Ecological Atlas of the Bering, Chukchi, and Beaufort Seas, 2nd Edition: Metadata

Chapter 3: Biological Setting

Shortcut to metadata for

Map 3.1 Primary Productivity

MAPPING METHODS (MAP 3.1)

Map 3.1 shows maximum measured integrated chlorophyll content (mg/m^2) for the top 330 feet (100 m) of water-column depth during the open-water season. Chlorophyll is used as a proxy for primary productivity because it is found in phytoplankton and algae, which are estimated to make up approximately 57–67% of water-column and sea-ice productivity in the Arctic (Horner and Schrader 1982, Gosselin et al. 1997).

Our map is based on data from water-column samples collected and analyzed for chlorophyll content across the Beaufort and Chukchi Seas, and the eastern portion of the Bering Sea. These samples were collected over several decades (1959–2012) and compiled into two datasets (Ashjian 2013, Grebmeier and Cooper 2014b) in the Earth Observing Laboratory online database as part of the Pacific Marine Arctic Regional Synthesis (PacMARS) project.

To produce the primary productivity map, we interpolated the chlorophyll sample data in Esri's Geostatistical Analyst extension using empirical Bayesian kriging with four sectors. In instances where there were multiple sample values in one location, we used only the maximum value at that location for the interpolation. The resulting raster was clipped to a 62-mile (100-km) buffer around the sample points.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

Integrated water column chlorophyll data are likely the best proxy available for the project area. However, much of the data used in this interpolation are old, as they were gathered as long ago as 1959 (Ashjian 2013). The open-water season is an important time for production, as sea-ice cover does not limit light penetration into the water column. While algal growth at the ice edge, in polynyas, in and under the ice, and in melt ponds may also contribute significantly to primary productivity, accurate measurements are not available for the project area (Krembs et al. 2000, Hill and Cota 2005, Arrigo et al. 2012, Frey et al. 2012, Boetius et al. 2013). Kelp forests may also significantly increase primary production in nearshore environments, especially along the Aleutian Islands (Duggins et al. 1989). However, we were unable to find spatial information regarding kelp forests in our project area.

While there are satellite data available for the region, these data may not reflect biomass accurately because of subsurface plumes of phytoplankton and, in coastal waters, the turbidity and dissolved organic matter content of river inputs (Chaves et al. 2015, Tremblay et al. 2015).

MAP DATA SOURCES

Integrated Chlorophyll Sample Data (mg/m^2) for 0–100 m Depth: Audubon Alaska and Oceana (2017) based on Ashjian (2013) and Grebmeier and Cooper (2014b)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

Reference list available here.

Map 3.2 Zooplankton

MAPPING METHODS (MAP 3.2)

All zooplankton data for the study region were obtained from *COPEPOD: The Global Plankton Database* (National Oceanic and Atmospheric Administration 2012). This database is a synthesis of zooplankton data collected from various studies. Details on how zooplankton data were combined and calculated can be found in Moriarty and

O'Brien (2013). Sample points for average annual zooplankton total carbon mass were extracted from the database and mapped. A 60x60 km grid was then overlaid on data points within the extent of the study area. The average carbon mass (measured in mg carbon per m3) per grid cell was then calculated. Those grid cells with associated average values were then converted to points based on the centroid of each grid cell. To create a continuous coverage over the entire study area, those points were interpolated using the Inverse Distance Weighted tool in ArcMap version 10.5 using a power of 2 and a search radius of 12 points.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality
Because this dataset was created with the express purpose of creating a continuous global coverage for zooplankton biomass, this dataset generally has excellent spatial coverage. Some of the more remote, offshore areas may be represented by only a few data points, which may be the case in the far western Bering Sea. In this case, small hotspots may likely be represented by single measurements at historical sampling locations. There were no sample points for the waters of the Beaufort Sea and the western Chukchi Sea. We suspect that weather, ice conditions, and remoteness play the largest role in this lack of data and that this is not an indication of low zooplankton productivity. As climate change continues to impact ice conditions in the Arctic it is possible that future researchers will have increased sampling opportunities to measure zooplankton abundance in this region.

MAP DATA SOURCES
Zooplankton: Oceana (2017b) based on Moriarty and O'Brien (2013) and National Oceanic and Atmospheric Administration (2012)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

Reference list available here.

Map 3.3 Benthic Biomass

MAPPING METHODS (MAP 3.3)
Benthic biomass was estimated by combining two datasets: one with robust spatial coverage in the Chukchi, Beaufort, and northern Bering Seas and another with robust spatial coverage from the northern Bering Sea to the Aleutian Islands. Combining these two datasets provided us with survey data for benthic invertebrates throughout the majority of our study area. Those two studies, as well as the methods used to combine them, are outlined below.

Also shown on Map 3.3 are the locations of documented coral and sponge gardens in the Aleutian Islands. Those locations are from Stone (2014) and National Oceanic and Atmospheric Administration (2016a).

The sea-ice data shown on Map 3.3 approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Trawl Survey Data (National Oceanic and Atmospheric Administration 2016a)
A trawl survey database was created by combining multiple bottom trawl surveys which employed consistent methodologies and sampled waters within the US exclusive economic zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell et al. 2010). This database contained 29,296 sample points and has excellent spatial and temporal coverage for much of our study area, though less so in the Arctic.

From that database, the catches of all benthic invertebrates were summed for each haul of the trawl surveys. Catches included 1,356 benthic species or species groups recorded from the trawl survey samples. These included crabs, echinoderms (sea stars, sea urchins, sea cucumbers), bivalves, sponges, corals, tunicates, anemones, worms, snails, and octopus. Not included were jellyfish and ctenophores, salps, and squids since these are pelagic rather than benthic organisms.

Of the observations made (species or species groups caught, identified, and weighed), there were:

- 216,138 in the EBS
- 79,674 in the Gulf of Alaska
- 60,301 in the Aleutian Islands
- 9,749 in the northern Bering Sea
- 3,269 in the Bering Sea slope
- 2,705 in the Chukchi Sea
- 387 in the Beaufort Sea

The most common species of benthic invertebrates were basketstars *Gorgonocephalus eucnemis* (n = 11,549), Tanner crabs *Chionoecetes bairdi* (n = 10,566), snow crabs *Chionoecetes opilio* (n = 9,840), purple-orange sea stars *Asterias amurensis* (n = 8,185), and Oregon tritons *Fusitriton oregonensis* (n = 7,865).

PacMARS Benthic Infaunal Parameters (Grebmeier and Cooper 2014a)
This dataset contained 2,015 unique sample points with summary measurements of average benthic macroinfaunal taxa to the family level collected using a van Veen grab (0.1 m^2 sediment grab). Three to five samples were taken at each station and parameters of station, abundance, wet weight biomass, carbon dry weight biomass, number of taxa, Shannon-Weaner diversity and evenness indices, and number of grabs collected per station were recorded for each sample. For the purposes of combining this dataset with trawl survey sample data, this dataset was mapped based on wet weight biomass (gww/m^2).

Analysis
To obtain a continuous coverage estimate of the relative benthic biomass for our entire study area, we combined the macroinfaunal benthic survey data from Grebmeier and Cooper (2014a) and a compilation of benthic invertebrate samples from the National Marine Fisheries Service trawl survey data (discussed above). Both datasets measured benthic biomass; however, because their survey methods and measurements differ, simply combining the datasets would be inappropriate. Instead, the Oceana Important Ecological Area approach was used (Oceana and Kawerak 2014). This method provides a framework for combining multiple types of data regardless of their sample design, measurements, units, or whether they are quantitative or qualitative in nature. Using this method allows us to see those areas which are above average, or those areas with the highest benthic productivity.

The steps for the Important Ecological Area approach were:

- Overlay 60x60 km grid on top of entire extent of all survey points
- Calculate the average value of all sample points within each grid cell for each dataset separately
  - For the PacMARS data, average biomass of macrofauna in grams wet weight per meter squared (gww/m^2)
  - For the trawl survey data, average kilograms per hectare (kg/ha)
- Calculate the standard deviate per grid cell for each dataset separately
  - To calculate the standard deviate per grid cell for each dataset, the following formula was used:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_i}{\sigma_i}$$

Where (Z_{ij}) is the standard deviate of grid cell j for the i^{th} dataset, (X_{ij}) is the average value for grid cell j for the i^{th} dataset, and (X_{ij}) and (σ_i) are the overall mean and overall standard deviation of all the calculated grid cell average values for the i^{th} dataset.

- Join the two datasets together using the grid cell unique identifier to ensure both datasets align properly, and then calculate the weighted average standard deviate, weighted by sample size, per grid cell of the two datasets
- Join the weighted average standard deviate values back to the 60x60 km grid to view spatial distribution
- Convert grid cells to points based on the center of each cell
- To obtain continuous coverage, interpolate those points using the Inverse Distance Weighted tool with the following parameters in ArcMap version 10.5:
  - Power = 2
  - Search radius = variable
  - Maximum search radius = 12 points

Converting grid cell values to standard deviates allows us to see how far above or below average each value is from the mean relative to the dispersion of the data. A standard deviate close to zero means the value is close to average, while a large standard deviate means the value is well above average. Similarly, a negative standard deviate indicates the value is below average (Oceana and Kawerak 2014).

Data Quality
The NOAA trawl database contained 29,296 sample points and had excellent spatial and temporal coverage for much of our study area, though less so in the Arctic. Bottom trawl surveys in the Aleutian Islands were conducted every 3 years from 1983 to 2000 and on even years from 2002 to 2016. Surveys on the Bering Sea slope were conducted on even years from 2002 to 2016, except for 2006 and 2014. Surveys on the EBS shelf were conducted from 1982 to 2016. Surveys in the northern Bering Sea occurred from 1982 to 2010. Gulf of Alaska surveys were conducted in 1984 and 1987, every 3 years from 1990 to 1999, and on odd years between 2001 and 2015.

The PacMARS infaunal biomass dataset contained 2,015 unique sample points with summary measurements of average benthic macroinfaunal taxa to the family level. This dataset had excellent spatial coverage from 1970 to 2012 in the northern Bering Sea and Chukchi Sea, including both US and Russian waters. Sample data also included some coverage in the nearshore Beaufort Sea, in both US and Canadian waters. This dataset, however, lacked sample data in the southern Bering Sea and Aleutian Islands.

These two datasets were combined to utilize the best of both, as described above.

MAP DATA SOURCES

Benthic Biomass: Oceana (2017a) based on Conner and Lauth (2016), Goddard et al. (2014), Grebmeier and Cooper (2014a), Hoff (2016), Logerwell et al. (2010), Oceana and Kawerak (2014), Raring et al. (2016), and von Szalay and Raring (2016)

Coral and Sponge Gardens in the Aleutian Islands: National Oceanic and Atmospheric Administration (2016a); Stone (2014)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

Reference list available here.

Map 3.4 Snow Crab

MAPPING METHODS (MAP 3.4)

The relative abundance of snow crab was estimated by interpolating datasets from bottom trawl surveys which employed similar and consistent methodologies and sampled waters within the US exclusive economic zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell et al. 2010). Data points for snow crab presence and absence were extracted and mapped based on catch per unit effort (CPUE) in kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted tool in ArcGIS version 10.5 based on CPUE values. A radius of the 12 nearest points was set as the search distance and interpolation was limited to the study area boundaries of the trawl surveys.

Possible nursery sites for snow crab were digitized directly from Figure 9 in Parada et al. (2010) which depicts the centroids of areas of potential larval settlements based on a model of individual-based larval transport from 1978 to 2002. The south and southwesterly migration arrows were digitized from Figure 7 in the same study which summarizes the general migration patterns of female snow crab. The general distribution of snow crab is based on adult and juvenile snow crab Essential Fish Habitat (EFH) areas which were obtained directly from National Oceanic and Atmospheric Administration (2016b). Snow crab EFH is described as habitats along the inner (0–165 feet [0–50 m]), middle (165–330 feet [50–100 m]), and outer shelf (330–660 feet [100–200 m]) throughout the Bering Sea and Aleutian Islands wherever there are substrates consisting mainly of mud. Due to their smaller overall population, limited distribution in the EBS, smaller commercial harvest, and limited range, only Tanner crab EFH is mapped (Figure 3.4-1).

Data Quality

Trawl survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea. The interpolation of the trawl survey data estimates the distribution of snow crab during the summer months and may not represent the year-round distribution.

Bottom trawl surveys in the Aleutian Islands were conducted every three years from 1983 to 2000 and on even years from 2002 to 2016. Surveys on the Bering Sea slope were conducted on even years from 2002 to 2016 except for 2006 and 2014. Surveys on the EBS shelf were conducted from 1982 to 2016. Surveys for the northern Bering Sea occurred from 1982 to 2010. Gulf of Alaska surveys were conducted in 1984 and 1987, every 3 years from 1990 to 1999, and on odd years from 2001 to 2015. Bottom trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

MAP DATA SOURCES

Trawl Density: Oceana (2017d) based on Conner and Lauth (2016), Goddard et al. (2014), Hoff (2016), Logerwell et al. (2010), Raring et al. (2016), and von Szalay and Raring (2016)

Possible Nursery Sites: Parada et al. (2010)

Essential Fish Habitat: National Oceanic and Atmospheric Administration (2016b)

Management Areas: National Oceanic and Atmospheric Administration (2016a)

Reference list available here.

Map 3.5 Red King Crab

MAPPING METHODS (MAP 3.5)

The relative abundance of red king crab was estimated by interpolating datasets from bottom trawl surveys which employed similar and consistent methodologies and sampled waters within the US EEZ of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell et al. 2010). Data points for red king crab presence or absence were extracted and mapped based on catch per unit effort (CPUE) in kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted (IDW) tool in ArcGIS version 10.5 based on CPUE values. A radius of the 12 nearest points was set as the search distance and interpolation was limited to the study area boundaries of the trawl surveys.

The red king crab generalized distribution polygon was digitized from North Pacific Fishery Management Council (2015) which broadly describes the range of red king crab in Alaskan waters. Essential Fish Habitat (EFH) areas for red king crab were obtained directly from National Oceanic and Atmospheric Administration (2016b). These EFH areas are considered to be the general distribution for late juvenile and adult red king crab. These areas are described as being located in bottom habitats along the nearshore (spawning aggregations) and the inner (0–165 feet [0–50 m]), middle (165–330 feet [50–100 m]), and outer shelf (330–660 feet [100–200 m]) throughout the Bering Sea and Aleutian Islands wherever there are substrates consisting of sand, mud, cobble, and gravel.

Management area polygons were all obtained directly from National Oceanic and Atmospheric Administration (2016a). These areas were displayed because they are known important areas for red king crab spawning or migration. National Marine Fisheries Service Management Area 516 is closed to commercial bottom trawling from March 15 to June 15 to protect spawning stock of red king crab. The Red King Crab Savings Area is closed year-round to commercial bottom trawling to protect important red king crab habitat and migration area and to protect spawning stock biomass. Additionally, the Pribilof Islands Habitat Conservation Area is closed year-round to commercial bottom trawling to protect blue king crab from overexploitation as bycatch.

Data Quality

Trawl survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea for red king crab. The interpolation of the trawl survey data estimates the distribution of red king crab during the summer months and may not represent the year-round distribution.

Bottom trawl surveys in the Aleutian Islands were conducted every 3 years from 1983 to 2000 and on even years from 2002 to 2016. Surveys on the Bering Sea slope were conducted on even years from 2002 to 2016 except for 2006 and 2014. Surveys on the EBS shelf were conducted from 1982 to 2016. Surveys for the northern Bering Sea occurred from 1982 to 2010. Gulf of Alaska surveys were conducted in 1984 and 1987, every 3 years from 1990–1999, and on odd years from 2001 to 2015. Bottom trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

MAP DATA SOURCES

Trawl Density: Oceana (2017c) based on Conner and Lauth (2016), Goddard et al. (2014), Hoff (2016), Logerwell et al. (2010), Raring et al. (2016), and von Szalay and Raring (2016)

Distribution: North Pacific Fishery Management Council (2015)

Essential Fish Habitat: National Oceanic and Atmospheric Administration (2016b)

Management Areas: National Oceanic and Atmospheric Administration (2016a)

Reference list available here.