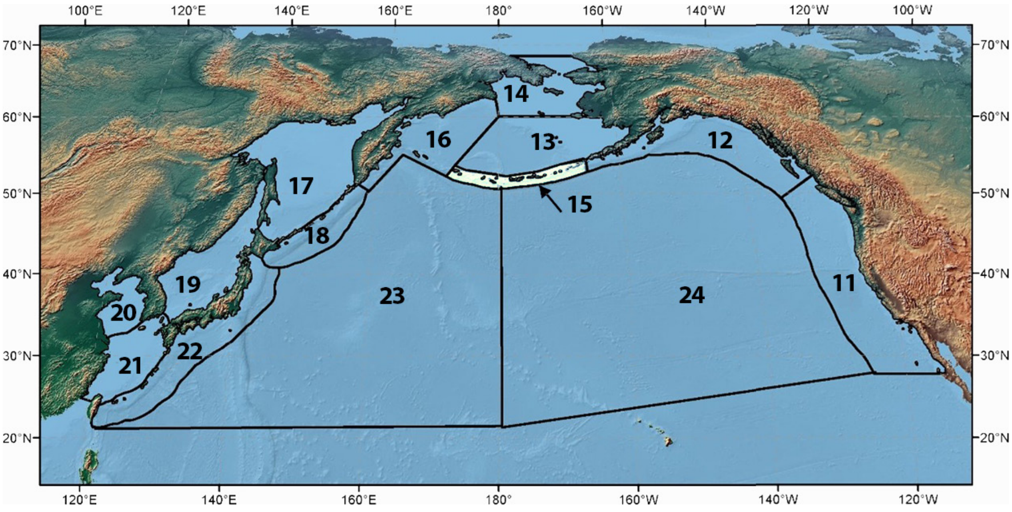


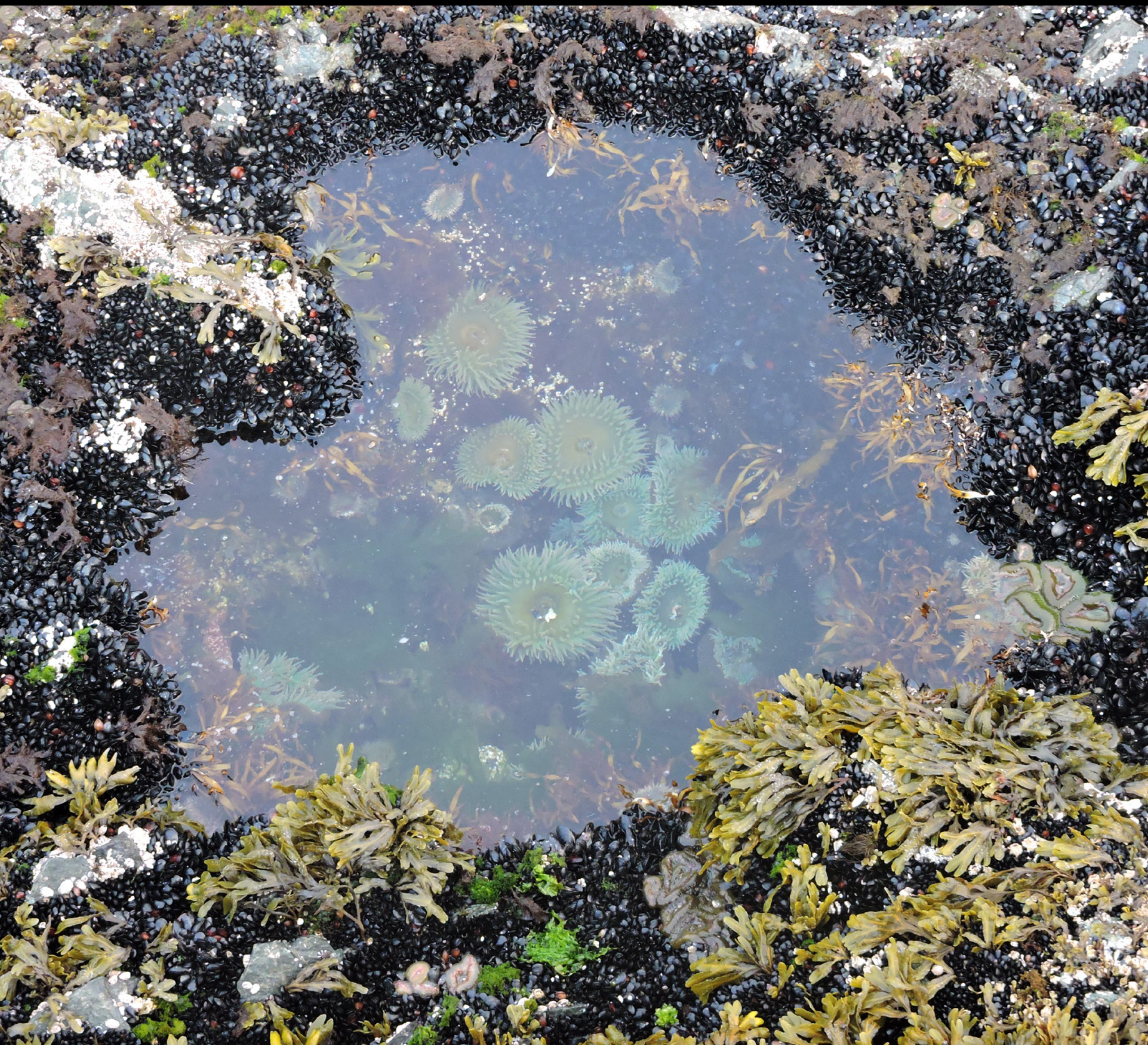
PICES

Regional Report for PICES Region:

15

PICES SPECIAL PUBLICATION 7

Marine Ecosystems of the North Pacific Ocean 2009–2016



PICES North Pacific Ecosystem Status Report, Region 15 (Aleutian Islands)

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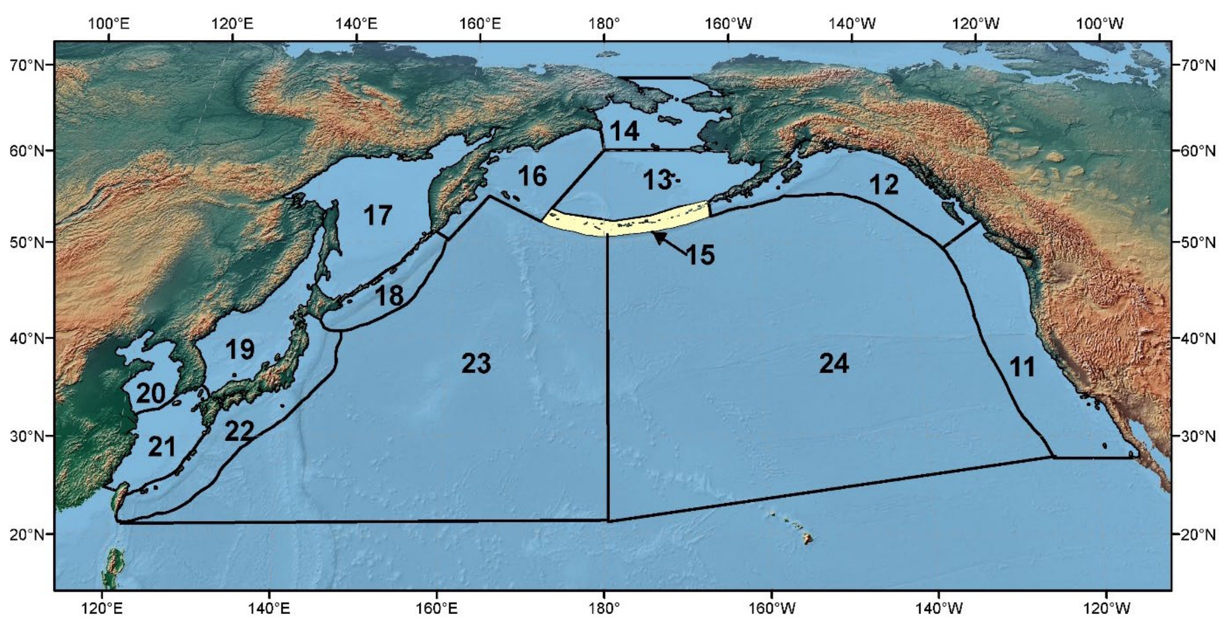


Figure R15-1. The PICES biogeographical regions and naming convention for the North Pacific Ocean with the area discussed in this report highlighted.

Highlights

- The NPI was positive for the winters of 2009-10 through 2013-14 during a period that included mostly negative states for the NINO3.4 and PDO indices.
- Eddies were particularly strong south of Amukta Pass (172°W) in 2009/10 and summer 2012. These eddies may have increased flow from the Pacific to the Bering Sea with potentially increased volume, heat, salt and nutrient fluxes. Past 2012, strong eddies have moved along east of Amukta Pass, towards the western Aleutians with increased smaller anticyclonic eddies along the north side of the Aleutian chain.
- Sea surface temperature was anomalously warm starting in the summer and winter of 2014, and cooling down again during summer 2018, but staying above the long-term mean. The warm water was estimated to penetrate to 100 m or deeper.
- Mesozooplankton appear to be more numerous after 2008 than before, and copepod size shows a declining trend from 2008. However, these changes are small, and because of the low sampling effort, significance is uncertain.
- The composition of the main pelagic foragers has changed from the early 1990s, when two thirds of the pelagic foragers' biomass was made up by Atka mackerel and walleye pollock, and is now half or even two thirds composed by rockfish (Pacific ocean perch and northern rockfish).
- The overall biomass of apex predators has decreased, particularly that of Pacific cod, which is an important predator of other fish species but also prey for Steller sea lions and harbor seals in the region.
- The ratio of pelagic foragers to apex predators has increased, where apex predators used to contribute slightly above 20% of the biomass and now contribute 15%.
- Total abundance of eastern Kamchatka pink salmon reached record abundances (`200 million fish) in 2009 and 2011.
- Squid and sculpin abundance appeared to be trending upward while lanternfishes and smelts appeared to be decreasing in recent survey years.
- In 2016 all five rockfish groups were found at the highest mean-weighted temperature in the time series and the trend for all species has been upward since the 2012 survey.
- In the western Aleutians, tufted puffins had lower reproductive success during the years 2009-2012, including complete failure in 2011. In the eastern Aleutians, reproductive success was normal, with timing of tufted puffin breeding earlier for all years 2008-2014 compared to the long-term average.
- Tufted puffin chick diets of western Aleutian colonies were dominated by Atka mackerel and squids, while those from eastern Aleutians colonies were dominated by gadids and sand lance.
- Steller sea lions declined between 7 and 1% in four of the 6 management areas, all within the western and central Aleutians. The other two areas, located in the eastern Aleutians and eastern Bering Sea, saw modest increases between 1 and 3%.
- Harbor seal abundance and trend is largely driven by dynamics within the eastern Aleutians, where approximately 70% of the seals in this stock reside. Abundance and trend estimates from 1998 to 2011 suggest the stock has been stable.
- Seabirds with and without plastic particles detected in their stomach contents had detectable levels of phthalates in their muscle tissues.
- A database with 70,000 organic and inorganic mercury samples will be available for the Aleutians, with plans to extend it to include other contaminants/ pollutants.

Introduction

The Aleutian Arc, of volcanic origin, is comprised by over 300 islands where several volcanoes are active and both earthquakes and tsunamis are common. It extends from False Pass at the western tip of the Alaska Peninsula, roughly 163°30'W, to west of the Commander Islands at 165°E. Here the Aleutian Islands region (PICES region 15) is defined as the area from 172°E to west of Unimak Pass, with the westernmost island being Attu and the easternmost being Ugamak and Akun Islands. A common subdivision of the archipelago is based on three larger islands groups which have distinct ecological characteristics: i) Eastern Aleutian Islands: located east of Samalga Pass, they include the group known as the Fox Islands; ii) Central Aleutian Islands: located between Samalga and Amchitka Pass, they include the Andreanof Islands and the Islands of Four Mountains; and iii) Western Aleutian Islands: found west of Amchitka Pass, they include the Rat Islands and the Near Islands (Figure R15-2).

The Aleutian chain forms a porous boundary that separates the sub-arctic North Pacific Ocean from the Bering Sea. Most of the islands are within the Alaska Maritime National Wildlife Refuge. The three major currents are: the Alaska Coastal Current (ACC), a wind-driven nutrient-poor current with a freshwater core; the Alaskan Stream (AS), a nutrient-rich, narrow, deep, high-speed current that flows southwestward along the south slope of the islands; and the Aleutian North Slope Current (ANSC), a narrow high-speed current flowing northeastward along the north slope of the islands. Both the ACC and the AS flow northward through the passes (Figure R15-2). Currents and bathymetry favor a longitudinal gradient with lower salinity, warmer temperatures and depleted nutrients in the Eastern Aleutians compared to higher salinity, colder temperatures and more nutrients towards the west (Mordy et al., 2005; Hunt and Phyllis et al., 2005). The shelf starts wide on the south side of the Eastern Aleutian Islands, narrowing towards the west and finally broadening again around the Near Islands; passes tend to be relatively narrow and shallow in the east, with deeper and wider passes towards the west that allow higher flows (Stabeno et al., 2005). In general, this favors piscivorous food webs in the east while the more oceanic nature of the west favors planktivorous food webs (Hunt and Phyllis 2005; Byrd et al., 2005).

The region has some of the largest seabird colonies, including large colonies of tufted puffins, and several species of auklets (Byrd et al., 2005). Steller sea lion and harbor seal rookeries and haul outs are distributed along the chain, and the primary commercial fish species include Atka mackerel, Pacific cod, Pacific Ocean perch and northern rockfish.

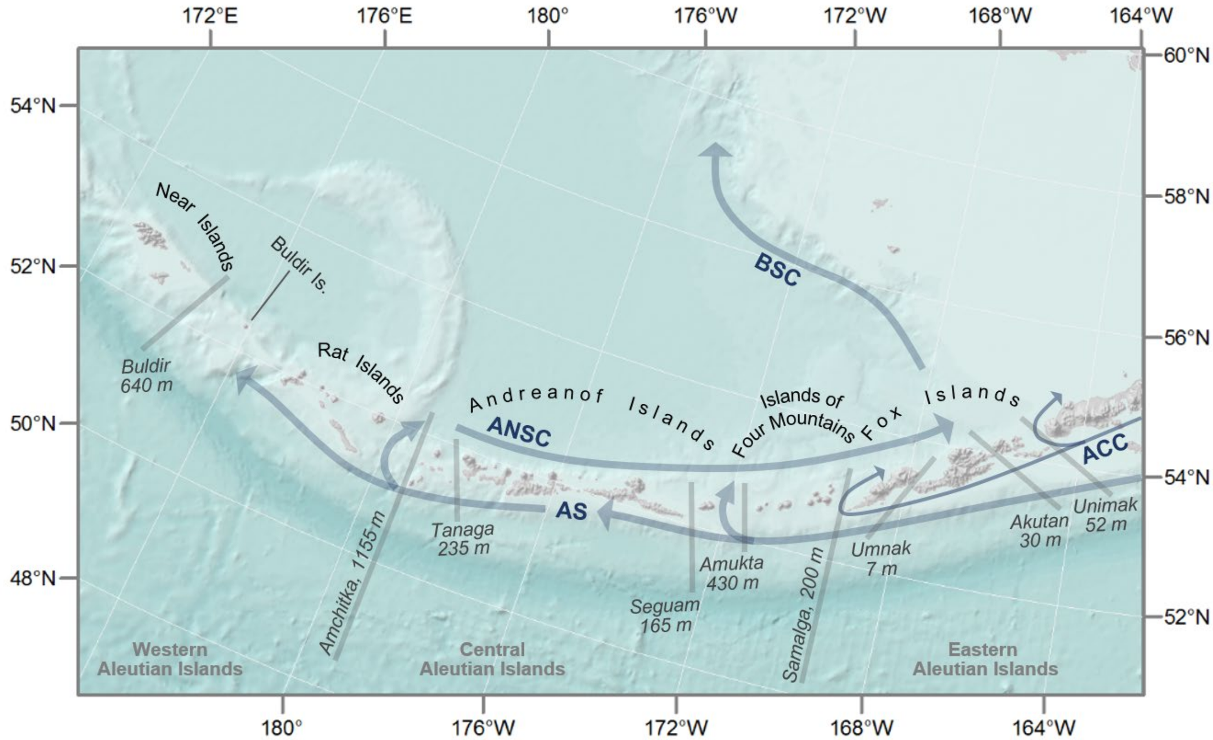


Figure R15-2. General circulation along the U.S. Aleutian Islands shown with topographic and bathymetric relief, geographic place names, and depth (in meters) of the main passes. ANS - Aleutian North Slope Current, AS - Alaskan Stream, ACC – Alaskan Coastal Current, BSC – Bering Slope Current.

2. Atmosphere

(Nicholas Bond)

2.1 Temperature, sea level pressure, winds

The regional climate in the Aleutian Islands reflects large scale atmospheric ocean systems, particularly that of the Aleutian Low, the strength of which is best characterized by the North Pacific Index. When the NPI is positive, the Aleutian Low is weak, and storms track north over the Central Aleutian Islands; and when the NPI is negative the Aleutian Low is strong, and storms track south of the Aleutian Islands. The Aleutian Low is centered near the Aleutian Islands and is strongest (lowest pressure) during the winter, almost disappearing in the summer. As the Aleutian Low strengthens, it shifts east and south. When it is weak (high NPI), it often splits into two centers, one in the Northwest Pacific towards the Western Aleutians and the second in the Gulf of Alaska. The western center, being stronger, is considered the center of the Aleutian Low. Although the strength of the Aleutian Low does not correspond to the number of storms, its position and the corresponding storm tracks do determine year to year climate variability (Rodionov et al., 2007). The Eastern and Western Aleutians have very different trends in Surface Air Temperature (SAT) with a transition zone around 170°W. While in the east the climate had been warmer since 1977, the west had shown a decline in winter SAT since the 1950s. The SAT winter doubled variance in the Western Aleutians whereas in SE Alaska SAT variance decreased by half and November has been warming while January has been cooling, so that the overall seasonal cooling has increased since the 1950s (Rodionov et al., 2005).

The winter (DJF) Sea Level Pressure anomaly for 2009 through 2016 is shown in Figure R15-3. Winter averages show strongly positive values for 2008-09 and moderately negative values for the winters of 2009-10 and 2015-16, each of which featured El Niño. The former event was substantially weaker than the latter event as gauged by the NINO3.4 index, but the remote atmospheric responses in terms of the NPI were comparable. The NPI was positive for the winters of 2009-10 through 2013-14 during a period that included mostly negative states for the NINO3.4 and PDO indices. The center of the Aleutian Low moved eastward in 2010 and 2014-2016, likely shifting storm tracks during these years south of the Aleutians. The SLP data are from the NCEP/NCAR Reanalysis project. Both data are made available by NOAA's Earth System Research Laboratory (ESRL) at http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

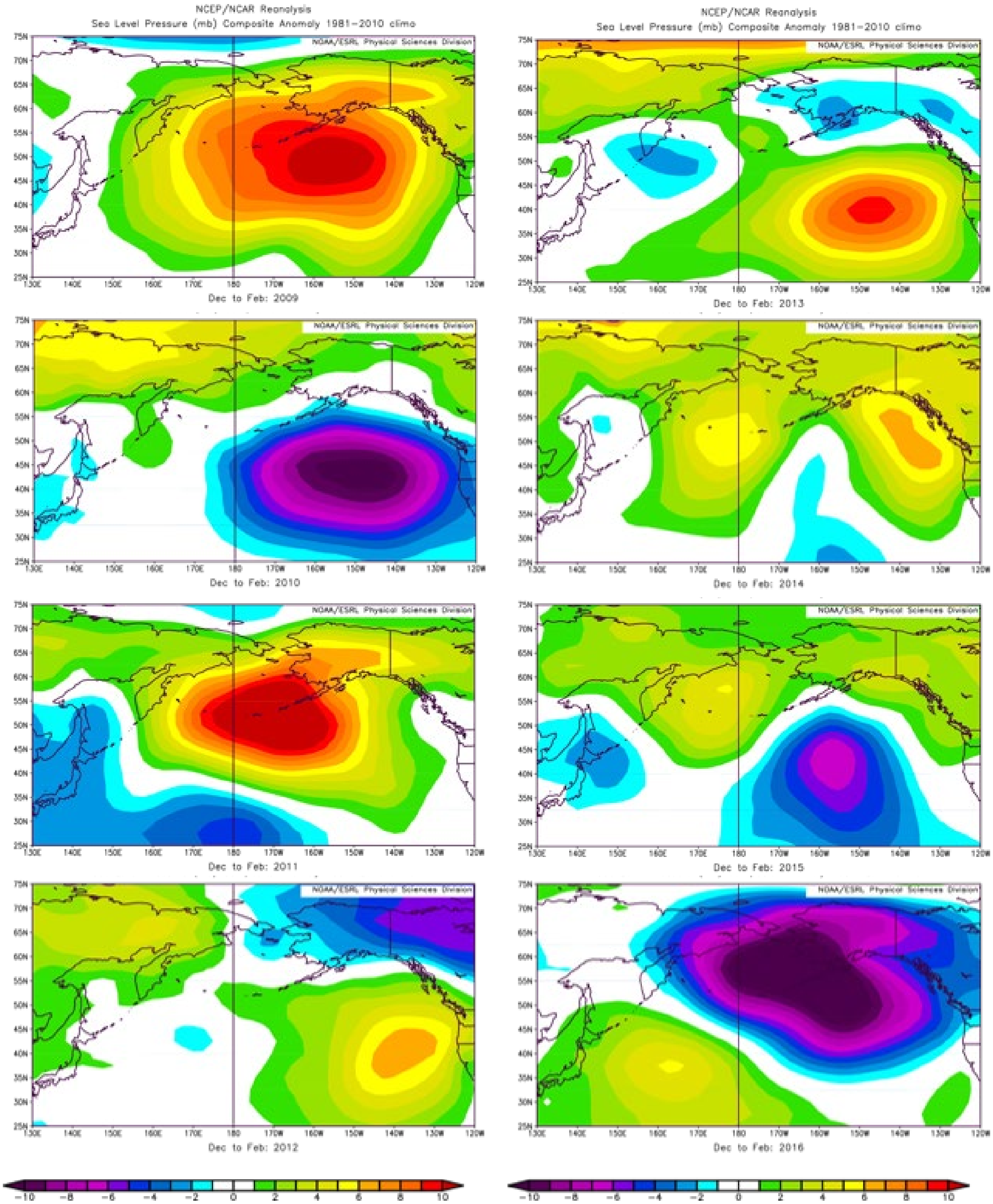


Figure R15-3. Winter (DJF) Sea Level pressure anomalies for 2009 – 2012 (left, top to bottom) and 2013- 2016 (right, top to bottom).

3. Physical Oceanography

(Carol Ladd, Jordan Watson, Peter Chandler, Phyllis Stabeno)

3.1 Altimetry and Current Speed

Eddies in general advect and mix water along the Alaska Stream impact the distribution of chlorophyll a in the central subarctic North Pacific (Ueno et al., 2010), and numerical models have suggested that eddies near Amukta Pass may result in increased flow from the Pacific to the Bering Sea (Maslowski et al., 2008) with potentially increased volume, heat, salt and nutrient fluxes. Eddy kinetic energy calculated from altimetry data is particularly high in the Alaska Stream from Unimak Pass to Amukta Pass, which indicates the occurrence of frequent and strong eddies in that stretch of the Aleutian chain. Eddies were particularly strong south of Amukta Pass (172°W) in 1997, 1999, 2004, 2006/2007, 2009/10 and the summer of 2012 (Ladd, 2014). Past 2012, strong eddies have moved along east of Amukta Pass, towards the western Aleutians with increased smaller anticyclonic eddies along the north side of the Aleutian chain. Figure R15-4 shows altimetry data for the Aleutian Islands, from 164°W to 170°E for May-August of 2009-2016.

A suite of satellite altimetry system has been monitoring sea surface height since 1992. The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS) (http://www.marine.copernicus.eu).

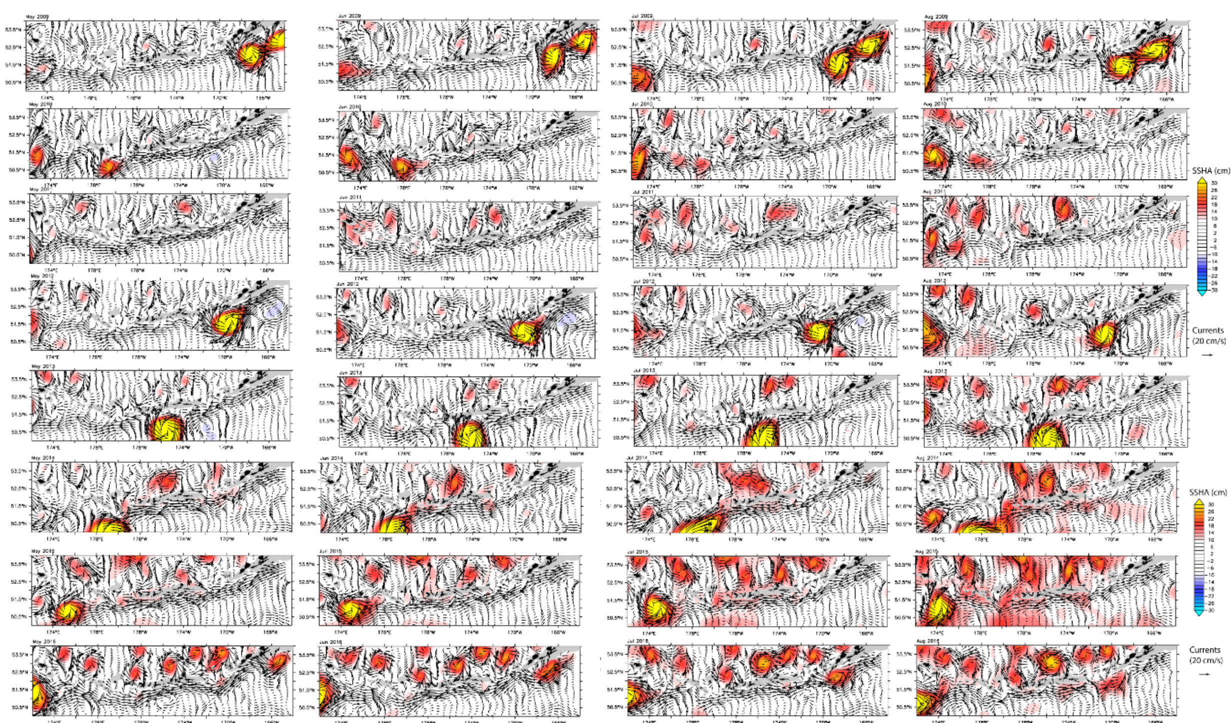


Figure R15-4. Altimetry during summer months May-August (left right) for years 2009-2016 (top to bottom).

3.2 Time series of MODIS –Aqua satellite sea surface temperature.

MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths (see MODIS Technical Specifications).

Global Level 3 Mapped sea surface temperature (SST) products have been derived from the MODIS sensors onboard the NASA Terra (launched in 1999) and Aqua (launched in 2002) platforms by the NASA Ocean Biology Processing Group (O BPG). These SST products include MODIS Aqua and Terra mid-Infrared SST products which are derived from the 3 and 4 mid-IR bands (MODIS channels 20,21,22 and 23) and the thermal IR infrared (IR) SST products which are derived from the 11 and 12 µm thermal IR infrared bands (MODIS channels 31 and 32). Both daytime and nighttime SST products are available for the thermal IR Infrared bands. Daily, weekly (8 day), monthly and annual MODIS SST products are available at both 4.63 km and 9.26 km spatial resolution for both daytime and nighttime passes.

The sea surface temperature measured by MODIS is commonly referred to as the skin temperature of the ocean. This is because the radiance measured by infrared radiometers originates in the surface skin layer of the ocean and not the body of water below. The surface skin layer of the ocean is less than 1mm thick and as a rule will be cooler than the underlying water due to heat flux, with the direction of flux typically from the ocean to the atmosphere. Three distinct processes impact near surface ocean temperature gradients: absorption of solar isolation, heat exchange with the atmosphere, and sub-surface turbulence. Generally, at night or when wind speeds are greater than 6m/s the relationship between the skin temperature and the subsurface is often quite stable. It is under these conditions that validation and uncertainty estimates relative to sub- surface *in situ* buoys are typically reported. The relationship can however be very variable under conditions of high insolation, low wind speeds, and reduced sub-surface turbulence.

Figure R15.5 shows the timeseries at spot locations in the eastern (53ºN 168ºW) and western (52ºN 175ºE) Aleutian Islands. The east to west longitudinal gradient of warmer to colder temperatures is evidenced in the timeseries, however both locations show an increase in 2014-2016, particularly during winter – which can be seen in both the day and night time data.

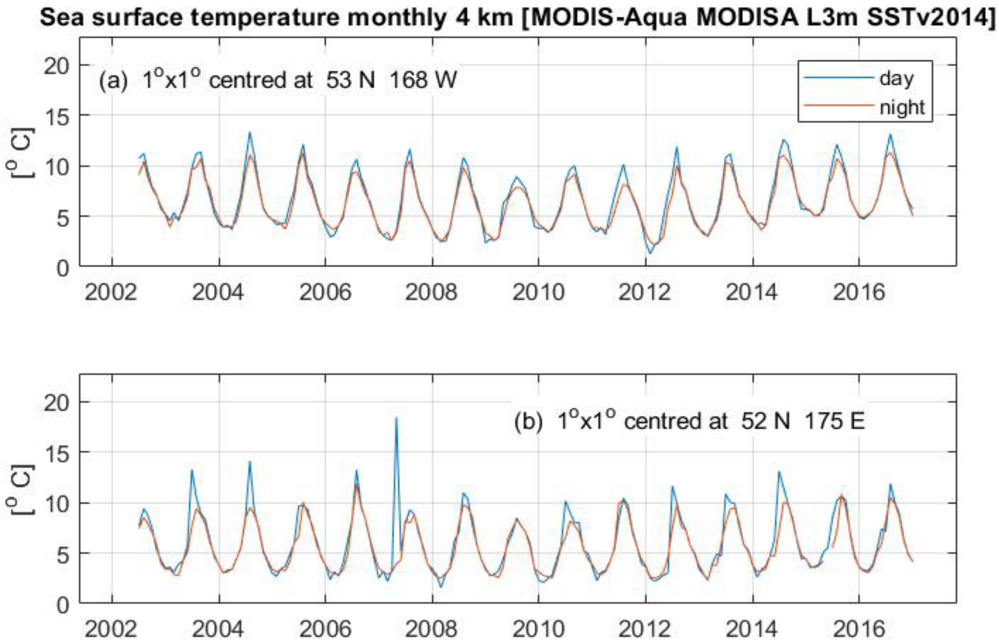


Figure R15-5. Time series of MODIS SST data observed at two locations in PICES region 15 (green dots in map) representing the Western and the Eastern Aleutian Islands (AI). Each panel represents the SST data sensed at 11 microns (day) averaged over an area 1° latitude by 1° longitude centered at the location given in Figure R15-6. Data source is MODIS-Aqua MODISA L3m SSTv2014.

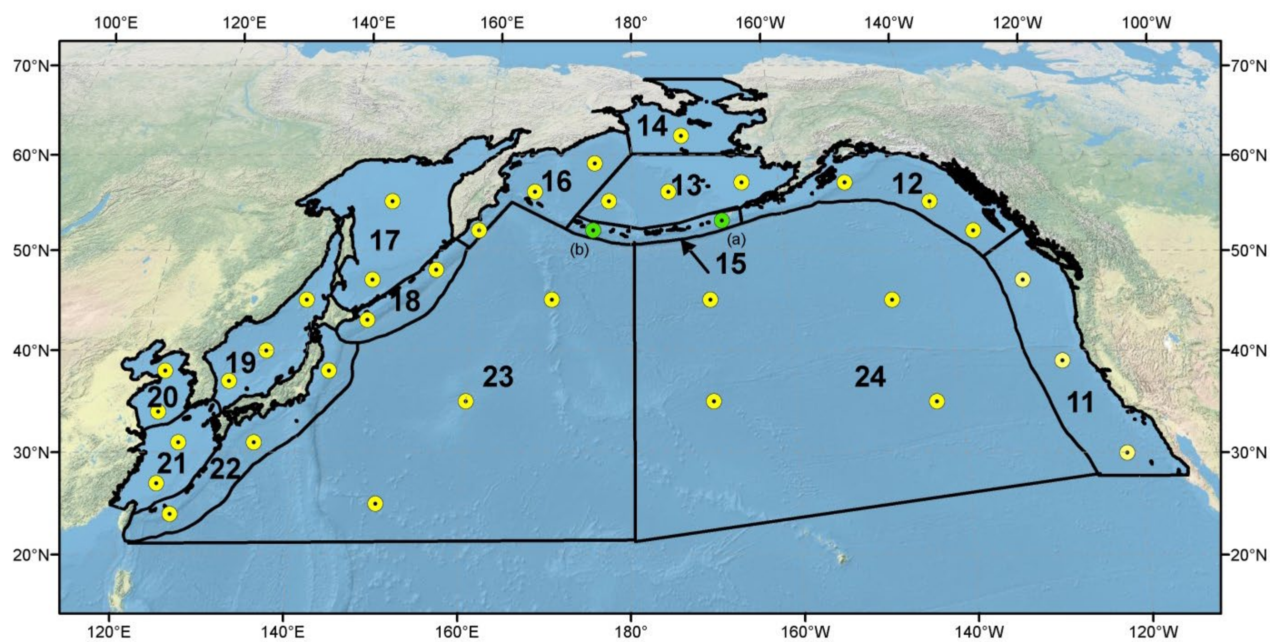


Figure R15-6. Center location of 1° latitude by 1o longitude areas for which monthly SST data was averaged.

3.3 Satellite-derived Sea Surface Temperature for the Eastern and Western Aleutian Islands regions

Sea surface temperature (SST) is often used to explore relationships between commercial fisheries and environmental dynamics. During interpretation of fishery and ecological data, it is often useful to evaluate whether the environmental conditions can be categorized as a warm or a cold. Using satellite data allows the evaluation of SST across spatial scales that are not limited to the location of a single buoy or data collected during seasonal surveys.

A common limitation of SST records derived from satellites has been missing data as a result of cloud cover. Using the NASA multi-scale ultra-high resolution (MUR) SST dataset however, a combination of collection modalities creates a gap-free blend of data (https://mur.jpl.nasa.gov/InformationText.php). Data are available at the daily level for the North Pacific from mid-2002 to present, and can be downloaded from the NOAA Coast Watch West Coast Node ERDDAP server (https://coastwatch.pfeg.noaa.gov/erddap/) where they are searchable as *"Multi-scale ultra-high resolution (MUR) SST Analysis fv04.1, Global, 0.01°, 2002–present, daily".* More than 24 billion individual daily temperature records were downloaded (October 1, 2002–September 30, 2018) and the data were averaged daily by Alaska Department of Fish and Game (ADF&G) groundfish statistical areas (also called stat6 areas; http://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByFishery.statmaps), yielding about 10 million temperature records (a daily record for each of the 1,736 statistical areas). More detailed methods are available online (github.com/jordanwatson/ERDAPP).

Daily temperatures were averaged by month for the Aleutian Islands (AI) ecosystem regions (from ADF&G statistical areas in the western AI [WAI], west of 177°W, central AI [CAI], 170°–177°W, and east AI (EAI), 163°W–170°W, https://alaskafisheries.noaa.gov/maps) and aggregated by winter (October–March) and summer (April–September) (Figure R15-7). In Figure R15-8, the temperature difference since winter 2002-2003 (refers to October–December 2002 and January–March 2003) and summer 2003 is shown. The increase in temperature is more noticeable starting 2013 and particularly for winter in the east.

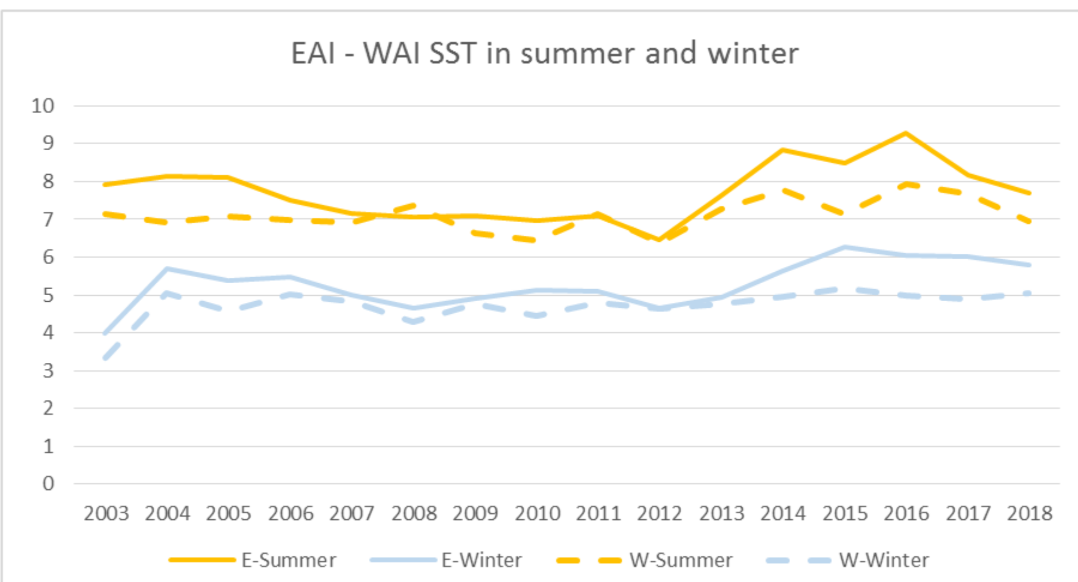


Figure R15-7. Mean summer (April-September) and winter (October-March) Sea Surface Temperature trends since 2003 for the Eastern and Western Aleutian Islands.

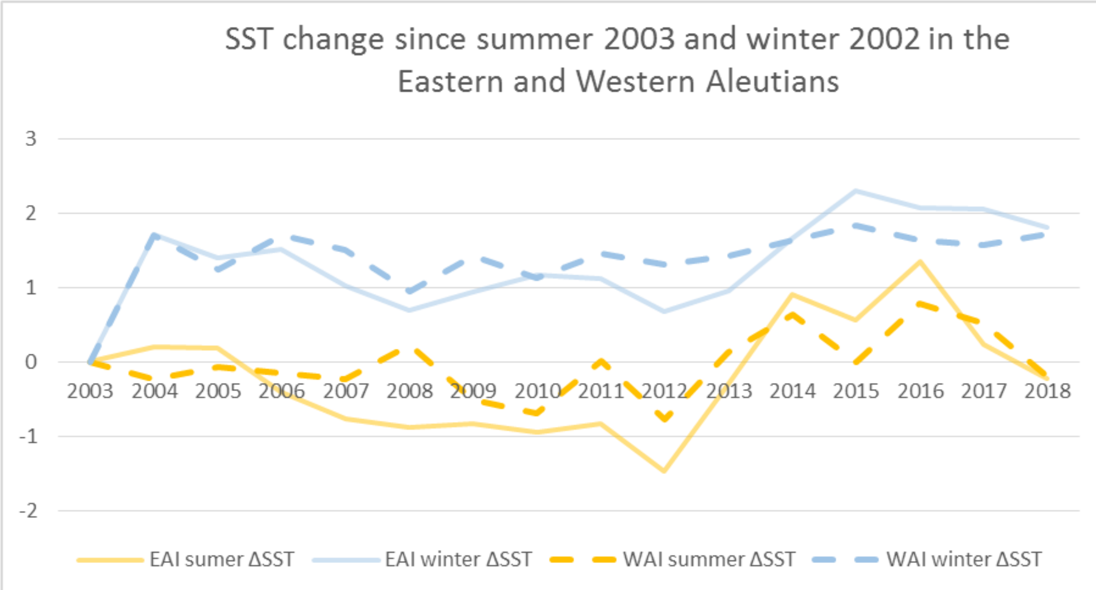


Figure R15-8. Mean summer (April-September) and winter (October-March) Sea Surface Temperature difference from that in 2003 for the Eastern and Western Aleutian Islands.

Status and trends: There was a general consistency in temperature anomalies within each year for the central and eastern Aleutian Island areas, whereas the western Aleutian Island region was more likely to diverge from the other areas in the direction of temperature anomaly within a season. The first few years of the time series were mixed in terms of warm versus cold, before turning consistently cold during the summer and winter of 2006 through 2012 for the eastern and central Aleutian Islands. Summer and winter temperatures were anomalously warm starting in the summer and winter of 2014, and cooling down again during summer 2018.

It may be important to note that the Aleutian Island ecosystem regions include waters both north and south of the Aleutian chain. Thus, temperature anomalies will be driven by the combined dynamics of both Bering Sea and Gulf of Alaska waters. The trends in warming during recent years are consistent with the remarkably warm periods throughout both the Bering Sea and Gulf of Alaska (Bond et al., 2015; Hu et al., 2017).

Implications: A large body of research has explored the effects of stanzas of warm water observed in the Bering Sea over the last two decades, and recent work in particular has attempted to understand what impacts the most recent warming may have on fishery ecosystems (e.g., Stabeno et al., 2017). While most of this work has focused on the eastern Bering Sea in particular, similar patterns of impacts on prey quality and recruitment of juvenile fish may occur in the Aleutian Islands. The ecosystem indicator presented here provides an example of ways that satellite data can be explored at aggregated spatial and temporal scales. The temperature data set can be utilized across a range of scales: fine (e.g., daily temperatures by state statistical area) to coarse (e.g., monthly temperatures by Aleutian Island ecosystem region), depending on the questions being asked by researchers or policy makers. Compared to temperature in 2003 in both winter and summer, the western Aleutians have experienced an overall increase in mean temperature, whereas this is not the case for the Eastern Aleutian Islands.

3.4 Sea Surface Temperature Anomaly

The intensity and magnitude of the overall and regional SST anomalies can be better appreciated in the composites for SST satellite data for summer, May through August for the years 2009 to 2016 shown in Figure R15-9. The increase in temperatures was higher towards the eastern Aleutians. The warmer anomalies (2014 - 2016) were estimated to penetrate to 100 m or deeper, based on predicted thermal anomaly profiles from water temperature measurements collected on the Aleutian Islands bottom trawl surveys (Zador and Ortiz, 2018).

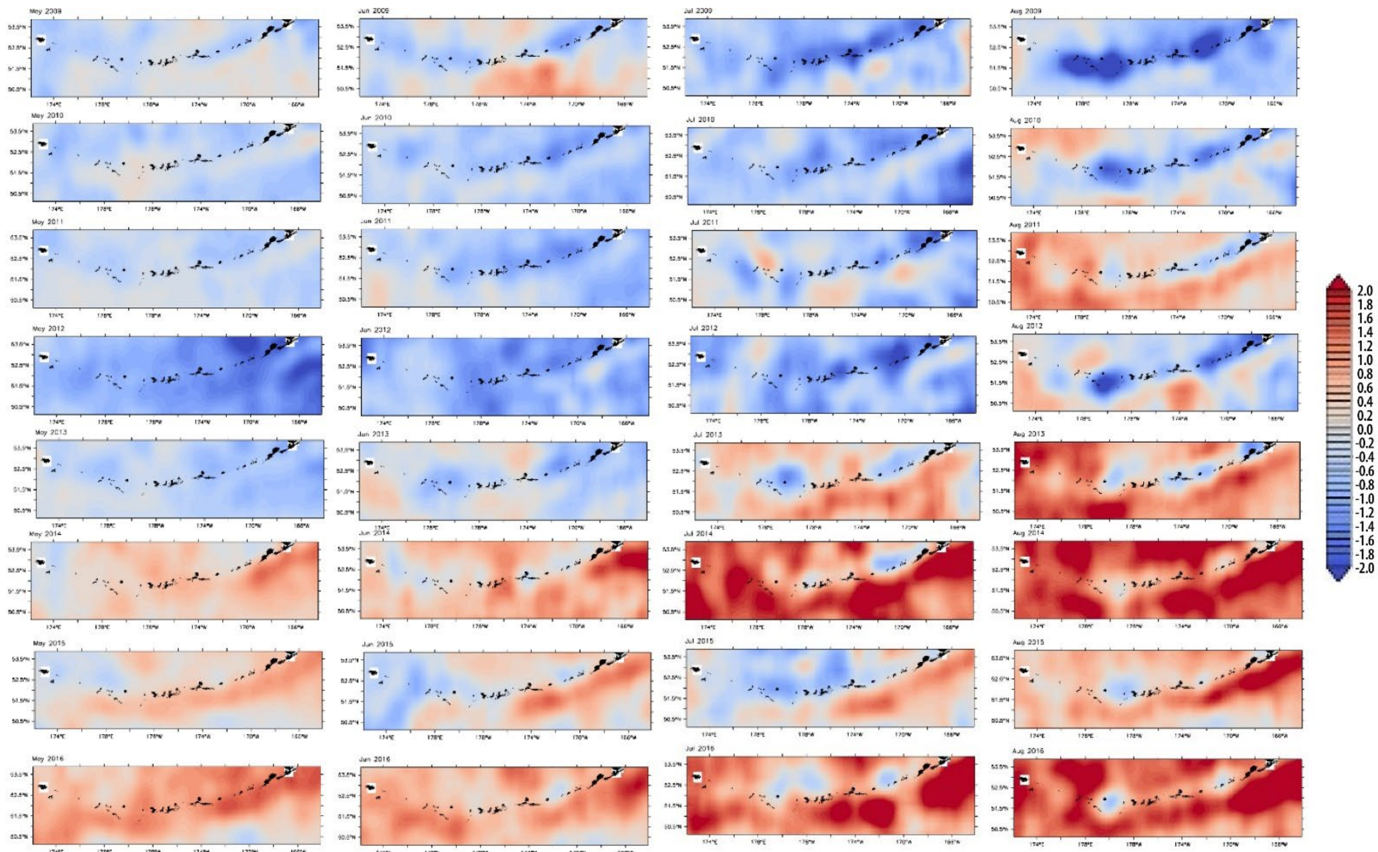


Figure R15-9. Sea Surface Temperature Anomaly for May - August (from left to right) for years 2009-2016 (top to bottom).

4. Phytoplankton and Zooplankton

(Sonia Batten, Carol Ladd, Peter Chandler)

4.1 Satellite derived chlorophyll concentration

The same MODIS instrumentation (described previously) that provides SST data can also be used to derive Chlorophyll concentrations.

Chlorophyll a concentration is expressed in units of mg/m-3, indicating the concentration of the photosynthetic pigment chlorophyll a (the most common "green" chlorophyll) in ocean. Figure R15-10 shows higher chlorophyll concentrations in the Eastern Aleutians south of the islands, compared to that estimated for the Western Aleutian Islands. The corresponding maps in Figure R15-11 also show the spottiness of the satellite data due to cloud coverage, which in general is about less than 30% throughout the Aleutians, thus the timeseries in Figure R15-10 should be interpreted with caution.

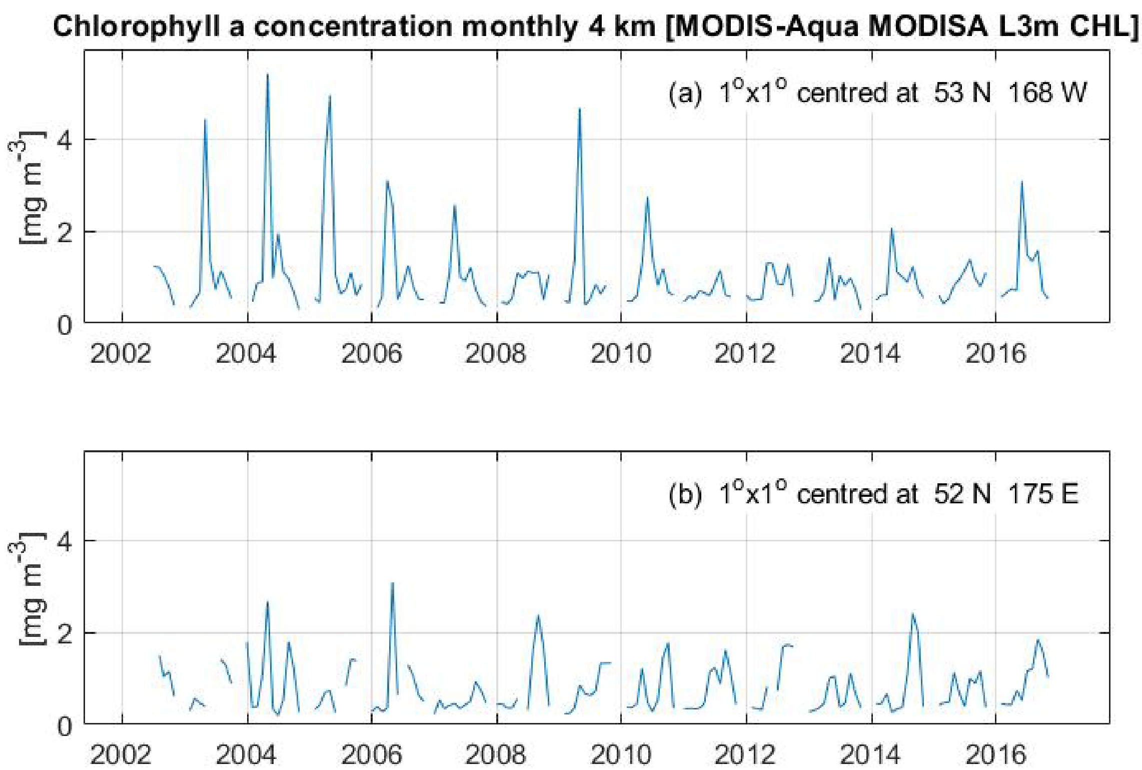


Figure R15-10. Time series of MODIS Chl-a data observed at two locations in PICES region 15. The panel represents the Chl-a concentration averaged over an area is 1° latitude by 1° longitude centered at 53°N 168°W for the eastern Aleutians (top) and 52°N 175°E for the Western Aleutians, as shown by the green dots in Figure R15-6).

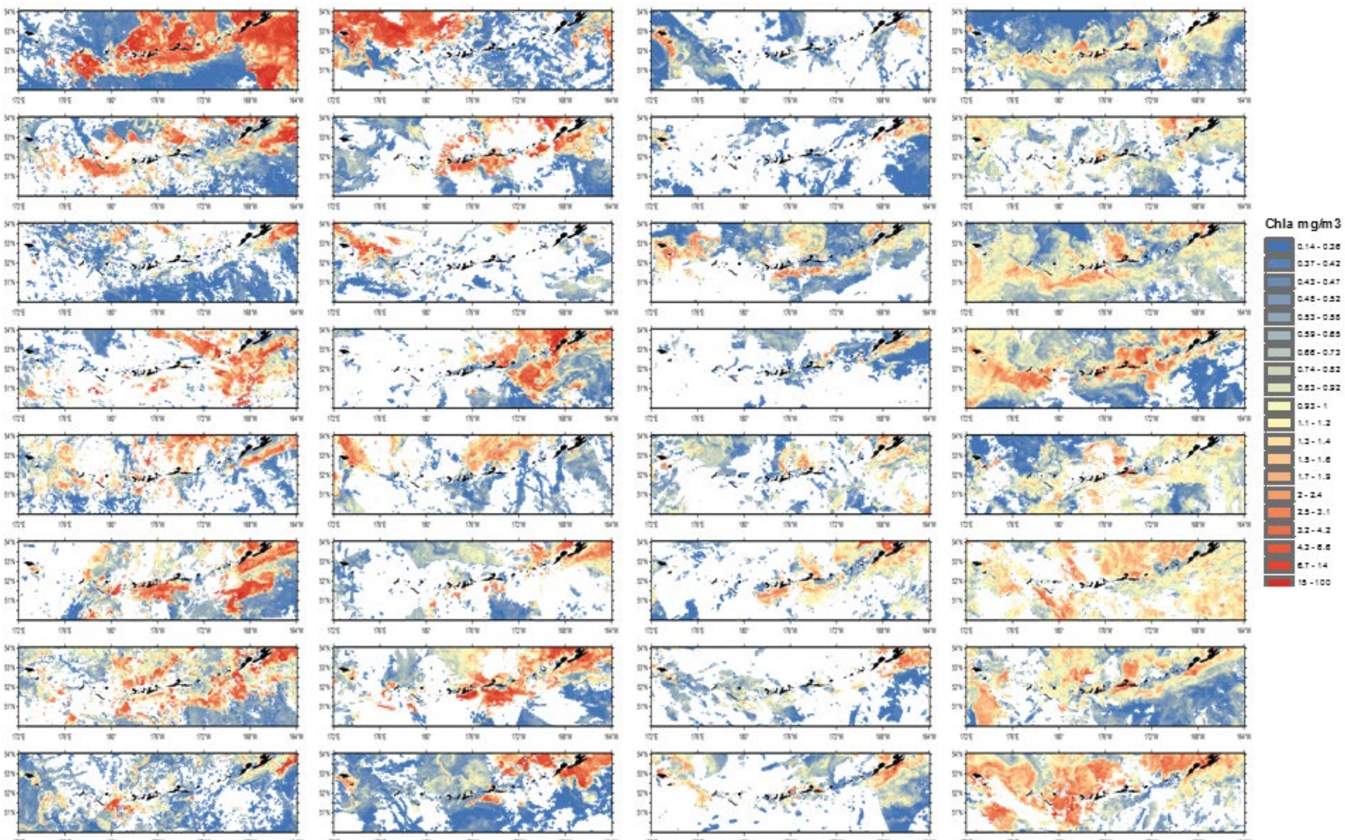


Figure R15-11. Chlorophyll a concentration monthly 4km Modis-Aqua MODISa L3M CHL (from left to right) May, June, July and August for years 2009-2016 (top to bottom).

4.2 Surface phytoplankton and zooplankton

Continuous Plankton Recorder Time Series: The Continuous Plankton Recorder (CPR) is towed behind a commercial ship at a depth of about 7 m. The plankton are collected continuously but then sectioned into 18.5 km samples (10 nautical miles), and normally every fourth sample is processed. Position, date, and time information of the sample is taken from ship's log information and refers to the midpoint of the 18.5 km sample. Constant speed between log entries is assumed. Sampling began in 2000 and data are complete up to June 2016. Sampling is sparse in this region, as it is heavily dependent on the ship's route.

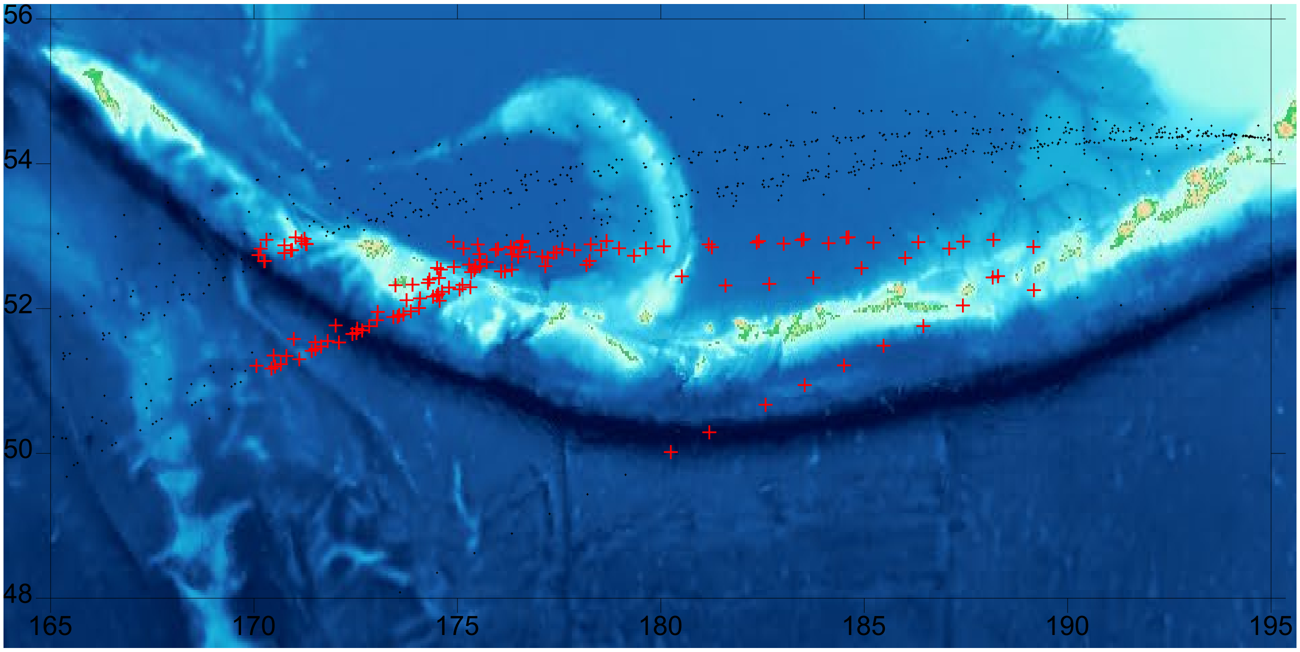


Figure R15-12. Location of CPR samples in region 15, shown in red.

We identify and count the zooplankton and larger hard-shelled phytoplankton. The phytoplankton data are semi-quantitative and are only a part of the community as not all cells are preserved by formalin, and many are too small to be retained by the 270 µm mesh or recorded under a light microscope. After cutting into samples, each sample is viewed under a microscope. Twenty fields of view are examined across the sample and phytoplankton taxa are counted as a presence or absence in each. Equivalent numbers of cells per sample are then calculated for ten levels of abundance (1 or 2 fields = level 1, 3 or 4 fields = level 2 and so on up to 19 or 20 fields = level 10).

Taxonomic resolution of zooplankton varies, most copepods are identified to species, certainly to genus, and sometimes to stages. Gelatinous plankton are not well sampled and are identified to only a coarse level of resolution. Up until 2010, a category system of counting was employed such that 1, 2 or 3 organisms were recorded as Category 1, 2 or 3 respectively while between 4 and 11 individuals in the sample were recorded as Category 4, 12 to 25 as category 5, 26 to 50 as Category 6 and so on up to Category 12 (2001 to 4000). ‘Accepted values’ are then recorded being the mean abundance if 100 examples of each category were accurately counted so that the accepted values given are; 1, 2, 3, 6, 17, 35, 75, 160, 310, 640, 1300, 2690 for categories 1-12. Furthermore, organisms smaller than 2 mm are counted in a subsample that represents 1/49 of the whole sample, so accepted values are multiplied to give numbers per sample.

Organisms larger than 2mm are not usually subsampled, unless numbers are very high. From 2010 onwards all zooplankton have been accurately counted (although the smaller organisms are still counted from a subsample), and the category system does not apply, although of course categories are still recorded for consistency with previous data. (Note, in regions where multiple samples are averaged to give a single representative value, as in this case, this change will make no difference to the abundances obtained). Accuracy of taxonomic entities cannot be guaranteed, however SAHFOS has a team of analysts and no one person analyses adjacent samples. After analysis, adjacent samples are compared, and unusual results flagged and checked before data are finalized. Further information on CPR analysis can be found in Batten et al. (2003).

Three time series have been submitted: 1. Total diatom abundance, which is the combined abundance of all diatom taxa recorded per sample 2. Mesozooplankton abundance, which is the combined abundance of all zooplankton taxa recorded per sample, with the exception of ciliates and eggs of copepods/euphausiids/fish. Note that all abundances given are 'per sample'. Theoretically a sample is 3 cubic meters of filtered seawater, but it isn't actually measured and filtration efficiency can vary. 3. The time series “Copepod Size” which is defined as:

$$\overline{S} = \frac{\sum_{i=1}^{N}(L_i \times X_i)}{\sum_{i=1}^{N} X_i}$$

Where for each sample, the length L (in mm) of each copepod species i (adult female length), is multiplied by its abundance Xi, summed over all species (N) and divided by the total abundance, according to Beaugrand et al. (2003).

Data for all samples collected in the region per month were averaged to give a monthly mean, presented as black bars. The red line indicates a 12-month running mean to show the long term trends.

Status and trends: Sampling is very sparse in this region, and did not occur at all in 2000 and 2009. Diatoms were relatively high in 2011 and 2014 compared to other years in the time series, but no trend is evident. Mesozooplankton appear to be more numerous after 2008 than before, and Copepod Size shows a declining trend from 2008. However, these changes are small, and because of the low sampling effort significance is uncertain.

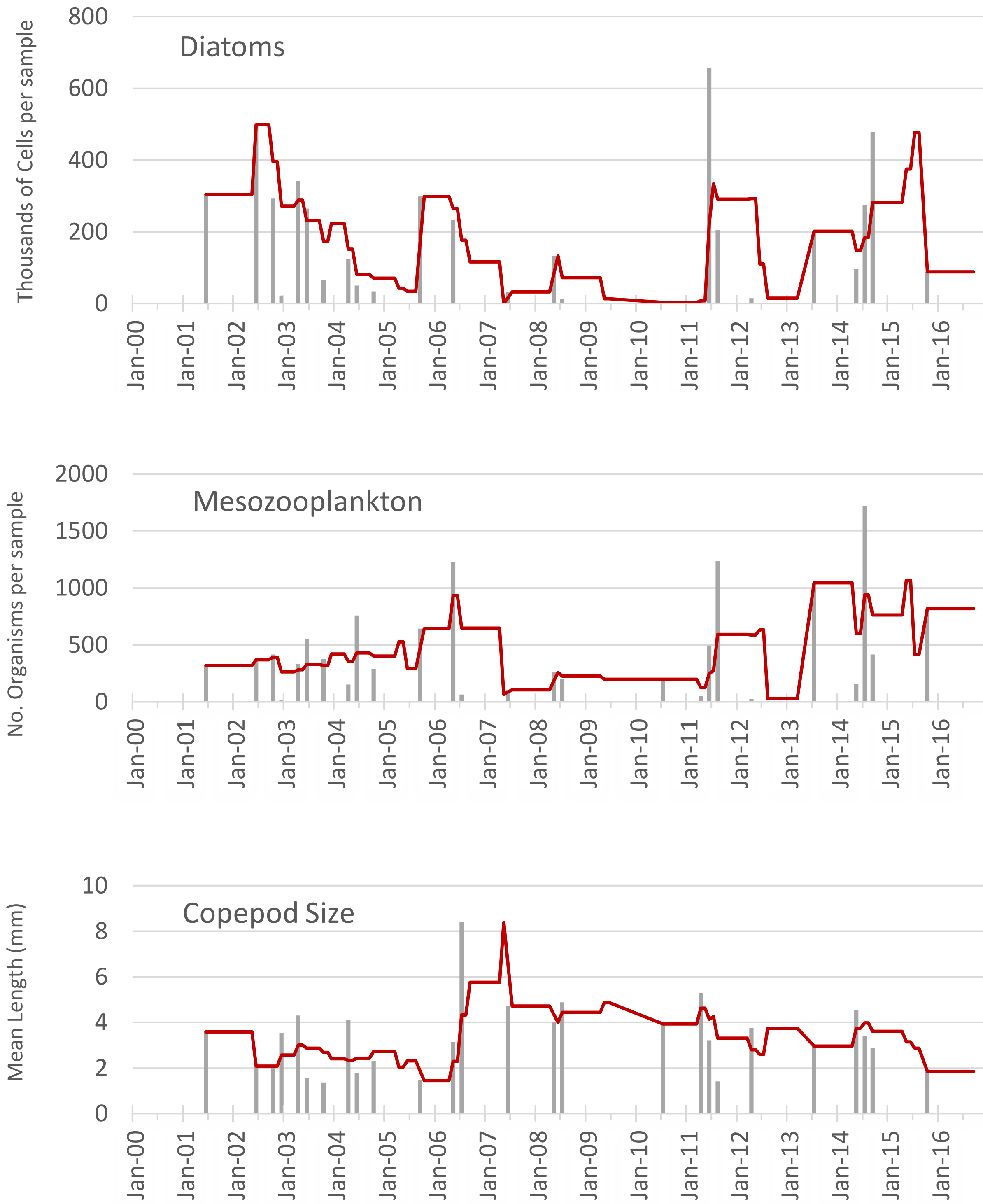


Figure R15-13. Phytoplankton and Zooplankton time series from January 2000 – December 2016. Top panel: Total diatom abundance, the combined abundance of all diatom taxa recorded per sample. Middle panel: Mesozooplankton abundance, which is the combined abundance of all zooplankton taxa recorded per sample, with the exception of ciliates and eggs of copepods/euphausiids/fish. Bottom panel: Mean copepod size. Black bars represent monthly means; red lines indicate a 12-month running mean to show the long-term trends.

5. Fishes and invertebrates

(Ned Laman, Chris Rooper, Ivonne Ortiz, Greg Ruggerone, James R. Irvine)

5.1 Biomass Trends by Foraging Guild

The largest total biomass of both apex predators and pelagic foragers is located in the central Aleutians, the region with the largest shelf area under 500m. The lowest apex predator biomass is located in the western Aleutians whereas that of pelagic foragers is found in the eastern Aleutians. This pattern has been constant since 1991, though individual species groups fluctuations do not necessarily follow the same behavior. Both western and central Aleutians have a larger total biomass of pelagic foragers compared to that of apex predators, while in the eastern Aleutians the largest total biomass alternates between apex predators and pelagic foragers.

Pelagic foragers: Total pelagic foragers biomass is slightly under 2 million tons over the entire Aleutian archipelago, with lower overall biomass across all three regions compared to 2014. This trend, however, does not characterize all pelagic foragers; in fact, there is a consistent long-term trend whereby the proportion of rockfish (Pacific ocean perch, POP, and northern rockfish) has been consistently increasing compared to that of Atka mackerel and pollock biomass. What in the early 1990 was a system where two thirds of the pelagic foragers biomass was made up by Atka mackerel and pollock, is now half or even two thirds composed by rockfish (see Figure R15-14). This may cause several minor but consistent disruptions in the structure of the system: i) on one hand Atka mackerel and pollock are shallow foragers distributed mostly between 100-200 m depth, while northern rockfish and POP are found generally in waters 100-300 m. This is relevant because they are an important fish prey for seabirds (such as tufted puffin), marine mammals (such as Steller sea lions), and a variety of other fish. In contrast, POP and northern rockfish are a much weaker trophic link across the Aleutians, very different from their role in the California Current where seabirds prey heavily on rockfish juveniles (at least based on summer diets for the Aleutians). Most pelagic piscivorous predators will complement their diets with squid and myctophids, however for central foragers, that implies longer trips from their respective colonies and haul outs.

Apex predators: Overall apex predator fish biomass decreased across all AI regions. Both Pacific cod and Arrowtooth flounder continue to be the largest biomasses within the guild across all AI regions as well, however the biomass of Pacific cod has been decreasing. The apex predator fish guild can be roughly separated into three trophic preferences: those that eat primarily: fish; fish and crustaceans/invertebrates; or primarily crustaceans and invertebrates. Large rockfish and large flatfish eat mostly fish (shown in blue tones in Figure R15-15), Pacific cod and AK skates feed approximately equal parts fish and crustaceans (AK skate less so) (shown in olive green tones), while large sculpins and other skates (shown in brown tones) feed primarily on crustaceans and invertebrates. Piscivorous apex predators make up the largest proportion in the Eastern Aleutians decreasing towards the Western Aleutians, where the shelf is wider and there are more apex predators feeding on crustaceans and invertebrates. While this is to be expected, there is a slow non-monotonic increasing trend in their biomass not only in the western, but also the central and eastern Aleutians (albeit to a lesser degree). Pacific cod, being able to switch equally between fish and crustacean/ invertebrate availability, though shown here as an apex predator within fish, is in fact a prey source to a few other fish and marine mammals (e.g. Steller sea lions and harbor seals), so changes in its biomass can affect prey as well as predators. This means that perhaps more important than the sheer biomass of apex predator fish, is their composition, as several of the piscivorous fish consume Atka mackerel and pollock and may be impacted by the larger proportion of rockfish in the system.

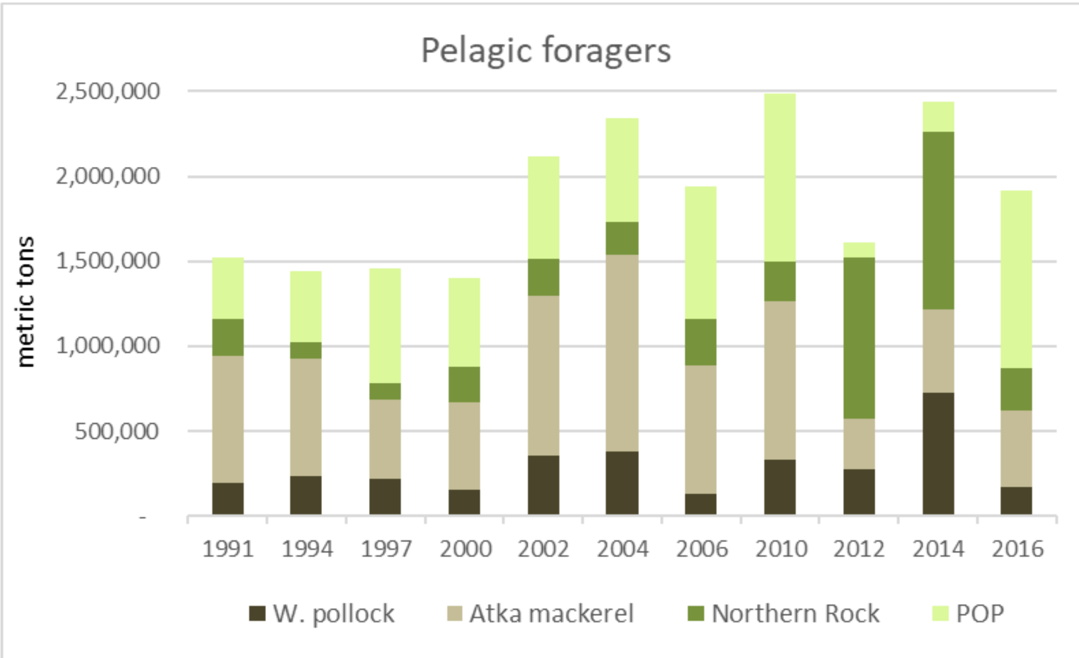


Figure R15-14. Biomass trend for main fish comprising pelagic foragers in the Aleutian Islands as estimated from the Aleutian Islands Bottom Trawl biennial survey.

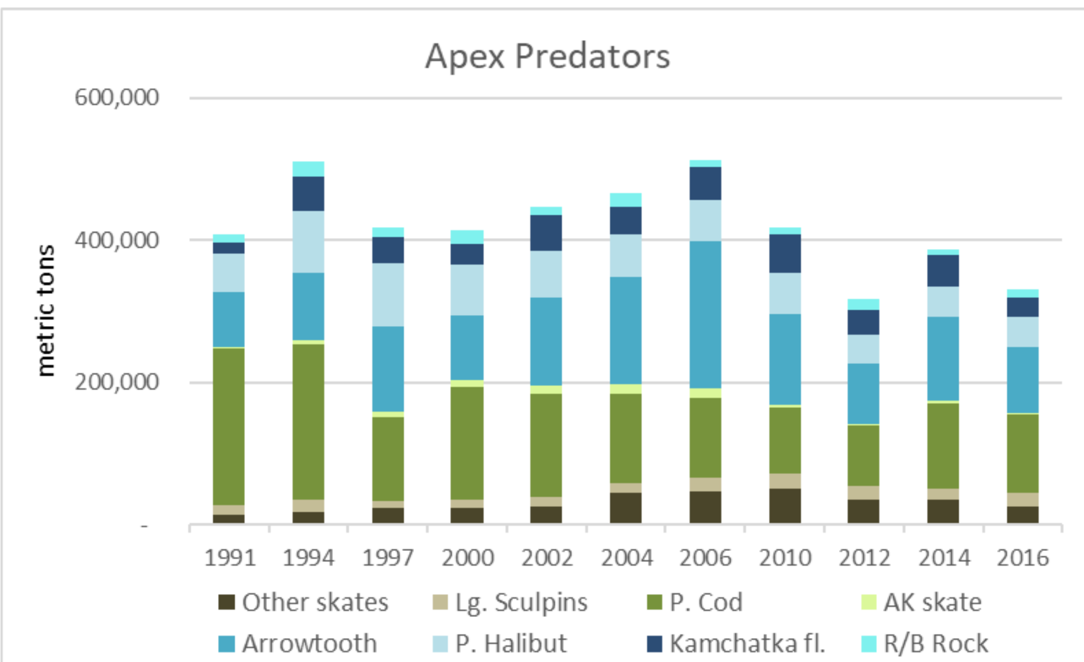


Figure R15-15. Biomass trend for main fish comprising apex predators in the Aleutian Islands as estimated from the Aleutian Islands Bottom Trawl biennial survey.

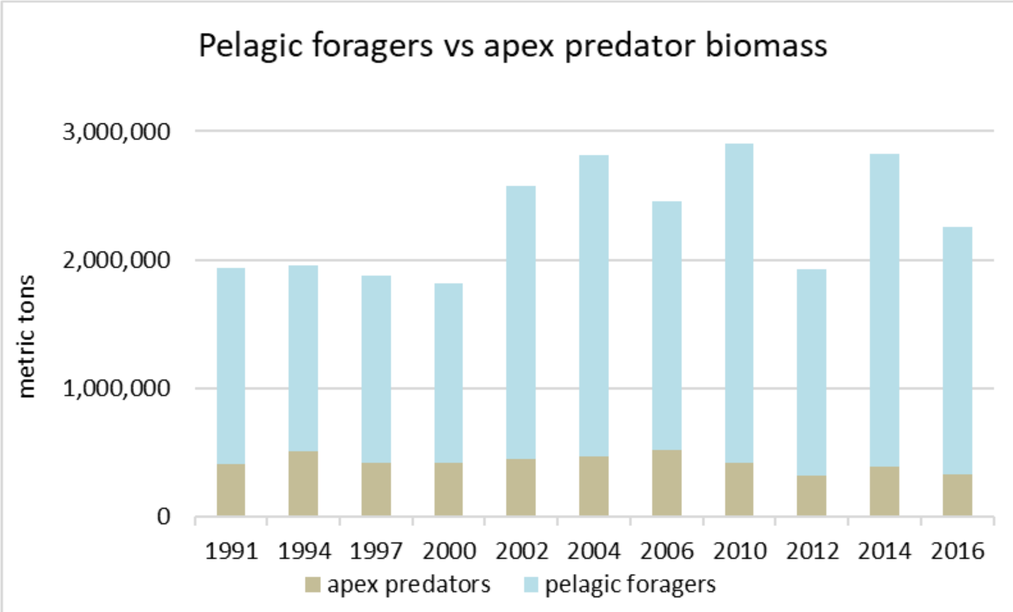


Figure R15-16. Total biomass of main pelagic foragers and apex predators as estimated from the Aleutian Islands Bottom Trawl biennial survey.

5.2 Trends in biomass of Pink Salmon

Pink salmon originating from the eastern Kamchatka Peninsula are the primary pink salmon stock occurring in the central Bering Sea and central subarctic North Pacific Ocean (Takagi et al., 1981; Myers et al., 1996). The stock exhibits a strong biennial pattern, as do many pink salmon stocks, with high abundances in odd-years (avg. 106 million pink salmon since 1990) and lower abundances in even-years (average 24 million pink salmon). Total abundance of pink salmon across the Pacific Rim is exceptional, reaching records abundances (650 million fish) in 2009 and 2011, averaging nearly 70% of all Pacific salmon since 1990 (see Figure R15-17).

The biennial pattern of pink salmon provides a natural experimental control for testing hypotheses about top-down effects of pink salmon on the structure of the pelagic ecosystem because physical oceanographic conditions do not explain these biennial patterns. Evidence indicates pink salmon affect zooplankton abundance, which in turn affects phytoplankton abundance (Batten et al., 2018); growth, age, and survival of other species of salmon (Ruggerone et al., 2016; Ruggerone and Connors, 2015), and diet and reproduction of seabirds (Springer and van Vliet, 2014). There is growing evidence that pink salmon may have influenced the decline in length-at age, survival and abundance of Chinook salmon.

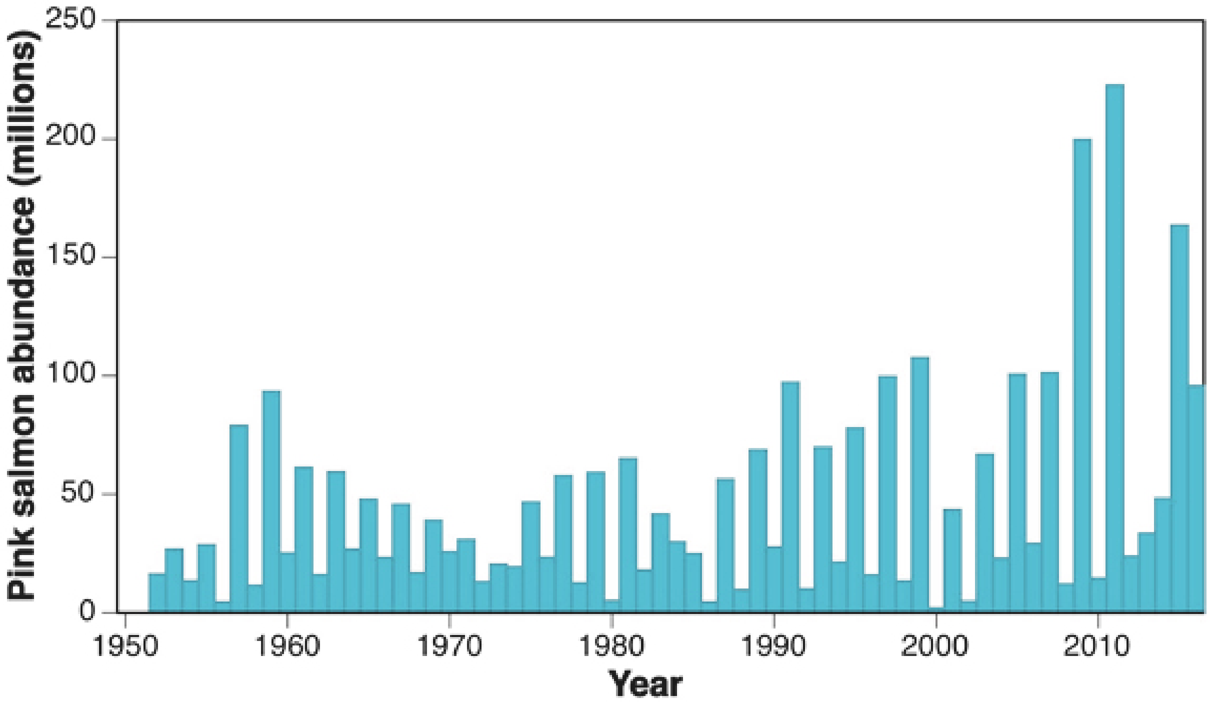


Figure R15-17. Abundance of pink salmon returning to the eastern Kamchatka Peninsula, 1952-2016 (Ruggerone and Irvine, 2018). Catch and spawning escapement since 1991 were compiled from annual NPAFC reports by Russia (http://www.npafc.org). Prior to 1992, catch data reported by the INPFC were expanded to total abundance using the harvest rate approach.

5.3 Trends in forage taxa abundance

The Alaska Fisheries Science Center's (AFSC's) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE GAP) of the U.S. National Marine Fisheries Service (NMFS) has conducted systematic bottom trawl surveys for stock assessment in the Aleutian Islands (AI) since 1980. Trawl gear, tow speed, and duration have been standardized since 1997 and follow established national protocols (Stauffer, 2004). These standardized RACE GAP bottom trawl surveys have been conducted biennially during summer months since 1997 with the exception of summer 2008 when the survey was not conducted due to lack of funding.

A stratified-random design and a modified Neyman optimum allocation sampling strategy (Cochran, 1977) were employed to select stations in primarily trawlable areas shallower than 500 m throughout the Aleutian archipelago. The survey area extends on the north side of the Aleutian Islands from Unimak Pass in the east (165°W) to Stalemate Bank in the west (170°E); on the south side of the Aleutian archipelago, the survey extends from Samalga Pass (170°W) westward. The study area is divided into four depth strata (20–100 m, 101–200 m, 201–300 m, and 301–500 m) which are further divided by bottom topography and passes between islands into contiguous sampling areas.

The fishing gear used in the Aleutian Islands bottom trawl survey is a poly Nor'Eastern high-opening bottom trawl with 24.2 m roller gear constructed with 36 cm rubber bobbins separated by 10 cm rubber disks. Trawl tows since 1997 were conducted at a standard target speed (5.6 km·h^{-1} or 3 knots) and duration (15 minutes). Vessel position, bottom contact, and net dimensions were recorded throughout each trawl using vessel-mounted global positioning systems (GPS) along with a bottom contact sensor and net mensuration equipment deployed on the trawl. Trawl tows were judged satisfactory if the net opening was within a predetermined normal range, the roller-gear maintained contact with the seafloor, and the net suffered little or no damage during the tow. Distance towed, derived from ship-mounted GPS locations, and net width, estimated from the net mensuration, were used to compute the catch-per-unit-effort (CPUE; no.·ha–1) using the area-swept method (Alverson and Pereyra, 1969; Wakabayashi et al., 1985) for each taxon considered. Estimated CPUE values for each taxon were log-transformed (ln(CPUE) + 1) prior to analyses.

Forage fishes and invertebrates can be key food sources for many marine mammal, seabird, and fish species. We considered six families of fishes and one class of invertebrates that were present in the RACE GAP AI (1997–2014) bottom trawl catches (Table R15-1). These seven groups represent numerous families, orders, genera, and species of organisms. Most of the animals caught and identified from these groups are not effectively sampled by our trawl net (e.g., escapement through the net meshes, escapement under the ground gear, etc.) or are incidental catches during the up or down cast (e.g., pelagic animals like squid, sand lance, herring, lanternfish, and smelt). However, with our standardized operating procedures and relatively consistent deployment and retrieval of the net, indexes of abundance for these taxa may still be informative.

Anomalies (A) of annual mean abundance ($\overline{CPUE_Y}$) from the long-term mean ($\overline{CPUE_{97-14}}$) were calculated as

$$A = \frac{\overline{CPUE_Y} - \overline{CPUE_{97-14}}}{SD_Y}$$

where SD_Y is the annual standard deviation. These anomalies from the long-term mean, indicated by the dashed line on the graphs, were visually compared for the six families of fishes and one class of invertebrates to assess trends in abundance (Figure R15-18).

Status and trends: The RACE GAP AI summer bottom trawl survey targets benthic fishes and invertebrates. Many of the animals encompassed by the taxonomic forage groups presented here are incidentally caught by our bottom trawl survey gear and, therefore, resulting CPUE estimates are indexes rather than true abundance. The anomaly plots from the CPUE estimates demonstrate high inter-annual variability in forage taxa abundance indexes, but also suggest long term trends in several cases (Figure R15-18). Squid and sculpin abundance appeared to be trending upward while sand lance, lanternfishes, and smelts appeared to be decreasing in recent survey years. Herring were relatively uncommon during the survey period; occurring in just half of the survey years. Greenling abundance was variable and appeared to be centered around the long-term mean.

None of these taxa support directed fisheries in the Aleutian Islands so observed scatter or trends from the RACE GAP bottom trawl survey data likely result from variations in natural mortality, natality, immigration, and emigration. Variability or apparent trends may also be influenced by the incidental nature of the trawl gear's captures of these taxa so caution should be used when interpreting these results.

Implications: Forage taxa represent potential prey for higher trophic level organisms. When their abundance levels are relatively stable or increasing it may indicate prey availability to predator species. Conversely, abundance levels decreasing may suggest a reduction in prey availability.

For the seven forage taxa considered, trends were mixed with some increasing, some decreasing, and some remaining stable or inconclusive. The implications for predator populations are likely species-specific depending on prey preferences. These changes in forage taxa abundance can directly affect predator populations by altering prey availability. Because capture of forage taxa in RACE GAP bottom trawl surveys is largely incidental, caution should be used when informing policy decisions utilizing these data. Combining the trawl survey results with other sources of data impinging on forage taxa populations (e.g., seabird or Stellar sea lion diet studies, benthic predator abundance estimates from bottom trawl survey, climate change studies, etc.) would be beneficial for assessing ecosystem implications of these data for management decisions.

Table R15-1. Forage Taxa (fishes and invertebrates) present in summer bottom trawl survey catches from the Aleutian Islands conducted by the U.S. National Marine Fisheries Service, Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering Division, Groundfish Assessment Program (1997–2014). Shown below are species grouped by Class or Family with their corresponding scientific and common names.

GROUP TAXON	*SCIENTIFIC NAME*	*COMMON NAME*
FISHES		
AMMODYTIDAE		
	Ammodytes sp.	*sand lance*
CLUPEIDAE		
	Clupea pallasii	*Pacific herring*
COTTIDAE		
	Icelinus sp.	
	Thyriscus anoplus	*sponge sculpin*
	Icelinus borealis	*northern sculpin*
	Gymnocanthus sp.	
	Gymnocanthus pistilliger	*threaded sculpin*
	Gymnocanthus tricuspis	*Arctic staghorn sculpin*
	Gymnocanthus galeatus	*armorhead sculpin*
	Radulinus asprellus	*slim sculpin*
	Artediellus pacificus	*hookhorn sculpin*
	Bolinia euryptera	*broadfin sculpin*
	Hemilepidotus gilberti	*banded Irish lord*
	Hemilepidotus zapus	*longfin Irish lord*
	Hemilepidotus hemilepidotus	*red Irish lord*
	Hemilepidotus jordani	*yellow Irish lord*
	Triglops sp.	
	Triglops forficata	*scissortail sculpin*
	Triglops metopias	*highbrow sculpin*
	Triglops scepticus	*spectacled sculpin*
	Triglops pingeli	*ribbed sculpin*
	Triglops macellus	*roughspine sculpin*
	Archistes biseriatus	*scaled sculpin*
	Myoxocephalus polyacanthocephalus	*great sculpin*
	Myoxocephalus jaok	*plain sculpin*
	Myoxocephalus sp.	
	Myoxocephalus quadricornis	*fourhorn sculpin*
	Leptocottus armatus	*Pacific staghorn sculpin*
	Enophrys lucasi	*leister sculpin*
	Enophrys diceraus	*antlered sculpin*
	Triglops xenostethus	*scalybreasted sculpin*
	Icelus spiniger	*thorny sculpin*
	Icelus canaliculatus	*blacknose sculpin*

	Icelus euryops	*wide-eye sculpin*
	Icelus spatula	*spatulate sculpin*
	Icelus uncinalis	*uncinate sculpin*
	Rastrinus scutiger	*roughskin sculpin*
	Icelus sp.	
HEXAGRAMMIDAE		
	Pleurogrammus monopterygius	*Atka mackerel*
	Hexagrammos lagocephalus	*rock greenling*
	Hexagrammos decagrammus	*kelp greenling*
MYCTOPHIDAE		
		lanternfish unid.
	Stenobrachius sp.	
	Stenobrachius leucopsarus	*northern lampfish*
	Stenobrachius nannochir	*garnet lampfish*
	Diaphus sp.	
	Diaphus theta	*California headlightfish*
	Lampanyctus sp.	
	Nannobrachium ritteri	*broadfin lanternfish*
	Nannobrachium regale	*pinpoint lampfish*
	Lampanyctus jordani	*brokenline lampfish*
	Nannobrachium sp.	
	Protomyctophum sp.	
	Protomyctophum thompsoni	*northern flashlightfish*
	Tarletonbeania sp.	
	Tarletonbeania crenularis	*blue lanternfish*
OSMERIDAE		
		smelt unid.
	Thaleichthys pacificus	*eulachon*
	Mallotus villosus	*capelin*
INVERTBRATES		
CEPHALOPODA		
		cephalopod unid.
	Octopodidae	*octopus unid.*
	Benthoctopus leioderma	*smoothskin octopus*
	Benthoctopus sibiricus	
	Octopus sp.	
	Japetella diaphana	
	Opisthoteuthis californiana	*flapjack devilfish*
	Enteroctopus dofleini	*giant octopus*
	Octopus rubescens	
	Benthoctopus sp.	
	Sasakiopus salebrosus	*pygmy benthoctopus*
	Vampyroteuthis infernalis	*vampire squid*
	Decapodiformes	*squid unid.*
	Decapodiform egg	*squid egg unid.*
	Rossia pacifica	*eastern Pacific bobtail*
	Rossia pacifica eggs	
	Doryteuthis opalescens	*California market squid*
	Gonatus sp.	
	Gonatus middendorffi	
	Berryteuthis magister	*magistrate armhook squid*
	Gonatopsis sp.	
	Gonatopsis borealis	*boreopacific armhook squid*
	Moroteuthis robusta	*robust clubhook squid*
	Onychoteuthis borealijaponicus	*boreal clubhook squid*
	Galiteuthis phyllura	
	Chiroteuthis calyx	
	Cranchiidae	
	Taonius pavo	

	Belonella borealis
	Octopoteuthis deletron
	Histioteuthis hoylei
	Stigmatoteuthis dofleini

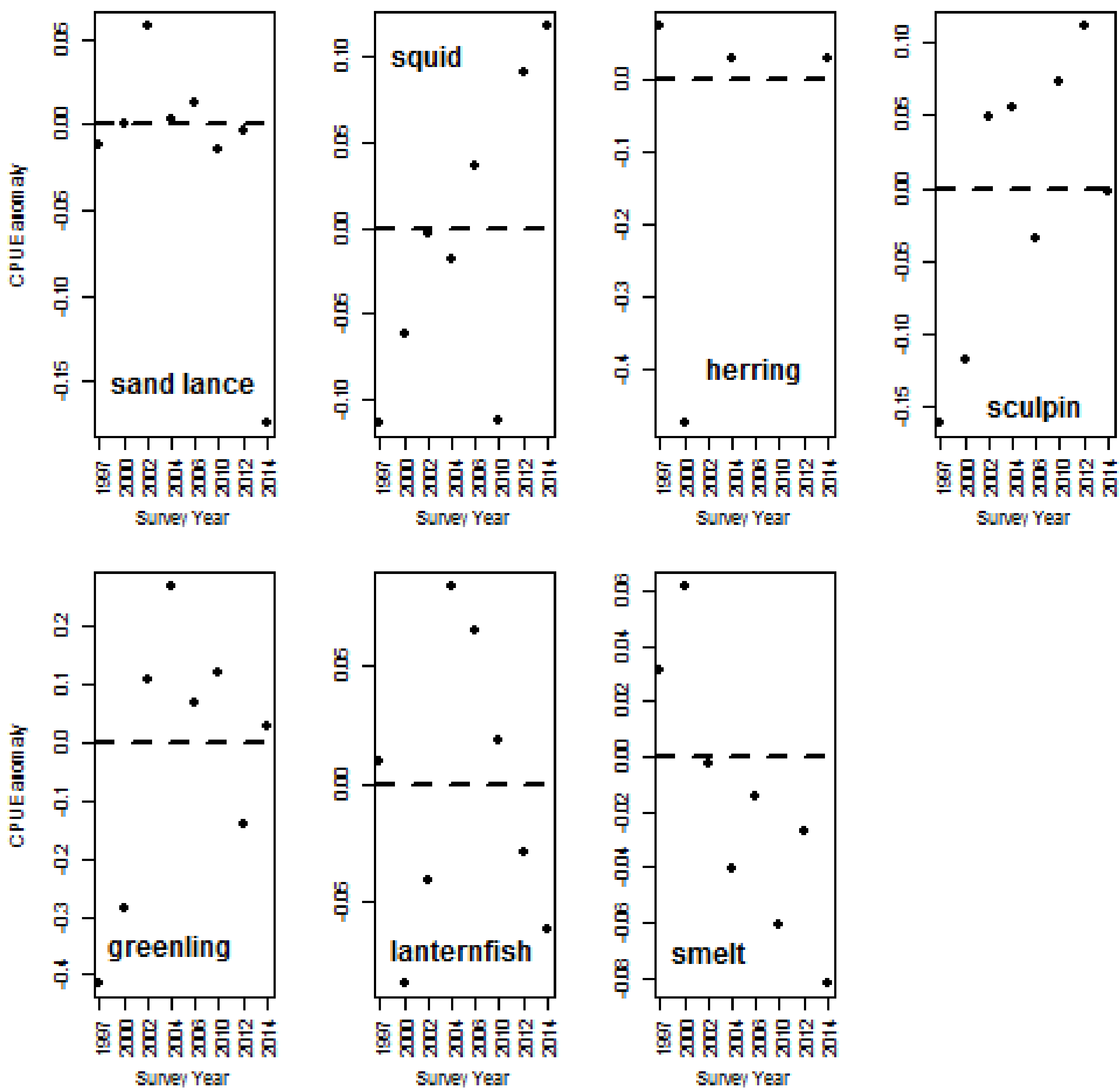


Figure R15-18. Log-transformed annual mean catch-per-unit-effort anomalies from the long-term mean abundance estimated using RACE GAP summer bottom trawl survey catches from the Aleutian Islands and standardized by the annual standard deviations for forage taxa groups sand lance (Ammodytidae), squid (Cephalopoda), herring (Clupeidae), sculpin (Cottidae), greenling (Hexagrammidae), lanternfish (Myctophidae), and smelt (Osmeridae).

5.4 Distribution

5.4.1 Distribution of rockfish species along environmental gradients in Gulf of Alaska and Aleutian Islands bottom trawl surveys

Previous analysis of rockfish from 14 bottom trawl surveys in the Gulf of Alaska and Aleutian Islands (Rooper, 2008), defined five species assemblages based on similarities in their distributions along geographical position, depth, and temperature gradients. The 180 m and 275 m depth contours were major divisions between assemblages inhabiting the shelf, shelf break, and lower continental slope. Another noticeable division was between species centered in southeastern Alaska and those found in the northern Gulf of Alaska and Aleutian Islands.

In this time-series, the mean-weighted distributions of six rockfish (five Sebastes spp. and *Sebastolobus alascanus*) species along the three environmental gradients (depth, temperature, and position) were calculated for the Aleutian Islands. A weighted mean value for each environmental variable was computed for each survey as:

$$Mean = \frac{\sum(f_i x_i)}{\sum f_i},$$

where fi is the CPUE of each rockfish species group in tow i and xi is the value of the environmental variable at tow i. The weighted standard error (SE) was then computed as:

$$SE = \frac{\sqrt{\dfrac{\left(\sum\left(f_i x_i^2\right)\right) - \left(\left(\sum f_i\right) * mean^2\right)}{\left(\sum f_i\right) - 1}}}{\sqrt{n}},$$

where n is the number of tows with positive catches. Details of the calculations and analyses can be found in Rooper (2008). These indices monitor the distributions of major components of the rockfish fisheries along these environmental gradients to detect changes or trends in rockfish distribution.

Status and trends: There are three statistically significant depth-related trends over the time series that have continued over the last couple of surveys, as the distribution of adult rougheye rockfish, adult Pacific Ocean perch and shortraker rockfish have been shallower in the most recent surveys of the Aleutian Islands (Figure R15-19). Northern rockfish have continued to show a significant trend over the last few surveys in their mean-weighted distribution towards the western Aleutians, although the trend has been flat over the last few surveys. There were no significant trends in mean-weighted temperature distributions for any species and all species were found within about 1°C over the entire time series. Probably because of the increased temperatures observed during the Aleutian Islands surveys in 2016, increases in mean weighted temperature have been observed for this year. This is a trend to continue monitoring in the next survey if water temperatures remain high.

The observed changes in depth and spatial distributions for adult rougheye rockfish, shortraker rockfish, northern rockfish and adult Pacific Ocean perch in the AI are probably related to changes (increases) in overall abundance. Although it is interesting to note that in the cases of adult rougheye rockfish, adult Pacific Ocean perch and shortraker rockfish their depth range has become shallower while the temperatures occupied by the species have not changed significantly in recent surveys (with the possible exception of the 2016 survey).

Implications: The trends in the mean-weighted distributions of rockfish should continue to be monitored, with special attention to potential causes of the shift in depth and position distributions of rockfish, especially as they relate to changing temperatures. In 2016 all five rockfish groups were found at the highest mean-weighted temperature in the time series and the trend for all species has been upward since the 2012 survey.

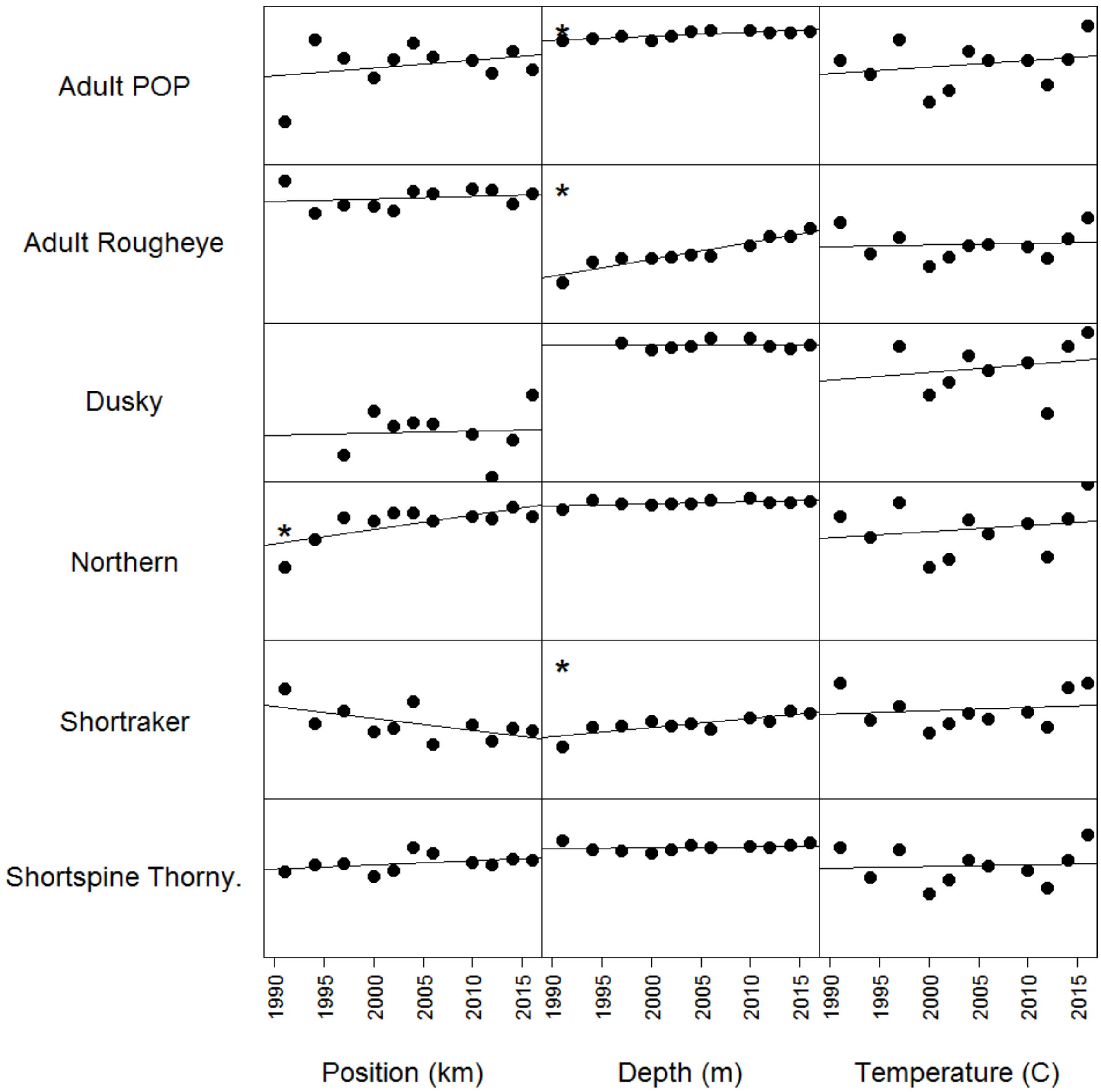


Figure R15-19. Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Aleutian Islands. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance from Hinchinbrook Island, Alaska, with positive values west of this central point in the trawl surveys and negative values in southeastward. Asterisk indicates significant trend over the time series.

6. Marine Birds

(Heather Renner, Nora Rojek)

6.1 Puffins

At least thirty species of seabirds are known to breed in the Aleutian Islands. While it is not possible to monitor all species and all breeding colonies, multiple species are monitored at several monitoring sites to provide long-term, time-series data for a number of different parameters including breeding timing, reproductive success, diet, and breeding population numbers (Table R15-2) (Byrd, 2007). Results of monitoring are summarized in annual reports (see Youngren et al., 2017; Dragoo et al., 2017; Pietrzak et al., 2017). Species were selected for long-term monitoring that include birds that forage in different ways and eat different kinds of prey in order to utilize the seabirds as indicators of change in different parts of the marine food web (Byrd, 2007). This includes two major subdivisions of breeding birds, the fish feeders (piscivores; e.g., murres) and the plankton feeders (planktivores; e.g., storm-petrels). Within the Aleutians, long-term monitoring is conducted at Buldir Island in the western Aleutians, at Aiktak Island in the eastern Aleutians, and formerly at Kasatochi Island (and neighboring islands) in the central Aleutians (Table R15-2). Annual monitoring at Kasatochi Island ended after 2008 due to logistical issues following a volcanic eruption.

Seabirds are typically long-lived; as a result, populations usually respond gradually to changes in rates of recruitment and productivity. Reproductive rates vary inter-annually in response to marine food web conditions. Shifts in diet can provide indication of changes in prey, which are likely affected by oceanographic shifts, such as changes in sea temperature or large-scale fluctuations in ocean climate. Evaluation of these parameters for any particular short time period many not be biologically meaningful, but here we provide a few interesting observations that occurred during the time period covered by this status report for the Aleutian Islands for 2009-2014.

The tufted puffin (*Fratercula cirrhata*) is currently a *species of conservation concern*, with documented steep declines in population numbers in the southern part of its range within the North Pacific (Hanson and Wiles, 2015) and a decline in the Gulf of Alaska (Goyert et al., 2017). The species has been listed as *Endangered* by Washington State and has been petitioned for Federal listing for the Pacific coast population. Aiktak Island, a long-term monitoring site in the eastern Aleutians with a large tufted puffin colony, is within the center of its breeding distribution, thus an important site for understanding the status of the Alaska population. Tufted puffins are piscivores with a broad diet; during the breeding season they consume the most abundant and available prey within close proximity to breeding colonies, which is typically small forage fish, but also invertebrates, particularly for colonies close to oceanic habitats (Piatt and Kitaysky, 2002).

During the 2009-2014 time period, at Buldir Island, in the western Aleutians, tufted puffins had lower reproductive success during the years 2009-2012, including complete failure in 2011, compared to most years prior to this time period. At Aiktak Island, in the eastern Aleutians, reproductive success was normal, although timing of tufted puffin breeding was earlier for all years 2008-2014 compared to the long-term average (see Figures R15-20, 21).

During the time period 2009-2014, at Aiktak Island, the percent composition of *Ammodytes* spp. (sand lance) in chick diets declined compared to 1998-2008, and gadids (pollock and Pacific cod) increased. Also, the frequency of occurrence and biomass of capelin (Mallotus villosus) generally increased in most of the years of this time period (see Figure R15-22). In contrast, at

Buldir Island, tufted puffin chick diets are dominated by Atka mackerel (*Pleurogrammus monopterygius,* Hexagrammidae) and squid (Gonatidae), with more Atka mackerel showing up in diets in recent years, including 2009-2014, compared to the majority of previous years (see Figure R15-23). The difference in puffin diets between Buldir and Aiktak islands is further complemented by additional sampling at multiple colonies in eastern Aleutians in 2012 and western Aleutians in 2013, which showed per cent mass of chick diets of western Aleutian colonies were dominated by Atka mackerel and squids, while eastern Aleutians colonies were dominated by gadids and sand lance (Piatt et al., 2013; Schoen et al., 2013; Sydeman et al., 2017). Seabird diets are often used as an indicator of the prey available in the surrounding areas, showing evidence of the potential prey field for fish of commercial importance or other predators, such as marine mammals.

Table R15-2. Foraging guilds of breeding seabirds monitored at Aiktak and Buldir islands.

Foraging guild	*Primary domain*	*Seabird species*	*Monitored on:*	
			Aiktak	*Buldir*
Diving fish-feeder	*Offshore*	*Common murre*	*Yes*	*Yes*
		Thick-billed murre	*Yes*	*Yes*
		Tufted puffin	*Yes*	*Yes*
		Horned puffin	*Yes*	*Yes*
	Inshore	*Double-crested cormorant*	*Yes*	
		Red-faced cormorant	*Yes*	*Yes*
		Pelagic cormorant	*Yes*	*Yes*
		Pigeon guillemot	*Yes*	*Yes*
Surface fish-feeder	*Offshore*	*Black-legged kittiwake*		*Yes*
		Red-legged kittiwake		*Yes*
Diving plankton-feeder	*Offshore*	*Ancient murrelet*	*Yes*	
		Least auklet		*Yes*
		Crested auklet		*Yes*
	Inshore	*Parakeet auklet*		*Yes*
		Whiskered auklet		*Yes*
Surface plankton-feeder	*Offshore*	*Fork-tailed storm-petrel*	*Yes*	*Yes*
		Leach's storm-petrel	*Yes*	*Yes*
Opportunistic feeder		*Glaucous-winged gull*	*Yes*	*Yes*

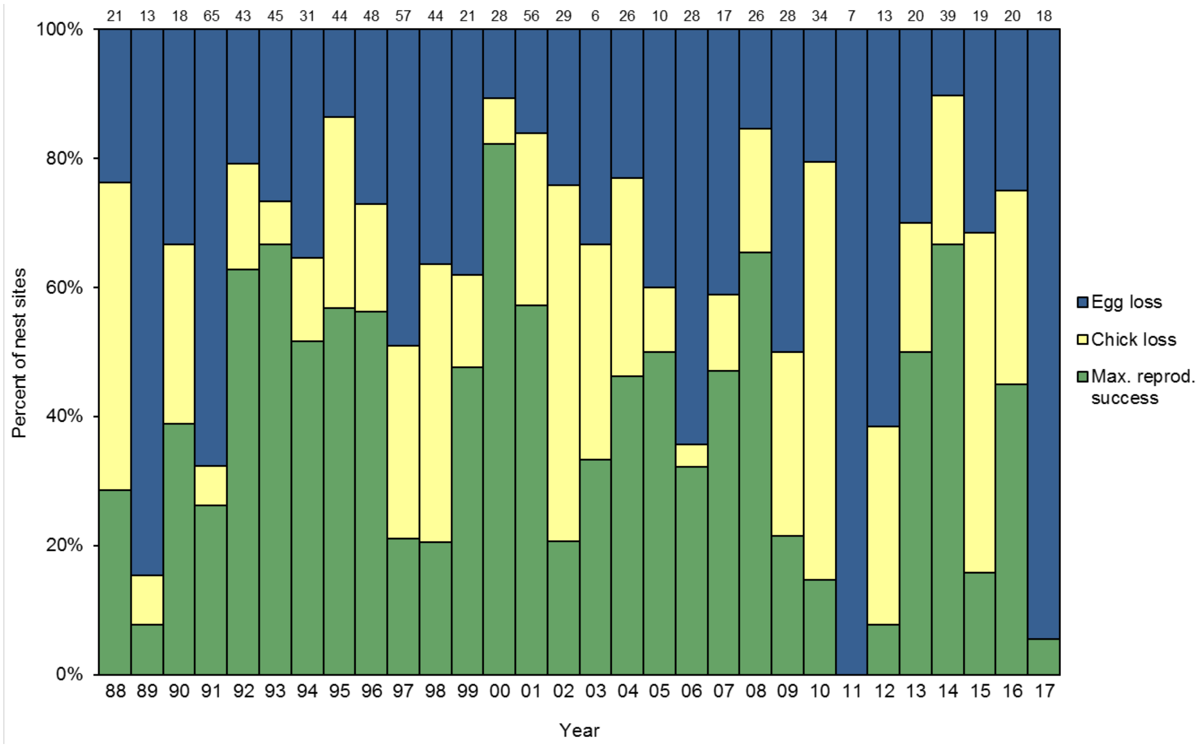


Figure R15-20. Reproductive performance of tufted puffins at Buldir Island, Alaska. Values represent maximum potential success, including nest sites with chicks too young to consider fledged at the last check. Numbers above columns indicate sample sizes.

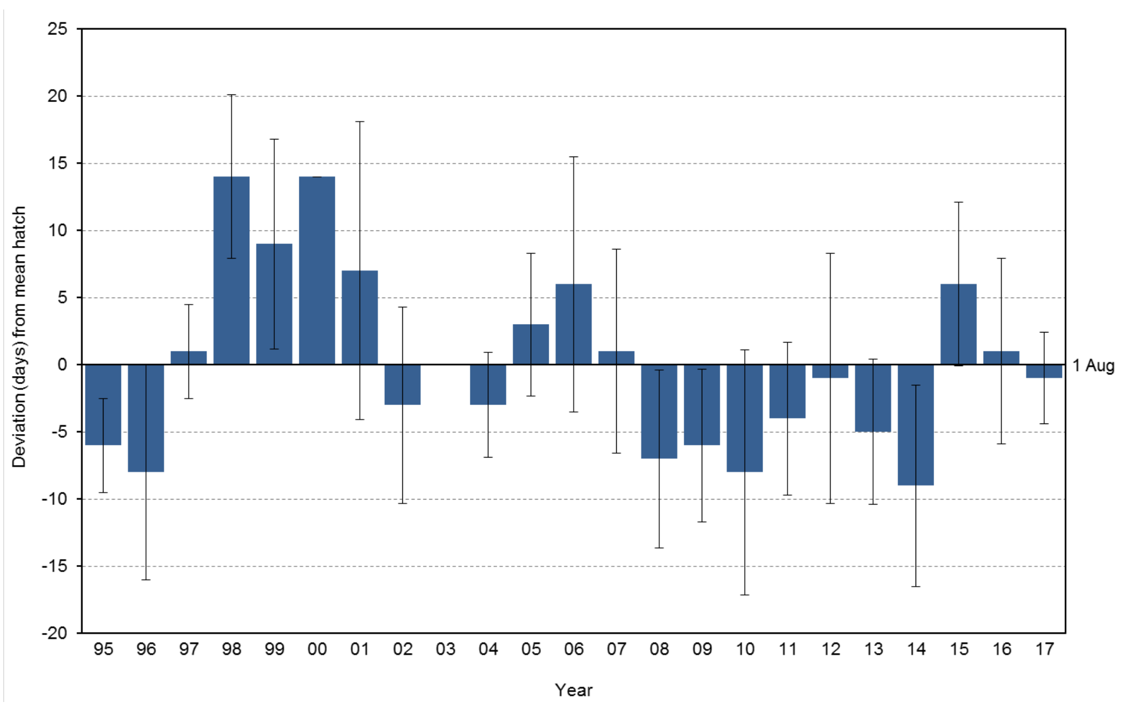


Figure R15-21. Yearly hatch date deviation for tufted puffins at Aiktak Island, Alaska. Negative values indicate earlier than mean hatch t=date, positive values indicate later than mean hatch date. Error bars represent standard deviation around each year’s mean hatch date.

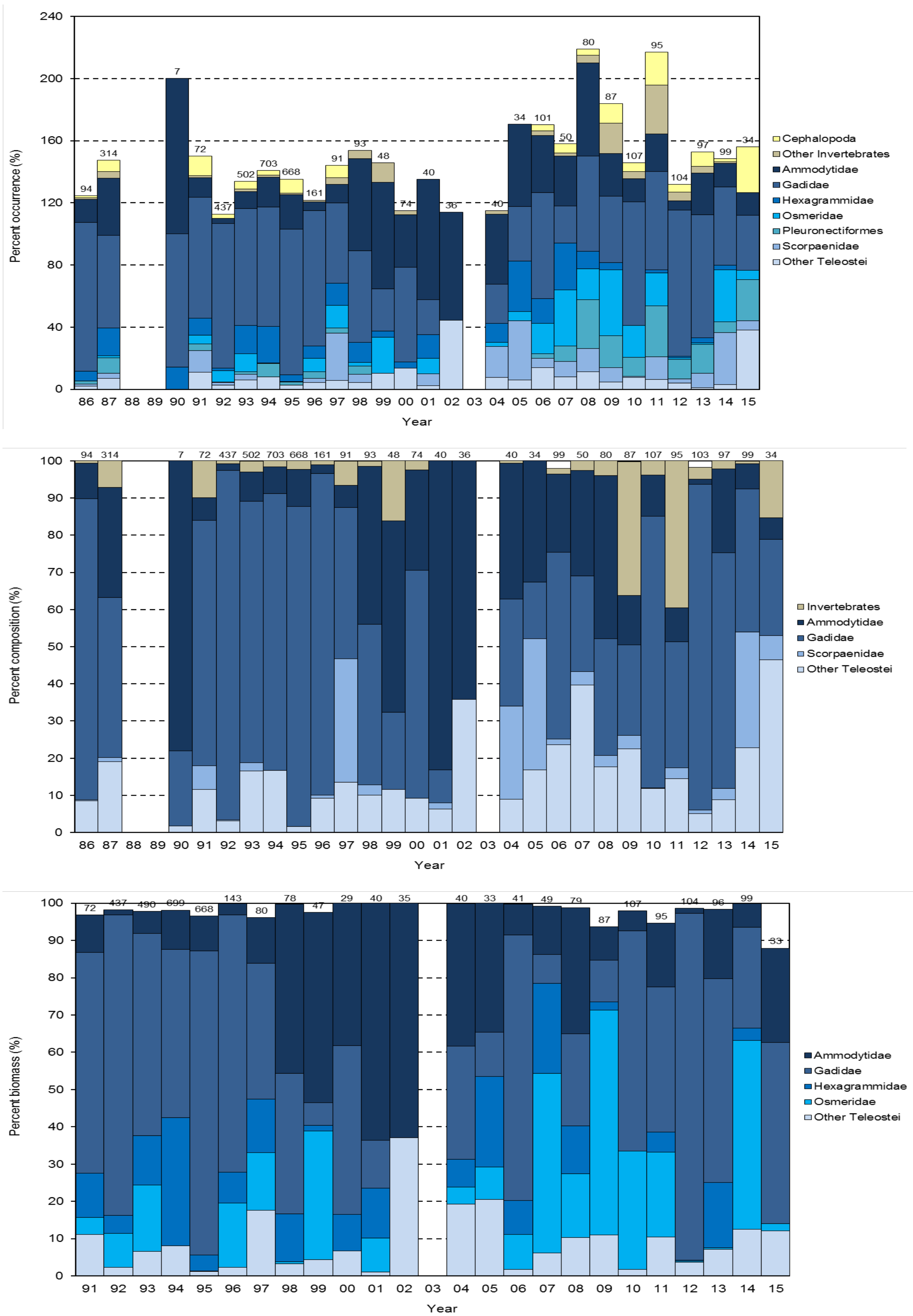


Figure R15-22. Diet figures at Aiktak Island. Top panel: Frequency of occurrence; Middle panel: percent composition, and Bottom panel: relative biomass).

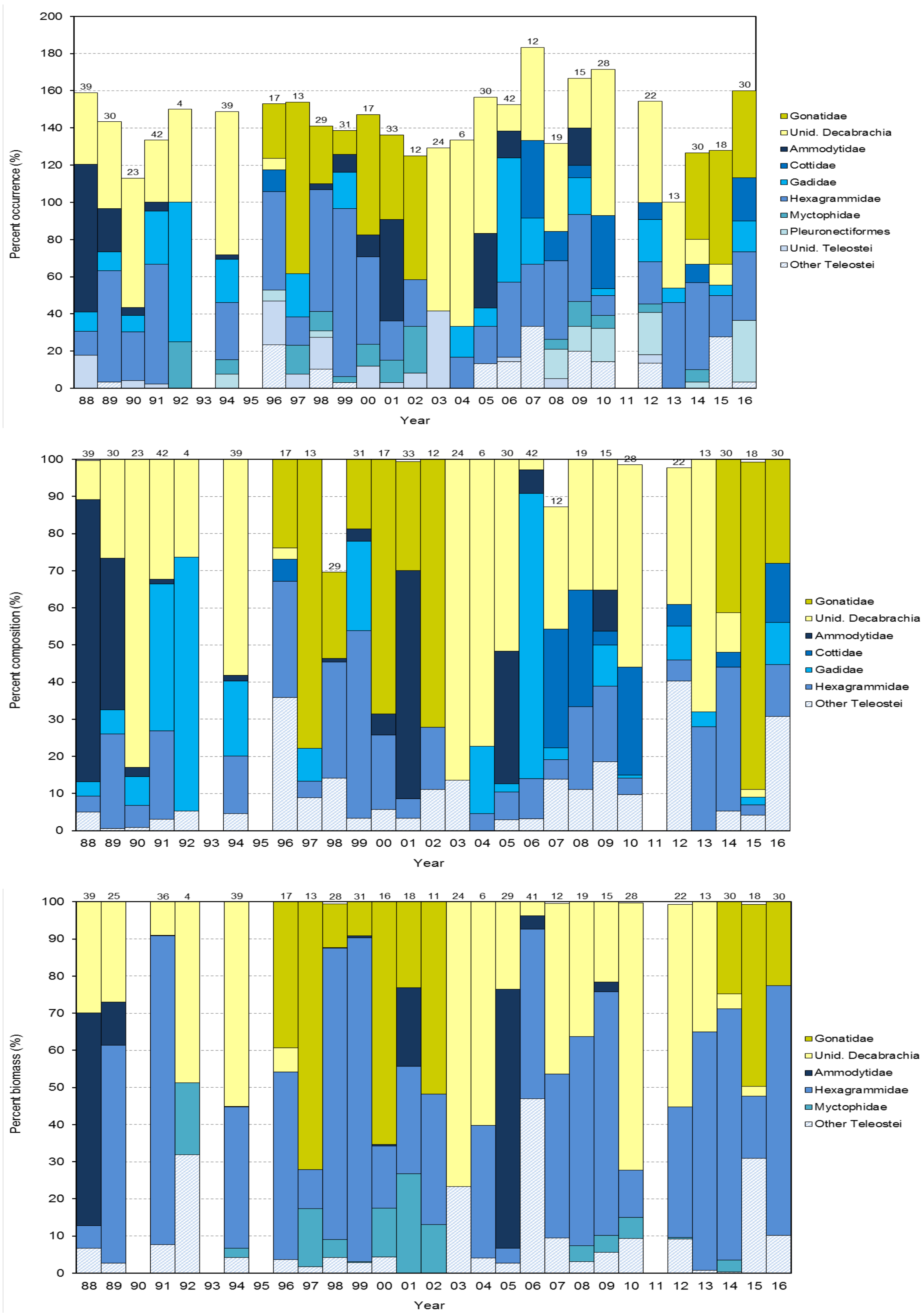


Figure R15-23. Diet figures at Buldir Island. Top panel: Frequency of occurrence; Middle panel: percent composition, and Bottom panel: relative biomass).

7. Marine mammals

(Lowell Fritz, Katie Sweeney, Tom Gelatt (Steller sea lions), Josh London, Shawn Dahle (harbor seals)).

7.1 Estimated production of Steller sea lion pups, 1978-2016, by region in the Aleutian Islands and eastern Bering Sea

Steller sea lion (*Eumetopias jubatus*) pup production in the Aleutian Islands has been monitored and assessed using both ground-based (a team moving slowly through the rookery and counting pups) and aerial methods (high-resolution aerial photography; Snyder et al., 2001; Fritz et al., 2016). Pups are not counted every summer, nor are all rookery sites consistently surveyed, which leaves holes (missing cells) in the rookery-year time series matrix, which can make trend estimation problematic. To address this, we used agTrend (Johnson and Fritz, 2014) to fill in the missing data, enabling trends to be estimated for any region (aggregation of sites) and period of interest.

Steller sea lion pup production reported here is for 6 regions in western Alaska, regions 1 through 6 from west to east (see Figure R15-23). The primary rookeries within each region are (see https://www.nodc.noaa.gov/cgi-bin/OAS/prd/accession/details/129877):

- Region 1: Attu-Cape Wrangell, Agattu-Gillon Point, Agattu-Cape Sabak, Buldir
- Region 2: Kiska-Cape St. Stephens, Kiska-Leif Cove, Ayugadak, Amchitka-Column Rock
- Region 3: Ulak-Hasgox Point, Gramp, Tag, Kanaga-Ship Rock
- Region 4: Adak-Lake Point, Kasatochi-North Point
- Region 5: Amlia-East Cape, Seguam-Saddleridge, Yunaska
- Region 6: Adugak, Ogchul, Bogoslof, Akutan-Cape Morgan, Akun-Billingshead, Ugamak, Sea Lion Rock (Amak), Walrus

Steller sea lion pup production data reported here is for PICES areas 13 and 15, and bounded by 172°E-163°W, 51°N-57°N.

Steller sea lions are large (adult males up to 1000 kg, females up to 300 kg), K-selected, apex predators that have a large breeding range in the North Pacific sub-arctic ecosystem spanning from eastern Russia to the west coast of the United States. Population trends vary across their range: the eastern stock (breeding range southeast Alaska USA south to California USA, including British Columbia, Canada) has been increasing at ~3% per year since at least the late 1970s (NMFS, 2013), while the western stock (from Prince William Sound, Alaska, USA west to eastern Russia) had a steep decline in abundance in the 1980s, a slower decline through the 1990s, and a slow (but regionally variable) recovery since the early 2000s (Fritz et al., 2016). Declines in abundance throughout most of the US Aleutian Islands continued through 2016, and in the western Aleutians (region 1) have resulted in a 94% decline in abundance between 1978 and 2016; regions 2 and 3 (to the east of region 1) declined ~80% over that period. Steller sea lions in the Aleutian Islands eat primarily fish and cephalopods, and most of their primary prey are also commercially exploited (Sinclair and Zeppelin, 2002; Sinclair et al., 2013; Tollit et al., 2017). Competition with fisheries remains a threat to recovery for the western Steller sea lion population, along with environmental change, killer whale predation, and pollution (NMFS 2008).

Status and trends: In 1997, the western Steller sea lion was listed as *Endangered* under the US *Endangered Species Act*. It remained listed as *Endangered* in 2017.The 2003-2016 trends in Steller sea lion pup production in regions of the Aleutian Islands and overall changes in annual pup production between 1978 and 2016 are (see Figure R15-24):

a. Region 1: -7% per year between 2003 and 2016; -94% overall between 1978 and 2016
b. Region 2: -4% per year between 2003 and 2016; -81% overall between 1978 and 2016
c. Region 3: -3% per year between 2003 and 2016; -81% overall between 1978 and 2016
d. Region 4: stable (-1% per year) between 2003 and 2016; -58% overall between 1984 and 2016
e. Region 5: stable (+1% per year) between 2003 and 2016; -79% overall between 1978 and 2016
f. Region 6; +3% per year between 2003 and 2016; -67% overall between 1978 and 2016

Competition with fisheries remains a threat to recovery for the western Steller sea lion population, along with environmental change, killer whale predation, and pollution (NMFS, 2008). An 80+% decline in pup production (and abundance) of Steller sea lions in the Aleutian Islands means less predation on several important groundfish stocks, but what this means for the Aleutian ecosystem overall is not known.

The trends indicate that the Aleutian Island ecosystem is currently far less capable of supporting a robust Steller sea lion population than ~40 years ago. This decline in Steller sea lion carrying capacity may be caused by climate/oceanographic changes, the long-term consequences of commercial fishing, an increase in rates of predation (or abundance, or both) of killer whales, and/or pollution. These trends are important because Steller sea lions are listed as *Endangered* under the US *Endangered Species Act*, and the species is not meeting its recovery goals and objectives as established by NMFS (2008). NMFS is required to ensure that other federal actions (e.g., authorizing commercial groundfish fisheries in US waters) are not significantly affecting Steller sea lion recovery.

These trends should help policy makers make informed decisions about how to manage fisheries and other human activities to stem the decline in pup production and foster Steller sea lion recovery.

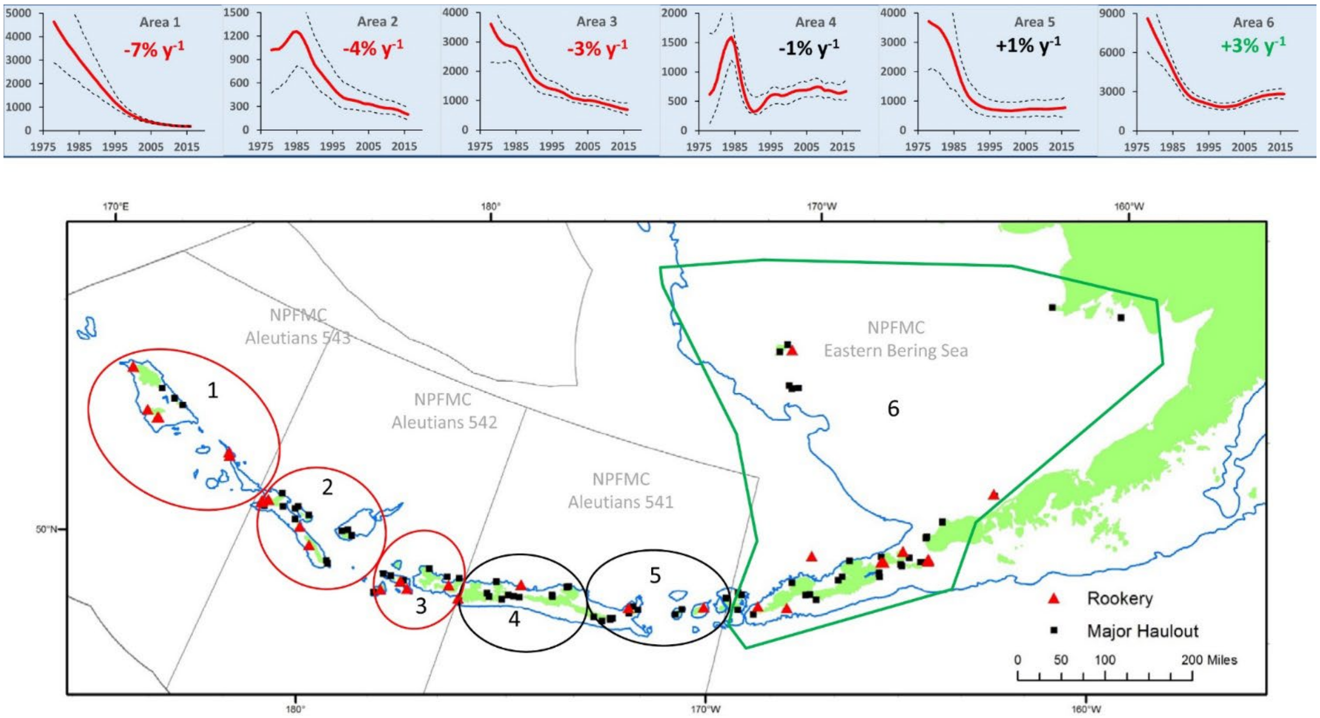


Figure R15-24. Western Steller Sea Lion pups in the Aleutian Islands. Predicted counts (1978-2016) and annual rates of change (2003-16).

7.2 Harbor seals

Harbor seals (*Phoca vitulina richardsi*) are distributed throughout the Aleutian Islands where they comprise one of 12 management stocks in Alaska. The most recent abundance estimate (including data through 2011) is 6,431 seals (SE: 882). The most recent 5-year population trend estimate (from 2007 to 2011) suggests the stock is increasing by 75 seals per year (SE: 220), however, there is a 36% probability that the trend is actually declining rather than increasing. Abundance and trend estimates from 1998 to 2011 suggest the stock has been stable or perhaps slightly increasing for several years (see Figure R15-25). This is largely driven by dynamics within the eastern Aleutians, primarily the Fox Islands, where approximately 70% of the seals in this stock reside.

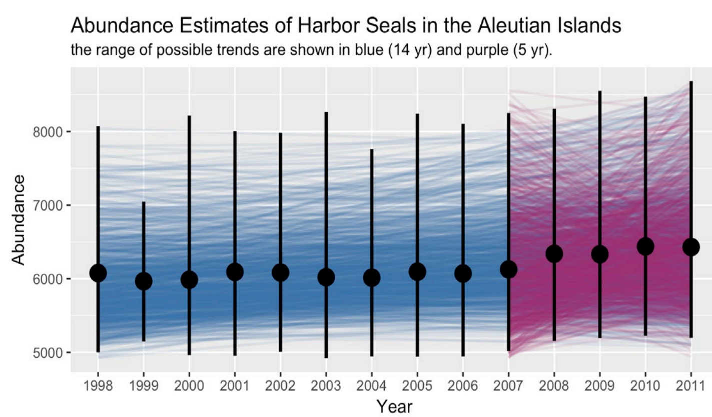


Figure R15-25. Abundance estimates for Harbor Seals in the Aleutian Islands.

The recent stability of this stock follows a period of significant decline. A partial estimate of harbor seal abundance in the Aleutian Islands was determined from skiff-based surveys conducted at 106 islands from 1977 to 1982 (Small et al., 2008). When researchers compared this estimate (8,601 seals) to aerial survey counts at the same islands conducted in 1999 (2,859 seals), the number of harbor seals had declined by 67 percent. Regionally, the strongest declines occurred in the western Aleutians (Near Islands, 86%) with progressively lower declines in the central (Rat and Andreanof Islands, 66%) and eastern (Fox Islands, 45%) Aleutians. The magnitude and geographic pattern of the harbor seal declines was similar to that of Steller sea lions in the Aleutian Islands from 1985 to 2000 (Small et al., 2008). The factors responsible for these declines remains unknown.

Aerial surveys

The Aleutian stock covers the largest geographic range of any harbor seal stock in Alaska (over 1,600 km long) and is challenging to adequately survey due to frequent and extensive fog cover, turbulent winds, and access to only three viable airports (located on the islands of Unalaska, Adak, and Shemya). Aerial surveys are conducted from fixed-wing aircraft flown at a target altitude of 750 feet. High-resolution photographs (taken with handheld DSLR cameras) and GPS coordinates are recorded at each location that harbor seals are spotted hauled out along the shoreline. Seals are later counted from survey photos back at the laboratory. Recent survey efforts have improved the dataset for this population, but analysis efforts are still in progress and there remain significant gaps. Due to the logistical challenges associated with conducting aerial surveys in the remote central and western regions, the majority of our survey effort has been concentrated in the eastern Aleutians. Recent survey results are indicative of a decrease in the occurrence of harbor seals in the central and western islands compared to the eastern islands, and ongoing work will determine the overall trend of the stock.

Telemetry studies

Between 2014 and 2016, the Alaska Fisheries Science Center deployed satellite telemetry devices on 80 harbor seals at 11 locations distributed throughout the archipelago. These deployments are just ending, and, while some preliminary analysis has been done, final research products will not be available until late 2018 or 2019. Initial indications from the seal movement and dive behavior show that most seals remain within a few kilometers of their haul out and have an affinity for a close network of haul out sites. A few seals, many of whom were younger or sub-adults, undertook larger trips off the Aleutian shelf or to haul out locations 50 or more kilometers away. Dive behavior records indicate harbor seals are targeting the bottom of the water column, as their dive depths often match the bathymetry. While no scats have been analyzed for identifiable hard parts, seals are likely feeding on benthic aggregations of forage fish.

A key component of these telemetry studies is an improved understanding of the haul out behavior of harbor seals in the Aleutian Islands. Aerial survey counts of seals must be corrected to account for the proportion of seals that were in the water (i.e., not available to be counted) when the survey photographs were taken. To estimate this proportion, we rely on haul out records from telemetry deployments. The haul out behavior is linked to other key covariates like time of day, day of year, and tidal features, to form a statistical model that can be used to correct the photographic counts to abundance estimates.

Subsistence harvest

The Alaska Native subsistence harvest of harbor seals has been estimated by the Alaska Native Harbor Seal Commission (ANHSC) and the Alaska Department of Fish and Game (ADF&G).

Information from the ADF&G indicates the average harvest levels for the Aleutian Island stock of harbor seals identified in Alaska from 2004 to 2008, including struck and lost, is ninety seals per year. The minimum annual harvest from 2004-2008 was fifty seals with a maximum of 146 seals. These harvest levels are below the estimated potential biological removal of 173 seals per year.

8. Pollutants/ Contaminants

(Veronica Padula, Douglas Causey (plastics- seabirds), Aaron Poe (overall contaminants, pollutants))

8.1 Phthalate concentrations in seabirds breeding in the Aleutian Island Archipelago, 2009-2015

Plastic debris can cause physical harm to wildlife, however, plastic ingestion does not always result in ulcerations, starvation or death for seabirds. In the marine environment, plastic debris continuously degrades into much smaller "microplastics," which are more easily carried by ocean currents and more easily mistaken for small prey items such as plankton (Moore, 2008). For example, microparticles and nanoparticles fall within the size range of the staple phytoplankton diet of zooplanktons such as the Pacific Krill (Andrady, 2011). These microplastics can pass through an animal's stomach and intestine, where chemicals leach off these particles and may be incorporated into the animal's tissue. Plastics are coated in toxic chemicals, such as phthalates, that can be metabolized upon exposure.

Phthalates are chemicals of particular concern for organisms in the marine environment. Phthalates are colorless, odorless, oily liquids that are diesters of phthalic acid with low-volatility and low water solubility (Lyche et al., 2009), with 25 known congeners. Phthalates are endocrine-disrupting compounds (Latini, 2005; Kamrin, 2009; Meeker et al., 2009), which are natural or synthetic compounds that mimic or interfere with the biosynthesis, metabolism or action of endogenous hormones and thus, interfere with homeostatic maintenance (Crisp et al., 1998). Seabirds are model organisms for studying contaminants like phthalates, as they are at the top of the food web and at high trophic levels in their marine ecosystem. In addition, they are exposed to a wide range of contaminants and prone to bioaccumulation (Burger et al., 2007). Preliminary data from our work started in 2009 indicate that seabirds in the Aleutian Islands are exposed to these harmful chemicals.

The objective of this research is to determine the rate and level of phthalate exposure among various seabird species breeding in the Western Aleutian Islands. To date, we have run phthalate analyses on muscle tissue from 78 individuals, representing eleven species of seabirds breeding in the far western Aleutian Islands. Although not all six phthalate congeners were detected in all 78 individuals, every individual had detectable levels of at least one of the congeners in their muscle tissue. We harvested embryonic tissue from 12 females, and each individual embryo had detectable levels of at least one phthalate congener. The impacts of phthalate exposure during development are still not fully understood, causing concern over the health of seabird chicks, and by extension, seabird populations, in the Bering Sea. Our results suggest that at least one phthalate congener, Di-n-octyl phthalate (DnOP), may selectively sequester in embryonic tissue, as it was detected in two embryos, but not in the parent birds' muscle tissue, highlighting the importance of screening all tissue types for phthalate exposure.

Phthalate concentrations reported here come from 11 seabird species breeding in the Bering Sea, from a geographic range spanning the six major island groups in the Aleutian Island

Archipelago (Figure R15-24). The species reported here include: Black-legged Kittiwake (BLKI, *Rissa tridactyla*); Common Murre (COMU, *Uria aalge*); Crested Auklet (CRAU, *Aethia cristatella*); Glaucous-winged Gull (GWGU, *Larus glaucescens*); Horned Puffin (HOPU, *Fratercula corniculata*); Northern Fulmar (NOFU, *Fulmarus glacialis*); Parakeet Auklet (PAAU, *Aethia psittacula*); Pelagic Cormorant (PECO, *Phalacrocorax pelagicus*); Pigeon Guillemot (PIGU, *Cepphus columba*); Red-faced Cormorant (RFCO, *Phalacrocorax urile*); and Tufted Puffin (TUPU, *Fratercula cirrhata*).

The six major island groups from which samples were collected include (from east to west):

1. Fox Islands: Umnak Island
2. Island of Four Mountains: Chagulak Island, Herbert Island, Kagamil Island, Yunaska Island
3. Andreanof Islands: Adak Island, Agliuga Island, Ilak Island, Kanaga Island, Little Tanaga Island, Tanaga Island, Ulak Island, Unalga Island
4. Rat Islands: Amchitka Island, Hawadax Island, Litte Kiska Island, Segula Island
5. Buldir Island
6. Near Islands: Agattu Island, Attu Island, Nizki-Alaid

Figure R15-26. Map of island groups in the Aleutian Island Archipelago.

We collected seabird specimens through collaboration with the US Fish and Wildlife Service Alaska Maritime National Wildlife Refuge (AMNWR) aboard the R/V *Tiglax* over the course of six field seasons (2009-2011, 2013-2015). The samples used in the phthalate analyses were representative of seabirds breeding in all six island groups of the Aleutian Island archipelago (from east to west): Fox Islands, Island of Four Mountains, Andreanof Islands, Rat Islands, Buldir Island, and Near Islands (Figure R15-24). We collected specimens from the eleven species mentioned above. Upon field collection, we immediately wrapped specimens in aluminum foil to reduce phthalate exposure, froze them, and transferred them to the University of Alaska Anchorage for dissection in the laboratory.

There is growing concern over microfibers entering the environment and food webs. We have been processing recent seabird samples collected in 2016 with these developments in mind, and microfibers have been found in seabird gastroenteric tracts (unpublished data). These analyses are ongoing, but to date we have processed stomach contents from 24 species, and have detected plastic particles in approximately 27% of the samples.

We analyzed muscle tissue samples for concentrations of six phthalate congeners with liquid chromatography tandem mass spectrometry (LC MS/MS) with atmospheric pressure photo-ionization (APPI). These congeners were: Dimethyl phthalate (DMP); Diethyl phthalate (DEP);

Benzyl butyl phthalate (BBP); Dibutyl phthalate (DBP); diethyl hexyl phthalate (DEHP); and Di-n-octyl phthalate (DnOP) (Figure R15-27).

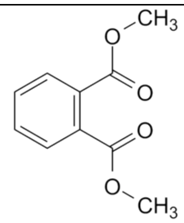
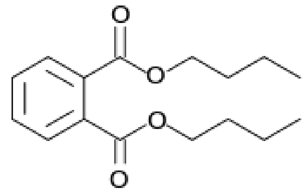
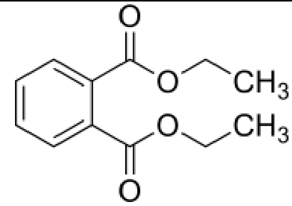
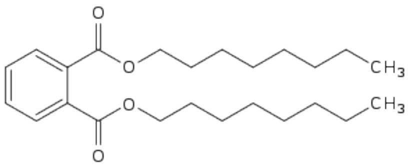
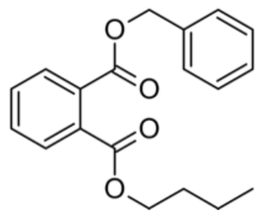
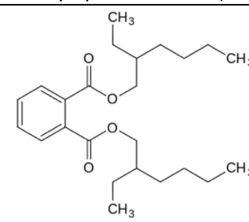
		
Dimethyl phthalate (DMP)	Di-n-butyl phthalate (DBP)	Diethyl phthalate (DEP)
		
Di(n-octyl) phthalate (DnOP)	Butyl benzyl phthalate (BBP)	Di(2-ethylhexyl) phthalate (DEHP)

Figure R15-27. Molecular structures of the six phthalate congeners analyzed in this study.

Status and trends: Seabirds with and without plastic particles detected in their stomach contents had detectable levels of phthalates in their muscle tissues. DEHP was a commonly detected congener, with detectable concentrations across all eleven species and all six island groups. Average DEHP concentrations were also a magnitude higher in crested auklets in comparison to other species. DnOP was the least commonly detected phthalate congener in the samples, and was only detected above the LOD in three of eleven species (BLKI, RFCO, and TUPU).

<u>Trends by species (Table R15-3)</u>

Crested Auklet: the average value of DEHP was high due to several exceptionally high concentrations in samples (11-039, 1019.3 ng/g; 11-045, 793.98 ng/g; 11-043, 418.82 ng/g). All samples were collected on Segula Island. One sample from Segula (11-041) had either zero or below limits of detection (<LOD) for all phthalate congeners.

Glaucous-winged gull: nine GWGU (15-175 from Adak; 15-025 from Attu; 15-153 from Buldir; 15-144 from Ulak; 15-057 and 15-059 from Umnak; 14-065, 14-066, and 14-068 from Nizki-Alaid) had either zero or <LOD for all phthalate congeners.

Red-faced Cormorant: no BBP has been detected in the muscle tissue from the RFCO sampled.

Tufted Puffin: five TUPU (13-082 from Little Kiska; 13-089 from Nizki-Alaid; 15-082 from Kagamil; 15-138 from Chagulak; 15-107 from Yunaska) had either zero or <LOD for all phthalate congeners.

Trends by island groups (Table R15-4)

DBP was not detected in the Fox Islands or the Island of the Four Mountains.

DnOP was not detected in the Island of the Four Mountains, Andreanof Islands, and the Rat Islands.

Average DEHP concentration was a magnitude higher in the Rat Islands in comparison to the other island groups and phthalate congeners, which is the result of the crested auklet samples that had exceptionally high DEHP concentrations.

Table R15-3. Phthalate concentrations in seabirds by species (Mean ± SD, n that were <LOD) by species.

Species	*n*	*DMP (ng/g) n<LOD*	*DEP (ng/g) n<LOD*	*BBP (ng/g) n<LOD*	*DBP (ng/g) n<LOD*	*DEHP(ng/g) n<LOD*	*DnOP (ng/g) n<LOD*	*Σ Phthalates (ng/g)*
Black-legged Kittiwake (Rissa tridactyla)	*11*	*15.64 ± 16.24 5*	*4.99 ± 4.87 2*	*19.52 ± 29.73 8*	*42.92 ± 60.7 9*	*13.87 ± 9.11 4*	*29.68 10*	*37.27 ± 34.28*
Common Murre (Uria aalge)	*9*	*5.14 ± 7.27 7*	*2.11 ± 2.98 7*	*2.02 ± 0.76 7*	*65.87 ± 135.85 2*	*20.36 ± 14.83 2*	*<LOD 9*	*69.13 ± 116.52*
Crested Auklet (Aethia cristatella)	*17*	*11.94 ± 5.17 9*	*13.62 ± 8.36 6*	*11.07 ± 4.22 10*	*41.22 ± 19.7 7*	*337.05 ± 319.83 7*	*<LOD 16*	*256.6 ± 303.76*
Glaucous-winged Gull (Larus glaucescens)	*16*	*0.28 ± 0.58 9*	*3.14 ± 4.90 9*	*0.00 10*	*1.87 ± 4.57 10*	*5.98 ± 8.95 7*	*<LOD 16*	*5.36 ± 7.50*
Horned Puffin (Fratercula corniculata)	*4*	*5.43 ± 9.6 0*	*20.25 ± 26.23 2*	*1.17 3*	*3.19 3*	*16.14 3*	*<LOD 4*	*20.69 ± 26.87*
Northern Fulmar (Fulmarus glacialis)	*7*	*2.98 ± 5.17 4*	*3.44 ± 0.61 5*	*0.58 ± 0.82 5*	*0.00 5*	*8.7 ±8.83 2*	*<LOD 7*	*10.08 ± 6.25*
Parakeet Auklet (Aethia psittacula)	*1*	*5.29 0*	*<LOD 1*	*<LOD 1*	*2.74 0*	*<LOD 1*	*<LOD 1*	*8.03*
Pelagic Cormorant (Phalacrocorax pelagicus)	*10*	*0.31 ± 0.39 5*	*5.83 ± 4.76 6*	*3.03 ± 3.63 7*	*10.67 ± 12.78 3*	*45.76 ± 71.24 4*	*<LOD 10*	*38.33 ± 57.97*
Pigeon Guillemot (Cepphus columba)	*6*	*0.00 5*	*3.22 ± 4.57 3*	*1.07 ± 1.52 4*	*7.92 ± 7.5 3*	*32.74 ± 29.16 1*	*<LOD 6*	*33.21 ± 31.69*
Red-faced Cormorant (Phalacrocorax urile)	*11*	*30.61 ± 26.11 7*	*18.65 ± 8.85 8*	*<LOD 11*	*12.5 ± 4.05 4*	*34.08 ± 16.39 2*	*47.85 10*	*56.41 ± 20.01*
Tufted Puffin (Fratercula cirrhata)	*33*	*7.66 ± 10.82 4*	*8.31 ± 19.71 16*	*1.13 ± 1.37 19*	*36.58 ± 116.55 14*	*12.99 ± 24.39 15*	*19.49 32*	*44.25 ± 94.79*

Table R15-4. Phthalate concentrations in seabirds by island groups (Mean ± SD, n that were <LOD) by island group.

Island Group	*n*	*DMP (ng/g) n<LOD*	*DEP (ng/g) n<LOD*	*BBP (ng/g) n<LOD*	*DBP (ng/g) n<LOD*	*DEHP (ng/g) n<LOD*	*DnOP (ng/g) n<LOD*	*Σ Phthalates (ng/g)*
Fox Islands	*10*	*15.90 ± 15.43 6*	*15.18 ± 18.30 6*	*3.62 ± 0.82 8*	*0.00 8*	*20.98 ± 24.19 4*	*19.49 9*	*27.69 ± 36.91*
Island of Four Mountains	*12*	*5.64 ± 9.25 3*	*1.32 ± 1.71 6*	*0.35 ± 0.51 6*	*0.00 6*	*12.05 ± 27.82 3*	*<LOD 10*	*18.47 ± 34.38*
Andreanof Islands	*23*	*5.73 ± 11.61 13*	*18.99 ± 24.38 13*	*1.50 ± 1.99 18*	*12.86 ± 19.72 10*	*33.66 ± 51.86 11*	*<LOD 23*	*35.91 ± 45.83*
Rat Islands	*22*	*7.51 ± 7.91 6*	*9.46 ± 1.97 12*	*11.07 ± 4.22 13*	*31.18 ± 20.10 10*	*337.05±319.83 12*	*<LOD 22*	*201.84 ± 291.24*
Buldir Island	*16*	*8.89 ± 5.77 7*	*4.81 ±4.37 9*	*27.05 ± 37.75 14*	*124.94±191.44 10*	*12.73 ± 8.12 9*	*29.68 15*	*69.08 ± 128.01*
Near Islands	*42*	*9.63 ± 17.46 20*	*4.93 ± 7.22 20*	*1.23 ± 1.82 25*	*21.78 ± 72.15 16*	*18.32 ± 19.03 9*	*47.85 41*	*37.14 ± 59.15*

Samples span 2009 to 2015, but sample sizes from each year are relatively small, and trends in phthalate exposure are better understood across species and geographically.

The data show that seabirds with and without plastic particles detected in their stomach contents had detectable levels of phthalates in their muscle tissues. This result could have come about from several scenarios: 1) the methods by which we examined stomach contents for plastic particles may have been too coarse to detect extremely microscopic plastic particles or microfibers; 2) plastic particles and/or microfibers may have been lodged in the intestines of seabirds, which we did not examine; 3) seabirds may have ingested plastic particles at some point in their lifetime and consequently excreted them prior to sample collection; 4) seabirds may have consumed prey items that contained phthalates in their tissues; or 5) seabirds may have been exposed to phthalates through the environment itself, as they are ubiquitous in the environment, and have been detected in soils (Bauer and Herrmann, 1997; Cartwright et al., 2000), surface water (Taylor et al., 1981; Staples et al., 1997; Horn et al., 2004), as pollutants in indoor air (Becker et al., 2004) and in the atmosphere (Thuren and Larsson, 1990).

As we have been able to show that seabirds are exposed to phthalates regardless of detection of plastic ingestion at the time of sample collection, this raises the question of whether or not other factors impact the risk of phthalate exposure amongst seabirds in the Bering Sea.

It is not fully understood as to whether or not phthalates bioaccumulate in trophic webs. With respect to seabirds, does trophic level and feeding behavior impact risk of phthalate exposure? The phthalate concentrations by species will be coupled with stable isotope data of individuals to better elucidate whether or not seabirds feeding at higher trophic levels are at risk of higher levels of phthalate exposure. Our current data do not show obvious trends that seabirds feeding at higher trophic levels contain higher concentrations of phthalates in their muscle tissues. The data also show that planktivorous seabirds contain higher concentrations of certain congeners in comparison to piscivorous birds. For example, Crested Auklets have exceptionally high DEHP concentrations. The underlying mechanism for such high concentrations is unclear, but may be related to the idea that microplastic particles can be easily confused with plankton, and therefore birds such as auklets target these small particles when feeding.

Examining rates of phthalate exposure with respect to geography may help us gain insight into distribution of these contaminants across the Bering Sea. To date, the phthalate concentration data, when categorized by island group, show unresolved trends in the six phthalate congeners examined. Overall, almost all phthalate congeners were detected in all island groups, except for DBP in the Fox Islands or the Island of the Four Mountains, and DnOP in the Island of the Four Mountains, Andreanof Islands, and the Rat Islands. The underlying processes determining why certain phthalate congeners are detected in one island group and not another are unclear, but may be related to ocean current patterns that transport both debris and contaminants to the areas surrounding these islands.

Implications: Ingestion of plastic marine debris is problematic for many marine organisms, causing physical harm, starvation, or contaminant exposure. Plastic pollution in the world's oceans is a growing problem, which continues to weigh heavily on the marine environment with each passing year, as plastic does not biodegrade. As plastic pollution accumulates, risks to marine organisms grow. In addition to the physical encounters with plastic marine debris, marine organisms are at risk of contaminant exposure (particularly chemicals such as phthalates, which are known endocrine-disrupting compounds) through plastic ingestion. While the long-term impacts of phthalate exposure on seabird species are currently unknown, seabirds are at risk of negative health impacts through such exposure. More research is needed to better understand these long-term impacts.,

Our results indicate that these types of contaminants are likely pervasive in the marine environment, and marine organisms are at risk of exposure, primarily through ingestion of plastic marine debris, potentially through bioaccumulation in the food web, and through exposure in the direct marine environment. While the long-term effects of phthalate exposure are currently unclear for seabirds, human medical research suggests phthalates have downstream developmental effects. The threshold at which phthalates cause harm to wildlife is not known at present.

Microplastics are likely passed through birds' intestines without much evident physical harm, thus the rate of incidence of plastic ingestion might not accurately reflect ingestion. It is consequently important to quantify phthalate concentrations in the tissues from these seabirds, as phthalates can sequester in tissues and remain in birds' bodies longer than some microplastics.

The seabirds sampled in this study inhabit some of the most remote islands in the Aleutian Island Archipelago, far from human habitation. However, our research shows that they are still ingesting plastic particles, and the only source of plastic is anthropogenic. Furthermore, in the muscle tissues of these seabirds, we have detected compounds that are associated with plastic use, such as phthalates, showing that they are widespread in the marine environment. These chemicals are harmful because they are known endocrine disruptors, and have been shown to negatively impact human health. Such information about the widespread contamination by harmful chemicals such as phthalates can be useful for policy makers in the future when considering the use and regulation of plastics and associated compounds.

8.2 Overall contaminants/ pollutants

Aaron Poe

Understanding risks to wildlife and human communities from contaminants and pollutants in the Aleutian Islands and Bering Sea.

Project collaborators include: Kenrick Mock, LeeAnn Munk, Dr. E. Jamie Trammell, and Marcus Geist (University of Alaska); Leah Kenney and Mari Reeves (U.S. Fish and Wildlife Service); and Frank Von Hippel (Northern Arizona University).

The Aleutian and Bering Sea Islands Landscape Conservation Cooperative (ABSI) is a public-private partnership focused on addressing large-scale conservation challenges that face the managers and communities in the Aleutian Islands and Bering Sea. Understanding and addressing the risks associated with pollutants and contaminants is one of four focal topics of for research and collaboration identified the ABSI's Strategic Science Plan (Poe and Burn, 2013).

The Arctic acts as a "cold trap" and is a hemispheric sink for a number of pollutants and contaminants that are transported via prevailing atmospheric and oceanic currents from warmer, more densely populated regions of the globe. A number of these global transport pathways converge within, and travel through, the Aleutian Islands and Bering Sea, bringing contaminants to the region ranging from harmful bio-accumulating heavy metals like mercury to Persistent Organic Pollutants (POPs), as well as plastics and other marine debris. The remoteness of this region has also not spared it from local point sources of contaminants, primarily from former military operations in the region. Though remediation efforts are designed to remove contamination from these known point sources, like Formerly Used Defense Sites (Rudis, 2012), questions remain about the effectiveness and completeness of these cleanup efforts. Further, exposure to contaminants from distant sources is likely to increase due to increased globalization (AMAP, 2013) and the effects may be compounded by climate change (Sonke and Heimburger, 2012).

Contaminants and pollutants were identified by ABSI as a key stressor because of expected impacts to priority species, including marine mammals and seabirds, as well as subsistence harvesting communities in the region. The *Aleutians and Bering Sea Contaminants and Pollutants Technical Working Group* was established in fall of 2012 to prioritize potential investments by ABSI and its partner entities. This working group identified mercury deposition and cycling as an initial area of focus. Additionally, the neighboring *Western Alaska Landscape Conservation Cooperative* identified contaminants as a topic of concern (Reynolds and Wiggins, 2012), with mercury also an emerging focus because of changes in stream and lake water temperature affecting its biological availability in freshwater systems.

In 2014, ABSI launched a partnership with researchers from the University of Alaska, Anchorage (UAA) and the U.S. Fish and Wildlife Service Anchorage Field Office to synthesize contaminants information for the geography of the Aleutians and Bering Sea. A key focus of this effort is to compile all published mercury samples from biological tissue data, water quality data and water geochemistry data, and rock geochemistry data.

Not wanting to lose sight of other potential risks associated with contaminants and pollutants beyond mercury, ABSI and UAA conducted a stepwise, holistic evaluation of all contaminant threats to species and communities in the ABSI and Western Alaska Landscape Conservation Cooperatives (Figure R15-28). We worked with *Nautilus Impacting Investing* to conduct an Open Standards (OS) workshop in fall of 2016 to identify conservation targets, evaluate risks, and develop strategies for better understanding or mitigating risks (for more on the OS process see: http://cmp-openstandards.org/about-os/faqs/).

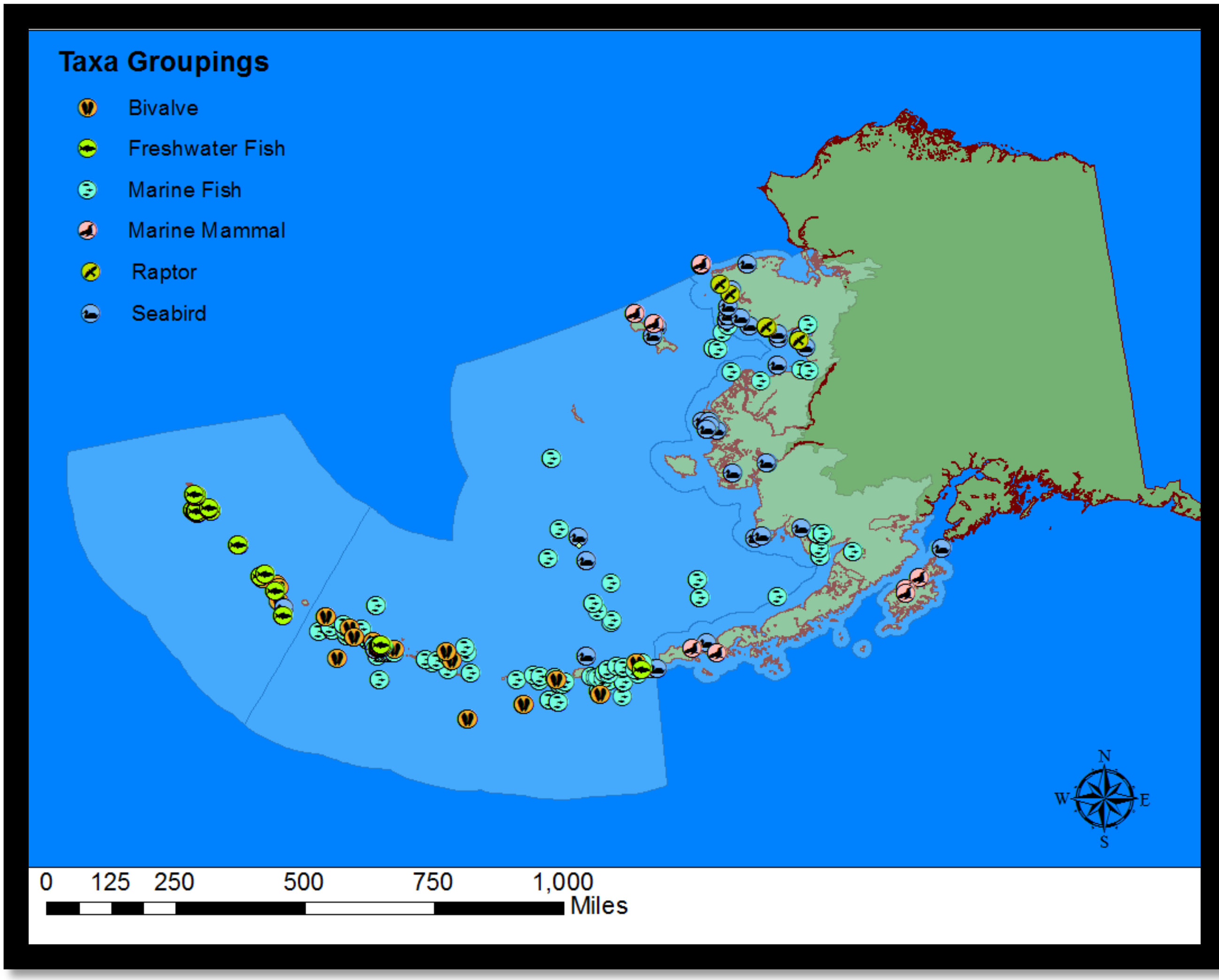


Figure R15-28. Distributions of species from the study area of the Aleutian and Bering Sea Islands (ABSI) and Western Alaska Landscape Conservation Cooperatives.

Progress to date

The data will be derived from various sources including published studies, smaller sets of data from agencies such as the: USGS Water Resources division; USGS Alaska Volcano Observatory; Alaska Geological Materials Center; other agencies and Alaska Native Corporations. Our initial searches have showed that several sources for water and rock data are kept, but there is no single database that incorporates all the water and rock data for the region of interest. Biological samples for mercury were also identified from numerous sources and were contributed for analysis by the U.S. Fish and Wildlife Service, Alaska Department of Environmental Conservation, and researchers from the *Pollutants and Contaminants Working Group.*

We used Microsoft Access, Excel, and custom code to map existing datasets into a format that can be imported into a MySQL database with over 70,000 organic and inorganic mercury samples that will ultimately be made accessible via a web portal. Data can be queried and spatially visualized either within a web browser or downloaded to ArcGIS/Google Earth. The MySQL database affords scalability, which is important given the size of many of the datasets.

Following completion of the initial database, Custom C# software was used to extract Hg data from the data sources and import them into a MySQL database, filtered through user-specified fields through a web page (e.g., specify tissue type or sample type), and spatially visualized using the interactive Leaflet toolkit. Extracted concentrations of mercury were analyzed for spatial and temporal trends in wildlife taxa using linear model residuals and random forest analysis. Numerous species were included, from benthic consumers (e.g., mussels and clams) to top predators (e.g., polar bear and raptors). In general, variation in Hg was predictable by species and taxa groupings, where those taxa with higher trophic position had higher Hg concentrations. Preliminary results from the Hg synthesis analysis indicate spatial trends in Hg concentrations, with highest Hg concentrations in numerous taxa collected from the western Aleutian Islands.

The OS workshop on pollutants and contaminants was a holistic opportunity to assess the nature of threats to ecosystems and communities posed by pollutants and contaminants in the Aleutian and Bering Sea Island region (Dutton et al., 2016). Although there is limited knowledge of many pollutants of interest, the workshop confirmed the importance of a continued focus on the threats posed by pollutants at local, regional, and international scales. The workshop generated three actionable projects for further consideration by ABSI that will enable stakeholders (particularly community and agency partners), to better understand, monitor and communicate the nature of risks posed by contaminants to subsistence food security and ecosystem health, as well as highlighting opportunities for pollutant reduction.

Project 1: GIS Regional analysis of subsistence / wildlife and threats

There is insufficient granularity in available information to identify the nexus between natural system targets and the threats posed by contaminants and pollutants. The workshop group identified numerous areas of potential interaction between human communities and natural systems at both the coarse filter (habitat) and fine filter (species) level, but felt unable to move further into strategy development until more information was available, particularly on the scale and significance of pollution and contamination from known point sources. One initial step in this spatial risk assessment that was taken by ABSI in 2017 was to fund additional collection and synthesis of spatial data describing subsistence harvest. Several datasets exist (see Figure R15-28), describing the distribution of species concentration areas, as does substantial information about the point source locations for contaminants. This key gap describing use was prioritized for action to be completed by 2020.

Project 2: Community-based monitoring pilot

Given both the growing opportunities for citizen science to monitor and inform management of areas such as the ABSI LCC and the efficiency of engaging the public in ongoing data acquisition, the group proposed a pilot community-based monitoring program that was launched in the summer of 2017 as a collaboration between the Qawalangin Tribe of Unalaska and Northern Arizona University, supported by ABSI. Results for this pilot are expected in summer of 2018.

Project 3: Action steps: Research project on fish discharges

After review of these threats and discussion of sewage discharge and plastic pollution in the marine environment as worthy of consideration, the group selected Fish Processing wastes as a priority threat that was of potential human health concern. That selection led into a further discussion of specific threat pathways/vectors and processes that include: biotoxins (link to nutrient enrichment and harmful algal blooms and bacteria); changes in microbiology (disease, bacteria, phytoplankton); disinfectants and metals; food web affects (feeding ecology and disease); and potential changing migration patterns for species. The group proposed geospatial mapping of volumes of process waste discharge and taxonomy and subsequent conversations with the Alaska Department of Environmental Conservation (DEC) concentrations found that the agency is actively working on mapping this information. Rather than launching a potentially parallel effort, ABSI will seek to review and support the DEC efforts with subsequent analysis if desired by DEC.

Finally, the workshop group also discussed various options for collaborative action with the commercial fishing industry to foster an exchange of best practices between other Arctic countries (e.g., Iceland) that have significantly reduced waste discharge by monetizing former waste products. No specific follow-up actions were identified, though workshop participants thought this would be a good opportunity for collaborative research with commercial fisheries.

Expected outcomes

This project will conclude during summer of 2018. Data and tool deliverables associated with this work will include 1) a MySQL database with over 70,000 organic and inorganic mercury samples that can be queried and spatially visualized within a web browser or downloaded to ArcGIS/Google Earth; and 2) a map book available as a pdf and as a downloadable compendium of ArcGIS data layers; and 3) a report summarizing risks from contaminants that will identify further actions that can be taken by ABSI partners to mitigate impacts and fill key knowledge gaps.

The efforts launched from the OS workshop are expected to continue through 2020 facilitating a better understanding of subsistence use area overlap with contaminated sites, and the efficacy of locally-driven contaminant sampling efforts. Pending availability of funding and continued interests of partners, we also hope to conduct robust spatial analytical wildlife risk assessment to identify location-specific assessment of species at risk to contaminants.

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