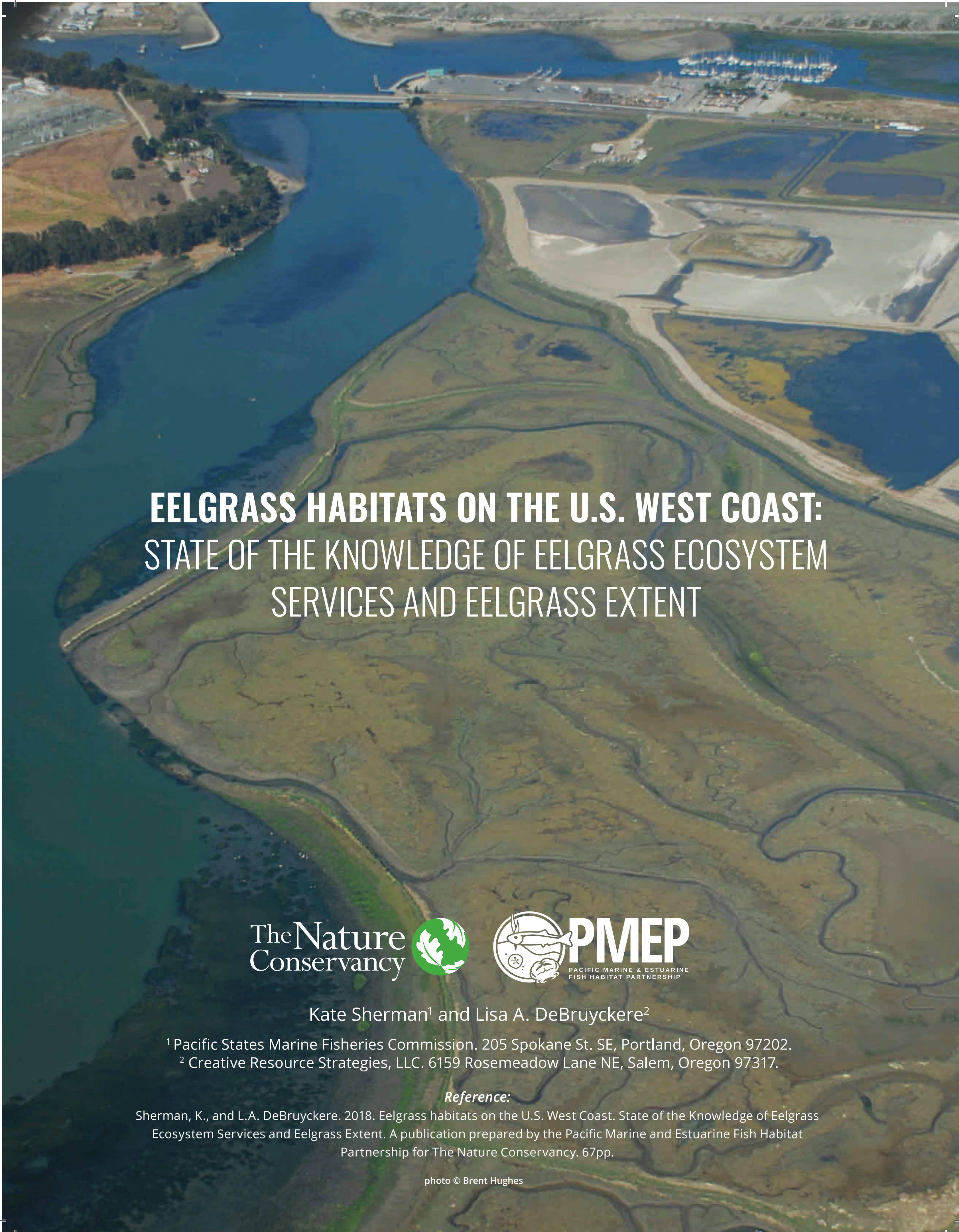

EELGRASS HABITATS ON THE U.S. WEST COAST:
STATE OF THE KNOWLEDGE OF EELGRASS ECOSYSTEM SERVICES AND EELGRASS EXTENT

The Nature Conservancy

PMEP
PACIFIC MARINE & ESTUARINE FISH HABITAT PARTNERSHIP

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EXECUTIVE SUMMARY

Eelgrass, a type of marine flowering plant, can serve as a biological indicator of ecosystem health and is threatened by numerous human activities. Eelgrass populations along the U.S. West Coast are genetically unique; therefore, conservation and restoration of these habitats should be guided by information gained from these populations. This report was commissioned by The Nature Conservancy to provide a synthesis of the state of scientific knowledge of U.S. West Coast estuary eelgrass habitats and the ecosystem services they provide. The Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) synthesized the literature relevant for the U.S. West Coast and standardized existing geospatial data on the current and historic extent of eelgrass for *Zostera spp*. We investigated the role of 444 U.S. West Coast estuaries in providing eelgrass habitat and compiled our findings in a geodatabase. This report synthesizes information on: 1) Presence and extent of eelgrass along the U.S. West Coast, 2) Ecosystem services provided by eelgrass habitats, 3) Important and emerging threats to eelgrass habitats in U.S. West Coast estuaries, 4) Knowledge and data gaps, and 5) Management strategies to conserve and restore eelgrass habitats and their ecosystem functions along the U.S. West Coast.

To compile information on extent of eelgrass *(Zostera spp.)* and services provided by eelgrass, we reviewed nearly 550 peer-reviewed articles and reports and consulted with U.S. West Coast eelgrass experts (see acknowledgements). To avoid duplicating prior efforts, we relied on summary or synthesis documents when available, and then expanded on them, using more focused references that were associated with the goals of this report.

A companion geodatabase of eelgrass data was also compiled illustrating presence/absence and, where able, current and historic extent of eelgrass in 444 estuaries along the U.S. West Coast. This information was organized into four ecoregions: (1) Salish Sea, (2) Washington, Oregon, Northern California Coast, (3) Central California, and (4) Southern California Bight. These regions and designations align with boundaries used by PMEP and the Pacific Fisheries Management Council as well as The Nature Conservancy's Marine Ecoregions of the World. Data collection relied on a data call; no new field studies were conducted for this project. To view the data online visit http://www.pacificfishhabitat.org/data/.

Overall, we found that eelgrass occurs in 162 (36 percent) of 444 U.S. West Coast estuaries. A total of 24 percent of the 444 estuaries either did not have eelgrass or were not suitable for eelgrass. The remaining 40 percent of the estuaries had no eelgrass data. We documented current or historic presence of eelgrass in the following ecoregions:

- Salish Sea ecoregion—98 of 166 estuaries.

- Washington/Oregon/Northern California Coastal ecoregion—24 of 110 estuaries.
- Central California coast ecoregion—18 of 107 estuaries as well as areas of the nearshore from Monterey Bay southward.
- Southern California Bight—22 of 61 estuaries and throughout the mainland nearshore and the Channel Islands.

Summary information on presence by ecoregion is provided in the table below.

Although this report builds on past efforts to summarize coastwide extent of eelgrass, we remain limited in the ways we can accurately use this information for regional analysis. Data collection dates, methods for data collection, and data post-processing methods vary across estuaries and datasets, making it challenging to compare data across the U.S. West Coast. Although we can more easily determine presence/absence of eelgrass from existing data, determining adequate eelgrass extent is limited by lack of data. Limited monitoring on the extent of eelgrass (using a consistent methodology) makes it difficult to quantitatively measure eelgrass habitat loss. As a result, identifying and monitoring specific threats to eelgrass habitat is challenging on a coastwide scale.

Numerous reports document existing and emerging threats to eelgrass. We identified 19 threats specific to the U.S. West Coast. Four were identified in all four ecoregions: increased sedimentation, coastal development, sea level rise, and sea temperature changes. Previous reviews of ecosystem service values of eelgrass beds have focused on a particular estuary or a specific service. This report details the information provided in the literature based on four ecosystem service categories — supporting, regulating, provisioning, and cultural and amenity services. For all ecosystem services reviewed, a key challenge remains that few studies capture the value of these services quantitatively.

Based on our findings, we recommend the following management strategies to conserve and restore eelgrass habitats and their ecosystem functions:

Ecoregion	Salish Sea	Washington, Oregon, Northern California	Central California	Southern California Bight
Estuaries with eelgrass present (%)	59%	21%	17%	36%
Estuaries with eelgrass absent/unsuitable habitat (%)	6%	17%	39%	49%
Estuaries with no data (%)	35%	50%	44%	15%
Nearshore eelgrass?	Present	NA	Present	Present
Species present	*Zostera marina, Zostera japonica*	*Zostera marina, Zostera japonica*	*Zostera marina*	*Zostera marina, Zostera pacifica* (Channel Islands, nearshore mainland)
Depth range	Eelgrass (both *Zostera marina* and *Zostera japonica*): -11m to +1.4m MLLW	*Zostera marina*: -2.1m to +2.1m MLLW; *Zostera japonica*: +1.5m to +1.8m MLLW	*Zostera marina*: -4m to 0.4m MLLW	*Zostera marina* (in estuaries): -3.7 to +0.1m MLLW; *Zostera marina* (in nearshore of Channel Islands and mainland): -22m to -3m MLLW
Eelgrass extent data availability	Well documented extent throughout Salish Sea	Limited extent data	Well documented extent for a few estuaries, Limited extent data for many estuaries	Well documented extent for a few estuaries, limited extent data for many estuaries
Other eelgrass data	Well documented (Shorezone, WDFW Herring Spawning Surveys, SeagrassNet)	Shorezone (Washington and Oregon only)	NOAA ESI	NOAA ESI

Use more standardized approaches to data collection to enhance our knowledge of ecosystem service values of eelgrass habitats along the U.S. West Coast.

- Develop a regionally appropriate suite of methods that will best measure the extent of eelgrass meadows, monitor the depth range and scale, and process data consistently, which will help improve our understanding of long-term changes in extent of eelgrass across the U.S. West Coast.
- The U.S. West Coast fish and habitat science community should engage in conversation, through a focused workshop, about the best available data collection techniques to develop another suite of methods, based on species, season, and life stage of fish, and how they can be sampled efficiently across different habitat types to better understand quantitative ecosystem service values of different habitat types.

Consider the entire estuarine and nearshore landscape when managing resources and planning for restoration. Efforts should consider historic evidence of habitats; the potential for threats, both localized and long-term climate change considerations; the structure of the habitat; and the desired ecosystem service values in a restored area.

- Incorporate public outreach about the value of eelgrass ecosystem services into future management strategies to help reduce local threats through increased conservation and restoration initiatives.

This report serves as a summary of existing knowledge and identifies gaps in that knowledge and understanding of this important habitat type and associated threats. This information can serve as a guide for future research on U.S. West Coast eelgrass habitats and the ecosystem services and functions they provide.

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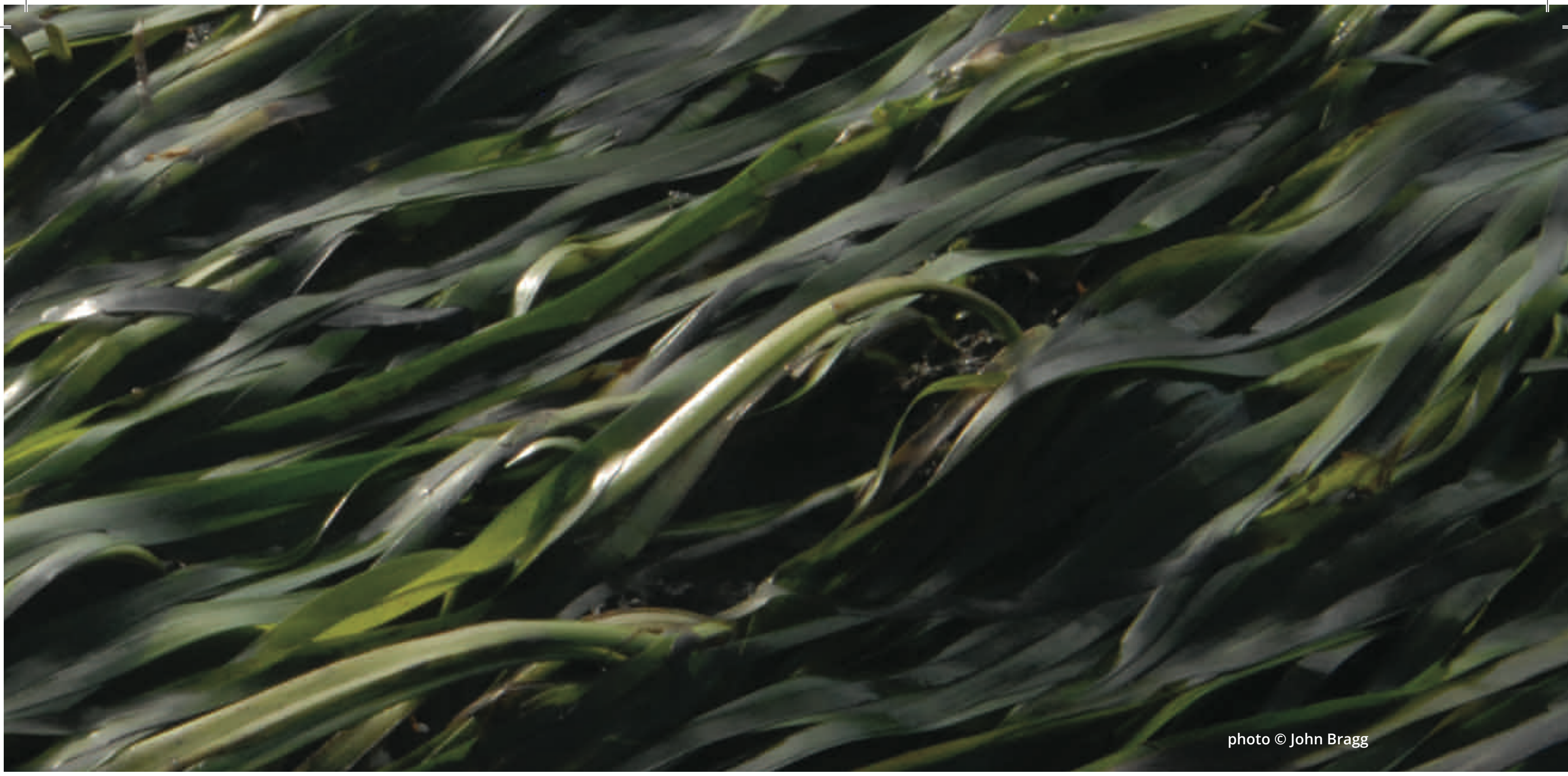

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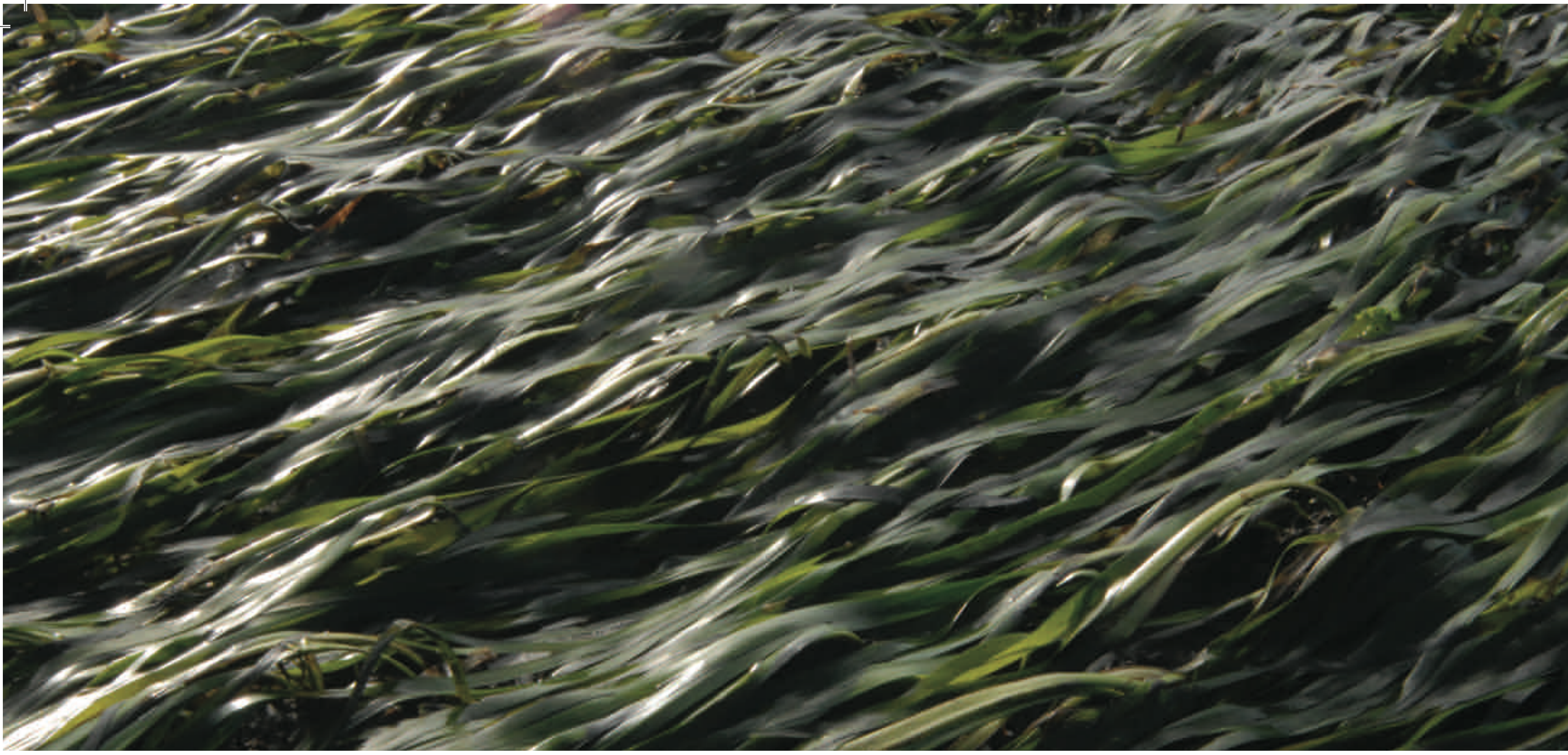

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BACKGROUND AND PROJECT OVERVIEW

BACKGROUND

Seagrass meadows include a group of subtidal and intertidal flowering plants that are widespread throughout coastal and estuarine environments worldwide (Moore and Short 2006; Orth et al. 2006; Cullen-Unsworth and Unsworth 2013). Seagrass meadows provide a variety of important ecological functions and ecosystem services, including supporting primary production and nutrient cycling (Larkum, Orth, and Duarte 2006); protecting shoreline and stabilizing sediment (Hansen and Reidenbach 2012); providing habitat for commercially, recreationally, and ecologically important species (Duarte 2002); mitigating ocean acidification (Fourqurean et al. 2012); improving water quality (Gacia, Granata, and Duarte 1999); and supporting cross-boundary trophic subsidies to other marine ecosystems (Beck et al. 2001). Despite the well-documented importance of seagrass habitat in marine ecosystems, there is growing evidence of worldwide decline caused by both direct and indirect human disturbances, such as physical alteration of habitats and deteriorating water quality (Duarte 2002). Seagrass habitats are also experiencing threats from large-scale climactic influences, such as ocean and atmospheric temperature increases, as well as sea level rise (Orth et al. 2006).

Eelgrass *(Zostera spp.)* is the most common and widespread seagrass taxon in estuaries and embayments along the U.S. West Coast , and is found worldwide in temperate zones in soft-bottom habitats within sheltered bays and estuaries (Phillips 1984). Along the U.S. West Coast, eelgrass occurs from Alaska to Baja California (California Department of Fish and Wildlife 2008). There are three species of *Zostera: Z. marina L.,* commonly known as eelgrass; *Z. japonica*, commonly known as dwarf eelgrass, or Japanese eelgrass; and *Z. pacifica*, wide-leaved eelgrass. *Z. marina* and *Z. pacifica* are native to the U.S West Coast, whereas *Z. japonica* is introduced. For the purposes of this report, we will refer only to the most commonly studied and mapped of the three species, *Z. marina*, and will note literature and data on the other species when information is available.

Eelgrass, similar to other seagrasses, is considered to be a "foundation" or habitat forming species because it creates a highly structured habitat in areas of loose sand or silt (Ort et al. 2014; Thom, Southard, and Borde 2014) and supports key ecological functions in coastal and estuarine ecosystems (Nordlund et al. 2016). Eelgrass meadows are recognized globally as nursery areas for many taxa, and are considered one of the most important juvenile habitats for numerous fish species (Short et al. 2000; Heck, Hays, and Orth 2003;

Thom et al. 2003; Larkum, Orth, and Duarte 2006). Eelgrass is considered an ecologically and economically important group of aquatic plants in the United States and can serve as a biological indicator of ecosystem health (Larkum, Orth, and Duarte 2006; Puget Sound Partnership 2015). By providing habitat, nourishment, and spawning areas for fish and invertebrates as well as stabilizing sediments and improving water quality, eelgrass meadows play several important roles in coastal and estuarine ecosystems (Goodman, Moore, and Dennison 1995; Larkum, Orth, and Duarte 2006).

During the last 40 years, federal, regional, and state conservation targets and environmental legislation have helped protect eelgrass habitats along the U.S. West Coast. At the federal level, the Clean Water Act 404(b)(1) (40 CFR 230) (1972) gives the U.S. Environmental Protection Agency authority to regulate waste discharge in the waters of the United States and requires minimizing or avoiding impact to special aquatic sites, including vegetated shallows that support eelgrass. Via the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (M-SA), federal agencies are required to consult with National Oceanic and Atmospheric Administration (NOAA) Fisheries on the effects of authorized actions on essential fish habitat (EFH), including measures that can be taken to avoid or minimize adverse impacts to eelgrass. Eelgrass habitat is also considered a habitat area of particular concern (HAPC) for various federally managed fish species within the Pacific Coast Groundfish Fishery Management Plan (FMP) (Pacific Fishery Management Council 2016). This designation helps focus consultations and alert action agencies to the need to avoid impacts where possible.

At the state level, many agencies have undertaken steps to conserve and enhance eelgrass habitats. For example, the Washington Department of Natural Resources (WA DNR) facilitated development of a multi-agency strategy for protection and restoration of eelgrass (Washington Department of Natural Resources 2015). In the State of Washington, eelgrass is considered to be a vital sign of Puget Sound ecological health (Puget Sound Partnership 2015). As part of a recovery strategy, Puget Sound Partnership set a management goal of a 20 percent increase in eelgrass area by 2020 (Puget Sound Partnership 2014). The Washington State Department of Fish and Wildlife (WDFW) designated seagrass meadows as habitats of special concern (WAC 220-110-250) via its statutory authority relating to construction projects in state waters (RCW 77.55.021). Similarly, the Washington State Department of Ecology (WDOE) designated eelgrass areas as critical habitat (WAC 173-26-221) via its statutory authority associated with implementing the state's Shoreline Management Act (RCW 90.58).

In Oregon, protection and management of eelgrass is structured within the Statewide Planning Goal 16 for Estuarine Resources (OAR 660-015-0010(1)). This goal requires inventorying significant fish and wildlife habitats, such as seagrass, as well as documenting and reviewing all projects that may affect eelgrass habitats.

In California, eelgrass impact and mitigation guidance is primarily structured within the California Eelgrass Mitigation Policy (CEMP) (Region 2014). Several California state agencies use the CEMP framework to establish standards and guidelines for eelgrass management. NOAA Fisheries adopted the CEMP and implementing guidelines, including the goal of "no net loss" of eelgrass habitats in California (Gilkerson and Merkel 2014). The CEMP guidelines and standards also include creating or restoring 20 percent more eelgrass habitat than was previous eliminated as part of mitigation efforts. Prior to the adoption of the CEMP, the Southern CEMP (1991) helped ensure eelgrass impacts were mitigated in most circumstances in Southern and Central California (Region 2014).

Despite various levels of protection within the waters of U.S. West Coast states, eelgrass systems and the ecosystem services they provide are threatened by numerous human activities, such as land runoff and eutrophication, dredging, boat grounding and anchoring, introduction of non-native species, construction of overwater structures, and aquaculture (Duarte 2002; Thom et al. 2011; Cullen-Unsworth and Unsworth 2013). Eelgrass grows in a narrow depth range, thus global climate change and associated sea level rise is predicted to negatively influence eelgrass habitats (Orth et al. 2006).

Much remains to be learned relative to the science of restoration and mitigation of eelgrass habitats (Thom, Southard, and Borde 2014). Documenting the factors that negatively affect eelgrass ecosystems as well as those that enhance eelgrass habitat, is both difficult and challenging (Short et al. 2000; Duarte 2002; Thom, Southard, and Borde 2003). Using historical records and monitoring data to track changes to eelgrass habitat is a helpful tool. Monitoring change in eelgrass habitats through consistent sampling methodology is crucial to evaluating causes of decline and factors contributing to success of restoration efforts (Boyer and Wyllie-Echeverria 2010; Thom, Southard, and Borde 2014; Washington Department of Natural Resources 2015).

Efforts to synthesize existing spatial data on the extent of eelgrass along the U.S. West Coast has occurred at national and regional scales. These efforts include a coastwide review in 2004 that included all seagrass species found along the U.S. West Coast (National Oceanic and Atmospheric Administration 2004). The 2004 effort was based on available data and did not distinguish among eelgrass and other seagrass species. A national effort in 2015 resulted in the compilation of eelgrass datasets that were already publicly available through state and federal agencies (BOEM 2015), however, this effort did not consistently extract accurate eelgrass extent information. The effort presented here in this report greatly expands our understanding of the coastwide current and historic extent of eelgrass along the U.S. West Coast by compiling both literature and data on eelgrass presence and absence in 444 estuaries, including incorporating nearshore eelgrass meadows.

This report was commissioned by The Nature Conservancy and developed by the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) to provide a synthesis of the state of scientific knowledge for eelgrass habitats in U.S. West Coast estuaries and the ecosystem services they provide. We were graciously helped in our efforts by hundreds of scientists and managers on the U.S. West Coast, who contributed their knowledge and/or data.

Eelgrass populations along the U.S. West Coast have a unique genetic and demographic history compared to populations of eelgrass from other regions (Wyllie-Echeverria, Olson and Hershman 1994), therefore, conservation and restoration of these habitats should be guided by information obtained from these particular populations. We summarized current knowledge of ecosystem services of eelgrass, synthesized the literature, and standardized existing geospatial data on the current and historic extent of eelgrass for *Zostera spp*. on the U.S. West Coast. We investigated the role of 444 U.S. West Coast estuaries in providing eelgrass habitat by compiling, in a geodatabase, information on presence and absence of eelgrass as well as areas unsuitable for eelgrass. Information was obtained from the literature, existing data sources, personal communications with scientists monitoring eelgrass in estuaries, and other local experts. The estuaries included in the geodatabase derive from a PMEP effort to create a comprehensive inventory and modeling of current and historic tidal wetlands in Washington, Oregon, and California (Pacific Marine and Estuarine Fish Habitat Partnership 2017). We also synthesized information on: 1) important and emerging threats to eelgrass habitats in U.S. West Coast estuaries, 2) knowledge and data gaps, 3) considerations to help fill data gaps, and 4) management strategies to conserve and restore eelgrass habitats and their ecosystem functions along the U.S. West Coast.

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METHODS

LITERATURE REVIEW, DATA CALL, AND OUTREACH TO EXPERTS

To compile information on the current and historic extent of eelgrass *(Zostera spp.)* and habitat as well as ecosystem services provided by eelgrass, we reviewed nearly 550 peer-reviewed articles and reports and consulted with U.S. West Coast eelgrass experts.

Information from the literature on ecosystem service values of eelgrass habitat was assembled by category of services (provisioning, regulating, cultural and supporting ecosystem services) based on the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005). To create a state of the knowledge, we extracted information on ecosystem services of eelgrass, and summarized information specific to the U.S. West Coast. To avoid duplicating prior efforts, we relied on summary or synthesis documents when available, and then expanded on them using more focused references that were associated with the goals of this report.

We assembled data and literature describing current and historic extent of eelgrass along the contiguous U.S. West Coast. This information was organized into four U.S. West Coast Ecoregions: (1) Salish Sea, (2) Washington, Oregon, Northern California Coast, (3) Central California, and (4) Southern California Bight (Figure 1). These regions and designations align with boundaries used by PMEP and the Pacific Fisheries Management Council as well as The Nature Conservancy's Marine Ecoregions of the World.

Additionally, we hosted a total of eight webinars with regional experts to inform our outcomes:

- February 13, 2017: Project initiation (public)
- February 14, 2017: Eelgrass data call and survey review (PMEP Science and Data Committee)
- June 12, 2017: Methods (PMEP Science and Data Committee)
- July 19, 2017: Ecosystem services and threats (regional experts)
- July 26, 2017: Data (regional experts)
- October 23–25, 2017: (In-person PMEP meeting and review of report outline)
- January 24, 2018: Science and Data Committee call, review draft report)
- January 31, 2018: Project conclusion (public)

In total, nearly 200 members of the public attended the project initiation and project conclusion webinars, 30 regional experts participated in targeted review

FIGURE 1. The four U.S West Coast ecoregions.

webinars, and 12 members of PMEP's Science and Data Committee participated in review of materials and results throughout the project. Attendees and invitees unable to participate in the webinars were contacted via email to solicit feedback on data and literature summaries. All feedback gathered from the webinars and surveys were evaluated and incorporated in report tables and text.

GEODATABASE OF EELGRASS PRESENCE AND EXTENT

Eelgrass Presence

We summarized and georeferenced the available data and literature on the extent of eelgrass habitat in 444 estuaries along the contiguous U.S. West Coast. The geodatabase of 444 estuaries (including current and historic extent) was developed by the NOAA Northwest Fisheries Science Center, the Pacific States Marine Fisheries Commission, the Oregon Coastal Management Program, and PMEP, with the technical assistance of the Institute for Applied Ecology (Pacific Marine and Estuarine Fish Habitat Partnership 2017).

Eelgrass presence, absence, and status of data availability for each estuary was compiled from literature, reports, and existing spatial data. This information was summarized at the genus level *(Zostera sp.)* for each estuary, as well as by attributes that describe the source data, including: current data collection year, other data collection years, dataset availability count, maximum known extent (acres), current known extent (acres), notes related to habitat change (such as habitat loss), and other notes or observations. Personal communications from managers and researchers supplemented documented sources of information.

Eelgrass Extent

No new field studies were conducted for this project. Data collection relied on a data call to obtain relevant existing data across the contiguous U.S. West Coast. The PMEP used its partner organizations and professional networks to solicit data as well as identify others who might have relevant data sources. As a part of this effort, we compiled a table of contact names for estuary-specific eelgrass information and datasets, which is available at www.pacificfishhabitat.org/data.

We were especially interested in collecting spatially referenced data, specifically in polygon format, depicting the extent of eelgrass for each of the three U.S. West Coast species *(Z. marina, Z. japonica, Z. pacifica)*. Spatially referenced data, in point and line format, were accepted and used in developing an eelgrass presence by estuary feature class, but these data were not included in the extent data compilation. Ultimately, more than 130 datasets depicting the spatial extent of eelgrass were identified and used.

We also compiled habitat suitability models (depicting potential for eelgrass habitat), however, we did not include them in this analysis.

Data Processing

Each unique dataset was processed and then merged to create a single coastwide "feature class" depicting maximum observed extent of eelgrass based on best available data. Submitted datasets were compiled and uploaded into an ArcGIS 10.4 file geodatabase for processing. Each dataset was re-projected into a common projection and given a standardized set of attributes (estuary name or a geographic location descriptor information, eelgrass extent data source, species of eelgrass, and data collection year), which were calculated based on the source data.

From the source data, we summarized the eelgrass extent data into four categories:

1. Maximum observed extent of eelgrass;
2. Most current year;
3. Frequency of data collection; and
4. Coastal and Marine Ecological Classification Standard (CMECS) Code of the CMECS Biotic Component (Federal Geographic Data Committee 2012).

Maximum observed extent represents the full spatial extent of all datasets collected for an estuary or location. Data collection year highlights the range of years of data collection within an estuary or location; the most recent year of data collection was prioritized. Frequency of data collection represents the count of data collection events for a particular location within an estuary. The two CMECS codes used as part of the CMECS biotic component include the group level Seagrass Meadow (2.5.2.1) and the community level *Z. marina* (2.5.2.1.16). There are currently no CMECS codes available for either *Z. pacifica* or *Z. japonica*.

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EELGRASS SPECIES AND U.S WEST COAST DISTRIBUTION

Of the three species of eelgrass considered, *Z. marina* is the dominant species along the U.S. West Coast. It is found in both intertidal and subtidal areas to a depth of about 20 meters from southeastern Alaska to southern Baja California, Mexico (Green and Short 2003; Coyer et al. 2008) in coastal lagoons, estuaries, and coastal fjords (Short et al 2010a). *Z. japonica* is found from Vancouver Island, Canada south to Humboldt Bay, California (Hay 2011), and is believed to have been introduced to the U.S. West Coast when it was used as packing material for imported oyster seed (Thom and Hallum 1990). *Z. japonica* occurs in the intertidal zone and is generally found in more shallow areas compared to other *Zostera* species. *Z. japonica* is found in broadly sheltered bays on sandy or muddy coasts from -1m to -3m depth (Short et al. 2010b). Genetic studies in the Channel Islands off the coast of California recently identified *Z. pacifica* as a different species than *Z. marina* (Coyer et al. 2008). *Z. pacifica* is native to California and found in protected bays and estuaries from the low intertidal to a depth of about -20m (Short and Gaeckle 2010). The three species, though similar, are somewhat distinguishable by their blade width. *Z. japonica* tends to have thinner blades than *Z. marina* (Hay 2011), whereas *Z. pacifica* tends to have wider blades than *Z. marina*. There are some instances of *Z. marina* with wide blades; the best way to distinguish among species is via genetic testing (Coyer et al. 2008). For the purposes of this report, we focus on the most widely distributed species, *Z. marina*, and refer to it as eelgrass unless otherwise noted, and provide information on the distribution of the other two species when available.

The presence of eelgrass depends on a variety of geographically influenced environmental conditions, including light availability, temperature, salinity, and depth distribution (Moore and Short 2006; Thom et al. 2014). Optimal growth of eelgrass occurs in salinities between 10–30 psu and temperatures ranging from 10–20 degrees Celsius (Phillips 1984). *Zostera japonica* can tolerate long-term exposure to salinity between 5–35 psu (Shafer et al 2011). The uppermost, or shallow edge, of eelgrass meadows is controlled by desiccation and temperature in estuaries (Boese, Robbins, and Thursby 2005), and in Southern California island, or open coast habitats, it is limited by wave energy or desiccation (Merkel and Associates 2016). However, this can also be locally influenced by activities, such as aquaculture and shoreline development (Boese, Robbins, and Thursby 2005). The deep edge, or maximum depth, of eelgrass can be directly related to the submarine light environment (Boese, Robbins, and Thursby 2005; Merkel and Associates 2016). Depth distribution is the most common parameter collected in conjunction with eelgrass distribution, and is described for each ecoregion along with known distribution.

Unlike other estuarine and nearshore habitats along the U.S. West Coast, such as kelp beds and marshes, eelgrass meadows are not typically designated navigational hazards; therefore, historically there was no economic justification for assessing the extent of eelgrass (Thom and Hallum 1990). During the 1930s, the importance of eelgrass to coastal and marine ecosystems was highlighted when wasting disease caused a large scale die-off of eelgrass on both the western and eastern North Atlantic coasts (Moore and Short 2006). The disease resulted in more than 90 percent loss of the North Atlantic eelgrass population, which had significant impacts on estuarine and coastal productivity, including the disappearance of the scallop *(Arcgopecten irradians)* fishery as well as drastic reductions in black brant *(Branta bernicla nigricans)* populations (Moore and Short 2006). Growing awareness of the importance of eelgrass habitat led to the passage of federal, state, and local regulations that protect eelgrass, which in turn produced the need for a better understanding of the extent of eelgrass in estuarine and coastal systems (Thom and Hallum 1990).

Eelgrass habitat surveys have been conducted for many years across the U.S. West Coast. Although there are many references to the presence of eelgrass, it wasn't until the 1980s when initiatives, such as the Coastal Zone Atlas of Washington and the Estuary Plan Book for Oregon, resulted in mapping biological resources, including eelgrass, on a more regional scale. During this time period, NOAA began developing Environmental Sensitivity Index (ESI) maps to identify vulnerable coastal locations and resources to assist with oil spill response planning; one of the biological resources identified was eelgrass meadows. During the late 1980s and early 1990s, the need for more detailed coastal ecological investigations led to more detailed mapping of specific estuaries and locations that were used as ports, or identified as ecological reserves, such as Mission Bay in Southern California and Padilla Bay in Puget Sound, Washington. Methods used to collect eelgrass extent data have varied through time and evolved with technological advances, such as the use of side-scan sonar in the late 1980s. Because of these advances, the quality of data showing the extent of eelgrass varies through time and by estuary, making it challenging to analyze U.S. West Coast changes in eelgrass extent. Additionally, eelgrass extent may vary "naturally" from year to year. Having a better understanding of the historic and current extent of eelgrass and these variations will inform future planning for conservation and restoration of eelgrass resources.

Eelgrass extent surveys and monitoring activities conducted along the U.S. West Coast, with a focus on estuaries that support, or historically supported, eelgrass are described in the following section. Results are organized by ecoregion to summarize the best available information. Tables 1–4 summarize the timeline of data collection by regional datasets depicting the current and historic extent of eelgrass within estuaries. Overall, 162 estuaries coastwide (36 percent of estuaries) have documented eelgrass presence, 23 percent of estuaries have no eelgrass, or are considered unsuitable habitat, and 41 percent of estuaries have no data on the status of eelgrass. Examples of eelgrass extent results for each ecoregion are available in Appendix A. To view full extent results, see PMEP's website:

http://www.pacificfishhabitat.org/data/.

HISTORIC AND CURRENT EXTENT OF EELGRASS ALONG THE U.S. WEST COAST

Salish Sea Ecoregion

The Salish Sea ecoregion has the longest history of eelgrass extent data collection on the U.S. West Coast. Data date back to hydrographic charts from the 1800s. Currently, the Submerged Vegetation Monitoring Program (SVMP), managed by the Washington Department of Natural Resources (WA DNR), is a research program specifically dedicated to monitoring the spatial extent of eelgrass in the region. Historically, eelgrass surveys in the Salish Sea focused on *Z. marina*, or generalized the observation as eelgrass or seagrass. Recent efforts have begun to distinguish between two species found in this region: *Z. marina* and *Z. japonica*. In the Salish Sea ecoregion, eelgrass is documented in 98 of PMEP's 166 estuaries (Figures 2a, 2b, and 2c, Table 1); extensive meadows also exist in the exposed nearshore of the Salish Sea, in addition to protected estuaries and embayments (examples in Appendix B). There are 10 estuaries in which eelgrass is absent, or it is considered unsuitable habitat, and 58 estuaries with no data in the region.

Thom and Hallum (1990) summarized known geospatial eelgrass datasets in Puget Sound. The history of data collection indicates the extent of eelgrass in the region spans back to hydrographic charts from the late

1800s. Datasets referenced in this report include: (1) Ron Phillip's thesis from 1962–1963, which reports on boat-based observations and SCUBA surveys, (2) the Coastal Zone Atlas based on data collected by aerial photographs and ground truthing, (3) Washington Department of Fish and Wildlife (WDFW) Pacific herring *(Clupea pallasii)* spawning surveys, in which eelgrass presence was recorded from rake-based vegetation assessments, and (4) 1852–1899 hydrographic charts. Thom and Hallum (1990) summarized existing data, which documents the best-known spatial extent of eelgrass at the time, summarized the results of all sources, and organized the datasets into five regions (Straits, North Sound, Hood Canal, Main Basin, and South Sound) and 94 subregions. These data are available in report format, but details on the specific extent of beds are not available. However, the results were inventoried in WA DNR's Marine Vegetation Atlas (www.dnr.mva.org), which uses index polygons to identify presence of eelgrass. The report does not provide area estimates for extent of eelgrass in Puget Sound, however, results show that at least 25 percent (659 km) of shoreline within Puget Sound historically had, or currently has, eelgrass meadows.

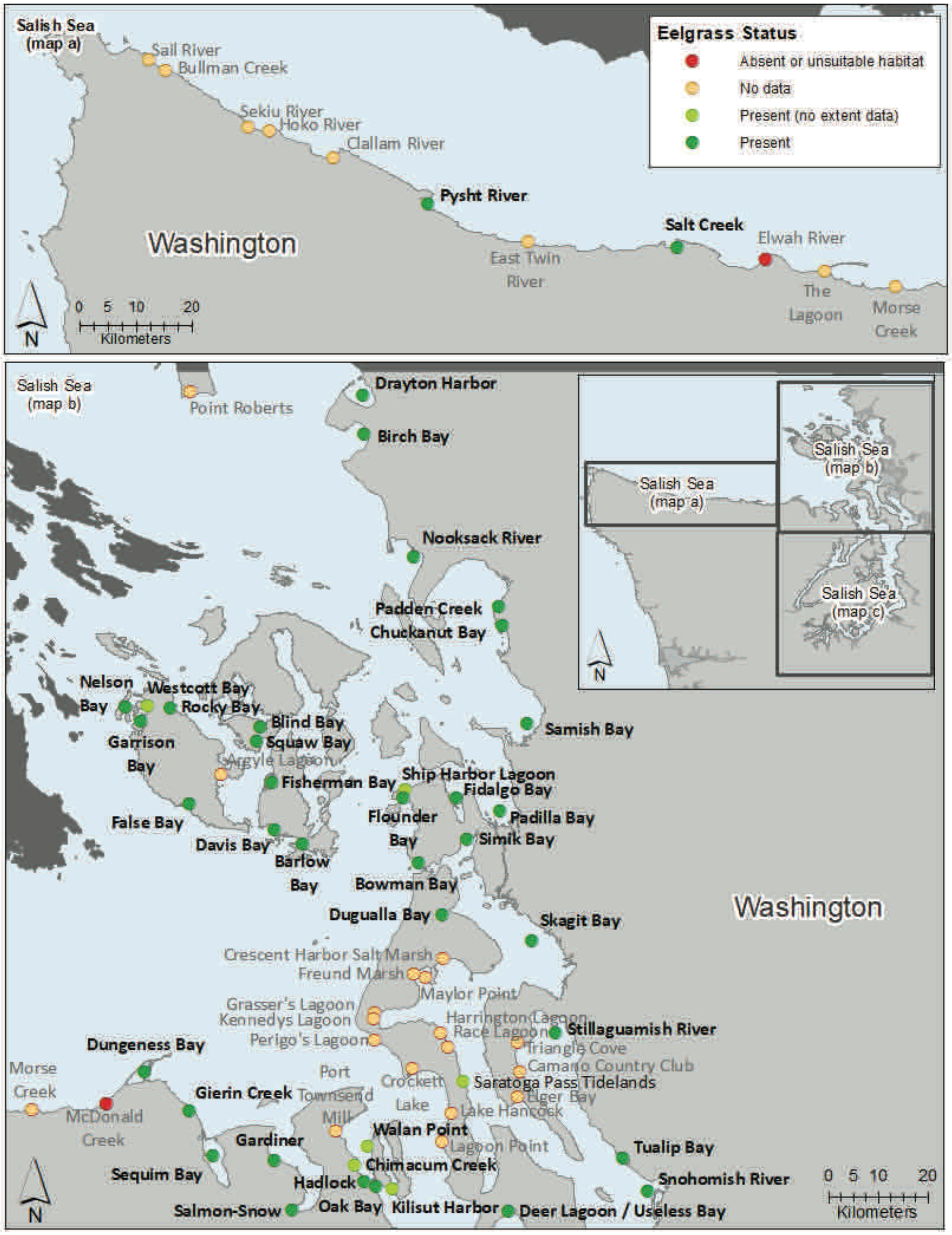
From 1994–2000, the WDFW and WA DNR conducted the ShoreZone Inventory of nearshore classification in Washington State, including eelgrass presence along the shoreline (Berry et al. 2001). ShoreZone methods for eelgrass classification involved aerial survey interpretation of biotic habitat along the shorelines, applied to line features (i.e., units) that span the whole coastline of Washington State (including both Puget Sound and the outer coast of Washington). Results of this effort show presence or absence of eelgrass; about 43 percent (1,703 km) of the shoreline had patchy or continuous eelgrass present in the Salish Sea ecoregion during that time period. This effort did not distinguish between *Z. marina* and *Z. japonica*. NOAA's Environmental Sensitivity Index for the region incorporated ShoreZone results to identify eelgrass habitats in Puget Sound.

The WDFW gathers information on observations of eelgrass during Pacific herring spawning surveys. During herring spawning season in Puget Sound, WDFW personnel survey nearshore spawning habitats for herring eggs by dropping a specifically designed metal rake to the shallow nearshore benthos from a small boat, ensnaring benthic vegetation, retrieving the rake, and identifying presence of benthic vegetation, including the most common *Zostera spp.* (Stick, Lindquist, and Lowry 2014). Several dozen rake deployments occur twice weekly within most known spawning grounds, and most areas are surveyed for a 6–8 week period covering the known spawning duration of each herring stock. Eelgrass presence as part of this effort, prior to 1990, was summarized (Thom and Hallum 1990). Because this is an ongoing monitoring program, data showing observations of eelgrass continue to be collected. Since 1990, 63 percent of herring spawning samples had eelgrass present. No eelgrass area estimates are included in this effort, though georeferenced locations are available for each rake deployment.

The WA DNR SVMP has monitored the extent of eelgrass in Puget Sound since 2000, with the goal of increasing overall area of eelgrass habitat by 20 percent by the year 2020 (Puget Sound Partnership 2014; Washington Department of Natural Resources 2015). Eelgrass is an ecosystem indicator and is monitored by the WA DNR as one of the Puget Sound Partnership's 25 Vital Signs (Puget Sound Partnership 2015). The WA DNR uses towed underwater video as the main data collection methodology to provide estimates of seagrass area and depth of deep edge of the meadow (Christiaen et al. 2017). In 2015, the Puget Sound-wide estimate for seagrass area was about 23,150 +/- 1,640 ha (57,204 acres). This estimate excludes *Z. japonica* because it is considered non-native, however, the estimate includes surfgrass *(Phyllospadix spp.)* because it is a native type of seagrass in the region (Washington Department of Natural Resources 2017). The SVMP data suggests Puget Sound-wide native seagrass area has remained relatively stable during the last 15 years. A recent study that analyzed the WDFW herring spawning eelgrass presence dataset in Puget Sound also indicates patterns of overall stability of *Zostera* (Shelton et al. 2016). Despite this region-wide result, both WA DNR (2016) and Shelton et al. (2016) identify eelgrass loss at smaller spatial scales.

Depth Distribution

A 1962–1963 study (Phillips 1974) concluded that eelgrass is restricted to a belt from MLLW (mean low lower water) to a depth of -6.6 m (-22 ft) in Puget Sound. The WA DNR (2017) documented eelgrass between -11m (-36 ft) and +1.4 m (+4.6 ft) relative to MLLW, but noted that the maximum depth at which it is found varies by site and region. The deepest meadows tend to be found in the comparatively clear waters of San Juan Islands and the Strait of Juan de Fuca, whereas shallow meadows are located in areas with higher turbidity, such as Skagit Bay and Bellingham Bay (Washington Department of Natural Resources 2017). The optimal habitat for eelgrass, which grows to greater depths in Puget Sound than in other coastal estuaries in the



FIGURES 2a (top) and 2b (bottom). The Salish Sea ecoregion, depicting eelgrass current or historic presence in 98 of 166 estuaries. Green indicates eelgrass is present; red indicates eelgrass is either absent, or unsuitable habitat exists; and orange indicates no data.

FIGURE 2c. The Salish Sea ecoregion, depicting eelgrass current or historic presence in 98 of 166 estuaries. Green indicates eelgrass is present; red indicates eelgrass is either absent, or unsuitable habitat exists; and orange indicates no data.

TABLE 1. The timeline of data collection depicting the current and historic extent of eelgrass in estuaries within the Salish Sea ecoregion. Green boxes indicate presence of eelgrass and survey year, or range of years; yellow boxes indicate absence of eelgrass and survey year, or range of years; empty boxes indicate no available eelgrass data.

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	WA DNR (2000-2015)	WDFW Herring Spawning Surveys (1990-2012) **	Estuary Specific Extent Data Source	Historic Extent Observations**
Drayton Harbor	1994-2000	2008	1990, 1991, 1992, 1993, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009,2010, 2011, 2012		Thom and Hallum 1974-1989
Birch Bay	1994-2000	2009, 2010, 2011, 2012, 2013	1990, 1991, 1992, 1993, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Washington Department of Natural Resources 2005	Thom and Hallum 1974-1989
Nooksack River	1994-2000	2003, 2004, 2005, 2006, 2007, 2008, 2015	1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Washington Department of Natural Resources 2005	Thom and Hallum 1974-1989
Padden Creek	1994-2000	2008			
Chuckanut Bay	1994-2000	2008		Washington Department of Natural Resources 2005	
Nelson Bay	1994-2000	2003, 2004, 2009	2007	San Juan County MRC 2003**	Thom and Hallum 1974-1989
Westcott Bay	1994-2000	2000, 2001, 2008, 2009, 2012	2006, 2008	San Juan County MRC 2003**	Thom and Hallum 1974-1989
Rocky Bay	1994-2000			San Juan County MRC 2003**	
Garrison Bay	1994-2000	2003, 2008, 2009, 2012	2006	San Juan County MRC 2003**	Thom and Hallum 1974-1989
Blind Bay	1994-2000	2003, 2004, 2009	1990, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	San Juan County MRC 2003**	Thom and Hallum 1974-1989
Squaw Bay	1994-2000	2006, 2007, 2008, 2009, 2010		San Juan County MRC 2003**	Thom and Hallum 1974-1989
Fisherman Bay	1994-2000	2003, 2010		San Juan County MRC 2003**	
False Bay	1994-2000	2003, 2004, 2009		San Juan County MRC 2003**	Thom and Hallum 1974-1989
Davis Bay	1994-2000			San Juan County MRC 2003**	
Barlow Bay	1994-2000	2003, 2004, 2009, 2010, 2011, 2012, 2013, 2014		San Juan County MRC 2003**	

*** Spatial extent data was not available and/or included in extent data compilation.*

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	WA DNR (2000-2015)	WDFW Herring Spawning Surveys (1990-2012) **	Estuary Specific Extent Data Source	Historic Extent Observations**
Samish Bay	1994-2000	2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015	1992, 1993, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Washington Department of Natural Resources,1996	Thom and Hallum 1974-1989
Padilla Bay	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015	1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Washington Department of Natural Resources 1996	Thom and Hallum 1974-1989
Fidalgo Bay	1994-2000	2008, 2009, 2010, 2011, 2012, 2013	1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009,2010, 2011, 2012	Washington Department of Natural Resources,1996	Thom and Hallum 1974-1989
Ship Harbor Lagoon	1994-2000				
Flounder Bay	1994-2000			Washington Department of Natural Resources 1996	
Simik Bay	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2010, 2011, 2013, 2014, 2015	1995, 1996, 1997, 1998, 1999, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Washington Department of Natural Resources 1996; Skagit Coop 2006	Thom and Hallum 1974-1989
Bowman Bay	1994-2000	2008, 2009, 2010, 2011, 2012		Washington Department of Natural Resources, 1996, Skagit Coop 2006	Thom and Hallum 1974-1989
Dugualla Bay	1994-2000	2006, 2011	1995, 1996, 1997, 1999, 2001, 2002, 2003, 2005, 2006, 2010, 2011, 2012	Washington Department of Natural Resources, 1996; Skagit Coop 2006	Thom and Hallum 1974-1989
Skagit Bay	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015	1995, 1996, 1997, 1999, 2001, 2002, 2003, 2005, 2010 ,2011, 2012	Washington Department of Natural Resources, 1996; Skagit Coop 2006; USGS 2004**	Thom and Hallum 1974-1989
Stillaguamish River	1994-2000	2006, 2011		Snohomish County Marine Resources Committee, 2007	

*** Spatial extent data was not available and/or included in extent data compilation.*

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	WA DNR (2000-2015)	WDFW Herring Spawning Surveys (1990-2012) **	Estuary Specific Extent Data Source	Historic Extent Observations**
Saratoga Pass Tidelands	1994-2000				
Tualip Bay	1994-2000	2006, 2011, 2013, 2014	1990, 1991, 1992, 1993, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Snohomish County Marine Resources Committee, 2007	Thom and Hallum 1974-1989
Snohomish River	1994-2000	2000, 2001, 2002, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015		Snohomish County Marine Resources Committee, 2007	Thom and Hallum 1974-1989
Deer Lagoon / Useless Bay	1994-2000	2007, 2012			
Cultus Bay	1994-2000	2014			Thom and Hallum 1974-1989
Appletree Cove	1994-2000	2014			
Miller Bay	1994-2000	2014	1990, 1992, 1993, 1994, 1995, 1996, 2003, 2004, 2006, 2012		Thom and Hallum 1974-1989
Liberty Bay	1994-2000		2011		
Keyport Lagoon	1994-2000		1990, 2003		Thom and Hallum 1974-1989
Port Madison	1994-2000	2016	1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2011		
Burke Bay	1994-2000	2014	1990, 1991, 1992, 1993, 1995, 1997		Thom and Hallum 1974-1989
Clear Creek	1994-2000		1994		
Barker Creek	1994-2000		1994		
Eagle Harbor	1994-2000	2014			
Schel-chelb	1994-2000	2005, 2006, 2007, 2008, 2009, 2013, 2016			Thom and Hallum 1974-1989
Phinney Bay	1994-2000		1994		
Clam Bay	1994-2000	2016			Thom and Hallum 1974-1989
Curley Creek	1994-2000	2009, 2010, 2011, 2012, 2013			
Harper	1994-2000	2016			
Miller Creek	1994-2000				

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	**WA DNR (2000-2015)**	**WDFW Herring Spawning Surveys (1990-2012) ****	**Estuary Specific Extent Data Source**	**Historic Extent Observations****
Olalla Creek	1994-2000				
Gig Harbor	1994-2000			Pierce County 2003**	
Burley Lagoon	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013,2014, 2015	2008, 2009, 2010, 2011, 2012	Pierce County 2003**	Thom and Hallum 1974-1989
Minter Creek	1994-2000		2011	Pierce County 2003**	
Glen Cove	1994-2000			Pierce County 2003**	
Wollochet Bay	1994-2000		2006, 2007, 2008, 2009, 2010, 2011, 2012	Pierce County 2003**	
Days Island Harbor	1994-2000				
Chambers Creek	1994-2000				
East Oro Bay	1994-2000			Pierce County 2003**	
Oro Bay	1994-2000			Pierce County 2003**	
Nisqually River	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2012, 2013, 2014, 2015		USGS, 2012, 2014, 2017	
Vaughn Bay	1994-2000	2004, 2005, 2006, 2007, 2008, 2010, 2013, 2014, 2015			
Rocky Bay	1994-2000	2004, 2005, 2006, 2007, 2008, 2010, 2013, 2014, 2015		Pierce County 2003**	
North Bay	1994-2000	2014			
Lynch Cove	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015	1991, 1992, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012		Thom and Hallum 1974-1989

*** Spatial extent data was not available and/or included in extent data compilation.*

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	**WA DNR (2000-2015)**	**WDFW Herring Spawning Surveys (1990-2012) ****	**Estuary Specific Extent Data Source**	**Historic Extent Observations****
Tahuya River	1994-2000				Thom and Hallum 1974-1989
Skokomish River	1994-2000	2004, 2005, 2006, 2007, 2008, 2010, 2013, 2014, 2015		USGS, 2013**	Thom and Hallum 1974-1989
Dewatto Bay	1994-2000				
Lillwaup Bay	1994-2000	2005, 2010, 2013, 2014			
Hamma Hamma River	1994-2000				
Anderson Creek	1994-2000	2005, 2006, 2007, 2008, 2009, 2010			
Duckabush River	1994-2000		1994		Thom and Hallum 1974-1989
Stavis Bay	1994-2000		2001, 2002		Thom and Hallum 1974-1989
Seabeck Bay	1994-2000		2001, 2002, 2008, 2009		Thom and Hallum 1974-1989
Big Beef Creek	1994-2000	2005, 2006, 2007, 2008, 2009	2008, 2009		
Pleasant Harbor	1994-2000		1994		
Anderson Creek	1994-2000	2005, 2010			
Fisherman Harbor	1994-2000				
Dosewallips River	1994-2000	2004, 2005, 2006, 2007, 2008, 2010, 2015	1994, 2000, 2002, 2007		Thom and Hallum 1974-1989
Zelatched Point Lagoon	1994-2000				
Right Smart Cove	1994-2000		2000, 2001, 2002, 2003, 2004, 2007, 2008, 2010, 2012		Thom and Hallum 1974-1989
Jackson Cove	1994-2000		2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012		Thom and Hallum 1974-1989
Quilcene Bay	1994-2000	2005, 2006, 2007, 2008, 2009, 2010, 2015	1991, 1992, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012		Thom and Hallum 1974-1989
Broad Spit	1994-2000				
Thorndyke Creek	1994-2000	2005, 2010			Thom and Hallum 1974-1989

*** Spatial extent data was not available and/or included in extent data compilation.*

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	WA DNR (2000-2015)	WDFW Herring Spawning Surveys (1990-2012) **	Estuary Specific Extent Data Source	Historic Extent Observations**
Tarboo Bay	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2010, 2015	2010		
Port Gamble	1994-2000		1990, 1991, 1992, 1993, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012		Thom and Hallum 1974-1989
Bridgehaven	1994-2000				Thom and Hallum 1974-1989
Shine Creek	1994-2000		1992		Thom and Hallum 1974-1989
Coon Bay	1994-2000	2010, 2011, 2012, 2013, 2014	1990		Thom and Hallum 1974-1989
Foulweather Bluff	1994-2000				Thom and Hallum 1974-1989
Twin Spits	1994-2000				
Mats Mats Bay	1994-2000	2013, 2014			Thom and Hallum 1974-1989
Kilisut Harbor	1994-2000		2002,2003, 2005		Thom and Hallum 1974-1989
Oak Bay	1994-2000	2007, 2008, 2009, 2010, 2011, 2012			
Hadlock	1994-2000	2000, 2001, 2002, 2010			
Chimacum Creek	1994-2000		2009	Jefferson County MRC, 2007	
Walan Point	1994-2000			Jefferson County MRC 2007	
Salmon-Snow	1994-2000		1990, 1991, 1992, 1993, 1994, 1995, 1996, 1998, 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	Jefferson County MRC 2010	Thom and Hallum 1974-1989
Gardiner	1994-2000			Jefferson County MRC 2010	
Sequim Bay	1994-2000	2000, 2001, 2012, 2013, 2014	1993, 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011		Thom and Hallum 1974-1989
Gierin Creek	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015		Clallam County 2009	Thom and Hallum 1974-1989

*** Spatial extent data was not available and/or included in extent data compilation.*

PMEP Estuary (with eelgrass present)	Regional Summary Datasets		Eelgrass Observations	Local Data Source	Literature Only
	Shorezone (1994-2000)	WA DNR (2000-2015)	WDFW Herring Spawning Surveys (1990-2012) **	Estuary Specific Extent Data Source	Historic Extent Observations**
Dungeness Bay	1994-2000	2011, 2012, 2013, 2014	1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 200, 2010, 2011, 2012	Clallam County 2009	Thom and Hallum 1974-1989
McDonald Creek		2014			
Elwah River	1994-2000			Clallam County 2006	
Salt Creek	1994-2000	2000, 2001, 2002, 2003, 2004, 2005, 2009, 2012, 2013, 2015		Clallam County 2009	

*** Spatial extent data was not available and/or included in extent data compilation.*

northeastern Pacific Ocean (Young et al. 2012), is between -2 m (-6.6 ft) to 0 m relative to MLLW in most of Puget Sound (Washington Department of Natural Resources 2017).

Washington/Oregon/Northern California Coast Ecoregion

Eelgrass is documented in 24 of the 125 estuaries in the Washington/Oregon/Northern California Coastal ecoregion (Figure 3, Table 2). There are 21 estuaries where eelgrass is absent, or the estuary is considered unsuitable habitat, and 65 estuaries with no data. Both *Z. marina* and *Z. japonica* are present in this ecoregion. *Z. japonica* was first reported in 1957 in Willapa Bay, Washington, and in 1976 in Yaquina Bay, Oregon, (Young et al. 2008), but was thought to be first introduced in the early twentieth century along with oyster stock imported from Japan (Shafer, Kaldy, and Gaeckle 2014). The southernmost extent of observations of *Z. japonica* occur in Humboldt Bay and the Eel River in California (Schlosser and Eicher 2012).

In the Washington portion of this ecoregion, knowledge of eelgrass presence is limited to Willapa Bay and Grays Harbor along the outer coast, and Baker Bay near the mouth of the Columbia River. There are no documented occurrences of eelgrass on the outer coast north of Grays Harbor to Makah Bay at the northwest portion of the Olympic Peninsula, likely because suitable habitat does not exist (L. Antrim, personal communication, 2016).

The extent of eelgrass for Grays Harbor, WA, was initially documented in 1975 in the Grays Harbor Estuary Management Plan (Washington Department of Ecology 1986). Two species, *Z. marina* and *Z. noltii*, a seagrass native to Europe, were described. The 1975 observation is the only documented occurrence of *Z. noltii* in the region, and no genetic testing confirmed species identification. In Willapa Bay, WA, a 1990 report by NOAA estimated 510 ha (1,260 acres) of eelgrass (Thom et al. 2003).

Data showing the extent of eelgrass in Willapa Bay first became available from aerial photography as part of NOAA's Coastal Change Analysis Program (C-CAP) in 1995 (Hazen 1996). This dataset documents both *Z. marina* and *Z. japonica* in the estuary; however, the maps identifying extent combine the two into a general eelgrass category. There is very little data on the extent of eelgrass in the Columbia River Estuary, however, data do exist as a result of dive surveys and conservation restoration efforts in Baker Bay, WA (Judd et al. 2009). Anecdotal information from the Lewis and Clark expedition indicates that eelgrass may have existed at the mouth of the Columbia River due to the historic presence of black brant, a bird highly associated with eelgrass habitats (Thom et al. 2016). The Columbia River is not currently recognized as a spring migration or wintering site for black brant (Pacific Flyway Council 2002).

In the early 2000s, geospatial changes in potential tidal habitats, with a focus on unvegetated flats and

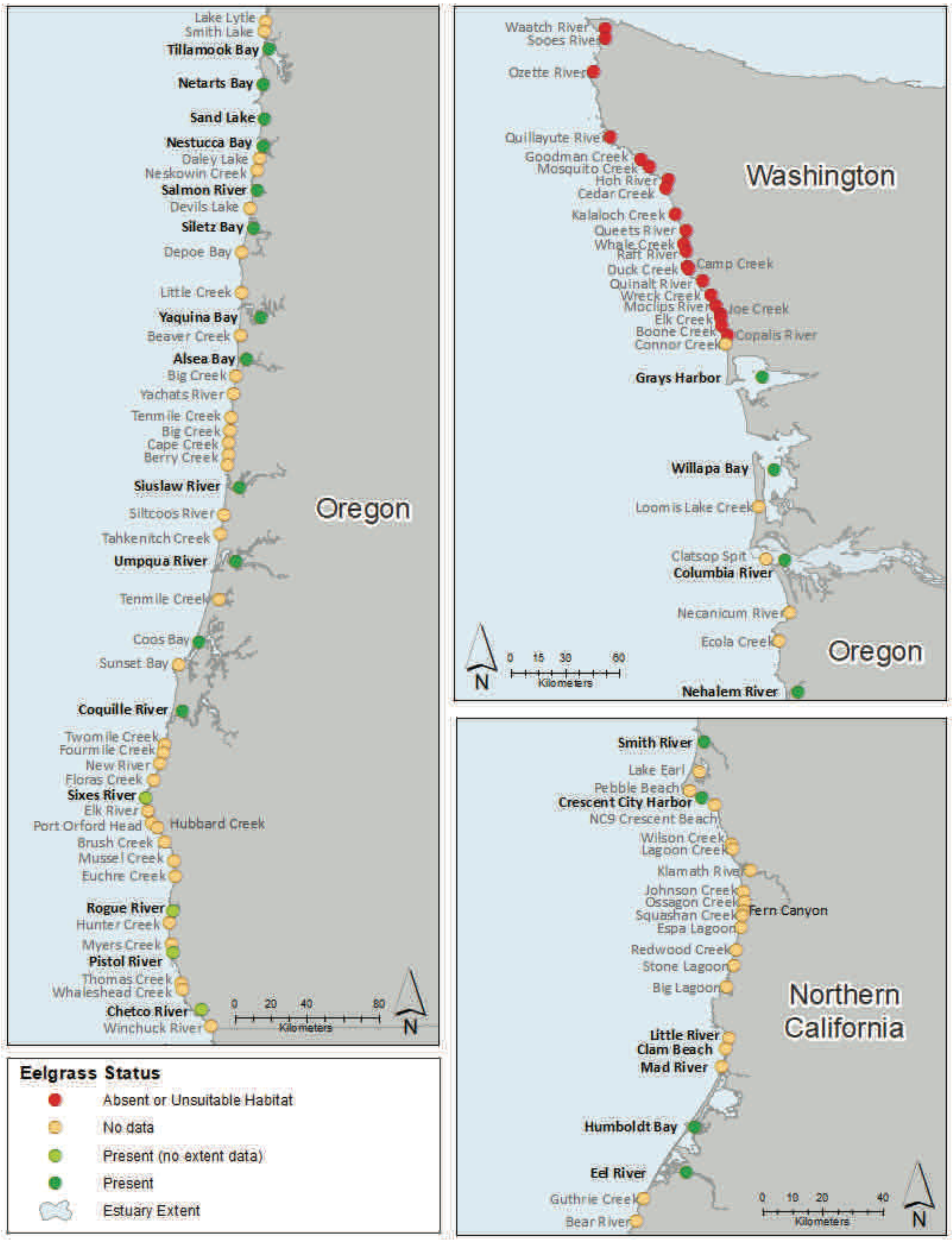


FIGURE 3. The Washington/Oregon/Northern California Coast ecoregion, depicting eelgrass current or historic presence in 24 of 110 estuaries. Green indicates eelgrass is present; red indicates eelgrass is either absent, or unsuitable habitat exists; and orange indicates no data.

eelgrass, was assessed (Borde et al. 2003). This effort documented increases in eelgrass extent in Grays Harbor and Willapa Bay through time based on field data and the knowledge of the distribution of eelgrass habitat along elevation and salinity gradients in the estuaries. Grays Harbor had an estimated 1,306 ha (3,227 acres) of eelgrass in 1883 and an estimated 3,099 ha (7,658 acres) of eelgrass in 1956, and Willapa Bay had an estimated 3,130 ha (7,734 acres) of eelgrass in 1855 and an estimated 4,845 ha (11,972 acres) of eelgrass in 1954.

The first data documenting estimates of historical eelgrass extent in Oregon are derived from the Estuary Plan Book (1972–1973), in which aerial photographs were interpreted for habitat classification by the Oregon Department of Fish and Wildlife (ODFW) (Cortright, Weber, and Bailey 1987). The Estuary Plan Book identified eelgrass *(Zostera spp.)* in 13 estuaries in Oregon (Table 2), and noted it was the most predominant species of seagrass in Oregon. However, the map products used in the classification system denoted the general descriptor of "seagrass" versus species-specific designations.

The ShoreZone Inventory was conducted in Washington (1994–2000) and Oregon (2013) (Berry et al. 2001; ShoreZone 2014). In Grays Harbor and Willapa Bay, eelgrass was classified into polygons compared to line features that were used for the remainder of the state, and the units of classification were based on geology, not biology (Berry et al. 2001). Therefore, data for these estuaries may overestimate the actual extent of eelgrass present at the time. This effort indicated patchy or continuous occurrence of *Z. marina* along the Oregon and Washington coast; about 27 percent (310 km) of the shoreline in Oregon, and 11 percent (110 km) of the outer Washington Coast had patchy or continuous eelgrass present during their respective sampling time periods (Berry et al. 2001; ShoreZone 2014).

More recent efforts to map the spatial extent of eelgrass in Oregon come from the Environmental Protection Agency (EPA) (2004–2007, seven estuaries, aerial photography), the ODFW SEACOR dataset (2010–2015, five estuaries, dive surveys and land-based surveys), and the South Slough National Estuarine Research Reserve (2016, Coos Bay Estuary, aerial imagery and side-scan sonar).

Aerial photographs and ground surveys from 1997–2014 were used to document major expansions in distributions (~1,500 percent increase) of *Z. japonica* in the Yaquina Bay estuary in Oregon, however, there was no indication that the large shift in extent was accompanied by an actual change in areal extent of *Z. marina* in the system (Young et al. 2008).

From the northern California border to Cape Mendocino, the earliest regional summary of information on the extent of eelgrass is from the Environmental Sensitivity Index (2008), which does not provide area estimates. In general, eelgrass area estimates are available on an estuary-by-estuary basis. In this portion of Northern California, information on eelgrass extent is limited to four estuaries: Smith River, Crescent City Harbor, Humboldt Bay, and the Eel River.

- In 2014, a study on the distribution of juvenile salmonids in Smith River identified <1 ha (1.67 acres) of *Z. marina*, which was the first documented observation of eelgrass in this estuary (Parish and Garwood 2015). The extent of eelgrass meadows in Smith River was mapped by delineating the outer edge of the bed using a kayak and GPS (Parish and Garwood 2015). An estimated 0.86 acres (less than 1 ha) of eelgrass in Crescent City harbor has been observed as part of pre-dredge surveys using side-scan sonar (California Coastal Commission 2016).

- The history of eelgrass surveys in Humboldt Bay is documented in the Humboldt Bay Eelgrass Comprehensive Management Plan (Gilkerson and Merkel 2014). The first surveys date back to 1959, however algal beds were not distinguishable from eelgrass in aerial photos (Gilkerson and Merkel 2014). The plan identified other efforts that mapped eelgrass extent in 1972, 1979, 2000, and 2004 for the entire Humboldt Bay area. In 2009, the Humboldt Bay and Eel River Estuary Benthic Habitat Project estimated about 2,280 ha (5,642 acres) of eelgrass in Humboldt Bay and 21 ha (51 acres) in Eel River using aerial photograph interpretation (Schlosser and Eicher 2012). One plan documented a total of 1,902 ha (4,700 acres) of estimated eelgrass area (Gilkerson and Merkel 2014).

Depth Distribution

In Grays Harbor, WA, *Z. marina* occurred between -0.9m (-3ft) and–2.1 m to +1.8 m (6–7 ft.) MLLW, and *Z. japonica* was most abundant between + 1.5 m (5 ft) and +1.8 m (6 ft) MLLW (Washington Department of Ecology 1986). A total of 90 percent of eelgrass in three Oregon estuaries (Tillamook Bay, Yaquina Bay, and Alsea Bay) occurred within the -1.0 m (-3.3 ft) to +1.0 m (+3.3 ft) MLLW (Young et al. 2012). In Humboldt Bay, CA, maximum depths of *Z. marina* differed from north bay (-1.3 m MLLW) to south bay, (-2.1 m MLLW);

TABLE 2. The timeline of data collection depicting the current and historic extent of eelgrass in estuaries within the Washington/Oregon/Northern California Coast ecoregion. Green boxes indicate presence of eelgrass and survey year, or range of years; yellow boxes indicate absence of eelgrass and survey year, or range of years; empty boxes indicate no available eelgrass data.

PMEP Estuary (with eelgrass present)	Regional Eelgrass Extent Summary Datasets					Other Local Data Sources	Literature Only
	EPB	NOAA ESI	EPA	ODFW (SEACOR)	Shorezone (OR & WA)	Estuary Specific Extent Data Source	Historic Extent Observations
Grays Harbor			2001		2000		1987
Willapa Bay					2000	NOAA C-CAP 1995	
Baker Bay, Columbia River						Pacific Northwest National Labs 2008	U.S. ACE, 1987
Nehalem River	1978				2011		1980
Tillamook Bay	1978		2007	2010-2011	2011	Tillamook Estuary Partnership 1995**	1980
Netarts Bay	1978			2013-2014	2011		
Sand Lake	1978				2011		
Nestucca Bay	1978		2004		2011		1980
Salmon River	1978		2004		2011		
Siletz Bay	1978			2013-2015	2011		1980
Yaquina Bay	1978		2007	2012	2011		1980
Alsea Bay	1978		2004	2013-2015	2011		1980
Siuslaw River	1978				2011		
Umpqua River	1978		2005		2011		1980
Coos Bay	1978		2005		2011	South Slough National Estuarine Research Reserve 2016	1980
Coquille River	1978				2011		1980
Sixes River					2011		1980
Rogue River	1978				2011		1980
Pistol River					2011		1980
Chetco River	1978				2011		1980
Smith River						Parish and Garwood 2015	
Crescent City Harbor						California Coastal Commission 2016	
Humboldt Bay		1998*				CA Seagrant 2009	1959
Eel River		1998*				CA Seagrant 2009; Salt River Restoration Project 2015-2017**	

*** Spatial data was not available and/or included in this analysis.*

upper limits ranged from +0.3 m (1 ft) to +0.4 m (+1.3 ft) MLLW (Gilkerson and Merkel 2014).

Central California Ecoregion

Eelgrass is documented in 18 of 107 estuaries in the Central California coast ecoregion (Figure 4, Table 3) as well as areas of the nearshore from Monterey Bay southward. There are 42 estuaries where eelgrass is absent, or it is considered unsuitable habitat, and 47 estuaries with no data.

NOAA's Environmental Sensitivity Index (2006) summarized knowledge from 1994–2005 and provides a regional summary of eelgrass extent for the Central California region. Areal estimates for eelgrass were not included because much of the data was derived from personal communication with experts. However, eelgrass was identified as present in 15 estuaries in Central California (Table 3).

In 2011, the Marine Protected Area (MPA) monitoring effort mapped the extent of 20 nearshore and estuarine habitats, including eelgrass, in the North-Central California (Svejkovsky 2013). The regional coverage included the entire coastline between Pigeon Point and Pt. Arena (290 km; 180 mi) as well as the inland area, including estuarine, bay, and river MPAs. Data were collected using multi-spectral remote sensing and aircraft imaging sensors. A total of 217 ha (537.4 acres) of eelgrass habitat was identified in five estuaries (Russian River, Bodega Bay, Estero Americano, Estero de San Antonio, and Drakes Estero), and no eelgrass was observed in the nearshore areas of the survey area (Svejkosvky 2013).

As part of the California Department of Fish and Wildlife's (CDFW) Aquaculture and Bay Management Project, eelgrass extent is monitored for six estuaries: Tomales Bay (521 ha, 1,287.42 acres), Estero Americano (<1 ha, <2.5 acres), Albion River Estuary (12.4 ha, 30.6 acres), Big River Estuary (3.9 ha, 9.6 acres), Estero de San Antonio (~0.1 ha, ~.2 acres), and Ten Mile River Estuary (~1 ha, ~2.5 acres) (CDFW 2016). Data were collected from 2013–2016, using a combination of aerial imagery classification and groundtruthing. This dataset provides the most current estimate of eelgrass area in these estuaries.

A report titled, "Eelgrass Conservation and Restoration in San Francisco Bay: Opportunities and Constraints," summarized the state of knowledge of the extent of eelgrass in San Francisco Bay (Boyer and Wyllie-Echeverria 2010). The report documented the history of eelgrass surveys conducted in the bay since 1987. The 1987 data estimated 127.9 ha (316 acres) of eelgrass. The most recent survey (Merkel and Associates 2014) estimated 1,500 ha (3,700 acres) of eelgrass in the bay. The report suggested improved mapping technologies may be responsible for the estimated increase in abundance of eelgrass in the bay, however, an increase in areal extent of eelgrass was found between 2003 and 2009 when similar mapping methodologies were used. Consistent surveys through time need to be conducted to determine whether this increase is a trend or simply a variation in extent between years.

In Elkhorn Slough, an effort to illustrate trends in eelgrass abundance through time was conducted using aerial photographs from 13 different flights that occurred from 1931–2005 (Dyke and Wasson 2005). Area of eelgrass estimates were analyzed in four different time periods (1931–1937, 1956–1957, 1980–1992, and 2000–2005). The earliest known areal extent, from 1931–1937, estimated 22 ha (54 acres) of eelgrass. The extent of eelgrass in Elkhorn Slough was mapped in 2007–2009 (Grant 2009), 2014, and 2015–2016 (Walton, Garcia-Garcia, and Endris 2016); the most recent effort estimated about 14.2 ha (35 acres) of eelgrass.

The CDFW conducted field surveys and reported 136 ha (335 acres) of eelgrass in Morro Bay in 1960 (Morro Bay National Estuary Program 2017). Other eelgrass extent estimates were made in 1970, 1988, 1994, 1997, and 1999, and estimates ranged from a low of 40 ha (98 acres) in 1997 to a peak of 183 ha (452 acres) in 1970 (Morro Bay National Estuary Program 2017, Figure 3). The Morro Bay National Estuary Program (MBNEP) began monitoring the extent of eelgrass in 2002 using true color aerial imagery (Kitajima, personal communications, 2017). This first effort estimated about 60 ha (149 acres) of eelgrass in Morro Bay. Additional monitoring efforts were completed in 2003, 2004 2006, 2007, 2009, 2010, 2013, and 2015 using either true or infrared aerial imagery. The most recent estimate of eelgrass area was 5.2 ha (13 acres) in 2015. Since 2007, eelgrass acreage in Morro Bay has declined by more than 95 percent.

Depth Distribution

Information on the depth distribution of eelgrass within this ecoregion is limited to research from Tomales Bay and San Francisco Bay estuaries. In Tomales Bay, eelgrass meadows are restricted to a narrow band along the shore at depths less than -4 m (-13 ft) MLLW (Spratt 1989). In San Francisco Bay, the greatest depth found for any bed was at Richardson Bay at -3.0 m (-9.8 ft) MLLW, but this was a very unusual occurrence (Boyer and Wyllie-Echeverria 2010). A total

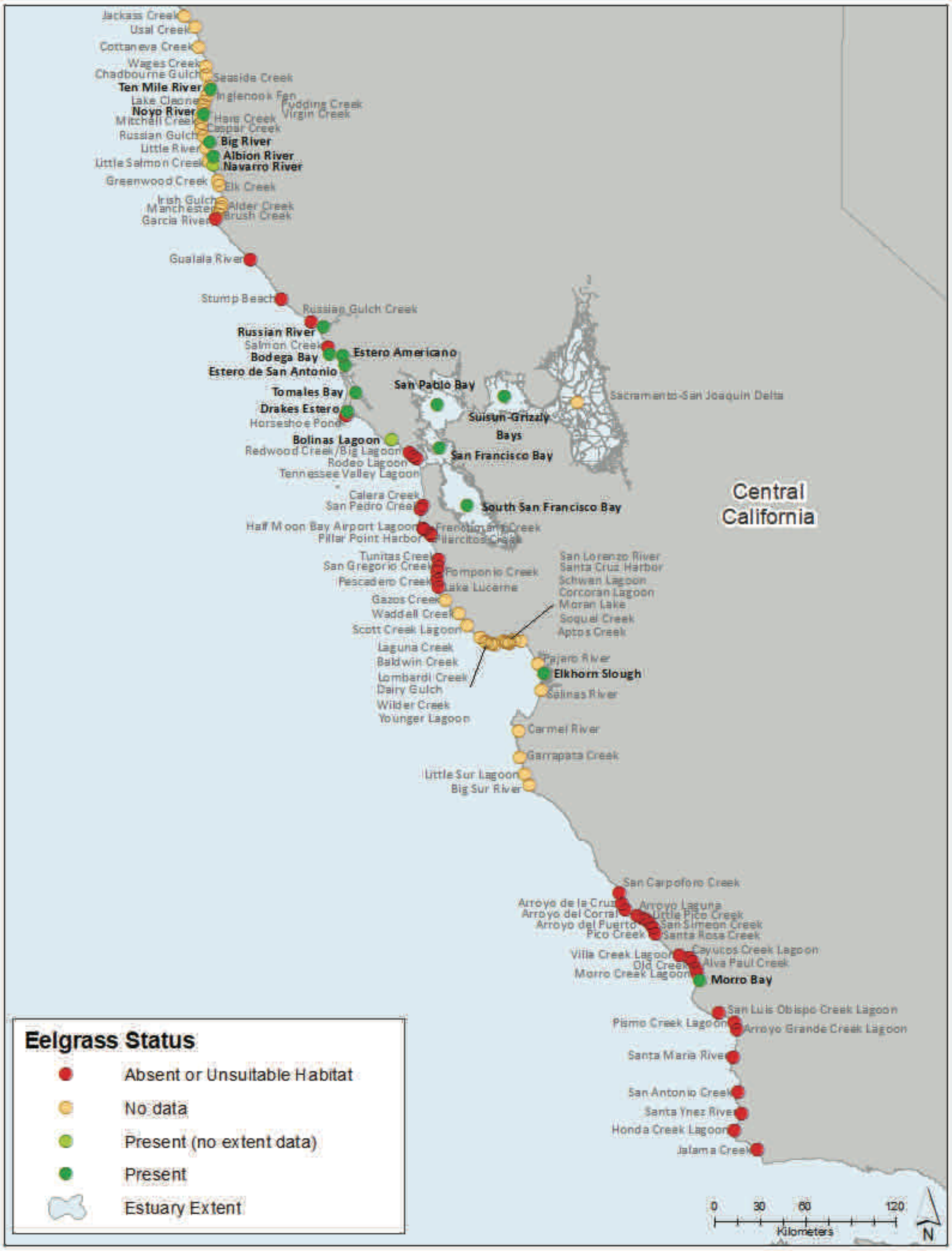


FIGURE 4. The Central California ecoregion, depicting eelgrass current or historic presence in 18 of 107 estuaries. Green indicates eelgrass is present; red indicates eelgrass is either absent, or unsuitable habitat exists; and orange indicates no data on eelgrass is available.

TABLE 3. The timeline of data collection depicting the current and historic extent of eelgrass in estuaries within the Central California ecoregion. Green boxes indicate presence of eelgrass and survey year, or range of years; empty boxes indicate no available eelgrass data.

PMEP Estuary (with eelgrass present)	Regional Eelgrass Extent Summary Datasets					Other Local Data Sources	Literature Only
	NOAA ESI	Ocean Imaging (MPA)	CDFW	NOAA	Merkel and Associates	Estuary Specific Extent Data Source	Historic Observations
Ten Mile River	2007		2016				
Noyo River	2007					2017 (Merkel and Associates)	
Big River	2007		2015				
Albion River	2007		2014, 2015				
Navarro River	2007						
Russian River		2010					
Bodega Bay	2007	2010					
Estero Americano	2007	2010	2014, 2016				
Estero de San Antonio		2010	2016				
Tomales Bay	2005		1992, 2000, 2002, 2010, 2013		2015		1985 (CDFG)
Drakes Estero	1994	2010				2005 (Point Reyes National Seashore)	
Bolinas Lagoon	1994*						
San Francisco Bay							
San Francisco Bay	1987*, 1998				2003, 2009, 2013		
South San Francisco Bay	1987*, 1998				2003, 2009, 2013		
San Pablo Bay	1987*, 1998				2003, 2009, 2013		
Suisun-Grizzy Bays					2013		
Elkhorn Slough	2005					1931, 1937; 1356, 1966, 1976; 1980, 1987, 1992; 2000 (Palacios and Zimmerman 2000); 2000, 2003, 2005 (Van Dyke 2005); 2007-2009 (Grant 2009); 2014-2015; 2016 (ESNERR 2016).	
Morro Bay	2005				2005*, 2006, 2007, 2009, 2013, 2015	2002, 2003 (Golden State Aerial), 2004, 2006, 2007, 2009, 2010 (Ocean Imaging)	1960 (CDFG), 1970, 1988, 1994, 1997, 1999

** Extent in ESI based up on professional opinion, and not from extent mapping, therefore not included in the spatial dataset but noted as a reference.*

of 98.8 percent of all mapped eelgrass in San Francisco Bay was found between -1.77 m (-5.8 ft)and +0.4 m (+1.3 ft) MLLW (Boyer and Wyllie-Echeverria 2010).

Southern California Bight Ecoregion

Eelgrass is documented in 22 of the 61 estuaries in this ecoregion and throughout the mainland nearshore and the Channel Islands (Figure 5, Table 4). There are 31 estuaries where eelgrass is absent, or it is considered unsuitable habitat, and eight estuaries with no data. The Southern California Bight ecoregion is the only ecoregion on the U.S. West Coast with known observations of *Z. pacifica*, which is found throughout the Channel Islands and the nearshore of mainland California.

NOAA's Environmental Sensitivity Index provides a regional summary of eelgrass extent for the Southern California ecoregion, which was conducted in 1980 and again in 2010. No area estimates for eelgrass were associated with this particular effort because much of the data was derived primarily from expert opinion, however, eelgrass was identified as present in eight estuaries in the Southern California Bight (Table 4). The report, "Recommendations for a Southern California Regional Eelgrass Monitoring Program," provides the most comprehensive summary of system-wide monitoring history for eelgrass in the region (Bernstein et al. 2011). The report, which was based on system-wide inventories in 2010, estimated a total known maximum extent of eelgrass of 2,068 ha (5,111.5 acres) in the region, including eelgrass meadows that occurred along the Channel Islands. The report discussed system-wide eelgrass monitoring history, and stated that eelgrass mapping efforts were almost non-existent in the region prior to the 1960s. The first eelgrass extent surveys for small-scale mapping efforts used techniques such as trawl and grab sampling and diver transects, and large-scale efforts relied on true color and infrared aerial imagery. In 1988, side-scan sonar was first used to map eelgrass throughout Mission Bay. The data showing extent of eelgrass in this ecoregion was created using a variety of methods, however, for system-wide repeatable results, two methods have dominated—sidescan sonar and multispectral, or true color aerial imagery. The data summarized in the report is available through the California EcoAtlas (www. Ecoatlas.org), and NOAA's Environmental Response Management Application (ERMA) for the Southwest (ERMA 2015).

As a result of the recommendations from the report by Bernstein et al. (2011), three regional survey efforts were conducted in 2013, 2015, and 2016 to better understand regional eelgrass distribution and patterns (Merkel and Associates 2014). In 2013, six estuaries were surveyed using a combination of aerial photography, sidescan sonar surveys, and groundtruthing: Alamitos Bay (9.4 ha, 23.3 acres), San Gabriel River Estuary (0 ha), Anaheim Bay/Huntington Harbor (36.1 ha, 89.2 acres), Agua Hedionda Lagoon (17.4 ha, 43.1 acres), Batiquitos Lagoon (49.6 ha, 122.5 acres), and San Dieguito Lagoon (12.9 ha, 31.9 acres). A total of 125 ha (310 acres) of eelgrass was documented in the survey area. Batiquitos Lagoon had the largest portion of eelgrass area (47 percent) (Merkel and Associates 2014).

In 2015 the regional efforts focused on the extent of eelgrass along mainland nearshore and the Channel Islands, and included seven different regions surveyed: Santa Cruz Island (76 ha, 187.8 acres), Ventura/LA County line to Point Dume (8.5 ha, 21 acres), Point Dume to Marina del Ray (5.5 ha, 13.6 acres), and Santa Ana/Huntington Beach (11.5 ha, 28.4 acres) (Merkel and Associates 2015). The 2016 effort inventoried extent of eelgrass in West Santa Cruz Island (2.3 ha, 5.7 acres), Anacapa Island (4.7 ha, 11.6 acres), East San Pedro Bay (3.9 ha, 9.7 acres), and the mainland nearshore areas from Carlsbad to Del Mar (absent), and estimated eelgrass extent based on monitoring transects in West San Pedro Bay (~19.1 ha, ~47.1 acres), Anaheim Bay/Huntington Harbor (4.3 ha, 10.7 acres), Mission Bay (248.8, 614.8 acres), and San Diego Bay (747.7 ha, 1,847.7 acres) (Merkel and Associates 2017).

Depth Distribution

Information on depth distribution is generally summarized by estuary or nearshore region in the Southern California Bight ecoregion. However, regional eelgrass surveys occurred within the ecoregion in 2013 and 2015 to support development of a better understanding of regional eelgrass distribution and patterns (Merkel and Associates 2014). Results show that the typical upper elevation of eelgrass in estuaries in the ecoregion is at 0 m to +0.1 m (+0.3 ft) MLLW and, in general, does not extend deeper than -3.7 m (-12.1 ft) MLLW (Bernstein et al. 2011; Merkel and Associates 2014). However, this does vary by estuary. In Mission Bay, eelgrass depth distribution ranges from -4.5 m (-14.8 ft) to +0.5 m (+1.6 ft) MLLW (Bernstein et al. 2011, Figure 6).

The depth distribution of eelgrass in nearshore areas of the Southern California Bight Ecoregion are greater compared to other estuaries in neighboring ecoregions. In the Channel Islands, the depth distribution of eelgrass was -3 m (-9.8 ft) to -22 m

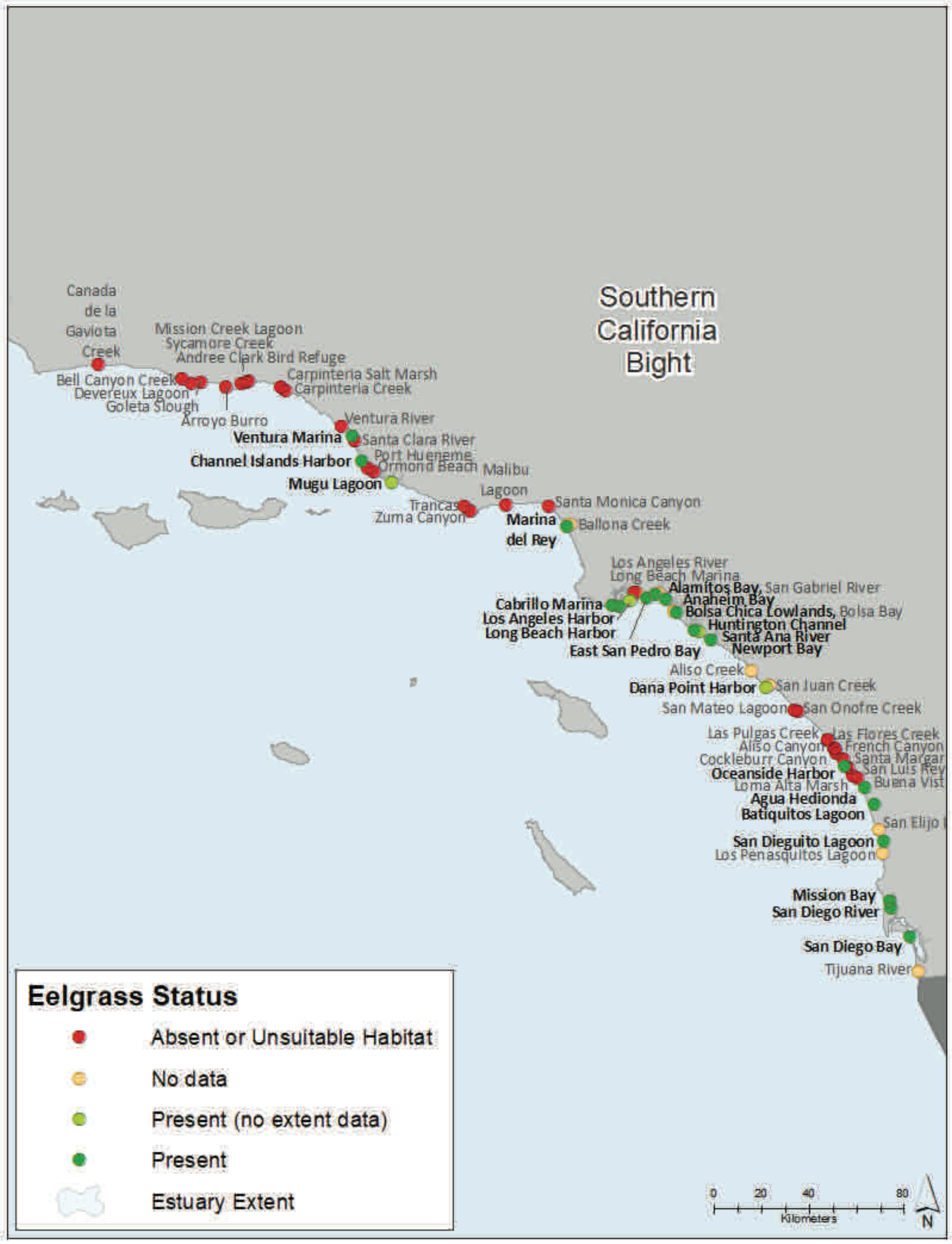


FIGURE 5. The Southern California Bight ecoregion, depicting eelgrass current or historic presence in 22 of 61 estuaries. Green indicates eelgrass is present; red indicates eelgrass is either absent, or unsuitable habitat exists; and orange indicates no data.

TABLE 4. The timeline of data collection depicting the current and historic extent of eelgrass in 22 estuaries within the Southern California Bight ecoregion. Green boxes indicate presence of eelgrass and survey year, or range of years; empty boxes indicate no available eelgrass data.

Estuary (with eelgrass present)	Regional Eelgrass Extent Summary Datasets		Local Data Source	Literature Only
	NOAA ESI	Merkel and Associates	Estuary Specific Extent Data Source	Historic Observations
Ventura Marina		2005		
Channel Islands Harbor		2005		
Mugu Lagoon	(no date)			Present (before 1977), Absent (1978) USFWS 1987
Marina del Rey		2005		
Cabrillo Marina		2000, 2009, 2016		
Los Angeles Harbor		2000, 2016		
Long Beach Harbor				(date unknown) SCCWRP 2011
East San Pedro Bay			2006 (MBC Analytical Consultants)	
Alamitos Bay	2006	2005, 2013	2000 (NMFS), 2008, 2009 (Tetra Tech, Inc)	
Anaheim Bay	2009	2005, 2013		
Bolsa Chica Lowlands		2007, 2008, 2009		
Huntington Channel		2008		
Santa Ana River	2006	2004		
Newport Bay	2006	2006	2004, 2006-2007, 2008-2009, 2012-2014 (Coastal Resource Associates)	
Dana Point Harbor				(date unknown) SCCWRP 2011
Oceanside Harbor	2009	2009		
Agua Hedionda		2001, 2004, 2008, 2009, 2013		
Batiquitos Lagoon		1997, 1998, 1999 ,2000, 2001, 2003, 2005, 2006		
San Dieguito Lagoon		2013		
Mission Bay	1980	1988, 1992, 1997, 2003, 2007, 2009, 2013, 2016	2009 (MBC Analytical Consultants)	
San Diego River		2007		
San Diego Bay	1980, 2006	1993, 1999, 2004, 2008, 2011, 2014, 2016	1994 (Scientific Services), 2000 (Tierra Data Systems, Inc.)	

(-722.2 ft) MLLW, and the distribution at specific sites varied depending on swell exposure (Engle and Miller 2011). In 2015 regional eelgrass surveys, the depth distribution on the north side of Santa Cruz Island ranged from -1.2 m (-3.9 ft) to -15.2 m (-49.9 ft) MLLW (Merkel and Associates 2015). On the south side of the island, eelgrass depth ranged from -8.5 m (-27.9 ft) to -17.7 m (-58 ft) MLLW (Merkel and Associates 2015). The mainland part of the Southern California Bight coast was also surveyed in 2015, from Point Dume to Marina del Rey (Merkel and Associates 2015). The depth range for eelgrass occurred between -6.7 m (-22 ft) and -17.7 m (-58 ft) MLLW (Merkel and Associates 2015).

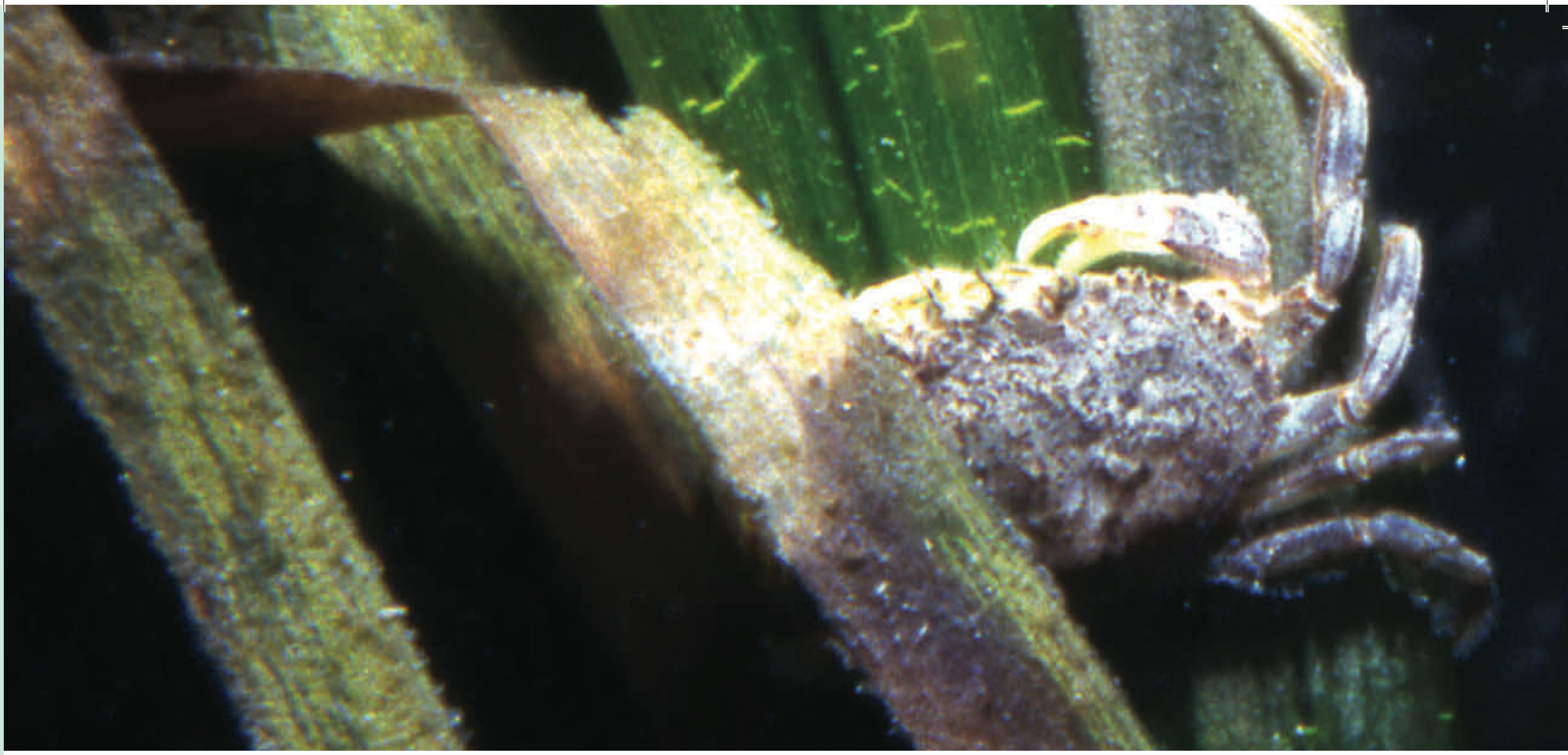


photo © Tom Gaskill

ECOSYSTEM SERVICES OF EELGRASS

Eelgrasses provide a variety of supporting, regulating, provisioning, and culture and amenity ecosystem services (see pages 33-34, Table 5) as described in the Millennium Ecosystem Assessment (2005). Provisioning services are benefits to people that can be extracted from nature; regulating services keep natural processes in check, or moderate natural phenomena; culture and amenity services enrich lives, contributing to the development and cultural advancement of people; and supporting services serve as the foundation for all services, sustaining basic life forms, whole ecosystems, and people.

Supporting Services

Habitat Provision and Food Web Support

Eelgrass has been called a "foundation" species (Kenworthy et al. 2006) because of its role in structuring communities of organisms. Eelgrass meadows are essential habitat; they form a basis of primary production and contribute to the food web in support of healthy estuarine and coastal ecosystems (Moore and Short 2006). Many studies have documented a significant diversity of plant and animal life associated with eelgrass meadows, including epiphytes, epibenthic organisms, infauna, and nekton (Phillips 1984). Eelgrass meadows, and their associated complex structure, exhibit high species diversity and fish abundance (Bayer 1981; Orth, Heck, and Montfrans 1984; Bell and Pollard 1989; Lubbers, Boynton, and Kemp 1990; Fonseca, Kenworth, and Thayer 1992; Orth 1992; Murphy, Johnson, and Csepp 2000; Duffy 2006; Washington Department of Natural Resources 2015), and provide habitat for numerous commercially important fish and shellfish species (Moore and Short 2006). In areas throughout the world, significantly higher faunal diversity and species richness have been observed in seagrass habitats than other habitats, particularly those seagrass habitats with extensive coverage (McCloskey and Unsworth 2015). Conversely, decreases in habitat complexity have been correlated with decreased abundance, biomass, species richness, dominance, and life history diversity in eelgrass meadows (Hughes et al. 2002).

Use of eelgrass habitat by fish and invertebrates can vary based on the life history patterns of residents (i.e., both adult and juvenile life stages are present year round), seasonal residents or transients (species spawn offshore, or young-of-the-year (YOY) or juveniles are present at varying times of the year), and rare or occasional species or migrants (Phillips 1984; Jackson et al. 2001). Birds feed on eelgrass, or its epiphytes, from the water surface, or at low-tide (Phillips 1984). Along the U.S. West Coast, much of our understanding of the habitat provision of eelgrass meadows comes from data on species assemblages (Bayer 1981; Valle, O'Brien, and Wiese 1999; Murphy, Johnson, and Csepp

2000; Johnson and Thedinga 2005), seasonal variability of fish and shellfish use of eelgrass habitat (Wang and Tzeng 1997; Akin et al. 2003; Pinnix et al. 2005; Rountree and Able 2007), and specific life-history patterns of species. In 1984, Phillips (1984) summarized the ecology of eelgrass meadows from Cape Flattery, Washington, to Cape Mendocino, California, and created a list of invertebrates, fish, and birds associated with eelgrass in the region based on observations. In 1991, NOAA published a report on the distribution and abundance of fishes and invertebrates in U.S. West Coast estuaries (focusing on commercially, recreationally, ecologically important, and threatened species), and identified species associated with eelgrass meadows (Emmett et al. 1991), including the horseneck gaper *(Tresus nuttallii)*, softshell clam *(Myidae spp.)*, Dungeness crab *(Metacarcinus magister)*, Pacific herring *(Clupea pallasii)*, juvenile Chinook salmon *(Oncorhynchus tshawytscha)*, topsmelt *(Atherinops affinis)*, kelp bass *(Paralabrax clathratus)*, barred sand bass *(Paralabrax nebulifer)*, and shiner surfperch *(Cymatogaster aggregata)*. South of Cape Mendocino to the border of Mexico, much of the information on species associations with eelgrass is documented on an estuary-by-estuary basis. Table 6 identifies commercially, recreationally, ecologically important, threatened, and endangered species observed in eelgrass, and identifies specific uses of eelgrass (as adopted from Phillips 1984 and Emmett et al. 1991).

<u>Washington</u>

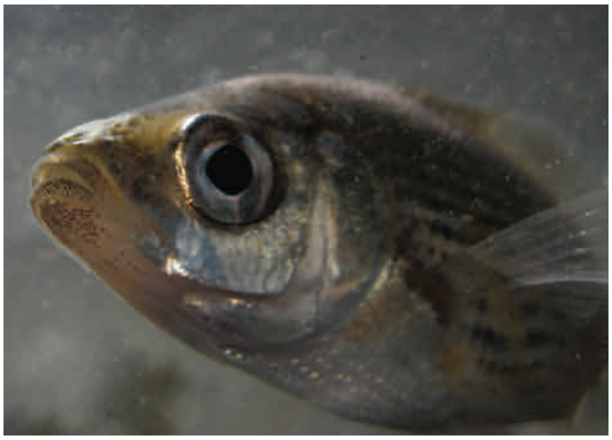
Thom et al. (1989) investigated the abundance of fish, Dungness crab, and small epibenthos in four estuarine habitat types in Drayton Bay, WA, and found that eelgrass meadows were important habitats and food for fish and crabs for an extended period in summer. The number of species ranged from five in October to 27 in mid-April; shiner surfperch and three-spined stickleback were the most common. Mean densities of these species increased in August during recruitment of YOY (Thom et al. 1989). In the Nisqually River Delta, eelgrass meadows may be especially important for Chinook salmon late in the outmigration period (July–August), which was identified through higher catches in eelgrass habitats in these months compared with other habitat types (Hodgson et al. 2016).

<u>Oregon</u>

Motley (2017) used minnow traps and dip net sweeps in Netarts Bay, Yaquina Bay, and Coos Bay to examine changes in abundance of fish and epifauna with changes in eelgrass density, and other physical parameters, within eelgrass meadows. Fourteen species of fish were observed in eelgrass meadows in Coos Bay, followed by 12 species in Netarts Bay, and nine species in Yaquina Bay; the majority of observations included Pacific staghorn sculpin in all three estuaries (Motley 2017). Bayer (1981) identified a total of 30 fish species in eelgrass habitats in Yaquina Bay, Oregon; up to 75 percent of the catch was dominated by shiner surfperch, bay pipefish, English Sole *(Parophrys vetulus)*, and surf smelt (Bayer 1981). The diversity of species changed seasonally—peak observations occurred in the summer (19 species), and a minimum diversity of observations occurred in February (seven species). Juvenile rockfish *(Sebastes spp.)* were observed and re-captured at higher rates at anthropogenic sites (piers) in Yaquina Bay, however, a greater diversity of rockfish species was found in eelgrass habitats compared to anthropogenic sites (Lindsley 2016). From 1998 through 2001 in Tillamook Bay, Ellis (2002) collected fish using a variety of methods; topsmelt and Chinook salmon were frequently observed at sites with known eelgrass meadows (Ellis 2002), however, species richness specific to eelgrass meadows was not summarized.

<u>California</u>

Eelgrass habitat in San Diego Bay, California supports a unique assemblage of juvenile and adult fish that use other habitats (Pondella and Williams 2009). In a 24-year study of fish assemblages in eelgrass meadows in San Diego Bay and Mission Bay, California, 299 individuals of 50 species of fish were caught during 168 sampling events (Obaza, Hoffman, and Clausing 2015). Topsmelt was the most abundant species in both estuaries whereas California grunion *(Leuresthes tenuis)* and northern anchovy *(Engraulis mordax)* were almost exclusively found in San Diego Bay and in very few samples (Obaza, Hoffman, and Clausing 2015). Observations of California halibut *(Paralichthys californicus)*, a commercially fished species, occurred at



Shiner Surfperch, photo © Jonathan W Moore both sites. In Alamitos Bay, California, Valle, O'Brien, and Wiese (1999) identified a total of 42 species in eelgrass habitats. Catch was dominated by unidentified gobies (Gobiidae), bay pipefish *(Syngnathus leptorhynchus)*, and shiner surfperch (Valle, O'Brien, and Wiese 1999), although California halibut were observed. In eelgrass meadows throughout the Channel Islands, the number of fish species identified ranged from 4–18, and varied by site and season (Santa Barbara Channelkeeper 2010).

In Morro Bay, California, a total of 30–35 species were observed in zones of the estuary with eelgrass meadows (Fierstine, Kline, and Garman 1973). These areas contained nearly all of the observations of sharks and rays that were made during data collection (Fierstine, Kline, and Garman 1973). In Elkhorn Slough, a total of 21 species of fish and invertebrate species were found; species were more abundant in eelgrass habitat than other vegetated and bare habitat types (Grant 2009). Species richness in eelgrass habitats was greatest during the fall and lowest during the winter (Grant 2009). The most abundant species in the fall included juvenile three-spined stickleback *(Gasterosteus aculeatus)*.

(Gasterosteus aculeatus), juvenile shiner surfperch and juvenile-specific Pacific staghorn sculpin *(Leptocottus armatus)* (Grant 2009). A total of 43 species of fish representing 20 families used eelgrass meadows in Humboldt Bay (Garwood, Mulligan, and Bjorkstedt 2013). Four species—black rockfish *(Sebastes melanops)*, bay pipefish, shiner surfperch, and tubesnout *(Aulorhynchus flavidus)*—comprised nearly 75 percent of the total fish collected. Commercially and ecologically important species, such as Pacific sardine *(Sardinops sagax)*, steelhead *(Oncorhynchus mykiss)*, and lingcod *(Ophiodon elongates)*, were observed. Other research on fish distribution by habitat type in Humboldt Bay found 22 species of fish associated with eelgrass meadows; shiner surfperch and surf smelt *(Hypomesus pretiosus)* were the most abundant fish observed in eelgrass meadows (Schlosser 2007).

Species-specific observations, preferences, and life history use of eelgrass meadows have been documented along the U.S. West Coast. Pacific staghorn sculpin prefers estuarine habitat with muddy or sandy bottoms, which includes eelgrass, or other vegetation (Love 2011). Shiner surfperch prefer estuarine habitat that is shallow, calm, and complex, including eelgrass meadows (Onuf 1987; Pondella and Williams 2009; Dumbauld, Hosack, and Bosley 2015). Shiner surfperch are found in greatest densities in Yaquina Bay eelgrass meadows from June–October (Bayer 1985). Rockfish produce planktonic larvae that settle in the shallower portions of kelp beds, in eelgrass meadows, and floating kelp mats (Buckley 1997; Dean et al. 2000, Murphy, Johnson, and Csepp 2000, Wright et al. 2000, Gomez-Buckley 2001). Misitano (1970) found that English sole had the most dense concentrations in areas with mud and sparse eelgrass in Humboldt Bay (Toole 1987). Eelgrass is one of three preferred estuarine habitat types used by leopard sharks *(Triakis semifasciata)* in Northern California, including intertidal mudflats and tidal creeks (Hughes et al. 2014). In Alamitos Bay, barred sand bass *(Paralabrax nebulifer)* were captured almost exclusively in eelgrass (Valle, O'Brien, and Wiese 1999). Eelgrass meadows and green algae vegetation classes comprised more than 70 percent of the area used by bull trout *(Salvelinus confluentus)* in an acoustic telemetry study in the Skagit River, Washington (Hayes et al. 2011). Salmon and trout have been observed in eelgrass meadows throughout the U.S. West Coast, including San Francisco Bay (Boyer and Wyllie-Echeverria 2010), Humboldt Bay (Pinnix et al. 2013), Willapa Bay (Semmens 2008), Grays Harbor (Sandell et al. 2011), and Puget Sound (Simenstad, Fresh, and Salo 1982; Thom et al. 1989). In addition, coho salmon were observed in association with floating rafts of eelgrass in Humboldt Bay (Pinnix et al. 2013).

Although there is a general understanding globally of the relationship between eelgrass meadows and faunal abundance, few studies along the U.S. West Coast have examined the preference of fish and shellfish use of eelgrass habitats in comparison with other habitat types (Valle, O'Brien, and Wiese 1999).

In the Channel Islands off the coast of California, species diversity in eelgrass meadows can be nearly twice as high as on nearby sandy intertidal and subtidal habitats (Engle et al. 1995). Bed size and uniformity played a role in the diversity and abundance of fish observed; some fish (black surfperch—*Embiotoca jacksoni*) congregated around patch edges, whereas shiner surfperch were found in uniform beds compared to patchy sites (Santa Barbara Channelkeeper 2010). In Mugu Lagoon, decreases in fish abundance (specifically bay pipefish and shiner surfperch) were observed after eelgrass meadows were buried by sediments in a storm (Onuf and Quammen 1983). In Alamitos Bay, habitat use of juvenile fishes was documented for eelgrass meadows and unvegetated habitat; bay pipefish, shiner perch, giant kelpfish *(Heterostichus rostratus)*, spotted kelpfish *(Gibbonsia elegans)*, and others preferred, or were found exclusively in, eelgrass habitats (Valle, O'Brien, and Wiese 1999). Research conducted in North Humboldt Bay from 2003–2005 to understand fish community

ECOSYSTEM FUNCTION AND SERVICES

SUPPORTING SERVICES

Services necessary for the production of all other ecosystem services

PRIMARY PRODUCTION	Production of energy for the ecosystem.
HABITAT PROVISION AND FOOD WEB SUPPORT	General habitat provision and food web support for fish, birds,and invertebrates.
Trophic subsidy to other marine and terrestrial systems	Contributes to the food web and trophic support to neighboring habitats, including carbon export to adjacent systems and other nutrient cycling.
Food source and forage areas	Base of detrital food chain. Primary and secondary level food source.
Nursery habitat	Habitat serves as nursery ground, providing food and shelter for juvenile or spawning fish and shellfish.
Refuge	Habitat serves as refuge from predation, currents, or other disturbances.
Enhanced Reproduction	Habitat serves as a substrate for reproduction, or other use for reproductive purposes.

REGULATING SERVICES

Services that help regulate processes that benefit people and other parts of the ecosystem.

SHORELINE PROTECTION AND SEDIMENT STABILITY	Coastal protection through wave attenuation and sediment stabilization and accretion acting as a buffer against erosion. Prevention of sediment resuspension.
CLIMATE CHANGE REGULATION	Lessen impacts of anticipated climate change.
Mitigation of ocean acidification	Serving as a carbon sink to mitigate the threat of ocean acidification through time.
Carbon sequestration/storage	Global carbon sink, through uptake and long-term storage.
IMPROVEMENT OF WATER QUALITY	Trapping and storing particles and nutrients, including uptake of toxic contaminants such as PAH's and PCBS's. Reducing abundance of Harmful Algal Blooms (HABS).

PROVISIONING SERVICES

Products people obtain from the ecosystems, such as food, fuel, fiber, fresh water, and genetic resources

FISH AND SHELLFISH AS FOOD	Production of commercially important fish and shellfish species.
EELGRASS AS FOOD SOURCE	Eelgrass as a food source dipped in fish oil, and as tonic for health.
INSULATION AND FERTILIZER	Used in domestic insulation for buildings, as quilts, and as compost fertilizer.

CULTURAL & AMENITY SERVICES

Non-material benefits obtained from ecosystem

OPPORTUNITIES FOR RECREATION	Provide habitat for wildlife viewing opportunities and other recreational opportunities such as swimming through clearer, cleaner water and stable beaches, as well as recreational fishing.
AESTHETIC VALUES	Enjoyment of estuarine and coastal visitors through beauty and function.
EXISTENCE AND BEQUEST	Knowledge of system existence and continued existence for enjoyment by future generations.

photo © Scott Groth

structure in eelgrass, mudflat, and oyster culture habitats documented the greatest number of fish associated with eelgrass and oyster culture habitats; species diversity was higher in eelgrass compared to oyster culture (Pinnix et al. 2005).

In Coos Bay, Oregon, eelgrass meadows had a much greater biomass of fish than other channel or flat habitats (Bottom, Jones, and Rodgers 1988).

In Willapa Bay, Washington, juvenile Chinook salmon had a strong preference for remaining in native eelgrass, and exhibited no habitat preference for other structures, such as oyster beds, non-native eelgrass *(Z. japonica)*, and non-native cordgrass *(Spartina alterniflora)* (Semmens 2014). Hosack et al. (2006) found that benthic invertebrate densities were greatest in seagrass, however, fish and decapod species richness, and size of ecologically important species in Willapa Bay, were not significantly related to habitat type (Hosack et al. 2006). Monitoring after restoration of eelgrass and oyster reefs in San Francisco Bay showed that both habitat types supported unique invertebrate assemblages compared to pre-treatment and control plots (Pinnell et al. 2016).

Community associations of fish species in two species of eelgrass (*Z. japonica* and *Z. marina*) differed in Willapa Bay, WA and Yaquina Bay, OR (Sund 2015). The relative distribution of *Z. marina* and *Z. japonica* were different between bays—eelgrass meadows in Yaquina Bay were separated by a large band of unstructured mud, and those in Willapa Bay were growing together into one uniformly structured habitat type. Associations in Yaquina Bay differed between the two eelgrass habitats, whereas in Willapa Bay there were similar community compositions. This suggests that the presence of a continuous structured habitat serves to homogenize community composition across the entire range of tide heights. The distinct separation between the two seagrass habitats in Yaquina Bay seems to influence community structure more than tide height. In Yaquina Bay, 95 percent of the 22,171 shiner surfperch sampled were found in eelgrass sites sampled compared to mudflat sites sampled (Bayer 1985).

Research in Hood Canal, Washington, assessing mesopredator diversity across eelgrass vegetated, eelgrass edge, and unvegetated habitats found that overall abundance of fish was greater in eelgrass meadows than unvegetated habitats, however, this result was primarily due to the abundance of a few groups of species, namely surfperches and pelagic fusiform fishes (Gross et al. 2017). Several species of fish sampled in Nisqually River Delta, Washington, showed some affinity for eelgrass sites sampled compared to sites without eelgrass (Hodgson et al. 2016).

Conversely, species often associated with eelgrass meadows prefer other habitat types. Juvenile

TABLE 5. Commercially, recreationally, and ecologically important fish and invertebrate species use of eelgrass on the U.S. West Coast. Table adapted from Phillips (1984).

Scientific Name	Common name	Resident or Transient	Abundance	Living mode	Feeding Habits
Invertebrates					
Mytilus edulis	Blue mussel	R	X	S	SF
Crassostrea gigas	Pacific oyster	R	U	S	SF
Tresus capax	Horseneck gaper	R	C	B	SF
Tresus nuttalli	Pacific gaper	R	C	B	SF
Tagelus californianus	California jackknife clam	R	C-U	B	SF
Leukoma staminea	Native littleneck clams	R	C	B	SF
Venerupis phillippinarum	Manila clam	R	C	B	SF
Mya arenaria	Softshell clam	R	C	B	SF
Panopea abrupta	Geoduck	R	A-U	B	SF
Cancer magister	Dungeness crab	R	A	S-B	C
Fish					
Clupea harengus pallasi	Pacific herring	T	C	N	C
Clupea larvae		R**, T**	C	OB	X
Engraulis mordax	Northern anchovy	T	A-U	N	C
Anchoa delicatissima	Slough anchovy	?	C-U	N	X
Pleuronectes vetulus	English sole	R	A	S	C
Pleuronectes vetulus (juv)	English sole	R	A	S	C
Platichthys stellatus	Stary flounder	T	U	S	C
Paralichthys californicus	California halibut	R	C	N	C
Leptocottus arrnatus	Pacific staghorn sculpin	R	A	N	C
Ophiodon elongatus	Lingcod	T	U	N	C
Cymatogaster aggregata	Shiner perch	R*	A	N	C

Resident status	R= resident; T= transient; *seasonal occurrence; **= life cycle occurrence such as juvenile, larval
Abundance status	A= abundant, often observed in the field; C= common, present but not always observed in the field; U= uncommon, present in small numbers and seldom observed; X= unknown.
Living mode status:	OB= on blades; B=burrower; N= nekton; S= feeding or slightly above sediment surface
Feeding habit:	H= herbivore; D= detritivore; DP= deposit feeder; SF= suspension feeder; C= consumes fauna in eelgrass and eelgrass substrate; F= filter feeder, X= unknown
References:	Fierstine, Kline, and Garman, 1973; Peterson et al. 1983; Phillips, 1984; Thom et al. 1989; Emmett et al. 1991; Valle, O'Brien, and Wiese, 1999; Schlosser 2007; Hughes et al. 2014; Obaza, Hoffman, and Clausing, 2015; SEACOR, ODFW, 2017.
Credits:	Table adopted and modified from Phillips, 1984 (Table 13 a & b) using species identified in Emmett et al, 1991 and Hughes et al, 2014 to focus on commercially, recreationally, and ecologically important species on the West Coast. Additional life history details in references.

Scientific Name	Common name	Resident or Transient	Abundance	Living mode	Feeding Habits
Fish					
Ammodytes hexapterus	Pacific sand lance	R*	A	N	C
Hypomesus pretiosus pretios	Surf smelt	T	C	N	C
Spirinchus thaleichthys	Longfin smelt	T	U	N	C
Atherinops affinis	Topsmelt	R	C	N	C
Atherinops larvae		R	C	OB	
Microgadus proximus	Pacific tomcod	T	U	N	C
Gasterosteus aculeatus	Threespine stickleback	R	A-C	N	C
Atherinopsis californiensis	Jacksmelt	R	U	N	X
Paralabraw clathratus	Kelp bass	T**	C-U	N	X
Paralabrax nebulifer	Barred sand bass	R**	C-U	N	C
Atractascion nobilis	White seabass	T	C-U	N	X
Clevelandia ios	Arrow goby	R	C	N-S	X
Hypsopsetta guttulata	Diamond turbot	R	C	S	X
Anadromous Fish					
Oncorhynchus gorbuscha (juvenile)	Pink salmon	T**	C	N	C
O. keta (juvenile)	Chum salmon	T**	C	N	C
O. kisutch (juvenile)	Coho salmon	T**	A-U	N	C
O. tshawytcha (juvenile)	Chinook salmon	T**	U	N	C
O. clarkii	Cutthroat trout	T	C	N	C
O. nerka	Sockeye salmon	T	X	N	X
O. mykiss	Steelhead trout 6 (3 races)	T	X	N	X
Elasmobranchs					
Triakis semifasciata	Leopard shark	T*	C	N	C
Myliobatis californica	Bat ray	T	U	S	X

Resident status	R= resident; T= transient; *seasonal occurrence; **= life cycle occurrence such as juvenile, larval
Abundance status	A= abundant, often observed in the field; C= common, present but not always observed in the field; U= uncommon, present in small numbers and seldom observed; X= unknown.
Living mode status:	OB= on blades; B=burrower; N= nekton; S= feeding or slightly above sediment surface
Feeding habit:	H= herbivore; D= detritivore; DP= deposit feeder; SF= suspension feeder; C= consumes fauna in eelgrass and eelgrass substrate; F= filter feeder, X= unknown
References:	Fierstine, Kline, and Garman, 1973; Peterson et al. 1983; Phillips, 1984; Thom et al. 1989; Emmett et al. 1991; Valle, O'Brien, and Wiese, 1999; Schlosser 2007; Hughes et al. 2014; Obaza, Hoffman, and Clausing, 2015; SEACOR, ODFW, 2017.
Credits:	Table adopted and modified from Phillips, 1984 (Table 13 a & b) using species identified in Emmett et al, 1991 and Hughes et al, 2014 to focus on commercially, recreationally, and ecologically important species on the West Coast. Additional life history details in references.

Dungeness crab tended to favor unstructured habitats compared to seagrass meadows and oyster reefs (Holsman et al. 2006), and under laboratory conditions, crab preferred shell habitat to eelgrass (Fernandez, Iribarne, and Armstrong 1993). In Yaquina Bay, Oregon, juvenile rockfish preferred anthropogenic habitat (e.g., docks, pilings, and jetties) more than other habitat types, including eelgrass (Gallagher and Heppell 2010). California halibut densities were significantly different in Oceanside Harbor, Agua Hedionda, Batiquitos, Mission Bay and San Diego Bay, California. Valle, O'Brien, and Wiese (1999) found that California halibut were 2–6 times more abundant in unvegetated areas than in eelgrass meadows in Alamitos Bay. In Yaquina Bay, 70 percent of Pacific staghorn sculpins were captured from an upper intertidal site compared to an eelgrass meadow (Bayer 1985), suggesting that habitat structure may play a larger role in habitat preference than specific habitat type (Hosack et al. 2006).

Food Source and Foraging Areas

Eelgrass habitats serve as foraging areas for estuarine consumers through either direct herbivory of eelgrass leaves and seeds, or through secondary, or higher consumer level consumption of epibenthos, or the detritus their decaying leaves produce (Wyllie-Echeverria, Olson, and Hershman 1994; Blackmon, Wyllie-Echeverria, and Shafer 2006). Changes in eelgrass habitat cover can have profound effects on associated food web ecosystem services (Schmidt et al. 2011). In estuaries in Beaufort, North Carolina, food produced within eelgrass meadows, such as the eelgrass itself, crustaceans, gastropods, and detritus, could account for about 56 percent, by weight, of the diet of the eelgrass fish community (Adams 1976).

The importance of herbivory has been widely documented in seagrass systems worldwide (Thom, Miller, and Kennedy 1995). Although most trophic linkages in eelgrass meadows are at the secondary or higher consumer level, there are species that directly forage on eelgrass (Wyllie-Echeverria, Olson, and Hershman 1994). These include black brant, Canada geese *(Branta canadensis)*, American widgeon *(Mareca americana)*, gadwall *(Anas strepera)*, Northern pintail *(Anas acuta)* and mallard ducks *(Anas platyrhynchos)* (Wyllie-Echeverria, Olson, and Hershman 1994; Boyer and Wyllie-Echeverria 2010). Black brant forage almost exclusively on *Z. marina* as well as *Z. japonica* during overwintering in estuaries along the U.S. West Coast, including Morro Bay and Humboldt Bay in California, Yaquina Bay and Netarts Bay in Oregon, and Willapa Bay and Padilla Bay in Washington (Phillips 1984; Pacific Flyway Council 2002; Moore et al. 2004).

Isopods are another important eelgrass herbivore, contributing to important ecological processes in estuarine systems (Thom, Miller, and Kennedy 1995). In Padilla Bay, Washington, eelgrass density was positively correlated with the density of two ispopod grazers, Lacuna and Idotea (Thom, Miller, and Kennedy 1995), which was similar for both *Z. marina* and *Z. japonica* habitats.

Detritus contributes to coastal nutrient cycles and indirectly promotes the health of a fishery (Jackson et al. 2001). The basis of the fish food chain in eelgrass meadows is detritus and its associated microbial community (Adams 1976). Brook (1977) bridged the gap between detritus and higher trophic level predators (including valuable commercial and sport fishes) by identifying a number of transient foragers (Jackson et al. 2001). In the Strait of Juan de Fuca, conversion of nearshore vegetation to detritus was the most important food web process in the region (Simenstad et al. 1977).

Eelgrass meadows harbor a variety of species of infauna and epifauna that are known prey for many commercially valuable fish and invertebrates (Irlandi and Peterson 1991; Jewett et al. 1999). Eelgrass meadows are considered forage areas for a variety of fish species at the secondary or higher consumer level (Wyllie-Echeverria, Olson, and Hershman 1994). Micro-invertebrates associated with eelgrass, such as harpacticoid copepods, provide important contributions to the diets of juvenile Pacific salmonids, herring, smelts, and flatfishes (Sibert 1979; Simenstad et al. 1980; Simenstad and Wissmar 1985; D'Amours 1987; Simenstad et al. 1988; Thom et al. 1989; Webb 1989; Simenstad and Cordell 1992; Wyllie-Echeverria et al. 1995). In San Francisco Bay, California, invertebrate epifauna provide food resources for resident fishes, such as bay pipefish and shiner surfperch (Boyer and Wyllie-Echeverria 2010). In Humboldt Bay, California, 16 prey types of black rockfish and copper rockfish *(Sebastes caurinus)* were identified within eelgrass meadows (Studebaker and Mulligan 2009). In addition, the timing and location for pupping of leopard sharks seems to coincide with the availability of herring fish eggs in Humboldt Bay (Ebert and Ebert 2005). Grey smooth hound sharks *(Mustelus californicus)* may be foraging along eelgrass meadow edges at night where they have a higher chance of finding prey (Espinoza, Farrugia, and Lowe 2011).

Nursery Habitat

In general, a habitat is considered a nursery if a juvenile fish or invertebrate species occurs at higher densities, avoids predation more successfully, or grows faster compared to growth in other habitat types (Beck et al. 2001). In other parts of the United States and the world, decreased abundances commercially and recreationally important juvenile fish and shellfish species have been clearly associated with seagrass declines (Heck, Hays, and Orth 2003). Eelgrass-associated fish assemblages in Alaska often contain juvenile salmonids, sometimes in large numbers (Murphy et al. 2000; Johnson and Thedinga 2005). Off the coast of Washington, Oregon, and California, there has been limited research dedicated specifically to the role of eelgrass meadows as nursery habitat. Observations of juvenile fish tend to be limited to research on species richness and abundance of fish and invertebrates, or from general life history information.

Nursery functions of U.S. West Coast Estuaries (Hughes et al. 2014) identified preferred habitats for 15 fish and invertebrate focal species. Of these species, 12 had documented juvenile life stage associations with seagrass meadows including: Dungeness crab, leopard shark, bat ray, Chinook salmon, coho salmon *(Oncorhynchus kisutch)*, California halibut, English sole, starry flounder *(Platichthys stellatus)*, brown rockfish *(Sebastes auriculatus)*, Pacific staghorn sculpin, shiner surfperch, and Pacific herring. Blackmon, Wyllie-Echeverria, and Shafer (2006) identified eelgrass meadows as nursery grounds for Dungeness crab, juvenile rockfishes, juvenile salmonids, English sole, and Pacific herring in the Pacific Northwest

In Humboldt Bay, California, an eelgrass meadow received a large influx of YOY fishes May–August, including large numbers of YOY black rockfish, copper rockfish, shiner surfperch, and striped surfperch *(Embiotoca lateralis)*. Eelgrass meadows in Humboldt Bay also provide protection and prey for newborn leopard sharks (Ebert and Ebert 2005).

Eelgrass systems have specifically been identified as nursery habitat for YOY and juvenile rockfish (Bayer 1981; Matthews 1989; Love et al. 1991; Appy and Collson 2000; Murphy et al. 2000). In Yaquina Bay, Oregon, rockfish used eelgrass as habitat in the first year of their life (Bayer 1981; Appy and Collson 2000; Lindsley 2016), and most of the shiner perch observed were one year old or less during periods when they were most abundant (Bayer 1985).

Refuge

The structural complexity of eelgrass habitats can provide refuge from predators compared to less vegetated, or unvegetated, habitats (Orth, Heck, and Montfrans 1984; Wyllie-Echeverria, Olson, and Hershman 1994). Through small spatial and temporal scales, seagrass provides protection from predators and entrains invertebrate prey (Gotceitas, Fraser, and Brown 1997; Levin, Petrik, and Malone 1997; Linehan, Gregory, and Schneider 2001). In San Diego Bay and Mission Bay, California, a long-term study of fish assemblages did not demonstrate changes in the fish community, suggesting that eelgrass habitat may also provide refuge from long-term disturbances (Obaza, Hoffman, and Clausing 2015). In Grays Harbor, Washington, predation rates of Pacific staghorn sculpin on juvenile Dungeness crab were much lower in eelgrass meadows than in unvegetated habitat types (Armstrong, Armstrong, and Mathews 1995). Seagrass serves as a refuge against predators for some bivalve species, however, juvenile oysters were easily preyed upon by crabs when deployed to the bottom of the seagrass meadow (Smith 2016). The largest source of mortality for Pacific herring is predation by fishes, crabs, and birds, suggesting that eelgrass may provide an important refuge from predation for young herring (Blackmon, Wyllie-Echeverria, and Shafer 2006). In addition, drift vegetation (including seagrass), has been shown to provide refuge from predation for juvenile splitnose rockfish *(Sebastes diploproa)* (Blackmon, Wyllie-Echeverria, and Shafer 2006). Juvenile salmon, and in particular, pink salmon *(Oncorhynchus gorbuscha)* and chum salmon *(Oncorhynchus keta)*, may use eelgrass meadows during the day to avoid predators (Simenstad and Fresh 1982).

Enhanced Reproduction

Reproduction of fish and shellfish in eelgrass meadows is generally associated with plant substrate—the seagrass itself, or macroalgae associated with the seagrass community (Wyllie-Echeverria, Olson, and Hershman 1994). Eelgrass is the primary substrate used by Pacific herring to deposit eggs (Phillips 1984; Pentilla 2007; Fisheries and Ocean Canada 2009; Thom et al. 2014). Pacific herring spawning is associated with eelgrass meadows in U.S. West Coast estuaries, including multiple areas of Puget Sound in Washington, Tillamook Bay and Nehalem Bay in Oregon, and bays in California north of Monterey, including Humboldt, Tomales, and San Francisco bays. In Puget Sound, local seagrass declines caused local extinctions of spawning Pacific herring (Wyllie-Echeverria, Talbot, and Rearick 2010).

Coho Salmon, photo © Morgan Bond

Similarly, topsmelt spawn in eelgrass meadows, and the eelgrass blades are used as substrate to deposit eggs (Hart 1973). Topsmelt spawning occurs April–October along the Pacific coast from Monterey, California, to Southern British Columbia, including (but not limited to) Tomales Bay, California, Coos Bay, Oregon, and throughout Puget Sound, Washington. Topsmelt have also been observed spawning in restored eelgrass meadows in Frenchy's Cove of the Channel Islands (Santa Barbara Channelkeeper 2010).

Primary Production and Nutrient Cycling

Eelgrass meadows have high levels of primary production, ranking among the most productive ecosystems on the planet (Fourqurean et al. 2012; Cullen-Unsworth and Unsworth 2013). Eelgrass meadows form the basis of both grazer and detrital food webs, contributing to the trophic cascade of coastal ecosystems (CEC 2016). In addition, seaweeds and diatoms epiphytic or closely associated with seagrasses can form a significant proportion of the total primary production in the system (Thom 1988).

Numerous research efforts have been conducted to quantify primary production of organic material from seagrass meadows, including estimates specific to eelgrass on the U.S. West Coast. Although seagrasses occupy 0.2 percent of the area of the world's oceans, they are estimated to make use of about 10 percent of the yearly estimated organic carbon burial in the ocean (Cullen-Unsworth and Unsworth 2013). The average local net annual primary production rate of seagrasses is 278 g C m-2 (Kennedy et al. 2010; Duarte et al. 2013). Phillips (1984) summarized research on annual primary production in g C m-2 for eelgrass meadows in Humboldt Bay (266) in California, Netarts Bay (383) in Oregon, and Puget Sound (84–480) in Washington. In Grays Harbor, Washington, average annual total primary production from eelgrass was estimated to be 130 g C m-2 (Thom 1984). In 1988, Thom estimated the average net primary productivity for *Z. japonica* (44.7 g C m-2) and *Z. marina* (199.7 g C m-2) in Padilla Bay, Washington, which accounted for 2 percent and 48 percent of production in the eelgrass system, respectively (Thom 1988).

Trophic Subsidy to Adjacent Systems

Seagrass ecosystems provide a large subsidy to both nearby and distant locations through the export of particulate organic matter and living plant and animal biomass (Duarte, Middelburg, and Caraco 2005; Kaldy 2006; Heck et al. 2008, Kennedy et al. 2010). High proportions of net primary production can be exported across meters to hundreds of kilometers (Hyndes et al. 2014). Several pathways exist for seagrasses to subsidize other marine and terrestrial habitats (Heck et al. 2008), including seagrass leaves that directly enter the detrital pool, which can then be transported passively by currents and waves to provide habitat structure and trophic subsidy (Heck et al. 2008). Another pathway is through finfish that forage in seagrass meadows, and then transfer secondary production from seagrass to predators (Heck et al. 2008).

The influence of eelgrass on the local environment can extend up to 10 m from individual eelgrass patches, the distance being a function of the extent and density of eelgrass comprising the bed as well as local biologic, hydrographic, and bathymetric conditions (Webster et al. 1998; Böstrom and Bonsdorff 2000; Böstrom 2001; Ferrell and Bell 1991; Peterson et al. 2004; van Houte-Howes, Turner, and Pilditch 2004; Smith et al. 2008). Detrital enrichment will generally extend laterally as well as down slope from the beds, whereas fish and invertebrates that use eelgrass meadows may move away from the eelgrass core to areas around the bed margins for foraging and in response to tides or diurnal cycles (Smith et al. 2008).

From 1–20 percent of net annual primary production is exported from eelgrass meadows in North Carolina (Bach, Thayer, and LaCroix 1986). Substantial export of organic matter to surrounding habitats is based on primary production values in Puget Sound (Thom 1984, 1988).

Regulating Services

Shoreline and Sediment Stabilization

Eelgrass exerts an important influence on the sedimentary regime in two primary ways: (1) Through its extensive rhizome and root system, which form an interlocking matrix that bonds and helps to stabilize sediments and prevent coastal erosion (Phillips 1984; Larkum, Orth and Duarte 2006; Barbier et al. 2011); and (2) through its complex leaf structure, which slows current flow, reducing water velocity near the sediment-water interface, resulting in sedimentation of particles and inhibited resuspension of organic and inorganic material (Phillips 1984; Christianen et al. 2013). Seagrasses may contribute to bathymetric changes through sediment accumulation and shoreline accretion, which aids in shoreline protection (Duarte et al. 2013).

In Chesapeake Bay (U.S. East Coast), *Z. marina* stabilized sediments through reduction of water flow through roots and rhizome structures (Orth 1997). In Virginia, *Z. marina* meadows reduced near-bottom current velocities by 70–90 percent and wave heights by 45–70 percent compared to nearby unvegetated sediments, changing the seafloor from an erosional to a depositional environment (Hansen and Reidenbach 2012). To our knowledge, no specific research has been conducted along the U.S. West Coast to assess the ability of eelgrass to stabilize sediments and shorelines.

Water Quality and Clarity

Eelgrass meadows improve water quality locally and regionally by trapping and storing particulates and nutrients (Short and Short 1984; Gacia, Granata, and Duarte 1999; Asmus and Asmus 2000; Short et al. 2000; Wright 2002; Verwij et al. 2008). One study in Virginia demonstrated that water clarity was measurably improved as *Z. marina* became denser through an 8-year period (Orth et al. 2012). A 60-week-long feasibility study was conducted in seawater-supplied outdoor ponds to determine whether eelgrass *(Z. marina)* was capable of removing polynuclear aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) from submerged marine sediments (Huesemann et al. 2009). All PAHs and PCBs were removed to a much larger extent in sediments planted with *Z. marina* compared to unplanted controls. After 60 weeks of treatment, the concentration of total PAHs decreased by 73 percent in planted sediments, and only 25 percent in unplanted controls (Huesemann et al. 2009). To our knowledge, on the U.S. West Coast, no information is available on how eelgrass meadows improve water quality and clarity.

Bacteria associated with eelgrass meadows inhibits the growth of algae associated with Harmful Algal Blooms (HABs) (Inaba et al. 2014, 2017). In a recent study conducted in Padilla Bay, North Bay, and Dumas Bay in Puget Sound, Washington, algicidal and growth-inhibiting bacteria were found to be associated with *Z. marina* and *Z. japonica*, and algae associated with HABs was found in Westcott Bay, a location where eelgrass disappeared in 2002 (Inaba et al. 2017).

Ameliorating the Effects of Climate Change

<u>Carbon Storage</u>

Seagrasses reduce carbon dioxide in the water column while photosynthesizing, incorporating carbon into its tissues. Much of this leaf material remains in the seagrass meadow. Seagrass tissues, in addition to other organic matter filtered by seagrasses, become incorporated and stored in seagrass meadows. This process sequesters water-column organic carbon, facilitating carbon burial in sediments (Duarte et al. 2010; McCleod et al. 2011; CEC 2016). Consumption of seagrasses, their epiphytes, and nearby phytoplankton by grazers, and subsequent predation of grazers, contributes to the complex carbon capture, storage, and sequestration function in seagrasses (Lutz and Martin 2014). Carbon stored in coastal and marine ecosystems, such as seagrass meadows, is referred to as blue carbon (Smithsonian Museum of Natural

History website, http://ocean.si.edu/seagrass-and-seagrass-beds, accessed 5 February 2017).

Seagrass meadows are an important global source of blue carbon, accounting for an estimated 15 percent of net global CO2 uptake by marine organisms (Duarte and Chiscano 1999). Duarte et al. (2010) assessed that global seagrass carbon sink capacity is between 0.035 and 0.071 Gt C year-1. A study in Sweden shows 1 ha of *Z. marina*, sequesters 98.6 tons of carbon and 466 kilograms of nitrogen during a 20–50-year period (Cole and Moksnes 2016). One hectare of eelgrass, despite its much smaller living biomass, may hold as much carbon as one hectare of tropical rainforest due to high accumulation of carbon in sediments and belowground biomass (Pendleton et al. 2012).

Other studies have estimated "emissions" as a result of loss of coastal ecosystems. The loss of one hectare of eelgrass will lead to an immediate nominal loss of about 15.4 tons of carbon from live eelgrass and sediment to atmospheric CO2 (Cole and Moksnes 2016). Seagrasses, despite containing the lowest per-hectare carbon stocks of other coastal systems, may contribute the second most (first being mangroves) to global blue carbon emissions due to their larger areal extent globally (Pendleton et al. 2012).

A recent effort by Short et al. (2016) to develop information on blue carbon for eelgrass meadows along the Pacific Northwest coast estimated, using location-specific rates of CO2 sequestration by eelgrass and regional area estimates of eelgrass, that eelgrass in British Columbia absorbs up to 23,403 tons of CO2 annually. In Puget Sound, Washington, eelgrass absorbs 11,722 tons of CO2 annually; and in Oregon, 4,217 tons of CO2 are absorbed annually (Short et al. 2016).

<u>Mitigation of Ocean Acidification</u>

Seagrasses demonstrate potential to mitigate the effects of ocean acidification because they make use of dissolved forms of inorganic carbon for photosynthesis whereas other types of coastal vegetation use CO2 from the atmosphere, and they have a widespread distribution, representing the most productive and extensive submerged aquatic vegetation in estuaries and along rocky coastlines (Nielsen et al. 2018). Seagrasses are also likely often carbon-, rather than nutrient-, limited, owing to a dependence on dissolved carbon dioxide (relative to other marine photosynthesizes which are better able to utilize bicarbonate ion), and to the eutrophic state of coastal waters (Zimmerman et al. 1997).

Instantaneous photosynthetic rates may be more relevant for mitigating ocean acidification in the short term than the long-term effects of carbon cycling and storage (Miller 2016). Short-term carbon drawdown on the hourly scale coincides with timescales of rapid development for calcifiers, for whom sensitivity to ocean acidification is driven by the duration and intensity of exposure (Kurihara 2008; Talmage and Gobler 2009; Hettinger et al. 2012; Waldbusser et al. 2015b). This suggests that seagrasses may be able to improve times of favorable carbonate chemistry and lessen episodic extremes of unfavorable carbonate chemistry on hourly timescales, thus lessening the duration and magnitude of exposure to extreme acidification (Smith 2016).

This concept and mitigation strategy has been proposed by the Washington State Blue Ribbon Panel on Ocean Acidification (2012) and is currently being explored along the U.S. West Coast as a means to locally mitigate ocean acidification. In addition, recent legislation in California (Senate Bill No. 1363, Monning 2016) called for scientific and evidence-based approaches to protect and restore eelgrass meadows as a critical strategy in enhancing California's ability to withstand ocean acidification.

Provisioning Services

Human Food Source

Traditional ways of life have long been associated with seagrass meadows (Unsworth and Cullen 2010). On the U.S. West Coast, the Kwakwaka'wakw (formerly Kwakiutl) gathered eelgrass using eelgrass twisting sticks to harvest the plants (Boas and Hunt 1921; Kuhnlein and Turner 1991), which they then ate after dipping in fish oil. The Haida used eelgrass rhizomes to create a tonic for uterine or stomach problems (Turner and Efrat 1982). The Makah ate the rhizomes of several aquatic marine plants, including possibly eelgrass (Swan 1870; Gunther 1945; Gill 1982). The Hesquiat, of Vancouver Island, distinguished among two varieties of Z. marina based on leaf width and rhizome thickness and taste (Turner and Efrat 1982). Eelgrass ecosystems were recognized as a sustaining environment of the Straits Salish in the northern Puget Sound Basin (Suttles 1951). Among several cultures, the presence of eelgrass was recognized as an indicator that other desired food items were present (Wyllie-Echeverria et al. 1995).

Insulation and Fertilizer

Since European colonization, fishing communities have used detached leaves, deposited on the beach by tide and wind, as green manure and domestic insulation. Submerged *Z. marina* once formed the basis of a vigorous insulation industry in North America

Eelgrass Habitat photo © Andrew Weltz

(Wyllie-Echeverria and Cox 1999). Two companies manufactured seagrass quilts that were installed in many buildings of the period, including some of the first skyscrapers (Wyllie-Echeverria and Cox 1999).

Commercial Fishing

Seagrass meadows serve as critical habitat for commercially important finfish and shellfish (Gotceitas, Fraser, and Brown 1977; Phillips 1984; Stevens and Armstrong 1984; Fonseca, Kenworth, and Thayer 1992; Muehlstein and Beets 1992). For a list of commercially important species on the West Coast that are associated with eelgrass beds, see Table 5. Eelgrass provides a variety of services that are important to commercial fish, which are described above in the supporting services section (such as habitat provision, food web support, nursery habitat, refuge, and enhanced reproduction).

Cultural and Amenity Services

Today, eelgrass meadows contribute to recreational activities, such as swimming, by supporting clearer water and stable sandy beaches (Short et. al. 2000; Ronnback et al. 2007; Barbier et al. 2011; Tanner et al. 2014). Recreational fishing is improved in areas that depend on seagrass (Johnston et al. 2002; Francis 2012). This habitat type also has aesthetic value, which contributes to the enjoyment by many visitors of estuaries and coastlines (Wyllie-Escheverria et al. 1995). The beauty and function of seagrasses have been expressed through art and poetry (Darwin 1791; Standing, Browning, and Speth 1975; Felger and Moser 1985; Whitt 1988). Recreational opportunities, such as birdwatching, hunting, marine mammal watching, and recreational fishing enrich the lives of those that participate in these activities. For many people, merely knowing that rockfish exist and have habitat is valued (Short et al. 2000).

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RESULTS AND DISCUSSION

Expanding Knowledge of U.S. West Coast Eelgrass Extent

Previous efforts to summarize the extent of eelgrass along the U.S. West Coast have focused on available spatial data showing extent, or on literature and data from a particular ecoregion. In 2004, as part of the Essential Fish Habitat (EFH) designation process, a coastwide review was conducted that included all seagrass species found along the U.S. West Coast (NOAA 2004). The data compilation was based on spatial data available. Since that time, a significant amount of additional spatial data has been collected. A national effort in 2015 compiled eelgrass datasets that were already publicly available through state and federal agencies (BOEM 2015), although this effort did not always accurately extract eelgrass extent information. These efforts summarized known presence. In 1990, the Wetland Ecosystem Team at the University of Washington compiled historic data sources that described the areal extent of eelgrass in Puget Sound (Thom and Hallum 1990). This document summarizes the state of knowledge of the historic extent of eelgrass in Puget Sound. This summary was used in this current report as part of the historic summary of extent of eelgrass for the Salish Sea ecoregion.

Eelgrass extent data has been summarized on a state-by-state basis by the WA DNR SVMP database and Marine Vegetation Atlas, EPA aerial photography interpretation of eelgrass meadows in Oregon, ODFW SEACOR dataset in Oregon, CDFW eelgrass extent dataset in California, NOAA California eelgrass datasets, and the EcoAtlas eelgrass data layer. These efforts summarize spatial data depicting the extent of eelgrass in the region of focus, and were used in the current report summary and the complementary spatial dataset that was created as part of this effort.

Building on and expanding from this previous work, this current effort provides a fuller understanding of the coastwide eelgrass extent, including current and historic extent of eelgrass along the U.S. West Coast. It includes literature and data on eelgrass presence and absence as well as unsuitable habitat in 444 estuaries.

Limitations of Eelgrass Data on the U.S. West Coast

Eelgrass has been documented in 163 of 444 estuaries along the U.S. West Coast, including many areas of the nearshore within Puget Sound, and from Monterey Bay south to the border of Mexico. Dates of data collection, methods for data collection, and data post-processing methods vary across estuaries and datasets. This makes it challenging to standardize and compare data across the coast. Differences in data make it challenging to compare changes in eelgrass

extent over time; consistent methodology for data collection and processing is needed to accurately identify eelgrass extent changes.

A variety of data is collected in point and line format, which provides information on presence or absence of eelgrass, but does not provide information on spatial extent. To use these datasets to understand the spatial extent of eelgrass, data processing methods to interpret the extent can be used, but may not provide as accurate areal estimates of extent as other methods for collected eelgrass extent data.

Eelgrass is dynamic and varies by season and by year, therefore a change in eelgrass extent from one year to another does not necessarily indicate eelgrass loss or gain. Limited monitoring on the spatial extent of eelgrass using consistent methodology for data collection makes it difficult to quantitatively measure eelgrass habitat loss. In addition, timing of surveys may not correspond with high seasonal abundance periods of eelgrass, making it challenging to know whether or not changes in eelgrass extent are from natural variability or habitat loss or gain (Boyer and Wylie-Echeverria 2010). These limitations make identifying and monitoring specific threats to eelgrass habitat challenging, particularly on a U.W. West Coast-wide scale. Long-term monitoring of eelgrass extent, using consistent methodology, data processing methods, and timing is valuable for understanding eelgrass habitat losses.

Expanding our Understanding of the Ecosystem Service Values of Eelgrass Meadows on the U.S. West Coast

Previous reviews of ecosystem service values of eelgrass meadows have focused on a particular estuary, or have had a broad geographic scope. Boyer and Wyllie-Echeverria (2010) described information on ecosystem services provided by eelgrass meadows in San Francisco Bay. The Humboldt Bay Eelgrass Comprehensive Management Plan describes ecosystem functions and their values within Humboldt Bay (Gilkerson and Merkel 2014). Nordlund et al. (2016) describe the variability of seagrass ecosystem services among genera and geographic regions, including Zostera spp. in the temperature North-Pacific, which ranges from Korea to Baja Mexico.

Other reviews have focused on specific ecosystem services provided, such as habitat use of eelgrass meadows by fish and invertebrates. In 1994, the EPA published results from a seminar series in the Pacific Northwest, including a review on, "faunal associations and ecological interactions in seagrass communities of the Pacific Northwest Coast" (Wyllie-Echeverria and Phillips 1994). Simenstad et al. (1999) identified four ecosystem services relating to fish and invertebrate use of eelgrass meadows, including (1) unique or enhanced reproduction, (2) optimum foraging that results in significantly higher growth rates, (3) refuge from predation, and (4) optimization of physiological conditions affecting both growth and survival. In 2006, the U.S. Army Corps of Engineers sponsored a comprehensive summary of research related to fish use of seagrass and kelp habitats in the Pacific Northwest (Puget Sound north to Alaska) (Blackmon, Wyllie-Echeverria, and Shafer 2006). This research identified a data gap in evidence to support the nursery role of eelgrass habitats in the Pacific Northwest region. In our analysis, we have expanded the scope of the review to include Washington, Oregon, and California as well as the full suite of ecosystem services provided by eelgrass.

We expanded the understanding of the state of knowledge of ecosystem service information for U.S. West Coast eelgrass meadows. A key challenge in this literature review was that information in the literature is rarely presented in the context of the ecosystem service they provide (Nordlund et al. 2016). This effort advanced our knowledge of eelgrass ecosystem services by organizing literature along the U.S. West Coast into relevant ecosystem service categories.

Patterns of Fish and Invertebrate Use of Eelgrass Habitat

Based on this review of literature, much of our understanding of fish use, or habitat provision, of eelgrass meadows by fish and invertebrates along the U.S. West Coast comes from data associated with species assemblages, seasonal variability in use of eelgrass habitat, and species-specific life history patterns. Much of the eelgrass literature on the U.S. West Coast identifies a few fish species dominating a large proportion of the species assemblages within eelgrass meadows. Species include topsmelt, California grunion, northern anchovy, three-spined stickleblack, shiner perch, Pacific staghorn sculpin, black rockfish, bay pipefish, tubesnout, surf smelt, English sole, and Chinook salmon (Bayer 1981; Thom et al. 1989; Ellis 2002; Schlosser 2007; Grant 2009; Garwood, Mulligan, and Bjorkstedt 2013; Obaza, Hoffman, and Clausing 2015; Motley 2017). Eight of these 12 species dominate a large proportion of species assemblages in eelgrass meadows and are considered commercially, recreationally, or ecologically important species along the U.S. West Coast (Table 5).

Eelgrass extent and productivity can vary seasonally in temperate eelgrass meadows (Moore and Short 2006). Percent cover, shoot density, canopy height, and biomass are generally greater in summer months and lesser in winter months (Olesen and Sand-Jensen 1994; Hauxwell, Cebrian, and Valiela 2006; Kennish, Haag, and Sakowicz 2008; Rumrill and Sowers 2008; Hammerstrom and Grant 2012). Along the U.S. West Coast, seasonal changes in fish assemblages occur in the late spring and summer. In certain estuaries, such as San Diego Bay and Humboldt Bay in California, Yaquina Bay in Oregon, and Bellingham Bay in Washington, increases in species abundance are likely due to recruitment of YOY life stages of fish (Bayer 1981; Thom et al. 1989; Garwood, Mulligan, and Bjorkstedt 2013; Obaza, Hoffman, and Clausing 2015). Research in other regions suggests that temporal changes in species abundance of fishes and invertebrates correspond with changes in density of eelgrass (Mateo and Tobias 2008; Xu et al. 2016), suggesting a potential link between species abundance and eelgrass extent and productivity along the West Coast.

Along the U.S. West Coast, eelgrass meadows provide important habitat for commercially, recreationally, and ecologically important fish and invertebrate species. Numerous fish and invertebrate species use eelgrass habitat during one or more life cycle stages (Emmett et al. 1991; Hughes et al. 2014). Phillips (1984) provides the most extensive list of eelgrass-associated fish and invertebrate species based on regional literature and observations, documenting 69 species of fish, 191 species of invertebrates, and 80 species of birds associated with eelgrass meadows in the Pacific Northwest (Puget Sound to Cape Mendocino, CA). Table 5 was adopted from Philips (1984), and modified based on species from Emmet et al. (1991), with additions of missing focal species from the PMEP Nursery Assessment (2014). The table includes information from literature south to the border of Mexico, and describes the different uses of fish and invertebrates along the U.S. West Coast.

Important and Emerging Threats to U.S. West Coast Eelgrass Habitat

Along the U.S. West Coast, numerous reports document existing and emerging regional and worldwide threats to eelgrass. Table 6 lists the threats to eelgrass habitat by ecoregion, incorporating expert feedback from webinars and a survey. Overall, 19 threats to eelgrass habitat were identified specific to the U.S. West Coast in the literature and through expert input.

Of the threats identified, four were identified in all four ecoregions along the West Coast: increased sedimentation, coastal development, sea level rise, and sea temperature changes. Although destructive fishing practices and increases in CO_2 from climate change influences are frequently mentioned as a threat to seagrass habitats worldwide, they were not identified as threats to eelgrass habitats along the U.S. West Coast.

Increased Sedimentation

Increasing sediments to estuaries and the nearshore reduces water clarity and can stress eelgrass growth by reducing available photosynthetic light (Washington Department of Natural Resouces 2015). Major causes of sedimentation are channelization of rivers and deltas as well as agriculture, which can lead to changes in river discharge and stormwater runoff. Sediment loading can also lead to burial or fragmentation of eelgrass meadows (Washington Department of Natural Resources 2015).

Many of the rivers along the U.S. West Coast have been channelized, resulting in changes to sediment patterns (Bernstein et al. 2011; Washington Department of Natural Resources 2015). The report, "Recommendations for a Southern California Regional Eelgrass Monitoring Program," identified a need for research that examines the effects of sediment inputs on environmental parameters to help improve management of eelgrass meadows. In Puget Sound, restoration efforts of many riverine deltas and tidal wetlands are underway to reestablish natural levels of sediment delivery and storage to estuarine and nearshore systems.

Coastal Development

Coastal development leads to activities, such as shoreline armoring, overwater structures, impervious surfaces, outfalls, and general coastal infrastructure construction, all of which have localized impacts on eelgrass meadows. Shoreline armoring can disrupt natural sediment delivery and transport. Construction of overwater structures can have direct physical impacts on eelgrass meadows, and result in reduced light to eelgrass meadows, which can inhibit growth and increase eelgrass plant mortality. In-water construction includes installation of pilings, overwater structures, underwater cables, and outfalls and can lead to eelgrass plant mortality by physical uprooting or burying plants. Coastal infrastructure construction

TABLE 6. Threats to eelgrass habitats on the U.S. West Coast.

Threat	Salish Sea	Washington/Oregon, Northern California Coast	Central California	Southern California Bight
Biological and Chemical				
Invasive species	Thom et al. 2011; WA DNR 2015		Carr et al. 2011	PMEP Survey 2017
Nutrient-driven harmful algal blooms (HAB)	Thom et al. 2011; WA DNR 2015			Bernstein et al. 2011
Overfishing	Thom et al. 2011; WA DNR 2015			
Disease	Thom et al. 2011; WA DNR 2015		Boyer & Wyllie-Echeverria 2010; PMEP Survey 2017	Bernstein et al. 2011; PMEP Survey 2017
Herbivory	Thom et al. 2011		Boyer & Wyllie-Echeverria 2010	
Bioturbation	Thom et al. 2011; WA DNR 2015			Bernstein et al. 2011
Anthropogenic contaminants	Thom et al. 2011; WA DNR 2015; PMEP Survey 2017	PMEP Survey 2017		Bernstein et al. 2011; Huntington 2007
Physical and Land/Water Use				
Aquaculture	Thom et al. 2011; WA DNR 2015; PMEP Survey 2017	Tallis et al. 2009; PMEP Survey 2017		
Dredging & filling	Thom et al. 2011; WA DNR 2015			Bernstein et al. 2011; Melrose et al. 2015;
Freshwater input changes	Thom et al. 2011; WA DNR 2015			
Increased sedimentation	Thom et al. 2011; WA DNR 2015	PMEP Survey 2017	PMEP Survey 2017	PMEP Survey 2017
Coastal development	PMEP Survey 2017; Thom et al. 2011; WA DNR 2015; Fresh et al. 1995; Nightingale and Simenstad 2001; Thom et al. 2011	PMEP Survey 2017	PMEP Survey 2017; Boyer and Wyllie-Echeverria 2010	PMEP Survey 2017; Bernstein et al. 2011; Melrose et al. 2015
Propeller wash/ boat wake	Thom et al. 2011; WA DNR 2015		Boyer and Wyllie-Echeverria 2010	Bernstein et al. 2011
Boat grounding/ anchor	Thom et al. 2011; WA DNR 2015		Boyer and Wyllie-Echeverria 2010	
Climate and Geologic Events				
Sea level rise	Thom et al. 2011; WA DNR 2015; Shaughnessy et al. 2012	Shaughnessy et al. 2012; PMEP Survey 2017	Boyer and Wyllie-Echeverria 2010; Shaughnessy et al. 2012; PMEP Survey 2017	Shaughnessy et al. 2012; Melrose et al. 2015; PMEP Survey 2017
Sea temperature changes	Thom et al. 2011; WA DNR 2015; PMEP Survey 2017	PMEP Survey 2017	Boyer and Wyllie-Echeverria 2010; PMEP Survey 2017	Johnson et al. 2016; Melrose et al. 2015; PMEP Survey 2017
Storm events	Thom et al. 2011; WA DNR 2015			
Tectonic changes			Shaughnessy et al. 2012	
Other human impacts				
Lack of awareness		PMEP Survey 2017		

along the coast can increase runoff, sedimentation, and pollution. In San Francisco Bay, California, coastal development and settlement of the region led to filling and dredging of extensive areas, which likely would have been suitable for eelgrass habitat (Boyer and Wyllie-Echeverria 2010). As human populations continue to grow, increases in coastal development activities will likely occur, thus continuing to threaten eelgrass habitats in the future.

Sea Temperature Changes

Elevated temperatures directly affect eelgrass productivity and respiration. Extended periods of high temperatures can reduce eelgrass growth and survival. In Chesapeake Bay, Maryland, sustained high temperatures (>30 degrees C) in July–August 2005 are believed to have been the major driver for a massive dieback of eelgrass (Moore and Jarvis 2008). Experiments to test the effects of salinity and water temperature on the ecological performance of Z. marina showed that the optimum water temperature for eelgrass seemed to be between 10–20 degrees C (Nejrup and Pedersen 2008).

Changes in sea temperature may make shallow embayments or lagoons with poor tidal flushing most vulnerable to changes in sea temperature (Thom et al. 2011). In addition, elevated sea temperatures may also increase the risk of eelgrass to disease (Boyer and Wyllie-Echeverria 2010; Thom et al. 2011) and increase the frequency and severity of harmful algal blooms (Mauger 2015).

Sea Level Rise

Sea level is projected to rise in response to a global increase in air temperature, resulting in a shift in the distribution of existing eelgrass habitats (Short and Neckles 1999). Relative rates of sea level rise will vary depending on local factors, including eustatic sea level rise (related to change in the quantity of water or the shape and capacity of ocean basins), sediment elevation change, and tectonic elevation change (Shaughnessy et al. 2012). For example, in central Puget Sound, sea level is rising faster than the global eustatic rate because of land mass subsidence (Thom et al. 2011). Eelgrass habitat losses will occur when the rate of bottom change surpasses the eustatic rate and the eelgrass cannot survive the levels of desiccation and wave energy occurring at shallower depths into which it is being pushed (Fonseca and Bell 1998; Koch 2001; Boese, Robbins, and Thursby 2005). This is known as the ejection effect (Shaughnessy et al. 2012).

Another possible change in eelgrass meadows occurs with changes in light attenuation as the depth of the eelgrass meadow increases. These changes will be especially prominent at the deep edge of the bed, and impact varies by location. In eelgrass meadows in which water is more turbid, the changes in light attenuation may have a greater impact. For example, eelgrass is distributed across a much wider depth range in central Puget Sound than in Willapa Bay, Washington, most likely because light penetrates further in the clearer waters of Puget Sound (Thom, Southard, and Borde 2014). In this scenario, the survival of eelgrass meadows will depend on the availability of suitable eelgrass habitat on the landward side of the bed (i.e., a landward migration zone). Where habitat is available, eelgrass may be able to respond and move upslope. However, areas that have been heavily modified from coastal development (shoreline armoring and other coastal infrastructure) will have limited landward migration opportunities. This scenario is known as the extinction effect (Shaughnessy et al. 2012). In areas on the U.S. West Coast that are more limited in the depth band for eelgrass, such as estuaries in the Washington, Oregon, and Northern California ecoregion, the ability for eelgrass meadows to migrate landward may be more important than in other regions. In general, estuaries demonstrate a wide variety of bottom change directions, rates, and upland slopes, thus the consequences of sea level rise on total eelgrass habitat size will vary among estuaries.

Additionally, changes in salinity from sea level rise may influence eelgrass distribution and abundance. Salinity intrusion into predominantly fresh water environments and stress from elevated salinities may impact eelgrass meadows (Short and Neckles 1999).

Several entities have predicted eelgrass response to sea level rise along the U.S. West Coast. Clinton and others at EPA in Newport, Oregon, recently constructed a spatial model that mapped eelgrass distribution under SLR scenarios (Clinton, Young, and Specht 2014), using elevation (bathymetry), distance to the mouth of the estuary, and distance to the center of the channel (thalweg) as the major inputs. Shaughnessy et al. (2012) modeled the effects of sea level rise on total eelgrass habitat area availability to foraging black brant in seven estuaries, including estuaries in Washington and California. In South Humboldt Bay in California and Willapa Bay and Padilla Bay in Washington, eelgrass will eventually decline because of the extinction effect as beds move into upland barriers. On a shorter timescale, a relative elevation model for Padilla Bay demonstrates that, during the next century, there may be expansion of eelgrass within Padilla Bay (Kairis and Rybczyk 2010). The ejection effect in North Humboldt Bay and Morro Bay poses a more immediate threat (Shaughnessy et al. 2012).

There is a complex interaction among water level variation, temperature, and light as mechanisms that regulate variation in eelgrass, complicating the ability to predict the effects of climate variation and climate change on this important resource (Thom, Southard, and Borde 2014). Although coastal development and increased sedimentation can be ameliorated at the local level, larger scale impacts from climate change will increase vulnerabilities to eelgrass habitats.

Data and Knowledge Gaps

This effort to collect and compile currently available data and information describing the extent of eelgrass along the U.S. West Coast identified many data gaps (Table 7). Eelgrass extent varies, both seasonally and annually, thus the current status of eelgrass meadows

TABLE 7. Data and knowledge gaps and limitations of eelgrass habitats on the U.S. West Coast.

Data or Knowledge Gap	State	Estuaries
No Shorezone Data	California	All estuaries
Present in Shorezone only, no other extent data	Washington	Ship Harbor Lagoon, Flounder Bay, Saratoga Pass Tidelands, Days Island Harbor, Chambers Creek, East Oro Bay, Oro Bay, Dewato Bay, Hamma Hamma River, Fisherman Harbor, Zelatched Point Lagoon, Broad Spit, Twin Spits, Tahuya River, Foulweather Bluff, Bridgehaven
Present in Shorezone, absent in other data sources	Washington	North Bay, Elwah River, Tahuya River, Foulweather Bluff, Bridgehaven, Clear Creek, Barker Creek, Phinney Bay
Present in Shorezone and literature, no spatial extent data exists	Oregon	Barker Creek, Rogue River, Chetco River
Data representing deep edge of the bed, most data collected through aerial imagery.	Oregon	All estuaries in Oregon (except Coos Bay)
Estuaries in Washington, Oregon, Northern California Coast ecoregion: 56% have no data	Washington Oregon, California	62 estuaries in ecoregion
Present in literature, no extent data	California	Long Beach Harbor, Dana Point Harbor
Estuaries with the most current extent data over 10 years old	Washington	Willapa Bay
	Oregon	Nehalem River, Sand Lake, Nestucca Bay, Salmon River, Siuslaw River, Umpqua River, Coquille River
	California	Ventura Marina, Channel Islands Harbor, Marina del Rey, Los Angeles Harbor, San Diego River


photo © Andrew Weltz

is difficult to quantify. Nearly 40 percent of U.S. West Coast estuaries have no data or information for eelgrass, likely a result of unsuitable habitats within particular estuaries. However, lack of data and information on particular estuaries may also be due to the size of the estuary and the lack of attention certain estuaries receive along the U.S. West Coast. Although little is known about smaller, or less studied, estuaries, they may play a key role in habitat provision on the U.S. West Coast, particularly as ecological conditions change. In a variety of locations where observations of eelgrass presence have been made, there have been insufficient efforts to map the extent of eelgrass in the area. Other estuaries have data depicting the extent of eelgrass, however, the methods used to delineate the extent are unknown, or the information itself is outdated. Table 8 lists estuaries along the U.S. West Coast with data gaps and limitations.

In general, monitoring of the distribution of all eelgrass species is needed to document losses of this critical habitat type. There have been documented losses of eelgrass throughout the world, however, knowledge of these losses on the U.S. West Coast is limited to estuaries and nearshore areas that are well monitored. For example, eelgrass extent has been consistently monitored in Morro Bay in California since 2002. In 2013, the estuary exhibited significant losses of more than 90 percent of eelgrass habitat within the bay (Morro Bay National Estuary Program 2017). These losses were recognized and quantifiable as significant (and not just due to inter-annual variability) because of consistent annual monitoring using consistent methodology and geographic scope of eelgrass meadows in the bay. Investigations into the cause of eelgrass loss and investments in restoration of habitat in Morro Bay are currently underway. Monitoring requires consistent effort and yields valuable information on changes to the habitat that might be otherwise unrecognized (Moore and Short 2006).

The dynamic nature of eelgrass meadows seasonally and annually make it difficult to manage. Policies that manage habitats tend to consider eelgrass as "static" and do not take into consideration the changes in eelgrass habitat that occur naturally over time. In the Salish Sea, it is estimated that the extent of eelgrass meadows will expand or contract by 4-5 meters annually (Washington Department of Natural Resources 2012), however, general changes in extent are not well understood for other regions. Better understanding of how eelgrass meadows can expand and contract over time, and integrating that information into management plans and policies, may help better protect eelgrass habitats in the future.

Although eelgrass ecosystem services are well-documented worldwide, this review of ecosystem services on the U.S. West Coast identified information gaps relative to the function these services provide specific to this region. A better understanding of the ecosystem services associated with specific seagrass genera and regions are important to improve management decisions (Nordlund et al. 2016). Regulating services, such as the ability of eelgrass to stabilize sediment and shoreline, filter and improve water quality, mitigate ocean acidification, sequester carbon, and uptake toxic chemicals, have not been well studied or quantified along the U.S. West Coast. Although supporting services are well described, including habitat provision and food web support, how fish and invertebrates use this habitat type is not well understood. Significant information gaps exist on how eelgrass provides refuge, enhances reproduction, and maintains life cycles of migratory species (such as anadromous fish) on the U.S. West Coast. Little information is available on the relationship of density of eelgrass and/or eelgrass patchiness and fish and invertebrate use and abundance along the U.S. West Coast.

A global review of seagrass ecosystem services by Nordlund et al. (2017) indicates that the only "unknown" ecosystem service for the North Pacific region (Korea to Baja Mexico) is human food from associated eelgrass species (such as fish). However, this conclusion is in stark contrast from the general understanding that eelgrass provides habitat for commercially important fish and invertebrate species. Table 6 in this report lists commercially, recreationally, and ecologically important fish and invertebrate species and their habitat association with eelgrass along the U.S. West Coast. Despite the link between habitat and fish use, a more direct quantitative understanding of how eelgrass habitats support fisheries is needed for the U.S. West Coast.

More research is needed to quantitatively understand the value of eelgrass as nursery habitat along the U.S. West Coast and its relative contribution to recruitment and survival of adult fish and invertebrates compared with other habitats. The concept that eelgrass plays a unique role in providing nursery function has been challenged by the concept that structure of habitat may be the more important function than the habitat type itself (Beck et al. 2001; Heck, Hays, and Orth 2003; Blackmon, Wyllie-Echeverria, and Shafer 2006). There is research that demonstrates that the abundance, growth, and survival of fish and invertebrates is generally greater in eelgrass habitats than in unvegetated habitats (Valle, O'Brien, and Wiese 1999; Pinnix et al. 2005; Hodgson et al. 2016; Gross et al. 2017). However, these direct comparisons of eelgrass habitats and other habitat types are rare, especially along the U.S. West Coast (Deangelis et al. 2016). Some studies on the U.S. West Coast do not demonstrate preferential use of juvenile fish and invertebrate use of eelgrass compared to other habitat types. Other studies that have compared multiple habitat types (Levin, Petrik, and Malone 1996; Fodrie and Mendoza 2006; Hosack et al. 2006; Espinoza, Farrugia, and Lowe 2011; Dumbauld, Hosack, and Bosley 2015; Sund 2015; Lindsley 2016), have concluded that structure, compared to habitat type, plays a more critical role in nursery function (Heck, Hays, and Orth 2003; Hosack et al. 2006). Some research comparing habitat types supports the nursery hypothesis specifically for the U.S. West Coast, i.e., fish and invertebrates were found in great abundance, or had a greater species richness in eelgrass habitat than other habitat types (Thom et al. 1989; Valle, O'Brien, and Wiese 1999; Pinnix et al. 2005; Semmens 2008; Grant 2009), however, information for this region is limited.

Both *Z. marina* and *Z. japonica* are referred to, in the literature, as ecosystem engineers (Larkum, Orth, and Duarte 2006; Orth et al. 2006; Sund 2015), although *Z. japonica*, a non-native species to the U.S. West Coast, is considered a nuisance species in Washington and in California. *Z. japonica* is found higher in the intertidal zone, and may compete for non-vegetated habitats, such as mudflats and shellfish beds (Sund 2015), which provide values and services to the ecosystem. *Z. japonica* may actually be "reserving" space for future migration of *Z. marina* as habitats shift with sea level rise. In addition, two different studies suggest that *Z. japonica* has a higher photosynthetic rate than *Z. marina*, and therefore, may better mitigate local and short-term ocean acidification events compared to its native counterpart (Miller 2016; Smith 2016). It is unknown if the expansion of *Z. japonica* will have a long-term positive or negative impact on ecosystem function (Shafer, Kaldy, and Gaeckle 2014; Sund 2015). In general, there is an intrinsic value associated with native species (Sund 2015).

Data depicting the extent of *Z. japonica* and *Z. pacifica* is limited along the U.S. West Coast (Mach et al. 2010). Future data collection efforts need to distinguish between native and non-native species.

Considerations and Approaches to Fill Data Gaps

Across the U.S. West Coast, different methods are used to collect and process data on eelgrass extent, however trends exist within regions of the coast. In the Salish Sea, the primary source of eelgrass extent data is from WA DNR SVMP, which uses towed underwater video along with depth measurements to identify the extent of eelgrass. On the outer coast of Washington, Oregon, and Northern California, aerial photography and satellite image interpretation, along with ground-truthing, are the main methods used to map the extent of eelgrass. In Central California, a combination of aerial imagery and side-scan sonar, along with ground-truthing, are typical methods used. In the Southern California Bight region, a combination of side scan sonar and ground-truthing is used. There are benefits and challenges to each of these methods. The method used in one region may not be the optimal method in another region because of the characteristics of the eelgrass. For example, large eelgrass meadows that have a more shallow depth range, such as those found in Oregon estuaries, can be productively assessed using aerial imagery with ground-truthing. Limitations to aerial imagery include missing the deeper edge of the eelgrass meadow, and challenges associated with distinguishing different types of submerged aquatic vegetation from eelgrass. Therefore, in places such as Puget Sound, where the deep edge of the meadow varies significantly, aerial imagery is not the optimal stand-alone monitoring method. Rather, side-scan sonar is the preferred method. A suite of methods that will best measure the extent of eelgrass meadows, monitor the depth range and scale, and process data consistently, will be most appropriate to understand long-term changes in extent of eelgrass across the U.S. West Coast.

The State of Washington has identified protocols for delineating the extent of eelgrass meadows (U.S. Army Corps of Engineers 2018). The protocols were developed to guide activities that require permits under Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403). The document describes several methods that should be used to map the extent of eelgrass based on the size of the eelgrass meadow. Methods include ground-truthing (walking, wading, snorkeling, or SCUBA diving), hydroacoustic mapping, or aerial photography. Strengths and limitations for each method are given, and recommendations for combining methods, such as aerial photography and ground-truthing, are outlined. Other regions along the U.S. West Coast should develop and adopt protocols that best suit the needs of the state or region. This will help encourage more standardized data collection within regions and along the U.S. West Coast, which in turn will lead to better monitoring and an understanding in the changes of extent of eelgrass along the U.S. West Coast.

In addition, the appropriate seasonal timing of surveys should be outlined in any eelgrass monitoring protocol recommendations. Extent monitoring should occur when eelgrass extent is known to be at its greatest during the year. In the Salish Sea, above-ground leaves and shoots are at their highest densities from June 1–October 1 in this region, thus mapping extent of eelgrass is recommended during this period (U.S. Army Corps of Engineers 2018). In the Southern California Bight, seasonal timing of surveys is recommended from August through October to capture the maximum developed extent of eelgrass beds (Bernstein et al 2011).

A variety of methods are used to collect information on fish and invertebrate use of eelgrass and other habitat types; lack of standardization is caused by data collection techniques that vary with season, location, species, and life stage of fish (Yoklavich et al. 1991). When standardized data collection methodologies are used, the paired habitat data collection methods for eelgrass and other habitat types is generally limited to notes of "presence" compared to collection of extent (describing quantitative area) data, limiting the analysis to generalized habitat associations. Additionally, certain methodologies used across habitat types found reduced sampling efficiency in eelgrass meadows (Simenstad et al. 1977); therefore, efficiency of sampling methodology should be taken into consideration when choosing sampling protocols. The U.S. West Coast fish and habitat science community should engage in conversation, through a focused workshop, about the best available data collection techniques to develop a suite of methods, based on species, season, and life stage of fish, and how they can be sampled efficiently across different habitat types to better understand quantitative ecosystem service values of different habitat types.

In general, to enhance our knowledge of ecosystem service values of eelgrass habitats along the U.S. West Coast, a suite of more standardized approaches to data collection should be used for monitoring both the eelgrass extent and fish and invertebrate use of eelgrass. The collection of areal extent of eelgrass habitat data in conjunction with fish and invertebrate sampling will help fill these data gaps and allow for more regional and coastwide scale analyses of the quantifiable contribution of eelgrass habitat services.

Management Strategies to Protect and Restore Eelgrass Habitats and Their Ecosystem Functions

Conservation and protection of eelgrass habitats along the U.S. West Coast is important to maintain the ecosystem functions provided by this habitat. Restoration is an important strategy in locations in which there have been declines in eelgrass extent, and where suitable eelgrass habitat exists. Eelgrass restoration and mitigation activities are needed due to habitat loss from coastal development, dredging and filling of bays, and other anthropogenic stressors.

Along the U.S. West Coast, eelgrass restoration efforts have had mixed results. One restoration effort in San Diego Bay in California demonstrated that within one year, the restored eelgrass meadow produced fish colonies similar to a reference site (Pondella et al. 2006). Restoration efforts in Anderson Island, Liberty Bay, and Westcott Bay in Puget Sound have had less successful results (Thom et al. 2014). Future restoration and mitigation efforts should incorporate ecosystem service values, such as habitat provision, as one of the key outcomes of design criteria to demonstrate success of the restoration effort.

Information about threats to eelgrass habitats (Thom et al. 2012) and habitat requirements of eelgrass should be considered before selecting eelgrass restoration sites. Considerations should include historic evidence of eelgrass; local potential threats (overwater structures, shoreline armoring, shipping and boating, water quality); longer-term climate change considerations, such as landward migration potential and projected temperature changes; depth; distance from ocean connection; salinity; temperature; substrate sediment type; local currents; waves and storminess; and local stakeholder input (Region 2014; Thom et al. 2014).

Other considerations for restoration and management of eelgrass habitat should include the suite of habitats available in the focus area. Much of the research on eelgrass ecosystem services suggests that it is the structure of habitat, compared to the specific habitat type, that may play a more important role in the enhancement of nursery functions (Peterson and Heck 2001; Heck, Hays, and Orth 2003). In San Francisco Bay, California, a unique invertebrate assemblage was supported during restoration of eelgrass and oyster reefs (Pinnell et al. 2016). In Elkhorn Slough, California, the heterogeneity of habitat (oyster racks and submerged rocks) resulted in increased species richness (Yoklavich et al. 1991). Considerations for the entire estuarine and nearshore ecosystem need to be considered when managing resources and planning for restoration.

The need exists for landscape-scale management considerations to mitigate effects from local threats and develop resilience-building adaptation strategies. Incorporating local, or regional, ecosystem service values into management considerations will be important to maintain the services provided by these critical habitats.

Future management strategies need to incorporate outreach to the public about the value of eelgrass ecosystem services. Relationships between humans and seagrass meadows throughout the world highlight the role that seagrasses play in human well-being (Cullen-Unsworth et al. 2014). Along the U.S. West Coast, recent research has demonstrated that more localized threats may be playing a large role in eelgrass decline (Washington Department of Natural Resources 2015; Shelton et al. 2016). Outreach on the value of eelgrass habitats may help reduce local threats through increased conservation and restoration initiatives.

Conclusion

In this report, we have summarized existing data and literature on the ecosystem services and spatial distribution of eelgrass habitats along the contiguous U.S. West Coast of the United States. We have documented eelgrass presence in 162 estuaries, identified specific ecosystem service values of eelgrass habitats in the region, and identified knowledge gaps in our understanding as well as threats to this important habitat type. This information can serve as a guide for future research on U.S. West Coast eelgrass habitats and the ecosystem services and functions they provide.

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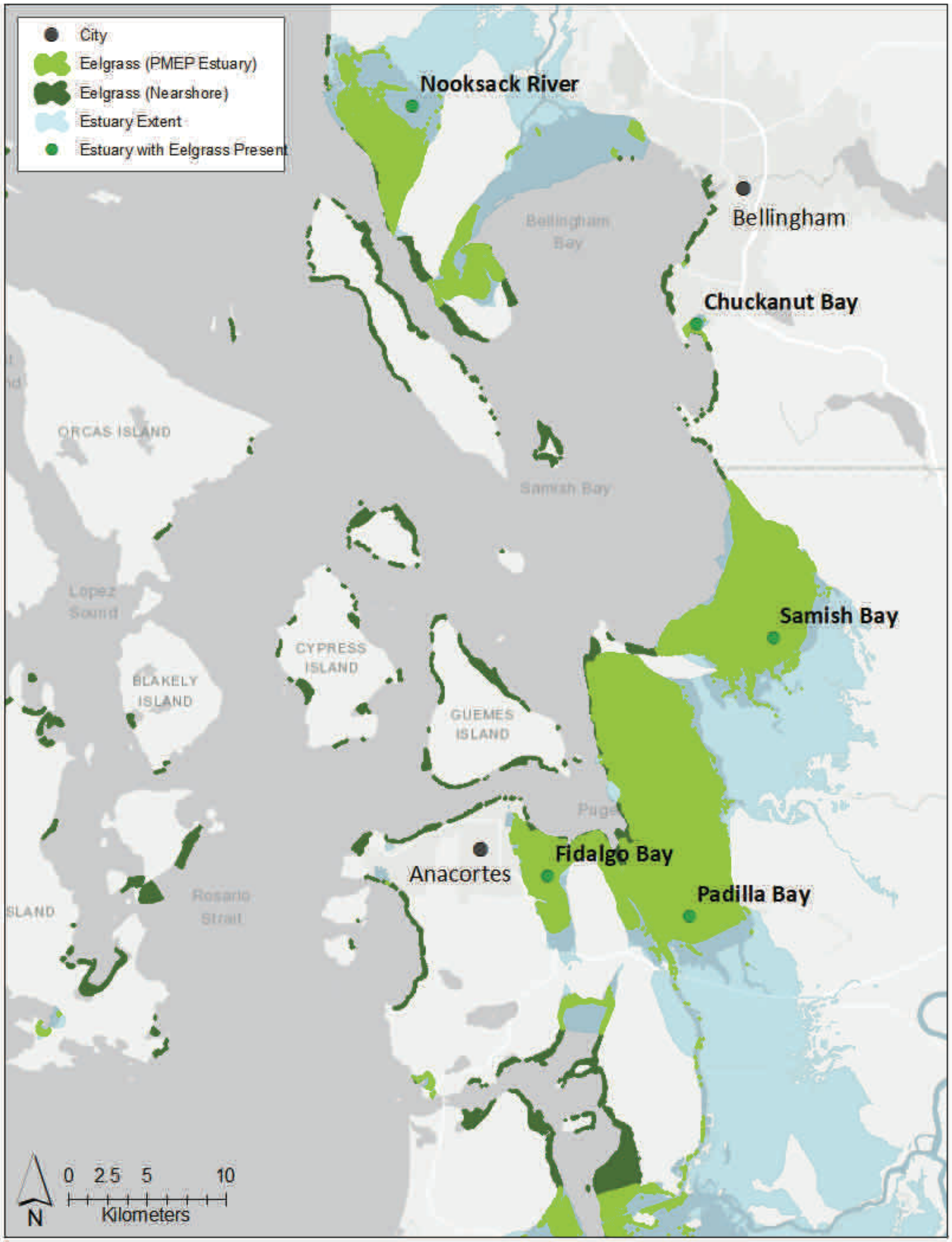
APPENDIX A

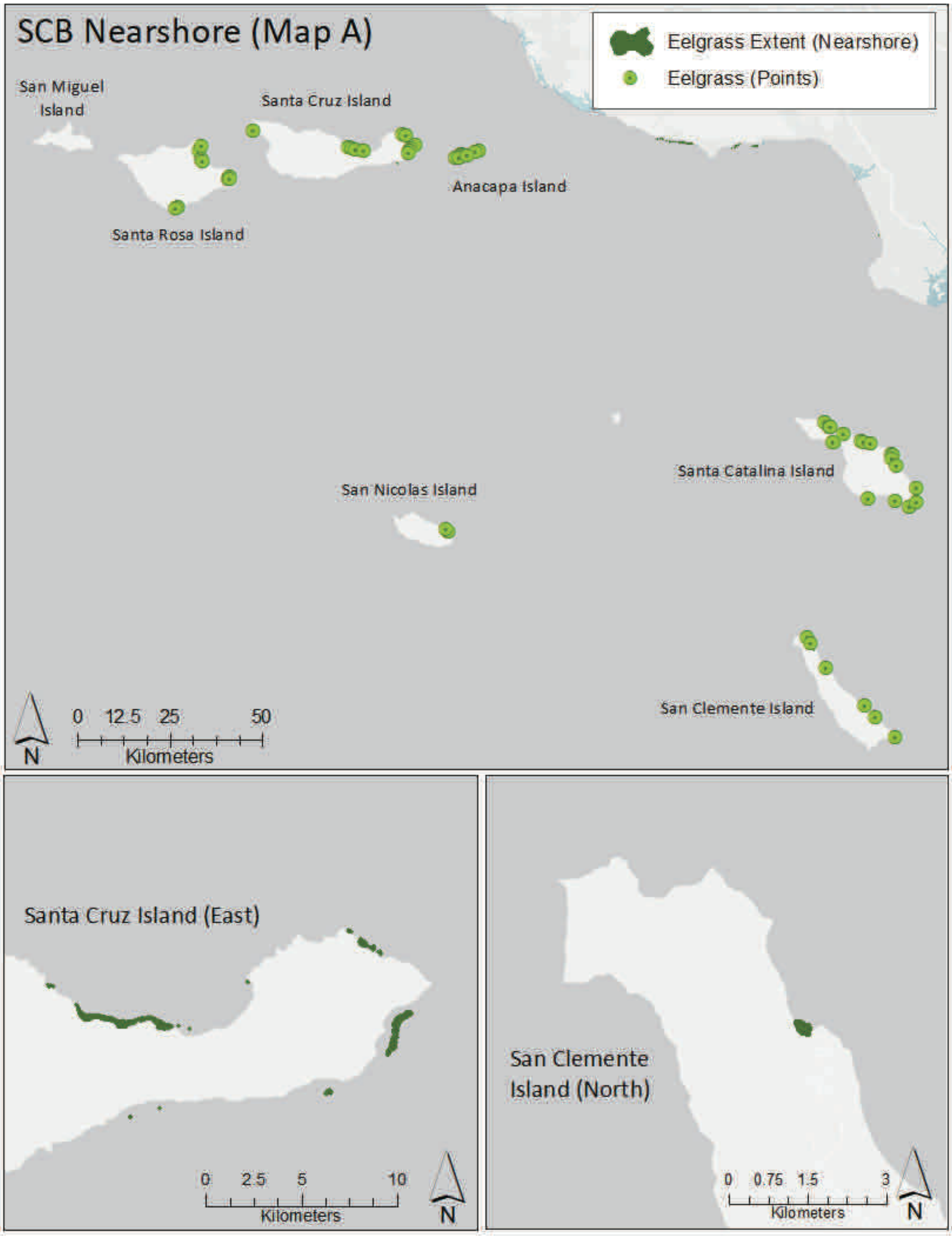
Example of eelgrass extent in estuaries and nearshore areas of the Salish Sea Region.
To view full extent of nearshore beds along the West Coast, go to: www.pacificfishhabitat.org/data.



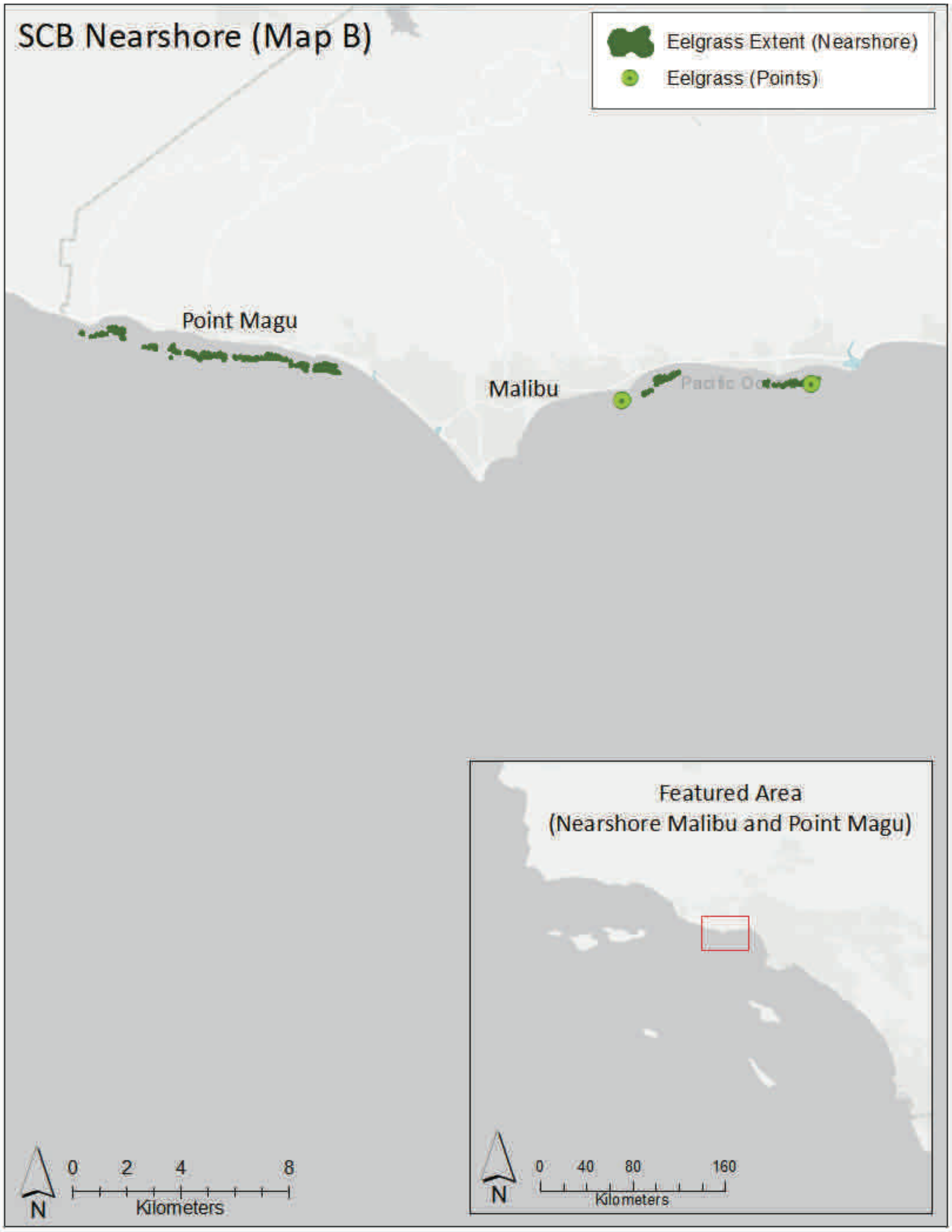
Overview map of eelgrass extent and observations of eelgrass in the Channel Islands and nearshore areas of mainland Southern California Bight.

To view full extent of nearshore beds along the West Coast, go to: www.pacificfishhabitat.org/data.

Map of eelgrass extent and observations of eelgrass in the Channel Islands.
To view full extent of nearshore beds along the West Coast, go to: www.pacificfishhabitat.org/data.

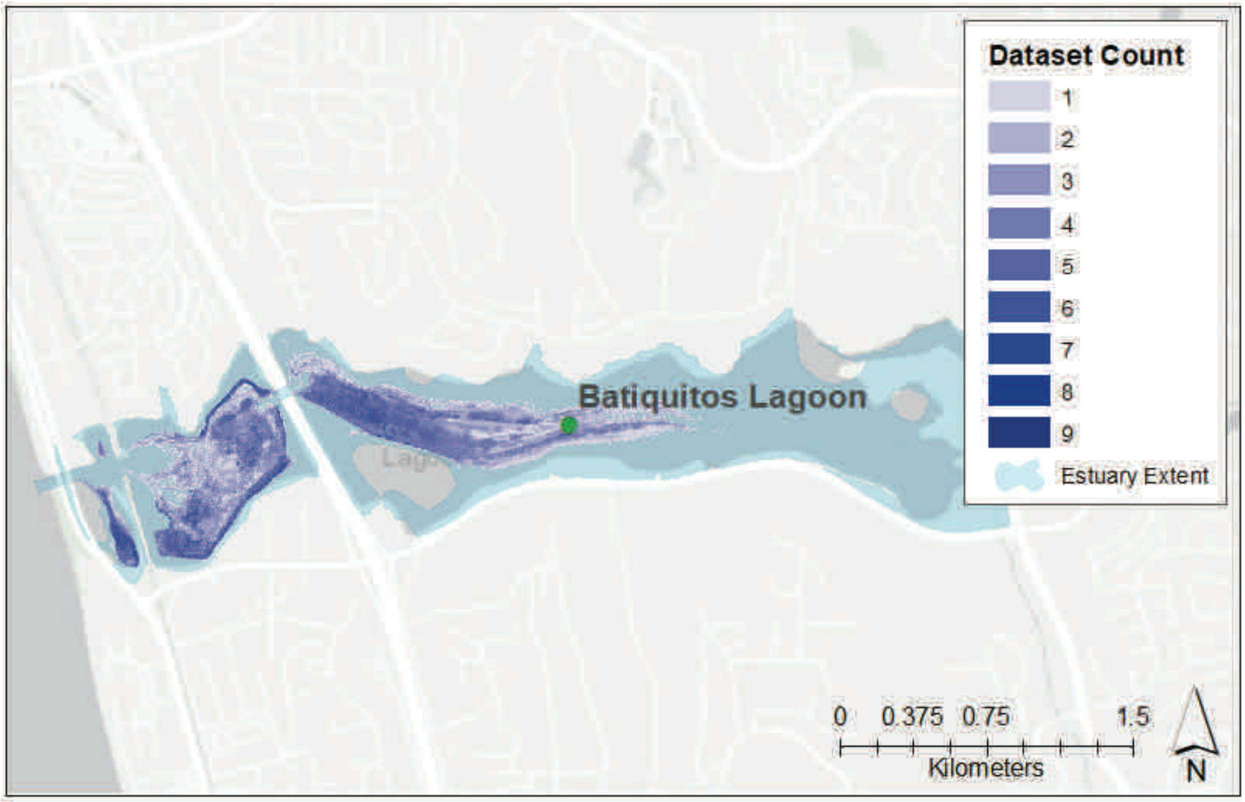


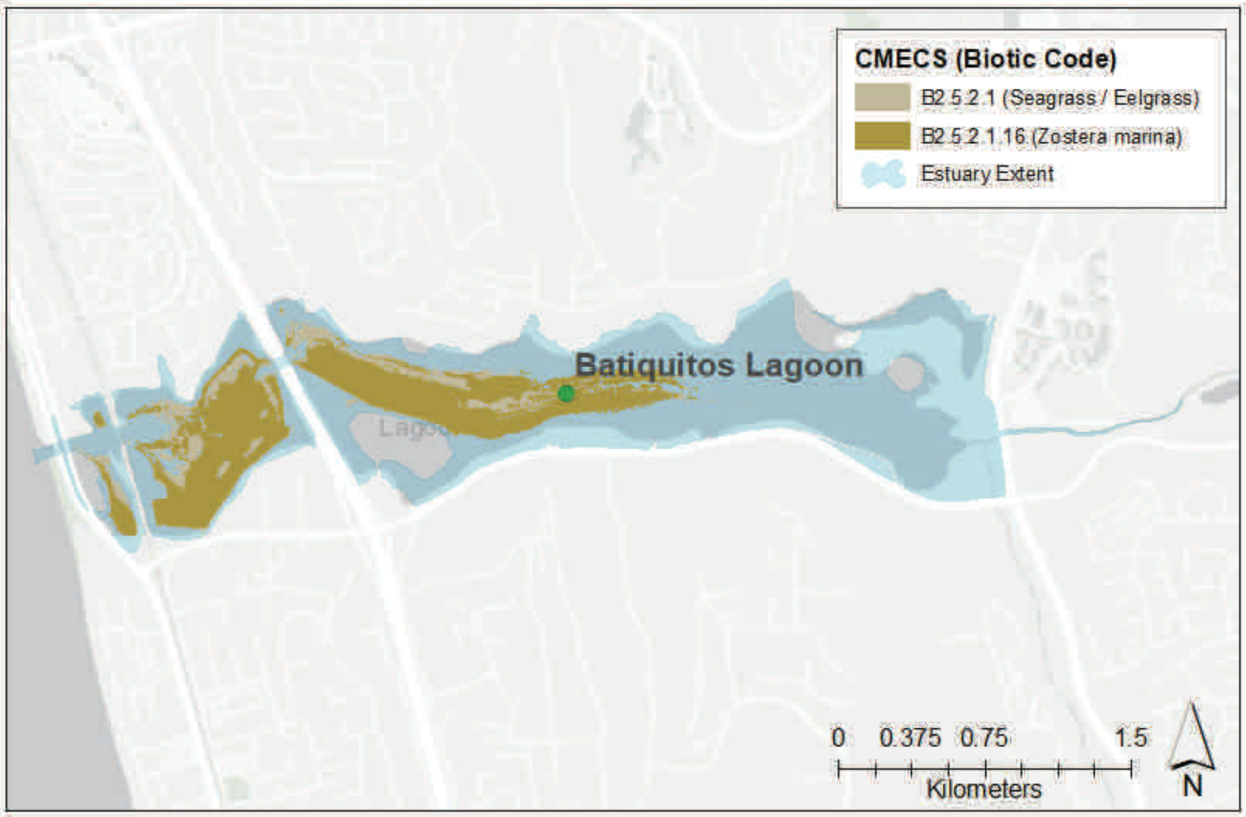
Map of eelgrass extent and observations of eelgrass along the mainland of California.
To view full extent of nearshore beds along the West Coast, go to: www.pacificfishhabitat.org/data.



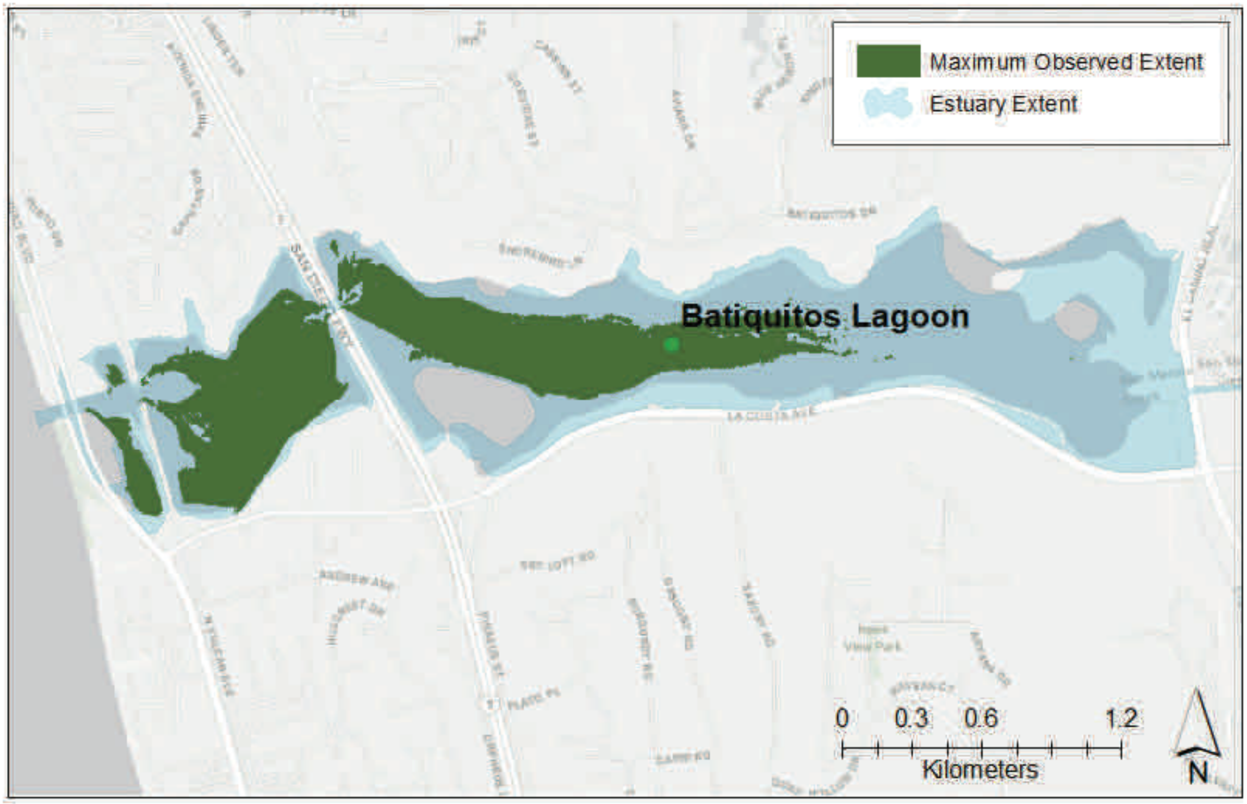
APPENDIX B

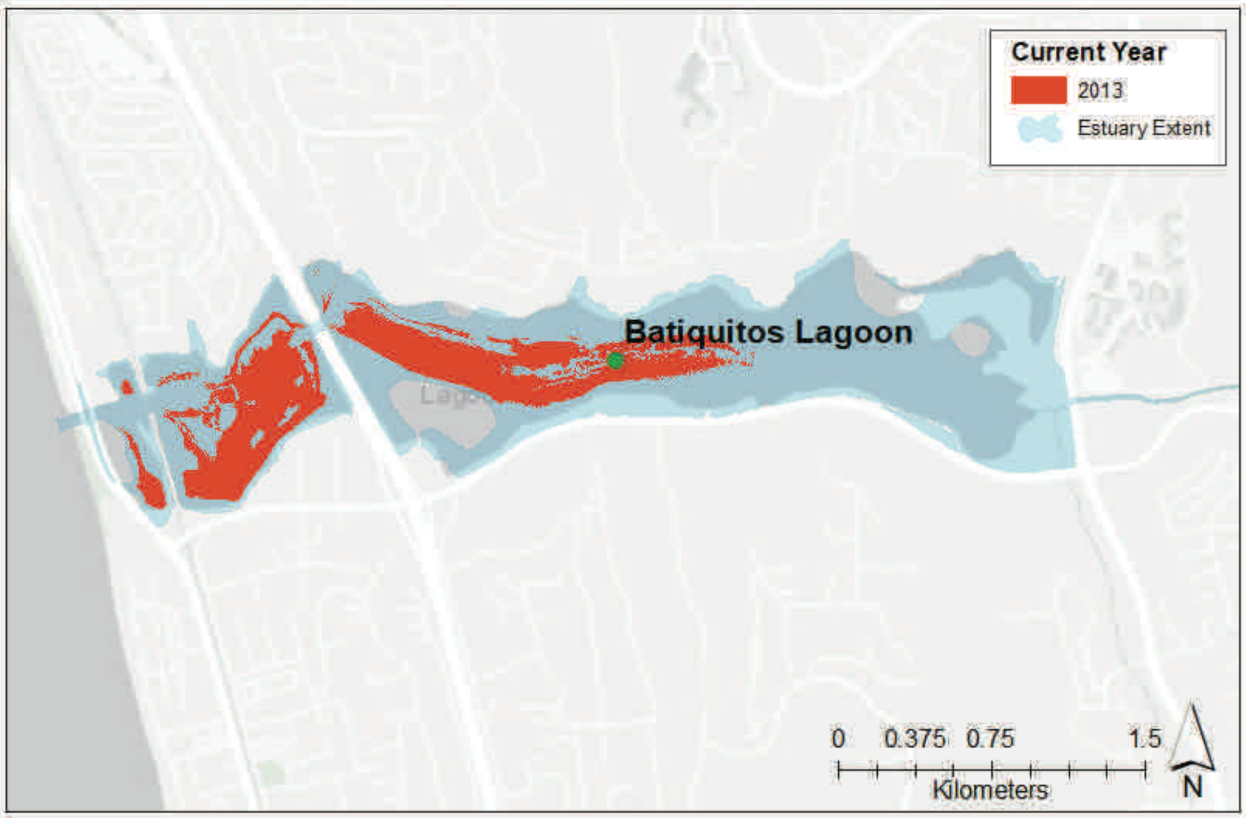
Southern California Bight Ecoregion Example of Eelgrass Dataset Count and CMECS Biotic Code



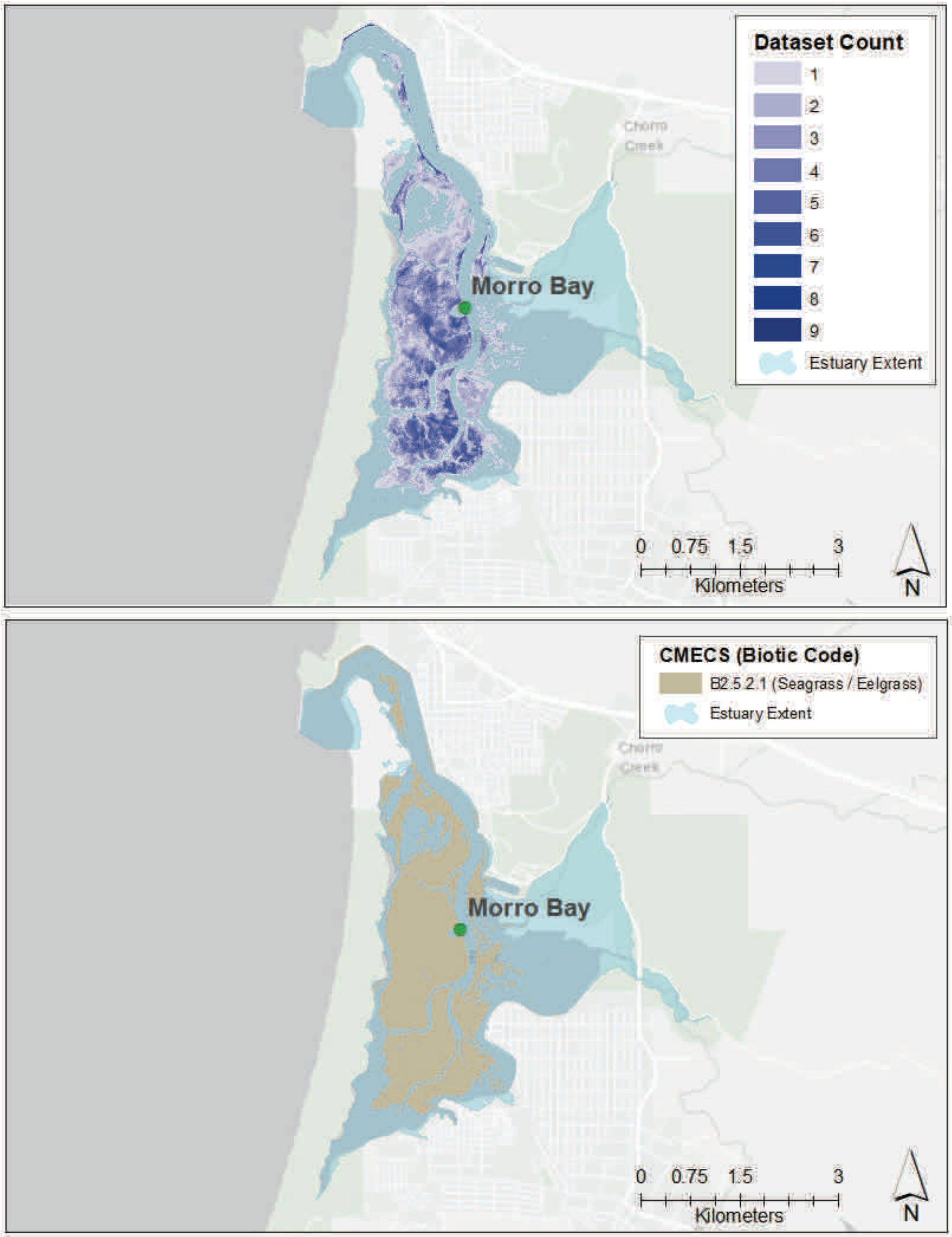


Southern California Bight Ecoregion Example of Eelgrass Maximum Observed Extent and Current Dataset Eelgrass Extent

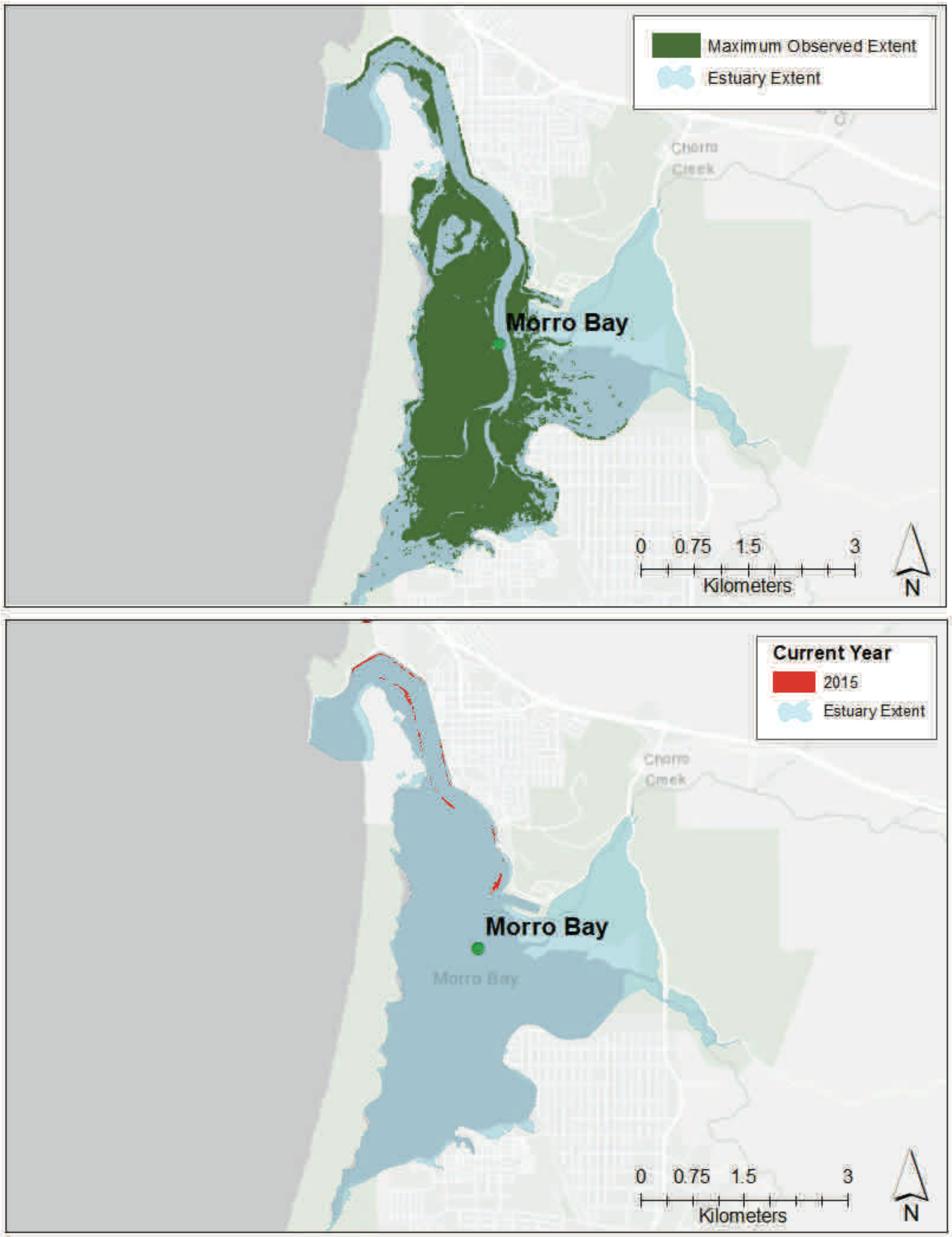




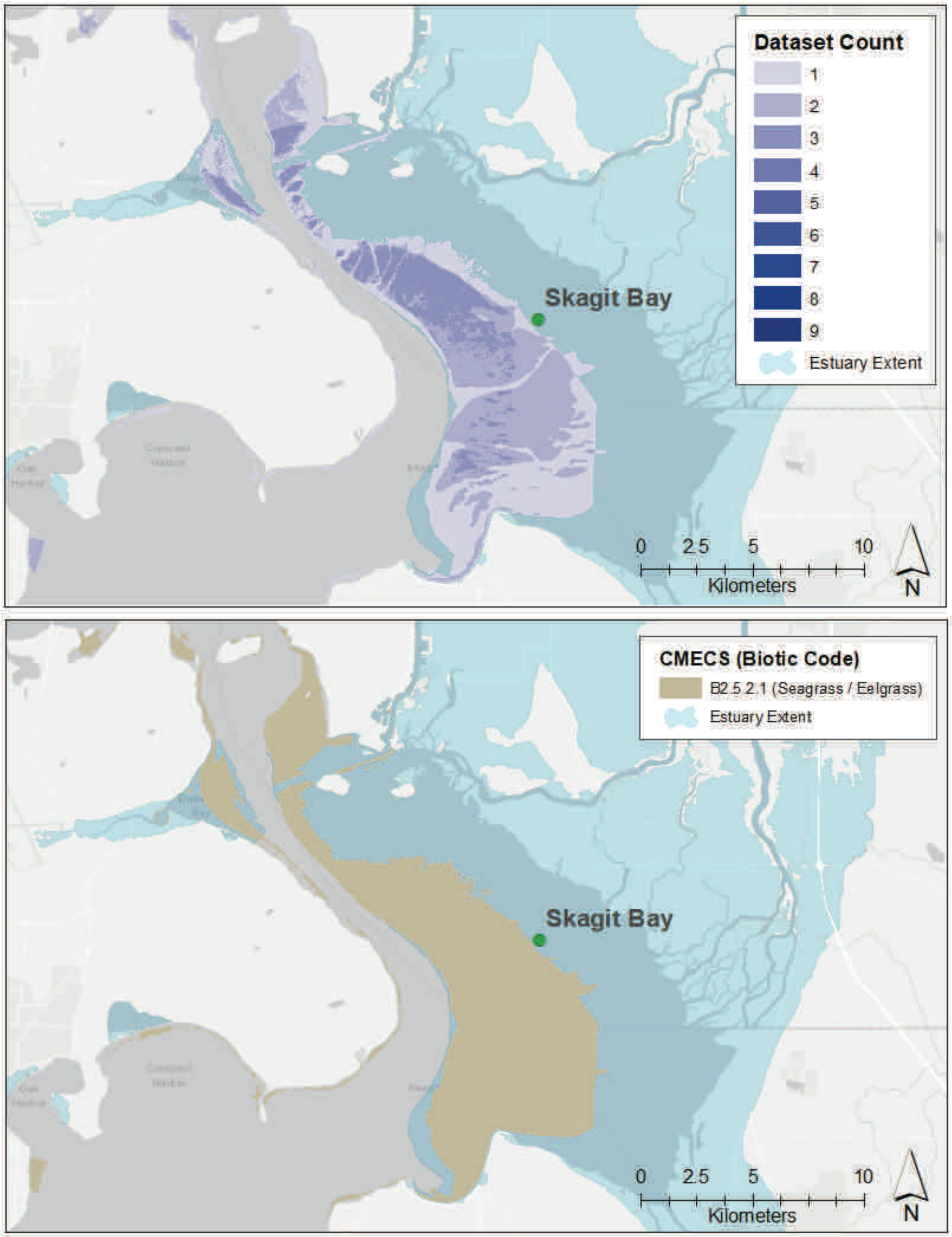
Central California Ecoregion Example of Eelgrass Dataset Count and CMECS Biotic Code



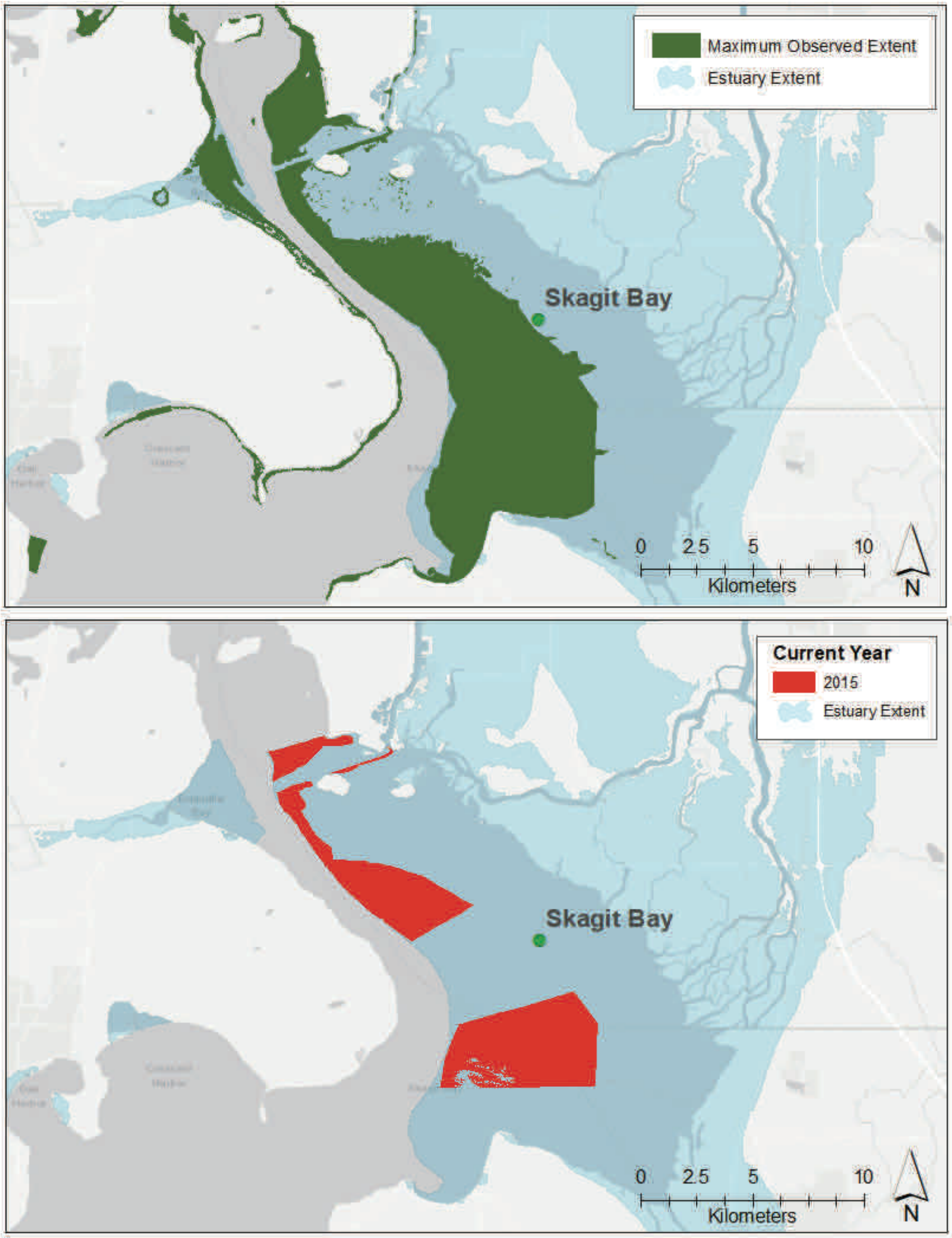
Central California Ecoregion Example of Eelgrass Maximum Observed Extent and Current Dataset Eelgrass Extent



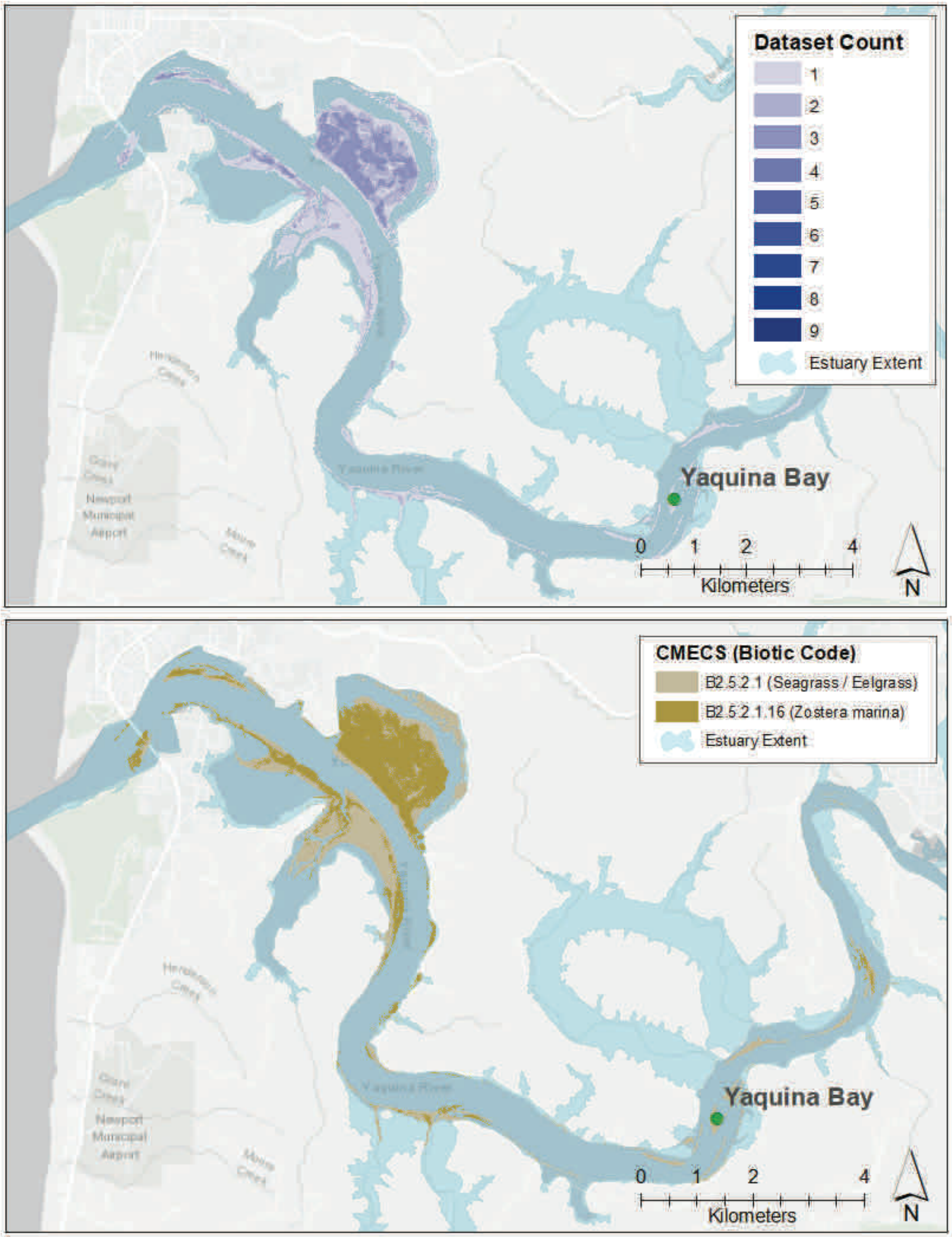
Salish Sea Ecoregion Example of Eelgrass Dataset Count and CMECS Biotic Code



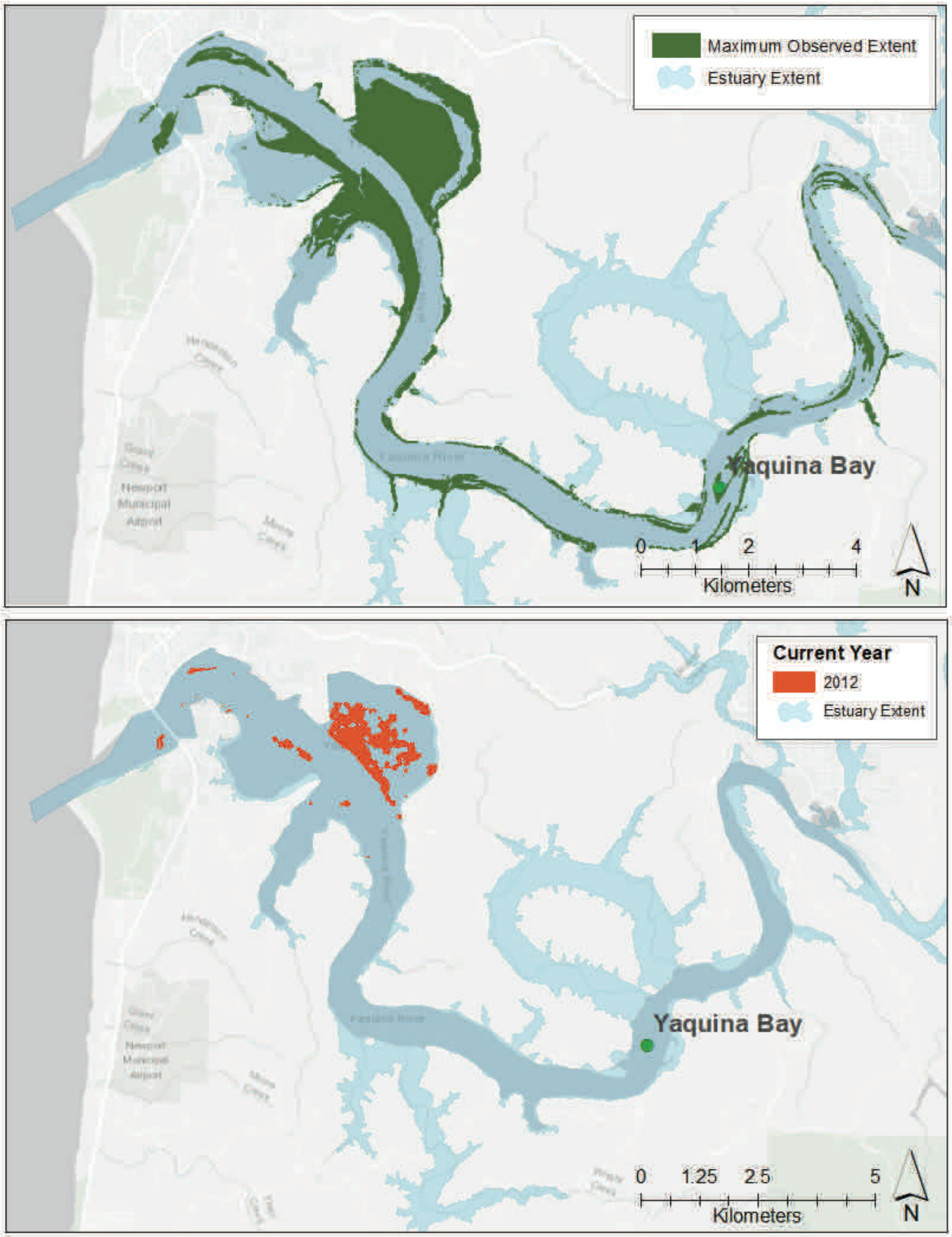
Puget Sound Ecoregion Example of Eelgrass Maximum Observed Extent and Current Dataset Eelgrass Extent



Washington, Oregon and Northern California Coast Ecoregion Example of Eelgrass Dataset Count and CMECS Biotic Code



Washington, Oregon and Northern California Coast Ecoregion Example of Eelgrass Maximum Observed Extent and Current Dataset Eelgrass Extent

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