- **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:
  - EOs and the mounted thermal/RGB camera systems;
  - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations; and
  - Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:
  - During transit between shore and the NPSG, vessels travel at slow speeds (<14 knots);
  - During towing in the NPSG, vessels travel at extremely slow speeds (0.5 to 2.5 knots);
  - MEIO mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 1 knot, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the event of a protected species observed in the vicinity; and
  - Change in vessel direction to implement vessel strike avoidance.

*Residual Impacts*

The data collected during S002 campaigns has shown that the mitigation measures are successful in minimizing impacts for vessel strike during the 12 campaigns; therefore, two components of impact consequence—intensity and likelihood—would be reduced. The residual impact significance would be **1 – Negligible** for both protected and non-protected marine mammals.

### 5.2.4.5 *Noise and Lights*

*Potential Impacts*

The Ocean Cleanup project activities will generate vessel and equipment noise that could disturb marine mammals. The sound types produced by the vessels and equipment are classified as non-pulsed, or continuous. Vessel noise is a combination of narrow-band (tonal) and broadband sound (Richardson et al., 1995). Tones typically dominate up to approximately 50 Hz, whereas broadband sounds can extend to 100 kHz. In many areas, radiated sound from ships is the dominant source of underwater noise at frequencies below 300 Hz (Okeanos, 2008).

Vessel and equipment noise, including those produce during towing, monitoring, and debris collection activities, typically would produce sound levels less than 190 $dB_{rms}$ re 1 µPa 1 m. The current acoustic thresholds for injurious (permanent threshold shift onset) and non-injurious (temporary threshold shift onset) exposure to a continuous noise source, based on marine mammal hearing group, are presented in **Table 5-8**.

Table 5-8. Underwater acoustic thresholds from continuous sound for onset of permanent and temporary threshold shifts and behavior thresholds in marine mammal hearing groups.

| Marine Mammal Hearing Group | PTS[1] | | TTS[2] | | Behavior[3] | |
|---|---|---|---|---|---|---|
| | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value |
| Low-frequency cetaceans (baleen whales) | $SEL_{24h}$ | 199 dB re 1 µPa$^2$ s | $SEL_{24h}$ | 179 dB re 1 µPa$^2$ s | SPL | 120 dB re 1 µPa |
| Mid-frequency cetaceans (dolphins, toothed whales, beaked whales, and bottlenose whales) | $SEL_{24h}$ | 198 dB re 1 µPa$^2$ s | $SEL_{24h}$ | 178 dB re 1 µPa$^2$ s | SPL | 120 dB re 1 µPa |
| High-frequency cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchids) | $SEL_{24h}$ | 173 dB re 1 µPa$^2$ s | $SEL_{24h}$ | 153 dB re 1 µPa$^2$ s | SPL | 120 dB re 1 µPa |
| Phocid pinnipeds (underwater) | $SEL_{24h}$ | 201 dB re 1 µPa$^2$ s | $SEL_{24h}$ | 186 dB re 1 µPa$^2$ s | SPL | 120 dB re 1 µPa |
| Otariid pinnipeds (underwater) | $SEL_{24h}$ | 219 dB re 1 µPa$^2$ s | $SEL_{24h}$ | 199 dB re 1 µPa$^2$ s | SPL | 120 dB re 1 µPa |

µPa = micropascal; dB = decibel; h = hour; PTS = permanent threshold shift; re = referenced to; s = second; $SEL_{24h}$ = sound exposure level over 24 hours; SPL = root-mean-square sound pressure level; TTS = temporary threshold shift.
[1] PTS thresholds derived from NMFS (2018).
[2] TTS thresholds derived from Southall et al. (2019).
[3] Behavioral thresholds derived from NMFS (2019).

The current acoustic threshold for behavioral effect exposure is 120 $dB_{rms}$ re 1 µPa (NMFS, 2018). The behavioral effect threshold is based on avoidance responses observed in whales, specifically from research on migrating gray whales and bowhead whales (Malme et al., 1983, 1984, 1988; Richardson et al., 1986, 1990; Dahlheim and Ljungblad, 1990; Richardson and Malme, 1993). Mysticetes are especially vulnerable to impacts from vessel noise because they produce and perceive low-frequency sounds (Southall, 2005). Broadband propulsion source levels for vessels are within the audible frequency range for most cetacean species and are anticipated to be in the range of 170 to 180 dB re 1 µPa m at the source. In the open ocean deepwater environment where spherical spreading conditions apply, an attenuation of 60 re 1 µPa m dB (e.g., reduction from a source level of 180 dB re 1 µPa m to the 120-dB continuous noise threshold) would occur within 1 km of the source. Where modified spherical spreading conditions may apply, the distance from source to the 120-dB threshold would be greater.

In addition to direct injurious or sub-injurious exposures, an additional effect of increased ambient noise on marine mammals is the potential for noise to mask biologically significant sounds. Studies of vessel noise on Gulf of Mexico sperm whales indicated a significant decrease in the number of acoustic clicks detected as a tanker ship approached an area (Azzara et al., 2013). Individuals of several small-toothed whale and dolphin species have been observed avoiding boats when they are within 0.5 to 1.5 km, with occasional reports of avoidance at greater distances (Richardson et al., 1995). Most beaked whales tend to avoid vessels (Würsig et al., 1998; Aguilar-Soto et al., 2006) and may dive for an extended period of time when approached by a vessel (Kasuya, 1986). Dolphins may tolerate boats of all sizes, often approaching and riding the bow and stern waves (Shane et al., 1986; Barkaszi et al., 2012). At other times, dolphin species that typically are attracted to boats will avoid them. Such avoidance is often linked to previous boat-based harassment of the animals (Richardson et al., 1995). Coastal bottlenose dolphins that are the subject of whale watching activities have been observed to swim erratically (Acevedo, 1991), remain submerged for longer periods of time (Janik and Thompson, 1996; Nowacek et al., 2001), display less cohesiveness among group members (Cope et al., 1999), whistle more frequently (Scarpaci et al., 2000), and display restless behavior (Constantine et al., 2004) when boats are nearby. During Campaigns 1 through 12, a total of 57 marine mammals were observed by the EOs on board the vessels during System towing operations. Most were observed 500 to 2,000 m from the vessels and the System.

The additional volume of vessel traffic associated with The Ocean Cleanup project activities would not constitute a significant increase to the existing vessel traffic noise offshore western Canadian and U.S. coasts. However, the presence of the vessels in the NPSG could present a novel, persistent noise source. Additionally, the use of a global training tracking system, motion reference units, and banana pingers will add novel anthropogenic noise to the local oceanic soundscape. Impacts to marine mammals from project-related vessel and equipment noise will be occasional but are expected to have a negligible impact consequence that would include temporary disruption of communication or echolocation from auditory masking; behavioral disruptions of individuals or localized groups of marine mammals; and limited, localized, and short-term displacement of individuals of any species, including strategic stocks, from localized areas around the vessels. Because the operation will occur in the open ocean, animals are expected to avoid the sound source and the potential for resultant auditory injuries. Consequently, impacts to marine mammals from project-related noise are expected to be **1 – Negligible**.

_Mitigation Measures_

The Ocean Cleanup implements the following proven mitigation measures to reduce potential impacts to marine mammal from noise:

- **Elimination of unnecessary acoustic energy** – Levels of anthropogenic noise are kept as low as reasonably practicable.
- **Acoustic deterrent** – Banana pingers are used to deter high-frequency hearing marine mammals from the System.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.

_Residual Impacts_

Based on the proven mitigation measures The Ocean Cleanup implements two components of impact consequence—intensity and likelihood—would be reduced. The residual impact significance would remain **1 – Negligible**.

#### *5.2.4.6 Loss of Debris*

Potential Impacts

Global entanglement records of marine mammals with trash and debris show entanglement is most common in pinnipeds, less common in mysticetes, and rare among odontocetes (Laist et al., 1999). Additionally, as discussed in **Section 5.2.4.3**, marine mammals have been known to ingest trash and debris.

MARPOL 73/78 is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. MARPOL 73/78 includes regulations aimed at preventing and minimizing pollution from ships (accidental and from routine operations) and currently includes six technical annexes. Special areas with strict controls on operational discharges are included in most annexes. Annex V ("Prevention of Pollution by Garbage from Ships") addresses different types of trash and debris, specifying the distances from land and the manner in which they may be disposed of; the most important feature of Annex V is the complete ban imposed on the disposal of all forms of plastics into the ocean. The revised Annex V prohibits the discharge of all trash and debris into the ocean, except as provided otherwise. All trash and debris must be returned to shore for proper disposal with municipal and solid waste.

Plastics extraction operations will occur on board a vessel as the RZ will be hauled on board and detached from the S03. The potential for lost debris is remote; If some collected debris is accidentally lost, it would return to its origin (i.e., the NPSG) and would not constitute additional debris.

Taking into account the MARPOL 73/78 regulations, the accidental loss of trash and debris from the transit, operations, or debris collection vessels is expected to be remote. As such, the associated impact consequence is expected to be negligible. Consequently, debris entanglement and ingestion impact significance from lost debris on marine mammals is expected to be **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following proven mitigation measure to reduce potential impacts to marine mammal from loss of debris:

- **Pollution prevention** – Compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence.

*Residual Impacts*

Based on compliance with MARPOL 73/78 the likelihood of impact consequence would remain the same as it is required of all vessels. The residual impact significance would remain **1 – Negligible**.

#### *5.2.4.7 Accidental Fuel Spill*

*Potential Impacts*

Diesel fuel most often is a light, refined petroleum product classified by the American Petroleum Institute as a Group 1 oil based on its specific gravity and density, and it is not persistent within the marine environment (Mediterranean Decision Support System for Marine Safety, 2017). When spilled on water, diesel fuel quickly spreads to a thin sheen; marine diesel, however, may form a thicker film of dull or dark colors. Because diesel oil is lighter than water (specific gravity is between 0.83 and 0.88, compared with 1.03 for seawater), it cannot sink and accumulate on the seafloor as pooled or free oil unless adsorption with sediment occurs. However, diesel oil dispersed by wave action may form droplets small enough to be kept in suspension and moved by currents (NOAA, 2017d). As diesel oil spreads on the sea surface, the oil's lighter components evaporate. Evaporation rates increase in conditions of high winds and sea state as well as high atmospheric and sea surface temperatures (American Petroleum Institute, 1999; Mediterranean Decision Support System for Marine Safety, 2017; NOAA, 2017d). Small diesel spills usually evaporate and disperse naturally within a day.

Marine mammals could be affected by spilled diesel fuel. Effects of spilled diesel fuel on marine mammals are discussed by Geraci and St. Aubin (1980, 1982, 1985, 1990) as well as Lee and Anderson (2005) and within spill-specific study results (Frost and Lowry, 1994; Paine et al., 1996; Hoover-Miller et al., 2001; Peterson et al., 2003). Quantities of diesel fuel on the sea surface may directly affect marine mammals through various pathways: surface contact of the fuel with skin and mucous membranes of eyes and mouth; inhalation of concentrated hydrocarbon vapors; or ingestion of fuel (direct ingestion or ingestion of oiled prey).

Whales and dolphins apparently can detect slicks on the sea surface but do not always avoid them (Dias et al., 2017); therefore, they may be vulnerable to inhalation of hydrocarbon vapors, particularly the components that readily evaporate. Ingestion of the light hydrocarbon fractions found in diesel fuel can be toxic to marine mammals. Ingested diesel fuel can remain within the gastrointestinal tract and be absorbed into the bloodstream, irritating or destroying epithelial cells in the stomach and intestines. Certain constituents of diesel fuel (e.g., aromatic hydrocarbons, polycyclic aromatic hydrocarbons) include well-known carcinogens. These substances, however, do not show significant biomagnification in food chains. While some hydrocarbon components may be metabolized, recent data indicate that following acute exposure to hydrocarbons (i.e., crude oil from the *Deepwater Horizon* spill), marine mammals exhibited symptoms of hypoadrenocorticism, consistent with adrenal toxicity (Schwacke et al., 2013). Released fuel may also foul the baleen fibers of mysticetes, thereby impairing food-gathering efficiency and resulting in the ingestion of fuel or fuel-contaminated prey.

The likelihood of a fuel spill during project activities is considered remote, and the potential for contact with and impacts to marine mammals would depend heavily on the size and location of the spill as well as weather and sea conditions at the time of the spill. For this scenario, fuel spilled on the sea surface is assumed to rapidly spread to a thin layer and break into narrow bands, or windrows, aligned parallel to the wind direction. Lighter volatile components of the fuel would evaporate almost completely within a few days.

Because of the thickness of the slick and rapid weathering, it is unlikely many animals would come into contact with fuel on the surface. Potential impacts are assumed to be negligible to minor mucous membrane irritation and behavioral alteration (temporary displacement from the affected area), resulting in a moderate impact intensity and minor impact consequence with remote likelihood. The impact significance of spilled fuel to marine mammals is expected to be **1 – Negligible**, depending on the species coming into contact with the spilled fuel and their exposure time to the spilled fuel.

*Mitigation Measures*

The Ocean Cleanup implements the following proven mitigation measures to reduce potential impacts to marine mammal from an accidental fuel spill:

- **SOPEP** – The Ocean Cleanup ensures a SOPEP is in place on all vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board all vessels.
- **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.
- **No re-fueling at sea** – No re-fueling occurs at sea.
- **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies.

*Residual Impacts*

Based on the proven mitigation measures The Ocean Cleanup implements the likelihood of impact consequence would be reduced. The residual impact significance would remain **1 – Negligible**.

#### 5.2.4.8 *Marine Mammal Impact Summary*

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Removal of plastics and debris from the environment | Removal of plastics and other marine debris (e.g., ghost nets) from the North Pacific Subtropical Gyre will reduce the potential for marine mammal entanglement, ingestion of plastics, and impacts from the release of degradation byproducts (i.e., toxic chemicals). | | | | | |
| Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | High | Immediate Vicinity Regional (Protected Species) | Short Term | Moderate | Remote | 2 – Low |
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Exposure to vessel strike resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| | High (Protected Species) | Immediate Vicinity (Protected Species) | Short Term (Protected Species) | Moderate (Protected Species) | Remote (Protected Species) | 2 – Low |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels) | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Entanglement with or ingestion of debris accidentally lost | Low | Immediate Vicinity | Short Term | Negligible | Remote | 1 – Negligible |
| Diesel fuel exposure, including inhalation of vapors, ingestion, and fouling of baleen | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |

*Mitigation Measures*

<table>
<tr><th>Impact</th><th>Mitigation Measures</th><th>Component of Impact Consequence Affected by Mitigation</th><th>Residual Impact Significance</th></tr>
<tr><td rowspan="4">Entanglement in the S03 or accumulated debris resulting in injury or mortality during plastics collection and extraction operations</td><td rowspan="4"><ul><li>Visual monitoring – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<ul><li>EOs and the mounted thermal/RGB camera systems;</li><li>Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ and not all, but multiple cameras and lights will operate simultaneously for observations; and</li><li>Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.</li></ul></li><li>Visual cues – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.</li><li>Acoustic deterrent – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System.</li><li>Escape aids – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for small marine mammals.</li><li>Breathing rings/hatches – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.</li><li>Routine debris extraction - Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.</li><li>Rescue of animals – Rescue attempts of entangled marine mammals in distress are performed according to the project procedures.</li></ul></td><td rowspan="2">Reduces Intensity and Likelihood</td><td>Plastics collection<br>1 – Negligible</td></tr>
<tr><td>Plastics extraction<br>1 – Negligible</td></tr>
<tr><td rowspan="2">Reduces Likelihood (Protected Species)</td><td>Plastics Collection<br>2 – Low<br>For Protected Species</td></tr>
<tr><td>Plastics Extraction<br>1 – Negligible For Protected Species</td></tr>
</table>

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
| --- | --- | --- | --- |
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | • **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ and not all, but multiple cameras and lights will operate simultaneously for observations; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Acoustic deterrent** – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System. | Reduces Likelihood | 1 – Negligible |
| Exposure to vessel strike resulting in injury or mortality | • **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ and not all, but multiple cameras and lights will operate simultaneously for observations; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Vessel operations** –<br>○ Between shore and the NPSG, transit vessels travel at slow speeds (<14 knots);<br>○ Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots);<br>○ Minimal Environmental Impact Operation mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 1 knot, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the event of a protected species observed in the vicinity; and.<br>○ Change in vessel direction to implement vessel strike avoidance. | Reduces Intensity and Likelihood | 1 – Negligible |

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (support vessels) | • **Elimination of unnecessary acoustic energy** – Levels of anthropogenic noise are kept as low as reasonably practicable.<br>• **Acoustic deterren**t – Banana pingers attached to the System to deter high-frequency hearing marine mammals from the System.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System. | Reduces Intensity and Likelihood | 1 – Negligible |
| Entanglement with or ingestion of debris accidentally lost | • **Pollution prevention** – Compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence. | No change | 1 – Negligible |
| Diesel fuel exposure, including inhalation of vapors, ingestion, and fouling of baleen | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on all vessels and an Oil Record Book, as required under the MARPOL 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.<br>• **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces Likelihood | 1 – Negligible |

EO = environmental observer; MARPOL = International Convention for the Prevention of Pollution from Ships; NPSG = North Pacific Subtropical Gyre; RZ = retention zone.

### 5.2.5 Potential Impacts on Sea Turtles

#### *5.2.5.1 Impact-Producing Factors*

- S03 – Entanglement/Entrapment
- S03 – Attraction/Ingestion of Plastics
- Vessel – Physical Presence/Strikes
- Noise and Lights
- Loss of Debris
- Accidental Fuel Spill

#### *5.2.5.2 S03 – Entanglement/Entrapment*

<u>*Potential Impacts*</u>

The physiology of sea turtles makes them susceptible to entanglement, as their surface area is large and they are not as streamlined as marine mammals. Feeding behavior also makes sea turtles susceptible to entanglement, as many species forage near the surface where floating debris often concentrates especially in the open ocean. Hamelin et al. (2017) summarized leatherback sea turtle bycatch offshore Canada in the Atlantic Ocean and reported entanglements were most common in pot gear that used polypropylene line near the surface. Sea turtles of several species also are common bycatch in gillnet and longline fisheries (Byrd et al., 2016).

Extensive research has been performed on bycatch of sea turtles (Wallace et al., 2013). Loggerhead, leatherback (*Dermochelys coriacea*), and green sea turtles are especially susceptible to impacts from bycatch during fishery activities. While exact numbers of entanglements by discarded fishing gear (e.g., ghost nets, marine debris) are not available, a report by the NOAA Marine Debris Program (NOAA, 2014a) suggests the percentage of entanglements of all sea turtles is 5%. Duncan et al. (2017) indicated more than 1,200 entangled sea turtles are encountered in passive ghost fishing gear globally per year, with a mortality rate of slightly more than 90%. Wilcox et al. (2015) estimated the total number of sea turtles caught by the 8,690 ghost nets sampled was between 4,866 and 14,600 animals, assuming nets drift for one year. Research considered plastic ingestion, a phenomenon widely observed in all sea turtles. All sea turtle species interact with marine plastic, with ingestion and entanglement being the two main types of interaction (Gall and Thompson, 2015).

Given the slow speeds of the S03 during deployment and operations in the NPSG, some sea turtles would be able to visually identify the System and actively avoid contact. Most of the sea turtles observed or found within the RZ were juveniles.

**Table 4-16** provides summary data about the species and life stages of the sea turtles that were encountered during Campaigns 1 through 12. There were varying outcomes of the sea turtles that encountered the System or support vessels as shown in **Figure 5-9.** Roughly 55% of the sea turtles (26 individuals) were either simply observed during vessel transit (4); prevented from entering the S002 (7); rescued from the S002 (6), or escaped on their own (9). The implementation of mitigation measures, including escape routes, resulted in beneficial outcomes for these sea turtles. There were five sea turtles (11%) that were captured by S002 and found dead, necropsied, and determined to have a low probability of death as a result of an interaction with the System (**Figure 5-9**). These turtles were in late stages of decomposition and determined to have been deceased long before being captured in the S002. When possible, necropsies were performed to best determine the cause of death, and to distinguish primary from secondary bycatch and previously deceased. Eleven sea turtle necropsies were performed on turtles captured from Campaigns 1 through 12. Conservatively, these 5 turtles were counted as primary bycatch along with the other five deceased sea turtles that had a high chance of dying from or were confirmed to have died from an interaction with the S002, for a total of 10 sea turtles (21% of all interactions). An additional six sea turtles (13%) were captured by the S002, found alive in the extraction of plastics, and were successfully returned to the ocean with positive signs of full recovery. A total of five sea turtles were determined to be previously deceased prior to collection by the System.

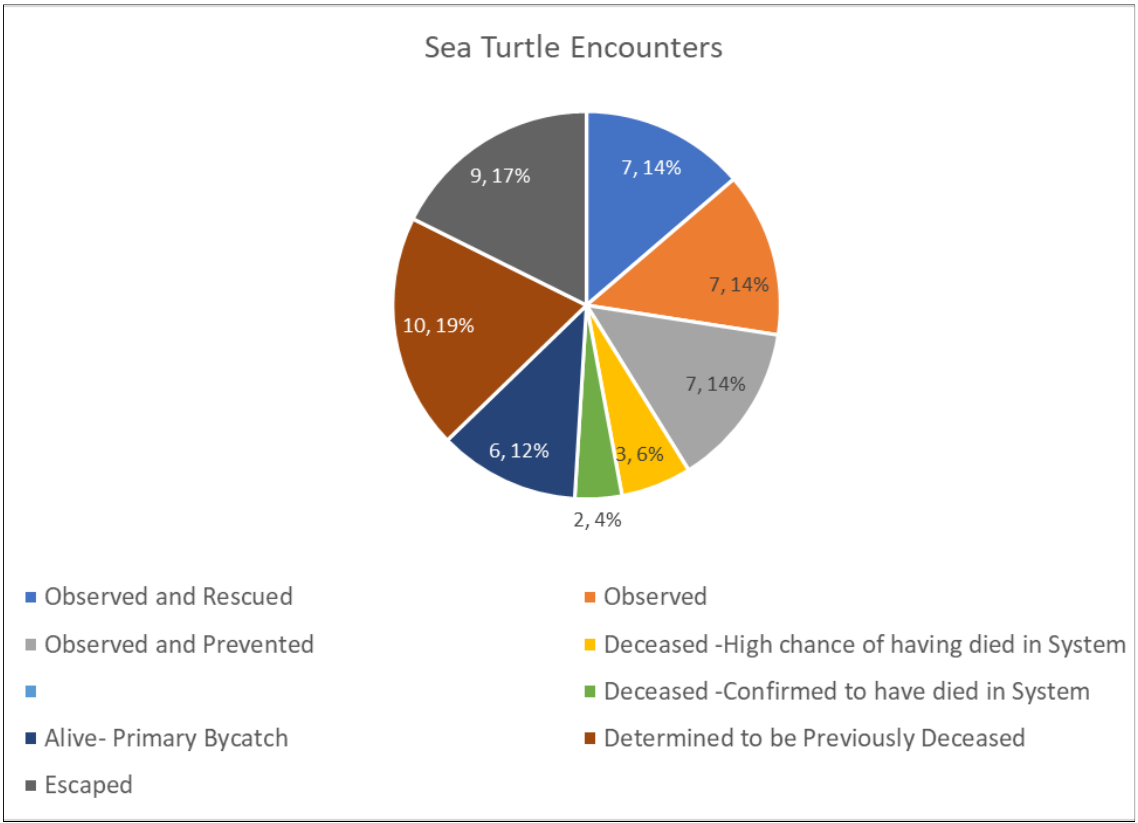



Figure 5-9. Sea turtle encounter results summary for Campaigns 1 through 12.

By design, the S03 is expected to accumulate marine debris during plastics collection operations, including lines, nets, and other materials. Sea turtles, especially juveniles and hatchlings, may be attracted to the structure and cover the S03 and plastics provide and become entangled. If a sea turtle becomes entangled in lines, nets, or chains connected to the S03 or in marine debris, nets, or lines accumulated within the S03, the animal could be harmed or drown if unable to untangle itself. This would result in an impact of high intensity with a regional extent. Based on observations during Campaigns 1 through 12, while it has occurred, the mortality of a sea turtle during plastics collection operations is considered occasional prior to implementation of mitigation measures. Overall, the long-term impacts of the S03 on sea turtles should be **Beneficial** due to the removal of large amounts of plastics and other marine debris from the NPSG (**Section 5.2.1**). Impacts on sea turtles from entanglement/entrapment are considered occasional and of high consequence severity (injury or mortality of individual sea turtles). Impact significance prior to mitigation is rated **3 – Medium** during plastics collection operations.

During plastics extraction operations, when the S03 is being towed by one vessel, at a slower speed, and with a narrowed wingspan (less than 5 m), the likelihood of a sea turtle becoming entangled is considered remote and is reduced from the likelihood during plastics collection operations due to the narrowed wingspan and slower towing speed. In the event a sea turtle becomes entangled, impact intensity, extent, duration, and consequence would remain the same as during plastics collection operations. Therefore, the overall impact significance rating of **2 – Low** would remain for plastics extraction operations prior to implementation of mitigation measures.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures that have proven effective to reduce potential impacts to sea turtles from entanglement/entrapment:

- **Visual monitoring** – Monitoring during the project identifies sea turtles that may be near the tow vessels with:
    - EOs and the mounted thermal/RGB camera systems;
    - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations; and
    - Crew trained in sea turtle observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, the use of green LED lights on the wings and RZ to enhance detectability of the System.
- **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped sea turtles and three bottom openings that could provide an escape route for sea turtles.
- **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.
- **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.
- **Rescue of animals** – Rescue attempts of entangled sea turtles in distress are performed according to the project procedures.
- **Turtle zone steering strategy** – avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region.

*Residual Impacts*

During Campaigns 1 through 12, the S002 was towed for a total of 4,554 hours and there were 51 sea turtles encountered (**Figure 5-9**). Of the 51 sea turtle encounters, the mitigation measures allowed the sea turtles to escape on their own (9), or successfully applied (i.e., underwater cameras allowed for seeing the sea turtles to initiate actions, slowing the vessel towing speed to allow for animal to find their way out, RZ release activated and turtle flushed from the System, RZ extraction, crew cut the netting to release the sea turtle) and resulted in saving a total of 14 sea turtles. Of the remaining 28 sea turtle encounters, seven were observed in the vicinity of the vessels, six were found alive in the bycatch and released, five considered as a confirmed death or a high probability of death caused by the System, and 10 were determined to be previously dead carcasses collected with the floating plastics (**Figure 5-9**).

Based on the mitigation measures The Ocean Cleanup implements during plastics collection operations and the proven effectiveness of those mitigation measures, one components of impact consequence—intensity—would be reduced. However, there is the possibility that the remotely triggered electric release for the end of the RZ may not be able to be activated or the FRC could not be deployed due to weather conditions to assist with entanglement in the rare possibility that a protected sea turtle becomes entangled in the S03. This could cause population level impacts with a regional extent. In addition, during the “wiggle” operations to clear plastic from the wings and help push it into the RZ, the cameras are blocked by the plastics and this reduces the ability to observe portions with the camera skiff of the RZ for the presence of sea turtles, increasing the potential for sea turtles to be “pushed” into the RZ with the plastics. Based on observations during Campaigns 1 through 12, while it has occurred, the mortality of a sea turtle during plastics collection operations is considered occasional with the implementation of mitigation measures. Therefore, the residual impact significance for protected species would be reduced to **2 – Low**.

During plastics extraction operations, the S03 is towed by one vessel, at a slower speed, and with a narrowed wingspan (<5 m), the likelihood of a sea turtle becoming entangled is considered remote and is reduced in likelihood during plastics collection operations due to the narrowed wingspan and slower towing speed. Although the remote release escape aids mitigation measure is not implemented during plastics extraction operations, the System is towed with the shortened RZ open and all other mitigation measures are in effect. In addition, extraction operations will be performed during daylight hours, which will allow for the visual monitoring mitigation measures to be most effective. Based on the considerations and additional operational actions that would be implemented (e.g., additional reduced vessel speed, shortening of catenary length, holding System wings in the current only), impact likelihood would remain remote and impact intensity would be reduced due to a smaller area for potential capture. Impact consequence would also reduce with the opened, shortened RZ. Therefore, the overall impact significance would be reduced to **1 – Negligible** during plastics extraction operations with the implementation of mitigation measures.

#### *5.2.5.3 S03 – Attraction/Ingestion of Plastics*

*Potential Impacts*

Most sea turtles, especially loggerheads, may be attracted to offshore structures (Lohoefener et al., 1990; Gitschlag et al., 1997), including floating plastics and the S03. Due to the relatively high concentrations of marine plastics expected in the vicinity of the S03, any sea turtles attracted to the floating plastics or the S03 may be at increased risk of consuming plastic particles. However, marine debris captured by the wings of the System is guided into the RZ, which is a closed net System, shortening the duration of potential access by sea turtles to the accumulated marine debris. Ingestion of debris can kill or injure sea turtles and is considered a significant stressor (Laist, 1987; Lutcavage et al., 1997; Fukuoka et al., 2016).

Gall and Thompson (2015) noted all species of sea turtles have published reports of entanglement or ingestion of marine debris. During Campaigns 1 through 12, one green turtle was observed alive but entangled in a floating ghost net and was able to be untangled and released safely and one loggerhead was also rescued when it was found alive as bycatch with plastic rope inside its mouth out all the way to out through the cloaca. The olive ridley turtles are considered the highest risk for consuming plastics because they spend most of their life in the pelagic environment (Bolten, 2003) and their foraging strategy on zooplankton and fish often occurs in current convergence zones where plastics also tend to collect (Schuyler et al., 2016). Fukuoka et al. (2016) reported green turtles had higher encounter/ingest ratios than loggerheads when studied using turtle-mounted cameras, but Pham et al. (2017) reported 83% of juvenile loggerheads investigated in the North Atlantic gyre had ingested plastic. Leatherback turtles can also be susceptible to floating plastics, particularly plastic bags, because they resemble their preferred food of jellyfish (Mrosovsky et al., 2009). Clukey et al. (2017) investigated stomach contents of 55 sea turtles caught as bycatch in the Pacific Ocean and found 100% of olive ridley (n= 37), 90% of green (n= 10), 80% of loggerhead (n= 5), and 0% of leatherback (n= 5) sea turtles had plastics in their stomachs or intestines. It should be noted, however, that not all sea turtles were caught from the same area and exposure to plastics may not have been equal.

Any impacts on sea turtles due to attraction to the S03 would likely be short term and of negligible consequence; however, plastic ingestion could cause chronic impacts to affected individuals. It is unknown if the sea turtle incidents discussed earlier were a result of attraction to the System or if the sea turtles were present in the area due to an attraction to the plastics present in the NPSG or if the turtles were in the area as a natural behavior. However, the 11 necropsies performed on the dead sea turtles noted most contained plastics in their digestive tracts. Due to the relatively small size of the S03 and the density of sea turtles in the remote open ocean area of the deployment, impacts to sea turtles from plastics ingestion associated with the S03 are not expected to be biologically significant to sea turtle populations. However, small juvenile sea turtles are mostly pelagic, spending most of their time in the open ocean. Juvenile loggerheads are known to use the project area (Kobayashi et al., 2008; Abecassis et al., 2013; Briscoe et al., 2016a,b) and may be vulnerable to impacts from plastic ingestion. Loggerhead sea turtles, which migrate through the area and potentially spend most of their juvenile lives within the broader central North Pacific (Briscoe et al., 2016b) which encompasses the S03 deployment area, also are known to eat plastic bags, possibly due to the resemblance to their preferred food of jellyfish and other surface and midwater prey. Impacts to regional populations are possible from ingestion of plastics collected in the S03 but considered unlikely due to the short time that the System is towed (2.5 to 6 days) between RZ extractions. Impacts on sea turtles from attraction to the S03 and the associated ingestion of plastics collected by the S03 are considered occasional, of moderate intensity, and of minor consequence severity. Overall impact significance prior to mitigation is rated **2 – Low**.

Plastics in the ocean, particularly abandoned fishing gear and lines, present a significant danger to sea turtle species. The S03, by facilitating removal of these materials from the ocean, presents a potential for long-term **Beneficial** impact to sea turtle species (**Section 5.2.1**).

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures that have proven effective to reduce potential impacts to sea turtles from attraction/ingestion of plastics:

- **Visual monitoring** – Monitoring during the project identifies sea turtles that may be near the tow vessels with:
  - EOs and the mounted thermal/RGB camera systems;
  - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations; and
  - Crew trained in sea turtle observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.
- **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped sea turtles and three bottom openings that could provide an escape route for sea turtles.
- **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.
- **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.
- **Rescue of animals** – Rescue attempts of entangled sea turtles are performed according to the project procedures.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements the likelihood component of impact consequence would be reduced to rare, resulting in a residual impact significance of **1 – Negligible**.

#### *5.2.5.4 Vessel – Physical Presence/Strikes*

Potential Impacts

There is a rare possibility of project vessels striking a sea turtle during transit or operations. Vessel strikes have been identified as a source of sea turtle injury and mortality and are among the threats affecting the endangered population status of several sea turtle species (National Research Council, 1990; Foley et al., 2019; NOAA unpublished data). Vessel strikes happen when a sea turtle or vessel fails to detect the other in time to react and avoid collision. Variables that contribute to the likelihood of a strike include vessel speed, vessel size and type, barriers to vessel detection by an animal (e.g., acoustic masking, heavy traffic, biologically focused activity), and, in some cases, mitigation measures. Most reports of vessel strikes involve large whales, but collisions with sea turtles have been reported (Foley et al., 2019).

When considering the level of commercial traffic off the western Canadian and U.S. coast, The Ocean Cleanup project activities do not significantly contribute to vessel traffic in the region. Studies indicate sea turtles are at the ocean surface only about 10% of the time and readily sound (dive) to avoid approaching vessels (Byles, 1989; Lohoefener et al., 1990; Keinath and Musick, 1993; Keinath et al., 1996). Based on these factors, the likelihood of a collision between a project vessel and a sea turtle is considered rare. In the event a vessel strikes a sea turtle, it could result in injury or mortality of the individual and an impact intensity of high. Due to the slow speed of the vessels during both transit (<14 knots) and operations (between 0.5 to 2.5 knots), collisions with sea turtles are not expected to occur with enough frequency to have population-level effects on any species, resulting in a moderate consequence. The likelihood of striking any sea turtle is considered rare. Overall impact significance is rated **2 – Low**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures that have proven effective to reduce potential impacts to sea turtles from vessel strikes:

- **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:
    - During transit between shore and the NPSG, vessels travel at slow speeds (<14 knots);
    - During towing in the NPSG, vessels travel at extremely slow speeds (0.5 to 2.5 knots);
    - MEIO mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 0.5 m $s^{-1}$, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the event of a protected species observed in the vicinity; and
    - Change in vessel direction to implement vessel strike avoidance.
- **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:
    - EOs and the mounted thermal/RGB camera systems;
    - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations; and
    - Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.
- **Turtle zone steering strategy** – avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region.

*Residual Impacts*

During Campaigns 1 through 12, there were 51 sea turtle sightings during the project activities and no vessel strike occurred. Collisions with sea turtles are not expected to occur with enough frequency to have population-level effects on any species. In addition, based on the mitigation measures The Ocean Cleanup implements two components of impact consequence—intensity and likelihood—would be reduced, resulting in a residual impact significance of **1 – Negligible**.

#### *5.2.5.5 Noise and Lights*

*Potential Impacts*

There is little information available regarding hearing and acoustic thresholds for sea turtles. However, what is known is that sea turtles have low-frequency hearing capabilities, typically hearing frequencies from 30 Hz to 2 kHz, with a maximum sensitivity range between 100 and 800 Hz (Ridgway et al., 1969; Lenhardt, 1994; Bartol and Ketten, 2006). Hearing below 80 Hz is less sensitive but may be important biologically (Lenhardt, 1994). Summaries of sea turtle hearing capabilities were prepared by Bartol (2014, 2017; Dow Piniak et al., 2012a; Dow Piniak et al., 2021b).

By species, hearing characteristics of sea turtles are as follows:

- **Loggerhead sea turtle** – Greatest sensitivities around 250 Hz or below for juveniles, with the range of effective hearing from at least 250 to 1,000 Hz (Lavender et al., 2012 a, b, c; 2014).
- **Green sea turtle** – Greatest sensitivities are from 300 to 500 Hz (Ridgway et al., 1969); juveniles and subadults detect sounds from 100 to 500 Hz underwater, with maximum sensitivity between 200 and 400 Hz (Bartol and Ketten, 2006) or between 50 and 400 Hz (Dow et al., 2008); peak response is at 300 Hz (Yudhana et al., 2010a).
- **Hawksbill sea turtle** – Greatest sensitivities between 50 and 500 Hz (Yudhana et al., 2010b).
- **Olive ridley sea turtle** – Juveniles of a congener (Kemp's ridley sea turtle [*Lepidochelys kempii*]) found to detect underwater sounds from 100 to 500 Hz, with maximum sensitivity between 100 and 200 Hz (Bartol and Ketten, 2006).
- **Leatherback sea turtle** – A lack of audiometric information is noted in this species. Their anatomy suggests hearing capabilities are similar to other sea turtle species, with functional hearing assumed to be 10 Hz to 2 kHz.

The current acoustic thresholds for injurious exposure (permanent threshold shift onset) and behavior from exposure to a continuous noise source, based on sea turtle hearing, is presented below in **Table 5-9**.

Table 5-9. Underwater acoustic thresholds from continuous sound (non-impulsive) for onset of permanent threshold shift and behavior threshold in sea turtles.

| Faunal Group | PTS[1] | | TTS[2] | | Behavior[3] | |
|---|---|---|---|---|---|---|
| | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value |
| Sea turtles | SPL | 180 dB re 1 µPa | - | - | SPL | 175 dB re 1 µPa |

- = not available; µPa = micropascal; dB = decibel; PTS = permanent threshold shift; re = referenced to; SPL = root-mean-square sound pressure level; TTS = temporary threshold shift.

[1] PTS threshold with injury is defined as the onset of potential mortal injury in sea turtles (Fisheries Hydroacoustic Working Group, 2008).

[2] TTS threshold is not available for sea turtles.

[3] Behavioral threshold derived from sea turtles (Blackstock et al., 2018).

Sounds can impact sea turtles in several ways: masking biologically significant sounds, altering behavior, trauma to hearing (temporary or permanent), and trauma to non-hearing tissue (barotraumas) (McCarthy, 2004). Anthropogenic noise, even below levels that may cause injury, can mask relevant sounds in the environment. Masking sounds can interfere with the acquisition of prey, affect the ability to locate a mate, diminish the ability to avoid predators, and, particularly in the case of sea turtles, adversely affect the ability to properly identify an appropriate nesting site (Nunny et al., 2008). However, there are no data demonstrating masking effects for sea turtles.

Based on transmission loss calculations (Urick, 1983), open water propagation of noise produced by typical sources using dynamic positioning thrusters are not expected to produce a root-mean-square sound pressure level ($SPL_{rms}$) greater than 160 dB re 1 µPa beyond 32 m from the source. Certain sea turtles, especially loggerheads, may be attracted to offshore structures (Lohoefener et al., 1990; Gitschlag et al., 1997; Colman et al., 2020) and thus more susceptible to impacts from sounds produced from dynamic positioning use during operations.

The most likely effects of vessel and equipment noise on sea turtles are behavioral changes. Vessel and equipment noise is transitory and generally does not propagate great distances from the vessel, and the source levels are too low to cause mortality or injuries such as auditory threshold shifts. Based on existing studies on the role of hearing in sea turtle ecology, it is unclear whether masking would realistically have any effect on sea turtles (Mrosovsky, 1972; Samuel et al., 2005; Nunny et al., 2008). Behavioral responses to vessels have been observed but are difficult to attribute exclusively to noise rather than to visual or other cues. It is conservative to assume noise associated with survey vessels may occasionally elicit behavioral changes in individual sea turtles near vessels. Behavioral changes may include evasive maneuvers such as diving or changes in swimming direction or speed, which would result in a low impact intensity. Evasive behavior is not expected to adversely affect individuals or the population, and impacts are not expected to be significant. Impact consequence from all noise sources to sea turtles is expected to be negligible.

Artificial lighting can disrupt the nocturnal orientation of sea turtle hatchlings (Tuxbury and Salmon, 2005; Berry et al., 2013; Simões et al., 2017). However, hatchlings may rely less on light cues when they are offshore than when they are emerging on the beach (Salmon and Wyneken, 1990). NMFS (2007) concluded the effects of lighting from offshore structures on sea turtles are insignificant. Therefore, no significant impacts are expected from lighting on the vessels. Therefore, given the likely nature of impact from noise and lights, the overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to sea turtles from noise and lights:

- **Elimination of unnecessary acoustic energy** – Levels of anthropogenic noise are kept as low as reasonably practicable. Sound generated by banana pingers is localized and well above hearing ranges of sea turtles.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.
- **Minimize nighttime lighting** – Light level on board the vessels is kept as low as reasonably practicable to maintain a safe work environment at night, and the number of lights is limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements two components of impact consequence—intensity and likelihood—would be reduced. The residual impact significance would remain **1 – Negligible**.

#### *5.2.5.6 Loss of Debris*

*Potential Impacts*

Disposal of trash and debris in the ocean is prohibited under MARPOL 73/78, and all project vessels will ensure adherence to MARPOL 73/78. However, the occasional and unintentional loss of debris may occur (e.g., floating trash, buckets containing paints or other chemicals). Materials accidentally lost overboard during the project may float on the ocean surface or within the water column (e.g., plastic bags, packaging materials). Floating debris, especially plastics and monofilament line, could entangle marine fauna or cause injury through ingestion. There is a remote possibility the S03 will fail or break apart at sea during deployment and become marine debris itself.

Marine debris is among the threats affecting the endangered population status of several sea turtle species (National Research Council, 1990). Ingestion of or entanglement with accidentally discarded debris can kill or injure sea turtles (Lutcavage et al., 1997). Leatherback and juvenile loggerhead sea turtles are especially attracted to floating debris, particularly plastic bags, because it resembles their preferred food, jellyfish. Ingestion of plastic and Styrofoam can result in drowning, lacerations, digestive disorders or blockage, and reduced mobility in sea turtles.

Taking into account the MARPOL 73/78 regulations, Impacts on sea turtles from the loss of debris are considered remote and would be of negligible consequence severity. Overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measure to reduce potential impacts to sea turtles from loss of debris:

- **Pollution prevention** – Compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence.

*Residual Impacts*

Based on compliance with MARPOL 73/78 the likelihood of impact consequence would remain the same as it is required of all vessels. The residual impact significance would remain **1 – Negligible**.

#### *5.2.5.7 Accidental Fuel Spill*

*Potential Impacts*

Diesel fuel in the marine environment may affect sea turtles through various pathways: direct contact, inhalation of diesel fuel or its volatile components, and ingestion of diesel fuel (directly or indirectly through the consumption of fouled prey species). Several aspects of sea turtle biology and behavior place them at risk, including lack of avoidance behavior, indiscriminate feeding in convergence zones, and inhalation of large volumes of air before dives (Milton et al., 2003). Diesel fuel can adhere to skin and shells. Sea turtles surfacing within or near a diesel fuel release likely would inhale petroleum vapors. Ingested diesel fuel, particularly the lighter fractions, can be toxic to sea turtles. Hatchling and juvenile sea turtles feed opportunistically at or near the surface in oceanic waters and are especially sensitive to released hydrocarbons (including diesel fuel), resulting in an impact of moderate intensity with minor consequence.

The likelihood of a fuel spill during project activities is considered remote, and the potential for contact with and impacts to sea turtles would depend heavily on the size and location of the spill as well as weather and sea conditions at the time of the spill. For this scenario, fuel spilled on the sea surface is assumed to rapidly spread to a thin layer and break into narrow bands, or windrows, aligned parallel to the wind direction. Lighter volatile components of the fuel would evaporate almost completely within a few days. Therefore, the impact consequence to sea turtles from an accidental diesel fuel spill is expected to be minor due to the low volume of the fuel spill, expected density of these resources, relatively short period of diesel fuel presence on the sea surface, and high degree of dissolution, spreading, and evaporation. The likelihood of impacts on sea turtles from a fuel spill is considered remote, and the overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to sea turtles from an accidental fuel spill:

- **SOPEP** – The Ocean Cleanup ensures a SOPEP is in place on all vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.
- **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.
- **No re-fueling at sea** – No re-fueling occurs at sea.
- **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements the likelihood of impact consequence would be reduced. The residual impact significance would remain **1 – Negligible**.

#### 5.2.5.8 Sea Turtle Impact Summary

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Removal of plastics and debris from the environment | Removal of plastics and other marine debris (e.g., ghost nets) from the North Pacific Subtropical Gyre will reduce the potential for sea turtle entanglement, ingestion of plastics, and impacts from the release of degradation byproducts (i.e., toxic chemicals). | | | | | |
| Entanglement or entrapment with the deployed S03 or accumulated debris | High | Regional | Short Term | Moderate | Occasional | 3 – Medium |
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Occasional | 2 – Low |
| Injury or mortality resulting from a vessel collision with a sea turtle | High | Immediate Vicinity | Short Term | Moderate | Rare | 2 – Low |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels); attraction to light | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Entanglement with or ingestion of debris accidentally lost | Low | Immediate Vicinity | Short Term | Negligible | Remote | 1 – Negligible |
| Diesel fuel exposure, including inhalation of vapors and ingestion | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |

*Mitigation Measures*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S03 or accumulated debris | • **Visual monitoring** – Monitoring during the project identifies sea turtles that may be near the tow vessels with:<br>○ EOs and the mounted thermal/RGB camera systems;<br>○ Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs and not all, but multiple cameras and lights will operate simultaneously for observations; and<br>○ Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for sea turtles.<br>• **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled sea turtles may be performed according to the project procedures.<br>• **Turtle zone steering strategy** – avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region. | Reduces Intensity<br><br>Reduces Intensity | Plastics Collection<br>2 – Low<br><br>Plastics Extraction<br>1 – Negligible |

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Attraction to S03; ingestion of congregated plastics resulting in injury or mortality | • **Visual monitoring** – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<br>  o EOs and the mounted thermal/RGB camera systems;<br>  o Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs and not all, but multiple cameras and lights will operate simultaneously for observations; and<br>  o Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and three bottom openings that could provide an escape route for sea turtles.<br>• **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled sea turtles may be performed according to the project procedures. | Reduces Likelihood | 1 – Negligible |

<table>
<tr><th>Impact</th><th>Mitigation Measures</th><th>Component of Impact Consequence Affected by Mitigation</th><th>Residual Impact Significance</th></tr>
<tr><td>Injury or mortality resulting from a vessel collision with a sea turtle</td><td><ul><li>Vessel operations –<ul><li>Between shore and the NPSG, transit vessels travel at slow speeds (<14 knots);</li><li>Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots);</li><li>Minimal Environmental Impact Operation mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 1 knot, or at a minimum speed to just keep the S03 in a U shape, which is implemented in the event of a protected species observed in the vicinity; and.</li><li>Change in vessel direction to implement vessel strike avoidance.</li></ul></li><li>Visual monitoring – Monitoring during the project identifies marine mammals that may be near the tow vessels with:<ul><li>EOs and the mounted thermal/RGB camera systems;</li><li>Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs and not all, but multiple cameras and lights will operate simultaneously for observations; and</li><li>Crew trained in marine animal observations and use of protected species identification posters displayed in select locations on board both vessels.</li></ul></li><li>Turtle zone steering strategy – avoidance of temperature and chlorophyll-a zones known to be preferred by loggerheads in the region.</li></ul></td><td>Reduces Intensity and Likelihood</td><td>1 – Negligible</td></tr>
<tr><td>Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (vessels), attraction to light</td><td><ul><li>Elimination of unnecessary acoustic energy – The levels of anthropogenic noise are kept as low as reasonably practicable. Sound generated by banana pingers is localized and well above the hearing ranges of sea turtles.</li><li>Visual cues – Use of green LED lights on the wings and RZ to enhance detectability of the System.</li><li>Limit lighting – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.</li></ul></td><td>Reduces Likelihood</td><td>1 – Negligible</td></tr>
<tr><td>Entanglement with or ingestion of debris accidentally lost</td><td><ul><li>Pollution prevention – Compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence.</li></ul></td><td>No change</td><td>1 – Negligible</td></tr>
</table>

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Diesel fuel exposure, including inhalation of vapors and ingestion | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on all vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels. | Reduces Likelihood | 1 – Negligible |
| Diesel fuel exposure, including inhalation of vapors and ingestion (cont.) | • **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings<br>• **No re-fueling at sea** – No re-fueling occurs at sea.<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces Likelihood | 1 – Negligible |

EO = environmental observer; MARPOL = International Convention for the Prevention of Pollution from Ships; NPSG = North Pacific Subtropical Gyre; RZ = retention zone.

### 5.2.6 Potential Impacts on Coastal and Oceanic Birds

#### *5.2.6.1 Impact-Producing Factors*

- S03 – Entanglement/Entrapment
- S03 – Attraction/Ingestion of Plastics
- Vessel – Physical Presence/Strikes
- Noise and Lights
- Loss of Debris
- Accidental Fuel Spill

For coastal and oceanic birds, the physical presence of the S03 and vessels and the attraction of birds to these (often due to lighting) are related and will be discussed together to avoid repetition.

#### *5.2.6.2 Entanglement/Entrapment and Attraction/Ingestion of Plastics; Vessel – Physical Presence/Strikes*

<u>*Potential Impacts*</u>

Many seabird species, such as frigatebirds, boobies, tropicbirds, albatrosses, gulls, jaegers, procellarid petrels, and some storm-petrels are attracted to offshore structures and vessels for a variety of reasons such as roosting sites, rest areas during migration, shelter during inclement weather, lighting, flaring, food availability, and other visual cues (Wall and Heinemann, 1979; Tasker et al., 1986; Montevecchi et al., 1999; Wiese et al., 2001; Black, 2005; Montevecchi, 2006; Ronconi et al., 2015). Additionally, some birds engage in ship-following as a foraging strategy, especially with commercial or recreational fishing vessels (Garthe and Huppop, 1994).

As such, birds in the project area may experience both beneficial impacts as well as negative impacts from the presence of the System and vessels. Some birds may use the System as a stopover site for resting and feeding, while others may be attracted to the lights and become engaged in nocturnal circulations (Russell, 2005; Montevecchi, 2006). During Campaigns 1 through 12, a total of 25 birds were observed resting on the vessels. Birds attracted to offshore structures may suffer mortality from collision or starvation (Russell, 2005; Montevecchi, 2006; Ellis et al., 2013; Ronconi et al., 2015). The presence of the System may also displace birds from otherwise suitable foraging habitat (Ronconi et al., 2015). However, the use of the System or vessels may increase the survivability of individuals using the structures to rest or for shelter during inclement weather in the open waters (Russell, 2005). The System may also provide additional foraging opportunities for seabirds (Tasker et al., 1986; Ronconi et al., 2015).

Birds using the System for roosting may be indirectly impacted by an increased possibility of entanglement or ingestion of plastic found in the NPSG. Birds such as albatrosses, petrels, shearwaters, storm-petrels, and diving petrels are recorded as ingesting more plastics than other bird groups (Blastic, 2017). In addition, these birds have small gizzards and many of them are unable to regurgitate indigestible items, making them even more vulnerable to the effects of plastic ingestion (Li et al., 2016). Plastic ingestion can affect foraging behavior, diet, breeding, molting, and distribution of species. The entanglement rate and amount of plastic ingested by seabirds varies with foraging practices, feeding technique, and diet (Li et al., 2016). During Campaigns 1 through 12, a total of 24 fatal vessel bird strike injuries of non-protected species occurred. Basic necropsies were performed on several birds, and the results determined there were plastics in their gastrointestinal tracts.

Pelagic seabirds feed according to three different methods: diving, plunge diving, or surface feeding (**Figure 5-10**). These three different feeding techniques affect the type of encounter birds have with marine plastic and the System. Birds that dive or plunge dive (e.g., albatross, boobies, gannets) have an increased chance of becoming entangled in debris, while surface feeders feeding on plankton have been shown to contain more plastic because it is easier to mistake plastic as food (Azzarello and Van Vleet, 1987; Li et al., 2016).

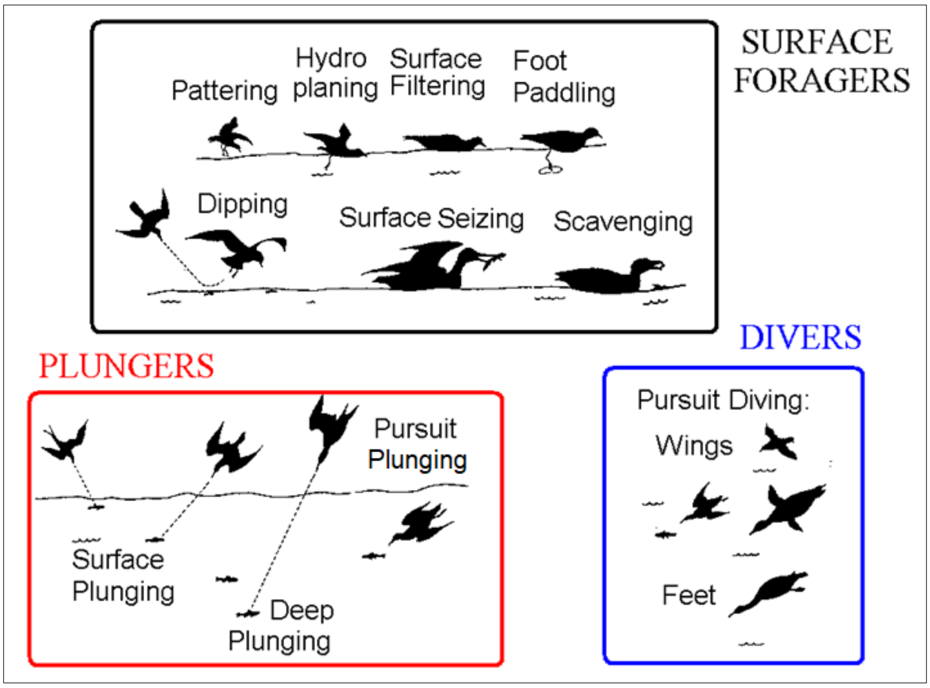



Figure 5-10. Seabird feeding modes (From: Nevins et al., 2005).

During Campaigns 1 through 12, very few birds were observed interacting with the System but were not captured within the RZ. For example, a Brown Booby was observed sitting on a System buoy and two Black-footed Albatrosses approached the System. From Cruises 1 through 12 there were a total of six birds that were captured within S002 as secondary bycatch, including two Northern fulmars (*Fulmarus glacialis*), one Leach's petrel (*Hydrobates leucorhous*), one storm petrel, and one albatross. These birds were highly decomposed carcasses, confirming that they were not impacted by the System, but rather retained within the RZ along with the marine debris.

The potential for bird strikes on a vessel is not expected to be significant to individual birds or their populations (Klem, 1989, 1990; Dunn, 1993; Erickson et al., 2005; Merkel, 2010). During Campaigns 1 through 12, there were 24 fatal vessel strike bird injuries of non-protected species, mostly Leach's Storm-petrels; however, most occurred close to land when the vessels were leaving the port in Ogden Point, Victoria. In addition, 25 stunned Leach's Storm-petrels were found on deck; all were placed in a dark, padded box to recover and 22 were released safely while three succumbed to their injuries. Given the rare likelihood of collision, mortality or serious injury to a significant number of individual birds is not expected, resulting in limited impacts to these types of seabirds from vessel attraction. Shorebirds are not known to be attracted to vessels. However, these birds may fly at lower altitudes during inclement weather conditions while migrating, which may increase the potential for a vessel strike.

Most impacts from operations and vessels would be short term and in the immediate vicinity of the NPSG or along vessel routes to and from port. Impacts likely would affect relatively few individuals or habitats as the majority of activities will occur far from the coastline and any sensitive bird habitats. Although rare, some mortality could occur for birds colliding with the tow vessels, resulting in a high impact intensity and moderate impact consequence; resulting in **2 – Low** impact significance for plastic collection operations. Impacts from such collisions are anticipated to affect relatively few birds and result in no population-level effects.

Plastics collection activities are not expected to significantly affect oceanic birds due to the low bird density at the remote deployment location in the NPSG. The long-term impacts of the System could be **Beneficial** for seabirds because the removal of plastics and other marine debris (e.g., ghost nets) from the NPSG will reduce the potential for seabird entanglement; ingestion of plastics; and impacts from the release of degradation byproducts (i.e., toxic chemicals).

Birds that use the System for resting or roosting could be indirectly impacted through a higher possibility of entanglement or ingestion of plastic found in the NPSG. Although rare, the possibility of harm or mortality of seabirds due to entanglement with the System or collected debris would result in a high impact intensity with a consequence severity of moderate. Therefore, impact consequence from entanglement/entrapment to coastal and oceanic birds is expected to range from minor to moderate for plastics collection operations. The likelihood of these impacts are remote, and the overall impact significance prior to mitigation is rated **2 – Low** for plastics collection operations prior to mitigation for plastic collection operations.

Any impacts on seabirds due to attraction would likely be short term and minor but impacts from plastic ingestion could cause chronic impacts to affected individuals. However, due to the relatively small size of the System and the low density of seabirds in the remote open ocean area of deployment and the data collected during Campaigns 1 through 12 which indicates a minimal number birds interacting with the System, impacts to seabirds from ingestion of plastics collected by the System would be remote and would result in impacts of moderate intensity and minor consequence resulting in **1 – Negligible** impact significance for attraction/ingestion of plastics for plastic collection operations.

During plastics extraction operations, when the System is towed by one vessel, at a slower speed, and with a narrowed wingspan (less than 5 m), the likelihood of a seabird becoming entangled is remote and is reduced from plastics collection operations. If a seabird becomes entangled, impact intensity, extent, duration, and consequence would remain the same as during plastics collection operations. Therefore, the overall impact significance rating of **2 – Low** would remain for plastics extraction operations prior to implementation of mitigation measures.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to coastal and oceanic birds from entanglement/entrapment, attraction, physical presence, and vessel strikes:

- **Visual monitoring** – Monitoring during the project identifies birds that may be near the tow vessels with:
  - EOs; and
  - Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs. Each will be directed to different areas of the RZ for increased camera coverage and not all, but multiple cameras and lights will operate simultaneously for observations.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.

- **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped birds and three bottom openings that could provide an escape route for diving birds.
- **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.
- **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.
- **Rescue of animals** – Rescue attempts of entangled birds may be performed according to the project procedures.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements during plastics collection operations and the short-term nature of the activities, two components of impact consequence — intensity and likelihood—would be reduced, resulting in a residual impact significance of **1 – Negligible** for plastics collection operations.

During S03 operations, the goal is to return the entire System to the water as quickly as possible (typically within 12 hours). Although the quick-release mitigation measure is not implemented during plastics extraction operations, the System is towed with the shortened RZ open behind one vessel, all other mitigation measures are in effect, and the vessel towing speed will be reduced to hold the wings in the current. Based on implementation of the mitigation measures and the reduced wingspan during extraction operations, the residual impact significance would remain **1 – Negligible** for plastics extraction operations.

#### *5.2.6.3 Noise and Lights*

*Potential Impacts*

Disturbance-related impacts to seabirds and other migratory birds from vessel noise and lights will vary depending on the type, intensity, frequency, duration, and distance to the disturbance source (Conomy et al., 1998; Blumstein, 2003). Seabirds may be affected by vessel noise in a variety of ways, including disturbance resulting in behavioral changes (Béchet et al., 2004; Agness et al., 2008; Schoen et al., 2013); selection of alternative habitats or prey that may be suboptimal; creating barriers to movement or decreasing available habitat (Bayne et al., 2008); decreases in foraging time and efficiency (Schwemmer et al., 2011); reduced time spent resting or preening (Tarr et al., 2010); and increases in energy expenditures due to flight behavior (versus resting, preening, or foraging) (Agness et al., 2008, 2013). The primary potential impacts to seabirds from vessel noise are from underwater sound generated by propeller(s), dynamic positioning, and machinery and would include behavioral modifications (e.g., disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels); and attraction to vessels lights.

Overall, disturbance-related impacts and behavioral changes do not typically result in direct mortality (Larkin et al., 1996; Carney and Sydeman, 1999). Birds disturbed by the presence of project vessels may flee a habitat and may or may not return. Displacement would be short term and transient in most cases and would not be expected to result in any lasting effects. Most underwater noise associated with vessels is low frequency (<200 Hz) (Richardson et al., 1995) and on the lower end of bird hearing range (Dooling and Popper, 2007). Potential impacts to diving seabirds are not expected to result in auditory injuries but will be limited to disturbance (behavioral) reactions (e.g., interruption of activities, short- or long-term displacement), resulting in low impact intensity. Due to the short-term duration of noise generated by the S03 operation, including vessels, impact consequence to birds from noise are expected to be negligible. Given the occasional nature of impacts from noise, overall impact significance prior to mitigation is rated **1 – Negligible**.

During Campaigns 1 through 5, there were 24 fatal vessel bird strike injuries (all non-protected species). All the strikes were associated with the birds being attracted to the vessel lights, but most occurred near Ogden Point as the vessels were leaving port. Impacts from lighting would include potential attraction to the vessels. Impact intensity, consequence, and likelihood associated with vessel strike and entanglement/entrapment is discussed in **Section 5.2.6.2**. Given the likely nature of impacts from lighting, overall impact significance prior to mitigation is rated **2 – Low**.

<u>*Mitigation Measures*</u>

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to coastal and oceanic birds from noise and lights:

- **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable. Sound generated by banana pingers is localized.
- **Minimize nighttime lighting** – Light level on board the vessels is kept as low as reasonably practicable to maintain a safe work environment at night, and the number of lights is limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.

<u>*Residual Impacts*</u>

Based on the mitigation measures The Ocean Cleanup implements the intensity and likelihood of impact consequence would be reduced, resulting in a residual impact significance of **1 – Negligible** for both noise and lights.

#### *5.2.6.4 Loss of Debris*

<u>*Potential Impacts*</u>

The disposal of trash and debris in the ocean is prohibited under MARPOL 73/78, and all project vessels will ensure adherence to MARPOL 73/78. However, the occasional and unintentional loss of debris may occur. Materials accidentally lost overboard during the project may float on the ocean surface or within the water column (e.g., plastic bags, packaging materials). Floating debris, especially plastics, poses a potential hazard to seabirds through entanglement and ingestion (Laist, 1987; Derraik, 2002; Li et al., 2016; Charlton-Howard et al., 2023). The ingestion of plastic by coastal and oceanic birds can cause obstruction and ulceration of the gastrointestinal tract, which can result in mortality (Li et al., 2016). In addition, accumulation of plastic in seabirds has been shown to be correlated with the body burden of polychlorinated biphenyls, which can cause lowered steroid hormone levels and result in delayed ovulation and other reproductive problems (Pierce et al., 2004). Additional impacts include blockage of gastric enzyme secretion, diminished feeding stimulus, reproductive failure, and adults that manage to regurgitate plastic particles could pass them onto the chicks during feeding (Derraik, 2002).

Seabirds are also vulnerable to entanglement encounters, which can lead to mortality (Li et al., 2016). The effects of entanglement can be summarized as drowning, suffocation, laceration, reduced fitness, a reduced ability to catch prey, or an increased probability of being entangled (Laist, 1987; Derraik, 2002; Li et al., 2016). The entanglement incidence for a species depends on its behavior (Derraik, 2002). The plunge-diving fishing method of some seabirds (e.g., gannets, boobies) has been shown to lead to a high rate of entanglement encounters, partly because the birds mistake floating plastic debris for fish or other food items (Li et al., 2016). This mode of feeding may be the primary reason for seabird entanglement encounters. The accidental loss of trash and debris associated with the operations and transit of The Ocean Cleanup activities is expected to be remote. As such, associated impact consequence is expected to be negligible. Overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measure to reduce potential impacts to coastal and oceanic birds from loss of debris:

- **Pollution prevention** – Verify compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence.

*Residual Impacts*

Based on adherence to MARPOL 73/78, the likelihood of impact consequence would remain the same as it is required of all vessels. The residual impact significance would remain **1 – Negligible**.

#### *5.2.6.5 Accidental Fuel Spill*

*Potential Impacts*

Direct contact of coastal and oceanic birds with diesel fuel, particularly in close proximity to the spill location, may result in the fouling or matting of feathers with subsequent limitation or loss of flight capability and insulating or water-repelling capabilities; irritation or inflammation of skin or sensitive tissues, such as eyes and other mucous membranes; and toxic effects from ingested or inhaled diesel fuel and its volatile components (Kennicutt et al., 1991; Mazet et al., 2002). However, impact consequences to coastal and oceanic birds from a diesel fuel spill are expected to be minor due to the low volume of fuel spilled, expected density of these resources, relatively short period of diesel fuel presence on the sea surface, and high degree of dissolution, spreading, and evaporation. The likelihood of impacts on coastal and oceanic birds from a fuel spill are considered remote, and the overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to coastal and oceanic birds from an accidental fuel spill:

- **SOPEP** – The Ocean Cleanup ensures a SOPEP is in place on all vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.
- **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.
- **No re-fueling at sea** – No re-fueling occurs at sea.
- **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements and the short-term nature of the activities, the likelihood of impact consequence would be reduced. The residual impact significance would remain **1 – Negligible**.

### 5.2.6.6 *Coastal and Oceanic Birds Impact Summary*

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Significance |
|---|---|---|---|---|---|---|
| Removal of plastics and debris from the environment | Removal of plastics and other marine debris (e.g., ghost nets) from the North Pacific Subtropical Gyre will reduce the potential for seabird entanglement, ingestion of plastics, and impacts from the release of degradation byproducts (i.e., toxic chemicals). | | | | | |
| Entanglement or entrapment with the deployed S03 | High | Immediate Vicinity | Short Term | Moderate | Rare | 2 – Low |
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Rare | 1 – Negligible |
| Behavioral modifications (e.g., disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels) | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Injury or mortality resulting from collision with a vessel due to attraction from lights | High | Immediate Vicinity | Short Term | Moderate | Rare | 2 – Low |
| Entanglement with or ingestion of debris accidentally lost | Low | Immediate Vicinity | Short Term | Negligible | Remote | 1 – Negligible |
| Diesel fuel exposure, including inhalation of vapors and ingestion | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |

*Mitigation Measures*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S03 | • **Visual monitoring** – Monitoring during the project identifies seabirds that may be near the tow vessels with:<br>o EOs; and<br>o Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs and not all, but multiple cameras and lights will operate simultaneously for observations.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Escape aids** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped birds and three bottom openings that could provide an escape route for diving birds.<br>• **Breathing rings/hatches** – Areas of floats are attached to multiple locations of the netting in the RZ to raise the netting to provide access to air for air-breathing animals.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled birds may be performed according to the project procedures. | Reduces Intensity and Likelihood | 1 – Negligible |

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Attraction to the S03; ingestion of congregated plastics resulting in injury or mortality | • **Visual monitoring** – Monitoring during the project identifies birds that may be near the tow vessels with:<br>o EOs; and<br>o Two camera skiffs each with eight cameras with integrated lights installed throughout the RZ for visual observations by the EOs and not all, but multiple cameras and lights will operate simultaneously for observations.<br>• **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, and the use of green LED lights on the wings and RZ to enhance detectability of the System.<br>• **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the RZ.<br>• **Rescue of animals** – Rescue attempts of entangled birds may be performed according to the project procedures. | Reduces Likelihood and Intensity | 1 – Negligible |
| Behavioral modifications (e.g., disruption of activities, departure from the area) from noise exposure; avoidance of noise sources (e.g., tow vessels) | • **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable. | Reduces Likelihood and Intensity | 1 – Negligible |
| Injury or mortality resulting from a collision to a vessel due to attraction from lights | • **Minimize nighttime lighting** – Light level on board the vessels is kept as low as reasonably practicable to maintain a safe work environment at night, and the number of lights is limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night. | Reduces Likelihood and Intensity | 1 – Negligible |
| Entanglement with or ingestion of debris accidentally lost | • **Pollution prevention** – Compliance with MARPOL 73/78 restrictions and implementation of vessel Waste Management Plans, reducing the likelihood of occurrence. | No change | 1 – Negligible |

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Diesel fuel exposure, including inhalation of vapors and ingestion | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on all vessels and an Oil Record Book, as required under MARPOL 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.<br>• **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.<br>• **No re-fueling at sea** – No re-fueling occurs at sea.<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces Likelihood | 1 – Negligible |

EO = environmental observer; MARPOL = International Convention for the Prevention of Pollution from Ships; RZ = retention zone.

### 5.2.7 Potential Impacts on Protected Areas

#### *5.2.7.1 Impact-Producing Factors*

- Vessel – Physical Presence/Strikes
- Accidental Fuel Spill

#### *5.2.7.2 Vessel Physical Presence/Strikes*

*Potential Impact*

Based on the route to the North Pacific Test site, The Ocean Cleanup vessels will transit past several coastal protected areas that can be avoided with strategic routing. However, once offshore, the likelihood of project vessels traversing a portion of the Endeavour Hydrothermal Vents MPA is high. No significant impacts are expected on this or other MPAs, but some minor disturbance of wildlife could occur due to vessel noise.

Wildlife in the MPAs likely have become accustomed to disturbances associated with vessel traffic due to the ubiquity of vessels originating from the Vancouver area and Victoria Harbour. Vessel strikes to wildlife are not expected to occur to resources within the MPAs; however, if a strike occurs, impacts could be significant and are discussed in **Sections 5.2.4**, **5.2.5**, and **5.2.6**. Impact consequence from the physical presence/strikes associated with project vessels to MPAs is expected to be negligible. Based on the short-term and transient nature of the transit through or adjacent to the MPAs, the likelihood of any impacts is rare and the overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to protected areas from vessel physical presence/strikes:

- **Strategic routing** – Avoid protected areas when practicable.
- **Vessel operations** – Vessel speeds are kept to a minimum for transit. Between shore and the NPSG, vessels will travel at slow speeds (<14 knots) and obey all separation scheme restrictions.

*Residual Impacts*

Based on the mitigation measures The Ocean Cleanup implements and the short-term nature of the activities, the likelihood of impact consequence would be reduced. The residual impact significance would remain **1 – Negligible**.

#### *5.2.7.3 Accidental Fuel Spill*

*Potential Impacts*

An accidental diesel spill in an MPA during vessel transit would dissipate rapidly and likely affect organisms only in the immediate vicinity of the release. Diesel fuel used for support vessels is light and would float on the water surface then rapidly disperse and weather, with volatile components evaporating.

Impacts to protected species, including marine mammals, sea turtles, and coastal and oceanic birds, will be similar to those previously noted for these resources (i.e., direct contact; inhalation of volatile components; ingestion, directly or indirectly through the consumption of fouled prey species; fouling or matting of feathers with subsequent limitation or loss of flight capability or insulating or water-repellent capabilities; and irritation or inflammation of skin or sensitive tissues).

Impact consequence to protected areas and habitats of concern from a diesel fuel spill is expected to be minor due to the low volume of a potential fuel spill, the relatively short period of diesel fuel presence on the sea surface, and the high degree of dissolution, spreading, and evaporation. The likelihood of impacts on protected areas from a fuel spill are considered remote, and the overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to wildlife within MPAs from an accidental fuel spill:

- **SOPEP** – The Ocean Cleanup ensures a SOPEP is in place on the towing, monitoring, and debris collection vessels, and an Oil Record Book, as required under MARPOL 73/78, is maintained.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.
- **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.
- **No re-fueling at sea** – No re-fueling occurs at sea.
- **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies.

*Residual Impact*

Based on the mitigation measures The Ocean Cleanup implements and the short-term nature of the activities, the likelihood of impact consequence would be reduced. The residual impact significance would remain **1 – Negligible**.

#### 5.2.7.4 *Protected Area Impact Summary*

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Significance |
|---|---|---|---|---|---|---|
| Disturbance of wildlife in marine protected areas from vessel transit | Low | Immediate Vicinity | Short Term | Negligible | Rare | 1 – Negligible |
| Exposure to diesel fuel, fouling of habitat | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |

*Mitigation Measures*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Disturbance of wildlife in marine protected areas from vessel transit | • **Strategic routing** – Vessels avoid protected areas when practicable.<br>• **Vessel operations** – Vessel speeds are kept to a minimum for transit. Vessels traveling between shore and the North Pacific Subtropical Gyre travel at slow speeds (<14 knots) and obey all separation scheme restrictions. | Reduces Likelihood | 1 – Negligible |
| Exposure to diesel fuel, fouling of habitat | • **Shipboard Oil Pollution Emergency Plan** (**SOPEP**) – The Ocean Cleanup ensures a SOPEP is in place on all vessels, and an Oil Record Book, as required under the International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78, is maintained.<br>• **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the survey vessels.<br>• **Fuel transfer protocols** – Strict fuel transfer procedures are implemented to prevent an accidental release during the loading of fuel at the port of mobilization. Fuel hoses will be equipped with dry-break couplings.<br>• **No re-fueling at sea** – No re-fueling occurs at sea.<br>• **Reporting procedures** – In the event of an accidental release of oil or other products, the incident will be immediately reported through the contractor chain of command to The Ocean Cleanup and regulatory bodies. | Reduces Likelihood | 1 – Negligible |

### 5.2.8 Potential Impacts on Commercial and Military Vessels

#### *5.2.8.1 Impact-Producing Factor*

- Vessel – Physical Presence/Strikes

#### *5.2.8.2 Vessel – Physical Presence/Strikes*

*Potential Impacts*

The Ocean Cleanup vessels will transit through the Strait of Juan de Fuca and the Salish Sea when traveling to and from Victoria Harbour. As described in **Section 4.4.1**, The Ocean Cleanup vessels will monitor NOTSHIP notifications prior to and during transit from the port. Once offshore, the project vessels are not expected to interact with commercial or recreational vessels; however, numerous vessels of these types will be located along the route. Additionally, military vessels may be present in the vicinity of Canadian Forces Base Esquimalt as The Ocean Cleanup vessels are transiting past.

The project vessels are not expected to pass through any Military Warning Areas, and no impacts on military training activities are expected. The Ocean Cleanup will comply with any Canadian military mandated area restrictions.

The impact consequence from vessel operations is expected to be negligible for commercial and military vessels. Given the short-term but likely nature of this impact, overall impact significance prior to mitigation is rated **1 – Negligible**.

*Mitigation Measures*

The Ocean Cleanup implements the following mitigation measures to reduce potential impacts to commercial and military vessels from vessel collisions:

- **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:
  - Between shore and the NPSG, transit vessels travel at slow speeds (<14 knots); and
  - Tow vessels in the NPSG travel at extremely slow speeds (0.5 to 2.5 knots).
- **Monitor notifications** – Vessels monitor NOTSHIP notifications prior to and during transit from the port.

*Residual Impact*

Based on the mitigation measures that The Ocean Cleanup implements and the short-term nature of the activities, the residual impact significance would remain **1 – Negligible**.

#### 5.2.8.3 *Commercial and Military Vessels Impact Summary*

*Impact Rating*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Significance |
|---|---|---|---|---|---|---|
| Temporary increase in vessel traffic | Low | Immediate Vicinity | Short Term | Negligible | Likely | 1 – Negligible |

*Mitigation Measures*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Temporary increase in vessel traffic | • **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:<br>○ Transit vessels traveling between shore and the North Pacific Subtropical Gyre travel at slow speeds (<14 knots); and<br>○ Tow vessels in the North Pacific Subtropical Gyre travel at extremely slow speeds (0.5 to 2.5 knots).<br>• **Monitor notifications** – Vessels monitor Notices to Shipping notifications prior to and during transit from the port. | None | 1 – Negligible |

# 6 Conclusions

The Ocean Cleanup is committed to adaptively managing activities and data collection to better characterize the potential impacts to the environment from project operations. One means of adaptive management is the implementation of active monitoring and using the data collected to modify the project methodologies and improve future designs of plastics collection systems. It is from this adaptive management approach and applying the data and knowledge collected from the completed campaigns that the design changes have been made to S03. These include a larger RZ, deeper wings, and longer wings. In addition, numerous mitigation measures have been improved upon and include, but are not limited to, three bottom openings in the RZ for additional escape routes, breathing rings/hatches in the RZ, improved camera skiff, additional green LED lights for visualization, and turtle zone steering strategy to avoid temperature and chlorophyll-a zones know to be preferred by loggerhead sea turtles.

A preliminary screening was completed (**Section 4.1**) to identify the biological and social resources at risk from the transit and deployment of the S03 in the NPSG. Resources that were determined to not be affected by the S03 or where impact consequences were deemed, *a priori*, to be negligible were air quality, sediment quality, water quality, benthic communities, human resources, land use and economics, recreational resources and tourism, and physical oceanography. An impact assessment on the remaining resources (plankton and neuston, fish/fishery resources, marine mammals, sea turtles, coastal and oceanic birds, protected areas, commercial and military vessels) was conducted from a risk-based perspective to determine the overall significance of each potential impact based on its intensity, extent, duration, consequence, and likelihood.

Biodiversity was included in the screening process, and it was determined that there is still not enough information at this time to fully address biodiversity impacts from the S03. After analyzing the plankton data collected during the 12 campaigns and reviewing potential Ecopath models, it was determined that the potential for developing an EwE model specific to the NPSG appears viable to assess the potential effects of removing a portion of the neuston on ecosystem dynamics. The most appropriate EwE candidate appears to be Godinot and Allain (2003), with further development of a simplified food web diagram. However, additional work is necessary to complete this effort (**Appendix E**). The data from the S002 campaigns may be used in an EwE model to better evaluate biodiversity in the future.

Impacts provided are based on the data obtained during Campaigns 1 through 12. Deployment of the previous S002 tested the efficacy of the System design as well as applied mitigation measures. Many of the design features and mitigation measures have proven to be effective in reducing potential impact to the environment and have been maintained and enhanced in the S03 design. As anticipated, the underwater cameras have been instrumental in reducing potential impacts by providing observations of protected species within the RZ. EOs as well as the underwater cameras and drone and underwater inspections identified sea turtles captured by the System and allowed for mitigation actions to be implemented to rescue the captured sea turtles. In addition, EOs have observed sea turtles and marine mammals in the path of the vessels and the System and been able to take mitigative measures (e.g., changing course, dead stop of vessel, slowed speed) to minimize risk to the animals from vessel strike or entanglement. As noted, the underwater camera system has been enhanced continuously and a more robust system is included in the S03 design, which should allow for even better detection of sea turtles that may be captured in the RZ. The impact analysis was performed on a resource-by-resource basis and could not fully consider impacts at the ecosystem level; however, where possible this has been discussed. As such, the analysis does not fully address potential impacts on the trophic cascade and food web and community structures; this component is complex and discussed further in **Appendix E**.

The net environmental benefit of plastic removal from the environment is also a complex topic; therefore, a literature review and NEBA-type analysis were previously performed (**Appendix B**). Comparing relative impacts associated with plastic removal versus no action (i.e., leaving plastic debris in the ocean), it can be concluded that removal of ocean plastics by the S03 provides a greater environmental benefit than leaving the plastic in the ocean for all marine resources, including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston.

An impact assessment of the removal of neuston (including ichthyoplankton) is difficult considering the variability within the community. The distribution and abundance of neuston species in the NPSG is largely unknown, further limiting the confidence level afforded any impact determination. Net sampling has provided some insight to the species present during Campaigns 1 through 12. Samples have predominantly consisted of crustaceans, with lesser amounts of tunicates and chaetognaths. In addition, the quantity of neuston, particularly *V. velella*, that is of potential concern based on their size and densities reported (Egger et al., 2021; The Ocean Cleanup, unpublished) that were anticipated could be captured by the System have not been observed in the net samples in high numbers nor captured in the System in the bycatch in significant numbers or clogging the System mesh.

The initial analysis of routine operations (i.e., prior to application of mitigation measures) produced impact determinations that were predominantly in the Negligible or Low categories, with sea turtles identified as Medium. Impacts from an accidental fuel spill were identified based on the accidental release of diesel fuel. Given the relatively small potential spill volume and weathering factors, the impacts to various resources from a fuel spill release were rated Negligible.

The Ocean Cleanup has prepared and implemented an EMP to identify and describe mitigation measures employed to reduce or eliminate the potential environmental impacts identified in this EIA. The EMP is continually updated as data and observations are made during the campaigns. Overall, when proper mitigation measures, maritime regulations, and industry best practices are applied, the significance of potential impacts of the project activities have been determined to be Negligible or Low for all resources for continuous operations based on the information obtained to date. Additionally, the long-term positive impacts of removing large amounts of floating plastic from the NPSG will likely benefit all biological resources in the region.

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# Appendices

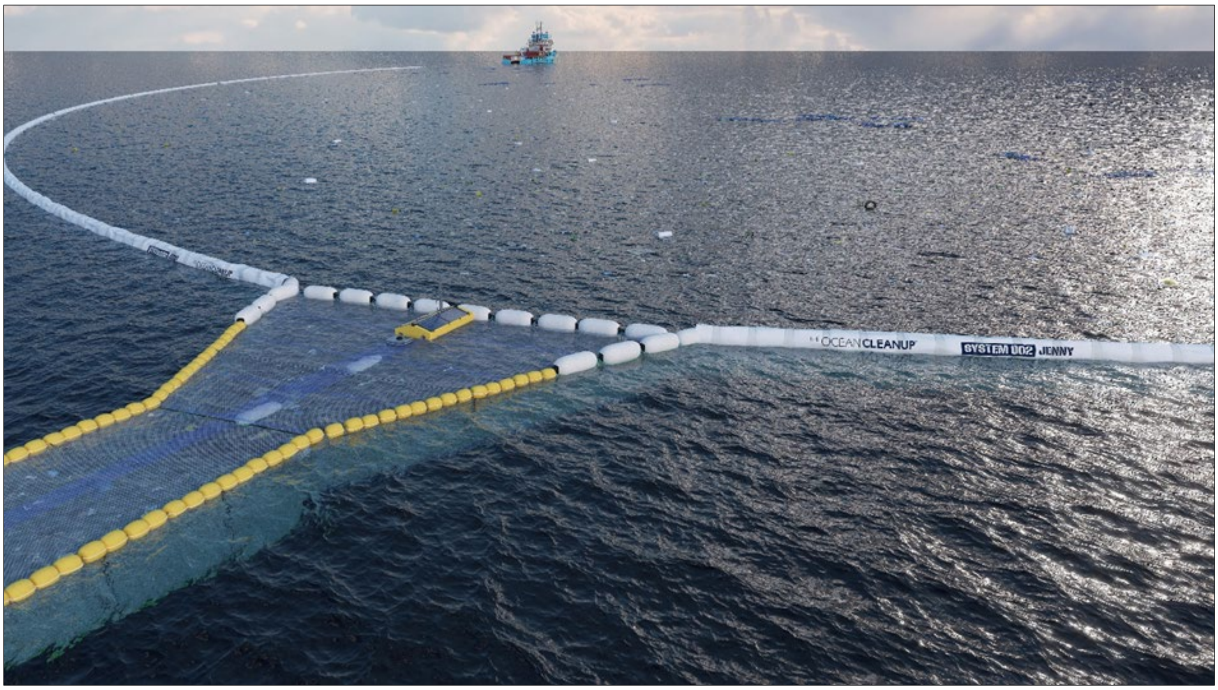
## Appendix A

## Environmental Impact Assessment Addendum – S002A/B

# The Ocean Cleanup

## Final S002 Environmental Impact Assessment Addendum

April 2023





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**THE OCEAN CLEANUP**

**S002 ENVIRONMENTAL IMPACT ASSESSMENT ADDENDUM**

DOCUMENT NO. CSA-THEOCEANCLEANUP-FL-22-81581-3648-PO741-005-REP-01-FIN

| Internal review process | | | | | |
|---|---|---|---|---|---|
| Version | Date | Description | Prepared by: | Reviewed by: | Approved by: |
| INT-01 | 08/09/2022 | Initial draft for science review | K. Olsen | R. Cady | K. Olsen |
| INT-02 | 08/18/2022 | TE review | K. Olsen | A. Lawson | K. Olsen |

| Client deliverable | | | |
|---|---|---|---|
| Version | Date | Description | Project Manager Approval |
| 01 | 08/25/2022 | Client deliverable | K. Olsen |
| FIN | 04/13/2023 | Final | K. Olsen |
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**BACKGROUND**

The Ocean Cleanup is updating their existing Ocean System (S002) that collects buoyant plastic debris from within the North Pacific Subtropical Gyre (NPSG) to expand the size of components of the System and collect additional operational data as they transition to their full-scale system currently under design, S03. This environmental impact assessment (EIA) addendum evaluates the potential impacts from the two design modifications to the existing S002 which will transform into S002A and S002B with a larger retention zone (RZ) and deeper wings, respectively (**Table ES-1**). Mitigation measures developed for S002 will be carried forward with new measures introduced for both S002A and S002B (**Table ES-2**).

**PURPOSE AND NEED**

The Ocean Cleanup has developed an updated S002 to collect buoyant plastic debris from within the NPSG. Specifically, The Ocean Cleanup is focusing on the area known as the Great Pacific Garbage Patch (GPGP), located roughly midway between California and Hawaii and approximately 2,250 km from The Ocean Cleanup mobilization port of Victoria-Vancouver, British Columbia. The existing S002 comprises a retention system (RS) and RZ that is towed by two vessels. The existing RS comprises two wings, each 391 m in length, designed to guide plastics greater than 10 mm in size into the RZ. The RS can be adjusted between a minimum span of 195 m and a maximum span of 700 m for standard plastics collection operations.

This addendum examines potential impacts to resources that could be affected from the modifications to the existing S002 as it transitions to S002A and S002B. Modifications include an increase in the length of the RZ to 70 m for S002A, and deeper (4 m) wings for S002B. The first step in the evaluation will be to screen the resources that were evaluated in the Revised S002 EIA (CSA, 2022) to determine if the System modifications have the potential to impact them, then impact determinations will be presented for those resources.

**ENVIRONMENTAL IMPACT ASSESSMENT ADDENDUM SUMMARY**

**Reason for Changes**

The Ocean Cleanup is committed to adaptively managing activities and data collection to better characterize the potential impacts to the environment from project operations. One means of adaptive management is the implementation of active monitoring and the use of the data collected to modify the project methodologies and improve future designs of plastics collection systems. For example, based on field data, the original RZ was modified to add in an 8-m extension section to reduce the drag on the system. It is from this adaptive management approach and through applying the data and knowledge collected from the completed campaigns, that the larger RZ with additional mitigation measures (S002A) and deeper wings (S002B) are being implemented as The Ocean Cleanup moves toward their full-scale System design.

Implementing the larger RZ (S002A) will allow more room for the plastics to collect within the RZ and reduce the potential for plastics blocking the view of the camera skiff system and the active monitoring for protected species within the RZ.

The deeper wings are being implemented to alleviate underflow of plastics beneath the wings thereby increasing collection efficiency.

**Project Design Modification Overview**

There are two primary design changes to the current S002, the first includes a larger RZ (S002A) and the second includes deeper wings (S002B). As described above, the current S002 RZ includes an additional 8-m extraction net extension.

Table ES-1. Summary of design parameters for S002, S002A, and S002B.

| Defined Parameters | Original S002 | Current S002 | S002A | S002B |
|---|---|---|---|---|
| RZ length | 39 m | 48 m | 70 m | 70 m |
| RZ width | 5 m | 5 m | 5.5 m | 5.5 m |
| RZ depth | 2 m | 2 m | 2.2 m | 2.2 m |
| RZ volume | 644.3 $m^3$ | 644.3 $m^3$ | 2,016.4 $m^3$ | 2,016.4 $m^3$ |
| RZ entrance length | 10 m | 10 m | 29 m | 29 m |
| RZ safe section length | 11.2 m | 18.7 | 19 m | 19m |
| RZ extraction section length | 17.8 m | 17.8 m | 22 m | 22 m |
| RZ mesh size | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer |
| Wing length | 391 m (per wing) | 391 m (per wing) | 391 m (per wing) | 391 m (per wing) |
| Wing depth | 3 m constant | 3 m constant | 3 m constant | 4 m constant |
| Wing height above water | 0.4 m | 0.4 m | 0.4 m | 0.4 m |
| Wing module length | 23 m (17 modules per wing) | 23 m (17 modules per wing) | 23 m (17 modules per wing) | 23 m (17 modules per wing) |
| Net mesh size | 10 mm (square) | 10 mm (square) | 10 mm (square) | 16 mm (square) |
| Wing top section | Permeable screen | Permeable screen | Permeable screen | Permeable screen |

RZ = retention zone.

**Added Mitigation Measures**

Table ES-2. Summary of mitigation measures between the System designs.

| Mitigation Measure | S002 | S002A | S002B |
|---|---|---|---|
| Number of fyke openings | 1 | 3 | 3 |
| Number of breathing hatches | 2 | 4 | 4 |
| Number of high-frequency acoustic pingers (RZ/wings) | 1/6 | 5/6 | 5/8 |
| Number of green flashing lights (RZ/wings) | 1/22 | 16/22 | 16/22 |

**Potential Impacts from Project Changes**

As determined by the screening, the following resources were determined to be at risk of changes to the impacts due to the design changes for S002A and S002B:

- Plankton and Neuston;
- Fish/Fishery Resources;
- Marine Mammals; and
- Sea Turtles.

All mitigation measures included in the S002 will remain in effect and are included in the base impact analysis of impacts prior to implementing the additional mitigation measures. Therefore, the starting point for impact determinations is the residual impacts from the Revised S002 EIA (CSA, 2022). In addition, all additional mitigation measures associated with S002A will remain in effect for S002B; therefore, the starting point for S002B impacts is the residual impact from S002A and evaluates only additional mitigation measures associated with S002B.

A tabular summary of residual impacts from plastic collection operations is presented below. With the additional mitigation measures associated with S002A and S002B along with the existing mitigation measures currently applied for S002, that will remain in place, the significance of potential impacts of the project activities will generally be Negligible or Low. Moreover, The Ocean Cleanup has removed approximately 64,833 kg of plastics during the first seven campaigns in the NPSG, which will have long-term positive (beneficial) impacts to biological resources in the area as presented in Appendix B of the Revised S002 EIA (CSA, 2022).

### *Plankton and Neuston Impact Summary*

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Low to Moderate | Local to Regional | Short Term | Negligible to Minor | Likely | Plastics Collection 1 – Negligible to 2 – Low |
| | Low | | | | Rare | Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to System) from lights | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |

*Mitigation Measures – S002A*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • None applied | None | Plastics Collection 1 – Negligible to 2 – Low<br>Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to the System) from lights | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability that will reduce shining on the water at night. | None | 1 – Negligible |

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Low to Moderate | Local to Regional | Short Term | Negligible to Minor | Likely | Plastics Collection<br>1 – Negligible to<br>2 – Low |
| | | | | | Rare | Plastics Extraction<br>1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to System) from lights | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • None applied<br>• Changed design to increase wing mesh to 16 mm square | None | Plastics Collection<br>1 – Negligible to<br>2 – Low<br>Plastics Extraction<br>1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to the System) from lights | • **Limit lighting** – The additional navigational lights on the system S002B will flash intermittently to reduce shining light on the water at night. | None | 1 – Negligible |

### *Fish and Fishery Resources*

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002A | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Attraction to the S002A and ingestion of plastics collected | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to lights | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |

*Mitigation Measures – S002A*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S002A | • **Additional escape aids** – The larger RZ includes 2 additional fyke openings to allow fish additional escape routes if accidentally collected by the System.<br>• **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | Plastics Collection 2 – Low<br>Plastics Extraction 1 – Negligible |
| Attraction to the S002A and ingestion of plastics collected | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | Plastics Collection 2 – Low<br>Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | • None applied | None | 1 – Negligible |
| Attraction to lights | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights which will reduce shining light on the water at night. | None | 2 – Low |

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002B | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Attraction to the S002B and ingestion of plastics collected | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to lights | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S002B | • None applied<br>• Changed design to increase wing mesh to 16 mm square | None | Plastics Collection<br>2 – Low<br><br>Plastics Extraction<br>1 – Negligible |
| Attraction to the S002B and ingestion of plastics collected | • None applied | None | Plastics Collection<br>2 – Low<br><br>Plastics Extraction<br>1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | • None applied | None | 1 – Negligible |
| Attraction to lights | • **Limit lighting** – The additional navigational lights on S002B will flash intermittently to reduce shining light on the water at night. | None | 2 – Low |

### ***Marine Mammals***

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Moderate (Non-Protected Species) | Immediate Vicinity (Non-Protected Species) | Short Term (Non-Protected Species) | Minor (Non-Protected Species) | Remote | Plastics Collection Non-Protected Species 1 - Negligible |
| | High (Protected Species) | Regional (Protected Species) | Long-Term (Protected Species) | Moderate (Protected Species) | | Plastics Collection Protected Species 2 – Low |
| | Moderate | Immediate Vicinity | Short Term | Minor | Remote | Plastics Extraction 1 - Negligible |
| Attraction to the S002A; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*Mitigation Measures – S002A*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • **Additional escape aids** – The larger RZ includes 2 additional fyke openings to allow small marine mammals additional escape routes if accidentally collected by the System.<br>• **Breathing ports** - The larger RZ includes 2 additional breathing hatches that incorporates a new design.<br>• **Acoustic deterrent** – The larger RZ includes 4 additional banana pingers to deter the approach of marine mammals.<br>• **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability.<br>• **RZ access openings** – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a marine animal enters the RZ. | Reduced intensity and likelihood | Plastics Collection Non-Protected Species 1 - Negligible<br>Plastics Collection Protected Species 2 – Low<br>Plastics Extraction 1 - Negligible |
| Attraction to the S002A; ingestion of congregated plastics resulting in injury or mortality | • **Acoustic deterrent** – The larger RZ includes 4 additional banana pingers to deter the approach of marine mammals.<br>• **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | • **Acoustic deterrent** – The larger RZ includes 4 additional banana pingers to deter the approach of marine mammals. | None | 1 – Negligible |
| Attraction to System lights | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | Beneficial |

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Moderate (Non-Protected Species) | Immediate Vicinity (Non-Protected Species) | Short Term (Non-Protected Species) | Minor (Non-Protected Species) | Remote | Plastics Collection Non-Protected Species 1 - Negligible |
| | High (Protected Species) | Regional (Protected Species) | Long-Term (Protected Species) | Moderate (Protected Species) | | Plastics Collection Protected Species 2 – Low |
| | Moderate | Immediate Vicinity | Short Term | Minor | Remote | Plastics Extraction 1 - Negligible |
| Attraction to the S002B; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • **Acoustic deterrent** –The deeper wings include 2 additional banana pingers attached to the wings spaced throughout the wings. | None | Plastics Collection Non-Protected Species 1 - Negligible<br>Plastics Collection Protected Species 2 – Low<br>Plastics Extraction 1 - Negligible |
| Attraction to the S002B; ingestion of congregated plastics resulting in injury or mortality | • **Acoustic deterrent** –The deeper wings include 2 additional banana pingers attached to the wings spaced throughout the wings. | None | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | • **Acoustic deterrent** –The deeper wings include 2 additional banana pingers attached to the wings spaced throughout the wings. | None | 1 – Negligible |
| Attraction to System lights | • None applied | None | Beneficial |

### *Sea Turtles*

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002A or accumulated debris | High | Regional | Short Term | Moderate | Rare | Plastics Collection<br>2 – Low |
| | Moderate | | | | Remote | Plastics Extraction<br>1 – Negligible |
| Attraction to the S002A; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*Mitigation Measures – S002A*

<table>
<tr><th>Impact</th><th>Mitigation Measures</th><th>Component of Impact Consequence Affected by Mitigation</th><th>Residual Impact Significance</th></tr>
<tr><td rowspan="2">Entanglement or entrapment with the deployed S002A or accumulated debris</td><td rowspan="2">• Additional escape aids – The larger RZ includes two additional fyke openings to allow sea turtles additional escape routes if accidentally collected by the System.<br>• Breathing ports - The larger RZ includes 2 additional breathing hatches that incorporates a new design.<br>• Visual Cues – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability.<br>• RZ access openings – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a sea turtle enters the RZ.</td><td>Reduces Intensity and Likelihood</td><td>Plastics Collection<br>1 – Negligible</td></tr>
<tr><td>None</td><td>Plastics Extraction<br>1 – Negligible</td></tr>
<tr><td>Attraction to S002A; ingestion of congregated plastics resulting in injury or mortality</td><td>• Additional escape aids – The larger RZ includes two additional fyke openings to allow sea turtles additional escape routes if accidentally collected by the System.<br>• Breathing ports - The larger RZ includes 2 additional breathing hatches that incorporates a new design.<br>• Visual cues – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability.<br>• RZ access openings – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a sea turtle enters the RZ.</td><td>None</td><td>1 – Negligible</td></tr>
<tr><td>Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights</td><td>• None applied</td><td>None</td><td>1 – Negligible</td></tr>
<tr><td>Attraction to System lights</td><td>• Visual cues – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability.</td><td>None</td><td>Beneficial</td></tr>
</table>

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002B or accumulated debris | High | Regional | Short Term | Moderate | Rare | Plastics Collection 2 – Low |
| | Moderate | | | | Remote | Plastics Extraction 1 – Negligible |
| Attraction to the S002B; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S002B or accumulated debris | • None applied | None | 1 – Negligible |
| Attraction to S002B; ingestion of congregated plastics resulting in injury or mortality | • None applied | None | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights | • None applied | None | 1 – Negligible |
| Attraction to System lights | • None applied | None | Beneficial |

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|---|---|
| μPa | micropascal |
| AIS | Automatic Identification System |
| dB | decibels |
| EIA | environmental impact assessment |
| EMP | environmental management plan |
| FRC | fast rescue craft |
| GPS | global positioning system |
| HDPE | high-density polyethylene |
| IPF | impact-producing factor |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| MEIO | Minimal Environmental Impact Operation |
| NMFS | National Marine Fisheries Service |
| NPSG | North Pacific Subtropical Gyre |
| PSO | protected species observer |
| PTS | permanent threshold shift |
| re | referenced to |
| RS | retention system |
| RZ | retention zone |
| S002 | The Current Ocean Cleanup Ocean System |
| $SEL_{24h}$ | sound exposure level over 24 hours |
| SPL | root-mean-square sound pressure level |
| TTS | temporary threshold shift |

## 1.1 INTRODUCTION

The Ocean Cleanup is updating their existing Ocean System (S002) that collects buoyant plastic debris from within the North Pacific Subtropical Gyre (NPSG) to expand the size of components of the System and collect additional operational data as they transition to their full-scale system currently under design, S03. This environmental impact assessment (EIA) addendum evaluates the potential impacts from the two design modifications to the existing S002 which will transform into S002A and S002B with a larger retention zone (RZ) and deeper wings, respectively. Mitigation measures developed for S002 will be carried forward with new measures introduced for both S002A and S002B.

## 1.2 BACKGROUND OF THE PROJECT

The Ocean Cleanup has developed an updated S002 to collect buoyant plastic debris from within the NPSG. Specifically, The Ocean Cleanup is focusing on the area known as the Great Pacific Garbage Patch (GPGP), located roughly midway between California and Hawaii (**Figure 1**) and approximately 2,250 km from The Ocean Cleanup mobilization port of Victoria-Vancouver, British Columbia. The existing S002 comprises a retention system (RS) and RZ that is towed by two vessels (**Image 1**). The existing RS comprises two wings, each 391 m in length, designed to guide plastics greater than 10 mm in size into the RZ. The RS can be adjusted between a minimum span of 195 m and a maximum span of 700 m for standard plastics collection operations.

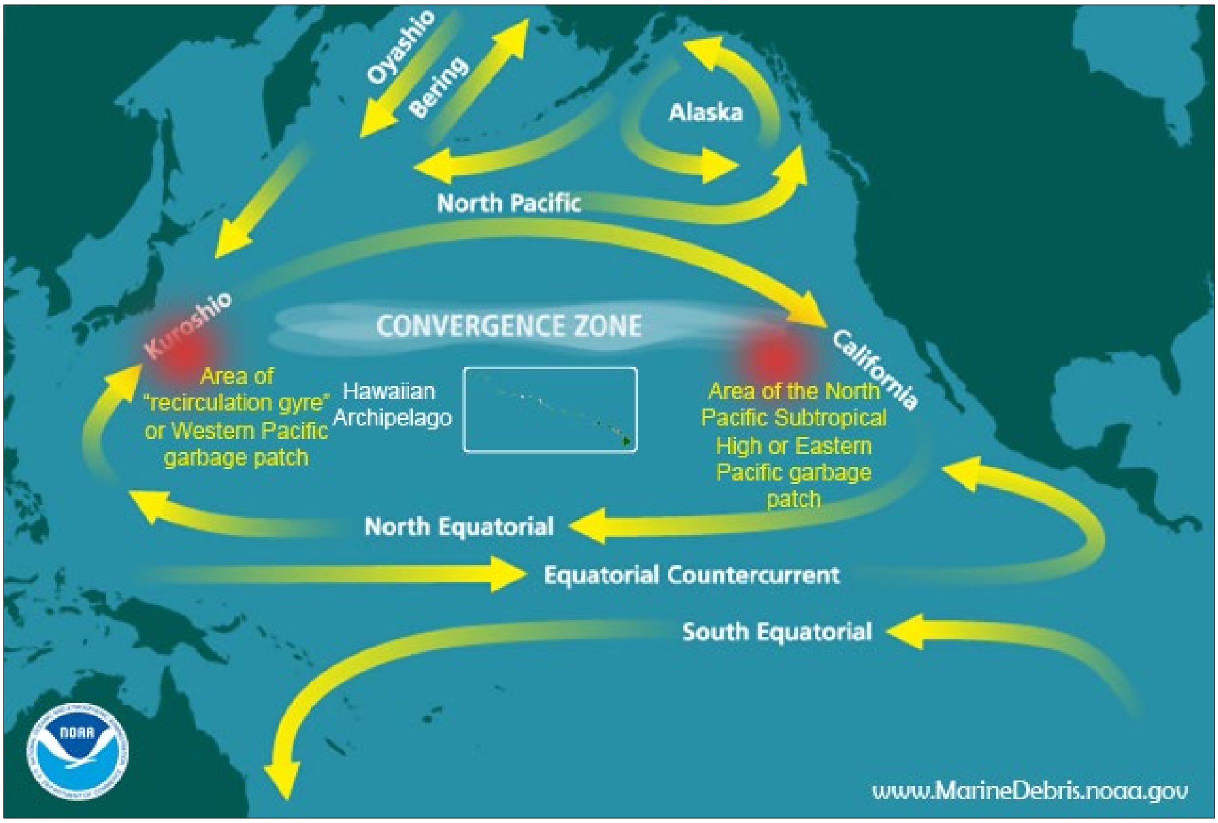



Figure 1. Map showing the major oceanic currents and zones in the North Pacific and the locations of Western and Eastern Pacific Garbage Patches.

Image 1. Towing lines (connected to each ship), retention system (white wings and submerged net), and retention zone (blue and yellow net attached to the back of the retention system).

The Ocean Cleanup has completed nine 6-week campaigns with S002 in the NPSG, with the tenth campaign currently under way. There are plans for continued campaigns (11 and 12) until December 2022. Fabrication and assembly of the S002 were completed and the original System was deployed in summer 2021. The S002 is modular in design and was transported from Norway in 40-ft containers to Canada and mobilized onto the M/V *Maersk Tender* or M/V *Maersk Trader* for transport to site.

## 1.3 THE OCEAN CLEANUP SYSTEM S002 DESIGN

The Ocean Cleanup developed the S002 with an RS and RZ that are towed by two vessels (**Images 1** and **2**). The RS comprises two wings, each 391 m in length. The RS span can be adjusted depending on the intended operation mode:

- Gathering mode allows for a maximum span of 700 m to capture plastic between the wings and transport it along the wings to the RZ;
- Nominal mode has a span of 520 m, which is the standard operational mode and has the optimum factor of span to length; and
- Minimum capturing mode has a span of 195 m for vessel safety.

During operations, The Ocean Cleanup adjusts the span distance to allow for large quantities of plastics to travel to the RZ. The RS wings are designed to gather and guide plastics greater than 10 mm in size into the RZ, minimize underflow, minimize overtopping, minimize bycatch, and limit drag. The wing design parameters are detailed in **Table 1**. The wings have a modular design, allowing them to fit onto one T-class vessel deck (the modules fit into 40-ft containers), and can be easily connected to the tow rigging. Each wing module is 23 m long, and 17 modules compose one wing.

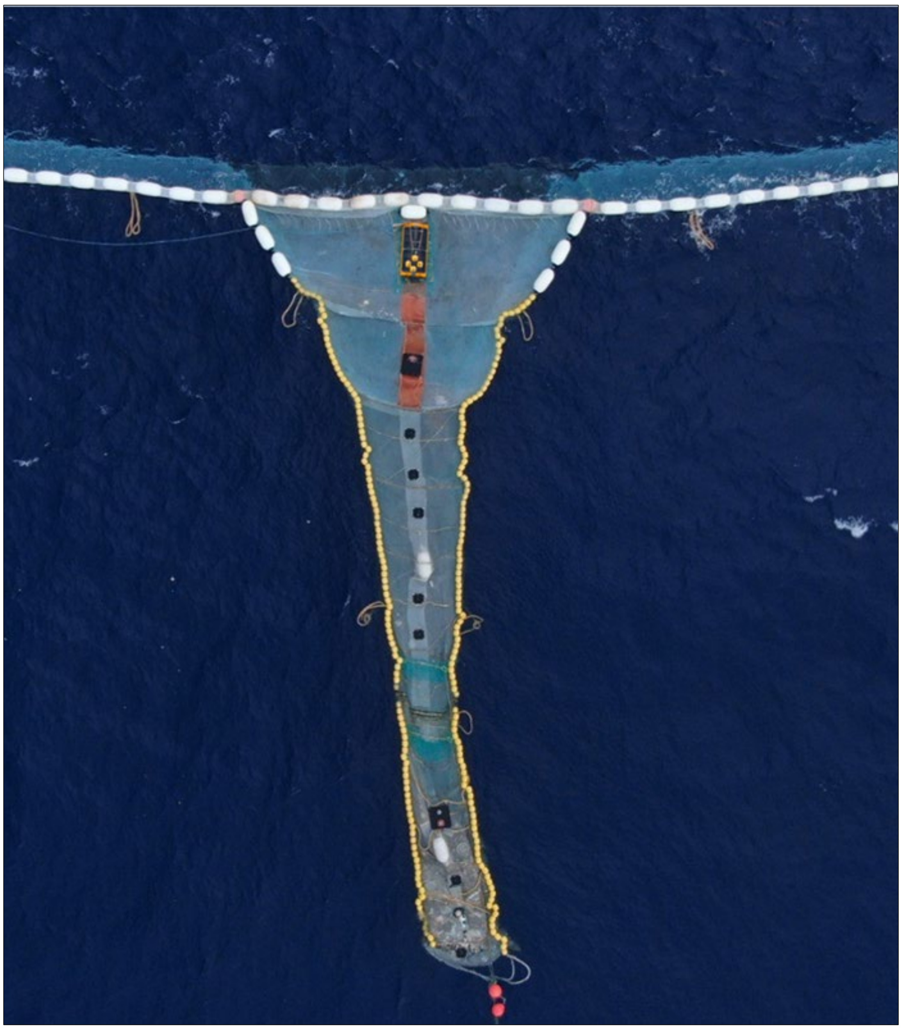


Image 2. Retention zone close-up.

Table 1. Retention system wing design parameters.

| Defined Parameters | Inputs |
|---|---|
| Wing length | 391 m (per wing) |
| Wing depth | 3 m constant |
| Wing height above water | 0.4 m |
| Wing module length | 23 m (17 modules per wing) |
| Net mesh size | 10 mm (square) |
| Wing top section | Permeable screen |

The wings are comprised of a float line, ballast line, and screen attached between the float and ballast lines (**Figure 2**). The float line consists of a single heavy-duty inflatable fender with a permeable cover at a height of 0.4 m above the water surface. Although the float line has a survivability of 5 years, its modular design means it can be replaced offshore in case of damage and can be easily stacked for storage in containers and on deck. The 10-mm × 10-mm Dyneema® netting composing the wings sits at a constant 3 m deep. The ballast line consists of chain wrapped in a fire hose and weighs 6 kg $m^{-1}$. It is used to keep the wings straight and reduce drag resistance. Like the float lines, the ballast lines are modular in design and can be replaced, modified, and removed, if needed.

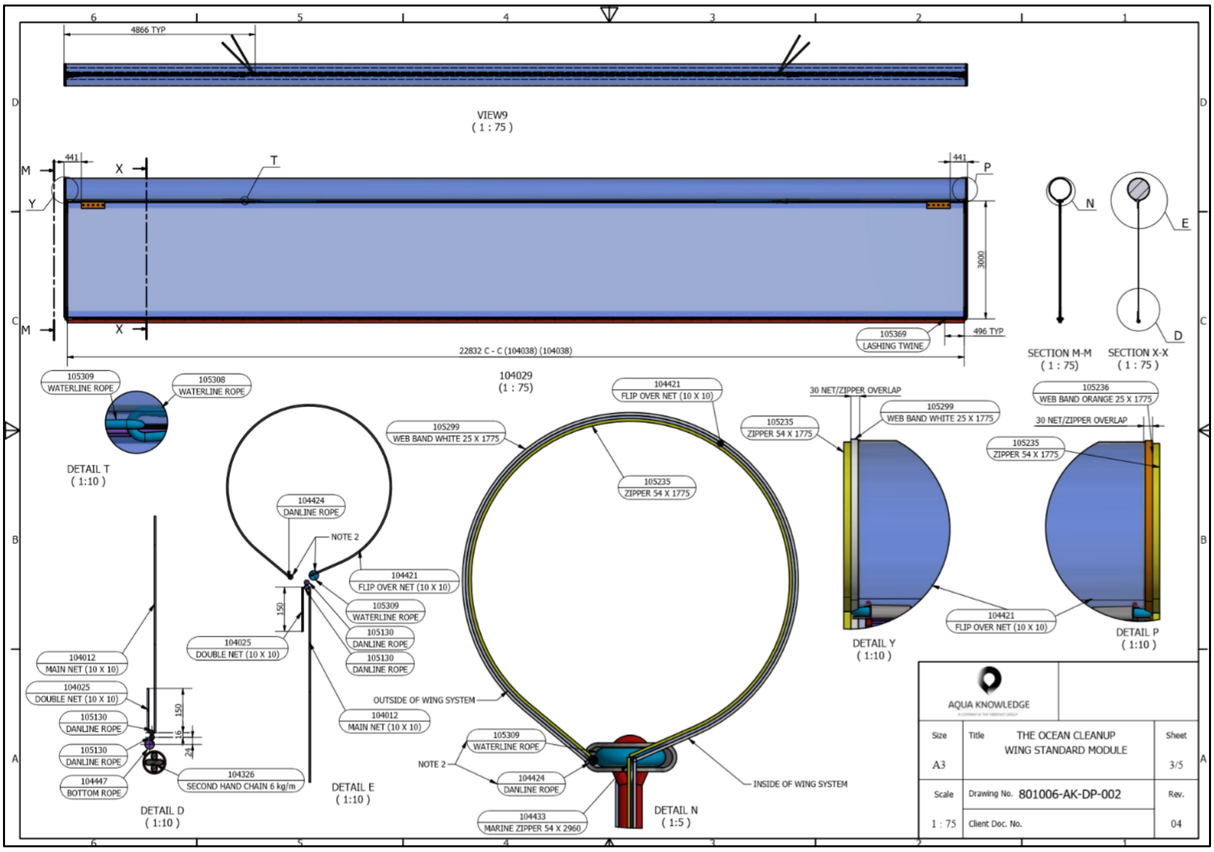


Figure 2.	Wings and float line design.

The wing to RZ connection is a smooth transition, limiting plastic overtopping, underflowing, and being pushed away. The connection is deployable via the vessel roller and is easily connected/disconnected on board the vessel. The assembled S002 is concave in shape, which is maintained with towing lines 500 m in length (**Image 1**). The wings are easily connected to tow rigging. The RS design allows for the integration of several design mitigation measures, 10 global positioning system (GPS) trackers, 10 motion reference units, 2 radar reflectors, 10 lanterns, 7 banana pingers (1 at the entrance of the RZ and 3 on each wing), and 22 green flashing LED lights placed 46 m apart along the wings and at the entrance of the RZ. The banana pingers use randomized pings with harmonics to prevent habituation that operate between frequencies of 50 and 120 kHz at a sound level of 145 decibels (dB) ± 3 dB referenced to (re) 1 micropascal (µPa) m.

Located equidistant between the wings (at the back end of the RS) is a 39-m long, 5-m wide, and 2- to 3-m deep RZ where all captured plastics are collected and retained. The RZ design allows for easy and rapid extraction of plastics on board a T-class vessel. The RZ modules are also made to be easily assembled on board the vessel. The RZ is made of a double layer of netting; the inner layer is a 5-mm × 5-mm Dyneema® netting, and the outer layer is a 50-mm × 50-mm layer of high-density polyethylene (HDPE) netting (**Image 3**). Only the bottom of the RZ entrance is composed of a single layer of 50-mm × 50-mm HDPE netting (**Image 3**). The RZ is composed of three different areas: entrance, safe section, and extraction section (**Figures 3** and **4**). To minimize plastic debris overtopping the RZ, the entrance has an initial height of 0.5 m above the water, which reduces to 0.2 m along the RZ sides. Due to its own weight, the top netting will be floating at the water surface for remaining portions of the RZ. In three locations (one for each section of the RZ) along the center line, the netting is raised 0.5 m from the water surface by using 1.5-m × 0.5-m heavy-duty floaters. This feature was added to the design to allow marine life to breathe in case of accidental entrapment. The safe section has an additional mitigation feature; as soon as the bottom of the

RZ entrance terminates, a “fyke opening” is present. This opening is 0.4 m deep and 5 m wide and has no netting at the front, allowing a possible escape route for bigger animals. The entrance and safe section have a minimum length of 25 m necessary to prevent plastic from exiting the RZ in the case of no speed or during an extraction operation. The extraction section is 103.3 $m^3$ in volume and approximately 14 m long and 5 m wide for a 2-m deep RZ (**Figure 5**).

The extraction section is designed to allow for extraction of plastics up to every 2 weeks and can support a weight of 12.4 T of plastics (dry). The extraction section length can be increased in 8-m increments (one unit) to a maximum total RZ length of 48 m, which increases the maximum collectable volume to 183 $m^3$ (664.6 T). After the first several Campaigns, an additional 8 m extraction net extension was added to the RS to reduce stress on the other components of the RS and camera skiff (**Figure 6**).

Image 3. Top: Retention system netting (5 mm × 5 mm); Bottom: retention zone entrance bottom netting with increased mesh size (50 mm × 50 mm).

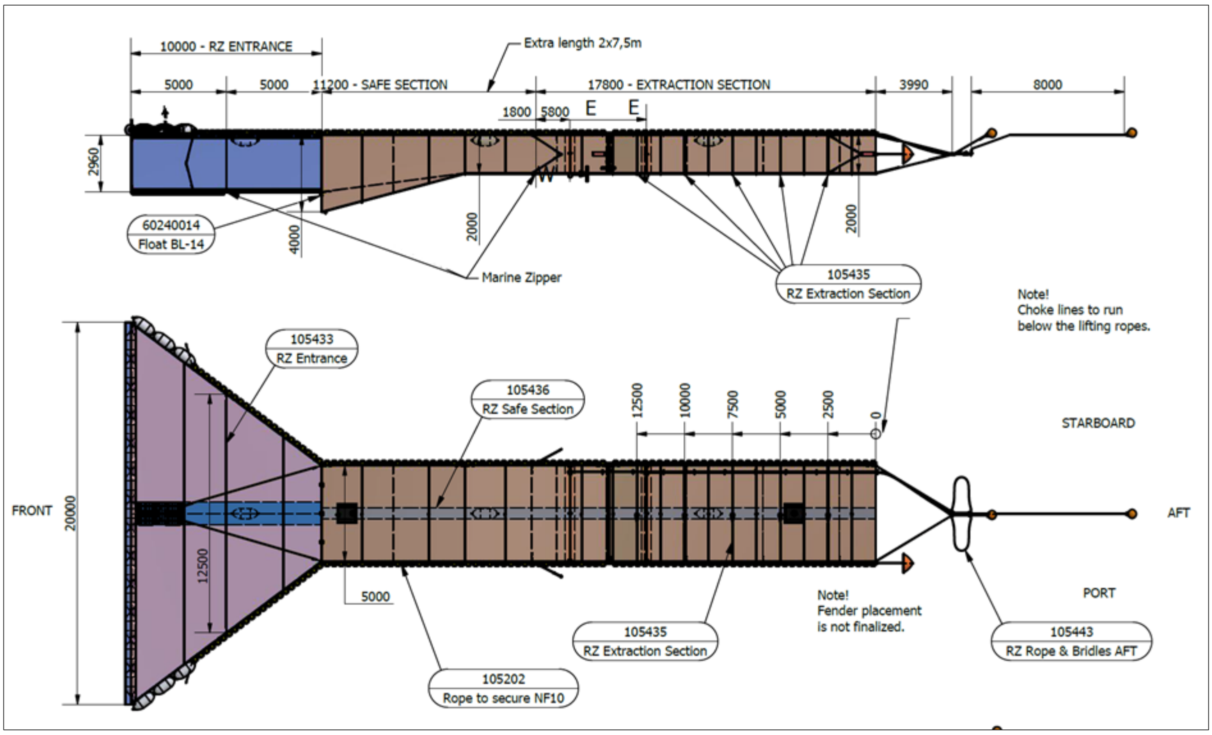



Figure 3. Details of the three areas of the retention zone of S002.

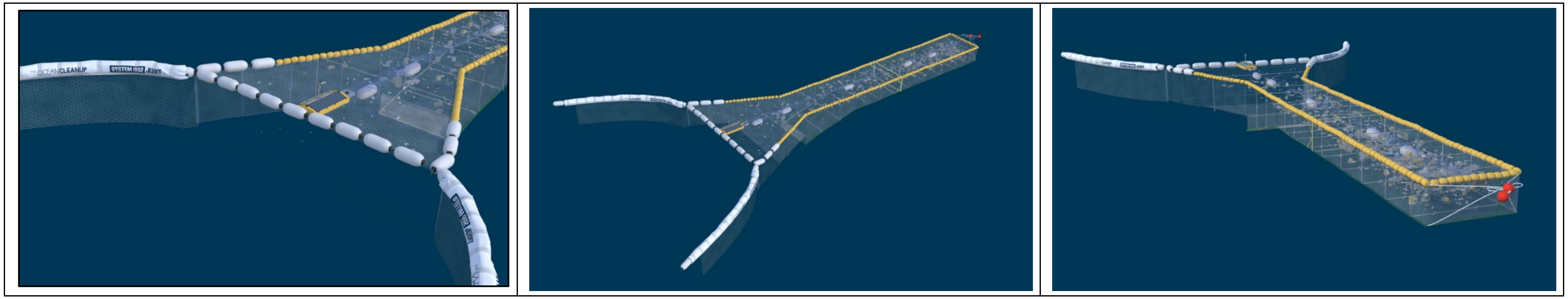


Figure 4.	Rendering illustrating the details of the three areas of the retention zone of S002.

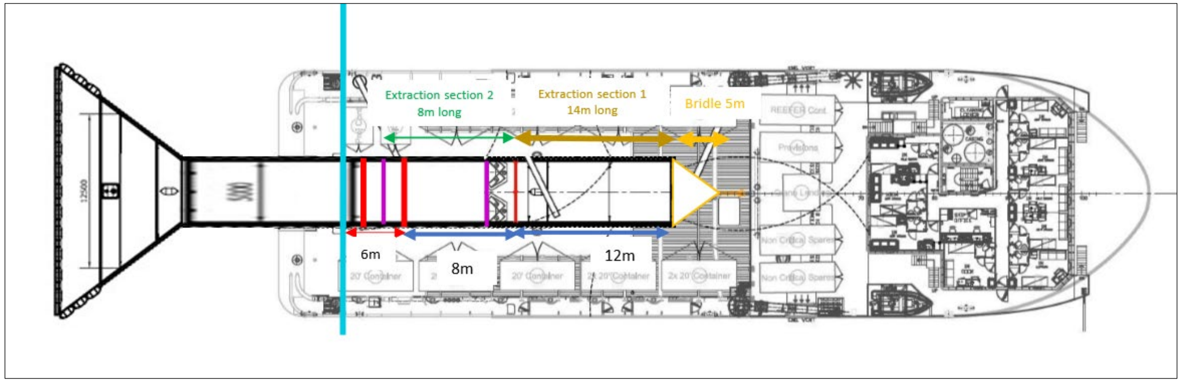
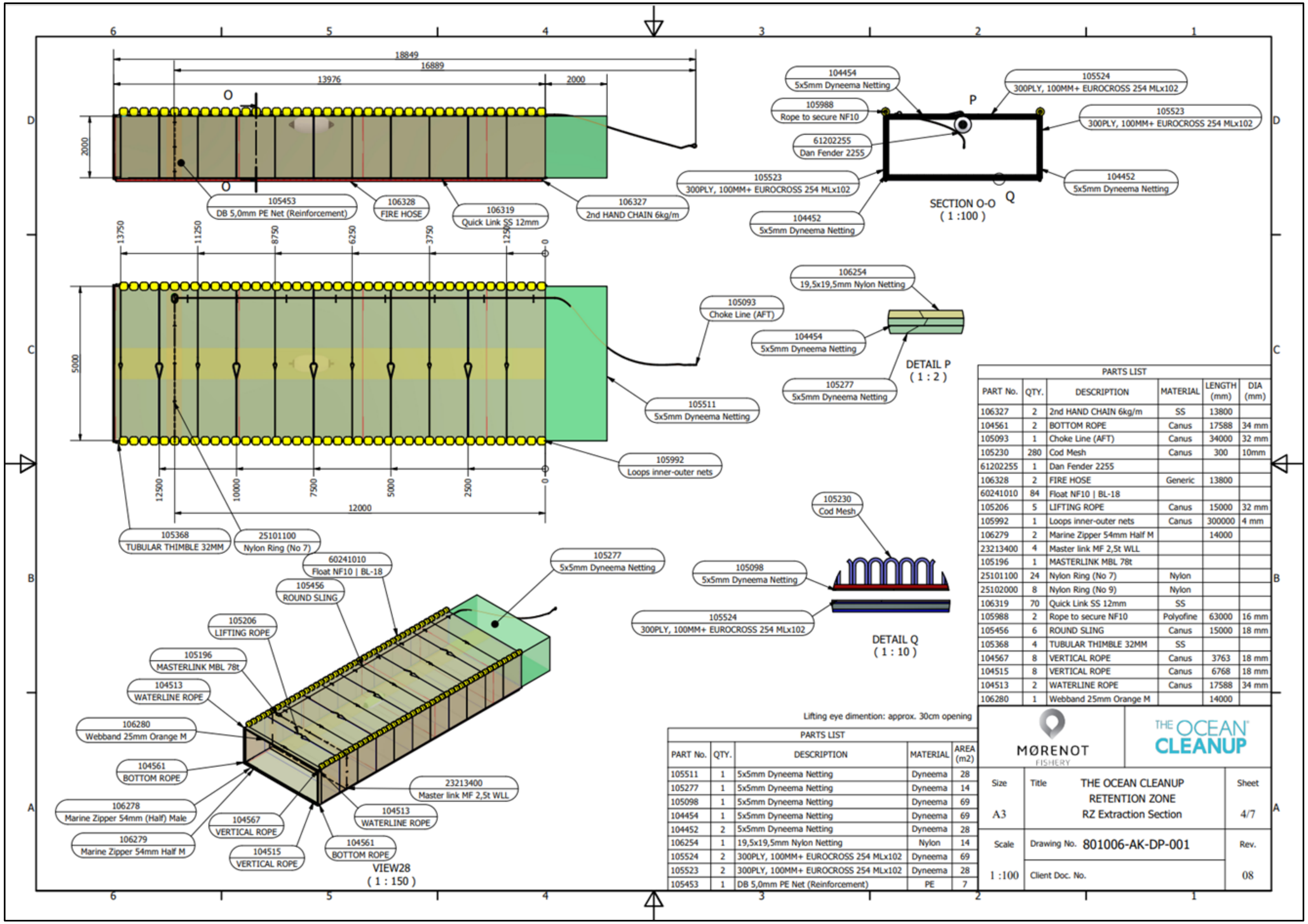



Figure 5.	Schematic of the retention zone extraction section on vessel deck.




PARTS LIST

| PART No. | QTY. | DESCRIPTION | MATERIAL | LENGTH (mm) | DIA (mm) |
|---|---|---|---|---|---|
| 106327 | 2 | 2nd HAND CHAIN 6kg/m | SS | 13800 | |
| 104561 | 2 | BOTTOM ROPE | Canus | 17588 | 34 mm |
| 105093 | 1 | Choke Line (AFT) | Canus | 34000 | 32 mm |
| 105230 | 280 | Cod Mesh | Canus | 300 | 10mm |
| 61202255 | 1 | Dan Fender 2255 | | | |
| 106328 | 2 | FIRE HOSE | Generic | 13800 | |
| 60241010 | 84 | Float NF10 \| BL-18 | | | |
| 105206 | 5 | LIFTING ROPE | Canus | 15000 | 32 mm |
| 105992 | 1 | Loops inner-outer nets | Canus | 300000 | 4 mm |
| 106279 | 2 | Marine Zipper 54mm Half M | | 14000 | |
| 23213400 | 4 | Master link MF 2,5t WLL | | | |
| 105196 | 1 | MASTERLINK MBL 78t | | | |
| 25101100 | 24 | Nylon Ring (No 7) | Nylon | | |
| 25102000 | 8 | Nylon Ring (No 9) | Nylon | | |
| 106319 | 70 | Quick Link SS 12mm | SS | | |
| 105988 | 2 | Rope to secure NF10 | Polyofine | 63000 | 16 mm |
| 105456 | 6 | ROUND SLING | Canus | 15000 | 18 mm |
| 105368 | 4 | TUBULAR THIMBLE 32MM | SS | | |
| 104567 | 8 | VERTICAL ROPE | Canus | 3763 | 18 mm |
| 104515 | 8 | VERTICAL ROPE | Canus | 6768 | 18 mm |
| 104513 | 2 | WATERLINE ROPE | Canus | 17588 | 34 mm |
| 106280 | 1 | Webband 25mm Orange M | | 14000 | |

PARTS LIST

| PART No. | QTY. | DESCRIPTION | MATERIAL | AREA (m2) |
|---|---|---|---|---|
| 105511 | 1 | 5x5mm Dyneema Netting | Dyneema | 28 |
| 105277 | 1 | 5x5mm Dyneema Netting | Dyneema | 14 |
| 105098 | 1 | 5x5mm Dyneema Netting | Dyneema | 69 |
| 104454 | 1 | 5x5mm Dyneema Netting | Dyneema | 69 |
| 104452 | 2 | 5x5mm Dyneema Netting | Dyneema | 28 |
| 106254 | 1 | 19,5x19,5mm Nylon Netting | Nylon | 14 |
| 105524 | 2 | 300PLY, 100MM+ EUROCROSS 254 MLx102 | Dyneema | 69 |
| 105523 | 2 | 300PLY, 100MM+ EUROCROSS 254 MLx102 | Dyneema | 28 |
| 105453 | 1 | DB 5,0mm PE Net (Reinforcement) | PE | 7 |

Figure 6. Retention zone extension details.

A self-floating unit called a camera skiff (**Image 4**), developed specifically for the S002 project by Seiche Ltd., is mounted on top of the RZ entrance. This unit is solar powered (four 100 W solar panels), includes a battery pack (four 90Ah lithium-ion batteries), has an integrated power management system, and is connected via WiFi to the vessel's monitoring station. In addition, the camera skiff has an Automatic Identification System (AIS) AtoN transceiver and Echomax active radar reflector, plus a navigational light (**Figure 7**). The camera skiff powers and live-streams footage from two above-water cameras mounted on the camera skiff unit itself (one forward-facing and one backward-facing) and three underwater cameras mounted inside the RZ (one forward-facing and two backward-facing) with lights. Based on recommendations by the protected species observers (PSOs) monitoring the cameras on board the vessels during Campaigns 1 through 3, the camera configuration was modified to four underwater cameras (two forward- facing and two aft-facing) (**Image 5**) and has been functioning in that configuration on subsequent campaigns. There are three LED lights also present; these lights are dimmable and can be operated by personnel from the control base station on the vessel. The camera skiff system was developed to allow constant monitoring from the vessel bridge outside and inside of the RZ and during nighttime and low-visibility conditions. Special focus for the cameras is on the marine life escape aids in the RZ entrance and safe section, as well as the areas where plastic accumulates, and where marine life may possibly be located if captured by the System.

Image 4. Camera skiff unit mounted on top of the retention zone entrance.

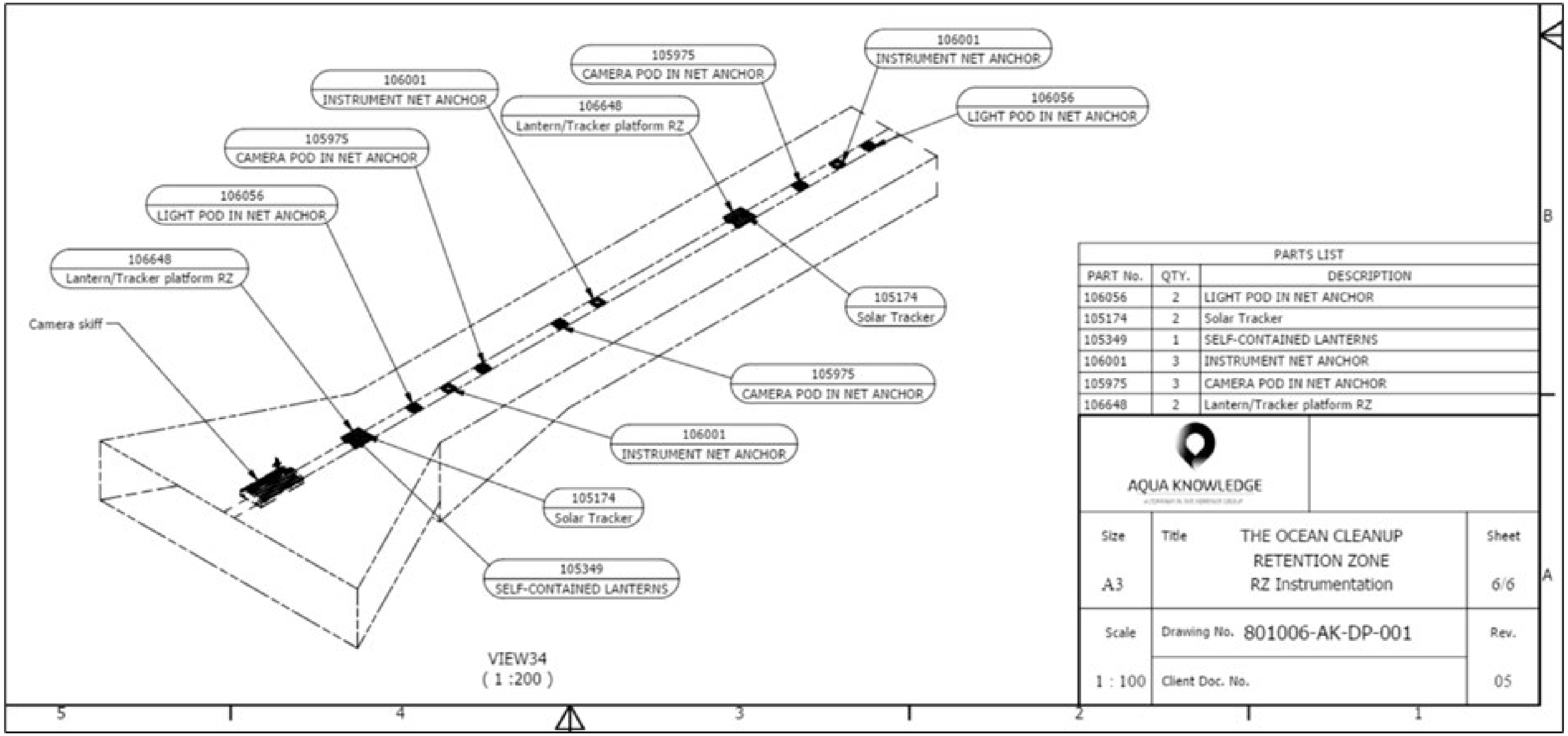



Figure 7. Schematic detailing the position of retention zone instrumentation.

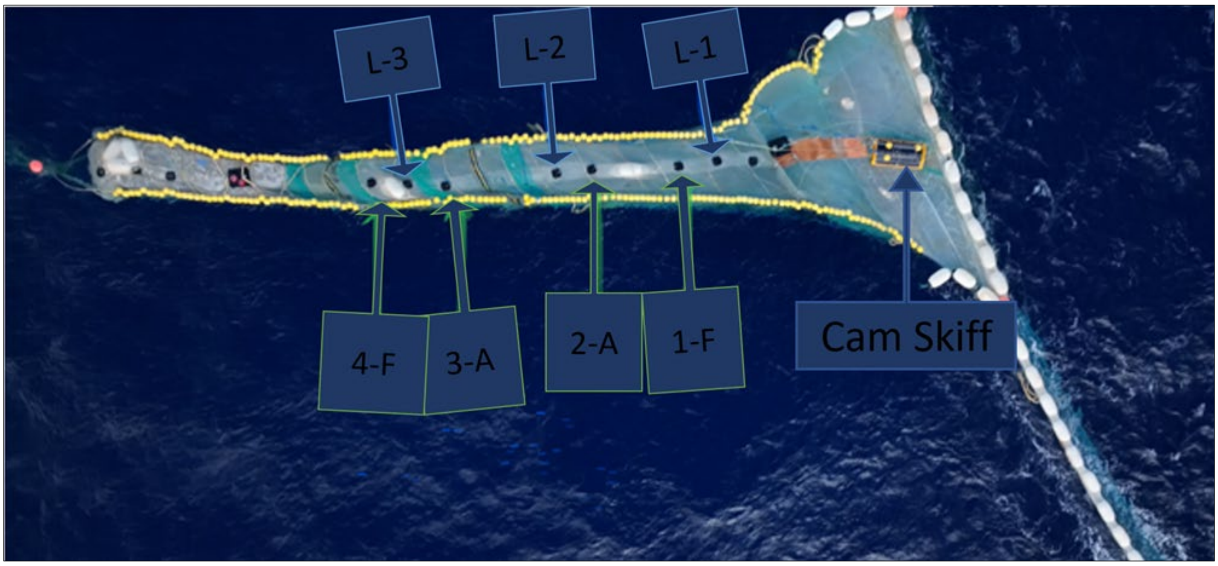



Image 5. Revised camera and light locations in the retention zone.
Blue outlined squares indicate light locations; green outlined squares indicate camera locations; a = aft-facing; f = forward-facing.

The RZ includes another mission-specific mitigation measure, a remotely triggered electric release system for the back end of the of the extraction section (**Figure 8**). When activated, a weight is released in the water, pulling the line that keeps the end of the RZ extraction section closed, and opening the end of the System. Once fully open, water can flow through and flush all contents of the RZ back into open water (**Image 6**). The remotely triggered release is activated to mitigate the consequences of a possible event of a protected species accidentally captured during S002 operation or in case visual observation and camera monitoring confirms concrete risk or high levels of marine life bycatch. Prior to the campaigns, the activation of the acoustic release was tested and confirmed at the production facility; however, it was not possible to perform a full-scale test with the S002 deployed. Therefore, a series of tests were conducted at the beginning of the campaigns to identify the remotely triggered acoustic release activation distance limits and operational constraints. In addition, offshore procedures were updated to guarantee the applicability of this mitigation measure, including multiple means of activating the acoustic release to be implemented depending on sea conditions and distance from the tow vessels.

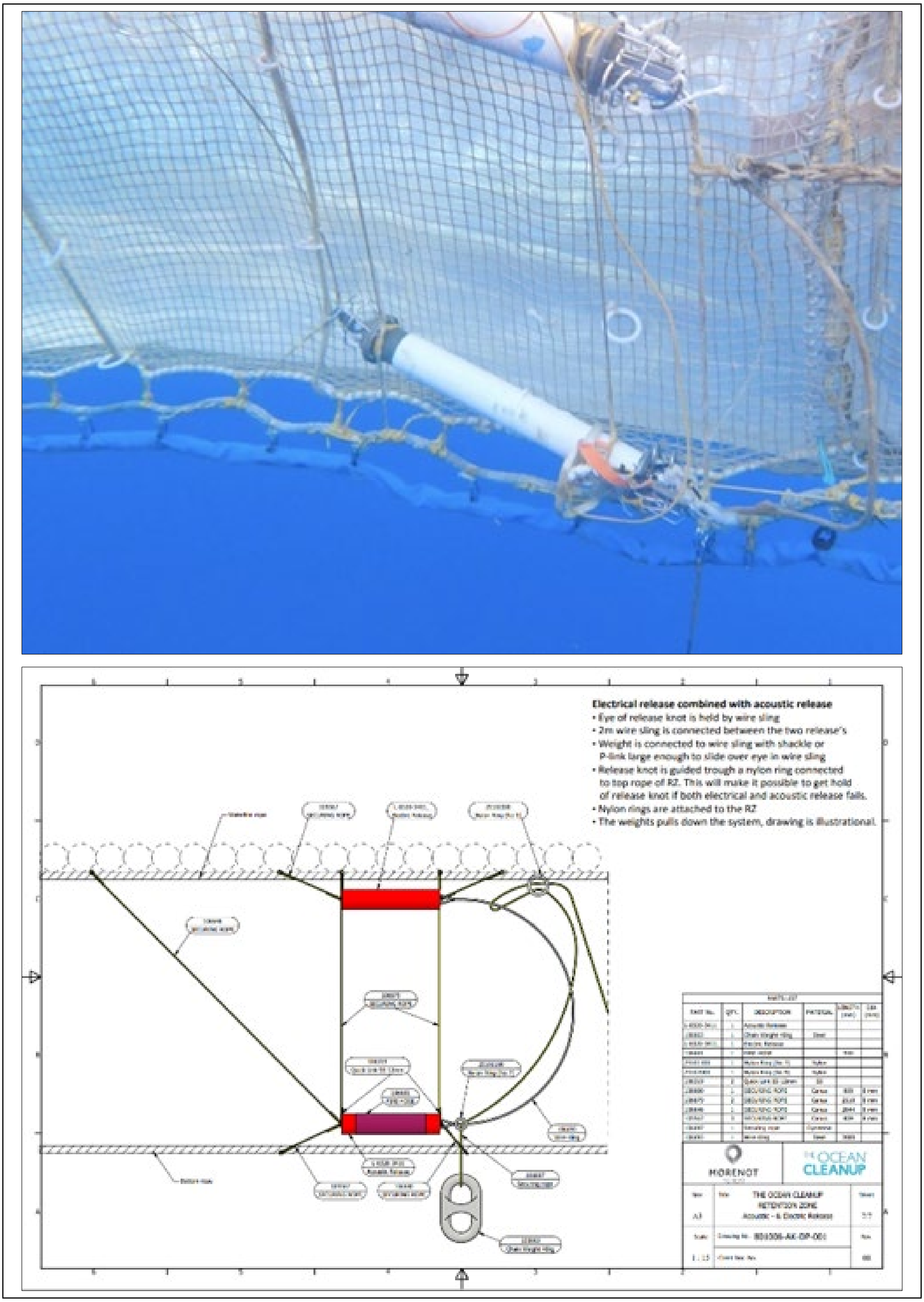



Figure 8. Remotely triggered electric release at the end of the retention zone.

Image 6. Plastics released from the retention zone after activation of the acoustic release.

### 1.4 PLASTICS COLLECTION OPERATIONS

Starting in 2021, the M/V *Maersk Tender* and M/V *Maersk Trader* traveled from Victoria Harbour, Vancouver, British Columbia, Canada to the deployment location within the NPSG for twelve 6-week campaigns that will last until December 2022. When the vessels arrive on location, the System modules are assembled on deck and deployed, and System towing operations and plastics collection begin. **Image 7** shows the S002 wings deployed as well as plastics collected on the wings being guided towards the RZ. The operations are supported by two smaller workboats (fast rescue craft [FRC]) for a variety of tasks, including monitoring activities (e.g., plankton net sampling, system inspections, assistance in releasing entangled sea turtles).

Prior to the commencement of plastics collection operations, the area is inspected for potential presence of marine mammals, sea turtles, sharks, and other protected species. Observations are performed visually by PSOs. Extraction operations do not begin until the area is free of any apparent marine mammals, sea turtles, sharks, and other protected species. As soon as the area has been declared clear of protected animals, the S002 is fully deployed, and testing operations commence. At select times, and only in case of necessity during the plastics collection operations, an acoustic deterrent device may be deployed to temporarily keep marine life out of the path of the towed System; however, the acoustic deterrent device has not been needed, thus far.

Wings deployed in the ocean.


Plastics collection along starboard wing.


Plastics collection along port wing.

Image 7. S002 wings deployed and plastics collecting on wings moving towards the RZ.

During the campaigns to date, multiple operational/tow speeds (between 0.5 and 2.5 knots) and System configurations have been implemented to collect data regarding the operations and performance of the S002. Additional tasks have included documenting primary and secondary bycatch composition and quantity and evaluating the performance of the environmental mitigation and monitoring measures. Different span widths of the wings have been tested to gather data regarding the efficiency of plastics collection, vessel fuel consumption, environmental factors from the operations, and other operational data. In addition, observations by PSOs and crew and implementation of monitoring and mitigation measures (e.g., above-water and underwater RZ camera systems, PSOs, thermal/RGB camera system, marine life fyke openings, deterrent devices) are being performed and evaluated to monitor the environmental impacts of the operations as well as evaluate the efficacy of the mitigation measures. Data has also been collected for future system design to determine a potential scale-up scenario and to minimize environmental impacts.

In addition, research is being conducted to assess the S002 bycatch composition and amount in different system operational configurations, to determine the amount of plastic recovered, and to document daily and seasonal variations and other possible variables. These data are being extrapolated to assess the ecological significance and impact of the bycatch for mission continuation and the scale-up scenario. Bycatch is classified as primary or secondary. Primary bycatch is defined as marine life (protected species or other marine life) which is caught unintentionally and alive as a direct consequence of System operation and or marine life the System caused the mortality of as a direct consequence of System operation, while secondary bycatch is considered any marine life that is incapacitated, entangled or otherwise not fully free (e.g., barnacles, crabs) and/or alive (e.g., fish, neuston, marine mammals, birds, and turtles) in the environment when caught by the System. The Ocean Cleanup is also assessing health and safety related to bycatch accumulation in the RZ.

The System deployment location is based on an expected area of highest plastic density from predictive models used by The Ocean Cleanup. These models incorporate sea surface current, wind, wave, sea level anomalies, mixed layer depth, and Langmuir number data combined with daily plastic dispersal data to perform contour shape, hotspot detection, and target assessment analyses to determine the deployment location. The Senior Offshore Representative supported by The Ocean Cleanup's engineering and environmental research teams evaluates all available data and makes a recommendation for each campaign prior to each deployment date. In addition, each campaign has moved to different areas of the NPSG to follow the high- and low-density areas, which are shifting, to better understand the System performance in different scenarios as well as to work around poor weather conditions in the fall/winter campaigns. The initial trial location was a generic position in the "center" of the NPSG (i.e., 35° N, 145° W).

## 1.5 PLASTICS EXTRACTION OPERATIONS

Prior to beginning plastics extraction operations from the extraction section of the RZ, the area is scanned for presence of marine mammals, sea turtles, sharks, and other protected species. PSOs look at the project area and the footage from the underwater camera system mounted on the RZ to visually monitor the entrance and inside of the RZ. As soon as the area is cleared of marine mammals, sea turtles, large fish, and sharks, the extraction operations begin. Towing operations transfer from two vessels to one vessel, reducing the wingspan of the system to approximately 5 m (**Figure 9**). The second vessel proceeds to the RZ end of the system, retrieves the buoy attached to the RZ bridle, and engages two chokes in the RZ to contain the plastics in the extraction section. The second vessel then recovers the RZ over the open stern and onto the main deck and secures the System (**Figure 10, Image 8**). After the RZ extraction section is detached and secured on deck, the remainder of the System is returned to the water and slowly towed by the single vessel while deck crew perform plastics extraction from the extraction section. This operation takes a maximum of 12 hours. The shortened System has the same design as the complete S002, including all mitigation measures (e.g., fyke opening, camera systems, deterrent lights), except for the remotely triggered acoustic release. The deck crew tries to fully empty the RZ (before and after the yellow choke), so that the shortened RZ can be deployed fully open in the water, which has been the predominant operational condition (**Image 9**). Only in the unlikely scenario that plastic cannot be recovered from inside the RZ area, the shortened RZ is re-deployed still closed and monitoring is continued by the onboard PSO, focusing on the four underwater cameras in the RZ.

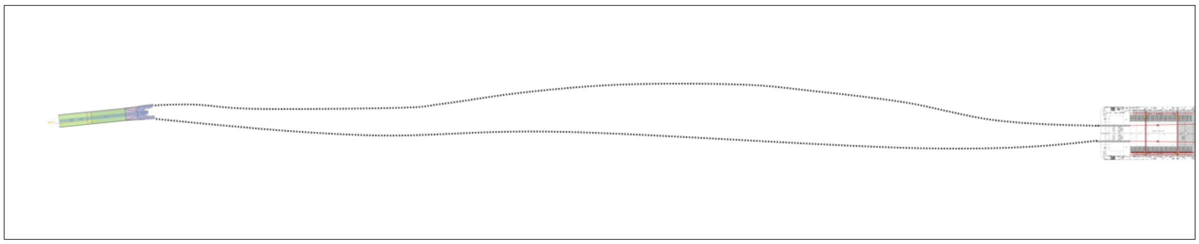


Figure 9. The S002 during extraction operations behind one vessel with reduced wingspan.

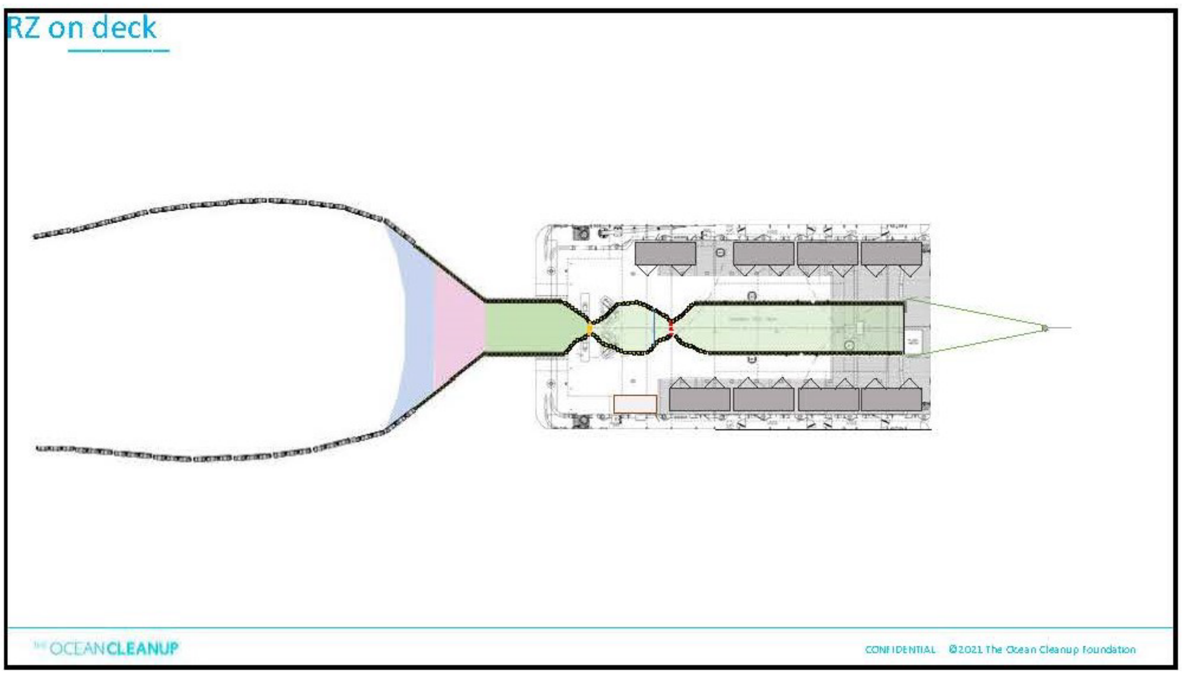



Figure 10. Retention zone with the two chokes (red and yellow lines) on the vessel deck.

Image 8. Extraction operations (Image Credit: Toby Harriman).

Image 9. Shortened retention zone being towed by one vessel during plastics extraction operations.

Once the plastic is extracted and transferred to the vessel storage units, the shortened System is retrieved by the attached buoy and recovered on board the vessel to re-attach the RZ extraction section. Once the RZ extraction section is re-attached, the entire System is re-deployed between the two vessels and normal plastics collection operations resume.

After the plastic is transferred to the vessel, living organisms (fish and other marine life) are manually separated to the extent possible, properly documented, and released back into the ocean (if feasible) or frozen for further analysis. This is done, in part, to understand the amount and type of bycatch for the specific operation just performed, but also to assist in identifying additional mitigation measures for future system improvement. If a living marine mammal, sea turtle, or other protected species is unexpectedly found entangled in a derelict net or other debris, a disentanglement and rescue procedure is initiated considering human safety, weather conditions, and the species involved.

The dead animals are also separated from the plastic, sorted by category (e.g., fish, barnacles, crabs) and classified as primary or secondary bycatch based on if it can be determined if the animal was dead prior to being captured in the S002 (e.g., condition) and if the animal was associated with the plastic (e.g., barnacles attached to plastic, crabs associated with floating plastic). Each group of primary and secondary bycatch is then further separated by species (if possible), photographed, weighed, and frozen for further laboratory analysis, including stomach content analysis.

On board, the plastics are roughly separated, and ghost nets are separated from other hard materials. Water is allowed to drip off the plastic, which then is allowed to partially dry while being sorted and inspected for biofouling or any other marine life presence. The plastics are packed on board the vessel and weighed before being loaded into containers according to the chain of custody guidelines.

The containers are unloaded at Victoria Harbour and remain sealed. Weights are verified on shore, and the containers forwarded to The Ocean Cleanup's partner facility in the Netherlands for sorting and distribution to other facilities in the Netherlands and Denmark. After packaging on board, materials are in the custody of The Ocean Cleanup Valorization project. Feasible options for further processing of the plastics continue to be assessed.

## 1.6 MITIGATION MEASURES

A variety of mitigation measures were researched for potential applicability to the project, their potential effectiveness evaluated, and then their potential for implementation determined in consultation with the S002 primary manufacturer, Mørenot, and from an operational perspective. Many of the mitigation measures developed and evaluated are emerging or new technologies used in different applications with some success (e.g., fyke openings, net coloring, pingers) while others were developed specifically for The Ocean Cleanup to reduce potential impacts from the operations (e.g., camera skiff, remotely triggered acoustic release). Some mitigation measures were designed to inform personnel to take action to prevent marine life from entering the S002 (e.g., PSOs, cameras) while others were designed to minimize impacts if an animal was caught within the S002 (e.g., remotely triggered electric release, fyke openings). Numerous mitigation measures were incorporated into the design of the S002 as well as additional monitoring tools implemented to reduce impacts to the environment and marine animals from System operations. Mitigation measures are summarized here.

*S002 Design Mitigation Measures*

- **Mesh size** – Use of netting with a larger mesh size (10 mm square), when possible, to allow smaller marine animals to exit the System.
- **Escape aid** – The System is equipped with a remotely triggered electric release for the end of the RZ to free potential clogs or trapped marine animals and a fyke opening just after the entrance to the RZ.
- **Visual monitoring** – A camera skiff with four underwater cameras and three lights installed inside the RZ for visual observation by the PSOs.
- **Visual cues** – Use of light-colored netting to increase visual detectability of the wings and RZ, with darker yellow netting used for fyke openings, and use of green flashing LED lights to enhance detectability of the System. Colored netting has resulted in lower collision rates with diving birds (Hanamseth et al., 2017), and Kraus et al. (2014) indicated whales detect red and orange ropes at a significantly greater distance than black or green ropes. In addition, LED lights have reduced primary bycatch of small cetaceans, sea turtles, and seabirds on stationary nets (Ortiz et al., 2016; Kakai, 2019; Allman et al., 2020; Bielli et al., 2020).
- **Acoustic deterrent** – Banana pingers attached to the System to deter porpoises and high-frequency hearing dolphins away from the System. Pingers may deter certain species of smaller cetaceans (Larsen et al., 2013; Mangel et al., 2013; Popov et al., 2020).
- **Breathing port** – Floaters are attached to the netting in the RZ to raise the netting approximately 15 to 20 cm to guarantee access to air for air-breathing animals.

*Operational Mitigation Measures*

- **Visual monitoring** – Monitoring by PSOs during transit and operations, and use of the thermal/RGB camera systems and the camera skiff.
- **Visual monitoring** – Crew trained in marine mammal and sea turtle observations and use of protected species identification posters (**Appendix A**) displayed in select locations on board both vessels.
- **Vessel operations** – Vessel speeds are kept to a minimum for specific operations, as follows:
  - During transit between shore and the NPSG, vessels travel at slow speeds (<14 knots);
  - During towing in the NPSG, vessels travel at extremely slow speeds (0.5 to 2.5 knots); and
  - Minimal Environmental Impact Operation (MEIO) mode is a specific operational mode to reduce the possibility of environmental impact and has a maximum speed of 0.5 m $s^{-1}$, or at a minimum speed to just keep the S002 in a U shape, which is implemented in the following circumstances:
    - Protected species observed in the vicinity/risk of entanglement;
    - Equipment malfunction;
    - Camera skiff not operational and low visibility; or
    - Remotely triggered acoustic release not operational and low visibility.
- **Elimination of unnecessary acoustic energy** – The levels of anthropogenic noise are kept as low as reasonably practicable.
- **Minimize nighttime lighting** – The light level on board the vessels is kept as low as reasonably practicable while maintaining a safe work environment at night, and lights are limited at night to the extent practicable. Navigational lights on the System flash intermittently to reduce shining light on the water at night.
- **Routine debris extraction** – Routinely remove accumulated debris (e.g., plastics, fishing nets) from the S002 RZ.

- **Drone inspections** – Routinely perform inspections of the S002 and surrounding area by drone to identify System issues or damage and observe any protected species within or around the S002.
- **Rescue of animals** – Rescue attempts of entangled marine mammals or sea turtles in distress are performed according to the Environmental Management Plan (EMP).
- **Net resting** – The net is allowed to rest prior to retrieval to give marine animals time to escape through the fyke openings.
- **Pollution prevention** – Compliance with International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 restrictions and implementation of vessel Waste Management Plans will reduce the likelihood of pollution.
- **Spill equipment on board** – Sorbent materials will be used to clean up any minor spill on board the vessels (should one occur).
- **No re-fueling at sea** – No re-fueling will occur at sea.

## 1.7 EXTENT OF THE ADDENDUM

This addendum examines potential impacts to resources that could be affected from the modifications to the existing S002 as it transitions to S002A and S002B. Modifications include an increase in the length of the RZ to 70 m for S002A, and deeper (4 m) wings for S002B, respectively. The first step in the evaluation will be to screen the resources that were evaluated in the Revised S002 EIA (CSA, 2022) to determine if the system modifications have the potential to impact them, then impact determinations will be presented for those resources.

# 2 Project Description Changes

## 2.1 REASON FOR CHANGES

The Ocean Cleanup is committed to adaptively managing activities and data collection to better characterize the potential impacts to the environment from project operations. One means of adaptive management is the implementation of active monitoring and using the data collected to modify the project methodologies and improve future designs of plastics collection systems. For example, based on field data, the original RZ was modified to add in an 8 m extension section to increase the distance between the camera skiff and the stern roller, avoiding potential damage. It is from this adaptive management approach and applying the data and knowledge collected from the completed campaigns that the larger RZ with additional mitigation measures (S002A) and deeper wings (S002B) are being implemented as The Ocean Cleanup moves toward their full-scale system design.

Implementing the larger RZ (S002A) will allow more room for the plastics to accumulate and reduce the potential for plastics blocking the view of the camera skiff system and the active monitoring for protected species within the RZ.

The deeper wings are being implemented to alleviate underflow of plastics beneath the wings thereby increasing collection efficiency.

## 2.2 PROJECT DESIGN MODIFICATION OVERVIEW

There are two primary design changes to the current S002, the first includes a larger RZ (S002A) and the second, deeper wings (S002B). As described above, the current S002 RZ includes an additional extraction net extension.

### 2.2.1 The Ocean Cleanup System Design Changes

As The Ocean Cleanup transitions to their full-scale system design, they will be testing two primary design modifications to the existing S002 design described in **Section 1.3**. The first design change, S002A, incorporates a larger RZ that measures 70 m in length, has an increased width and depth, and has a more streamlined shape to assist with plastic flow into the RZ and avoid blocking cameras. Each section of the RZ has increased. This larger RZ will also allow for longer extraction intervals (maximum of one week) resulting in more towing time per campaign.

The second design change, S002B, consists of adding additional wing modules next to the larger RZ until the two 800 m wings have been deployed. These larger wings will also increase in depth to 4 m from the current 3 m.

All other design and mitigation features in the current S002 design would remain in place. **Table 2** provides a summary of the existing S002 design and the modifications for S002A and S002B.

Table 2. Summary of design parameters for S002, S002A, and S002B.

| Defined Parameters | Original S002 | Current S002 | S002A | S002B |
|---|---|---|---|---|
| RZ length | 39 m | 48 m | 70 m | 70 m |
| RZ width | 5 m | 5 m | 5.5 m | 5.5 m |
| RZ depth | 2 m | 2 m | 2.2 m | 2.2 m |
| RZ volume | 644.3 $m^3$ | 644.3 $m^3$ | 2,016.4 $m^3$ | 2,016.4 $m^3$ |
| RZ entrance length | 10 m | 10 m | 29 m | 29 m |
| RZ safe section length | 11.2 m | 18.7 | 19 m | 19m |
| RZ extraction section length | 17.8 m | 17.8 m | 22 m | 22 m |
| RZ mesh size | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer | 5 mm × 5 mm inner layer, 50 mm × 50 mm outer layer |
| Wing length | 391 m (per wing) | 391 m (per wing) | 391 m (per wing) | 391 m (per wing) |
| Wing depth | 3 m constant | 3 m constant | 3 m constant | 4 m constant |
| Wing height above water | 0.4 m | 0.4 m | 0.4 m | 0.4 m |
| Wing module length | 23 m (17 modules per wing) | 23 m (17 modules per wing) | 23 m (17 modules per wing) | 23 m (17 modules per wing) |
| Net mesh size | 10 mm (square) | 10 mm (square) | 10 mm (square) | 16 mm (square) |
| Wing top section | Permeable screen | Permeable screen | Permeable screen | Permeable screen |

RZ = retention zone.

### 2.2.2 Plastics Collection Operations Changes

Operations during plastics collection for S002 will remain unchanged for both S002A and S002B.

### 2.2.3 Plastics Extraction Operations Changes

With the larger RZ, each section of the RZ has increased in length and size; and therefore, the shortened System that will remain in the water after extraction has increased in length to 56 m. However, as with the S002, this shortened System has the same design as the complete S002, including all mitigation measures (e.g., fyke opening, camera systems, deterrent lights), except for the remotely triggered acoustic release. The deck crew tries to fully empty the RZ (before and after the yellow choke), so that the shortened RZ can be deployed fully open in the water, which has been the predominant operational condition (**Image 9**). Only in the unlikely scenario that plastic cannot be recovered from inside the RZ area, the shortened RZ is re-deployed still closed and monitoring is continued by the onboard PSOs, focusing on the four underwater cameras in the RZ.

In addition, with the larger RZ, extractions will occur less frequently than with the S002 and are anticipated to occur approximately every 5-6 days (maximum of one week).

### 2.2.4 Added Mitigation Measures

Additional mitigation measures have been incorporated into the design revisions based on observational data obtained during the campaigns to date that provided information regarding mitigation measure effectiveness, identified potential improvements to existing mitigation measures, and overall design changes to the System. Additional or modified mitigation measures associated with the S002A and S002B systems are summarized below. **Table 3** provides a comparison of the designed mitigation measures between the three Systems.

Table 3. Summary of mitigation measures between the System designs.

| Mitigation Measure | S002 | S002A | S002B |
|---|---|---|---|
| Number of fyke openings | 1 | 3 | 3 |
| Number of breathing hatches | 2 | 4 | 4 |
| Number of pingers (RZ/wings) | 1/6 | 5/6 | 5/8 |
| Number of green flashing LED lights (RZ/wings) | 1/22 | 16/22 | 16/22 |

***S002A (larger RZ) Additional or Modified Mitigation Measures***

**Additional escape aids** – The larger RZ includes two additional fyke openings to allow marine animals additional escape routes if accidentally collected by the system.

**Breathing ports** - The larger RZ includes two additional breathing hatches that incorporates a new design.

**Acoustic deterrent** – The larger RZ includes four additional banana pingers attached to the RZ opening.

**Visual Cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

**RZ access openings** – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a marine animal enters the RZ.

**Figures 11** and **12** provide layouts of the larger RZ with the additional mitigation measures.

***S002B (addition of deeper wings to S002A) Additional Mitigation Measures***

All additional mitigation measures associated with the S002A are still in effect for S002B, while the following additional mitigation measures are included.

**Acoustic deterrents** – The deeper wings include two additional banana pingers attached to the wings spaced throughout the wings.

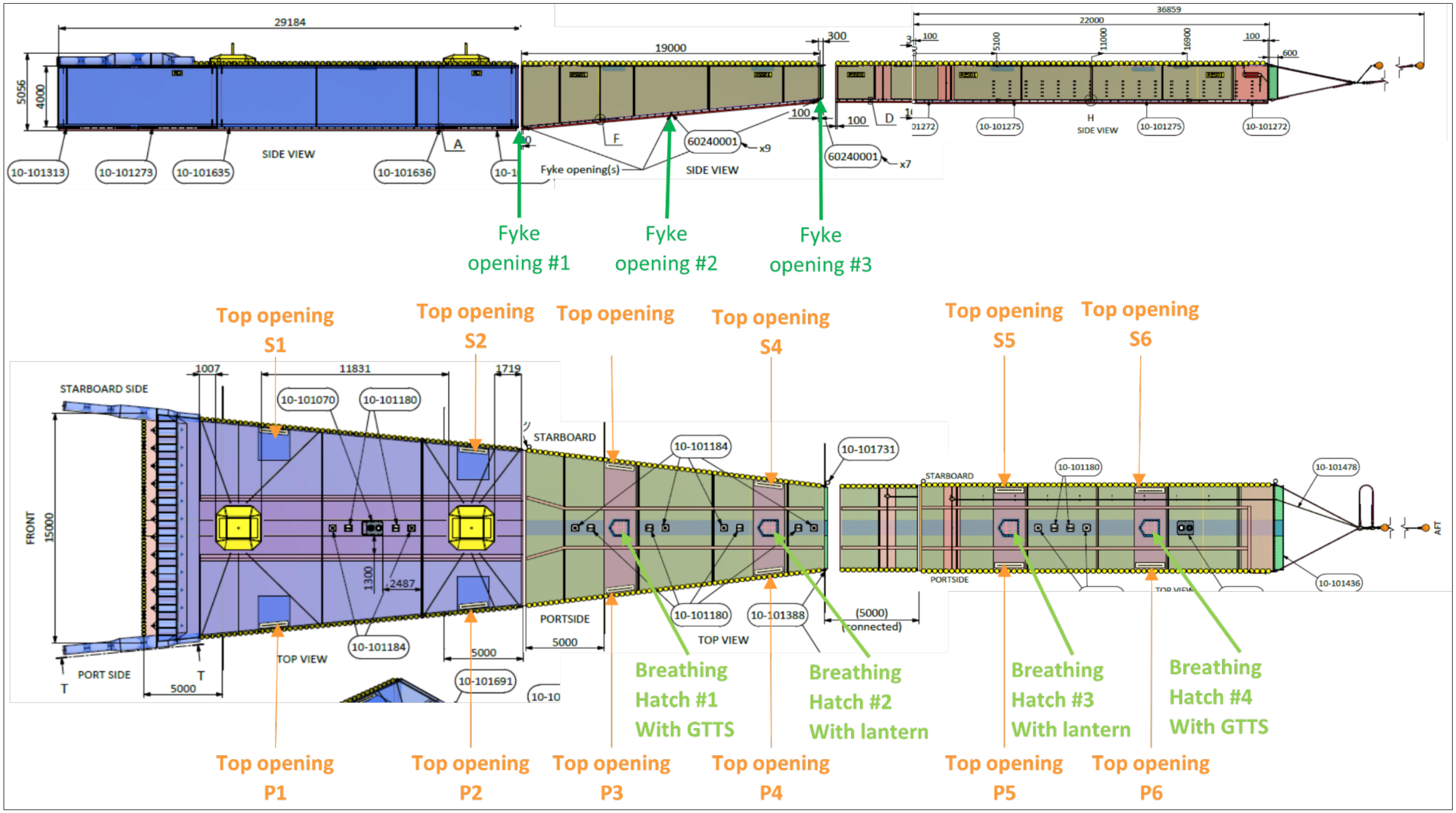
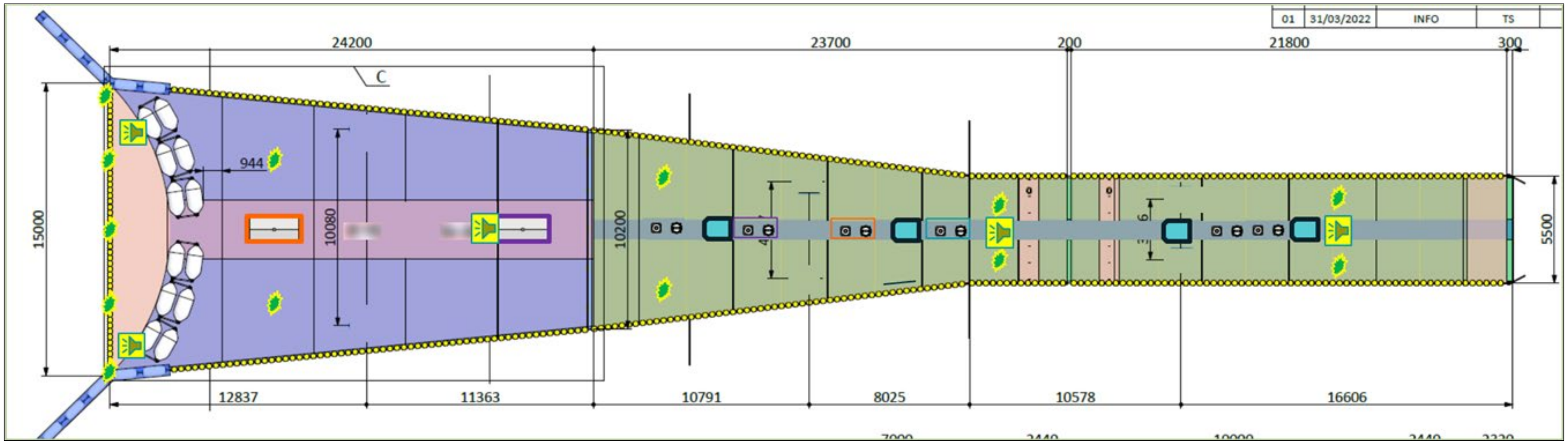



Figure 11. S002A and S002B layout of the larger RZ with the additional mitigation measures.




**RZ Pingers: 5**

**RZ Green Flashing Lights: 16**

**RZ Breathing hatches: 4**

Figure 12. S002A and S002B location of mitigation measures on larger RZ.

# 3 Potential Environmental Impacts and Mitigation Measures

## 3.1 SCREENING OF PREVIOUSLY EVALUATED RESOURCES

In the revised S002 EIA (CSA, 2022) the following resources were evaluated for potential impacts.

- Plankton;
- Neuston;
- Fish/Fishery Resources;
- Marine Mammals;
- Sea Turtles;
- Coastal and Oceanic Birds;
- Protected Areas;
- Biodiversity; and
- Commercial and Military Vessels.

A preliminary screening was conducted to identify the resources at risk from the modifications of the System with regards to the impact-producing factors (IPFs) from the deployment of S002A and S002B in the NPSG. Screening allows for completion of a focused impact analysis by eliminating (from detailed analysis) resources with little or no potential for adverse or significant impact. This approach focuses the analysis on the resources at greatest impact risk from the design changes in the System. A matrix was developed to list environmental resources evaluated in the revised S002 EIA (CSA, 2002) (**Table 4**) and each IPF. In this preliminary analysis, the level of impact associated with each interaction was categorized as "potential change in impact for analysis" (i.e., a measurable impact to a resource is predicted) or "no change in impact expected" (i.e., no measurable impact to a resource is evident). Those resourced determined to have a "potential change in impact for analysis" are carried forward for analysis in **Section 3.3**.

Table 4. Preliminary screening of potential impacts.

| Resource | Impact-Producing Factor | | | | | |
|---|---|---|---|---|---|---|
| | S002A/B – Entanglement/ Entrapment | S002A/B – Attraction/ Ingestion of Plastics | Vessel – Physical Presence/ Strikes | S002A/B Noise and Lights | Loss of Debris | Accidental Small Fuel Spill |
| Plankton | ● | -- | -- | ● | -- | -- |
| Neuston | ● | -- | -- | ● | -- | -- |
| Fish/Fishery Resources | ● | ● | -- | ● | -- | -- |
| Marine Mammals | ● | ● | -- | ● | -- | -- |
| Sea Turtles | ● | ● | -- | ● | -- | -- |
| Coastal and Oceanic Birds | -- | -- | -- | -- | -- | -- |
| Protected Areas | -- | -- | -- | -- | -- | -- |
| Biodiversity | -- | -- | -- | -- | -- | -- |
| Commercial and Military Vessels | -- | -- | -- | -- | -- | -- |

● indicates a potential change in impact; -- indicates no change in impact expected.

## 3.2 IMPACT ASSESSMENT METHODOLOGY

Potential impacts of the S002A and S002B deployment are evaluated using the methodology described below. Impact consequence and impact likelihood are two factors used to determine potential impact significance (**Figure 13**).

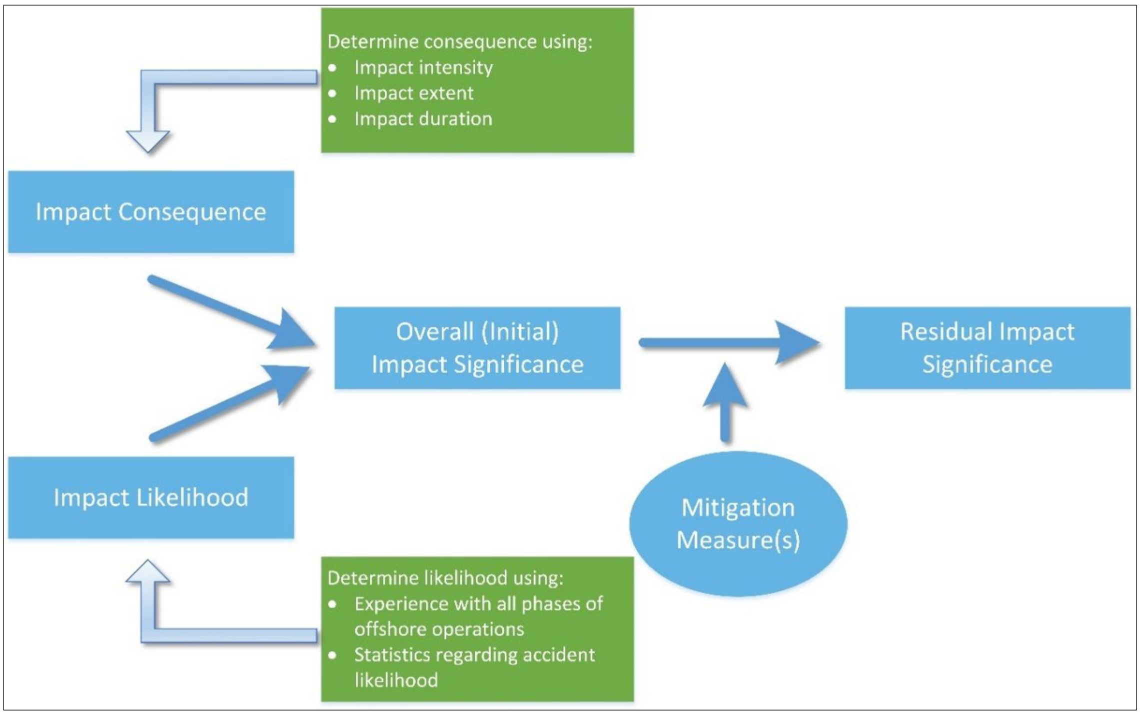



Figure 13. Impact assessment flow chart.

### 3.2.1 Determination of Impact Consequence

Impact consequence reflects an assessment of an impact's characteristics on a specific resource (e.g., fish/fishery resources, marine mammals) arising from one or more IPFs. Impact consequence is determined regardless of impact likelihood. Impact consequence classifications include Positive (Beneficial), Negligible, Minor, Moderate, and Severe, as defined below.

For negative impacts, where the change to the current situation of the resource is generally considered adverse or undesirable, the determination of impact consequence is based on the integration of three criteria (discussed below): intensity, extent, and duration. When appropriate, calculations were made to quantitatively characterize the intensity and extent of the impacts. These calculations are explained for each of the resources concerned. Positive impacts, where the change to the current situation of the resource is generally considered better or desirable, are noted, but their consequence is not quantified.

#### *3.2.1.1 Impact Intensity*

Impact intensity relates to the degree of disturbance associated with the impact and the alteration of the current state of the host environment. There are three levels of intensity[1]:

- **Low**: Small adverse changes unlikely to be noticed or measurable against background activities.
- **Moderate**: Adverse changes that can be monitored or noticed but are within the scope of existing variability without affecting the resource's integrity or use in the environment.

[1] The definitions presented here are general descriptions of the levels for each criterion. Not all resources have been included as examples, but specific explanations are provided in the assessment when needed.

- **High**: For the physical environment, extensive or frequent violation of applicable air or water quality standards/guidelines, or widespread contamination of sediments with hydrocarbons, toxic metals, or other toxic substances. For the biological environment, extensive damage to habitats to the extent that ecosystem functions and ecological relationships would be altered, or numerous mortalities or injuries of a protected species or continual disruption of their critical activities.

#### *3.2.1.2 Impact Extent*

The geographic extent of an impact expresses how widespread the impact is expected to be. It represents the area that will be affected, directly or indirectly. Impact extent is classified by the following levels:

- **Immediate vicinity:** Limited to a confined space within 2 km of project activities.

- **Local:** The impact has an influence that goes beyond the area of influence but stays within a relatively small geographic area (i.e., generally 5 to 20 km from the source of impact).

- **Regional:** The impact affects a large geographical area, generally more than 20 km from the source of impact.

In general, the extent of all impacts to resources from The Ocean Cleanup project would be limited to the immediate vicinity, except for potential behavior modifications in marine mammals due to noise, which would be local, and in neuston, which would range from local to regional.

#### *3.2.1.3 Impact Duration*

The duration of an impact describes the length of time over which the effects of an impact occur. It is not necessarily the same as the length of time of an activity or an IPF because an impact can sometimes continue after the source of impact has stopped or the impact can be shorter if there is an adaptation. Therefore, the impact duration can include the recovery period or the adaptation period of the affected resource. Impact duration can be:

- **Short term**: The impacts are felt continuously or discontinuously over a limited period, generally during the project period of activity, or when the recovery or adaptation period is less than a year.

- **Long term**: The impacts are felt continuously or discontinuously beyond the life of the project.

The duration for all impacts associated with The Ocean Cleanup project for this evaluation is expected to be short term, although the potential for long-term impacts for certain resources are continuing to be assessed (e.g., plankton, neuston).

**Table 5** lists the combinations of criteria used to delineate impact consequence.

Table 5. Matrix of impact consequence determinations for negative impacts.

| Intensity | Extent | Duration | Consequence Criteria | | | |
|---|---|---|---|---|---|---|
| | | | Negligible | Minor | Moderate | Severe |
| Low | Immediate vicinity | Short term | ● | - | - | - |
| | Local | Short term | ● | - | - | - |
| | Regional | Short term | ● | - | - | - |
| | Immediate vicinity | Long term | ● | - | - | - |
| | Local | Long term | - | ● | - | - |
| | Regional | Long term | - | ● | - | - |
| Moderate | Immediate vicinity | Short term | - | ● | - | - |
| | Local | Short term | - | ● | - | - |
| | Regional | Short term | - | ● | - | - |
| | Immediate vicinity | Long term | - | ● | - | - |
| | Local | Long term | - | - | ● | - |
| | Regional | Long term | - | - | ● | - |
| High | Immediate vicinity | Short term | - | - | ● | - |
| | Local | Short term | - | - | ● | - |
| | Regional | Short term | - | - | ● | - |
| | Immediate vicinity | Long term | - | - | ● | - |
| | Local | Long term | - | - | - | ● |
| | Regional | Long term | - | - | - | ● |

- = not applicable.

### 3.2.2 Determination of Impact Likelihood

The likelihood of an impact describes the probability that an impact will occur. The likelihood of impact occurrence was rated using the following categories:

- Likely (>50% likelihood)
- Occasional (10% to 49% likelihood)
- Rare (1% to 9% likelihood)
- Remote (<1% likelihood)

Impacts are evaluated or predicted prior to and following implementation of mitigation measures. Mitigation measures are identified based on industry best practice, international standards (e.g., MARPOL 73/78 requirements), or measures deemed applicable and practicable by The Ocean Cleanup. Impacts that remain after implementation of mitigation measures are described as residual impacts. To summarize the overall significance of each impact, impact consequence and likelihood were combined using professional judgment and a risk matrix (**Table 6**). According to this matrix, the overall impact significance for biological and social negative impacts using a numeric, descriptive, and color-coded approach is rated as follows:

- 1 – Negligible
- 2 – Low
- 3 – Medium
- 4 – High

Table 6. Matrix combining impact consequence and likelihood to determine overall impact significance.

| Likelihood vs. Consequence | | Decreasing Impact Consequence | | | | |
|---|---|---|---|---|---|---|
| | | Positive | Negligible | Minor | Moderate | Severe |
| Decreasing Impact Likelihood | Likely | Beneficial (no numeric rating applied) | 1 – Negligible | 2 – Low | 3 – Medium | 4 – High |
| | Occasional | | 1 – Negligible | 2 – Low | 3 – Medium | 4 – High |
| | Rare | | 1 – Negligible | 1 – Negligible | 2 – Low | 4 – High |
| | Remote | | 1 – Negligible | 1 – Negligible | 2 – Low | 3 – Medium |

Impacts of Negligible consequence were assigned the lowest overall significance value (1 – Negligible), regardless of impact likelihood. Severe impacts were assigned the highest significance value (4 – High) if the impacts were Likely, Occasional, or Rare and assigned a lower value (3 – Medium) if the likelihood was Remote. The most significant impacts (those rated as 3 – Medium or 4 – High) were primary candidates for mitigation. Mitigation was also considered for lower significance levels (1 – Negligible and 2 – Low) to further reduce the likelihood or consequence of impacts. A comprehensive discussion of the mitigation measures and corporate/subcontractor policies that The Ocean Cleanup will follow during project activities is presented in a separate EMP.

## 3.3 POTENTIAL IMPACTS FROM PROJECT CHANGES

As determined by the screening (**Section 3.1**), the following resources were determined to be at risk of changes to the impacts from the design changes for S002A and S002B:

- Plankton and Neuston;
- Fish/Fishery Resources;
- Marine Mammals, and
- Sea Turtles.

All mitigation measures included in the S002 will remain in effect and are included in the base impact analysis of impacts prior to implementing the additional mitigation measures. Therefore, the starting point for impact determinations is the residual impacts from the Revised S002 EIA (CSA, 2022).

### 3.3.1 Potential Change to Impacts on Plankton and Neuston

Because potential impacts to plankton and neuston are similar, they are discussed together to reduce redundancy.

#### *3.3.1.1 Impact Producing Factors*

- Entanglement/Entrapment
- Noise and Lights

#### *3.3.1.2 Entanglement/Entrapment*

<u>*S002A Potential Change to Impacts*</u>

Because the S002A is an actively towed system, it is likely that some zooplankton, phytoplankton, ichthyoplankton, and neuston with limited or no active mobility will become entrapped within the

RZ during deployment in the NPSG. During plastics collection operations, the S002A will collect plankton and neuston in the RS (two 391-m wings designed to guide plastics into the RZ). The wings extend 3 m below the water surface, have a mesh size of 10 mm × 10 mm, and the system opening between the wings is approximately 520 m, although it can reach a maximum of 700 m. Any plankton or neuston approximately 10 mm or larger that are within the area swept by the S002A will likely be retained in the RZ. During plastics extraction operations, the S002A is towed at a slower speed, and the opening between the wings is reduced to approximately 5 m, which significantly reduces the area swept by the system, possibly also reducing the amount of plankton and neuston retained in the RZ.

Estimating potential losses of neuston to the S002A is difficult for several reasons. There is a paucity of data regarding the structure and function of neuston communities in most of the world's oceans, as evidenced by the scarcity of peer-reviewed and gray literature. There is also limited information regarding the regional distribution of neuston within the NPSG, although data from Campaigns 1 through 6 strongly suggest most neustonic taxa exhibit a patchy distribution with extremely variable densities. The spatial and temporal distribution of the neuston community in the NPSG largely depends on the species composition of the community, their different diel and ontogenic migrations, their different life cycles, and their lifespan (i.e., generation times). Spatial distribution of neuston tend to follow mesoscale circulation patterns, temperature, salinity, and wind patterns within the area of interest (Thibault, 2021, personal communication).

Results of the S002 campaigns net sampling to date (The Ocean Cleanup, unpublished) indicate the neuston community was dominated by several taxa including calanoid copepods, chaetognaths, tunicates, hyperiid amphipods, *Lucifer* spp., cyclopoid copepods, Appendicularians, pteropods and fish eggs. Other neuston such as *Velella velella*, *Janthina* sp., and *Glaucus atlanticus* occurred less frequently in manta tows, and in much lower quantities than the dominant species (28, 13, and 10 tows of the 76 total tows, respectively). Occurrence of each taxon within the sampling data was highly variable with many taxa occurring on a very limited basis, and most taxa collected being intermittently present (e.g., collected in limited numbers during one campaign, not present in the remaining campaigns). For all gear types, the density of organisms decreased in samples from Campaigns 1 through 3 to Campaigns 4 through 6. These observations highlight the extremely patchy nature of the neuston distribution within the NPSG.

In addition, rafting neuston, including species found in association with floating debris, may be at particular risk from entanglement and entrapment as the removal of floating debris is the primary purpose of the S002A. Given the relatively high density of plastics and floating debris within the NPSG, there is likely a substantial rafting neuston community where the S002A will be deployed. Rafting materials are frequently dominated by three lepadomorph barnacle species—*Lepas anatife*ra, *L. pacifica*, and *L. (Dosima) fascicularis*. If these or other rafting species are attached to debris collected by the RS or RZ, they will likely not survive while in the RZ or when they are removed from the water during plastics collection.

However, with the larger RZ associated with S002A, the potential impacts to plankton and neuston are not anticipated to measurably change for entanglement/entrapment and will range from **1 – Negligible** to **2 – Low** during plastics collection operations prior to implementing the additional mitigation measures as determined in the Revised S002 EIA (CSA, 2022) since other than the larger size, the other design features of the RZ and operations during plastics collection remain the same as for S002.

Plastics extraction operations are still anticipated to take 12 hours per extraction and occur between four and five times during each 6-week campaign. The potential impacts to plankton and neuston for S002A would not measurably change for entanglement/entrapment from **1 – Negligible** determined for S002 during plastics extraction operations prior to implementation of the additional mitigation measures.

*S002B Potential Change to Impacts*

The addition of the deeper (4 m) wings to the larger RZ would not result in a larger area swept by the S002B. Therefore, the same area swept model applied for S002 from the updated S002 EIA (CSA, 2022) presented in **Table 7** would apply, acknowledging the same area-swept model limitations described below.

Neuston densities adapted from Egger et al. (2021) and The Ocean Cleanup (unpublished) are presented in **Table 7** along with the associated number of individuals that could be collected per day at different tow speeds during plastics collection, acknowledging the area-swept model limitations discussed below. In summary, these estimates should be considered extremely conservative, representing overestimates of potential neuston losses. During plastics extraction, the reduced mouth size of the system (i.e., 5 m) was calculated to collect approximately 99% fewer neuston. Because the S002B is actively towed, any plankton or neuston that become trapped in the RZ are unlikely to be able to free themselves and will remain trapped until opening of the RZ during plastics collection approximately every 5-6 days. Based on the comparison of manta and the half-submerged plankton net samples taken during Campaigns 1 through 3 of S002, comparing neuston densities in front of and behind the S002, respectively, some neuston appear to escape the system as well as be displaced in the water column due to the “wake” created by the System, though precise quantification of this is difficult. In addition, for S002B the mesh size of the wings will increase from 10 mm × 10 mm to 16 mm × 16 mm, which will allow additional neuston to pass through the mesh wings and not be captured.

Several important caveats or limitations to the swept model approach are warranted, the most important of which is that a uniform and constant density of neuston is assumed by the model. Per several sources (e.g., Goldstein et al., 2013; Helm, 2021), supplemented by data collected during the S002 campaigns using various gear types, (bongo, manta, and plankton nets) and different collection times (dawn, day, dusk, and night), neuston exhibit extremely patchy distribution.

Neuston blooms/aggregations are common, a fact that cannot be accounted for in a basic area-swept model. According to Brandon (2021, personal communication), the blooms or aggregations realized by some drifting neuston species may simply be the result of currents and winds accumulating them in one spot. In contrast, swarms, or blooms, of salps (which may occur in the neuston or deeper in the water column) are due to a life cycle that is highly adapted to patchy, unpredictable food sources. When there is little food available, their alternation of generations and hermaphroditism allows them to maintain genetic variability and to exist without reproducing (Alldredge and Madin, 1982). However, when they encounter abundant food sources, their high growth rate, short generation time, high fecundity, direct development, maternal nutrition of both the embryos and stolons, efficient morphology, and alternation of generations all combine to allow for population explosions (Alldredge and Madin, 1982).

Other caveats of the area-swept model include an inability to assess escapability (i.e., what percentage of the neuston can escape the system) and survivability (i.e., for the neuston species small enough to escape the wings with larger mesh [16-mm × 16-mm net], what percentage survives). The larger mesh size will likely allow additional neuston and plankton to escape the wings. Although this is not a mitigation measure, but a change in the design of the wings, this larger mesh size should allow additional neuston and plankton to escape.

Table 7. Estimated numbers of neuston individuals potentially collected by the S002B per day under plastics collection operations (520 m opening – Nominal Mode). Reported densities from Egger et al. (2021) and The Ocean Cleanup (unpublished) reflect calculated densities found in association with floating plastics (i.e., within the North Pacific Subtropical Gyre). Shaded cells represent minimum and maximum values used in the calculations, and corresponding numbers of individuals collected at each respective tow speed, model limitations notwithstanding.

| Species/Taxa | Reported Densities (individuals km$^{-2}$) | | | | Numbers of Individuals Collected at Different Vessel Speeds (Nominal Mode) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Egger et al. (2021) | | The Ocean Cleanup (unpublished) | | 0.5 m/s | | 1 m/s | | 1.5 m/s | |
| | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| Copepods | 43,545 | 1,731,593 | 3,298 | 15,435,976 | 74,086 | 346,753,765 | 148,173 | 693,507,530 | 222,259 | 1,040,261,295 |
| *Halobates* spp. | 9,429 | 32,655 | 4,552 | 404,314 | 102,256 | 9,082,510 | 204,512 | 18,165,019 | 306,768 | 27,247,529 |
| *Glaucus* spp. | 1,000 | 1,000 | NR | NR | 22,464 | 22,464 | 44,928 | 44,928 | 67,392 | 67,392 |
| Amphipods | 643 | 6,939 | 3,910 | 1,160,099 | 14,444 | 26,060,464 | 28,889 | 52,120,928 | 43,333 | 78,181,392 |
| Fish | 622 | 4,949 | NR | NR | 13,973 | 111,174 | 27,945 | 222,349 | 41,918 | 333,523 |
| Crabs | 604 | 3,501 | NR | NR | 13,568 | 78,646 | 27,137 | 157,293 | 40,705 | 235,939 |
| Euphausiacea | 570 | 25,320 | NR | NR | 12,804 | 568,788 | 25,609 | 1,137,577 | 38,413 | 1,706,365 |
| *Velella velella* | 557 | 855 | 2,946 | 166,457 | 12,512 | 3,739,290 | 25,025 | 7,478,580 | 37,537 | 11,217,870 |
| *Janthina janthina* | 542 | 4,566 | 2,947 | 72,532 | 12,175 | 1,629,359 | 24,351 | 3,258,718 | 36,526 | 4,888,077 |
| Squid | 371 | 588 | NR | NR | 8,334 | 13,209 | 16,668 | 26,418 | 25,002 | 39,626 |
| Pteropods, isopods, heteropods | 187 | 4,654 | NR | NR | 4,201 | 104,547 | 8,402 | 209,095 | 12,602 | 313,642 |
| *Porpita porpita* | 91 | 678 | NR | NR | 2,044 | 15,231 | 4,088 | 30,461 | 6,133 | 45,692 |

NR = not reported.

It is necessary, when applying the area-swept model and its acknowledged caveats, to also account for the two different tow configurations used by the S002B. It is anticipated that deployment of the S002B would last approximately 5-6 days for plastics collection operations. This would be followed by a shorter period (one day) for plastics extraction from the net. During plastics collection, the wing span of the S002 is approximately 520 m; during plastics extraction, the extraction section of the RZ is removed and the remainder of the system is towed with a mouth opening of 5 m and an open shortened RZ. In summary, during a 5-6 day System deployment, plastics collection was anticipated to occur for 5 days (83.3% of the time), with plastics extraction requiring one day (17% of the time).

Based on the tow speed of the S002B during plastics collection and the estimated size of the GPGP—1.6 million km$^2$ (Lebreton et al., 2018; The Ocean Cleanup, 2021), the area swept per day ranges from 22.5 km$^2$ at 0.5 m s$^{-1}$ tow speed to 67.4 km$^2$ at 1.5m s$^{-1}$ tow speed, representing between 0.0014% and 0.0042% of the total area of the GPGP. During plastics extraction, the area swept per day is calculated to be 0.22 km$^2$ at 0.5 m s$^{-1}$ tow speed, approximately 1% of the area swept under collection operations.

Sweeping activities might increase entanglement of neuston species, particularly crustaceans such as decapod larvae and copepods, which have large spines, protruding growths, or complex feather-like structures easily caught in fibers (Kang et al., 2020).

Zooplankton could be entangled within the System mesh and have little to no ability to swim away from the net even if deployed at low speed. Waves have been observed overtopping the S002 wings and may also occur with S002B although design changes have been made to minimize both overtopping and underflow of plastics, which may decrease some neuston and plankton overtopping the wings and instead being captured.

The long-term impacts of deploying the System should be **Beneficial** on plankton and neuston due to the removal of large amounts of plastics and other marine debris from the NPSG. The removal of macroplastics that would otherwise degrade into microplastics available for the potential ingestion by plankton will reduce potential impacts from the release of degradation byproducts (i.e., toxic chemicals) and transfer to higher levels of the food chain. There still are considerable knowledge gaps in the current understanding of how floating plastic debris accumulating in subtropical oceanic gyres may harm neuston. Removing floating plastic debris from the ocean surface can minimize potentially adverse effects of plastic pollution on neuston as well as prevent the formation of large quantities of secondary micro- and nanoplastics. However, due to the scarcity of observational data from remote and difficult-to-access offshore waters, neuston dynamics in subtropical oceanic gyres and thus the potential impacts of plastic pollution and cleanup activities on the neuston remain uncertain.

Based on the observations from S002 and data collected during Campaigns 1 through 6, limited numbers of neuston have been observed in the RZ as primary or secondary bycatch. In addition, with the larger mesh size of the wings, additional smaller neuston and plankton would be able to pass through the mesh openings. The net sampling (bongo, manta, and plankton) that has been performed during the S002 Campaigns was designed to evaluate those plankton and neuston species collected alongside the tow vessels (in front of the S002) by bongo and manta nets and behind the S002 (plankton nets) to evaluate the differences in the species and quantity collected. Over the six campaigns, bongo nets have been deployed the most (n=91 tows) followed by manta net (n=76 tows) and plankton ring-nets (n=37 tows). To best characterize the neuston and plankton of the upper water column bongo nets were towed no deeper than 3 m below the water's surface. The manta net sampled the very surface layer, approximately the upper 15 cm of the water column. The plankton net was towed at or near the water's surface as often as it was safe and feasible. The most frequently occurring taxa in 91 bongo tows over the six campaigns were calanoid copepods (89 tows, 96%), chaetognaths (86 tows, 96%), tunicates (86 tows, 96%), hyperiid amphipods (65 tows, 72%), fish eggs (64 tows, 71%), Appendicularians (61 tows, 68%), and pteropods (49 tows, 54%).

Manta net samples best characterize the neuston assemblage. Of the 76 manta net tows made during the six campaigns, calanoid copepods occurred in 72 (95%), chaetognaths in 69 (91%), tunicates in 69 (91%), *Halobates* spp. in 61 (80%), *Lucifer* spp in 48 (63%), Hyperiid amphipods in 44 (58%), and fish eggs in 43 (57%). Other neuston such as *V. velella* occurred in 28 (37%), *Janthina* sp. occurred in 13 (10%), and *G. atlanticus* occurred in 10 (9%) of the manta tows.

Abundant taxa collected in the plankton net tows were similar to those captured by the manta and bongo nets. In rank order of occurrence, the most frequently collected taxa in the 37 plankton tows were calanoid copepods (35 tows, 95%), chaetognaths (35 tows, 95%), tunicates (32 tows, 86%), hyperiid amphipods (31 tows, 84%), pteropods (23 tows, 62%) and fish eggs (22 tows, 59%).

The numerically dominant crustaceans were examined as a group to assess variability in the data by gear type and Campaign (1 to 6). **Figure 14** shows sample data among Campaigns and gear types. For all gear types, the density of organisms (numbers m$^{-3}$) decreased in samples from Campaigns 1 through 3 to Campaigns 4 through 6.

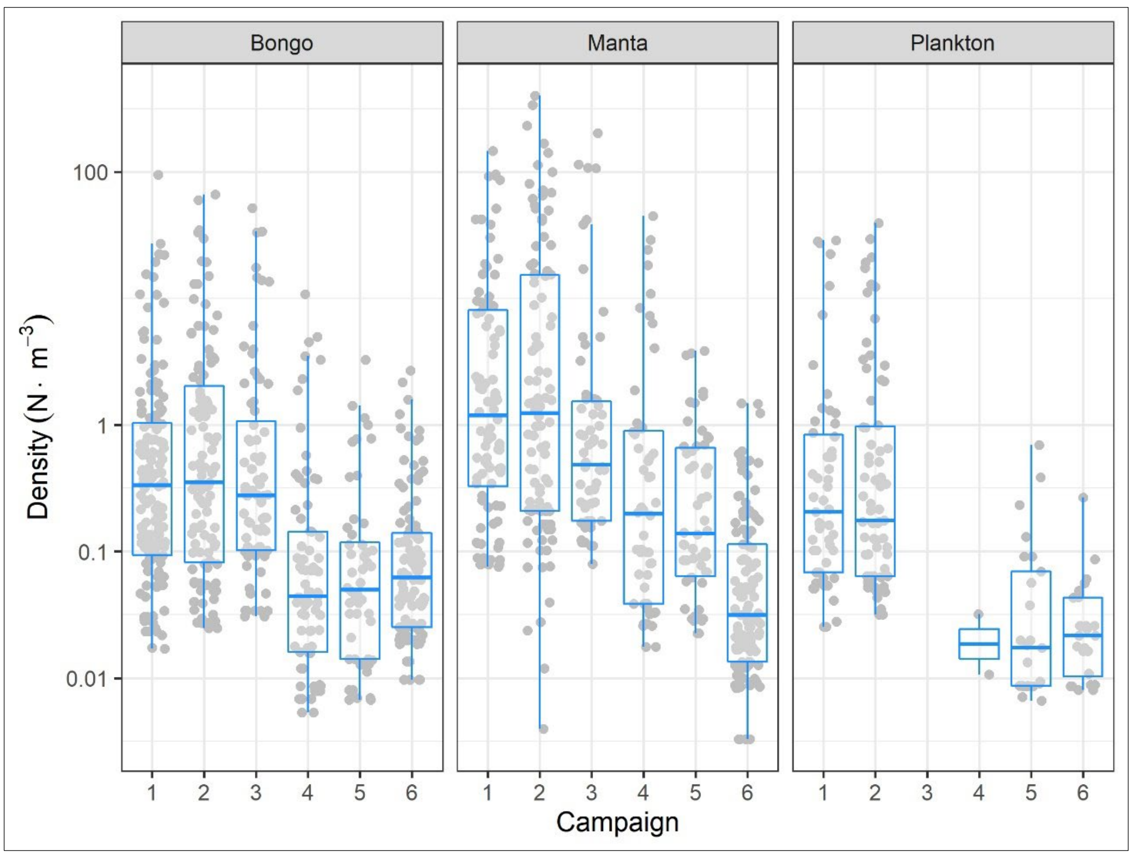



Figure 14. Density of crustacean zooplankton collected by bongo, manta, and plankton nets over six Campaigns. Boxplots represent 25th and 75th quartiles and the whiskers represent range of the data.

Data from the RZ processing of Campaigns 1 through 6 indicate primary bycatch predominantly consists of fish, with fewer small sharks, crustaceans (mostly crabs), barnacles, and mollusks (octopus, clam), and only a few cnidarians observed (e.g., *V. velella*). In addition, the anticipated biofouling of the RZ mesh was not observed by the Environmental Coordinators on board the M/V *Maersk Tender*. Based on observations and data collected during Campaigns 1 through 6, the anticipated mortality of plankton and neuston organisms from the S002 deployment within the area swept has not been realized and it is anticipated that a similar trend will continue with the S002B especially due to the increased mesh size of the wings associated with S002B.

This analysis has shown that there were not significant differences in the species of copepods and fish eggs and larvae from the bongo samples taken in front of the S002 and the plankton samples taken after the S002 except for anglerfish larvae. Based on the updated data collected during Campaigns 1 through 6, the variable plankton densities present in the NPSG, and the area-swept calculations used for S002 that are still applicable, impact intensity is rated as low, though it is possible the impact intensity could be moderate. The design of S002B, with the deeper wings, could potentially result in more neuston and plankton impacted by the System; however, this potential is not expected to result in measurable changes. The extent of impact is expected to range from local to regional, with a short duration (based on relatively short generation times). Resulting impact consequence is not anticipated to measurably be different than determined for S002 and would remain ranging from negligible to minor. Due to the likely nature of this impact, the overall impact significance rating is expected to remain to range from **1 – Negligible** to **2 – Low** during plastics collection operations prior to implementing the additional mitigation measures.

During plastics extraction operations the S002B is towed by one vessel at a slower speed, and has a narrowed wingspan, which significantly reduces the area swept by the System. Plastics extraction operations are anticipated to take 12 hours for each extraction and occur between three and five times during each 6-week campaign. The impact likelihood would be reduced, and the impact intensity would be reduced due to a smaller area for capture, resulting in an overall impact significance remaining **1 – Negligible** as determined for S002 during plastics extraction operations prior to implementation of mitigation measures.

*Additional Mitigation Measures S002A*

There are no additional mitigation measures associated with S002A that would reduce potential impacts to plankton and neuston from entanglement/entrapment.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B; but there are no additional mitigation measures that would reduce the potential impacts to plankton and neuston from entanglement/entrapment. However, The Ocean Cleanup has changed the design of the wings to include a larger mesh size (16 mm square) which will allow smaller marine animals to exit the system.

*S002A Residual Impacts*

Mitigation measure effectiveness will be affected if the RZ becomes severely clogged; however, to date, no clogging has been observed. Even with the remotely triggered acoustic release, few plankton/neuston organisms will survive after being compacted in the RZ although this has not been observed to date. Zooplankton could be entangled within the System mesh and have little to no ability to swim away from the net even if deployed at low speed. Waves have been observed overtopping the

S002 wings, which may be allowing some neuston and plankton to not be captured within the RZ or wing mesh and is expected to continue for S002A.

With no additional mitigation measures for neuston and plankton associated with S002A, the impacts from entanglement/entrapment would remain the same and range from **1 – Negligible** to **2 – Low** for plastics collection operations and **1 – Negligible** for plastics extraction operations.

*S002B Residual Impacts*

With no additional mitigation measures for neuston and plankton associated with S002B, the impacts from entanglement/entrapment would remain the same and range from **1 – Negligible** to **2 – Low** for plastics collection operations and **1 – Negligible** for plastics extraction operations.

#### *3.3.1.3 Noise and Lights*

*S002A Potential Change to Impacts*

Plankton and neuston that have limited active mobility may be attracted to the System due to lights on the vessel or the System itself. Conversely, there is some evidence that both natural and anthropogenic light pollution may suppress diel migration of zooplankton, which would reduce the number of organisms migrating into the surface layer (Ludvigsen et al., 2018). The S002A and its tow vessels will stand out in the project area as possibly the only artificial light sources.

Attraction of plankton and neuston to lighting on the System and tow vessels would be limited to the immediate vicinity and would primarily occur only when the vessels are traveling at extremely low speeds. However, it could result in increased predation by fishes or other predators similarly attracted to the noise and lights. Many plankton and neuston are free-floating, predominantly moving with currents and wind; therefore, impacts would mostly be applicable only to species able to actively move towards the system (e.g., planktohyponeuston, which vertically migrate) or free-floating plankton and neuston that happen to be in the vicinity.

Operations of S002A would remain the same and the larger RZ would not result any changes in the impact significance of **1 – Negligible** determined for S002 for plastics collection and extraction operations.

*S002B Potential Change to Impacts*

Operations of S002B would remain the same and the deeper wings would not create more noise or lights; therefore, there would not be any changes in the impact significance of **1 – Negligible** for neuston and plankton from noise or lights determined for S002 for plastics collection and extraction operations.

*Additional Mitigation Measures S002A*

The Ocean Cleanup will implement the additional following mitigation measures associated with S002A to reduce potential impacts to plankton and neuston from noise and lights:

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability that will reduce shining on the water at night.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. There are no additional mitigation measures associated with S002B to reduce potential impacts to plankton and neuston from noise and lights.

*S002A Residual Impacts*

The additional green flashing LED lights are not anticipated to change the impact significance determine prior to mitigation measures and would remain **1 – Negligible** for neuston and plankton from noise and lights for plastics collection and extraction operations.

*S002B Residual Impacts*

With no additional mitigation measures associated with S002B, there would be no change to the impact significance determine prior to mitigation measures and would remain **1 – Negligible** for neuston and plankton from noise and lights determined for plastics collection and extraction operations.

### 3.3.2 Potential Change to Impacts on Fish and Fishery Resources

#### *3.3.2.1 Impact Producing Factors*

- Entanglement/Entrapment
- Attraction/Ingestion of Plastics
- Noise and Lights

For fish and fishery resources, the impacts of S002A and S002B entanglement/entrapment and attraction/ingestion of plastics are interrelated. Therefore, potential impacts from these two IPFs are discussed together to avoid redundancy.

#### *3.3.2.2 Entanglement/Entrapment and Attraction/Ingestion of Plastics*

*S002A Potential Change to Impacts*

Fish species are attracted to offshore structures such as oil and gas platforms and various types of flotsam (Shomura and Matsumoto, 1982; Franks, 2000; Fabi et al., 2004). These structures can provide substrate habitat for invertebrates, protective habitat for finfish, and light attraction. There are numerous flotsam-associated species that have been shown to be attracted to the System or be present within the floating debris and this will not change with S002A. Numerous species of fish are attracted to offshore flotsam, likely in search of shelter and food. The most common flotsam-associated species are jacks and triggerfish, but more than 300 species have been identified associated with offshore debris (Castro et al., 2002).

Plastics collection and extraction operations during deployment of S002 resulted in the capture, injury, or mortality of individual fishes. During Campaigns 1 through 6, The Ocean Cleanup removed an average of 2,891 kg of plastic and debris (57,819 kg total) during each extraction operation. Campaigns 1 through 6 had a total of 203.43 kg of primary bycatch, which corresponds to 0.35% of primary bycatch weight in relation to the weight of plastic debris removed. This primary bycatch consisted of 14 fish groups, with the predominant groups being small blennies and Pacific sergeant majors (*Abudefduf* spp.) but also included flying fishes, juvenile amberjacks (*Seriola* spp.*)*, and pygmy sharks (*Euprotomicrus bispinatus*); however, very few large pelagic fishes were caught due to their robust swimming abilities; the slow tow speeds (0.5 to 2.5 knots); and their ability to escape via the fyke openings or by swimming under the wings or through the mesh holes, as observed by the underwater cameras. Schools of smaller fish congregate within the system for shelter and to search for food, and then some are unable to escape the RS and RZ. The number of fish captured would not be significant on the regional or population level for any of those species. Similar results are expected during S002A activities. Therefore, it is anticipated that no measurable changes in the impact significance of entanglement/entrapment of **2 – Low** determined for S002 during plastics collection operations would occur for fish or fishery resources.

The effects on fish and fishery resources from attraction/ingestion of plastics congregated by the S002A may increase slightly due to the larger size of the RZ and fish looking for shelter and food as schools of smaller fish congregate within the system. The effects are considered likely and are still expected to be of moderate intensity, short-term duration, and of minor consequence, resulting in no measurable changes in the impact significance of **2 – Low** for attraction/ingestion of plastics and no population-level effects on fish communities are expected. Even with the low amount of primary bycatch observed for S002 Campaigns 1 through 6 (0.35% per weight of plastic collected), there is a high likelihood of the impact occurring which may increase slightly due to the increased size of the RZ. This would result in a moderate impact intensity for fish and fishery resources being attracted to the larger S002A RZ. However, the impact consequence for attraction/ingestion of plastics would remain minor, resulting in the impact significance remaining **2 – Low** during plastics collection operations prior to implementation of the additional mitigation measures for fish and fishery resources.

During plastics extraction operations, the S002A is towed by one vessel, at a slower speed, with a narrowed wingspan and the shortened RZ open, albeit longer due to the longer overall RZ, which would still significantly reduce the area swept by the system and allow escape through the open RZ for those individuals captured. Each plastics extraction operation takes approximately 12 hours and is anticipated to occur 3 to 5 times during each 6-week campaign. While the impact likelihood would remain the same, the impact intensity would be reduced due to a smaller area for capture and the open RZ; therefore, even with the potential of slightly increased attraction due to the larger RZ, the impact intensity would be reduced due to a smaller area for capture, resulting in the overall impact significance remaining **1 – Negligible** during plastics extraction operations of S002B prior to implementation of the additional mitigation measures for both attraction/ingestion and entanglement/entrapment IPFs.

The long-term impacts of deploying the S002A would remain **Beneficial** on fish and fishery resources due to the removal of large amounts of plastics and other marine debris from the NPSG. Removal of plastics from the NPSG will reduce the potential for fish to ingest plastics and for impacts stemming from the release of degradation byproducts (i.e., toxic chemicals).

*S002B Potential Change to Impacts*

With the addition of the deeper (4 m) wings to the larger RZ added for S002A, plastics collection and extraction operations are anticipated to result in the capture, injury, or mortality of individual fishes to a slightly greater extent than S002 due to the deeper wings, which could decrease the ability for some fish to escape the wings. It could be more difficult for some fish species to swim under the deeper wings to escape, but most fish species that have been included in the S002 bycatch (e.g., amberjack, flying halfbeak [*Euleptorhamphus viridis]*, blennies [*Petroscirtes breviceps* and others], flying fish [*Cheilopogon* sp., *Hirundichthys* sp.], sergeant major, Pacific pomfret [*Brama japonica]*, sargassumfish [*Histrio histrio]*, scrawled filefish [*Aluterus scriptus]*) would not be affected. However, the wings for S002B are comprised of larger mesh, 16 mm × 16 mm square, which will allow additional small fish to escape through the wings mesh.

As with S002A, the effects on fish and fishery resources from attraction/ingestion of plastics congregated by the S002B are considered likely and are expected to be of moderate intensity, short-term duration, and of minor consequence, resulting in no measurable changes in the impact significance of **2 – Low** determined for S002 and no population-level effects on fish communities are expected. As observed with the primary bycatch data for S002 Campaigns 1 through 6, there is a high likelihood of the impact occurring and with the deeper wings, a moderate impact intensity, a short-term duration, and minor consequence of fish and fishery resources becoming entangled/entrapped in the deeper wings of the S002B. The impact consequence for this IPF would remain minor, resulting in an impact significance of **1 – Low** during plastics collection operations prior to implementing the additional mitigation measures.

During plastics extraction operations, the S002B is towed by one vessel at a slower speed, with a narrowed wingspan and the longer shortened RZ open, which would still significantly reduce the area swept by the system and allow escape through the open RZ for those individuals captured. Each plastics extraction operation takes approximately 12 hours and is anticipated to occur 3 to 5 times during each 6-week campaign. While the impact likelihood would remain the same, resulting in an overall impact significance of **1 – Negligible** during plastics extraction operations prior to implementation of additional mitigation measures for both attraction/ingestion and entanglement/entrapment IPFs.

The long-term impacts of deploying the S002B would remain **Beneficial** on fish and fishery resources due to the removal of large amounts of plastics and other marine debris from the NPSG. This will reduce the potential for fish to ingest plastics and for impacts stemming from the release of degradation byproducts (i.e., toxic chemicals).

*Additional Mitigation Measures S002A*

The Ocean Cleanup will implement the additional following new mitigation measures associated with S002A to reduce potential impacts to fish and fishery resources from entanglement/entrapment and attraction/ingestion:

- **Additional escape aids** – The larger RZ includes two additional fyke openings to allow fish additional escape routes if accidentally collected by the system.

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. There are no additional mitigation measures associated with S002B to reduce potential impacts to fish and fishery resources from entanglement/entrapment or attraction/ingestion.

*S002A Residual Impacts*

The additional mitigation measures may increase the attraction of some fish species to the System due to the increased size of the RZ and the associated fish aggregating device effect, fish looking for shelter or food, as well as due to the added flashing green LED lights. The additional green flashing lights may also attract phototaxic prey and provide enhanced lighting conditions for predators to locate and capture prey; however, the flashing aspect of the lighting will minimize that attraction effect and may provide enhanced escapement opportunities with the lights around the RZ opening (Lomeli and Wakefield, 2019). While the attraction of fish and fishery resources to the new RZ may increase slightly, the increase is not enough to change the residual impact significance determined for S002 and will remain **2 – Low** for plastics collection and **1 – Negligible** for extraction operations for attraction/ingestion.

For the entanglement and entrapment IPF, although fish were caught by the System as primary bycatch, observations made from the underwater cameras and system inspections showed many fish could readily swim into and out of the S002, including the RZ using the fyke openings, by swimming under the wings, or by swimming through the mesh holes, indicating effective mitigation measures to reduce the fish primary bycatch. With the increased number of fyke openings, the potential for escape increases and the mitigation measures would somewhat reduce the likelihood of impact occurrence; however, not enough to change the overall impact rating of **2 – Low** for plastics collection operations. During plastics extraction operations all mitigation measures would still be in place other than the remotely triggered acoustic release; however, the longer shortened RZ is open to allow free flow through the RZ. Therefore, the mitigation measures reduce the impact intensity from moderate to low and reduce the likelihood of impact occurrence, resulting in a reduction of impact significance to **1 – Negligible** for plastics extraction operations.

*S002B Residual Impacts*

With no additional mitigation measures to reduce potential impacts to fish and fishery resources associated with the deeper (4 m) wings, there would be no change to the impact significance from attraction and entanglement/entrapment and would remain **2 – Low** for both plastics collection and **1 – Negligible** for extraction operations for both IPFs.

#### ***3.3.2.2 Noise and Lights***

*S002A Potential Change to Impacts*

Fishes inhabiting or transiting the NPSG could be subjected to noise from the support vessel traffic as two support vessels will always be present during plastics collection and extraction operations. Vessels cause a path of physical disturbance in the water that could affect the behavior of certain fish species, depending on the type of vessel and ecology of the fish species. Vessel noise may disturb pelagic fish and alter their behavior by inducing avoidance, potentially displacing some species from preferred habitat, altering swimming speed and direction, and altering schooling behavior (Sarà et al., 2007). Pressure waves from vessel hulls could displace fish near the surface. Additionally, vessel noise can mask sounds that affect communication between fishes (Purser and Radford, 2011).

However, with the larger RZ associated with S002A there would be no change to the impacts from noise and although fish may exhibit avoidance behavior when subjected to loud noises from a vessel; vessel noise is inherently transient, rendering adverse temporary impacts. Vessel and equipment noise remain the same with S002A in the project area; and therefore, the impacts from noise are expected to be short term and only within the immediate vicinity resulting in negligible consequence and have an impact significance of **1 – Negligible** for both plastics collection and extraction operations prior to implementing the additional mitigation measures.

Operational lights create small “halos” of light in the water at night that attract fish and predators (Barker, 2016). The S002A and its tow vessels will stand out in the project area as possibly the only artificial light sources. As with S002, lights will be used during evening and night hours on the System and tow vessels, although efforts will be made to reduce lighting as much as practicable. The light may also attract phototaxic prey and provide enhanced lighting conditions for predators to locate and capture prey while foraging within the light field surrounding the vessels. Fish foraging in the light field may also attract larger predators, rendering each in turn vulnerable to other predators and to entanglement and entrapment by the system itself. However, the light field produced by the S002A and its associated vessels is expected to cover a significantly smaller area than what is produced by a typical offshore structure such as an oil and gas platform. As with S002, the light field will move as the System is towed, so no one location will receive a steady light field. Therefore, the impacts from light are expected to remain of moderate intensity, short-term duration, and of minor consequence, resulting in no measurable change in impact significance of **2 – Low** determined for S002 prior to implementing the additional mitigation measures during both plastics collection and extraction operations.

*S002B Potential Change to Impacts*

The addition of the deeper wings associated with S002B will not change the noise or light created by the project; and therefore, the impact significance would remain **1 – Negligible** for both plastics collection and extraction operations prior to implementing the additional mitigation measures for noise and **2 – Low** during both plastics collection and extraction operations for light prior to implementing the additional mitigation measures.

*Additional Mitigation Measures S002A*

The Ocean Cleanup will implement the additional following new mitigation measures associated with S002A to reduce potential impacts to fish and fishery resources from noise and lights:

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights which will reduce shining light on the water at night.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. There are no additional mitigation measures associated with S002B to reduce potential impacts to fish and fishery resources from noise and lights.

*S002A Residual Impacts*

The addition of the larger RZ associated with S002A is not anticipated to result in any measurable change in impact significance from S002 with respect to noise resulting in **1 – Negligible** during both plastics collection and extraction operations.

The addition of 15 green flashing lights on the larger RZ, including seven at the mouth of the RZ, may also attract phototaxic prey and provide enhanced lighting conditions for predators to locate and capture prey; however, the flashing aspect of the lighting will minimize that attraction effect and may provide enhanced escapement opportunities with the lights around the RZ opening (Lomeli and Wakefield, 2019). The attraction of fish and fishery resources to the additional lights on the new RZ may increase slightly, but not enough to change the residual impact significance determined prior to implementing the additional mitigation measure and would remain **2 – Low** for both plastics collection and extraction operations for lights.

*S002B Residual Impacts*

The addition of the deeper wings associated with S002B is not anticipated to result in any change in impact significance prior to implementing the additional mitigation measures with respect to noise resulting in **1 – Negligible** during both plastics collection and extraction operations.

There would be no change in the impact significance from lights and would remain **2 – Low** for both plastics collection and extraction operations.

### 3.3.3 Potential Change to Impacts on Marine Mammals

#### *3.3.3.1 Impact Producing Factors*

- Entanglement/Entrapment
- Attraction/Ingestion of Plastics
- Noise and Lights

#### *3.3.3.2 Entanglement/Entrapment*

*S002A Potential Change to Impacts*

There is a risk of entanglement any time gear, particularly lines and cables, are put in the water. Gall and Thompson (2015) reviewed previous literature and found 52 species of marine mammals have entanglement records with marine debris, primarily fishing gear or nets. However, there have been no entanglement/entrapment issues with marine mammals to date with S002 and that is not expected to change with the larger RZ associated with S002A. Therefore, impacts are not expected to measurably change from **1 – Negligible** for non-protected species and **2 – Low** for protected species from entanglement/entrapment during plastics collection and **1 – Negligible** during plastics extraction operations prior to implementing the additional mitigation measures as determined in the Revised S002 EIA (CSA, 2022) since other than the larger size, the other design features of the RZ and operations during plastics collection remain the same as for S002. In addition, the overall long-term impacts of the S002A on marine mammals should remain **Beneficial** due to the removal of large amounts of plastics and other marine debris from the NPSG.

*S002B Potential Change to Impacts*

There is a risk of entanglement any time gear, particularly lines and cables, are put in the water and with the addition of the deeper wings associated with S002B that entanglement risk could increase. However, there have been no entanglement/entrapment issues with marine mammals to date with S002 and that is not expected to change with the deeper wings associated with S002B as all marine mammals that could be encountered by the System are capable of diving beneath the deeper wings (4 m) in the event that they do get inside the wings. Therefore, impacts are not expected to measurably change from **1 – Negligible** from entanglement/entrapment for non-protected species and **2 – Low** for protected species during plastics collection operations and **1 – Negligible** during plastics extraction operations as determined for S002 prior to implementing the additional mitigation measures. In addition, the overall, the long-term impacts of the S002B on marine mammals should remain **Beneficial** due to the removal of large amounts of plastics and other marine debris from the NPSG.

*Additional Mitigation Measures S002A*

The Ocean Cleanup will implement the additional following mitigation measures for S002A to reduce potential impacts to marine mammals from entanglement/entrapment:

- **Additional escape aids** – The larger RZ includes two additional fyke openings to allow small marine mammals additional escape routes if accidentally collected by the system.

- **Breathing ports** – The larger RZ includes two additional breathing hatches that incorporates a new design.

- **Acoustic deterrent** – The larger RZ includes four additional banana pingers to deter the approach of marine mammals.

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

- **RZ access openings** – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a marine animal enters the RZ.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. In addition, The Ocean Cleanup will implement the following additional mitigation measure to reduce potential impacts to marine mammals from entanglement/entrapment:

- **Acoustic deterrents** – The deeper wings include two additional banana pingers attached to the wings spaced throughout the wings.

*S002A Residual Impacts*

Based on implementing the additional mitigation measures for S002A, two components of the impact consequence—intensity and likelihood—would be further reduced; however, the resulting impact significance would remain **1 – Negligible** for entanglement/entrapment for non-protected species. For marine mammal protected species, even though the S002A RZ includes additional escape routes and breathing ports, the results from S002 cruises has shown that the remotely triggered acoustic release for the end of the RZ may not be able to be activated and allow for escape in the remote possibility a protected species does become entangled in the S002A. Therefore, even though to date, no marine mammals have become entangled or entrapped in the System, the residual impact significance for protected species would remain **2 – Low** from entanglement/entrapment for plastics collection operations as determined for S002 since such an incident could be significant at the population level.

Although the remotely triggered acoustic release portion of the escape aids mitigation measure is not implemented during plastics extraction operations, all other mitigation measures are in effect, including towing the shortened RZ with the end open. Extraction operations will be performed during daylight hours, which will allow for the visual monitoring mitigation measures to be most effective. Based on implementation of the mitigation measures and additional operational actions that would be implemented as necessary (e.g., further reduced vessel speed, shortening of catenary length, holding System wings in the current only), the likelihood of entanglement would remain remote, and the impact intensity would be reduced due to a smaller area for capture. Impact consequence would also be reduced due to the open shortened RZ, which would allow a marine mammal to swim through the system and reduce the potential for entanglement. Therefore, the overall impact significance for marine mammals would remain **1 – Negligible** from entanglement/entrapment during plastics extraction operations with the implementation of mitigation measures.

_S002B Residual Impacts_

With the additional mitigation measure (additional pingers) implemented for S002B, there would not be a measurable change in the impact significance and would remain **1 – Negligible** for non-protected species and **2 – Low** for protected species from entanglement/entrapment during plastics collection operations and **1 – Negligible** during plastics extraction operations.

#### *3.3.3.2 Attraction/Ingestion of Plastics*

_S002A Potential Change to Impacts_

Some marine mammals may be attracted to offshore structures like S002, while others will avoid them. Marine mammals have also been known to ingest trash and debris (Gall and Thompson, 2015). Debris ingestion can lead to loss of nutrition, internal injury, intestinal blockage, starvation, and death (NOAA, 2015). However, records suggest entanglement is a far more likely cause of mortality to marine mammals than ingestion-related interactions (Laist et al., 1999). Through the end of Campaign 7 (July 2022) on the S002 campaigns, there have been a total of 23 marine mammal observations within the NPSG with most observed 500 to 2,000 m from the vessels and S002. Only two small groups of a total of five individuals and one individual have approached the System and mitigation measures were implemented to slow the vessels with continued monitoring by PSOs and all animals left the area unharmed and did not directly interact with the System. Therefore, it does not appear that many marine mammals are attracted to the System and with the S002A larger RZ, the impact significance would remain **1 – Negligible** from attraction/ingestion of plastics for plastics collection and extraction operations prior to implementing the additional mitigation measures.

_S002B Potential Change to Impacts_

The deeper wings associated with S002B would not increase the potential attraction of marine mammals to the system; and therefore, the impact significance would remain **1 – Negligible** from attraction/ingestion of plastics for plastics collection and extraction operations prior to implementing the additional mitigation measures.

_Additional Mitigation Measures S002A_

The Ocean Cleanup will implement the additional following mitigation measures for S002A to reduce potential impacts to marine mammals from attraction/ingestion of plastics:

- **Acoustic deterrent** – The larger RZ includes four additional banana pingers to deter the approach of marine mammals.

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. In addition, The Ocean Cleanup will implement the following additional mitigation measures to reduce potential impacts to marine mammals from attraction/ingestion of plastics:

- **Acoustic deterrents** – The deeper wings include two additional banana pingers attached to the wings spaced throughout the wings.

*S002A Residual Impacts*

The additional mitigation measures (additional pingers and flashing LEDs) associated with S002A RZ might further deter marine mammals from being attracted to the System, but would not measurably change the impact significance for attraction/ingestion of plastics for marine mammals and would remain **1 – Negligible** for plastics collection and extraction operations.

*S002B Residual Impacts*

The additional mitigation measure (additional pingers) associated with S002B wings might further deter marine mammals from being attracted to the System, but would not measurably change the impact significance for attraction/ingestion of plastics for marine mammals and would remain **1 – Negligible** for plastics collection and extraction operations.

#### *3.3.3.3 Noise and Lights*

*S002A Potential Change to Impacts*

The Ocean Cleanup project activities with S002A will still generate vessel and equipment noise that could disturb marine mammals. The sound types produced by the vessels and equipment are classified as non-pulsed, or continuous. Vessel noise is a combination of narrow-band (tonal) and broadband sound (Richardson et al., 1995). Tones typically dominate up to approximately 50 Hz, whereas broadband sounds can extend to 100 kHz. In many areas, radiated sound from ships is the dominant source of underwater noise at frequencies below 300 Hz (Okeanos, 2008).

Vessel and equipment noise, including those produced during towing, monitoring, and debris collection activities, typically would produce sound levels less than 190 $dB_{rms}$ re 1 μPa 1 m. The current acoustic thresholds for injurious (permanent threshold shift onset) and non-injurious (temporary threshold shift onset) exposure to a continuous noise source, based on marine mammal hearing group, are presented in **Table 8**.

Table 8. Underwater acoustic thresholds from continuous sound for onset of permanent and temporary threshold shifts and behavior thresholds in marine mammal hearing groups.

| Marine Mammal Hearing Group | PTS[1] | | TTS[2] | | Behavior[3] | |
|---|---|---|---|---|---|---|
| | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value |
| Low-frequency cetaceans (baleen whales) | $SEL_{24h}$ | 199 dB re 1 μPa$^2$ s | $SEL_{24h}$ | 179 dB re 1 μPa$^2$ s | SPL | 120 dB re 1 μPa |
| Mid-frequency cetaceans (dolphins, toothed whales, beaked whales, and bottlenose whales) | $SEL_{24h}$ | 198 dB re 1 μPa$^2$ s | $SEL_{24h}$ | 178 dB re 1 μPa$^2$ s | SPL | 120 dB re 1 μPa |
| High-frequency cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchids) | $SEL_{24h}$ | 173 dB re 1 μPa$^2$ s | $SEL_{24h}$ | 153 dB re 1 μPa$^2$ s | SPL | 120 dB re 1 μPa |
| Phocid pinnipeds (underwater) | $SEL_{24h}$ | 201 dB re 1 μPa$^2$ s | $SEL_{24h}$ | 186 dB re 1 μPa$^2$ s | SPL | 120 dB re 1 μPa |
| Otariid pinnipeds (underwater) | $SEL_{24h}$ | 219 dB re 1 μPa$^2$ s | $SEL_{24h}$ | 199 dB re 1 μPa$^2$ s | SPL | 120 dB re 1 μPa |

μPa = micropascal; dB = decibel; h = hour; PTS = permanent threshold shift; re = referenced to; s = second; $SEL_{24h}$ = sound exposure level over 24 hours; SPL = root-mean-square sound pressure level; TTS = temporary threshold shift.
[1] PTS thresholds derived from National Marine Fisheries Service (NMFS) (2018).
[2] TTS thresholds derived from Southall et al. (2019).
[3] Behavioral thresholds derived from NMFS (2019).

In addition to direct injurious or sub-injurious exposures, an additional effect of increased ambient noise on marine mammals is the potential for noise to mask biologically significant sounds. The presence of the vessels in the NPSG could present a novel, persistent noise source but the operations of S002A would not change the noise level from those associated with S002 and are expected to have a negligible impact consequence that would include temporary disruption of communication or echolocation from auditory masking; behavioral disruptions of individuals or localized groups of marine mammals; and limited, localized, and short-term displacement of individuals of any species, including strategic stocks, from localized areas around the System. Because the operation will occur in the open ocean, animals are expected to avoid the sound source and the potential for resultant auditory injuries. Consequently, impacts to marine mammals from project-related noise are expected to remain **1 – Negligible** for both plastics collection and extraction operations for marine mammals prior to implementation of the additional mitigation measures.

Bielli et al. (2020) has shown that the use of LEDs on nets can reduce the probability of bycatch of some small cetaceans. Therefore, the LEDs could be a deterrent to small cetaceans from approaching the System; and therefore, the impact would be **Beneficial**.

*S002B Potential Change to Impacts*

The deeper wings associated with S002B would not change the noise generated by project activities; therefore, the impact to marine mammals from project-related noise are expected to remain **1 – Negligible** for both plastics collection and extraction operations prior to implementation of the additional mitigation measures.

Bielli et al. (2020) has shown that the use of LEDs on nets can reduce the probability of bycatch of some small cetaceans. Therefore, the LEDs could be a deterrent to small cetaceans from approaching the System; and therefore, the impact would be **Beneficial**.

*<u>Additional Mitigation Measures S002A</u>*

The Ocean Cleanup will implement the additional following mitigation measures for S002A to reduce potential impacts to marine mammals from noise and lights:

- **Acoustic deterrent** – The larger RZ includes four additional banana pingers to deter the approach of marine mammals.

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

*<u>Additional Mitigation Measures S002B</u>*

All additional mitigation measures associated with S002A will remain in effect for S002B. In addition, The Ocean Cleanup will implement the following additional mitigation measures to reduce potential impacts to marine mammals from noise and lights:

- **Acoustic deterrents** – The deeper wings include two additional banana pingers attached to the wings spaced throughout the wings.

*<u>S002A Residual Impacts</u>*

The additional banana pingers associated with the larger RZ included in S002A will add additional novel anthropogenic noise to the local oceanic soundscape. However, no measurable change is anticipated and consequently, impacts to marine mammals from project-related noise are expected to remain **1 – Negligible** for both plastics collection and extraction activities.

Bielli et al.(2020) has shown that the use of LEDs on nets can reduce the probability of bycatch of some small cetaceans. Therefore, the additional LEDs associated with the larger RZ could be an additional deterrent to small cetaceans from approaching the System; and therefore, the impact would remain **Beneficial**.

*<u>S002B Residual Impacts</u>*

The additional banana pingers associated with the deeper wings included in S002B will add additional novel anthropogenic noise to the local oceanic soundscape. However, no measurable change is anticipated and consequently, impacts to marine mammals from project-related noise are expected to remain **1 – Negligible** for both plastics collection and extraction activities.

There would be no change in the beneficial impact as a deterrent to small cetaceans from approaching the System; therefore, the impact would remain **Beneficial**.

### 3.3.4 Potential Change to Impacts on Sea Turtles

#### *3.3.4.1 Impact Producing Factors*

- Entanglement/Entrapment
- Attraction/Ingestion of Plastics
- Noise and Lights

#### *3.3.4.2 Entanglement/Entrapment*

<u>S002A Potential Change to Impacts</u>

The physiology of sea turtles makes them susceptible to entanglement, as their surface area is large, and they are not as streamlined as marine mammals. Feeding behavior also makes sea turtles susceptible to entanglement, as many species forage near the surface where floating debris often concentrates especially in the open ocean. Hamelin et al. (2017) summarized incidental captures of leatherback sea turtles (*Dermochelys coriacea)* offshore Canada in the Atlantic Ocean and reported entanglements were most common in pot gear that used polypropylene line near the surface. Sea turtles of several species also are common bycatch in gillnet and longline fisheries (Byrd et al., 2016).

The S002A, just like S002, consists of nets, lines, floats, and chains that could potentially entangle sea turtles. **Table 9** provides a summary of sea turtle observations (29 total) during Campaigns 1 thorough 9, actions taken, and the results. Most all of the sea turtles found within the RZ were juveniles. The data has shown that the existing mitigation measures on S002 work, and most healthy sea turtles captured by the System are able to escape the System alive unaided using the existing mitigation measures or with assistance of the crew. Taking into account the 14 live sea turtles that have been observed or found in the System during Campaigns 1 through 9 (**Table 9**) and considering that the System has been operational within the NPSG for approximately 252 days, the likelihood of the S002A to capture sea turtles would be rare (5.5%). The other 15 observations included in **Table 9** were either animals observed near the vessels or System, or previously dead sea turtles captured with the floating plastics.

Given the slow speeds of the S002A during deployment and operations in the NPSG, many sea turtles presumably would be able to visually identify the System and actively avoid contact.

By design, the S002A is expected to accumulate marine debris during plastics collection operations, including lines, nets, and other materials. Sea turtles, especially juveniles and hatchlings, may be attracted to the structure and cover that the S002A and plastics provide and become entangled. If a sea turtle becomes entangled in lines, nets, or chains connected to the S002A or in marine debris, nets, or lines accumulated within the S002A, the animal could be harmed or drown if unable to untangle itself. This would result in an impact of high intensity with a regional extent. However, based on observations during Campaigns 1 through 9, while possible, the mortality of a sea turtle during plastics collection operations is considered rare and, to date, most of the sea turtles captured in the System have either been able to escape through use of existing mitigation measures including rescue or been found through necropsy to be either dead prior to collection or in significantly poor health with low fat reserves, plastics in their gastrointestinal tracts, or lung disease. Only one sea turtle captured in the RZ that did not survive was determined by necropsy to show no significant signs of poor health or other complicating factors.

Table 9. Summary of sea turtle observations during Campaigns 1 through 9.

| Encounter | Campaign Number | Date | Location | Number of Individuals | Species | Mitigation Measures Implemented | Results |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 27 Sept 21 | NPSG | 1 | Green sea turtle – juvenile | Reduced speed, performed rescue operation, and paused towing operations | Sea turtle was entangled in a floating ghost net and rescued safely[1] |
| 2 | 2 | 8 Oct 21 | NPSG | 1 | Loggerhead sea turtle – juvenile | Reduced speed, performed rescue operation and drone inspection, and increased speed | Sea turtle stuck in RZ; rescued alive and released[1] |
| 3 | 3 | 26 Nov 21 | Transit to Victoria Harbor | 1 | Unidentified sea turtle | None applied | Sea turtle swimming away from the system[2] |
| 4 | 4 | 18 Dec 21 | NPSG | 1 | Unidentified sea turtle | Changed direction and reduced speed | Sea turtle swimming close to a vessel[1] |
| 5 | 4 | 24 Dec 21 | NPSG | 1 | Unidentified sea turtle | Stopped towing operations, deployed FRC, and monitored via camera skiff | Sea turtle seen swimming close to the system for several minutes before it swam away[1] |
| 6 | 4 | 12 Dec 21 | NPSG | 1 | Unidentified sea turtle | Stopped for 1 hour, maintained visual contact with binoculars and drone flight, and monitored via camera skiff | Sea turtle was observed 200 m from vessel for 10 minutes, then not resighted[1] |
| 7 | 4 | 1 Jan 22 | NPSG | 2 | Loggerhead sea turtle – juvenile | Reviewed skiff footage | Two dead sea turtles were found in the RZ. Necropsy was performed, and results indicated the sea turtles were dead prior to collection[2] |
| 8 | 5 | 17 Jan 22 | NPSG | 1 | Loggerhead sea turtle | Vessel kept a distance | Sea turtle resting in the water, floating in the tuck position, which is predator-avoidance behavior[2] |
| 9 | 5 | 22 Jan 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Activated remotely triggered acoustic release and deployed FRC | Sea turtle inside the RZ; freed via net[1] |

Table 9. (Continued).

| Encounter | Campaign Number | Date | Location | Number of Individuals | Species | Mitigation Measures Implemented | Results |
|---|---|---|---|---|---|---|---|
| 10 | 5 | 29 Jan 22 | NPSG | 1 | Loggerhead sea turtle | Reviewed camera skiff footage, went into MEIO mode, activated remotely triggered acoustic release, changed vessel speed, and launched FRC | Sea turtle spotted inside the RZ then seen swimming away from the open cod-end in good condition[1] |
| 11 | 5 | 5 Feb 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Reviewed camera skiff footage; no others applied | Sea turtle found during the RZ extraction and released unharmed[1] |
| 12 | 6 | 7 Feb 22 | NPSG | 1 | Unidentified sea turtle | Activated MEIO mode and applied avoidance maneuvers | Unidentified sea turtle spotted 10 m directly in front of the vessel[2] |
| 13 | 6 | 8 Mar 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Activated MEIO mode, reviewed camera skiff footage, launched FRC, and opened cod-end | Live sea turtle observed in the RZ. Died within RZ as it did not escape the RZ. Necropsy was performed, and results indicated no clear external or internal wounds; however, found to be in poor health. Weather conditions were harsh[1] |
| 14 | 6 | 12 Mar 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | None applied; many FRC checks before discovery | Dead sea turtle recovered from the RZ extraction and found on deck. Necropsy performed and found the turtle was dead prior to collection in the S002[1] |
| 15 | 7 | 29 Apr 22 | NPSG | 1 | Unidentified sea turtle | Activated MEIO mode, launched FRC, activated remotely triggered acoustic release, multiple drone inspections | Sea turtle extracted itself from the RZ either through opened cod-end or fyke opening[1] |
| 16 | 7 | 2 May 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Live turtle observed in RZ, Activated MEIO mode, launched FRC | Sea turtle successfully released unharmed[1] |

Table 9. (Continued).

| Encounter | Campaign Number | Date | Location | Number of Individuals | Species | Mitigation Measures Implemented | Results |
|---|---|---|---|---|---|---|---|
| 17 | 7 | 3 May 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | None applied | Dead sea turtle recovered from RZ extraction and found on deck. Necropsy performed and found no signs of entanglement, fair fat reserves, no internal trauma or wounds, and dark spots on esophagus. Video reviewed and was not observed in any UW cameras[2] |
| 18 | 7 | 7 May 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Activated MEIO mode, drone inspection | Sea turtle observed exiting RZ through fyke opening[1] |
| 19 | 8 | 22 May 2 | Transit to NPSG | 1 | Loggerhead sea turtle – juvenile | None applied | Live turtle sighted 50 m portside from the M/V *Maersk Trader* swimming at the water surface and in opposite direction to the vessel[2] |
| 20 | 8 | 5 June 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | None applied | Live turtle in the bycatch RZ extraction suffering from plastic rope ingestion. Not seen by cameras. Debris was removed from the turtle and then safely released in the water[2] |
| 21 | 8 | 8 June 22 | NPSG | 1 | Green sea turtle carcass | None applied | Sea turtle carcass entangled in ghost net found in bycatch[2] |
| 22 | 8 | 8 June 22 | NPSG | 1 | Loggerhead sea turtle | Activated MEIO mode, activated remotely triggered acoustic release, performed extraction of RZ | Cod end did not fully open, live sea turtle found, evaluated, and safely released in the water[1] |
| 23 | 9 | 10 July 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | None applied | Dead sea turtle found in bycatch. Necropsy determined that the turtle was moderately decomposed and dead prior to entering the S002[2] |

Table 9. (Continued).

| Encounter | Campaign Number | Date | Location | Number of Individuals | Species | Mitigation Measures Implemented | Results |
|---|---|---|---|---|---|---|---|
| 24 | 9 | 11 July 22 | NPSG | 1 | Loggerhead sea turtle | None applied | Dead sea turtle found in bycatch. In later stages of decomposition and dead prior to entering the S002[2] |
| 25 | 9 | 21 July 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | None applied, video reviewed, and sea turtle not observed | Alive sea turtle found in the bycatch, evaluated, and safely released in the water[2] |
| 26 | 9 | 27 July 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Video observations indicated dead sea turtle in RZ | Dead sea turtle found in bycatch. Necropsy performed and found to be in severe decomposition and dead prior to entering the S002[2] |
| 27 | 9 | 28 July 22 | NPSG | 1 | Loggerhead sea turtle – juvenile | Vessel speed slowed, drone inspection, FRC launched, rescue | Live sea turtle was extracted from the RZ netting by FRC crew and released safely into the water[1] |
| 28 | 9 | 20 July 22 | NPSG | 1 | Loggerhead sea turtle | None applied | Sea turtle observed in RZ and within minutes seen exiting the RZ through the fyke opening[2] |
| 29 | 9 | 30 July 22 | NPSG | 1 | Loggerhead sea turtle | Adjusted vessel speed to open the system from net collapse, drone inspection | Adjusting speed to open the system allowed the sea turtle to escape the system through the RZ opening and drone observations sighted turtle outside of the RZ between the wings traveling in the same direction as the vessel[1] |

FRC = fast rescue craft; MEIO = minimal environmental impact operation; NPSG = North Pacific Subtropical Gyre; RZ = retention zone; UW = underwater.
[1] Project-related, defined as project applied mitigation measures upon encounter.
[2] Non-project-related, defined as either project did not apply any mitigation measures or the animal was determined (after necropsy) to have been dead prior to collection in the S002.

Based on the existing mitigation measures The Ocean Cleanup implements during plastics collection operations and the proven effectiveness of those mitigation measures, there is still the possibility that the remotely triggered electric release for the end of the RZ may not be able to be activated or that the FRC cannot be deployed due to weather conditions to manually activate the electric release or assist with entanglement in the rare possibility that a protected sea turtle becomes entangled in the S002A. This could result in the death of a sea turtle resulting in a high impact intensity. Overall, several factors must be considered in evaluating impacts of the System on sea turtles. Based on observations to date, most of the sea turtles captured in the System that have died have been in poor health with plastics present in their intestinal tracts. Necropsy results of several other sea turtles found within the System revealed those turtles to be dead prior capture. In addition, the NPSG is an environment where only a small portion of the juvenile sea turtles will be fit and strong enough to reach adulthood with the majority dying due to predation, diseases, and potentially plastic ingestion. The presence of project personnel has resulted in the saving of several sea turtles that were either entangled in plastic debris (e.g., ghost nets) or in the process of ingesting plastics and otherwise most likely would have died. Therefore, the findings seem to indicate that there are both **Beneficial** impacts from the removal of large amounts of plastics and other marine debris and personnel present to save entangled sea turtles as well as negative impacts from S002A. Based on these factors, the impact significance for sea turtles for entanglement/entrapment would be **2 – Low** during plastics collection operations.

During plastics extraction operations, the S002A is towed by one vessel at a slower speed, and with a narrowed wingspan, which significantly reduces the area swept by the system. Although the escape aids mitigation measure is not implemented during plastics extraction operations, the System is towed with the shortened RZ open, and all other mitigation measures are in effect. In addition, extraction operations will be performed during daylight hours, which will allow for the visual monitoring mitigation measures to be most effective. Based on the considerations and additional operational actions that would be implemented (e.g., additional reduced vessel speed, shortening of catenary length, holding system wings in the current only), impact likelihood would be remote and impact intensity would be reduced due to a smaller area for potential capture. Impact consequence would also reduce with the opened, shortened RZ. Therefore, the overall impact significance for sea turtles would be reduced to **1 – Negligible** for entanglement/entrapment during plastics extraction operations prior to the implementation of the additional mitigation measures.

*<u>S002B Potential Change to Impacts</u>*

The deeper wings associated with S002B may make is slightly more difficult for sea turtles to dive beneath the 4 m wings; however, the most common turtle encountered (loggerhead sea turtles, *Caretta caretta*) to date during S002 campaigns, typically dive shallow (less than or equal to 25 m) and the depth to which they dive typically changes with activity (e.g., foraging, migration/transiting). In the North Pacific Ocean, juveniles spend 80% of their time at very shallow depths (0 to 5 m), but also they make deeper, long dives in more dynamic waters (Iverson et al., 2019; Dalleau et al., 2013; Howell et al., 2010). Green sea turtles (*Chelonia mydas)* have been observed diving during resting between 18 and 20 m (Hays et al., 1999). Therefore, it is not anticipated that the deeper wings would have a measurable change to the impact significance to sea turtles from entanglement/entrapment of **2 – Low** for plastics collection activities determined for S002A prior to the implementation of the additional mitigation measures.

For plastic extraction operations, the S002B is towed by one vessel, at a slower speed, and with a narrowed wingspan, which significantly reduces the area swept by the system. Extraction operations will be performed during daylight hours, which will allow for the visual monitoring mitigation measures to be most effective. Therefore, the overall impact significance for sea turtles would remain **1 – Negligible** for entanglement/entrapment during plastics extraction operations for S002B prior to the implementation of the additional mitigation measures.

*Additional Mitigation Measures S002A*

The Ocean Cleanup will implement the additional following mitigation measures for S002A to reduce potential impacts to sea turtles from entanglement/entrapment:

- **Additional escape aids** – The larger RZ includes two additional fyke openings to allow sea turtles additional escape routes if accidentally collected by the system.

- **Breathing ports** - The larger RZ includes two additional breathing hatches that incorporates a new design.

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

- **RZ access openings** – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a sea turtle enters the RZ.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. There are no additional mitigation measures associated with S002B to reduce potential impacts to sea turtles from entanglement entrapment.

*S002A Residual Impacts*

The existing fyke openings on the S002 RZ have proven to work as escape routes for accidentally captured sea turtles, and with the longer RZ, sea turtles will have to navigate a longer net. The additional fyke openings could help provide additional opportunities for escape as well as the additional breathing hatches provide opportunities for surfacing for air in the event of capture. In addition, the additional green flashing LED lights may deter more sea turtles from becoming captured in the RZ. The RZ zippered access openings will make it easier and faster for FRC crew members to assist with extracting a captured sea turtle from the RZ. Therefore, with the additional mitigation measures, the likelihood of the impact would be reduced to remote, and the impact intensity would be reduced to moderate, resulting in an impact consequence of **1 – Negligible** for plastic collection operations for entanglement/entrapment.

For plastic extraction operations, the additional mitigation measures would not change the impact consequence from **1 – Negligible** determined prior to the implementation of the additional mitigation measures.

*S002B Residual Impacts*

With no additional mitigation measures to reduce potential impacts to sea turtles associated with the deeper (4 m) wings there would be no change to the impact significance determined for S002A from attraction and entanglement/entrapment and would remain **1 – Negligible** for plastics collection and plastics extraction operations.

#### *3.3.4.2 Attraction/Ingestion of Plastics*

*S002A Potential Change to Impacts*

Certain sea turtles, especially loggerheads, may be attracted to offshore structures (Lohoefener et al., 1990; Gitschlag et al., 1997), including floating plastics and the S002A just like for S002. Due to the relatively high concentrations of marine plastics expected in the vicinity of the S002A, any sea turtles attracted to the floating plastics or the S002A may be at increased risk of consuming plastic particles. However, marine debris captured by the wings of the System is guided into the RZ, which is a closed net system, shortening the duration of potential access by sea turtles to the accumulated marine debris. Ingestion of debris can kill or injure sea turtles and is considered a significant stressor on individuals and populations (Laist, 1987; Lutcavage et al., 1997; Fukuoka et al., 2016).

Gall and Thompson (2015) noted that all species of sea turtles have published reports of entanglement or ingestion of marine debris. Fukuoka et al. (2016) reported that green turtles had higher encounter/ingest ratios than loggerheads when studied using turtle-mounted cameras, but Pham et al. (2017) reported 83% of juvenile loggerheads investigated in the North Atlantic Gyre had ingested plastic. The necropsies performed on sea turtles during Campaigns 1 through 9 have shown that every sea turtle had some plastic in their gastrointestinal tract. In addition, a sea turtle that was saved after collection by the System was observed with a long piece of plastic fiber extending out of its mouth and also out of its cloaca (**Image 10**). This fiber was removed from the sea turtle and it was safely released back into the water.

Image 10. Juvenile loggerhead sea turtle collected in retention zone with ingested plastic fiber.

Any impacts on sea turtles due to attraction to the S002A would likely be short term and of minor consequence; however, plastic ingestion could cause chronic impacts to affected individuals. Based on observations and the sea turtles collected in S002, it is unknown if the sea turtles captured were a result of attraction to the S002 or if they were present in the area due to an attraction to the plastics present in the NPSG. In addition, sea turtles could be present in the area due to their natural behavior, considering that juvenile loggerhead and green turtles occur naturally in the region and tend to follow/aggregate in oceanographic features (i.e., surface currents, frontal zones) as do floating plastics. Due to the relatively small size of the S002 and the low density of sea turtles in the remote open ocean area of the S002 deployment, impacts to sea turtles from plastics ingestion associated with the S002A are not expected to be biologically significant to sea turtle populations since they are present in an area with high density of plastics. However, small juvenile sea turtles are mostly pelagic, spending most of their time in the open ocean. Juvenile loggerheads are known to use the project area (Kobayashi et al., 2008; Abecassis et al., 2013; Briscoe et al., 2016a,b) and may be vulnerable to impacts from plastic ingestion. Loggerhead sea turtles, which migrate through the area and potentially spend most of their juvenile lives within the broader central North Pacific (Briscoe et al., 2016b) which encompasses the S002A deployment area, also are known to eat plastic bags, possibly due to the resemblance to their preferred food of gelatinous animals and other surface and midwater prey. Impacts to regional populations are possible from the ingestion of plastics collected in the S002A, but considered unlikely and the necropsies have shown that most of the sea turtles captured had already consumed plastic. Plastics in the ocean, particularly abandoned fishing gear and lines, present a significant danger to sea turtle species. Therefore, S002A, by facilitating removal of these materials from the ocean, presents a potential for long-term **Beneficial** impact to sea turtle species. Impacts on sea turtles from attraction to the S002A and the associated ingestion of plastics collected by the S002A are of moderate intensity, and of minor consequence severity and the likelihood is considered remote. The longer RZ associated with S002A would not measurably change the impact significance from **1 – Negligible** during both plastics collection and extraction operations as determined for S002 prior to implementing the additional mitigation measures.

*<u>S002B Potential Change to Impacts</u>*

The deeper wings associated with S002B would not change the potential attraction of sea turtles to the S002B or the rare potential for ingestion of plastics collected by the S002B by sea turtles. Therefore, the impact significance would not change from **1 – Negligible** during both plastics collection and extraction operations as determined for S002A prior to implementing the additional mitigation measures.

*<u>Additional Mitigation Measures S002A</u>*

The Ocean Cleanup will implement the additional following mitigation measures for S002A to reduce potential impacts to sea turtles from attraction/ingestion of plastics:

- **Additional escape aids** – The larger RZ includes two additional fyke openings to allow sea turtles additional escape routes if accidentally collected by the system.

- **Breathing ports** - The larger RZ includes two additional breathing hatches that incorporates a new design.

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

- **RZ access openings** – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a sea turtle enters the RZ.

*<u>Additional Mitigation Measures S002B</u>*

All additional mitigation measures associated with S002A will remain in effect for S002B. There are no additional mitigation measures associated with S002B to reduce potential impacts to sea turtles from attraction/ingestion.

*<u>S002A Residual Impacts</u>*

The additional mitigation measures associate with S002A would not measurably change the potential for attraction to the System or ingestion of the plastic collected by the System. Therefore, the impact significance for sea turtles would remain **1 – Negligible** for attraction/ingestion during both plastic collection and extraction operations.

*<u>S002B Residual Impacts</u>*

With no additional mitigation measures associated with S002B, the impact significance for sea turtles would remain **1 – Negligible** for attraction/ingestion during both plastic collection and extraction operations.

#### 3.3.4.3 *Noise and Lights*

S002A Potential Change to Impacts

There is little information available regarding hearing and acoustic thresholds for sea turtles. However, what is known is that sea turtles have low-frequency hearing capabilities, typically hearing frequencies from 30 Hz to 2 kHz, with a maximum sensitivity range between 100 and 800 Hz (Ridgway et al., 1969; Lenhardt, 1994; Bartol and Ketten, 2006). Hearing below 80 Hz is less sensitive but may be important biologically (Lenhardt, 1994). Summaries of sea turtle hearing capabilities were prepared by Bartol (2014, 2017; Dow Piniak et al., 2012a,b).

By species, hearing characteristics of sea turtles are as follows:

- **Loggerhead sea turtle** – Greatest sensitivities around 250 Hz or below for juveniles, with the range of effective hearing from at least 250 to 1,000 Hz (Lavender et al., 2012a,b,c; 2014).

- **Green sea turtle** – Greatest sensitivities are from 300 to 500 Hz (Ridgway et al., 1969); juveniles and subadults detect sounds from 100 to 500 Hz underwater, with maximum sensitivity between 200 and 400 Hz (Bartol and Ketten, 2006) or between 50 and 400 Hz (Dow et al., 2008); peak response is at 300 Hz (Yudhana et al., 2010a).

- **Hawksbill sea turtle** (*Eretmochelys imbricata)* – Greatest sensitivities between 50 and 500 Hz (Yudhana et al., 2010b).

- **Olive ridley sea turtle** – Juveniles of a congener (Kemp's ridley sea turtle [*Lepidochelys kempii*]) found to detect underwater sounds from 100 to 500 Hz, with maximum sensitivity between 100 and 200 Hz (Bartol and Ketten, 2006).

- **Leatherback sea turtle** – A lack of audiometric information is noted in this species. Their anatomy suggests hearing capabilities are similar to other sea turtle species, with functional hearing assumed to be 10 Hz to 2 kHz.

The current acoustic thresholds for injurious exposure (permanent threshold shift onset) and behavior from exposure to a continuous noise source, based on sea turtle hearing, is presented below in **Table 10**.

Table 10. Underwater acoustic thresholds from continuous sound (non-impulsive) for onset of permanent threshold shift and behavior threshold in sea turtles.

| Faunal Group | PTS[1] | | TTS[2] | | Behavior[3] | |
|---|---|---|---|---|---|---|
| | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value | Acoustic Metric | Threshold Value |
| Sea turtles | SPL | 180 dB re 1 µPa | - | - | SPL | 175 dB re 1 µPa |

- = not available; µPa = micropascal; dB = decibel; PTS = permanent threshold shift; re = referenced to; SPL = root-mean-square sound pressure level; TTS = temporary threshold shift.

[1] PTS threshold with injury is defined as the onset of potential mortal injury in sea turtles (Fisheries Hydroacoustic Working Group, 2008).

[2] TTS threshold is not available for sea turtles.

[3] Behavioral threshold derived from sea turtles (Blackstock et al., 2018).

Sounds can impact sea turtles in several ways: masking biologically significant sounds, altering behavior, trauma to hearing (temporary or permanent), and trauma to non-hearing tissue (barotraumas) (McCarthy, 2004). Anthropogenic noise, even below levels that may cause injury, can mask relevant sounds in the environment. Masking sounds can interfere with the acquisition of prey, affect the ability to locate a mate, diminish the ability to avoid predators, and, particularly in the case of sea turtles, adversely affect the ability to properly identify an appropriate nesting site (Nunny et al., 2008). However, there are no data demonstrating masking effects for sea turtles.

The most likely effects of vessel and equipment noise on sea turtles are behavioral changes. Vessel and equipment noise is transitory and generally does not propagate great distances from the vessel, and the source levels are too low to cause mortality or injuries such as auditory threshold shifts. Based on existing studies on the role of hearing in sea turtle ecology, it is unclear whether masking would realistically have any effect on sea turtles (Mrosovsky, 1972; Samuel et al., 2005; Nunny et al., 2008). Behavioral responses to vessels have been observed but are difficult to attribute exclusively to noise rather than to visual or other cues. It is conservative to assume noise associated with survey vessels may occasionally elicit behavioral changes in individual sea turtles near vessels. Behavioral changes may include evasive maneuvers such as diving or changes in swimming direction or speed, which would result in a low impact intensity. Evasive behavior is not expected to adversely affect individuals or the population, and impacts are not expected to be significant. Since there are no additional sources of noise from the S002A operations, impact consequence from all noise sources to sea turtles is expected to remain **1 – Negligible** as determined for S002.

Artificial lighting can disrupt the nocturnal orientation of sea turtle hatchlings (Tuxbury and Salmon, 2005, Berry et al., 2013, Simões et al., 2017). However, hatchlings may rely less on light cues when they are offshore than when they are emerging on the beach (Salmon and Wyneken, 1990). The National Marine Fisheries Service (NMFS) (2007) concluded the effects of lighting from offshore structures on sea turtles are insignificant. Therefore, as with S002, there would be no additional sources of light from the S002A operations, and no significant impacts are expected from lighting on the vessels. Therefore, given the likely nature of impact from vessel lights, the overall impact significance prior to mitigation would remain **1 – Negligible** prior to implementing the additional mitigation measures for both plastics collection and extraction operations.

Bielli et al. (2020) has shown that the use of LEDs on nets can reduce the probability of bycatch of some sea turtles. Therefore, the LEDs could be a deterrent to sea turtles from approaching the System; and therefore, the impact would be **Beneficial**.

*S002B Potential Change to Impacts*

The deeper wings associated with S002B would not change noise or lighting from S002A; and therefore, the impact significance from both noise and light would remain **1 – Negligible** prior to implementing the additional mitigation measures for both plastics collection and extraction operations.

*Additional Mitigation Measures S002A*

The Ocean Cleanup will implement the additional following mitigation measures for S002A to reduce potential impacts to sea turtles from noise and lights:

- **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.

*Additional Mitigation Measures S002B*

All additional mitigation measures associated with S002A will remain in effect for S002B. There are no additional mitigation measures associated with S002B to reduce potential impacts to sea turtles from noise and lights.

*S002A Residual Impacts*

The impacts from other vessel lighting and noise would remain **1 – Negligible** for both plastics collection and extraction operations.

Bielli et al. (2020) has shown that the use of LEDs on nets can reduce the probability of bycatch of sea turtles and some small cetaceans. Therefore, the additional LEDs associated with the larger RZ could be an additional deterrent to sea turtles from approaching the System; and therefore, the impact would be **Beneficial**.

*S002B Residual Impacts*

With no additional mitigation measures associated with S002B; therefore, the impact significance would remain **Beneficial** for both plastics collection and extraction operations.

With no additional mitigation measures implements with S002B, the impact significance would not change for noise or lighting from S002A and therefore, the impact significance from both noise and vessel lights would remain **1 – Negligible** for both plastics collection and extraction operations.

# 4 Conclusions

The Ocean Cleanup is committed to adaptively managing activities and data collection to better characterize the potential impacts to the environment from project operations. One means of adaptive management is the implementation of active monitoring and using the data collected to modify the project methodologies and improve future designs of plastics collection systems. It is from this adaptive management approach and applying the data and knowledge collected from the completed campaigns that the larger RZ with additional mitigation measures (S002A) and deeper wings (S002B) are being implemented as The Ocean Cleanup moves toward their full-scale system design (S03).

Implementing the larger RZ (S002A) will allow more room for the plastics to collect within the RZ and reduce the potential for plastics blocking the view of the camera skiff system and the active monitoring for protected species within the RZ.

The deeper wings (S002B) have been implemented to alleviate underflow of plastics beneath the wings to increase collection efficiency.

A preliminary screening was conducted (**Section 3.1**) to identify the resources at risk from the modifications of the System with regards to the IPFs from the deployment of S002A and S002B in the NPSG. Resources that were previously examined in the Revised S002 EIA (CSA, 2022) determined to not be affected by the S002A or S002B or where impact consequences were deemed, *a priori*, to be negligible were coastal and oceanic birds, protected areas, and commercial and military vessels. An impact assessment on the remaining resources (plankton and neuston, fish/fishery resources, marine mammals, sea turtles) was conducted from a risk-based perspective to determine the overall significance of each potential impact based on its intensity, extent, duration, consequence, and likelihood. Biodiversity was included in the screening process, and it was determined that there is not enough information at this time to fully address biodiversity impacts from the S002.

In addition, screening of the IPFs was also performed to evaluate if the deployment and operations of S002A and S002B would result in changes to the IPFs. Screening determined that Vessel – Physical Presence/Strikes, Loss of Debris, and Accidental Small Fuel Spill IPFs would remain unchanged for all resources.

A tabular summary of impacts from plastic collection operations both prior to implementing the additional mitigation measures and with the additional mitigation measures applied is presented in the following sections. The resultant significance of potential impacts of the project activities will generally be Negligible or Low. Moreover, The Ocean Cleanup has removed approximately 64,833 kg of plastics during the first seven campaigns in the NPSG, which will have long-term positive (beneficial) impacts to biological resources in the area.

## 4.1 PLANKTON AND NEUSTON IMPACT SUMMARY

*Impact Rating – S002A*

<table>
<tr><th>Impact</th><th>Intensity</th><th>Extent</th><th>Duration</th><th>Consequence</th><th>Likelihood</th><th>Impact Significance</th></tr>
<tr><td rowspan="2">Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations</td><td>Low to Moderate</td><td rowspan="2">Local to Regional</td><td rowspan="2">Short Term</td><td rowspan="2">Negligible to Minor</td><td>Likely</td><td>Plastics Collection<br>1 – Negligible to<br>2 – Low</td></tr>
<tr><td>Low</td><td>Rare</td><td>Plastics Extraction<br>1 – Negligible</td></tr>
<tr><td>Behavioral modifications (e.g., suppress diel migration, attraction to System) from lights</td><td>Low</td><td>Immediate Vicinity</td><td>Short Term</td><td>Negligible</td><td>Occasional</td><td>1 – Negligible</td></tr>
</table>

*Mitigation Measures – S002A*

<table>
<tr><th>Impact</th><th>Mitigation Measures</th><th>Component of Impact Consequence Affected by Mitigation</th><th>Residual Impact Significance</th></tr>
<tr><td>Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations</td><td>• None applied</td><td>None</td><td>Plastics Collection<br>1 – Negligible to<br>2 – Low<br>Plastics Extraction<br>1 – Negligible</td></tr>
<tr><td>Behavioral modifications (e.g., suppress diel migration, attraction to the System) from lights</td><td>• Visual cues – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability that will reduce shining on the water at night.</td><td>None</td><td>1 – Negligible</td></tr>
</table>

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Low to Moderate | Local to Regional | Short Term | Negligible to Minor | Likely | Plastics Collection<br>1 – Negligible to<br>2 – Low |
| | | | | | Rare | Plastics Extraction<br>1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to System) from lights | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • None applied<br>• Changed design to increase wing mesh to 16 mm square | None | Plastics Collection<br>1 – Negligible to<br>2 – Low<br>Plastics Extraction<br>1 – Negligible |
| Behavioral modifications (e.g., suppress diel migration, attraction to the System) from lights | • **Limit lighting** – The additional navigational lights on the system S002B will flash intermittently to reduce shining light on the water at night. | None | 1 – Negligible |

## 4.2 FISH AND FISHERY RESOURCES

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002A | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Attraction to the S002A and ingestion of plastics collected | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to lights | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |

*Mitigation Measures – S002A*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S002A | • **Additional escape aids** – The larger RZ includes 2 additional fyke openings to allow fish additional escape routes if accidentally collected by the System.<br>• **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | Plastics Collection 2 – Low<br>Plastics Extraction 1 – Negligible |
| Attraction to the S002A and ingestion of plastics collected | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | Plastics Collection 2 – Low<br>Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | • None applied | None | 1 – Negligible |
| Attraction to lights | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights which will reduce shining light on the water at night. | None | 2 – Low |

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002B | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Attraction to the S002B and ingestion of plastics collected | Moderate | Immediate Vicinity | Short Term | Minor | Likely | Plastics Collection 2 – Low |
| | | | | | Rare | Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | Low | Immediate Vicinity | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to lights | Moderate | Immediate Vicinity | Short Term | Minor | Likely | 2 – Low |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S002B | • None applied<br>• Changed design to increase wing mesh to 16 mm square | None | Plastics Collection 2 – Low |
| | | | Plastics Extraction 1 – Negligible |
| Attraction to the S002B and ingestion of plastics collected | • None applied | None | Plastics Collection 2 – Low |
| | | | Plastics Extraction 1 – Negligible |
| Behavioral modifications (e.g., evasive swimming, disruption of activities, departure from the area) due to noise exposure | • None applied | None | 1 – Negligible |
| Attraction to lights | • **Limit lighting** – The additional navigational lights on S002B will flash intermittently to reduce shining light on the water at night. | None | 2 – Low |

## 4.3 MARINE MAMMALS

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | Moderate (Non-Protected Species) | Immediate Vicinity (Non-Protected Species) | Short Term (Non-Protected Species) | Minor (Non-Protected Species) | Remote | Plastics Collection Non-Protected Species 1 - Negligible |
| | High (Protected Species) | Regional (Protected Species) | Long-Term (Protected Species) | Moderate (Protected Species) | | Plastics Collection Protected Species 2 – Low |
| | Moderate | Immediate Vicinity | Short Term | Minor | Remote | Plastics Extraction 1 - Negligible |
| Attraction to the S002A; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*<u>Mitigation Measures – S002A</u>*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002A or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • **Additional escape aids** – The larger RZ includes 2 additional fyke openings to allow small marine mammals additional escape routes if accidentally collected by the System.<br>• **Breathing ports** - The larger RZ includes 2 additional breathing hatches that incorporates a new design.<br>• **Acoustic deterrent** – The larger RZ includes 4 additional banana pingers to deter the approach of marine mammals.<br>• **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability.<br>• **RZ access openings** – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a marine animal enters the RZ. | Reduced intensity and likelihood | Plastics Collection Non-Protected Species 1 - Negligible<br>Plastics Collection Protected Species 2 – Low<br>Plastics Extraction 1 - Negligible |
| Attraction to the S002A; ingestion of congregated plastics resulting in injury or mortality | • **Acoustic deterrent** – The larger RZ includes 4 additional banana pingers to deter the approach of marine mammals.<br>• **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | • **Acoustic deterrent** – The larger RZ includes 4 additional banana pingers to deter the approach of marine mammals. | None | 1 – Negligible |
| Attraction to System lights | • **Visual cues** – The larger RZ includes 15 additional green flashing LED lights to enhance the System detectability. | None | Beneficial |

*<u>Impact Rating – S002B</u>*

<table>
<tr><th>Impact</th><th>Intensity</th><th>Extent</th><th>Duration</th><th>Consequence</th><th>Likelihood</th><th>Impact Significance</th></tr>
<tr><td rowspan="3">Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations</td><td>Moderate<br>(Non-Protected Species)</td><td>Immediate Vicinity<br>(Non-Protected Species)</td><td>Short Term<br>(Non-Protected Species)</td><td>Minor<br>(Non-Protected Species)</td><td rowspan="2">Remote</td><td>Plastics Collection<br>Non-Protected Species<br>1 - Negligible</td></tr>
<tr><td>High<br>(Protected Species)</td><td>Regional<br>(Protected Species)</td><td>Long-Term<br>(Protected Species)</td><td>Moderate<br>(Protected Species)</td><td>Plastics Collection<br>Protected Species<br>2 – Low</td></tr>
<tr><td>Moderate</td><td>Immediate Vicinity</td><td>Short Term</td><td>Minor</td><td>Remote</td><td>Plastics Extraction<br>1 - Negligible</td></tr>
<tr><td>Attraction to the S002B; ingestion of congregated plastics resulting in injury or mortality</td><td>Moderate</td><td>Immediate Vicinity</td><td>Short Term</td><td>Minor</td><td>Remote</td><td>1 – Negligible</td></tr>
<tr><td>Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources</td><td>Low</td><td>Local</td><td>Short Term</td><td>Negligible</td><td>Occasional</td><td>1 – Negligible</td></tr>
<tr><td>Attraction to System lights</td><td></td><td></td><td></td><td></td><td></td><td>Beneficial</td></tr>
</table>

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement in the S002B or accumulated debris resulting in injury or mortality during plastics collection and extraction operations | • **Acoustic deterrent** –The deeper wings include 2 additional banana pingers attached to the wings spaced throughout the wings. | None | Plastics Collection Non-Protected Species 1 - Negligible<br>Plastics Collection Protected Species 2 – Low<br>Plastics Extraction 1 - Negligible |
| Attraction to the S002B; ingestion of congregated plastics resulting in injury or mortality | • **Acoustic deterrent** –The deeper wings include 2 additional banana pingers attached to the wings spaced throughout the wings. | None | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources | • **Acoustic deterrent** –The deeper wings include 2 additional banana pingers attached to the wings spaced throughout the wings. | None | 1 – Negligible |
| Attraction to System lights | • None applied | None | Beneficial |

## 4.4 SEA TURTLES

*Impact Rating – S002A*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002A or accumulated debris | High | Regional | Short Term | Moderate | Rare | Plastics Collection 2 – Low |
| | Moderate | | | | Remote | Plastics Extraction 1 – Negligible |
| Attraction to the S002A; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*<u>Mitigation Measures – S002A</u>*

<table>
<tr><th>Impact</th><th>Mitigation Measures</th><th>Component of Impact Consequence Affected by Mitigation</th><th>Residual Impact Significance</th></tr>
<tr><td rowspan="2">Entanglement or entrapment with the deployed S002A or accumulated debris</td><td rowspan="2">• Additional escape aids – The larger RZ includes 2 additional fyke openings to allow sea turtles additional escape routes if accidentally collected by the system.<br>• Breathing ports - The larger RZ includes 2 additional breathing hatches that incorporates a new design.<br>• Visual cues – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.<br>• RZ access openings – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a sea turtle enters the RZ.</td><td>Reduces Intensity and Likelihood</td><td>Plastics Collection<br>1 – Negligible</td></tr>
<tr><td>None</td><td>Plastics Extraction<br>1 – Negligible</td></tr>
<tr><td>Attraction to S002A; ingestion of congregated plastics resulting in injury or mortality</td><td>• Additional escape aids – The larger RZ includes two additional fyke openings to allow sea turtles additional escape routes if accidentally collected by the system.<br>• Breathing ports - The larger RZ includes 2 additional breathing hatches that incorporates a new design.<br>• Visual cues – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.<br>• RZ access openings – The larger RZ includes 12 zippered openings in the top of the RZ to facilitate access for animal rescue and removal in the event that a sea turtle enters the RZ.</td><td>None</td><td>1 – Negligible</td></tr>
<tr><td>Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights</td><td>• None applied</td><td>None</td><td>1 – Negligible</td></tr>
<tr><td>Attraction to System lights</td><td>• Visual cues – The larger RZ includes 15 additional green flashing LED lights to enhance the system detectability.</td><td>None</td><td>Beneficial</td></tr>
</table>

*Impact Rating – S002B*

| Impact | Intensity | Extent | Duration | Consequence | Likelihood | Impact Significance |
|---|---|---|---|---|---|---|
| Entanglement or entrapment with the deployed S002B or accumulated debris | High | Regional | Short Term | Moderate | Rare | Plastics Collection 2 – Low |
| | Moderate | | | | Remote | Plastics Extraction 1 – Negligible |
| Attraction to the S002B; ingestion of congregated plastics resulting in injury or mortality | Moderate | Immediate Vicinity | Short Term | Minor | Remote | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights | Low | Local | Short Term | Negligible | Occasional | 1 – Negligible |
| Attraction to System lights | | | | | | Beneficial |

*Mitigation Measures – S002B*

| Impact | Mitigation Measures | Component of Impact Consequence Affected by Mitigation | Residual Impact Significance |
|---|---|---|---|
| Entanglement or entrapment with the deployed S002B or accumulated debris | • None applied | None | 1 – Negligible |
| Attraction to S002B; ingestion of congregated plastics resulting in injury or mortality | • None applied | None | 1 – Negligible |
| Behavioral modifications (e.g., diving, evasive swimming, disruption of activities, departure from the area) from noise exposure; avoidance of noise sources, vessel lights | • None applied | None | 1 – Negligible |
| Attraction to System lights | • None applied | None | Beneficial |

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# Appendix B

# Plastics Literature Summary White Paper

# The Ocean Cleanup

## White Paper – Topical Review and Synthesis of Ocean Plastics

May 2022


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## Acronyms and Abbreviations

| | |
|---|---|
| C-PS | commercially available polystyrene |
| CSA | CSA Ocean Sciences Inc. |
| DMS | dimethyl sulfide |
| EF | effect factor |
| EIA | Environmental Impact Analysis |
| FADs | fish aggregation devices |
| GPGP | Great Pacific Garbage Patch |
| HDPE | high-density polyethylene |
| LCA | life cycle analysis |
| LDPE | low density polyethylene |
| MG | Marie-Galante |
| MP | microplastic |
| NEBA | net environmental benefit analysis |
| NP | nanoparticle/nanoplastic |
| PB | Petit-Bourg |
| PBAT | polybutylene adipate co-terephthalate |
| PD-PS | photodegraded polystyrene |
| PE | polyethylene |
| PET | polyethylene terephthalate (polyester) |
| Phe | phenanthrene |
| PLA | polylactic acid |
| PP | polypropylene |
| P-PS | pristine polystyrene |
| PS | polystyrene |
| PTE | potentially toxic element |
| PVC | polyvinyl chloride |
| ROS | reactive oxygen species |
| SSDR | specific surface degradation rate |
| TPT | triphenyltin |
| TCS | triclosan |
| UV | ultraviolet |

# 1.0 Introduction

CSA Ocean Sciences Inc. (CSA) developed a white paper on behalf of The Ocean Cleanup addressing a series of key topics associated with plastics present in the Great Pacific Garbage Patch (GPGP), including review and synthesis of the short- and long-term fate of ocean plastics; plastics toxicity; floating macroplastics as fish aggregation devices (FAD); changes in buoyancy resulting from colonization (and subsequent sinking through the water column); plastic degradation (i.e., macroplastics to microplastics); life cycle analysis for plastics; and potential removal impacts, particularly impacts to neuston. Although there are other impacts associated with plastics present in the GPGP, these key topics were identified as the primary factors impacting the North Pacific Subtropical Gyre ecosystem. The white paper is included an attachment to the Environmental Impact Assessment (EIA).

The purpose of this review is to provide the data necessary to reach conclusions using a net environmental benefit analysis (NEBA)-type approach. NEBA is a methodology for identifying and comparing net environmental benefits of alternative management options, usually applied to oil spills or contaminated sites being considered for remediation. Net environmental benefits are the gains in environmental services or other ecological properties attained by remediation or ecological restoration, minus the environmental injuries caused by those actions (e.g., Efroymson et al., 2003).

CSA's approach to the white paper entailed a synthesis of key environmental considerations associated with macroplastic removal (via System 002 [S002]) and associated impacts versus leaving the plastic in place. The white paper required an electronic database search (see **Section 2.0**) and a stepwise analysis of potentially applicable references (i.e., title review → abstract review → full article review and synthesis), followed by a summarization of key references. Results were further evaluated within a NEBA-type evaluation (**Section 4.0**), comparing relative impacts associated with plastic removal versus no action (i.e., leaving plastic debris in place).

# 2.0 Materials and Methods

## 2.1 LITERATURE REVIEW

Identification of relevant source material was based on a search of numerous bibliographic and library sources. An extensive search for all relevant scientific and technical information for the study area (GPGP; North Pacific Subtropical Gyre) published since early 2018 was conducted using four major sources, explained in detail below:

- Proquest Dialog https://dialog.proquest.com/professional/commandline;
- OCLC WorldCat http://www.oclc.org/us/en/worldcat/default.htm;
- Internet search engines to locate relevant websites https://www.google.com; https://www.bing.com; https://search.yahoo.com; and
- Digital Repositories, such as Aquatic Commons http://aquaticcommons.org; OnePetro https://www.onepetro.org/.

Proquest Dialog™ is a unique aggregation of the world's leading bibliographic and full text sources and offers the largest collection of authoritative content that can be searched at one time. Databases that were searched on Proquest Dialog™ included those listed below, with focus on recent (2018 and later) data sources:

- ASFA (Aquatic Sciences and Fisheries Abstracts)
- BIOSIS Previews® (Biological Abstracts)
- Conference Papers Index
- EI Compendex
- Environment Abstracts
- GEOBASE™
- GeoRef
- Meteorological and Geoastrophysical Abstracts
- NTIS – National Technical Information Service
- Oceanic Abstracts
- Pollution Abstracts
- Proquest Dissertations & Theses Professional
- SciSearch® – a Cited Reference Science Database (Web of Science)
- TULSA™ (Petroleum Abstracts)

Relevant books, proceedings, technical reports, and gray literature were located using OCLC™ WorldCat. WorldCat is a cooperative database of 452 million bibliographic records contributed by more than 72,000 libraries in 170 countries, making it the world's largest, most complete, and most consulted library union catalog of electronic, print, and digital resources. Items found in WorldCat were purchased or borrowed via the OCLC™ Interlibrary Loan System.

Internet search engines were used to locate relevant websites and the following digital document repositories, reliable sources of gray literature and conference papers, were consulted:

- Aquatic Commons http://aquacomm.fcla.edu/;
- Aquadocs.org https://www.aquadocs.org/ (formerly OceanDocs http://www.oceandocs.org/);
- OnePetro https://www.onepetro.org/; and
- Osti.gov https://www.osti.gov.

Search statement terms were developed in consultation with each identified subject matter expert. Once search parameters were established, CSA downloaded report and article titles for examination and deletion of irrelevant titles. In CSA's experience, title review has proved an efficient and effective step in identifying potentially relevant documents. CSA scientists are highly experienced in this technique. CSA utilized a conservative approach during this step; if there was a remote possibility that a title was pertinent, it was retained for the next step.

### 2.2 REVIEW APPROACH

Of the selected titles, abstracts were often required to determine if the document addresses the EIA needs, or if the subject matter was appropriate for the analysis. While title review is important, abstract review was the first critical step in the evaluation process; in theory, abstracts provide a comprehensive summary of the document. As with the title review step, CSA adopted a conservative approach during abstract review. If there was a remote chance that a document was applicable, it was retained in the working list of documents and analyzed during the next step.

After abstracts were reviewed, all selected and remaining citations were imported from publisher provided .ris files or manually entered into bibliographic management software. Any required missing information was determined and entered; PDF documents were attached to the citations in some cases. A bibliography was exported from bibliographic software to create a Microsoft Word document.

These newly acquired documents were reviewed and evaluated, concurrently with existing 2018 EIA material, to develop an up-to-date baseline and impacts section of the EIA. Each author reviewed the available documentation and updated the synthesis of available information. This exercise necessarily identified missing or incomplete information and will establish appropriate limitations on EIA determinations.

### 2.3 TERMINOLOGY

Throughout this white paper, different sizes of plastic are referenced. Macroplastics refer to plastic fragments greater than 20 mm, microplastics are small plastic fragments less than 5 mm typically derived from the breakdown of macroplastics, and nanoplastics are small microplastic particles defined in the range of 0.2 to 2 mm. Mesoplastics, though not addressed in this white paper, are plastic particles 5 to 20 mm in size.

## 3.0 Topical Review

References were identified, reviewed, and summarized for each of the seven major topics relevant to plastics present in the GPGP: floating macroplastics as FADs; changes in buoyancy resulting from colonization (and subsequent sinking through the water column); potential removal impacts, particularly impacts to neuston; the short- and long-term fate of ocean plastics; plastics toxicity; plastic degradation (i.e., macroplastics to microplastics); and life cycle analysis for plastics. Major findings from each reference are identified and summarized in **Table 1**.

Table 1. References initially identified, reviewed, and summarized in text box form for each key topic.

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Floating macroplastics as a fish aggregation device | Fish/Sharks and Fishery Resource<br>Juvenile and Pre-juvenile Fishes<br>Neuston<br>Seabirds<br>Sea Turtles | Plastic debris may provide a substrate for biota that produce infochemicals, such as dimethyl sulfide (DMS), because floating plastic debris is known to be an excellent substrate for biofouling. Biofouling is the gradual accumulation of organisms such as algae, bacteria, barnacles, and protozoa on underwater structures or surfaces. Some species use DMS as an olfactory cue to locate prey. Studies have shown that plastic ingestion frequency increased in seabirds when DMS was present, and also that loggerhead turtles showed increased foraging behavior when DMS was present. | Savoca et al., 2016;<br>Pfaller et al., 2020 |
| | | Chances of interactions with plastics may be increased by behaviors of certain species. Mammals, birds, and turtles which might not be normally attracted to debris may be attracted to mats of debris because they in turn, have caused attraction of prey species | Laist, 1987 |
| | | Floating plastics may result in opportunistic colonizers such as such as algae, bacteria, barnacles, and protozoa that aid the dispersion of species that could become invasive.<br><br>Large aggregations of marine debris provide habitat for larval and juvenile fishes and other organisms and may attract large predatory fish. | Gregory, 2009 |
| Changes in buoyancy resulting from colonization (and subsequent sinking) | Benthic habitat<br>Fish/Sharks and Fishery Resource<br>Juvenile and Pre-juvenile Fishes<br>Marine Mammals<br>Neuston<br>Seabirds<br>Sea Turtles | Ballasting and subsequent sinking of marine debris can occur due to microorganism growth (on small debris) or colonization of larger debris by mussels, barnacles, or other larger biota. Biofouling therefore does enhance seafloor deposition of plastics.<br><br>Density, fouling extent, and sample form (i.e., pellet or strip) affected sinking characteristics of plastics. | Cózar et al., 2014;<br>Kaiser et al., 2017;<br>Ryan, 2015;<br>Karkanorachaki et al., 2021 |
| | | Vertical movement of plastic particles is size dependent, and an empirical model predicted that biofouling will cause sinking of particles and result in a maximum plastic concentration at intermediate depths. De-fouling can also occur due to changes in depth, light availability, etc. once a particle sinks that can cause the particles to then become positively buoyant and rise back to the surface.<br><br>In experiments, smaller pieces of plastic lost buoyancy much faster than large pieces. | Kooi et al., 2017;<br>Fazey and Ryan, 2016 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Changes in buoyancy resulting from colonization (and subsequent sinking) (cont'd) | Continued from above | The long-term fate of microplastics (MP) is heavily dependent on the presence/absence of biota. Fouling can cause sinking, or ingestion by plankton can cause heavier than normal fecal pellets which can cause sinking and seafloor deposition. This study used a hydrodynamic/biogeochemical model, showing that seasonal changes in the plankton community has profound effects on the deposition/sinking rates of MPs. | Berezina et al., 2021 |
| | | The smallest plastic particles are the most sensitive to algal cell biofouling, as the added weight of the algal cells is proportionately more impactful to buoyancy of smaller particles. Given that plastics degrade over time, it is expected that most of the plastic in the ocean will be found subsurface, and not floating at the surface. | Kreczak et al., 2021 |
| | | Biofouling also causes sinking of MPs in freshwater environments. | Miao et al., 2021 |
| | | Vertical fates of MPs are also highly controlled by photodegradation, the extent of which is a result of the level of biofouling that occurs on floating plastics. Biofouling may slow photochemical transformation rates through light screening, but results demonstrated that even with biofouling, photodegradation remained a highly relevant process for the fate of marine plastics. | Nelson et al., 2021 |
| | | Different types of plastic may attract different types of bacteria/biofilms. The effect of this on vertical migration is unknown. Significant differences in microbial biological communities were found on polyethylene (PE) as compared with polypropylene (PP) and polystyrene (PS). | Vaksmaa et al., 2021 |
| Potential removal impacts (focusing on impacts to neuston) | Neuston | No papers found that discussed impacts of removal on neuston or other biota. However, Egger et al. (2021) noted that despite increasing research conducted on ocean plastic pollution over the last decade, there are still large knowledge gaps in the current understanding of how floating plastic debris accumulating in subtropical oceanic gyres may harm neuston. Removing floating plastic debris from the ocean surface can minimize potentially adverse effects of plastic pollution on neuston, as well as prevent the formation of large quantities of secondary micro- and nanoplastics. However, due to the scarcity of observational data from remote and difficult to access offshore waters, neuston dynamics in subtropical oceanic gyres and thus the potential impacts of plastic pollution as well as of cleanup activities on the neuston remain uncertain. | Egger et al., 2021 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Short- and long-term fate of ocean plastics | Fish/Sharks and Fishery Resource<br>Juvenile and Pre-juvenile Fishes<br>Marine Mammals<br>Neuston<br>Seabirds<br>Sea Turtles | Approximately 60–90% of plastic from land-based sources is expected to strand on beaches, but plastic standing stocks on beaches are much lower than global model predictions of land-based pollution. Burial in beaches and transport into backshore vegetation are significant sinks, although this plastic is likely to be released as the climate crisis leads to rising sea levels and more extreme storms. At sea, floating MP is concentrated close to urban centers. Farther offshore, plastic items tend to be large and buoyant because biofouling causes small, low buoyancy items to sink, although microplastics can still be found in surface waters. | Ryan, 2020;<br>Kooi et al., 2017 |
| | | MPs are ubiquitous contaminants of the marine environment, and the deep seafloor is their ultimate sink compartment- the depository where the plastics ultimately settle. The authors provide evidence of MP partial retention and fragmentation mediated by digestion activity of a Norwegian langoustine, a good bioindicator for MP contamination of the deep sea. In this study, langoustine were collected at depths between 402 and 656 m. These findings highlight the existence of a new peculiar kind of "secondary" MPs, introduced in the environment by biological activities, which could represent a significant pathway of plastic degradation in a secluded and stable environment such as the deep sea. | Cau et al., 2020 |
| | | A data-driven approach to elucidate degradation trends of plastic debris by linking abiotic and biotic degradation behavior in seawater with physical properties and molecular structures. The results reveal a hierarchy of predictors to quantify surface erosion as well as combinations of features, like glass transition temperature and hydrophobicity, to classify ocean plastics into fast, medium, and slow degradation categories. Slow degradation was characterized as $10^{-4}$ mm $cm^{-1}$ $day^{-1}$, medium degradation was $10^{-1}$ mm $cm^{-1}$ $day^{-1}$, and fast degradation was $10^{2}$ mm $cm^{-1}$ $day^{-1}$. | Min et al., 2020;<br>Saling et al., 2019 |
| | | The specific surface degradation rate (SSDR), is implemented and used to extrapolate half-lives. Using a mean SSDR for high-density polyethylene (HDPE) in the marine environment, linear extrapolation leads to estimated half-lives ranging from 58 years (bottles) to 1,200 years (pipes). Half-life refers to conversion of the first 50% of the polymer mass, assuming pseudo-zeroth-order kinetics (i.e., invariant surface area) | Chamas et al., 2020 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Short- and long-term fate of ocean plastics (cont'd) | Continued from above. | Electron microscopy observations showed that artificial seawater induces severe microcracking of the pellets' surfaces. Overall, the results showed that a relatively short period of time (eight weeks) of accelerated exposure can yield quantifiable chemical and physical impacts on the structural and morphological characteristics of PE pellets. | Da Costa et al., 2018 |
| | | MPs pervade the global seafloor, from abyssal plains to submarine canyons and deep-sea trenches (where they are most concentrated). Beyond the shelf, the principal agents for MP transport are: i) gravity-driven transport in sediment-laden flows; (ii) settling, or conveyance through biological processes, of material that was formerly floating on the surface or suspended in the water column; and (iii) transport by thermohaline currents, either during settling or by reworking of deposited MPs. | Kane and Clare, 2019; Wang et al., 2021; Panfeng et al., 2019 |
| | | Interactions between microorganisms and MP particles should have rather limited effects on ocean ecosystems. The majority of microorganisms growing on MPs seem to belong to opportunistic colonists that do not distinguish between natural and artificial surfaces. Thus, MPs do not pose a higher risk than natural particles to higher life forms by potentially harboring pathogenic bacteria. On the other hand, MPs in the ocean represent recalcitrant substances for microorganisms that are insufficient to support prokaryotic metabolism and will probably not be microbially degraded in any period of time relevant to human society. | Oberbeckmann and Labrenz, 2020; Rogers et al., 2020 |
| | | The presence of additives is of least equal significance to the behavior of polyolefins (PE-PP) plastics in marine systems. The authors compared barium, present largely as the filler, $BaSO_4$ (density = 4.5 g $cm^{-3}$), in consumer and beached plastics and established that the metal was more abundant and occurred at higher concentrations in the former samples, consistent with the environmental fractionation of plastics based on additive content. | Turner and Filella, 2020 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastics toxicity | Fish/Sharks and Fishery Resource<br>Juvenile and Pre-juvenile Fishes<br>Marine Mammals<br>Neuston Sea Turtles<br>Seabirds | Persistent plastics, with an estimated lifetime for degradation of hundreds of years in marine conditions, can break up into micro- and nanoplastics over shorter timescales, thus facilitating their uptake by marine biota throughout the food chain. These polymers may contain chemical additives and contaminants, including some known endocrine disruptors that may be harmful at extremely low concentrations for marine biota, thus posing potential risks to marine ecosystems, biodiversity, and food availability. | Gallo et al., 2018;<br>Llorca et al., 2020 |
| | | Nano-polymers have the greatest potential to cause the most harm to our oceans, waterways, and wildlife. Results show that a relatively short period of time of accelerated exposure can yield quantifiable chemical and physical impacts on the structural and morphological characteristics of polyethylene pellets. | Gangadoo et al., 2020 |
| | | In this study, 14, 15 and 12 Persian Gulf coastal sediment samples were collected in Bushehr province and analyzed, respectively, for potentially toxic elements (PTEs), polycyclic aromatic hydrocarbons and MPs. The results showed that almost all PTEs were not significantly enriched. Most elements exhibited their highest levels at stations close to urban areas and along the pathway of ships and boats. | Abbasi et al., 2019 |
| | | In this study, MPs and metals concentrations in muscles of both benthic and pelagic fish species from the northeastern portion of the Persian Gulf were investigated and the risk/benefit of their consumption was assessed. The results demonstrated that MPs and Hg in all species and Se in benthic species increase with size, while relationship between other metals and fish size is not consistent. Considering the chemical toxicity of MPs and metals, and their good linear relationships in some species, consumption of high doses of the studied fish may pose a health threat to the consumers. | Akhbarizadeh et al., 2017 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
| --- | --- | --- | --- |
| Plastics toxicity (cont'd) | Continued from above | Plastics rarely biodegrade but through different processes they fragment into MPs and nanoplastics, which have been reported as ubiquitous pollutants in all marine environments worldwide. Components of MPs are capable of being absorbed from the environment into organisms; absorbable components include organic contaminants, metals, and pathogens. Plastic ingestion causes blockage of the guts which may cause injury of the gut lining, morbidity, and/or mortality. Small sizes of the MPs enhance their translocation across the gastro-intestinal membranes via endocytosis-like mechanisms and distribution into tissues and organs. While in biological systems, MPs increase dysregulation of gene expression required for the control of oxidative stress and activating the expression of nuclear factor E2-related factor (Nrf) signaling pathway in marine vertebrates and invertebrates. This means the body is reacting to the introduction of a foreign body, as nuclear factor E2-related factor is a ubiquitous master transcription factor that upregulates antioxidant response elements-mediated expression of antioxidant enzyme and cytoprotective proteins. These alterations are responsible for MPs induction of oxidative stress, immunological responses, genomic instability, disruption of endocrine system, neurotoxicity, reproductive abnormities, embryotoxicity, and trans-generational toxicity. | Alimba and Faggio, 2019 |
| | | Toxicity of polyethylene microplastics (PE-MP) of size ranges similar to their natural food to zooplanktonic organisms representative of the main taxa present in marine plankton, including rotifers, copepods, bivalves, echinoderms, and fish, was evaluated. Treatments included particles spiked with benzophenone-3 (BP-3), a hydrophobic organic chemical used in cosmetics with direct input in coastal areas. No acute toxicity was found at loads orders of magnitude above environmentally relevant concentrations on any of the invertebrate models. The results obtained do not support environmentally relevant risk of MPs on marine zooplankton. | Beiras et al., 2018a |
| | | A 2-tier standardized protocol was designed to test the toxicity of MPs to planktonic organisms. This approach uses sea urchin (*Paracentrotus lividus*) and copepod (*Acartia clausi*) larvae because they are common biological models in marine research, and standard methods for toxicity testing with regulatory applications are available. Results point to chemical additives as being responsible for the toxicity found in certain plastic materials. | Beiras et al., 2018b |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastics toxicity (cont'd) | Continued from above | The objective of this study was to compare the effects of spherical or irregular shapes of MPs on changes in organ distribution, swimming behaviors, gene expression, and enzyme activities in sheepshead minnow (*Cyprinodon variegatus*). Both types of MPs accumulated in the digestive system, causing intestinal distention. However, when compared to spherical MPs, irregular MPs decreased swimming behavior (i.e., total distance travelled and maximum velocity) of sheepshead minnow. Both MPs generated cellular reactive oxygen species (ROS), while ROS-related molecular changes (i.e., transcriptional and enzymatic characteristics) differed. | Choi et al., 2018 |
| | | In order to assess the ecotoxicity of environmental MPs, samples were collected from the beaches of two islands in the Guadeloupe archipelago, Petit-Bourg (PB) located on the main island of Guadeloupe and Marie-Galante (MG) on the second island of the archipelago. MPs from MG contain more lead, cadmium, and organochlorine compounds while those from PB have higher levels of copper, zinc, and hydrocarbons. The leach test of these two samples of MPs induced sublethal effects on the growth of sea urchins and on the pulsation frequency of jellyfish ephyrae but not on the development of zebrafish embryos. The toxic effects are much more marked for samples from the PB site than those from the MG site. This result could be explained by the close proximity of an industrial area and harbor to the PB site. | Cormier et al., 2021 |
| | | In this study, fertilized eggs of marine medaka (*Oryzias melastigma*) were exposed to polystyrene MPs (0, 2, 20, 200 µg $L^{-1}$) and/or phenanthrene (Phe, 50 µg $L^{-1}$) for 28 days. The results revealed that MPs were accumulated on the chorion and ingested by larvae from 2 days post-hatching. High levels of MPs (20 and 200 µg $L^{-1}$) decreased the hatchability, delayed the hatching time, and suppressed the growth, whereas Phe inhibited hatching and caused malformations in larvae. The presence of MPs at 20 and 200 µg $L^{-1}$ did not alter the toxicity of Phe. By contrast, combined exposure to 2 µg $L^{-1}$ MPs and Phe increased the hatchability by 25.8%, decreased malformation and mortality rates, and restored Phe-induced abnormal expressions of cardiac development-related genes. The reduced early developmental toxicity could be attributed to the decreased bioavailability and bioaccumulation of Phe by the low level of MPs. | Li et al., 2019; Pannetier et al., 2019; Pannetier et al., 2020; Yan et al., 2020 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastics toxicity (cont'd) | Continued from above | This study aimed to evaluate the toxic responses of carboxylated (PS-COOH) and amino ($PS\text{-}NH_2$) polystyrene MPs on the developing clam larvae of *Meretrix meretrix* at three key life stages (i.e., fertilized eggs, D-veliger larvae, umbo larvae). PS-COOH and $PS\text{-}NH_2$ significantly decreased the hatching rates by 5.79–39.5% and developmental rates by 4.78–7.86% of the clam larvae relative to the unexposed clam larvae. The toxicity of MPs followed the order: hatching stage > metamorphosis > D-veliger larvae stage, showing stage-dependent toxic effects. Moreover, $PS\text{-}NH_2$ with a smaller hydrodynamic diameter showed a greater toxicity to the developing larvae compared to PS-COOH. | Luan et al., 2019 |
| | | This study aimed to evaluate effects induced by the exposure of key marine species to leachates and suspensions of different particle-size of polyethylene terephthalate (PET) microparticles, a plastic polymer that is considered safer for the environment than other plastics because it cannot penetrate biological barriers. Results obtained show that: i) conversely to larval stage of *P. lividus*, bacterial and algal tested species are not sensitive to PET pollution under all tested conditions; ii) different tested particle sizes of PET produce effects that are not always related to their particle-size; iii) differences comparing acidified and standard pH conditions were recorded; iv) concerning echinoderms, food availability produce significant differences compared to fasting conditions; v) special attention is needed on the possible interactions between MPs and other stressors (e.g., food, pH) in order to give a better picture of natural occurring dynamics on marine ecosystems especially in the future frame of global changes. | Piccardo et al., 2020 |
| | | In the present study, authors attempted to characterize and evaluate the in vitro toxicity of isolated MPs. Ten brands of commercial sea salts of different origins were used for the identification and characterization of MPs. The average abundance of MPs in all commercial brands was <700 MP $kg^{-1}$ and the particle size ranged from 3.8–5.2 mM. The most common types of MPs were identified as fragments, fibers, and pellets. Taken together, the MPs identified are the origin of anthropogenic derivatives and they exert a lethal effect on human cells, which might be associated with health risk complications in human beings. | Sivagami et al., 2021 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastics toxicity (cont'd) | Continued from above | In this study, investigations were made on the toxic effects of polystyrene nano- and microplastics on the marine bacterium *Halomonas alkaliphila* by determining growth inhibition, chemical composition, inorganic nitrogen conversion efficiencies and reactive oxygen species (ROS) generation. The results showed that both nano- and microplastics inhibited the growth of *H. alkaliphila* in concentrations of 80 to 200 mg $L^{-1}$, while nanoplastics rather than microplastics influenced the growth inhibition, chemical composition, and ammonia conversion efficiencies of *H. alkaliphila* at concentration of 80 mg $L^{-1}$. | Sun et al., 2018 |
| | | MPs in the marine ecosystem have an impact on the toxic effects of titanium dioxide nanoparticles ($TiO_2$ NPs). This study examined the impact of differently functionalized MPs on the toxic effects of P25 $TiO_2$ NPs to marine algae *Chlorella* sp. The median effective concentration for $TiO_2$ NPs was found to be 81 µM which indicates higher toxic effects of NPs toward algae. In contrast, MPs irrespective of their difference in functionalization had minimal toxic effect of about 15% at their higher concentration tested, 1000 mg $L^{-1}$. Plain and aminated polystyrene MPs enhanced the $TiO_2$ NPs toxicity which was further validated with oxidative stress determination studies like ROSs and lipid peroxidation assays. | Thiagarajan et al., 2019 |
| | | This study investigated the photolytic transformation of pristine polystyrene fragments (P-PS) by 60-day ultraviolet (UV) irradiation, and compared the toxicity of P-PS, photodegraded PS (PD-PS), and commercially available polystyrene microbeads (C-PS) to juvenile grouper (*Epinephelus moara*). Photodegradation reduced the size from ~55.9 µm of P-PS to ~38.6 µm of PD-PS, even produced nanoparticles (~75 nm) with a yield of 7.03 ± 0.37% (w/w), and induced surface oxidation and formation of persistent free radicals (e.g., CO•, COO•). Also, endogenous pollutants (chemical additives and polymer fragments) were leached out. Thus, PD-PS had the highest growth inhibition and lipidosis-driven hepatic lesions of grouper, followed by P-PS and C-PS, which was mainly explained by increased hepatic bioaccumulation of MPs/NPs and released endogenous toxicants. Furthermore, oxidative stress-triggered mitochondrial depolarization, suppression of fatty acid oxidation and transport, and promotion of inflammation were identified as the key mechanisms for the enhanced hepatotoxicity after photodegradation. | Wang et al., 2020a,b,c |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastics toxicity (cont'd) | Continued from above | The effect of polystyrene particles on the toxicity of triphenyltin (TPT) to the marine diatom *Skeletonema costatum* was investigated. The overall results of this study profiled the combined toxic effects of PS and TPT on marine phytoplankton species and highlighted the difference in adsorption of organic pollutants by MPs in different ambient mediums. | Yi et al., 2019 |
| | | This investigation studied the toxicity of triclosan (TCS) with four kinds of MPs namely polyethylene (74 mm), polystyrene (74 mm), polyvinyl chloride (PVC, 74 mm), and PVC800 (1 mm) on microalgae *Skeletonema costatum*. Both growth inhibition and oxidative stress including superoxide dismutase (SOD) and malondialdehyde (MDA) were determined. The authors found that TCS had obvious inhibition effect on microalgae growth within the test concentrations, and single MPs also had significant inhibition effect which followed the order of PVC800 > PVC > PS > PE. | Zhu et al., 2019 |
| | | This study primarily investigated the uptake and accumulation of a mixture of environmental MPs obtained during an artificial degradation process in early-juvenile sea bass (*Dicentrarchus labrax*). Moreover, authors evaluated their hazardous effects using biochemical markers of cytotoxicity. The findings revealed the size-dependent ingestion and accumulation of smaller MPs (0.45–3 µm) in fish tissues even after a short-term exposure (3 and 5 days). In addition to MPs, results showed the presence of plastic additives including plasticizers, flame retardants, curing agents, heat stabilizers, and fiber reinforced plastic materials in fish tissues, which contributed mostly to the larger-sized range (≥1.2 µm). The data showed that significant oxidative alterations were highly correlated with MPs size range. | Zitouni et al., 2021 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastic degradation | Fish/Sharks and Fishery Resource<br>Juvenile and Pre-juvenile Fishes<br>Marine Mammals<br>Neuston<br>Seabirds<br>Sea Turtles | In one of their own peer-reviewed studies on the life expectancy of plastics published in 2020, Ward and his team had found that polystyrene (PS), one of the world's most ubiquitous plastics, may degrade within decades when exposed to sunlight, rather than thousands of years as previously thought. The chamber used tested how environmental factors such as sunlight and temperature influenced the chemical breakdown of the PS. One of the biggest misconceptions surrounding the fate of plastics in the environment is that they simply break down into smaller bits that hang around forever. The authors had determined that in addition to plastics breaking down into smaller fragments, they also degrade partially into different chemicals, and these break down completely into carbon dioxide. These newly identified breakdown products no longer resemble plastic and would be otherwise missed when scientists survey the oceans for missing plastics. | Marine Pollution Bulletin, 2020 |
| | | A metric to harmonize disparate types of measurements, the specific surface degradation rate (SSDR), was implemented and used to extrapolate half-lives. SSDR values cover a very wide range, with some of the variability arising due to degradation studies conducted in different natural environments. SSDRs for high-density polyethylene (HDPE) in the marine environment range from practically 0 to approximately 11 µm $year^{-1}$. This approach yielded a number of interesting insights. Using a mean SSDR for HDPE in the marine environment, linear extrapolation led to estimated half-lives ranging from 58 years (bottles) to 1200 years (pipes). For example, SSDRs for HDPE and polylactic acid (PLA) were surprisingly similar in the marine environment, although PLA degrades approximately 20 times faster than HDPE on land. This study highlighted the need for better experimental studies under well-defined reaction conditions, standardized reporting of rates, and methods to simulate polymer degradation. | Chamas et al., 2020 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastic degradation (cont'd) | Continued from above | To better understand biodegradation in the natural marine environment, commercial compostable polymers (polybutylene adipate terephthalate, PBAT and semi-crystalline and amorphous PLA, and non-compostable polymers (low-density polyethylene [LDPE], PS, polyethylene terephthalate, polyvinyl chloride) were submerged *in situ* on the sediment and in the water column in the Mediterranean Sea. These samples were studied by chemical and microbiological approaches. After 82 days of immersion, no significant bacterial degradation of the different polymers was observed, except some abiotic alterations of PBAT and LDPE probably due to a photooxidation process. However, after 80 days in an enrichment culture containing plastic films as a main carbon source, *Marinomonas* genus was specifically selected on the PBAT and a weight loss of 12% was highlighted. A better understanding of the bacterial community colonizing these plastics is essential for an eco-design of new biodegradable polymers to allow a rapid degradation in aquatic environment. | Delacuvellerie et al., 2021 |
| | | LDPE was exposed to an ultraviolet (UV) fluorescence lamp in simulated aging and degradation experiments. Breaks in the polymer chain were easily seen in the plastics at the end of degradation and a fragile structure was formed throughout the polymer chain after accelerating UV light aging. The Fourier transform infrared spectrum clarified the changed and fractured molecular bond structures of UV exposed polyethylene. The change in the molecular structure of the plastic caused small changes in its color and small variations in this color change were detected by recording the Ultraviolet–Visible spectrum. | Dogan, 2021 |
| | | The samples that were aged underwater showed the smallest degradation effects for vinyl polymers (PE, PP, PS), whereas polyesters such as (PET) and PLA showed higher sensitivity to the weathering due to the hydrolysis phenomena. The most detrimental factor for vinyl polymer degradation appears to be UV light. | Fambri et al., 2020 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Plastic degradation (cont'd) | Continued from above | Oxidation, surface mechanical properties, crystallinity, and crack propagation were monitored to investigate their influence on fragmentation. Without any external stress, fragmentation only occurred in water despite a higher level of oxidation for films weathered in air. The cracking of the films did not appear correlated with the oxidation level and the presence of water appeared as a promoter of cracking propagation. The results also showed that the mechanical properties at the surface play a major role in the fragmentation pathway whereas the fabrication process may influence the propagation direction of the cracks. Consequently, the distribution in size of plastic fragments in the aquatic environment may be linked to the nature of the polymer but also to its manufacturing process. In this study, after 25 weeks of weathering in water, 90% of the fragments were >1 mm in size with very similar shapes, showing that micrometric fragments were not yet abundant. These results suggest that long times of weathering in water and many steps of fragmentation appear necessary from macroplastics to reach sizes <1 mm in the aquatic environment. | Julienne et al., 2019 |
| | | The test material (Mater-Bi) was shown to degrade (total dis-integration achieved in less than 9 months) when buried in wet sand (simulation test of the tidal zone), to lose mechanical properties but still maintain integrity (tensile strength at 66% in 2 years) when exposed to seawater in an aquarium (simulation of pelagic domain), and substantially biodegrade (69% in 236 days; biodegradation relative to paper: 88%) when located at the sediment/seawater interface (simulation of the benthic domain). | Tosin et al., 2012 |
| | | Twelve and six papers reported that bacteria and fungi, respectively, can degrade MPs. Nine articles indicated that bacterial consortia have the ability to degrade MPs, and six articles found that biofilms can also utilize MPs. Furthermore, to evaluate their associated degradation effects, the corresponding structural changes (i.e., macro size, surface morphology, functional groups) in MPs after microbial degradation were examined. In addition, MP biodegradation was affected by microbial characteristics and environmental factors; therefore, the environmental factors (i.e., temperature, pH, strain activity) influencing MP degradation and the associated degradation effects (i.e., weight loss, degradation rate, molecular weight change) were generalized. | Yuan et al., 2020 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Life cycle analysis for plastics | Fish/Sharks and Fishery Resource<br>Juvenile and Pre-juvenile Fishes<br>Marine Mammals<br>Neuston<br>Seabirds<br>Sea Turtles | These data were explored and analyzed to bring to light the possibilities in terms of effect factor (EF) developments and the existing relations between effect on aquatic ecosystems and different parameters such as particle size, polymer type, and shape. No significant differences were observed between the effect of the different subgroups of micro- and nanoplastics tested when considering a single species. However, when including many species in the analysis, differences were noted between polystyrene (PS) and other polymer types. The high uncertainty on the developed EFs combined with this lack of statistical difference among subgroups at the single species level suggested that the use of a single generic EF could be appropriate for now. | Bishop et al., 2021; Lavoie et al., 2021 |
| | | Results have shown a high variability in plastic losses depending on the fish species and the associated fishing method. During fishing activities, fishing gear (plastic) and other equipment is lost, and the type and amount can differ depending on the target species. Plastic losses computed with average rates range from 74–4344 mg $kg^{-1}$ of fish at the consumer. Most of the fish species result in plastic losses around 100 mg $kg^{-1}$ of fish at the consumer (e.g., mackerel, saithe, albacore, herring, yellowfin tuna, anchovy, sardine, skipjack tuna). The highest plastic losses were related to species that require high mass of passive fishing gear (e.g., swordfish, sole), since such gears present high loss rates. Fishing gear (macroplastics) and tire abrasion (microplastics) are the main plastic losses when considering average rates for all types of losses. When considering maximum rates, mismanaged plastic packaging at the end-of-life was the main source of plastic loss. The variability of results depending on the parameters (minimum, maximum, average) showed that there are research needs to better quantify several types of losses, mainly lost fishing gears and mismanaged waste. | Loubet et al., 2022 |

Table 1. (Continued).

| Topic | Target Resource(s) | Major Findings/Literature Synthesis | Literature |
|---|---|---|---|
| Life cycle analysis for plastics (cont'd) | Continued from above | A life cycle analysis (LCA) was conducted on composites containing recycled plastics to estimate environmental impacts when utilized in the construction and automotive markets in replacing virgin composites or traditional materials like wooden products. Composites based on recycled plastics were found to produce significant environmental benefits in the construction industry. Automotive applications, in a best-case scenario, were found to have an environmental profile similar to virgin material. However, combinations of construction and automotive applications are one of several potential opportunities available to increase the consumption rate of recycled plastics. | Rajendran et al., 2020 |
| | | LCA for four plastics demonstrated that PP and HDPE produces lower greenhouse gas emissions per kilogram of resin and solid waste per kilogram of resin than PET and general-purpose polystyrene. | Greene, 2014 (Sustainable Plastics Chapter 3) |

### 3.1 FLOATING MACROPLASTICS AS FISH AGGREGATION DEVICES (FADs)

Floating macroplastics have the potential to act as FADs, impacting fish/sharks and fishery resources, juvenile and pre-juvenile fishes, sea turtles, seabirds, and neuston resources. FADs are floating objects that are often designed and strategically placed to attract pelagic fish. Floating plastic debris may provide shelter, refuge, or habitat for a variety of marine organisms and their varied life stages.

Large aggregations of marine debris provide habitat for larval and juvenile fishes and other organisms, and may attract large predatory fish (Gregory, 2009). They may also attract mammals, birds, and turtles (species that might not normally be attracted to debris) if the aggregations have attracted prey species (Laist, 1987). Floating plastics may also result in opportunistic colonizers that aid the dispersion of species that could become invasive (Gregory, 2009).

Biofouled marine plastics produce dimethyl sulfide (DMS), which some species use as an olfactory cue to locate prey. Studies have shown that plastic ingestion frequency increased in seabirds when DMS was present, and also that loggerhead turtles showed increased foraging behavior when DMS was present (Savoca et al., 2016; Pfaller et al., 2020).

### 3.2 CHANGES IN BUOYANCY RESULTING FROM COLONIZATION (REMOVAL FROM THE SURFACE; SINKING)

Changes in buoyancy resulting from colonization have the potential to adversely affect several marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. Plastic debris sinking through the water column increases potential exposure to midwater and demersal organisms.

Ballasting and subsequent sinking of marine debris can occur due to microorganism growth (on small debris), the latter of which is highly controlled by photodegradation (Nelson et al., 2021), or colonization of larger debris by mussels, barnacles, or other larger biota. Biofouling therefore enhances seafloor deposition of plastics (Cózar et al., 2014; Kaiser et al., 2017; Ryan, 2015), while the density, fouling extent, and sample form (i.e., pellet or strip) affect sinking characteristics of plastics (Karkanorachaki et al., 2021). Seafloor deposition is also enhanced by ingestion by plankton, and this can cause heavier than normal fecal pellets which can cause sinking and seafloor deposition; consequently, seasonal changes in the plankton community has profound effects on the deposition/sinking rates of microplastics (Berezina et al., 2021).

Vertical movement of plastic particles is size dependent, and smaller pieces of plastic lose buoyancy much faster than large pieces (Kooi et al., 2017; Fazey and Ryan, 2016). The smallest plastic particles are the most sensitive to algal cell biofouling. Given that plastics degrade over time, it is expected that most of the plastic in the ocean will be found subsurface, and not floating (Kreczak et al., 2021).

### 3.3 POTENTIAL REMOVAL IMPACTS (FOCUS ON NEUSTON)

No papers were found that discussed impacts of plastic removal on neuston or other biota. However, Egger et al. (2021) noted that despite increasing research conducted on ocean plastic pollution over the last decade, there are still large knowledge gaps in the current understanding of how floating plastic debris accumulating in subtropical oceanic gyres may harm neuston.

Removing floating plastic debris from the surface ocean can minimize potentially adverse effects (e.g., from degradation by-products, toxicity) of plastic pollution on neuston, as well as prevent the formation of large quantities of secondary micro- and nanoplastics. However, due to the scarcity of observational data from remote and difficult to access offshore waters, neuston dynamics in subtropical oceanic gyres and thus the potential impacts of plastic pollution as well as of cleanup activities on the neuston remain uncertain.

### 3.4 SHORT- AND LONG-TERM FATE OF OCEAN PLASTICS

The short- and long-term fate of ocean plastics present a series of potential impact mechanisms to several marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. Expansion of the timeframes during which floating or sinking plastic debris remains in the marine environment has the potential for increasing the generation of microplastics and nanoplastics, as well as transporting plastic debris further within the marine environment.

Literature analysis revealed that, spatially, floating macroplastic is concentrated close to urban centers; farther offshore, plastic items tend to be large and buoyant because biofouling can cause small, low buoyancy items to sink (Ryan, 2020; Kooi et al., 2017). This is the reason the deep seafloor is the ultimate sink compartment for microplastics (Cau et al., 2020). Microplastics pervade the global seafloor, from abyssal plains to submarine canyons and deep-sea trenches (where they are most concentrated). Beyond the shelf, the principal agents for microplastic transport are: 1) gravity-driven transport in sediment-laden flows; 2) settling, or conveyance through biological processes, of material that was formerly floating on the surface or suspended in the water column; and 3) transport by thermohaline currents, either during settling or by reworking of deposited microplastics (Kane and Clare, 2019; Panfeng et al., 2019; Wang et al., 2021). However, partial MP retention and fragmentation can be mediated by marine fauna, highlighting the existence of a new peculiar kind of "secondary" MPs, introduced in the environment by biological activities, which could represent a significant pathway of plastic degradation in a secluded and stable environment such as the deep sea (Cau et al., 2020). Primary MPs are MPs that are introduced in the environment directly, not through mediation by marine fauna.

The temporal fate of ocean plastics is associated with degradation trends of plastic debris, as certain features like glass transition temperature and hydrophobicity can serve as predictors of how fast plastics may degrade (Min et al., 2020; Saling et al., 2019).

### 3.5 PLASTICS TOXICITY IN THE MARINE ENVIRONMENT (LEACHATES, RELATIVE TOXICITY)

Plastic toxicity in the marine environment has the potential to adversely affect several marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. Acute or chronic toxicity may result from the leaching of degradation by-products or the adsorption of various chemicals and compounds present in the marine environment.

Persistent plastics, with an estimated lifetime for degradation of hundreds of years in marine conditions, can break down into micro- and nanoplastics over shorter timescales, thus facilitating their uptake by marine biota throughout the food chain. Because their size range closely conforms to phytoplankton (e.g., algae) at the base of marine food web, micro- and nanoplastics could be available to a wide range of marine biota (e.g., copepods, crustaceans, fish, marine mammals) via feeding and trophic transfer (i.e., consumption of prey containing these particles) along the food chain (Luan et al., 2019). These polymers may contain chemical additives and contaminants, including some known endocrine disruptors that may be harmful at extremely low concentrations for marine biota, thus posing potential risks to marine ecosystems, biodiversity, and food availability (Gallo et al., 2018; Llorca et al., 2020).

Microplastics are capable of absorbing organic contaminants, metals, and pathogens from the environment into organisms. MPs were found to contain lead, cadmium, and organochlorine compounds as well as copper, zinc, and hydrocarbons, with higher concentrations of these contaminants found in closer proximity to industrial activities (Cormier et al., 2021). Toxins can be bioaccumulated in (built up in the tissues of) marine fauna, as MPs and Hg in all benthic and pelagic fish species from the northeast Persian Gulf investigated in a 2018 study increased with size, and Se increased with size for benthic species (Akhbarizadeh et al., 2017). Results also point to chemical additives as being responsible for the toxicity found in certain plastic materials (Beiras et al., 2018b).

While in biological systems, microplastics increase dysregulation of gene expression required for the control of oxidative stress and activate the expression of nuclear factor E2-related factor signaling pathway in marine vertebrates and invertebrates. These alterations are responsible for microplastics induction of oxidative stress, immunological responses, genomic instability, disruption of endocrine system, neurotoxicity, reproductive abnormities, embryotoxicity, and trans-generational toxicity (Alimba and Faggio, 2019). Oxidative stress-triggered mitochondrial depolarization, suppression of fatty acid oxidation and transport, and promotion of inflammation were identified as the key mechanisms for the enhanced hepatotoxicity after photodegradation in juvenile grouper (Wang et al., 2020a,b,c), and early-juvenile sea bass experienced significant oxidative alterations after size-dependent ingestion and accumulation of smaller MPs (0.45 to 3 µm) in fish tissues even after short-term exposure (3 and 5 days) (Zitouni et al., 2021). Microplastics that are big enough can also rupture wall linings of internal organs and block the digestive system of marine animals.

Certain plastics are more toxic to certain species. Nanoparticles displayed higher toxic effects toward algae (Thiagarajan et al., 2019), while photodegraded polystyrene (PD-PS) had the highest growth inhibition and lipidosis-driven hepatic lesions of grouper (Wang et al., 2020a,b,c); the combined effects of polystyrene (PS) and triphenyltin (TPT) are toxic to marine phytoplankton species (Yi et al., 2019). While toxicity of polyethylene microplastics did not pose an environmentally relevant risk of microplastics on marine zooplankton (Beiras et al., 2018a), plastic toxicity has been observed to cause sublethal effects on the growth of sea urchins and on the pulsation frequency of jellyfish ephyrae (Cormier et al., 2021); high levels of MPs (20 and 200 µg $L^{-1}$) decreased the hatchability, delayed the hatching time, and suppressed the growth of marine medaka (*Oryzias melastigma*) and phenanthrene (Phe) inhibited hatching and caused malformations in of marine medaka larvae (Li et al., 2019; Pannetier et al., 2018, 2019, 2020; Yan et al., 2020); and PS-COOH and PS-$NH_2$ significantly decreased the hatching and developmental rates of clam larvae, showing stage-dependent toxic effects (Luan et al., 2019).

## 3.6 PLASTIC DEGRADATION (MACROPLASTICS TO MICROPLASTICS)

Plastic degradation from macroplastics to microplastics has the potential to adversely affect several marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. Various degradation mechanisms have been identified for plastic debris found in the marine environment.

Bacteria and fungi can degrade plastics, and biodegradation is affected by microbial characteristics and environmental factors such as temperature, pH, and strain activity (Yuan et al., 2020). Plastics can also be degraded by sunlight. It was recently discovered that PS, one of the world's most ubiquitous plastics, may degrade within decades when exposed to sunlight, rather than thousands of years as previously thought. In addition to plastics breaking down into smaller fragments, they can also degrade partially into different chemicals, and these chemicals can break down completely into carbon dioxide (Marine Pollution Bulletin, 2020).

Degradation is also impacted by the composition of the plastic. Samples aged underwater showed the smallest degradation effects for vinyl polymers, whereas polyesters showed higher sensitivity to weathering due to hydrolysis phenomena (Fambri et al., 2020). Furthermore, mechanical properties at the surface play a major role in the fragmentation pathway of plastics whereas the fabrication process may influence the propagation direction of mechanical breakdown (e.g., formation of cracks). Consequently, the distribution in size of plastic fragments in the aquatic environment may be linked to the nature of the polymer but also to its manufacturing process (Julienne et al., 2019).

### 3.7 LIFE CYCLE ANALYSIS FOR OCEAN PLASTICS

The life cycle of ocean plastics has the potential to adversely affect several marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. Characterization of the life cycle of various plastic products provides insight into a broader perspective on the potential environmental impacts of a product. Life cycle analysis (LCA) is a comprehensive method for assessing all direct and indirect environmental impacts across the full life cycle of a product system, from materials acquisition, through manufacturing and use, to final disposition. The application of LCA is intended to foster the sustainable design and redesign of products and processes, leading to reduced overall environmental impacts and the reduced use and release of nonrenewable or toxic materials (Hill, 2013).

Different parameters of plastics such as particle size, polymer type, and shape pose differing effects on aquatic ecosystems. Life cycle analyses for four plastics demonstrated that polypropylene (PP) and high-density polyethylene (HDPE) produce lower greenhouse gas emissions per kilogram of resin and solid waste per kilogram of resin than polyethylene terephthalate (PET) and general-purpose polystyrene (Greene, 2014). Differences could also be noted between PS and other polymer types (Bishop et al., 2021; Lavoie et al., 2021).

Fishing gear (macroplastics) and tire abrasion (microplastics) are the main plastic losses when considering average rates for all types of losses. When considering maximum rates, mismanaged plastic packaging at the end-of-life is the main plastic loss. The variability of results depending on the parameters (min, max, average) show that there are research needs to better quantify several types of losses, mainly lost fishing gears and mismanaged waste (Loubet et al., 2022).

No papers were found that explicitly discussed a life cycle analysis for ocean plastics.

# 4.0 Net Environmental Benefit Analysis (NEBA)

A NEBA-like assessment of the option to leave plastic in place (Option 1) or remove ocean plastics using System 002 (S002, Option 2) was conducted for the seven key topics identified and summarized in the literature review.

## 4.1 NEBA METHODOLOGY

The NEBA follows the approach used by Kanmkamnerd et al. (2016) to determine the environmentally superior project alternative among several options, typically for offshore oil and gas infrastructure decommissioning. Key metrics outlined in the Kanmkamnerd NEBA model (termed the K model) include the following:

- Maximum Impact;
- Recovery;
- Maximum Benefit and Benefit Duration;
- Net Benefit;
- Weighting Factor;
- Weighted Net Benefit;
- Mean Net Benefit Score; and
- Net Environmental Benefit Rank.

Each metric is modified, as appropriate, to more fully align with the impact assessment approach and methodologies presented in **Section 5.1** of the EIA. In all instances, each metric is individually applied to each option, and considers all plastics removal-related impact-producing factors (IPFs).

### 4.1.1 NEBA Background and Decommissioning Context

NEBA was initially developed for oil spill response and contaminated site remediation to assess the environmental benefit of various oil spill damage assessment and remediation techniques (Efroymson et al., 2003). NEBA represents an extension of ecological risk assessment (i.e., a risk-based approach to impact assessment), with a fundamental difference: NEBA considers the environmental benefits of various alternatives, which traditional risk assessment does not (Nicolette et al., 2014). This approach is being applied to The Ocean Cleanup's S002 to determine if ocean plastic removal minimizes environmental harm and maximizes environmental benefit.

The basis for this NEBA includes 1) determining environmental impact, and 2) linking those resource-specific impacts to ecosystem services based on an initial ecosystem services characterization. Ecosystem services, termed "criteria" or "habitat value" per Kanmkamnerd et al. (2016), include:

- Air quality value;
- Behavioral response;
- Benthic habitat value;
- Fish habitat value;
- Fish production/fishing value;
- Terrestrial habitat value;
- Sediment value; and
- Water quality value.

A preliminary screening exercise was completed (EIA **Section 4.1**) to identify biological and social resources that will not be affected by The Ocean Cleanup activities or where impact consequence was deemed, *a priori*, to be negligible. Resources for which more extensive analysis will not be performed include air quality; sediment quality; water quality; benthic communities; archaeological resources; human resources, land use and economics; recreational resources and tourism; and physical oceanography.

The focus of the current NEBA-base approach was shifted from an ecosystem services-based assessment to a topical comparison using the seven subcriteria reviewed and characterized as the initial exercise in this assessment.

#### 4.1.2 Impact Determinations

Impact assessment methodology is detailed in **Section 5.1** of the EIA (CSA, 2022). Overall impact significance is a product of impact consequence and impact likelihood**.** The impact likelihood is deemed likely for all environmental impacts. Differences in impact likelihood are the reason for the differences between impact consequence and overall impact significance. The K model approach requires that the focus of the analysis shifts to impact consequence as the initial starting point for the NEBA.

### 4.2 IMPACT ASSESSMENT TO SUPPORT NEBA

The literature review yielded comprehensive results for several key topics relevant to plastics present in the GPGP including floating macroplastics as FADs, changes in buoyancy resulting from colonization (and subsequent sinking through the water column), the short- and long-term fate of ocean plastics, plastics toxicity, and plastic degradation (i.e., macroplastics to microplastics). Despite an exhaustive search following CSA document search and review methodology, literature was lacking for the life cycle analysis for ocean plastics and for potential removal impacts, particularly impacts to neuston. Data collected by The Ocean Cleanup will be crucial in informing future literature for these key topics.

#### 4.2.1 Floating Macroplastics as Fish Aggregation Devices (FADs)

The impact of floating macroplastics as FADs on marine resources in the GPGP is discussed in **Section 3.1**. Floating macroplastics have the potential to act as FADs, impacting fish/sharks and fishery resources, juvenile and pre-juvenile fishes, sea turtles, seabirds, and neuston resources. This could pose a net environmental benefit for these species, as large aggregations of marine debris provide habitat for larval and juvenile fishes and other organisms, and may attract large predatory fish (Gregory, 2009). This could lead to increased prey availability and habitat for these species. However, biofouled marine plastics produce DMS, which some species use as an olfactory cue to locate prey. Studies have shown that plastic ingestion frequency increased in seabirds when DMS was present, and these floating macroplastics as FADs could consequently harm seabirds. Overall, floating macroplastics serving as FADs pose a **Low** impact on marine resources, as species may experience a higher likelihood of consuming contaminated prey, but could potentially benefit from habitat provided and aggregated prey due to increased feeding opportunities. Option 2 poses a **Medium** impact, as removing floating plastics would decrease the likelihood of consuming contaminated prey, but would also reduce prey and habitat availability for fish/sharks and fishery resources, juvenile and pre-juvenile fishes, sea turtles, seabirds, and neuston resources. However, it is important to note that floating plastic habitat is not a natural habitat; the floating plastic that make up the artificial habitat has the potential to harbor toxins and be ingested by fauna.

#### 4.2.2 Changes in Buoyancy Resulting from Colonization

The impact of changes in buoyancy of plastics resulting from colonization on marine resources in the GPGP is discussed in **Section 3.2**. Changes in buoyancy resulting from colonization cause plastics to travel deeper in the water column (Cózar et al., 2014; Kaiser et al., 2017; Ryan, 2015), increasing their uptake by zooplankton (Berezina et al., 2021), which could lead to bioaccumulation of plastics in larger organisms.

This could lead to plastic toxicity (detailed in **Section 3.5**), as plastic polymers may contain chemical additives and contaminants, including some known endocrine disruptors that may be harmful at extremely low concentrations for marine biota, thus posing potential risks to marine ecosystems, biodiversity, and food availability (Gallo et al., 2018; Llorca et al., 2020). As plastics often settle and accumulate on the benthos, the impact of changes in buoyancy poses a **Medium** impact on marine resources under Option 1 and a **Low** impact under Option 2; removal will prevent current floating plastics from sinking but will not remove plastics that have already sunk lower in the water column below the depth of S002's nets that are still able to be ingested by marine fauna.

### 4.2.3 Short- and Long-Term Fate of Ocean Plastics

The impact of the short- and long-term fate of ocean plastics on marine resources in the GPGP is discussed in **Section 3.4**. Offshore, plastic items tend to be large and buoyant because biofouling causes small, low buoyancy items to sink (Ryan, 2020; Kooi et al., 2017). Plastics often settle and accumulate on the benthos over time (Cau et al., 2020). While the plastic that settles and accumulates on the benthos does not pose a direct risk to marine resources that inhabit the upper portion of the water column, buoyant plastics that are unable to sink, or have not yet sunk, still pose the risk of entanglement, contamination, and/or ingestion. Consequently, the short- and long-term fate of ocean plastics poses a **Medium** impact on marine resources under Option 1. The removal of plastic by S002 would reduce the short- and long-term fate of ocean plastics in the GPGP, as plastics that could potentially degrade and sink to the seafloor would be removed before they are able to do so. However, partial plastic retention and fragmentation can be mediated by marine fauna (Cau et al., 2020), and it is possible that plastic could be introduced in the environment by biological activities even after plastic is removed from the surface by S002. Consequently, the short- and long-term fate of plastics poses a **Low** impact on marine resources under Option 2.

### 4.2.4 Plastics Toxicity in the Marine Environment

The impact of plastic toxicity on marine resources in the GPGP is discussed in **Section 3.5**. Plastic toxicity in the marine environment impacts several marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. Plastics can be ingested by marine biota throughout the food chain which in turn can absorb organic contaminants, metals, and pathogens. These toxins can be bioaccumulated in marine fauna and can induce oxidative stress, immunological responses, genomic instability, disruption of endocrine system, neurotoxicity, reproductive abnormities, embryotoxicity, and trans-generational toxicity (Alimba and Faggio, 2019). As all of the resources in the GPGP have a high probability of ingesting plastic, and therefore plastic associated toxins, plastic toxicity poses a **High** impact on marine resources under Option 1. Under Option 2, plastic toxicity poses a **Medium** impact on marine resources, as a significantly reduced amount of plastic would yield less ingestion and less exposure to toxic chemicals associated with pelagic plastics, but plastics that have already begun to degrade and reside deeper in the water column, on the benthos, or inside fauna that are able to be ingested by predators can still be consumed by marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston.

#### 4.2.5 Plastic Degradation

The impact of plastic degradation on marine resources in the GPGP is discussed in **Section 3.6**. Degradation allows plastics to be more readily digestible by fauna and can spread plastic-associated toxins across larger distances when larger plastics fragment into smaller pieces. When plastics are more readily digestible and available, uptake by fauna would likely increase. This could lead to plastic toxicity (detailed in **Section 3.5**), as plastic polymers may contain chemical additives and contaminants, including some known endocrine disruptors that may be harmful at extremely low concentrations for marine biota, thus posing potential risks to marine ecosystems, biodiversity, and food availability (Gallo et al., 2018; Llorca et al., 2020). As the spatial availability of plastics and likelihood of harmful uptake is increased by degradation, under Option 1 the impact on marine fauna is **High**. While plastics that have already begun to degrade and sink lower in the water column (due to biofouling) would persist even if plastics were removed under Option 2, plastic removal would prevent surface plastics from further degrading. The removal of plastics able to degrade would result in **Low** impacts to marine resources.

#### 4.2.6 Other Topics

There was not enough data gathered in the literature review to inform concrete impact determinations for life cycle analysis for ocean plastics or potential removal impacts, particularly impacts to neuston. Consequently, tentative impact determinations were assigned as **Medium** until more information becomes available.

### 4.3 NEBA DETERMINATIONS

In the following analysis, environmental and social benefits of each plastic removal option have been identified, based on numerical determinations for several NEBA-based factors including impact consequence, recovery capacity, and relative weight (i.e., relative importance). Each of these NEBA-based metrics are assessed in the following subsections, then summarized via a comparison. Multiple IPFs have been considered for each plastic removal option. Regulatory requirements, safety concerns, and technical feasibility (per UK Department for Business, Energy & Industrial Strategy, 2018 guidelines), normally part of a Comparative Assessment, are not considered in the NEBA, in alignment with the K model approach.

For the current analysis, three key metrics were evaluated: impact consequence, recovery capability, and relative weight, to reach an overall impact score, the latter of which allowed for a direct, model-based comparison between two options – plastic removal vs. leaving plastic debris in place.

#### 4.3.1 Impact Consequence

Impact consequences were determined in **Section 4.2** and correspond to the following values: 1 – Very Low; 2 – Low; 3 – Medium; 4 – High. Results of the impact determinations were variable, typically **Low** or **Medium**, with two **High** determinations:

- **Low**: For the biological and physical environment, this impact level is characterized by small adverse changes unlikely to be noticed or measurable against background activities;
- **Medium**: For the biological and physical environment, this impact level is characterized by adverse changes that can be monitored and/or noticed but are within the scope of existing variability without affecting the resource's integrity or use in the environment; or

- **High**: For the physical environment, this impact level is characterized by extensive or frequent violation of applicable air or water quality standards/guidelines, or widespread contamination of sediments toxic substances. For the biological environment, this impact intensity level is characterized by extensive damage to habitats to the extent that ecosystem functions and ecological relationships would be altered, or numerous deaths or injuries of a protected species and/or continual disruption of their critical activities.

### 4.3.2 Recovery Capacity

Recovery from impact is an important consideration when conducting a NEBA. Values assigned potentially range from -5 to 5, per the K model. Recovery from an impact may surpass baseline conditions, offering some environmental benefit for a time (score >0); conditions may improve following the impact and return to baseline (score = 0); or conditions may recover but to some point considered degraded relative to baseline conditions (score <0 but improved over the impact). Recovery may be rapid, quick, delayed, or very slow. In most cases, it is expected that either rapid recovery or quick recovery will occur. Recovery scores range as follows:

- Rapid recovery, <1 year (5);
- Quick, 1 to 5 years (2);
- Delayed, >5 to 20 years (-2); and
- Very slow, >20 to 100 years (-5).

For this assessment, the recovery capacity was standardized; all subcriteria across all options were assigned a value of “1”, as there is no information available regarding how quickly conditions improve following ocean plastic removal.

### 4.3.3 Relative Weight

Following the K model approach, each topic (considered equivalent to ecosystem services criterion per the K model) was assigned a Weighting Factor based on its relative importance within the habitat being assessed, or its sensitivity to activities and/or benefits associated with each plastic removal option.

Weighting Factor scores range from -5 to 5 (with no zeroes), as outlined in **Table 2**. The value differences between various weighting factors are noted, with the relative value of each affected resource and corresponding ecosystem services area properly reflected. A value of -5 represents the least environmental benefit, and 5 represents the greatest environmental benefit. Relative weight is equivalent to relative importance, for comparison of individual subcriteria between options, not between subcriteria without further qualification.

Table 2. Weighting Factors for each individual ecosystem services area, adapted from Kanmkamnerd et al. (2016).

| Resource Affected | IPF | Ecosystem Services Area | Weighting Factor |
|---|---|---|---|
| Marine water quality | Marine plastics | Marine water quality value | -2 |
| Disposal/waste management | Sediment and water quality: offshore | Sediment/water quality value | -2 |
| Sediment quality | Seafloor disturbance | Sediment quality value | -3 |
| Benthic communities | Seafloor disturbance | Benthic community value | -4 |
| Fish communities | Seafloor disturbance; plastic presence | Fish ecology value | -4 |
| Marine mammals and sea turtles | Marine plastics | Megafauna value | -4 |
| Marine fish production | Marine plastics | Fishing/fish production value | -3 |
| Ecosystem Services | All IPFs | Ecosystem services – composite | 2 |

Kanmkamnerd et al. (2016) made no accommodation for other marine uses; for the present analysis, and in the absence of coastal/nearshore impacts, the coastal habitat value of Kanmkamnerd et al. (2016) has been eliminated and replaced by other marine uses value.

#### 4.3.4 Impact Score

Relative Weights were applied by multiplying each Impact Consequence score by its respective Relative Weight to derive a Net Benefit score. This step – calculation of a Weighted Net Benefit score for each criterion – reflects a consideration of the relative value of each topic and associated criteria.

Impact Scores for The Ocean Cleanup plastic removal options are presented in **Table 1**. The lowest impact scores were identified for Option 1 (leave in place) for plastics toxicity (-12) and plastics degradation (-16). The impact scores for Option 2 were higher overall, with the highest scores for life cycle analysis for ocean plastics (6) and the short- and long-term fate of ocean plastics (4). Based on the NEBA approach, it can be concluded that Option 2, removal of ocean plastics by S002, provides a greater environmental benefit than leaving the plastic in place for all marine resources including marine mammals, sea turtles, fish/sharks and fishery resources, juvenile and pre-juvenile fishes, seabirds, and neuston. It is noted that there is limited data pertinent to life cycle analysis for ocean plastics and for potential removal impacts, particularly impacts to neuston; these topics require additional information and possibly reanalysis within the NEBA-based assessment.

#### 4.3.5 NEBA Results

This NEBA-like analysis is just one tool that we have applied to assessing impact, to help further differentiate subcriteria from one another. It is intended to supplement, or compliment and further refine, the impact determinations made for each subcriterion. Based on numerical determinations for impact consequence, recovery capacity, and relative weight, total impact scores for all seven subcriteria were develop (**Table 2**). Higher scores indicate a greater net environmental benefit (e.g., -16 least environmental benefit; 6 greatest environmental benefit). Favorable NEBA determinations (i.e., comparisons between options) were evident for only two of the seven subcriteria under Option 1: floating macroplastics as FADs (scores: 4 under Option 1; -6 under Option 2) and removal impacts, particularly for neuston (scores: 6 under Option 1; -6 under Option 2).

The remaining determinations favored Option 2, including NEBA-based advantages associated with plastic removal, where short- and long-term fate, toxicity, buoyancy changes, degradation, and life cycle analysis results underscore the relative importance of plastic removal.

Total NEBA-based scores were also developed for both options (**Table 3**). Consistent with the prior comparison of NEBA-based determinations, Option 2 (removal of ocean plastics by S002) offers the highest degree of environment benefit (i.e., Option 1 score: -31; Option 2 score: -5), with data limitation notwithstanding.

Table 3. Proposed net environmental benefit analysis (NEBA)-like assessment of options, based on key subcriteria. The score is calculated by multiplying the impact consequence value by relative weight.

| Subcriteria | Option 1: Leave in Place | | | | Option 2: Removal of Ocean Plastics by System 002 | | | |
|---|---|---|---|---|---|---|---|---|
| | Impact Consequence | Recovery Capacity | Relative Weight | Score | Impact Consequence | Recovery Capacity | Relative Weight | Score |
| Short- and long-term fate of ocean plastics | 2–Low | 1 | -2 | -4 | 2–Low | 1 | 2 | 4 |
| Plastics toxicity | 4–High | 1 | -3 | -12 | 3–Medium | 1 | -1 | -3 |
| Floating macroplastics as fish aggregation devices | 2–Low | 1 | 2 | 4 | 3–Medium | 1 | -2 | -6 |
| Changes in buoyancy resulting from colonization | 3–Medium | 1 | -1 | -3 | 2–Low | 1 | 1 | 2 |
| Plastic degradation | 4–High | 1 | -4 | -16 | 2–Low | 1 | -1 | -2 |
| Life cycle analysis for ocean plastics | 3–Medium (tentative) | 1 | -2 | -6 | 3–Medium (tentative) | 1 | 2 | 6 |
| Potential removal impacts, particularly impacts to neuston | 3–Medium (tentative) | 1 | 2 | 6 | 3–Medium (tentative) | 1 | -2 | -6 |
| **Total NEBA-based Score, Option 1** | | | | **-31** | **Total NEBA-based Score, Option 2** | | | **-5** |

Impact Consequence: 1–Very Low; 2–Low; 3–Medium; 4–High.
Recovery: -5 to 5.
Relative Weight: -5 to 5, no zeroes; equivalent to relative importance, for comparison of individual subcriteria between options, not between subcriteria without further qualification; Note: these are subjective evaluations and rankings.
NEBA = net environmental benefit analysis.

**Table 4** provides a comparison between the relative weights of each Option by subcriteria and includes the rationale for the relative weights applied.

Table 4. Comparison of relative weight for each Option by subcriteria and the rationale for scoring.

| Subcriteria | Relative Weight | | Rationale | Difference Between Relative Weights |
|---|---|---|---|---|
| | Option 1: Leave in Place | Option 2: Removal of Ocean Plastics by System 002 | | |
| Short- and long-term fate of ocean plastics | -2 | 2 | For this subcriterion, removal significantly alters the short- and long-term fate of ocean plastics; consequently, Option 2 carries higher relative weight | 4 |
| Plastics toxicity | -3 | -1 | Potential toxicity remains high under Option 1, reduced slightly under Option 2; Option 2 has a higher relative weight | 2 |
| Floating macroplastics as fish aggregation devices | 2 | -2 | Option 1, with plastic remaining in place, has a higher relative weight than Option 2 as plastics left in place will continue to offer FAD, while those removed will not. One instance where Option 1 is favored. | 4 |
| Changes in buoyancy resulting from colonization | -1 | 1 | Changes in buoyancy favor Option 2, the latter of which has a higher relative weight; plastic removed will no longer have the ability to be colonized, reduce buoyancy, and sink | 2 |
| Plastic degradation | -4 | -1 | Option 1, with plastic remaining in place, has a lower relative weight than Option 2; plastics left in place will continue to degrade | 3 |
| Life cycle analysis for ocean plastics | -2 | 2 | Option 2 has a higher relative weight; removal of ocean plastics shortens the life cycle for plastic | 4 |
| Potential removal impacts, particularly impacts to neuston | 2 | -2 | Option 2 has a lower relative weight, as leaving in place (Option 1) will have no removal impacts to neuston (higher relative weight). A second instance where Option 1 is favored. | 4 |

# 5.0 Summary and Conclusions

A synthesis of key environmental considerations was conducted associated with macroplastic removal via S002 and associated impacts versus leaving the plastic in place. This analysis presented the results of a focused electronic database search and the stepwise analysis of potentially applicable references. Of 331 sources initially identified for review, 120 were selected for further analysis, and 67 were included in the final literature review. Based on the literature review, a full article review and synthesis of key identified data sources was conducted, followed by a summarization of key references. Seven major topics relevant to plastics present in the GPGP were characterized: floating macroplastics as FADs; changes in buoyancy resulting from colonization (and subsequent sinking through the water column); potential removal impacts, particularly impacts to neuston; the short- and long-term fate of ocean plastics; plastics toxicity; plastic degradation (i.e., macroplastics to microplastics); and life cycle analysis for plastics. Results of the topic-by-topic summarization were variable, with results presented in both tabular and discussion form.

The literature review yielded comprehensive results for several key topics relevant to plastics present in the GPGP including floating macroplastics as FADs, changes in buoyancy resulting from colonization (and subsequent sinking through the water column), the short- and long-term fate of ocean plastics, plastics toxicity, and plastic degradation (i.e., macroplastics to microplastics). Despite an exhaustive search following CSA document search and review methodology, literature was lacking for the life cycle analysis for ocean plastics and for potential removal impacts, particularly impacts to neuston. Data collected by The Ocean Cleanup will be crucial in informing future literature for these key topics.

Results of this data search and synthesis effort were further evaluated within a NEBA-type evaluation, comparing relative impacts associated with plastic removal versus no action (i.e., leaving plastic debris in place). Three key metrics were evaluated: impact consequence, recovery capability, and relative weight, to reach an overall impact score, the latter of which allowed for a direct, model-based comparison between two options – plastic removal vs. leaving plastic debris in place.

Based on numerical determinations for each NEBA metric (i.e., impact consequence, recovery capacity, relative weight), total impact scores for all seven subcriteria were develop. Higher scores indicate a greater net environmental benefit. Favorable NEBA determinations (i.e., comparisons between options) were evident for only two of the seven subcriteria under Option 1: floating macroplastics as FADs (scores: 4 under Option 1; -6 under Option 2) and removal impacts, particularly for neuston (scores: 6 under Option 1; -6 under Option 2). Remaining determinations favored Option 2, including NEBA-based advantages associated with plastic removal, where short- and long-term fate, toxicity, buoyancy changes, degradation, and life cycle analysis results underscore the relative importance of plastic removal. It is noted that there was limited data pertinent to life cycle analysis for ocean plastics and for potential removal impacts, particularly impacts to neuston; these topics require additional information and possibly reanalysis within the NEBA-based assessment.

Total NEBA-based scores were also developed for both options. Consistent with the prior comparison of NEBA-based determinations, Option 2 (removal of ocean plastics by S002) offers the highest degree of environment benefit, with data limitations notwithstanding.

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## Appendix C

## Net Sampling Taxonomic Breakdown by Gear Type by Campaign

Table C-1. Summary of ichthyoplankton, neuston, and zooplankton taxa captured by bongo (60 cm opening), manta (90 × 15 cm opening), and plankton (60 cm opening) nets during twelve field Campaigns. The neuston category refers only to five primary taxa (*Halobates* spp. [Diptera], Porpitidae, *Glaucus atlanticus*., *Velella velella* [Velellidae], and *Janthina* spp.) Numbers in are individuals per $m^3$.

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Ichthyoplankton | Bongo | *Aristostomias scintillans* | 0 | 0 | 0 | 0 | 0 | 0.0102 | 0.0052 | 0 | 0.0014 | 0 | 0 | 0 |
| | | *Bathophilus brevis* | 0 | 0 | 0 | 0 | 0 | 0.0199 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Bathophilus flemingi* | 0 | 0 | 0 | 0 | 0 | 0.0156 | 0 | 0 | 0.0024 | 0 | 0 | 0 |
| | | *Bathophilus* spp. | 0 | 0 | 0 | 0.0020 | 0 | 0 | 0 | 0.0021 | 0.0029 | 0 | 0 | 0.0023 |
| | | Blenniidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0076 |
| | | *Brama* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0056 | 0 | 0 | 0 |
| | | Bramidae | 0 | 0 | 0 | 0.0029 | 0 | 0.0066 | 0 | 0 | 0 | 0.0051 | 0 | 0 |
| | | *Caulophryne* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0106 | 0 | 0 |
| | | *Ceratoscopelus townsendi* | 0.0005 | 0.0038 | 0 | 0.0020 | 0.0054 | 0.0065 | 0.0152 | 0.0058 | 0.0699 | 0.0016 | 0 | 0.0007 |
| | | *Cololabis saira* | 0 | 0 | 0 | 0 | 0 | 0.0779 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Congridae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0094 | 0 | 0 | 0 | 0 |
| | | *Coryphaena hippurus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0161 | 0 | 0 | 0 | 0 |
| | | *Coryphaena* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0152 | 0 | 0 |
| | | *Cubiceps baxteri* | 0 | 0 | 0 | 0.0054 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cyclothone* spp. | 0.0014 | 0.0013 | 0.0005 | 0 | 0 | 0.0016 | 0.0059 | 0.0043 | 0.0080 | 0.0005 | 0 | 0 |
| | | *Desmodema lorum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0079 | 0 | 0 | 0 |
| | | *Diaphus pacificus* | 0 | 0 | 0 | 0 | 0.0257 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diaphus* spp. | 0.0347 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diaphus theta* | 0.0004 | 0.0116 | 0 | 0 | 0.0020 | 0 | 0 | 0 | 0.0333 | 0.0030 | 0 | 0 |
| | | *Diplophos taenia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0056 | 0 | 0 | 0 |
| | | Exocoetidae | 0.0052 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Exocoetus monocirrhus* | 0.0079 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Gigantactis* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0104 | 0 | 0 |
| | | Gonostomatidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0081 | 0 | 0 | 0 | 0 |
| | | *Hirundichthys* spp. | 0.0127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Ichthyoplankton (cont'd) | Bongo (cont'd) | *Howella* spp. | 0 | 0 | 0 | 0.0043 | 0 | 0 | 0 | 0 | 0.0044 | 0 | 0 | 0 |
| | | *Hygophum reinhardtii* | 0.0022 | 0 | 0.0029 | 0.0022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0018 |
| | | *Hygophum* spp. | 0 | 0.0136 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampadena urophaos* | 0.0014 | 0.0006 | 0 | 0.0007 | 0.0016 | 0.0622 | 0.0119 | 0.0932 | 0.0161 | 0.0036 | 0 | 0 |
| | | *Lampanyctus acanthurus* | 0 | 0 | 0 | 0.0029 | 0.0070 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampanyctus parvicauda* | 0 | 0 | 0 | 0 | 0.0257 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampanyctus* spp. | 0 | 0 | 0 | 0.0026 | 0 | 0.0133 | 0 | 0 | 0.0050 | 0 | 0 | 0 |
| | | Lophiiformes | 0 | 0.0132 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0009 | 0.0024 | 0 | 0 |
| | | *Melanocetus johnsonii* | 0 | 0.0026 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0094 | 0 | 0 | 0 |
| | | Melanostomiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0187 | 0 | 0 | 0 |
| | | Myctophidae | 0.0069 | 0.0112 | 0.0048 | 0.0035 | 0.0008 | 0.0123 | 0.0004 | 0.0147 | 0.0070 | 0.0026 | 0 | 0 |
| | | *Myctophum aurolaternatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0.0069 | 0 | 0 | 0 | 0 | 0 |
| | | *Myctophum nitidulum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0072 |
| | | *Nannobrachium idiostigma* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0140 |
| | | *Nannobrachium* spp. | 0 | 0.0024 | 0.0017 | 0.0066 | 0 | 0 | 0 | 0 | 0.0015 | 0 | 0 | 0 |
| | | *Notoscopelus resplendens* | 0 | 0 | 0 | 0.0089 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Oneirodes* spp. | 0.0063 | 0.0198 | 0 | 0 | 0 | 0 | 0 | 0.0021 | 0.0049 | 0.0004 | 0 | 0 |
| | | Oneirodidae | 0.0062 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Paralepididae | 0 | 0.0122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pteraclis aesticola* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0137 | 0 | 0 | 0 |
| | | *Seriola lalandi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0088 | 0 | 0 | 0 | 0 |
| | | *Stenobrachius leucopsaurus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0168 | 0 | 0 | 0 |
| | | Stomiiformes | 0 | 0 | 0 | 0 | 0 | 0.0136 | 0 | 0 | 0 | 0.0035 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Ichthyoplankton (cont'd) | Bongo (cont'd) | *Taaningichthys minimus* | 0 | 0 | 0 | 0 | 0.0164 | 0 | 0 | 0.0010 | 0 | 0 | 0 | 0.0144 |
| | | *Tetragonurus atlanticus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0210 | 0 | 0 | 0 |
| | | *Tetragonurus cuvieri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0096 | 0.0132 | 0 | 0 | 0 |
| | | *Tetragonurus* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0094 | 0 | 0 | 0 |
| | | *Triphoturus mexicanus* | 0.0006 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0427 | 0.0012 | 0 | 0 | 0 |
| | | *Triphoturus nigrescens* | 0.0021 | 0.04109 | 0 | 0 | 0 | 0 | 0 | 0.0027 | 0.0024 | 0 | 0 | 0 |
| | | *Triphoturus* spp. | 0.0042 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Unid. fish | 0.0054 | 0 | 0.0008 | 0 | 0.0007 | 0 | 0 | 0.0008 | 0.0020 | 0.0007 | 0 | 0.0007 |
| | | Unid. fish eggs | 0.0089 | 0.0341 | 0.0155 | 0.0210 | 0.0283 | 0.0308 | 0.0260 | 0.0759 | 0.0242 | 0.0211 | 0 | 0.0036 |
| | | *Vinciguerria lucetia* | 0.0011 | 0.0205 | 0.0015 | 0.0099 | 0 | 0 | 0 | 0 | 0.0027 | 0 | 0 | 0 |
| | | *Zu cristatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0079 | 0 | 0 | 0 |
| | Manta | *Aristostomias scintillans* | 0 | 0 | 0 | 0 | 0 | 0.0008 | 0.0236 | 0 | 0.0161 | 0 | 0 | 0 |
| | | *Bathophilus brevis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0215 | 0 | 0 | 0 | 0 |
| | | *Bathophilus flemingi* | 0 | 0 | 0 | 0 | 0 | 0.0090 | 0 | 0 | 0.0100 | 0 | 0 | 0 |
| | | Beloniformes | 0.0433 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Blenniidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0406 |
| | | *Brama* spp. | 0 | 0 | 0 | 0 | 0 | 0.0109 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Carangidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1562 | 0.0062 | 0 | 0 | 0 |
| | | *Caulophryne* spp. | 0.0140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0136 | 0 | 0 |
| | | *Ceratoscopelus townsendi* | 0.0022 | 0 | 0.0077 | 0.0030 | 0.0246 | 0.0052 | 0.0084 | 0 | 0.0120 | 0 | 0.0185 | 0.0044 |
| | | *Cheilopogon* spp. | 0.0313 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0077 | 0.0102 | 0 |
| | | *Chiasmodon niger* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0215 | 0 | 0 | 0 | 0 |
| | | *Cololabis saira* | 0 | 0.1400 | 0 | 0.0056 | 0.0249 | 0.0076 | 0.0070 | 0 | 0.0045 | 0 | 0 | 0 |
| | | *Coryphaena equiselis* | 0.0216 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0157 | 0 | 0 |
| | | *Coryphaena hippurus* | 0.0287 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Ichthyoplankton (cont'd) | Manta (cont'd) | *Coryphaena* spp. | 0.0144 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0122 | 0 |
| | | *Cryptopsaras couesii* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0318 | 0 | 0 | 0 |
| | | *Cyclothone* spp. | 0.0041 | 0 | 0 | 0 | 0 | 0.0019 | 0.0115 | 0.0090 | 0.0108 | 0 | 0 | 0 |
| | | *Diaphus theta* | 0.0099 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0070 | 0.0106 | 0 | 0 | 0 |
| | | *Dolopichthys* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0272 | 0 | 0 | 0 |
| | | *Eustomias* spp | 0 | 0 | 0 | 0 | 0 | 0.0135 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Exocoetidae | 0.0050 | 0.0125 | 0 | 0 | 0 | 0 | 0 | 0.0452 | 0 | 0 | 0 | 0 |
| | | *Gigantactis* spp. | 0.0216 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0070 | 0 | 0 | 0 |
| | | *Gonichthys tenuiculus* | 0.0207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gonostomatidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0108 | 0.0153 | 0 | 0 |
| | | *Hirundichthys* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0242 | 0 | 0 | 0 |
| | | *Hirundichthys* spp. | 0.0229 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0234 | 0.0120 | 0.0037 | 0 |
| | | *Howella* spp. | 0 | 0 | 0 | 0 | 0 | 0.0063 | 0 | 0 | 0.0133 | 0 | 0 | 0 |
| | | *Hygophum reinhardtii* | 0.0289 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Hygophum* spp. | 0.0894 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampadena urophaos* | 0 | 0.0052 | 0 | 0.0060 | 0.0119 | 0.0030 | 0.0085 | 0.0075 | 0.0232 | 0.0190 | 0 | 0 |
| | | *Lampanyctus parvicauda* | 0 | 0 | 0 | 0 | 0.0327 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampanyctus steinbecki* | 0 | 0.0309 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Lophiiformes | 0.0134 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0374 | 0 | 0 |
| | | *Melanocetus johnsoni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0479 | 0 |
| | | Myctophidae | 0.0295 | 0.0124 | 0.0017 | 0.0152 | 0.0022 | 0.0025 | 0 | 0.0164 | 0.0042 | 0 | 0.0205 | 0.0054 |
| | | *Myctophum nitidulum* | 0 | 0 | 0 | 0 | 0 | 0 | 0.0168 | 0 | 0 | 0 | 0 | 0 |
| | | *Myctophum* spp | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.041396 | 0 | 0 | 0 | 0 |
| | | *Nannobrachium* spp. | 0 | 0.0338 | 0 | 0.0203 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Oneirodes* spp. | 0.0049 | 0.0204 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0206 | 0 | 0 | 0 |
| | | Ophidiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0246 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Ichthyoplankton (cont'd) | Manta (cont'd) | *Parvilux ingens* | 0 | 0 | 0.0277 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Petroscirtes breviceps* | 0 | 0 | 0 | 0.0176 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Seriola lalandi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0296 | 0 | 0 | 0 | 0 |
| | | *Symbolophorus californiensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0509 | 0 | 0 |
| | | *Symbolophorus* spp. | 0.0289 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0408 | 0 |
| | | *Taaningichthys minimus* | 0 | 0 | 0 | 0 | 0 | 0.0267 | 0 | 0.0090 | 0 | 0 | 0.0780 | 0.0336 |
| | | *Tetragonurus cuvieri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0215 | 0 | 0 | 0 |
| | | *Tetragonurus* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0352 | 0 | 0 | 0 |
| | | *Triphoturus mexicanus* | 0.0778 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Triphoturus nigrescens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0141 | 0 | 0 | 0 |
| | | Unid. fish | 0.0083 | 0.0325 | 0 | 0 | 0 | 0.0019 | 0 | 0.0080 | 0.0060 | 0 | 0 | 0 |
| | | Unid. fish eggs | 0.0299 | 0.1742 | 0.0431 | 0.0357 | 0.0616 | 0.0726 | 0.2190 | 0.0798 | 0.0383 | 0.0888 | 0.0403 | 0.0330 |
| | | *Vinciguerria lucetia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0619 | 0 | 0 |
| | Plankton | *Aristostomias scintillans* | 0 | 0 | 0 | 0 | 0 | 0 | 0.0085 | 0 | 0.0023 | 0 | 0 | 0 |
| | | *Bolinichthys longipes* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0093 | 0 | 0 |
| | | *Caulophryne* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0263 | 0 | 0 |
| | | *Ceratoscopelus townsendi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0029 | 0.0276 | 0 | 0 | 0 |
| | | *Cololabis saira* | 0 | 0 | 0 | 0.0054 | 0 | 0 | 0 | 0 | 0.0097 | 0 | 0 | 0 |
| | | *Coryphaena* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0111 | 0 | 0 | 0 | 0 |
| | | *Cyclothone* spp. | 0.0034 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0037 | 0.0181 | 0 | 0 | 0 |
| | | *Desmodema lorum* | 0.0127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diaphus* spp. | 0.0102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diaphus theta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0182 | 0 | 0 | 0 |
| | | *Diplophos taenia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0094 | 0 | 0 | 0 |
| | | *Dolopichthys* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0051 | 0 | 0 | 0 |
| | | Exocoetidae | 0.0047 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0018 | 0.0010 | 0.0021 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ichthyoplankton (cont'd) | Plankton (cont'd) | *Gigantactis* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0100 | 0 | 0 |
| | | *Hirundichthys* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0103 | 0 | 0 | 0 |
| | | *Hygophum reinhardtii* | 0.0127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lampadena urophaos* | 0.0021 | 0 | 0 | 0 | 0.0015 | 0 | 0.0105 | 0.0150 | 0.0071 | 0 | 0 | 0 |
| | | *Lampanyctus* spp. | 0.0120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Lophiiformes | 0 | 0.0057 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0047 | 0 | 0 | 0 |
| | | Melanocetidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0142 | 0 | 0 |
| | | *Melanocetus johnsonii* | 0 | 0.0102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Myctophidae | 0.0015 | 0.0028 | 0 | 0 | 0.0009 | 0.0012 | 0 | 0.0048 | 0.0104 | 0.0031 | 0 | 0 |
| | | *Oneirodes* spp. | 0.0035 | 0.0073 | 0 | 0 | 0.0024 | 0 | 0 | 0 | 0.0037 | 0 | 0 | 0 |
| | | Oneirodidae | 0.0268 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Ophidiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0123 | 0 | 0 | 0 |
| | | *Pteraclis aesticola* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0051 | 0 | 0 | 0 |
| | | *Tetragonurus cuvieri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0100 | 0 | 0 |
| | | *Triphoturus* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0278 | 0 | 0 | 0 |
| | | Unid. fish | 0.0014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0039 | 0.0035 | 0 | 0 |
| | | Unid. fish eggs | 0.0066 | 0.0267 | 0 | 0 | 0.0218 | 0.0100 | 0.0081 | 0.0376 | 0.0466 | 0.0057 | 0 | 0 |
| Neuston | Bongo | Diptera | 0 | 0 | 0.0125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Glaucus atlanticus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0686 | 0 | 0 |
| | | *Halobates* spp. | 0.0340 | 0.0009 | 0 | 0.0016 | 0 | 0 | 0 | 0.0008 | 0.0007 | 0 | 0 | 0.0038 |
| | | *Janthina* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0019 | 0 | 0 | 0.0043 |
| | | *Velella velella* | 0.0064 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Manta | *Glaucus atlanticus* | 0 | 0 | 0 | 0.0054 | 0 | 0.0048 | 0.0034 | 0.0170 | 0.0024 | 0.4169 | 0.0272 | 0.0156 |
| | | *Halobates* spp. | 0.3590 | 0.6367 | 0.3159 | 0.1080 | 0.0846 | 0.0247 | 0.0023 | 0.2615 | 0.1217 | 1.0916 | 0.2225 | 0.4459 |
| | | *Janthina* spp. | 0 | 0.0217 | 0.0834 | 0.0030 | 0 | 0 | 0 | 0.2309 | 0.0397 | 0.1177 | 0.5242 | 0.2136 |
| | | Porpitidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0139 | 0.0306 | 0.0810 | 0.0444 | 0 |
| | | *Velella velella* | 0.1005 | 0.0044 | 0.2051 | 0.0015 | 0.0038 | 0.0021 | 0 | 1.3025 | 0.0837 | 0.1529 | 0.2241 | 0.0050 |
| | | Velellidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0381 | 0 |
| | Plankton | *Glaucus atlanticus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0185 | 0 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Neuston (cont'd) | Plankton (cont'd) | *Halobates* spp. | 0.0295 | 0.0011 | 0 | 0 | 0.0054 | 0.0014 | 0 | 0.0139 | 0.0058 | 0 | 0 | 0 |
| | | *Janthina* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0074 | 0 | 0.0256 | 0 | 0 |
| | | Porpitidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0011 | 0.0079 | 0 | 0 |
| | | *Velella velella* | 0.0039 | 0.0015 | 0 | 0 | 0 | 0 | 0 | 0.0833 | 0.0145 | 0.0025 | 0 | 0 |
| Zooplankton | Bongo | Amphionidacea | 0 | 0.1233 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Amphionides* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.038913 | 0 | 0 |
| | | Amphipoda | 0.0322 | 0.0200 | 0.0017 | 0.0015 | 0.0059 | 0.0032 | 0.0008 | 0.0010 | 0.0018 | 0.0183 | 0 | 0.0052 |
| | | Anostraca | 0 | 0 | 0 | 0 | 0 | 0.0097 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Anthozoa | 0 | 0.001723 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0022 | 0.0026 | 0 | 0.0019 |
| | | Appendicularia | 0.1227 | 0.8829 | 0.0607 | 0.0297 | 0 | 0.0682 | 0.0004 | 0.0036 | 1.7434 | 0.3062 | 0 | 0.2588 |
| | | *Atlanta* spp. | 0 | 0 | 0 | 0.0163 | 0.0178 | 0.0211 | 0.0282 | 0.0313 | 0.0290 | 0.1104 | 0 | 0.0084 |
| | | Brachyura | 0.0023 | 0.0197 | 0.0027 | 0.0016 | 0 | 0 | 0.0141 | 0.0009 | 0.0016 | 0.0121 | 0 | 0.0005 |
| | | Bryozoa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0069 |
| | | Calanoida | 3.3773 | 11.1287 | 2.4069 | 1.2517 | 0.4290 | 0.4073 | 0.3987 | 2.1156 | 3.7968 | 2.9848 | 0 | 5.1601 |
| | | *Caligus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0231 | 0 | 0 | 0 |
| | | *Caligus* spp. | 0.0004 | 0.0144 | 0.0218 | 0.0196 | 0 | 0.0169 | 0 | 0 | 0.0181 | 0.0125 | 0 | 0 |
| | | Caprellidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0085 | 0 | 0 | 0 |
| Zooplankton (cont'd) | Bongo (cont'd) | Caridea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.020756 | 0 | 0 |
| | | *Carinaria* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0089 | 0.0191 | 0 | 0 |
| | | *Cavolinia* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0062 | 0 | 0 | 0 | 0 |
| | | Cavoliniidae | 0 | 0 | 0 | 0 | 0 | 0.0414 | 0 | 0 | 0 | 0.015116 | 0 | 0 |
| | | Cephalopoda | 0.0025 | 0.0075 | 0.0035 | 0.0037 | 0.0005 | 0.0048 | 0.0010 | 0.0021 | 0.0017 | 0 | 0 | 0.0021 |
| | | Cephalopoda egg case | 0 | 0.0144 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Chaetognatha | 0.7212 | 2.7498 | 0.3035 | 0.1806 | 0.0693 | 0.4689 | 0.1173 | 0.3104 | 1.3960 | 2.0094 | 0.0000 | 0.2582 |
| | | Cirripedia | 0.0104 | 0.0009 | 0.0008 | 0.0008 | 0 | 0 | 0 | 0.0025 | 0.0045 | 0.0064 | 0 | 0.0036 |
| | | *Clio polita* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0153 | 0 | 0 | 0 | 0 |
| | | *Clio pyramidata* | 0 | 0 | 0 | 0 | 0.0017 | 0 | 0 | 0.0047 | 0 | 0 | 0 | 0.0106 |
| | | *Clio* spp. | 0 | 0 | 0 | 0.0032 | 0.0010 | 0 | 0 | 0 | 0 | 0.0230 | 0 | 0 |
| | | Clionidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0124 | 0 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Bongo (cont'd) | Copepoda | 0.0122 | 0.0069 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Corycaeidae | 0.0318 | 0.1345 | 0.0291 | 0.0260 | 0 | 0.0811 | 0 | 0 | 0.1005 | 0.1687 | 0 | 0 |
| | | *Creseis acicula* | 0 | 0 | 0 | 0 | 0.0791 | 0 | 0 | 0.0389 | 0.0107 | 0.3582 | 0 | 0.0113 |
| | | *Creseis* spp. | 0 | 0 | 0 | 0.0077 | 0 | 0.0017 | 0 | 0 | 0.0063 | 0.0564 | 0 | 0 |
| | | *Creseis virgula* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0553 |
| | | Crustacea | 0.0560 | 0.0995 | 0.0035 | 0 | 0 | 0.0144 | 0 | 0 | 0.1025 | 0.0144 | 0 | 0 |
| | | Ctenophora | 0 | 0.0097 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cuvierina columnella* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0072 | 0 | 0 | 0 |
| | | *Cuvierina* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0126 | 0 | 0.0106 | 0 | 0 |
| | | Cyclopoida | 0.1487 | 0.0005 | 0 | 0 | 0.0019 | 0 | 0.0057 | 0.1010 | 0 | 0.3896 | 0 | 0.0151 |
| | | *Cyclothone* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0140 |
| | | Decapoda | 0.0020 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2069 | 0.0095 | 0 | 0 |
| | | *Diacria quadridentata* | 0 | 0 | 0 | 0 | 0.0010 | 0 | 0.0281 | 0.0548 | 0 | 0 | 0 | 0.00742 |
| | | *Diacria* spp. | 0 | 0 | 0 | 0 | 0 | 0.0100 | 0 | 0 | 0.0532 | 0 | 0 | 0 |
| | | *Diacria trispinosa* | 0 | 0 | 0 | 0.0011 | 0 | 0.0039 | 0.0283 | 0.0016 | 0 | 0 | 0 | 0.0042 |
| | | Doliolidae | 0 | 0.0248 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Echinodermata | 0.0070 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Eucalanus americanus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0250 | 0 | 0 | 0 |
| | | *Eucalanus californicus* | 0 | 0.0684 | 0.0189 | 0.0040 | 0 | 0.0010 | 0 | 0 | 0 | 0.10193 | 0 | 0 |
| | | Euphausiacea | 0.0892 | 0.6337 | 0.1513 | 0.1330 | 0 | 0.1857 | 0.0396 | 0 | 0.0660 | 0.0701 | 0 | 0 |
| | | Euphausiid calyptopsis | 0 | 0.0011 | 0 | 0 | 0.2265 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Euphausiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1142 | 0 | 0 | 0 | 0.2559 |
| | | Gastropoda | 0.0051 | 0 | 0 | 0 | 0.0225 | 0 | 0.0250 | 0.0563 | 0 | 0 | 0 | 0.0280 |
| | | Gelatinous form | 0 | 0.0616 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Harpacticoida | 0.0018 | 0 | 0 | 0 | 0.0064 | 0 | 0.0179 | 0.1132 | 0 | 0 | 0 | 0.0812 |
| | | *Heliconoides* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0484 | 0 | 0 |
| | | Holothuroidea | 0.0038 | 0 | 0 | 0 | 0 | 0 | 0.0034 | 0 | 0 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Bongo (cont'd) | *Hyalocylis* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0069 | 0 | 0 |
| | | Hyperiidae | 0.4712 | 1.1106 | 0.0925 | 0.0574 | 0.0272 | 0.1438 | 0.0467 | 0.1735 | 0.2890 | 0 | 0 | 0.1203 |
| | | Hyperiidea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4706 | 0 | 0 |
| | | *Limacina* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0439 | 0.0180 | 0 | 0 |
| | | *Loligo* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0061 | 0.0103 | 0 | 0 |
| | | *Lucifer* spp. | 0.1203 | 0.0338 | 0.1583 | 0.0754 | 0.0323 | 0.0109 | 0.1275 | 0.3594 | 0.0109 | 0.3884 | 0 | 0.0691 |
| | | Malacostraca | 0.0177 | 0.0770 | 0.0570 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mollusca | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0074 | 0 | 0 |
| | | Mysida | 0.1902 | 0.3845 | 0.0056 | 0 | 0.0455 | 0 | 0.0425 | 0.0036 | 0 | 0 | 0 | 0.0092 |
| | | Mysidacea | 0 | 0.3850 | 0 | 0.0106 | 0 | 0.0263 | 0 | 0 | 0.4383 | 0.0864 | 0 | 0 |
| | | Opisthobranchia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0145 | 0 | 0 | 0 | 0 |
| | | Ostracoda | 0.0014 | 0.0501 | 0.0467 | 0.0173 | 0.0037 | 0.0149 | 0.0069 | 0.5095 | 0.2121 | 0.0136 | 0 | 0.0230 |
| | | *Paraphronima* spp. | 0 | 0 | 0 | 0 | 0 | 0.1362 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Penaeidae | 0.0119 | 0.0225 | 0 | 0.0145 | 0 | 0.0106 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Phronima* spp. | 0 | 0.1078 | 0.0070 | 0 | 0.0232 | 0.0011 | 0.0052 | 0.0309 | 0.0408 | 0.0163 | 0 | 0.0085 |
| | | *Phylliroe* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0208 | 0 | 0 |
| | | Polychaeta | 0.0051 | 0.0424 | 0.0163 | 0.0175 | 0.0105 | 0.0299 | 0.0020 | 0.0061 | 0.0134 | 0.0219 | 0 | 0.0073 |
| | | Pteropoda | 0.0912 | 0.2228 | 0.1176 | 0.0072 | 0 | 0.0070 | 0 | 0 | 0 | 0 | 0 | 0.0004 |
| | | Pyrosoma | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0072 | 0 | 0 | 0 |
| | | Salpidae | 0 | 0 | 0 | 0 | 0.2010 | 0 | 2.7878 | 0 | 0 | 0 | 0 | 0.3879 |
| | | Scyphozoa | 0.0068 | 0.0394 | 0.0139 | 0.0304 | 0.0128 | 0.0096 | 0.0015 | 0.0034 | 0.0913 | 0.1460 | 0 | 0.0096 |
| | | *Sergestes* spp. | 0 | 0 | 0 | 0 | 0 | 0.1892 | 0 | 0 | 0.1371 | 0.0357 | 0 | 0 |
| | | Sergestoidea | 0.0321 | 0.3648 | 0.0387 | 0.0084 | 0 | 0 | 0 | 0 | 0 | 0.0460 | 0 | 0 |
| | | Siphonophora | 0 | 0 | 0 | 0 | 0.0596 | 0 | 1.8767 | 0 | 0 | 0 | 0 | 0.071708 |
| | | Sipuncula | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0073 | 0 | 0 | 0 |
| | | *Streetsia* spp. | 0 | 0 | 0 | 0.0013 | 0 | 0.0042 | 0 | 0 | 0.0012 | 0.0046 | 0 | 0 |
| | | *Styliola subula* | 0 | 0 | 0 | 0 | 0.0341 | 0 | 0.0317 | 0.1663 | 0 | 0 | 0 | 0.0043 |
| | | *Tomopteris* spp. | 0 | 0 | 0 | 0.0024 | 0.0006 | 0.0188 | 0 | 0.0013 | 0.0026 | 0.0259 | 0 | 0.0024 |
| | | Tunicata | 0.1997 | 3.9052 | 0.9453 | 0.8195 | 0.5527 | 2.3833 | 0.2816 | 0.6661 | 1.0631 | 1.7810 | 0 | 0.3067 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Bongo (cont'd) | Unid. Invertebrate eggs | 0.0053 | 0.1570 | 0.4430 | 0.3845 | 0.0514 | 1.1097 | 0 | 0.0077 | 0.1329 | 0.0940 | 0 | 0 |
| | Manta | Unid. invertebrates | 0.0727 | 0.0026 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Unid. shrimp | 0.0017 | 0 | 0 | 0 | 0.0068 | 0 | 0.0163 | 0.6413 | 0 | 0 | 0 | 0.0058 |
| | | *Acetes* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0164 | 0 | 0 | 0 | 0 |
| | | Actiniaria | 0 | 0 | 21.8483 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Amphipoda | 0.0204 | 0.0589 | 0.0379 | 0.0928 | 0.0307 | 0.0050 | 0.0019 | 0.0290 | 0.0055 | 0.0706 | 0.0518 | 0.0424 |
| | | Anostraca | 0 | 0 | 0 | 0 | 0 | 0.0269 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Anthozoa | 0.0272 | 0 | 0 | 0 | 0.0778 | 0 | 0.0168 | 0 | 0 | 0.0255 | 0 | 0 |
| | | Appendicularia | 0.0256 | 0.0018 | 0 | 0.0609 | 0 | 0.0074 | 0.0000 | 0.0025 | 2.5199 | 0.8327 | 0.4188 | 0.8159 |
| | | *Atlanta* spp. | 0 | 0 | 0 | 0.3988 | 0.1041 | 0.0137 | 0.1079 | 0.1053 | 0.1099 | 0.5003 | 0.0356 | 0.0689 |
| | | *Balanus* spp. | 0 | 0 | 0.3933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Brachyura | 0.0757 | 0.0425 | 0.0319 | 0.0011 | 0.0138 | 0.0092 | 0.0065 | 0.0163 | 0.0264 | 0.1202 | 0.0316 | 0.0183 |
| | | Branchiopoda | 0 | 0 | 0 | 0.1038 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Bryozoa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0414 |
| | | Calanoida | 5.8524 | 22.5190 | 7.8411 | 5.6570 | 0.5700 | 0.3212 | 0.3895 | 2.4837 | 7.4867 | 12.6999 | 10.4537 | 7.0307 |
| | | *Caligus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0558 | 0.0264 | 0.1102 | 0 | 0 |
| | | *Caligus* spp. | 0.0132 | 0 | 0 | 0 | 0 | 0.0057 | 0 | 0.0076 | 0.0136 | 0.0791 | 0.0125 | 0 |
| | | Caprellidae | 0 | 0 | 0 | 0 | 0 | 0.0126 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Caridea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0249 | 0 | 0 | 0 | 0 |
| | | *Carinaria* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0106 | 0.0633 | 0.0101 | 0 |
| | | *Cavolinia* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0248 | 0 | 0 | 0 | 0 |
| | | *Cavolinia* spp. | 0 | 0 | 0 | 0 | 0 | 0.0025 | 0 | 0.0103 | 0.0271 | 0 | 0 | 0 |
| | | *Cavolinia tridentata* | 0 | 0 | 0 | 0 | 0 | 0 | 0.0158 | 0 | 0 | 0 | 0 | 0 |
| | | Cavoliniidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0271 | 0 | 0 |
| | | Cavolinioidea | 0 | 0.0454 | 0.0569 | 0 | 0 | 0 | 0 | 0.4997 | 0 | 0 | 0 | 0 |
| | | Cephalopoda | 0.0087 | 0.0118 | 0.0063 | 0 | 0 | 0.0013 | 0 | 0.0035 | 0.0050 | 0.0024 | 0 | 0 |
| | | Chaetognatha | 1.5709 | 4.8962 | 0.3549 | 0.5394 | 0.5280 | 0.1228 | 0.12076 | 0.2969 | 1.2562 | 5.2365 | 1.6075 | 1.0275 |
| | | Cirripedia | 0.0418 | 0 | 0.0033 | 0 | 0 | 0.0071 | 0 | 0.0535 | 0.0801 | 0.3065 | 0.0415 | 0.0031 |
| | | *Clio polita* | 0 | 0 | 0 | 0 | 0 | 0 | 0.0238 | 0 | 0 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Manta (cont'd) | *Clio pyramidata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0408 |
| | | *Clio* spp. | 0 | 0 | 0 | 0 | 0 | 0.0005 | 0 | 0.0066 | 0 | 0.0658 | 0.0539 | 0 |
| | | Cnidaria | 0 | 0 | 0 | 0.0655 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Copepoda | 0 | 0.0309 | 0.0218 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0100 | 0 |
| | | Corycaeidae | 0.0112 | 0 | 0 | 0.0118 | 0 | 0.0292 | 0 | 0.0419 | 0.0705 | 0.4355 | 0.5277 | 0 |
| | | *Creseis acicula* | 0 | 0 | 0.0943 | 0.0020 | 0.0433 | 0.0017 | 0 | 0.0270 | 0.0060 | 0.6720 | 0.0925 | 0.0286 |
| | | *Creseis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4051 | 0.0349 | 0 | 0 | 0 |
| | | *Creseis* spp. | 0 | 0 | 0 | 0 | 0 | 0.0143 | 0 | 0.1398 | 0.1860 | 0.3465 | 0.0913 | 0 |
| | | *Creseis virgula* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2621 |
| | | Crinoidea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0304 | 0 |
| | | Crustacea | 0.0626 | 0.0037 | 0.1253 | 0 | 0 | 0.0052 | 0 | 0.0597 | 0.3911 | 0.0408 | 0.0119 | 0 |
| | | Ctenophora | 0.0207 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0072 | 0 | 0.0333 | 0 | 0 |
| | | *Cuvierina* spp. | 0 | 0 | 0.0051 | 0.0064 | 0.0132 | 0 | 0.0115 | 0 | 0.0053 | 0 | 0 | 0.0395 |
| | | Cyclopoida | 0.0444 | 1.4037 | 0.0493 | 0 | 0.0229 | 0.0002 | 0.0053 | 0.0150 | 0 | 0.2267 | 0.1124 | 0.0194 |
| | | Cypris | 0.0189 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Decapoda | 0 | 0.0091 | 0.0334 | 0 | 0 | 0 | 0 | 1.7049 | 1.1652 | 0.0233 | 0.0103 | 0 |
| | | *Diacria quadridentata* | 0 | 0 | 0 | 0 | 0.0947 | 0 | 0.0453 | 0 | 0 | 0 | 0 | 0.1932 |
| | | *Diacria* sp. | 0 | 0 | 0 | 0 | 0 | 0.0135 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diacria* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0030 | 0.0222 | 0.0106 | 0.0170 | 0 |
| | | *Diacria trispinosa* | 0 | 0.0658 | 0.0534 | 0.0081 | 0.0154 | 0 | 0.0157 | 0 | 0.0070 | 0 | 0 | 0 |
| | | *Eucalanus californicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1126 | 0.1363 | 0 |
| | | Euphausiacea | 0.1175 | 0 | 0 | 0.1321 | 0 | 0.1101 | 0.0146 | 0 | 0.0918 | 0.1094 | 0 | 0 |
| | | Euphausiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1126 | 0 | 0 | 0.2050 | 0.3592 |
| | | Gastropoda | 0.1091 | 0 | 0.0034 | 0 | 0.0729 | 0 | 0.0414 | 0.0034 | 0 | 0 | 0 | 0.0431 |
| | | Harpacticoida | 0.0036 | 0.0070 | 1.2064 | 0 | 0.0201 | 0 | 0.0108 | 0.0029 | 0 | 0 | 0 | 0.1325 |
| | | Heteropoda | 0 | 0.1982 | 0.1752 | 0 | 0 | 0 | 0 | 0.0036 | 0 | 0 | 0 | 0 |
| | | Holothuroidea | 0 | 0.0146 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0100 | 0 |
| | | *Hyalocylis* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0094 | 0.0150 | 0.0423 |
| | | Hydrozoa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0194 | 0.0322 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Manta (cont'd) | Hyperiidae | 1.0336 | 0.5217 | 0.1537 | 0.1687 | 0.1189 | 0.0354 | 0.0986 | 0.2319 | 0.6989 | 0.7005 | 0.6401 | 0.5960 |
| | | Isopoda | 0 | 0 | 0 | 0 | 0 | 0 | 0.0042 | 0.0046 | 0 | 0 | 0.0947 | 0.0322 |
| | | Jaeropsidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0238 | 0 |
| | | Janiridae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4846 | 0.0658 | 0 | 0 |
| | | *Limacina* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1759 | 0.1838 | 0.0055 | 0 |
| | | Limacinoidea | 0 | 0.2676 | 0.0084 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Loligo* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0390 | 0.0408 | 0 |
| | | *Lucifer* spp. | 1.2479 | 0.1138 | 0.1848 | 2.8510 | 0.5475 | 0.0175 | 0.1482 | 0.0503 | 0.0703 | 2.0027 | 0.9073 | 0.4433 |
| | | Malacostraca | 0.0560 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mollusca | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0115 | 0 | 0.0315 | 0 | 0 |
| | | Mysida | 4.8204 | 5.1265 | 0.0589 | 0 | 0.2847 | 0 | 0.0471 | 0 | 0 | 0 | 0 | 0.9499 |
| | | Mysidacea | 0 | 0 | 0 | 0.1427 | 0 | 0.1259 | 0 | 0.7513 | 2.7956 | 5.5663 | 0.8841 | 0 |
| | | Nematoda | 0 | 0 | 0 | 0.0165 | 0 | 0 | 0 | 0 | 0.0215 | 0 | 0 | 0 |
| | | Nemertean | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0119 | 0 | 0 | 0.0800 | 0 |
| | | Nudibranchia | 0 | 0 | 0.0189 | 0.0035 | 0.2081 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0086 |
| | | Opisthobranchia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3981 | 0 | 0 | 0 | 0 |
| | | Ostracoda | 0.3200 | 2.0576 | 0.0195 | 0.0359 | 0.0443 | 0.0242 | 0.0203 | 0.0903 | 2.9680 | 0.0993 | 0.0567 | 0.2912 |
| | | *Paraphronima* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0293 | 0 | 0 | 0 |
| | | Penaeidae | 0 | 0 | 0 | 0.0345 | 0 | 0.0223 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Phronima* spp. | 0.0224 | 0 | 0 | 0.0026 | 0 | 0.0022 | 0 | 0.0112 | 0.0632 | 0.0215 | 0.0127 | 0.0124 |
| | | Platyhelminthes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0304 | 0 |
| | | Polychaeta | 0.0096 | 0.0305 | 0.0179 | 0.0173 | 0.0142 | 0.0145 | 0.0049 | 0.0038 | 0.0398 | 0.0305 | 0.0085 | 0.0072 |
| | | Porifera | 0 | 0 | 0 | 0 | 0 | 0 | 0.0158 | 0 | 0 | 0 | 0 | 0 |
| | | Pteropoda | 0.2448 | 0 | 0 | 0.0629 | 0 | 0.0146 | 0 | 0.0011 | 0.0031 | 0.0085 | 0.0499 | 0 |
| | | Salpidae | 0.0058 | 0 | 0 | 0 | 0.6055 | 0 | 2.7592 | 0 | 0 | 0 | 0 | 1.6995 |
| | | Scyphozoa | 0.0652 | 0.0895 | 0.4894 | 0.1482 | 0.0245 | 0.0855 | 0.0061 | 0.1671 | 0.3468 | 0.3644 | 0.1352 | 2.0211 |
| | | *Sergestes* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.7187 | 0 | 0 | 0 | 0 |
| | | *Sergestes* spp. | 0 | 0 | 0 | 0 | 0 | 0.1463 | 0 | 0.1439 | 0.0190 | 0.0207 | 0.3521 | 0 |
| | | Sergestoidea | 0.0760 | 0 | 0 | 0.0028 | 0 | 0.0002 | 0 | 0.0473 | 0.1609 | 0.2748 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Manta (cont'd) | Siphonophora | 0 | 0 | 0 | 0 | 0.7256 | 0 | 1.002092 | 0 | 0 | 0 | 0 | 0.5939 |
| | | Sipuncula | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5575 | 0 | 0 |
| | | *Streetsia* spp. | 0 | 0 | 0 | 0.0087 | 0 | 0.0015 | 0 | 0 | 0 | 0.0221 | 0.0074 | 0 |
| | | *Styliola* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0152 | 0 | 0.0341 | 0 |
| | | *Styliola subula* | 0 | 0 | 0.0902 | 0 | 0.1125 | 0 | 0.0632 | 0 | 0 | 0 | 0 | 0.0458 |
| | | *Tomopteris* spp. | 0 | 0 | 0 | 0.0043 | 0 | 0.0104 | 0 | 0 | 0 | 0 | 0.0271 | 0 |
| | | Tunicata | 0.4860 | 4.9461 | 0.3839 | 0.8458 | 1.8291 | 0.8505 | 0.8744 | 2.7081 | 1.4567 | 5.6513 | 4.2125 | 2.8492 |
| | | Unid. Invertebrate eggs | 0.1493 | 0 | 0 | 1.2001 | 0.1152 | 0.3104 | 0 | 0.0868 | 0.4203 | 0.6258 | 0.5348 | 0 |
| | | Unid. invertebrates | 0.4843 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Unid. shrimp | 0 | 0 | 0 | 0 | 0 | 0 | 0.0356 | 0 | 0 | 0 | 0 | 0.0200 |
| | Plankton | Amphipoda | 0.00175 | 0 | 0 | 0 | 0 | 0.0020 | 0.0042 | 0.0046 | 0.0011 | 0.0048 | 0 | 0 |
| | | Anthozoa | 0 | 0 | 0 | 0 | 0.0044 | 0 | 0 | 0 | 0 | 0.0071 | 0 | 0 |
| | | Appendicularia | 0.2607 | 0.5331 | 0 | 0.0024 | 0 | 0 | 0 | 0.0040 | 1.0135 | 0.0420 | 0 | 0 |
| | | *Atlanta* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0287 | 0 | 0 | 0 |
| | | *Atlanta* spp. | 0 | 0 | 0 | 0 | 0.0104 | 0 | 0 | 0.0128 | 0 | 0.0621 | 0 | 0 |
| | | Brachyura | 0.0023 | 0 | 0 | 0 | 0.0014 | 0.0015 | 0.0728 | 0 | 0.0031 | 0.0046 | 0 | 0 |
| | | Calanoida | 2.7661 | 1.8363 | 0 | 0.0036 | 0.1619 | 0.0531 | 0.0374 | 0.1766 | 1.3917 | 3.9684 | 0 | 0 |
| | | *Caligus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0015 | 0.0351 | 0 | 0 | 0 |
| | | *Caligus* spp. | 0.0074 | 0.008475 | 0 | 0 | 0 | 0 | 0 | 0.0350 | 0 | 0.2178 | 0 | 0 |
| | | Caridea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0093 | 0 | 0 |
| | | *Carinaria* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0140 | 0 | 0 |
| | | Cavoliniidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0257 | 0 | 0 | 0 | 0 |
| | | Cephalopoda | 0.0077 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0037 | 0 | 0 | 0 | 0 |
| | | Chaetognatha | 0.6975 | 1.7230 | 0 | 0.0381 | 0.0562 | 0.0343 | 0.05648 | 0.0542 | 1.2393 | 0.9691 | 0 | 0 |
| | | Cirripedia | 0.0316 | 0.0047 | 0 | 0 | 0 | 0.0024 | 0 | 0.0054 | 0.0224 | 0.0836 | 0 | 0 |
| | | *Clio polita* | 0 | 0 | 0 | 0 | 0 | 0 | 0.0226 | 0 | 0 | 0.0197 | 0 | 0 |
| | | Cnidaria | 0.0121 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0050 | 0 | 0 | 0 | 0 |
| | | Copepoda | 0 | 0 | 0 | 0 | 0 | 0.0202 | 0 | 0.0039 | 0.0015 | 0 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Plankton (cont'd) | Corycaeidae | 0.0179 | 0.0049 | 0 | 0 | 0 | 0.0048 | 0 | 0.0238 | 0.0861 | 0.1846 | 0 | 0 |
| | | *Creseis acicula* | 0 | 0 | 0 | 0 | 0.0106 | 0 | 0 | 0.0015 | 0.0082 | 0.0408 | 0 | 0 |
| | | *Creseis* spp. | 0 | 0 | 0 | 0 | 0 | 0.0035 | 0 | 0.0140 | 0.0086 | 0.0134 | 0 | 0 |
| | | Crustacea | 0.0231 | 0.0013 | 0 | 0 | 0 | 0 | 0 | 0.0209 | 0.2876 | 0.0354 | 0 | 0 |
| | | Ctenophora | 0 | 0.0193 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Cyclopoida | 0.1340 | 0 | 0 | 0 | 0 | 0 | 0.0136 | 0 | 0 | 0 | 0 | 0 |
| | | Decapoda | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2412 | 0.1545 | 0.0097 | 0 | 0 |
| | | *Diacria quadridentata* | 0 | 0 | 0 | 0 | 0.0091 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diacria* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0559 | 0.0135 | 0 | 0 |
| | | *Eucalanus californicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1868 | 0 | 0 |
| | | Euphausiacea | 0 | 0.0062 | 0 | 0 | 0 | 0.0025 | 0 | 0 | 0.0052 | 0.0143 | 0 | 0 |
| | | Euphausiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.035042 | 0 | 0 | 0 | 0 |
| | | Gastropoda | 0 | 0 | 0 | 0 | 0.0121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Harpacticoida | 0 | 0 | 0 | 0 | 0.0339 | 0 | 0.0596 | 0 | 0 | 0 | 0 | 0 |
| | | Hyperiidae | 0.8563 | 0.1346 | 0 | 0 | 0.0057 | 0.0114 | 0.0328 | 0.0246 | 0.12150 9 | 0.065126 | 0 | 0 |
| | | Isopoda | 0.0077 | 0 | 0 | 0 | 0.0044 | 0 | 0.0054 | 0 | 0 | 0 | 0 | 0 |
| | | Janiridae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0130 | 0 | 0 |
| | | *Limacina* sp | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0091 | 0 | 0 | 0 |
| | | *Limacina* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0135 | 0.0113 | 0 | 0 |
| | | *Lucifer* spp. | 0.1007 | 0 | 0 | 0 | 0.0252 | 0 | 0.0240 | 0.0012 | 0.0511 | 0.0380 | 0 | 0 |
| | | Malacostraca | 0 | 0.0238 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mysida | 0.1574 | 0.1572 | 0 | 0 | 0.0047 | 0 | 0.0195 | 0 | 0 | 0 | 0 | 0 |
| | | Mysidacea | 0 | 0 | 0 | 0 | 0 | 0.0061 | 0 | 0.0025 | 0.1466 | 0.0130 | 0 | 0 |
| | | Nematoda | 0 | 0 | 0 | 0 | 0.0087 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Ostracoda | 0 | 0 | 0 | 0 | 0.0023 | 0 | 0 | 0 | 0.0320 | 0 | 0 | 0 |
| | | Penaeidae | 0.0352 | 0 | 0 | 0.0015 | 0 | 0.0051 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Phronima* spp. | 0 | 0.0079 | 0 | 0 | 0 | 0 | 0.0049 | 0 | 0 | 0.0034 | 0 | 0 |
| | | Polychaeta | 0.0026 | 0.0023 | 0 | 0 | 0.0016 | 0.0029 | 0.0026 | 0 | 0.0069 | 0.0017 | 0 | 0 |

Table C-1. (Continued).

| Major Group | Gear | Taxon | Campaign | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Zooplankton (cont'd) | Plankton (cont'd) | Polygonal gelatinous forms | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2317 | 0.4497 | 0 | 0 |
| | | Pteropoda | 0.1041 | 0.0292 | 0 | 0.0040 | 0 | 0.0063 | 0 | 0.0175 | 0.0052 | 0 | 0 | 0 |
| | | Salpidae | 0 | 0 | 0 | 0 | 0.0811 | 0 | 4.1576 | 0 | 0 | 0 | 0 | 0 |
| | | Scyphozoa | 0.0100 | 0.0072 | 0 | 0 | 0 | 0 | 0 | 0.0216 | 0.0314 | 0.1934 | 0 | 0 |
| | | *Sergestes similis* | 0 | 0 | 0 | 0 | 0 | 0.0259 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Sergestes* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0026 | 0.1410 | 0.0762 | 0 | 0 |
| | | Sergestidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.2782 | 0.0153 | 0 | 0 | 0 |
| | | Sergestoidea | 0.0234 | 0.0024 | 0 | 0 | 0 | 0.0052 | 0 | 0 | 0.0103 | 0 | 0 | 0 |
| | | Siphonophora | 0 | 0 | 0 | 0 | 0.0709 | 0 | 4.8469 | 0 | 0 | 0 | 0 | 0 |
| | | *Streetsia* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0074 | 0 | 0 |
| | | *Styliola subula* | 0 | 0 | 0 | 0 | 0.0155 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Tomopteris* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0093 | 0 | 0 |
| | | Tunicata | 0.1816 | 4.8704 | 0 | 0.1120 | 0.3955 | 0.1885 | 0.0341 | 0.1940 | 0.8497 | 1.8633 | 0 | 0 |
| | | Unid. Invertebrate eggs | 0.0079 | 0.1274 | 0 | 0.0095 | 0.0579 | 0.5102 | 0 | 0.0031 | 0.0970 | 0.0765 | 0 | 0 |
| | | Unid. invertebrates | 0.1165 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Unid. shrimp | 0 | 0 | 0 | 0 | 0 | 0 | 0.0170 | 0 | 0 | 0 | 0 | 0 |

# Appendix D

# Supporting Neuston Technical Data

Two neuston experts were contracted to provide guidance, identify key data sources, and to conduct a critical review of baseline, impacts, and mitigation measures text in support of EIA development in regards to neuston. Experts were contracted for their experience with neuston from the NPSG and their worldwide perspective on open ocean neuston communities. Neuston experts included: 1) Dr. Jenni Brandon, Applied Ocean Sciences, La Jolla, California; and 2) Dr. Delphine Thibault, Aix-Marseille Université, Mediterranean Institute of Oceanography, Marseille, France. Data and text provided by the neuston experts are cited in the EIA as Brandon (2021, personal communication) and Thibault (2021, personal communication). The data in the current appendix has undergone minimal editing (for consistency in presentation), and contains responses from each neuston expert to a series of questions pertaining to neuston distribution, generation times and life cycle information, and forcing mechanisms relevant to neuston presence.

## D.1 QUESTIONS AND RESPONSES

### D.1.1 Question 1: Is it possible to further define the spatial and temporal distribution patterns for neuston in the Eastern Pacific Garbage Patch (EPGP)?

Brandon: This is hard to do because many of these animals are truly drifters, and so their spatial distribution is really determined by the wind and weather/storm events. An interesting point is that *Velella velella* come in two orientations, a right-handed and a left-handed orientation, based on which way their sail orients, and they are thought to be equally mixed together in the center of the Pacific. By the time you get to the coasts of Asia and the coasts of North America on the edges of the Gyre, you almost always only find ones of one or the other orientation, as the wind has determined their distribution.

One of the larger animals of the neuston are the neon flying squid. They actually do have spatial and temporal migration patterns throughout the North Pacific, moving throughout the region for spawning and feeding as well as performing diel vertical migration. For other species, like many fish, they are only in the neuston as larvae, and then they enter the epipelagic or mesopelagic zones as later life stages.

Thibault: With only one published set of data available (Moore et al., 2001), we cannot currently properly assess the neuston community of the EPGP. There is an obvious lack of data regarding the structure/functioning of the neuston in most area of the world’s ocean as shown by the low number of published articles. Collection of data on the species composition, seasonal, diel variations should be a priority, potential role of this community being certainly way underestimated. Temporal distribution of the neuston community will largely depend on the taxa composition of the community, their different diel and onto genic migrations, their different life cycles, and lifespan. Spatial pattern will follow mainly the mesoscale circulation, temperature, salinity and wind patterns within the area.

The only way to further define the spatial and temporal variation in the neuston community structure and distribution is by conducting survey within the considered area (i.e., EPGP, the area of subtropical high pressure, or the entire PGP). Combining efforts with scientists measuring microplastics could be a way forward but the actual procedure is for microplastics studies to digest the whole “organic matter” present in the sample (Cole et al., 2014).

### D.1.2 Question 2: Are density estimates available for neuston in the EPGP (even a broad, high level range of density estimates is of interest)?

Brandon: The only density estimate available for the EPGP is Moore et al. (2001), that has the plankton:plastic density ratio as 5:1. An additional reference was found for the Atlantic gyre. I also found another paper that attempted to estimate it acoustically, although it is not purely neuston and it is a first attempt (Lehodey et al., 2015).

Thibault: A single study by Moore et al. (2001) dealt with neuston abundance and biomass in the EPGP. This study is based on 11 stations along two transects of measuring 174 and 85 nautical miles. Authors indicated that the collected plankton were identified down to class, but actually no details of the taxonomic composition was given. Zooneuston mean abundance was 1,837,342 organisms km$^{-2}$, ranging from 54,003 to 5,076,403 organism km$^{-2}$. No information on the spatial variation along those two transects were given. Authors only highlighted the strong day/night component in the neuston community with zooneuston being at least three times more abundant at night. Moore et al. (2002) and Lattin et al. (2004) mentioned only ratios in term of biomass between neuston and plastics in an area east of the EPGP, very close to the coast.

### D.1.3 Question 3: What are the generation times (or regeneration times) for key neuston species?

Brandon: Generation times are very dependent on the species. Some *Thalia* salp species complete the entire lifecycle in two days (Heron, 1972), and during blooms, they can be born already budding tails of the asexual clonal phase (Alldredge and Madin, 1982). Copepods are dependent on species and temperature but it is on the order of a week to 10 days. *V. Velella* are thought to take 125 days/4 months to reach maximum length (Bieri, 1977). For gooseneck barnacles it is on the scale of months.

Thibault: In order to understand truly the rate of population growth in a species it is actually important to know its generation (Cole, 1954). Different generation times (i.e., duration from egg to mature adults) will have a profound impact on several ecological processes and interactions (e.g., competition, predation) within a community. Differences in generation time among species can be attributed to size and weight, but also to life cycle complexity (e.g., number of stages). The neuston community is composed of species displaying different life strategies (i.e., holoplanktonic, meroplanktonic, and metagenic [metagenetic] species). Ontogenic and diel migrations are also important behaviors to account for when studying the neuston. *Note: The following group-specific summaries of generation time and life cycles for various neuston groups (**Sections D.1.3.1** through **D.1.3.5**) were provided by Dr. Thibault. Its presentation is intended to provide further details regarding life cycle stages, and is not intended to be North Pacific Subtropical Gyre-specific.*

#### *D.1.3.1 Crustacea*

##### *D.1.3.1.1 Copepods*

Fertilized eggs (from male and female gametes either directly released into the ocean or kept in a brooding/egg sac) hatch as nauplii and after six naupliar stages (molting between each stage), there are five copepodite stages (i.e., C1 through C5). The adult stage, stage copepodite C6 is then reached (**Figure D-1**). The development from egg to adult may take from less than a week to as long as several years; the life span of an adult female or male copepod ranges from six months to one year. Isochronally is usually reported for most stages; C5 duration is particularly variable and strategy dependent. Generation time is also affected by temperature and salinity (Baumgartner and Tarrant, 2017).

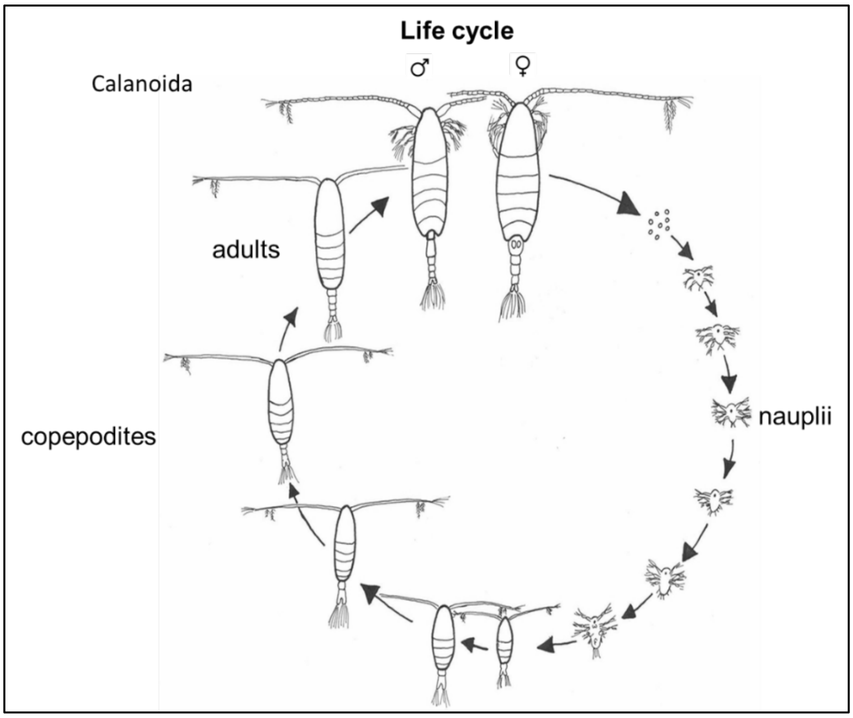


Figure D-1. Life cycle for calanoid copepods (From: National Oceanic and Atmospheric Administration, 2021).

Representative species and their respective generation times:

- *Temora longicornis*: 19 days (Klein Breteler et al., 1994);
- *Acartia clausi*: 17 days (Klein Breteler et al., 1994); and
- *Paraeuchaeta elongata*: 1 year (Ikeda and Hirakawa, 1996; Ozaki and Ikeda, 1997).

#### *D.1.3.1.2 Euphausia*

Generation time for euphausiids is approximately one year (Cuzin-Roudy et al., 2004). **Figure D-2** depicts the life stages for euphasiids.

#### *D.1.3.1.3 Amphipoda*

Most species complete their life cycle (egg to adult) in one year or less (Smith and Whitman, 1992).

### *D.1.3.2 Meroplanktonic Larvae (Crustacea, Echinodermata, Mollusca)*

For these organisms, the duration of the planktonic larval phase is crucial in the dispersal of the larvae (Sponaugle et al., 2002). Information on marine invertebrate larval development times is rare.

Crustacea: lobsters, rock lobsters (economically important species). The planktonic larval phase includes three larval stages and one postlarval stage; exhibits a complex life cycle that has a direct effect on the transport potential of larvae and the connectivity of benthic populations through larval exchange (**Figure D-3**).

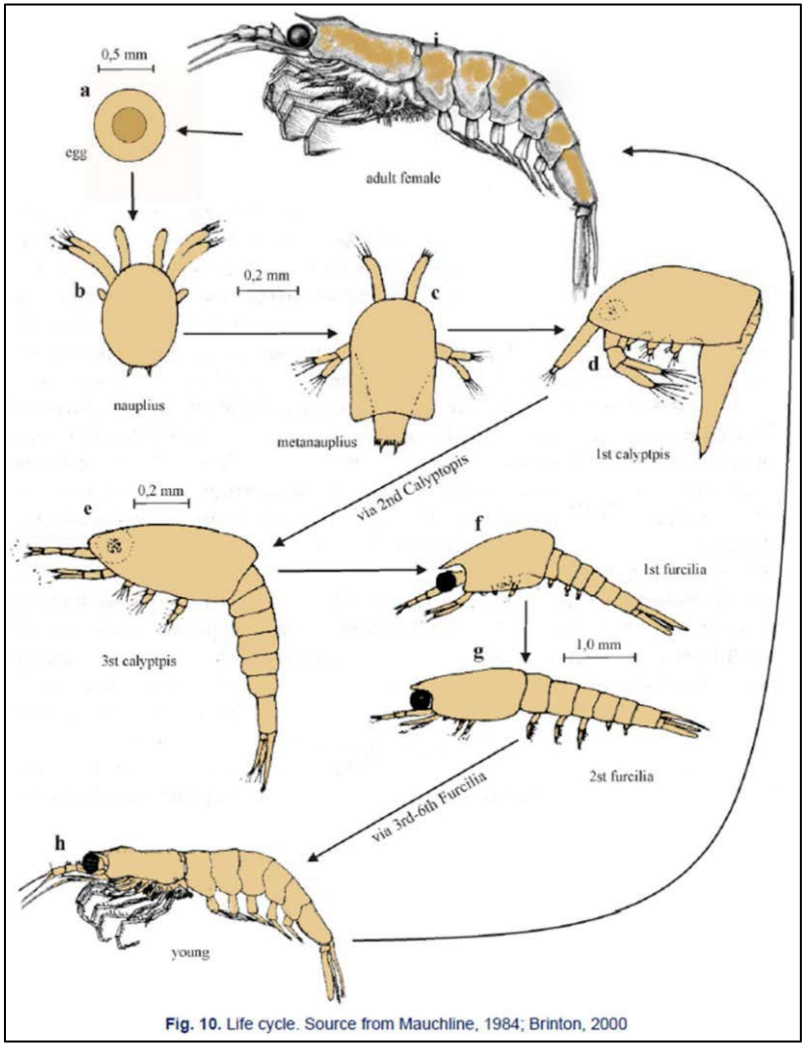


Figure D-2. Life cycle for euphasiids (From: Mauchline, 1984 and Brinton et al., 2000).

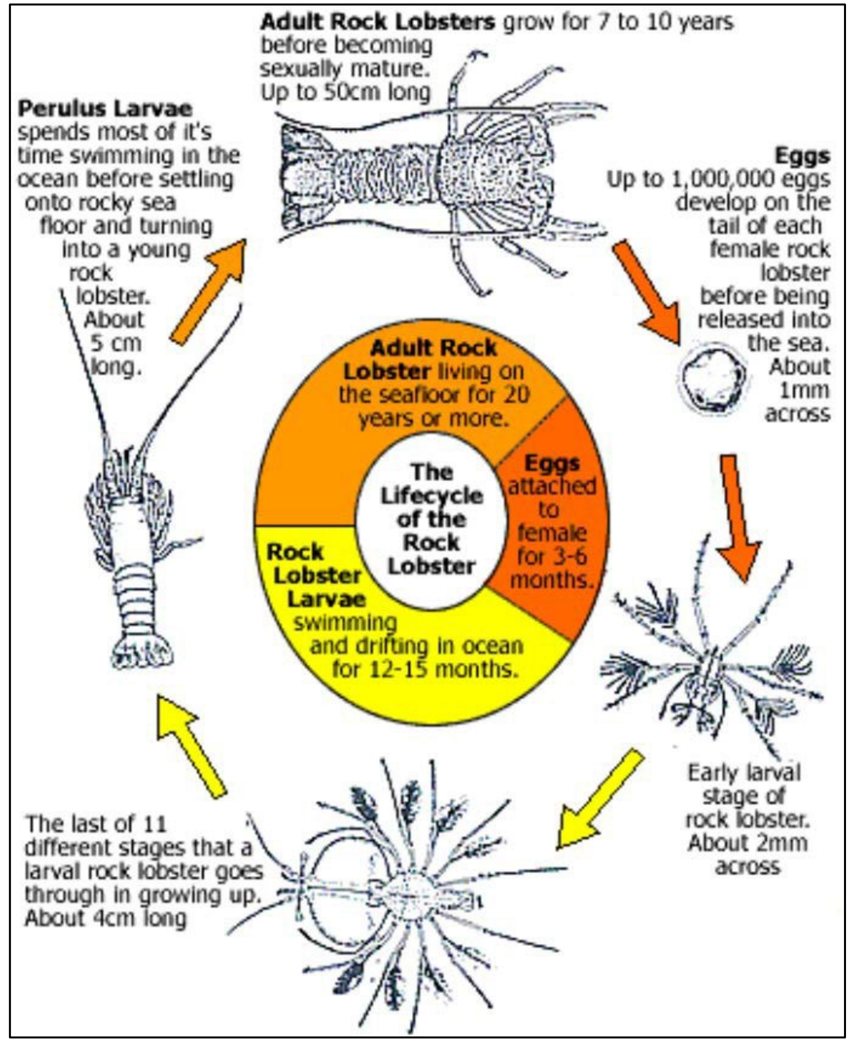


Figure D-3. Life cycle of rock lobster (From: New Zealand Rock Lobster Industry Council, 2021).

European spiny lobster (*Palinurus elephas*) is currently classified as **Vulnerable** under the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2021; Goni, 2014). Planktonic larval duration ranges from 5 to 12 months depending on the region and seawater temperature (Groeneveld et al., 2013). This species has the potential to cover thousands of kilometers before finally settling out of the water column and metamorphosing into juveniles.

Pronghorn spiny lobster (*Panulirus penicillatus*) has a long-lived teleplanic larval phase of at least 7 to 8 months (Matsuda et al., 2019).

Echinodermata (sea urchins, holothurians, sea stars, ophiuroids; **Figure D-4**). Sea urchin larval stages can last up to several months.

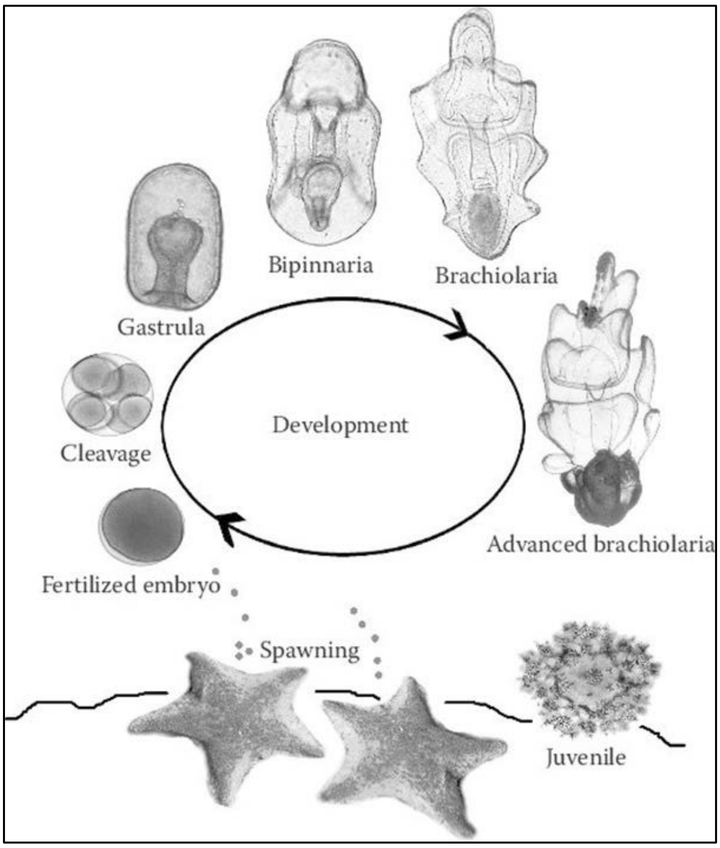


Figure D-4. Life cycle for echinoderms (From: Byrne, 2011).

Mollusca: Teleplanic (long-lived) larvae of meroplanktonic taxa are transported by currents across ocean basins (Laursen, 1981). Veliger larvae usually last for approximately two weeks before settling on the bottom of the ocean, but some species have been shown to live up to 4.5 years (e.g., *Fusitriton oregonensis*; Strathmann and Strathmann, 2007).

Pteropoda, holoplanktonic Mollusca, are permanent features in the neuston. They display year-round reproduction and an individual life span of approximately six months. Reared in the lab, the veliger stage was observed approximately seven days after egg fertilization, and metamorphosis into the juvenile stage occurred after approximately one month. Reproductive adults are usually observed after three months (Thabet et al., 2015).

### *D.1.3.3 Hydrozoans*

#### *D.1.3.3.1 Siphonophores*

The generation time for siphonophores is about 2 weeks at 24°C, or 3 weeks at 18°C (Carré and Carré, 1991; **Figure D-5**).

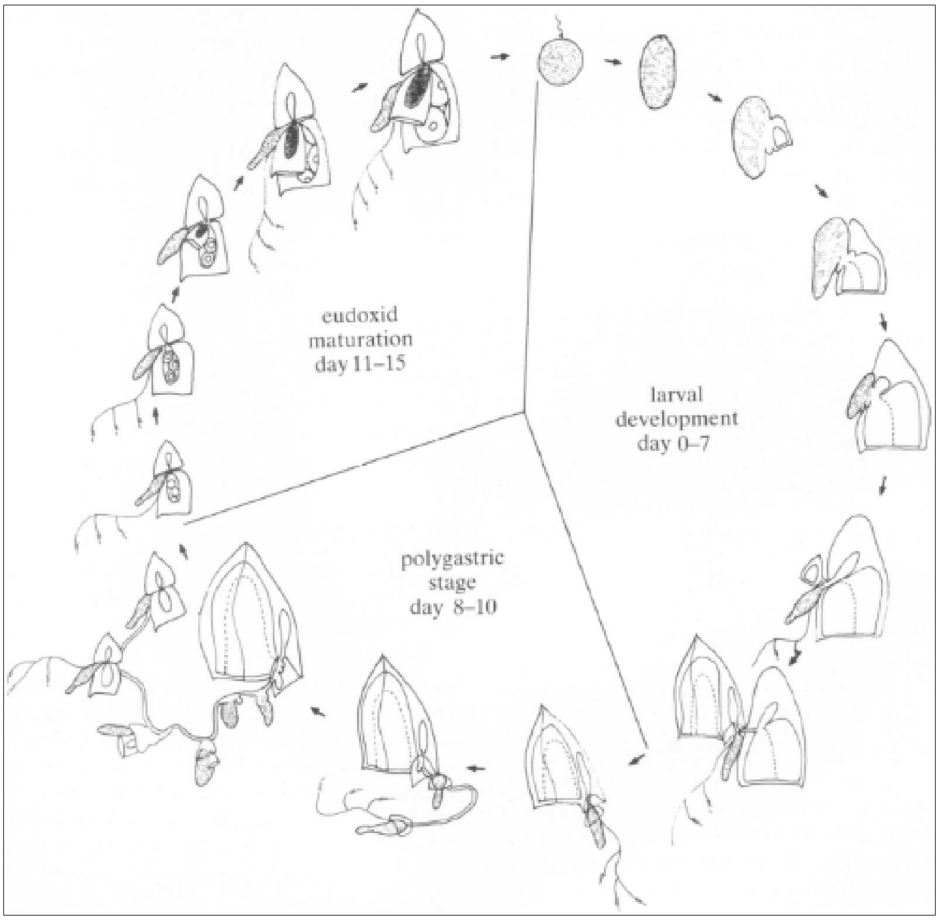


Figure D-5. Life cycle of siphonophores (From: Carré and Carré, 1991).

#### *D.1.3.3.2 Metagenic Hydromedusae and Jellyfish*

The generation time for metagenic hydromedusae and jellyfish is highly variable, ranging from a few weeks to several weeks, depending on temperature, salinity, daylight, and other environmental conditions. The life cycle of metagenic hydromedusae and jellyfish is depicted in **Figure D-6**. Potential development on floating debris of the benthic form (polyp) should be taken into consideration.

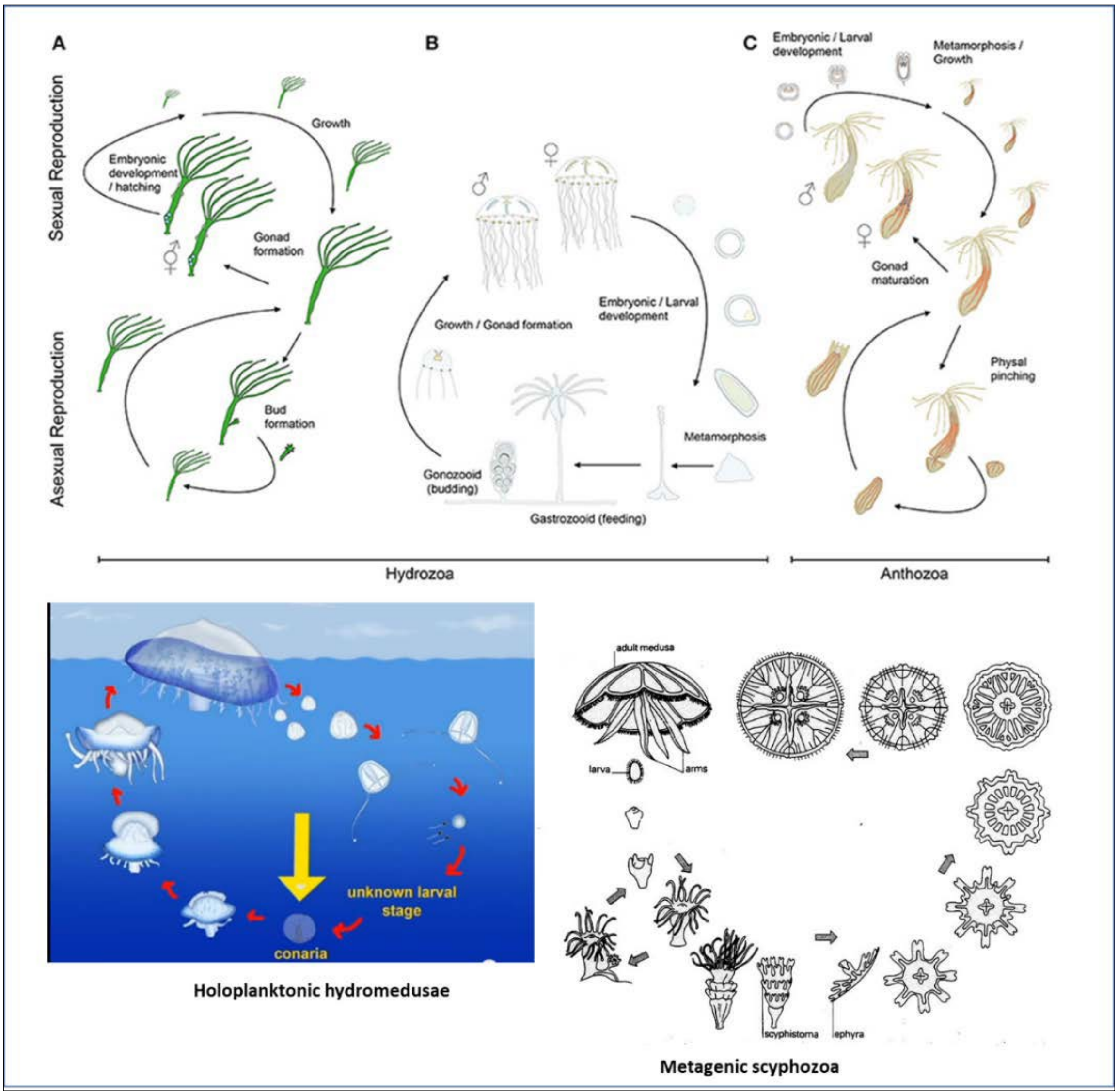


Figure D-6. Life cycle for metagenic hydromedusae and jellyfish (From: Leclère and Röttinger (2016), (top); Vidamarina (2021) (bottom left); Matveev et al. (2012) (bottom right).

#### *D.1.3.4.1 Salps and Doliolids*

The generation time for salps can be as long as nine months (Loeb and Santora, 2012) or as short as two days (Heron, 1972). Salps and doliolids have an obligatory alternation of generations with 2 or 3 stages, respectively: the solitary phase (asexual oozoid) and the colonial phases (blastozooid-sexually reproducing and phorozooid-only in doliolids). All stages can live at the same time.

### ***D.1.3.4 Pyrosomes***

Pyrosomes do not have a larval stage and the colony grows throughout their life span.

### D.1.4 Question 4: What factors, if known, drive neuston "blooms?"

Brandon: For some drifting organisms, the blooms may be nothing more than currents and winds accumulating them in one spot. The swarms, or blooms, of salps are due to a life cycle that allows them to be highly adapted to patchy, unpredictable food sources. When there is little food around, their alternation of generations and hermaphroditism allows them to maintain genetic variability and to exist without reproducing in times of low food (Alldredge and Madin, 1982). But when they come across abundant food sources, their high growth rate, short generation time, high fecundity, direct development, maternal nutrition of both the embryos and the stolons, efficient morphology and alternation of generations all combine to allow for population explosions (Alldredge and Madin, 1982).

Thibault: Aggregations of neuston rather than blooms are usually the result of a combination of one or more different forcing mechanisms, including:

a. large scale and mesoscale hydrographic processes involved in the horizontal distribution such as fronts, eddies, marine currents, Ekman transport and upwelling filaments;
b. winds (epineuston more exposed to wind constraints);
c. bottom depth;
d. sea surface temperature (will play a role in generation time, metabolic and survival rates);
e. sea surface salinity (low salinity following rain or in coastal region river inflow can limit the presence of taxa such as some siphonophores);
f. food availability; neuston species are mostly carnivorous as conditions in that ecotone in term of light intensity and temperature usually drives phytoplankton further down the water column;
g. ontogenic cycle;
h. day/night cycle (endogenous cycle linked to light cycle, predation avoidance, energy conservation, genetic mixing);
i. moon phase (diel migration is limited at night during full moon, less organisms reaching the neuston layer); and/or
j. damaging ultraviolet radiation protection.

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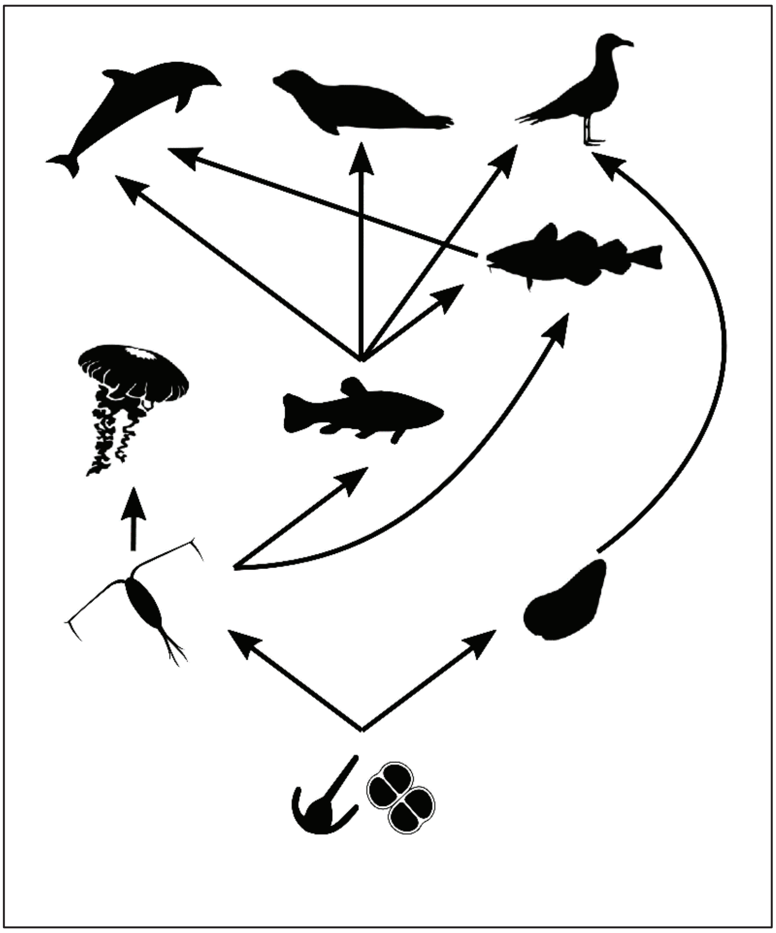
# Appendix E

# Ecopath with Ecosim Modeling Review

# Ecopath with Ecosim Modeling Review

May 2022



*Cover image adapted from: Niquil et al. (2021)*

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# Ecopath with Ecosim Modeling Review

DOCUMENT NO. CSA-TheOceanCleanup-FL-22-81581-3648-05-REP-01-FIN

*Appendix D to CSA-TheOceanCleanup-FL-22-81581-3648-01-REP-01-FIN-REV02*

| Internal review process | | | | | |
|---|---|---|---|---|---|
| Version | Date | Description | Prepared by: | Reviewed by: | Approved by: |
| INT-01 | 04/22/2021 | Initial draft for science review | A. Lawson | B. Balcom | K. Olsen |
| INT-02 | 02/25/2022 | Revised draft | A. Lawson / B. Balcom | M. Fonseca | K. Olsen |
| INT-03 | 03/07/2022 | TE review | A. Lawson / B. Balcom | J. Landgraf | K. Olsen |
| INT-04 | 04/27/20220 | Revised draft-post client review of draft | A. Lawson/ B. Balcom | B. Balcom | K. Olsen |

| Client deliverable | | | |
|---|---|---|---|
| Version | Date | Description | Project Manager Approval |
| 01 | 03/11/2022 | Client deliverable | K. Olsen |
| FIN | 05/09/2022 | Final deliverable | K. Olsen |
| | | | |
| | | | |

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# 1.0 Introduction

## 1.1 OVERVIEW

Following issuance of the initial Environmental Impact Assessment (EIA) for The Ocean Cleanup in 2018, the issue of impacts to the neuston were raised. The neuston community of the North Pacific Ocean has been studied, but only to a limited extent (e.g., Moore et al., 2001; Goldstein, 2012). Key references in this regard include recent publications from The Ocean Cleanup and professional affiliates (e.g., Egger et al., 2021), neuston-specific research (e.g., Moore et al., 2001, 2005), and peripheral data acquired during sampling and analysis of macro- and microplastics. The following assessment provides a limited review of existing ecosystem modeling results for the North Pacific Ocean to determine if the Ecopath with Ecosim (EwE)[1] modeling method is a suitable tool to better characterize the function of neuston in this open ocean ecosystem and in doing so, address the potential for System 002 impacts to the open ocean neuston community and overall ecosystem dynamics.

This modeling review is based upon investigation of several EwE model applications that were developed for the Pacific Ocean ecosystem. Models reviewed were developed primarily between 2002 and 2007 with a single, potentially applicable model published in 2019. The goal of the review was to identify one or more candidate modeling efforts which may be adaptable to The Ocean Cleanup Project Area to be used for System 002 testing. The details of each of these EwE models are incorporated here by reference, with essential characteristics, assumptions, data gaps, and major findings noted as appropriate. This review summarizes each model's feasibility to support ecosystem-based impact assessment (Landsberg et al., 2016; Holsman et al., 2017), a related component of ecosystem-based management (Lester et al., 2010; Curtin and Prellezo, 2010; Alexander et al., 2018). Ecosystem-based impact assessment, also termed the ecosystem approach, was initially introduced by the Convention on Biological Diversity (CBD, 2004), has been subsequently adopted for a variety of terrestrial, estuarine, and marine ecosystems, and has the potential to drive regulatory change (Diehl et al., 2016); assessment at an ecosystem level was defined by CBD as "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way." The following review also provides further insight into the relative role of individual ecosystem components to ecosystem functioning.

**Section 1.0** briefly describes EwE, including the scope of each model application in the reviewed studies, strengths, and drawbacks. **Table 1** outlines key points of the studies reviewed. **Section 2.0** describes similarities and differences and strengths and weaknesses of each study. Furthermore, **Section 3.0** assesses each study's applicability to the open ocean ecosystem potentially affected by The Ocean Cleanup and System 002, providing further recommendations for future model development and utilization.

## 1.2 ECOPATH WITH ECOSIM BACKGROUND

EwE provides a framework for the construction of mass-balance ecosystem models at one point in time which are generated from estimates of biomass, diet compositions, food consumption rates, and how efficiently resources are utilized in a given ecosystem (Olson and Watters, 2003). The model ecosystem created by Ecopath is described using functional groups that can either be comprised of a single species (e.g., bluefin tuna) or made up of several species with similar characteristics (e.g., large zooplankton,

[1] https://ecopath.org/

small zooplankton). Functional groups are species or collections of species that share similar population dynamics and ecological function (Ecopath, 2022). Godinot and Allain (2003) describe the two equations that every functional group must satisfy. The first equation describes the production term, assuming mass balance and the second equation is based on the principle of conservation of matter within a group. Further formulae details are provided in **Section 3.1**.

Ecopath models require the input of at least three of the following four parameters for each functional group: total biomass, production to biomass ratio (equivalent to total mortality), consumption to biomass ratio, and ecotrophic efficiency[2]. If only three of four parameters are entered, the model will estimate the missing values assuming mass balance. If all four parameters are entered, equilibrium will be reached using biomass accumulation or depletion. Diet composition data and fisheries catch data for each of the functional groups also need to be entered into Ecopath software. Once all parameters are entered, the software produces a point-in-time, mass-balanced trophic model of the ecosystem (Godinot and Allain, 2003).

Once populated, Ecosim allows testing for the effects of modifications on the ecosystem such as increased fishing efforts (Godinot and Allain, 2003) or other impacts to flow of ecosystem services among functional groups and the consequences for the status of those groups. The basics of Ecosim consist of a system of coupled differential equations derived from the Ecopath first equation which are described further by Godinot and Allain (2003).

A third component of the EwE approach, termed Ecospace, is a spatially and temporally dynamic module primarily designed for exploring impact and placement of protected areas (Pauly et al., 2000). The potential application of Ecospace to The Ocean Cleanup operations in the NPSG ecosystem appears limited and has not been assessed further in this analysis.

Per Ecopath, functional groups would be defined based on similar ecological function. For application to The Ocean Cleanup operations, a characterization of NPSG ecosystem trophic levels would be required (e.g., primary producers, primary consumers, secondary consumers, etc.). Mass would be the common metric, energy flow would be the pathway. The purpose of applying EwE would be to manipulate the neuston component, e.g., via initial estimation of existing mass and associated energy flow, then removal of neuston (via S002) at various levels to determine how the overall ecosystem may be affected by removal.

An advantage of the Ecopath approach to ecosystem modeling is that models can be constructed combining local data sets with regional information and estimates from empirical models (Godinot and Allain, 2003). This information can be used to explore ecological consequences of trophic shifts within an ecosystem; however, such combinations of data, often based on different spatial and/or temporal extents often have varying degrees of uncertainty associated with the parameters for many of the components which in turn can have an additive effect on overall model uncertainty. Identification and assessment of EwE modeling guidelines and best practice, including summarization of EwE advantages and pitfalls, can be found in Heymans et al. (2016).

[2] Fraction of production of an ecological group consumed by another ecological group.

Like any model, Ecopath cannot explain all relationships in an ecosystem and does not readily incorporate factors like habitat alterations and diet shifts. For example, Godinot and Allain (2003) explain that a model could show that a prey's biomass may stay stable, or even decrease, despite decreased predation due to increased predation mortality from another less competitive predator. Likewise, when specifying the diet of some predators it can be easy to overlook a minor diet species. While the minor species may not be critical for a specific predator, the associated predation mortality could represent a large component of total morality for the prey species. Moreover, EwE software does not consider seasonal changes or direct migration of species. Additionally, abiotic processes cannot be considered (Godinot and Allain, 2003).

# 2.0 Studies Reviewed

A series of studies using EwE models were reviewed for potential applicability to The Ocean Cleanup activities in the North Pacific Subtropical Gyre (NPSG). The bases for selection of a model for review included 1) location within the Pacific Ocean, preferably the central or northern Pacific, and 2) focus on one or more components of the pelagic ecosystem. Utilization of the Ecopath interactive mapping tool allowed for proper georeferencing for relevant studies. Each of the EwE models considered in this review is summarized in **Table 1**, including model focus, location, time period for model simulation, and reference source. The following summaries are derived directly from available abstracts and supplemented, as appropriate, from a review of major findings. Key findings and identified shortcomings of each Ecopath model application are discussed in the individual subsections below. The potential applicability of one or more of these tailored Ecopath models to The Ocean Cleanup is addressed in **Section 3**.

Table 1. Ecopath with Ecosim models included in this review.

| Model Focus | Location | Time Period | Source |
|---|---|---|---|
| Warm pool pelagic ecosystem | Pacific Ocean, western central, tropical | Variable, 1950–2001 | Godinot, 2002 |
| Warm pool pelagic ecosystem | Pacific Ocean, western central, tropical | Variable, 1950–2001 | Godinot, 2003 |
| Pelagic ecosystem | Pacific Ocean, western central, tropical | 1990–2001 | Godinot and Allain, 2003 |
| Trophic impacts; fishing and tuna dynamics | Pacific Ocean, central | 1990–1998 | Cox et al., 2002 |
| Pelagic ecosystem; commercial fishing and whaling | Pacific Ocean, central | 1990–1998 | Essington, 2006 |
| Sharks and longline fisheries | Pacific Ocean, central | 1990–1998 | Kitchell et al., 2002 |
| Pelagic ecosystem | Pacific Ocean, eastern tropical | 1993–1997 | Olson and Watters, 2003 |
| Geographic scale, climate, and trophic dynamics | Pacific Ocean, northeastern | 1950–2007 | Preikshot, 2007 |
| Small pelagic fishes, ecosystem | Pacific Ocean, western north | 2013 | Watari et al., 2019 |

## 2.1 GODINOT (2002, 2003)

Godinot (2002) designed and parameterized a preliminary Ecopath model of the most productive region in the western and central Pacific Ocean, the Warm Pool pelagic ecosystem (**Figure 1**). The model was created with the currently available data from other Pacific Ocean-based Ecopath models (e.g., Kitchell et al., 1999, 2002 for the central Pacific; Olson and Watters, 2003 for the tropical North Pacific) and also from the first results of the food web study (i.e., stomach analysis results) conducted specifically for this effort.

Several major weaknesses in the preliminary Ecopath model were identified by Godinot (2003), including the uncertainty associated with most parameters and diets. The authors noted that most species in the study area were poorly known, and that the model input parameters typically did not employ local data. This reliance on data from other regions led to a high level of uncertainty in the estimation of total biomass (B), production to biomass ratio (P/B), and consumption to biomass ratio (Q/B) values, as biological factors and abundance can vary strongly between regions.

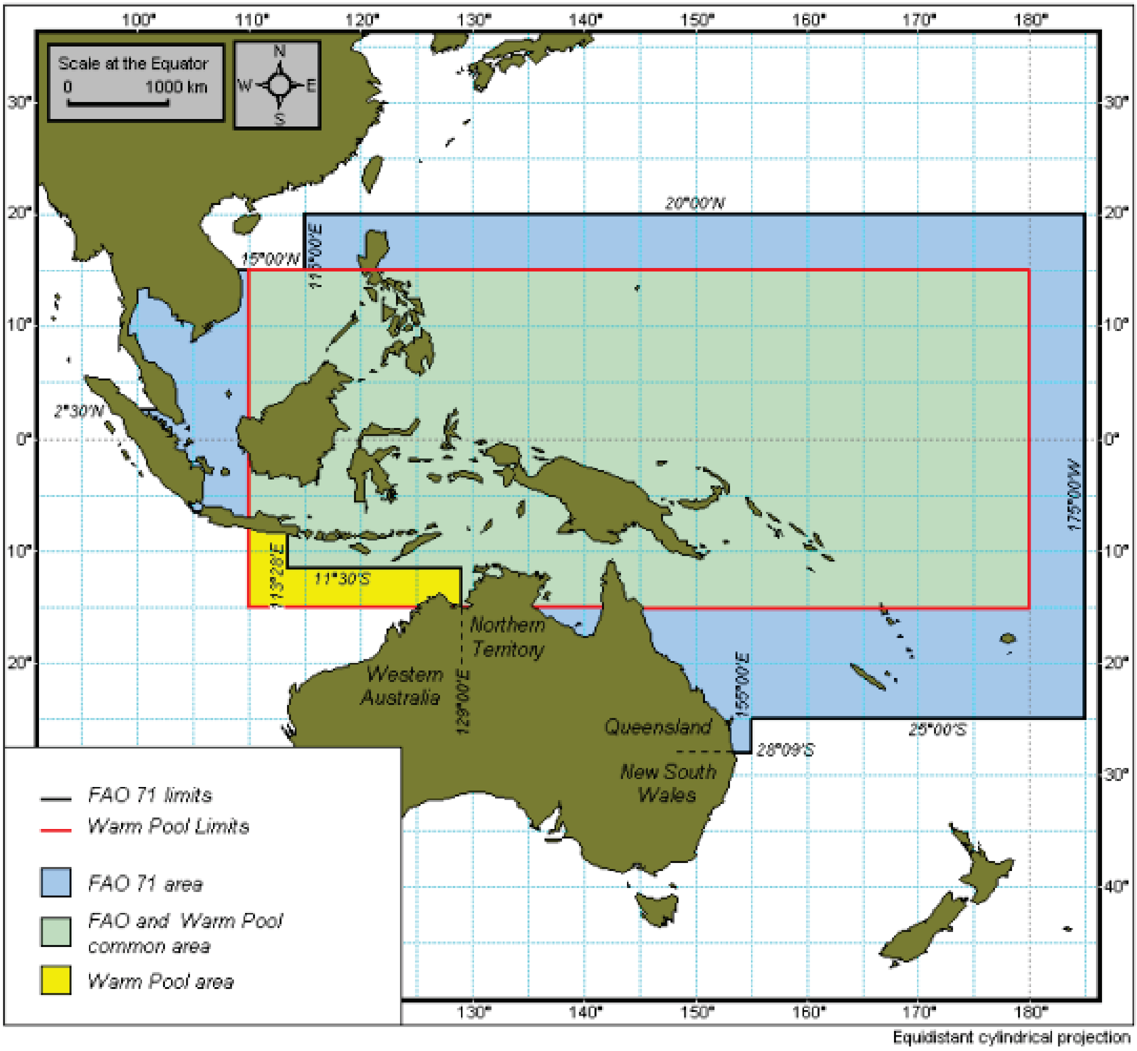


Figure 1. Location of the Warm Pool area studied by Godinot (2003, 2002) and Godinot and Allain (2003) during Ecopath modeling assessment (From: Ecopath, 2021).

The EwE results included 19 living groups, considered to be a relatively small number compared to other existing models. Key functional groups assessed included mesozooplankton, microzooplankton, large phytoplankton, small phytoplankton, and detritus. The limited number of groups assessed was based on the aggregation of several groups due to data gaps. Further, the authors noted that several groups were not included in the analysis due to a lack of data (e.g., whales, dolphins, marine birds, rays, skates, turtles). Other species such as bluefin tuna or albacore tuna were not included as they represent primarily temperate species. The authors noted that these groups may be present in relatively high numbers on a seasonal or permanent basis and should be included in future modeling efforts.

Godinot (2003) detailed improvements made to the preliminary model (Godinot, 2002) and also incorporated three Ecosim scenarios to test the model – doubling of fish mortality, a ±50% variation of phytoplankton biomass, and assessment of short-term variations (e.g., alternation of El Niño and La Niña phenomena). Uncertainties identified in the modeling conducted earlier by Godinot (2002) were addressed, including splitting the piscivorous fish group into four subgroups and significantly decreasing the uncertainty of the model. The distinction made between small and large phytoplankton was also a source of improvement, especially concerning diets. As a result a total of 19 living groups and one detritus group were assessed. Results indicated that four plankton groups constitute the basis of the ecosystem, whereas four micronekton groups represent the link between plankton and the 11 top predator groups: piscivorous fish, three groups of tunas, two groups of sharks, two groups of billfish and three groups of small size top predators (i.e., small scombrids, small sharks, small billfish).

Under the first modeling scenario, the doubling of fishing mortality resulted in a drastic biomass decrease for targeted species (i.e., tunas) as well as for bycatch species (sharks and billfish). Authors determined that top-down cascading effects were minor (i.e., the prey of top predators do not develop significantly). An alternate scenario, accounting for the biological links between different size-classes of the same predator (e.g., small and large swordfish), produced more moderate results concerning the biomass decrease of fished species, but similar results for non-fished species.

Results of the second scenario, where a 50% increase in phytoplankton biomass was modeled, resulted in an increase in biomass of all groups; alternately, a decrease of phytoplankton biomass had the opposite effect. Authors noted that 1) the top predators were more sensitive to a long-term change than other species; and 2) bottom-up cascading effects (i.e., from phytoplankton to top predators) were much more significant than top-down effects (i.e., from top predators to phytoplankton).

The third scenario, assessing the capacity of the model to react to short term variation in oceanographic parameters (i.e., alternation of El Niño and La Niña phenomena), resulted in 1) immediate reaction of zooplankton to climatic changes; and 2) sharks and billfish remained relatively unaffected by these fluctuations.

The second scenario could offer the most insight for The Ocean Cleanup which considers a ±50% variation of phytoplankton biomass. The model shows that a decrease in biomass results in a decrease in biomass of all other considered groups, highlighting that bottom-up cascading effects are much more significant than top-down effects (Godinot, 2003).

## 2.2 GODINOT AND ALLAIN (2003)

Godinot and Allain (2003) similarly designed and parameterized a preliminary Ecopath model of the Warm Pool pelagic ecosystem, the same study area used by Godinot (2002, 2003) (**Figure 1**). This study was made with currently available data, comprising other Pacific Ocean based Ecopath models and also with the first results of the food web study.

This model was built with a special interest in tuna; however, it is noted that the major weakness of this model is the uncertainty of most parameters and diets. The lack of local data required the use of data originating from other regions and as such, lead to uncertainty in the estimation of total biomass (B), production to biomass ratio (P/B), and consumption to biomass ratio (Q/B) values, as biological factors and abundance can vary strongly within the area.

The authors note that this model reveals little about the ecosystem that was not already known although it offers an easily accessible view of the system. Moreover, it provides a powerful tool to aggregate ecosystem data from different sources and represents a necessary framework for the refinement of input parameters so that a cohesive view of the whole marine ecosystem can emerge.

## 2.3 COX ET AL. (2002)

Cox et al. (2002) developed a multispecies model using the EwE software, incorporating time-series estimates of biomass, fishing mortality, and bycatch rates over a 46-year period (1952-1998) to evaluate the relative contributions of fishing and trophic impacts on tuna dynamics in the central Pacific (0°N to 40°N and 130°E to 150°W). The EwE model reproduced the observed trends in abundance indices and biomass estimates for most large tunas and billfishes.

A decline in predation mortality owing to depletion of large predators was greatest for small yellowfin tuna and could possibly account for apparent increases in biomass. For other tunas, however, predicted changes in predation mortality rates were small (small bigeye) or were overwhelmed by much larger increases in fishing mortality (skipjack and small albacore). Limited evidence of trophic impacts associated with declining apex predator abundance likely results from the difficulties of applying detailed trophic models to open ocean systems in which ecological and fishery data uncertainties are large.

The shortcomings of the Cox et al. (2002) approach (in a potential application to The Ocean Cleanup impact assessment) included the model's focus on predation as a component of natural mortality and the role of fishing mortality as a cause of changes in predation rates and abundance.

## 2.4 ESSINGTON (2006)

Essington (2006) utilized EwE to assess the role of apex predators as structuring agents in marine ecosystems, specifically assessing if whaling and fishing might have dramatically altered pelagic food webs. EwE was used to characterize contemporary food web structure and to reconstruct historical food web structure prior to the advent of industrial whaling and fishing. A total of 16 functional groups were employed in the model. The strategy for this modeling exercise was to specify the contemporary state of the food web in terms of biomass, productivity, consumption rates, food habits, and fisheries and to use this information to initialize a dynamic food web model. The dynamic food web model was then used to simulate the changes in food web structure that might be expected in a food web without whaling and fishing, with the intent to characterize what the pre-exploitation food web might have looked like.

The shortcomings of the Essington (2006) approach (in a potential application to The Ocean Cleanup impact assessment) included the model's historical focus on whaling and fishing.

## 2.5 KITCHELL ET AL. (2002)

Kitchell et al. (2002) employed EwE to evaluate changes in trophic interactions due to shark exploitation in the central North Pacific, investigating the potential ecosystem level effects of increased exploitation of pelagic sharks by longline fisheries and their effects upon local food webs. A total of 22 separate functional groups were modeled in the exercise, the vast majority of which were top predators (e.g., sharks, tunas). The authors determined that fisheries targeting blue sharks result in compensatory responses that favor other shark species and billfishes, with only modest effects on the majority of food web components. Modest levels of intraguild predation (i.e., where adult sharks eat juvenile sharks) produce strong, nonlinear responses in shark populations. In general, analysis of the central North Pacific model revealed that sharks are not keystone predators, but that increases in longline fisheries can have profound effects on the food webs that support various shark species.

The shortcomings of the Kitchell et al. (2002) approach (in a potential application to The Ocean Cleanup impact assessment) included the model's focus on pelagic sharks, with limited characterization of lower trophic groups, including an absence of neuston.

## 2.6 OLSON AND WATTERS (2003)

Olson and Watters (2003) modeled the pelagic ecosystem of the eastern tropical Pacific Ocean, addressing the need for a more holistic approach to fisheries management via use of a trophic mass-balance model of the ecosystem. The authors developed a model hypothesis of the pelagic ecosystem in the ETP to gain insight into the relationships among the various species in the system and to explore the ecological implications of alternative methods of harvesting tunas.

The six various biomass levels and fluxes between principal elements in the ecosystem were evaluated using Ecopath, allowing for an examination of the ETP ecosystem and its dynamic, time-series behavior using Ecosim. Olson and Watters (2003) parameterized the model using a total of 38 species or species groups. The authors described the sources, justifications, assumptions, and revisions of their estimates for various model parameters, diet relations, fisheries landings, and fisheries discards. Sensitivity analyses were also conducted with an intermediate version of the model, for both the Ecopath mass-balance and the dynamic trajectories predicted by Ecosim. Results of the analysis indicated that changes in the basic parameters for two components at middle trophic levels – cephalopods and *Auxis* spp., exert the greatest influence on the system. When the cephalopod Q/B and *Auxis* spp. P/B were altered from their initial values and the model was rebalanced, the trends of the biomass trajectories predicted by Ecosim were not sensitive, but the scaling was sensitive for several components.

The authors detailed the review process to which the model was subjected, including reviews by the several fishery-related expert groups. Using historical records, the authors fitted the model to historical time series of catches per unit of effort and mortality rates for yellowfin and bigeye tunas in simulations that incorporated historical fishing effort and a climate driver to represent the effect of El Niño-Southern Oscillation-scale variation on the system. Per Olson and Watters (2003), the model was designed to evaluate the possible ecological implications of fishing for tunas in various ways, noting the shortcomings associated with its use (i.e., the model cannot represent the overall complexity of a pelagic ocean ecosystem) are offset, to a certain extent, by its insight into the structure and function of the pelagic ETP.

The shortcomings of the Olson and Watters (2003) approach (in a potential application to The Ocean Cleanup impact assessment) included the model's focus on tunas, with limited characterization of lower trophic groups.

## 2.7 PREIKSHOT (2007)

Preikshot (2007) conducted dynamic simulation modeling of three nested North Pacific ecosystems – the Strait of Georgia, the British Columbia Shelf, and the Northeast Pacific. The purpose of the modeling and analysis was to assess how area scale affects modelled historic changes of trophic interactions, fisheries, and climate. Species groups were the same for all ecosystem models, with a focus upon commercially important fish species. The models were dynamic and spanned the period from 1950 to the start of the 21st Century. Time series data for biological indicators were compared to predicted model time series, under different scenarios of ecosystem control: top-down, bottom-up, or combinations thereof. Results suggested that while fisheries, and predation/competition effects explain most population changes for commercially important fish species, all species modelled also appear to experience bottom-up effects driven by climate change, and regime shifts. Results also suggested that such bottom-up dynamics may occur via predicted primary production anomalies similar to decadal cycling. Per Preikshot (2007), study findings indicate that both the area and scale over which indices of regime shifts and climate change are measured are linked, via bottom-up forcing, to changes in biomasses of all trophic levels in these ecosystems.

The shortcomings of the Preikshot (2007) approach (in a potential application to The Ocean Cleanup impact assessment) included the model's focus on fisheries, with limited characterization of lower trophic groups (i.e., zooplankton, phytoplankton).

### 2.8 WATARI ET AL. (2019)

Watari et al. (2019) recently conducted ecosystem modeling in the western North Pacific using Ecopath, focusing on small pelagic fishes (i.e., sardine, anchovy, mackerel), all of which are important commercial fish species in the region. Using a static, mass-balance Ecopath model, the authors focused on small pelagic fish species as an initial step in determining the role of these fishes in this ecosystem. Working in both coastal and offshore environments, the modeling exercise considered regional differences in bottom topography and oceanography and consisted of 41 functional groups, including endemics and migratory species.

Per Watari et al. (2019), the results of the analysis indicated comparable results to other ecosystems based on the L-index (i.e., the index of loss in secondary production due to fisheries exploitation) and the impact of fisheries targeting small pelagic fishes on the total production of this group. Both ecological indices indicate that the western North Pacific ecosystem is not overexploited.

The shortcomings of the Watari et al. (2019) approach (in a potential application to The Ocean Cleanup impact assessment) included the model's focus on small pelagic fishes, with limited characterization of lower trophic groups. Watari et al. (2019) also conducted a comparison of two coastal and one offshore environment; only the offshore component would be applicable to The Ocean Cleanup's current effort.

## 3.0 Applicability to The Ocean Cleanup

To address the potential applicability of the EwE modeling approach to the neuston impact issue in the NPSG region where The Ocean Cleanup is conducting plastic removal operations, it is necessary to summarize the basic EwE parameters required to run the model, to assess the available information being collected in the NPSG by The Ocean Cleanup to support EwE, to determine if it possible to define the complex trophic relationships in the open ocean environment of the NPSG, and to determine EwE feasibility. Each of these topics are addressed in the following discussion.

### 3.1 BASIC EwE PARAMETERS

The following discussion has been derived from Godinot and Allain (2003), supplemented with text and supporting documentation specific to The Ocean Cleanup.

The ecosystem is described using functional groups that can either be made of single species or gather several species with similar characteristics (e.g., filter feeders, marine mammals, small invertebrates).

For potential application to The Ocean Cleanup and its plastic removal operations in the NPSG region, characterization of the entire neuston ecosystem is of interest, with the intent of understanding how the removal of a portion of that ecosystem – neuston found in direct association with floating plastic – will affect overall ecosystem function.

Every group must satisfy two equations. The first equation describes the production term, assuming mass-balance:

$$P_i = Y_i + B_i * M2_i + E_i + BA_i + P_i * (1-EE_i)$$

The notations and units of Ecopath's primary equation are:

- $P_i$: production rate of group i, defined as body mass increase, in units of tons Wet Mass $km^{-2}$ $year^{-1}$ (i.e., tWM $km^{-1}$ $year^{-1}$);
- $Y_i$: fishery catch rate for this group ($year^{-1}$);
- $B_i$: biomass of the group averaged on one year (tWM $km^{-2}$);
- $M2_i$: predation mortality ($year^{-1}$);
- $E_i$: net migration rate (emigration – immigration) (tWM $km^{-2}$ $year^{-1}$);
- $BA_i$: biomass accumulation (or depletion) rate: set to zero by default, used if a group's biomass is not in equilibrium (tWM $km^{-2}$ $year^{-1}$);
- $P_i * (1-EE_i) = M_0$: other mortality rate ($year^{-1}$); and
- $EE_i$: ecotrophic efficiency that can be described as the proportion of the production that is utilized in the system (dimensionless, fraction of 1).

Use of the Ecopath model requires the input of three of the following four parameters **for each of the groups** which comprise the model simulation:

- total biomass, B (tWM $km^{-2}$);
- production to biomass ratio, P/B, equivalent to total mortality (Allen, 1971) ($year^{-1}$);
- consumption to biomass ratio, Q/B ($year^{-1}$); and
- ecotrophic efficiency, EE (fraction of 1).

Ecotrophic efficiency can be generated by the model if EE data are missing, based on the assumption of mass balance. When the four parameters are provided, the equilibrium will be reached using biomass accumulation or depletion (BA).

The Ecopath portion of the model employs a mathematically-based mass balance approach, while the Ecosim component allows for time-dynamic modeling based on the result of Ecopath (Murase et al., 2016). Secondary equations, not provided here, are utilized in the complete EwE exercise. Per Godinot and Allain (2003), the construction of an Ecopath model requires several parameters for each defined species or group including, per terms of the EwE model, 1) B; 2) P; 3) Q; 4) EE; 5) diet estimate; and 6) catch. The final term, catch, was of specific interest and applicability to the Godinot and Allain (2003) assessment. Adjustment of terms will be necessary for any EwE efforts to be conducted for The Ocean Cleanup.

Two types of data are routinely used in EwE modeling efforts: local data from the area of interest, and regional or proxy data. Because Godinot and Allain (2003) were focusing on fish stocks, their local data sources included 1) catch data (as compiled by various fishing groups), 2) other model outputs (e.g., Multifan-CL, a length-based, age-structured statistical model) which provide biomass estimates, and 3) natural and fishing mortality for the main commercial species of the area of interest.

For The Ocean Cleanup, the fundamental approach to EwE could potentially be based on trophic structure characterization. According to Albuquerque et al. (2021), the neuston of open ocean ecosystems occupies a delimited ecological niche and is generally grouped into three ecological categories:

- Euneuston: organisms with maximum abundance in the vicinity of the surface on which they reside day and night;
- Facultative neuston: organisms concentrating at the surface only during certain hours of the day, usually during darkness; and
- Pseudoneuston: organisms with maximum concentrations at deeper layers but reaching the surface layer at least during certain hours (Marshall and Burchardt, 2005).

This approach is slightly different from the neuston structure outline by Marshall and Gladyshev (2009) and Goldstein (2012):

- Epineuston: organisms that live on the water's surface and are exposed to air;
- Hyponeuston: organisms that live on the underside of the surface layer;
- Metaneuston or Exopleuston: organisms that occupy space both above and below the water (e.g., siphonophore *Physalia physalis*);
- Euhyponeuston: organisms that are associated with the surface film for their entire life cycle;
- Planktohyponeuston: organisms that vertically migrate; and
- Merohyponeuston or Endopleuston: organisms that inhabit this space for only a portion of their lives.

The structure of the neustonic community is affected by ambient solar radiation, endogenous factors (i.e., organic matter, respiratory, photosynthetic, decompositional processes), and exogenous factors (i.e., atmospheric deposition, inorganic matter, winds, wave action, precipitation, ultraviolet radiation, oceanic currents, surface temperature), as well as variables and processes affecting nutrient inputs and recycling (Marshall and Burchardt, 2005; Rawlinson et al., 2005; Rezai et al., 2019).

Hempel and Weikert (1972) determined that the neuston provides a food source to the zooplankton migrating from deeper layers to the surface. Other open ocean communities also utilize the neuston (e.g., seabirds; Cheng et al., 2010). The neustonic community is believed to play a critical role on the structure and function of marine food webs (Albuquerque et al., 2021).

## 3.2 TROPHIC RELATIONSHIPS IN AN OPEN OCEAN ENVIRONMENT

A series of published research is available for the North Pacific, including assessments of the linkages between the planktonic ecosystem and fisheries for a pelagic ecosystem in the subarctic Pacific (Kearney et al., 2012), evaluation of trophic structure of food webs in the Pacific Ocean using mercury contamination as a tracer (Ferris and Essington, 2014), pelagic food web connectivity using multiple biochemical tracers and diet in the NPSG (Choy, 2013), and physical forcing and the dynamics of the pelagic ecosystem in the eastern tropical Pacific (Watters et al., 2003). Outside the North Pacific region, other studies have compared community and trophic structure between five marine ecosystems based on energy budgets and system metrics (Gaichas et al., 2009). However, a detailed food web for the NPSG region has yet to be developed.

Focused analyses of the neuston community in the NPSG are limited, with minor exception. In their assessment of neuston across 11 separate marine regions, including the North Pacific, Albuquerque et al. (2021) argue that stable isotope analysis may be a useful tool to delineate food web structure and to identify the relative trophic position of species, drawing upon the work of earlier researchers in quantifying carbon, nitrogen, and energy fluxes and characterizing trophic niches (e.g., Fry, 2006; Bouillon et al., 2011; Middelburg, 2014). Key findings include: 1) stable isotopes undergo a predictable trophic enrichment between prey and consumer and reflect a species diet over a considerable period of time; 2) ratios of carbon isotopes (δ13C) generally have a low trophic enrichment and are commonly used to identify carbon sources, while nitrogen isotope ratios (δ15N) show progressive enrichment between prey and consumers and can be used to estimate trophic positions; and 3) by measuring the ratios of δ13C and δ15N, it is possible to infer the trophic structure of marine food webs.

Albuquerque et al. (2021) concluded that omnivory is an important characteristic of pelagic food webs, particularly in oligotrophic regions of the world's oceans. Flexibility (termed "plasticity") in feeding preferences increases trophic connectivity as well as ecosystem resilience and stability. However, such flexibility in feeding preference complicates the development of a simplified food web for the NPSG.

The authors conclude that further studies are required to explore additional neuston feeding groups and/or taxonomic diversity, to evaluate temporal variability, and to estimate neuston biomass, all of which are required to better characterize the trophic structure of the neuston.

## 3.3 DATA ACQUIRED BY THE OCEAN CLEANUP

The Ocean Cleanup has performed a variety of sampling and monitoring efforts in the NPSG during 2021 and 2022, obtaining an extensive data set regarding the plankton and neuston communities of the region as well as observations of marine mammals, sea turtles, and birds, and collections of fish communities associated with floating plastics while testing 3. Plankton and neuston sampling has included bongo, manta, and plankton net sampling. Based on sampling efforts completed during Campaigns 1 through 3, more than 100 net samples were acquired and organisms identified. EIA **Sections 2.0** and **4.3.1.6** summarize the results of these collections. The Ocean Cleanup plans on continuing its sampling efforts during all future Campaigns and will subsequently identify organisms collected and observed.

Results of bongo, manta, and plankton sampling indicate that the plankton and neuston communities present in the NPSG are diverse, represented by both attached and free swimming species dominated by calanoid copepods, chaetognaths, tunicates, and appendicularians, with minor contributions from a variety of other taxa (e.g., hyperiid amphipods, mysids, bryozoans, invertebrate egg cases, euphausiids, pteropods, hydrozoans). Comprehensive taxonomic identification and enumeration of plankton and neuston, using samples acquired by The Ocean Cleanup, is a fundamental step in establishing an appropriate trophic structure for plankton and neuston in the EwE approach to modeling the NPSG. Understanding the spatial distribution and temporal variability of these communities within the NPSG, as well as differentiation between floating plastic-associated and free swimming taxa, are also important caveats in EwE modeling and interpretation of modeling results.

In addition to plankton and neuston collections, observations by protected species observers (PSOs) have been documented for marine mammals (EIA **Section 4.3.4**), sea turtles (EIA **Section 4.3.5**), and birds (EIA **Section 4.6.6.2**), as well as fish observed with underwater cameras and from system bycatch during plastic extraction (EIA **Section 4.3.3.2**). Delineation of the trophic level(s) for each of these respective resources will also be important to future EwE modeling efforts.

### 3.4 EwE FEASIBILITY

The potential for development of an EwE model specific to the NPSG appears to be a viable means of assessing the potential effects of the removal of a portion of the neuston on ecosystem dynamics. The most appropriate EwE candidate appears to be Godinot and Allain (2003), with further development of a simplified food web diagram, an example of which is provided in **Figure 2**.

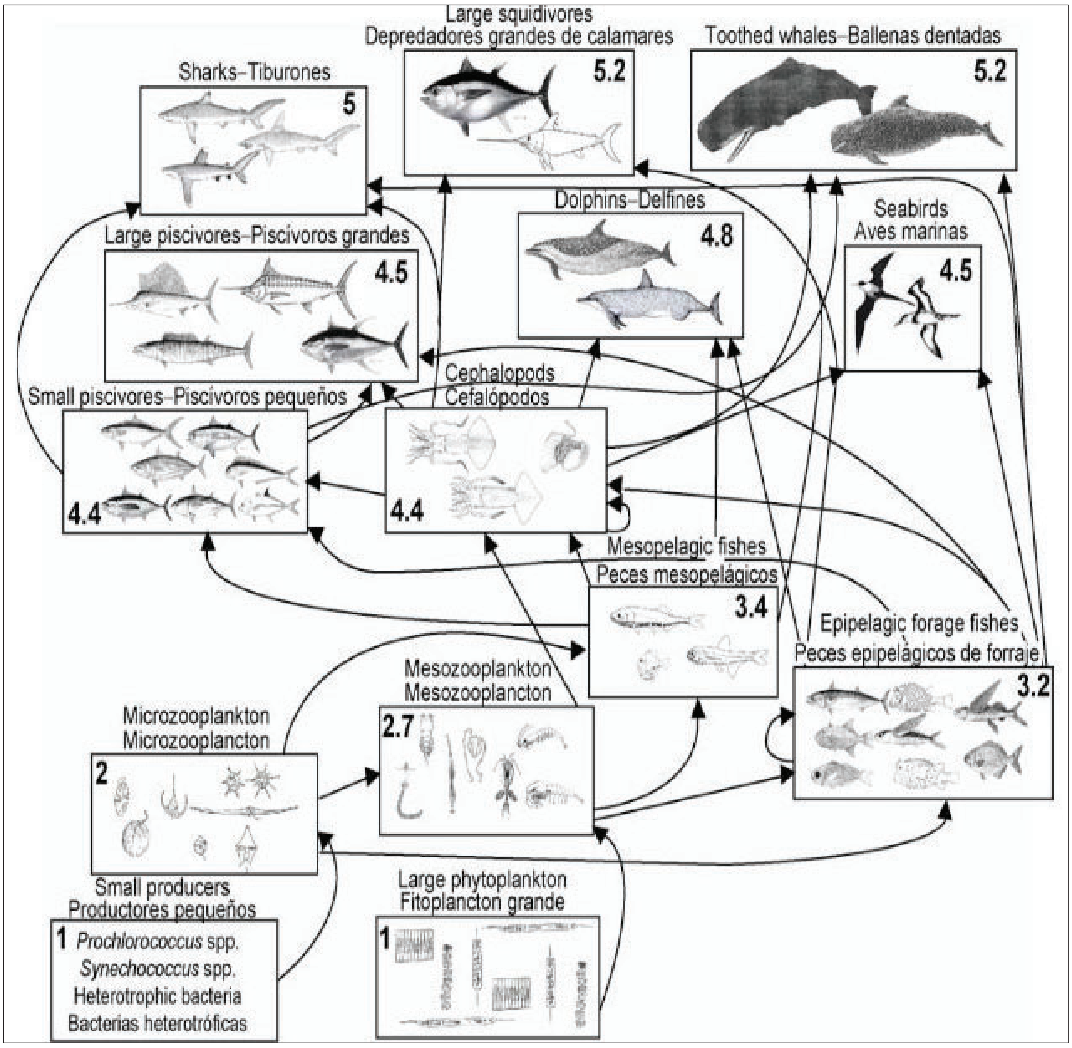


Figure 2. Simplified food web diagram as applied to the Ecopath model of the eastern Pacific pelagic ecosystem, as developed by Olson and Watters (2003). Numbers shown in each ecosystem component represent the assigned trophic level.

Our recommendation is for The Ocean Cleanup to continue to consider EwE development for this purpose. A moderate level of effort is anticipated, including 1) use of existing EwE model data, the latter of which have focused on various fish species (e.g., highly migratory fish, pelagics) as a historical reference; 2) characterizing the trophic structure of the pelagic ecosystem based on region-specific published information; 3) supplementing region-specific species lists with any additional data (or models) acquired by The Ocean Cleanup or others, including the other Pacific Ocean pelagic models reviewed in this analysis; and 4) review and potential integration of data from applicable scientific research studies in order to develop and parameterize a model more fit to The Ocean Cleanup project needs. Several versions of an Ecopath model may be required to define a range of potential ecosystem responses including such factors as the potential breadth that plastic feeding preferences may have on the neuston community. To meet these recommendations, it is suggested that the next steps involve 1) one or more neuston experts familiar with the NPSG; and 2) one or more EwE/Ecopath experts or practitioners. Model input parameters could be validated by the neuston expert(s), while trophic structure and Ecopath modeling runs could be critically reviewed, with model shortcomings, caveats, and assumptions clearly stated.

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