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# Bowhead Whale Distribution and Relative Density in Relation to Remote-Sensed Physical and Biological Environmental Data in the Pacific Arctic, 2014-2019

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# Bowhead Whale Distribution and Relative Density in Relation to Remote-Sensed Physical and Biological Environmental Data in the Pacific Arctic, 2014-2019

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### U.S. DEPARTMENT OF COMMERCE

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### Abstract

The 2019 bowhead whale (*Balaena mysticetus*) autumn migration across the western Beaufort Sea was unprecedented. During line-transect aerial surveys conducted during 2019 as part of the Aerial Surveys of Arctic Marine Mammals project, bowhead whales were mostly absent in September and October, and whales that were sighted were farther offshore and in deeper water than previous survey years with similarly light sea ice cover. These results were consistent with observations from subsistence hunters from Utqiagvik, Nuiqsut, and Kaktovik, Alaska. To investigate this anomalous migration, we conducted a preliminary investigation that incorporated a visual assessment of spatial patterns between bowhead whale relative density and remotely sensed physical and biological variables (sea ice, sea surface temperature, chlorophyll a, and net primary productivity of carbon) at the temporal resolution of one month over the period from 2014 to 2019.

Our overarching goal was to better understand the ecological linkages forcing spatiotemporal variability in the bowhead whale autumn migration across the western Beaufort Sea. We had three objectives. First, to compile year-round monthly composites of remotely sensed environmental data from 2014 to 2019; input the data into a GIS; and generate maps for each combination of environmental variable, month, and year, using a standardized color scale for each environmental variable. Second, to generate maps for each species, month, and year for ASAMM bowhead, gray, humpback, fin, and minke whale sighting and sighting rate data from 2014 to 2019. Third, to summarize published literature to create a conceptual model explaining the ecological mechanisms that shape the spatiotemporal variability in the bowhead whale autumn migration across the western Beaufort Sea. We found an apparent association between spring sea ice coverage in the Chukchi Sea and bowhead whale relative density in the western Beaufort Sea. Chukchi Sea spring sea ice coverage appeared lowest in 2019, a year in which few bowhead whales were sighted nearshore (0-20 m depth zone) in autumn off Point Barrow (154°-157°W), an area where bowhead whales often aggregate and feed during late summer and autumn. Chukchi Sea spring sea ice coverage appeared to be highest in 2014 and 2015; bowhead whale relative density was highest in the nearshore zone off Point Barrow in autumn 2015.

We did not find consistent relationships between bowhead whale data and the remotely sensed sea surface temperature, chlorophyll a, and primary productivity data at the monthly resolution. We suspect that additional environmental variables such as those summarizing water temperature and primary producers do relate to spatiotemporal variability in bowhead whale density in the western Beaufort Sea; however, the variables need to be sampled at a finer temporal resolution than one month to reveal patterns.

# Contents

Abstractiii
Introduction1
Methods3
Results4
Discussion5
Acknowledgments8
Citations9
Figure 1 Seasonal migration of the Bering-Chukchi-Beaufort Seas population of bowhead whales. <i>Note:</i> From "Satellite Tracking of Bowhead Whales, Movements and Analysis from 2006 to 2012 Final Report," by Quakenbush et al. (2013), U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, AK. OCS Study BOEM 2013-01110. 60 p. + appendices
Figure 2 Depth zones for the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas in the ASAMM study area
Figure 3 Mechanisms driving krill characteristics near Point Barrow, Alaska, during late summer and autumn that relate to bowhead whale feeding opportunities. The narrative for Figure 3 is below
Table 1. Remotely sensed satellite data for the Bering, Chukchi, and Beaufort seas and Amundsen Gulf
APPENDIX A: SEA ICE CONCENTRATION21
APPENDIX B: SEA SURFACE TEMPERATURE
APPENDIX C: CHLOROPHYLL A CONCENTRATION97
APPENDIX D: NET PRIMARY PRODUCTIVITY OF CARBON
APPENDIX E: BOWHEAD WHALE SIGHTINGS AND SIGHTING RATES 173
APPENDIX F: GRAY WHALE SIGHTINGS AND SIGHTING RATES
APPENDIX G: HUMPBACK WHALE SIGHTINGS AND SIGHTING RATES 201
APPENDIX H: FIN WHALE SIGHTINGS AND SIGHTING RATES213
APPENDIX I: MINKE WHALE SIGHTINGS AND SIGHTING RATES225

### Introduction

Bowhead whales (*Balaena mysticetus*) are endemic to the Arctic, spending all their lives in Arctic and sub-Arctic waters. The majority of the Bering-Chukchi-Beaufort Seas (BCB) population of bowhead whales migrates between wintering grounds in the Bering Sea and summer feeding grounds in the eastern Beaufort Sea and Amundsen Gulf (Citta et al. 2021, North Slope Borough 2021; Fig. 1), although they also feed in summer and during their autumn migration in the western Beaufort Sea (Clarke et al. 2020, Ferguson et al. 2021). They typically migrate westward across the western Beaufort Sea in September and October (Clarke et al. 2020, Citta et al. 2021).

In 2019, the bowhead whale autumn migration across the western Beaufort Sea (140°-157°W, shore to 72°N) was unexpected and unlike any on record. Indigenous peoples in Alaska have depended on marine mammals for subsistence over millennia. However, in autumn 2019, subsistence hunters from Kaktovik and Nuiqsut, Alaska, (in the eastern and central Alaskan Beaufort Sea, respectively) had to travel farther north than usual to search for whales. Bowhead whales were largely absent near Utqiaġvik, Alaska, from September to November, resulting in only one harvested whale, which was taken in mid-November, abnormally late in the season. More typically, whales in Utqiaġvik are harvested from about mid-September through mid-October. The Alaskan subsistence hunt in 2019 represented the lowest number of bowhead whales struck in a single year since 1989 (Suydam et al. 2020).

These observations from hunters were reflected in the observations from the Aerial Surveys of Arctic Marine Mammals (ASAMM) survey flights in autumn 2019, which covered the broad extent of the western Beaufort Sea shelf, slope, and basin (Clarke et al. 2020). From 1979 to 2019, ASAMM line-transect aerial surveys were conducted in the Alaska Arctic to study spatial and temporal patterns in the density, habitat, and behavior of marine mammals. ASAMM survey design and protocols focused on bowhead whales, but the project also collected information on all other marine mammal species observed. In 2019, ASAMM found that bowhead whales were mostly absent in the western Beaufort Sea during September and October; furthermore, bowhead whales that were sighted were farther offshore and in deeper water than previous survey years with similarly light sea ice cover (Clarke et al. 2020). ASAMM detected no bowhead whales during autumn 2019 in the eastern Chukchi Sea (67°-72°N, 157°-169°W), also unprecedented compared to previous years during which standardized broad-scale aerial surveys were conducted in the Chukchi Sea (1982-1991, 2008-2018; Clarke et al. 2020).

Due to an absence of observations outside the ASAMM study area, it is unclear where the majority of the BCB bowhead whale population was located during September and October 2019. It is possible that the migration was much farther north than usual, outside the ASAMM study area, and therefore fewer whales were detectable during aerial

surveys. It is also possible that the whales delayed their autumn migration, remaining in the eastern Beaufort Sea until later in the year. These explanations are not mutually exclusive: the bowhead whale autumn migration could have been both farther offshore and delayed.

Eastern North Pacific gray whales (*Eschrichtius robustus*) migrate north to the Bering and Chukchi seas to feed primarily on benthic organisms in the summer and fall. In each month from July through October 2019, ASAMM documented gray whales in the southcentral and northeastern Chukchi Sea where they have been sighted in past years (Clarke et al. 2020). Gray whales were also sighted in the eastern Beaufort Sea, outside their typical range (Clarke et al. 2020).

Humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), and minke (*Balaenoptera acutorostrata*) whales occur in the southcentral Chukchi Sea, where they were observed during ASAMM surveys in 2009-2019 (Clarke et al. 2013, Brower et al. 2018). However, in 2019 in the northeastern Chukchi Sea, all three species were observed on Herald Shoal for the first time in the history of broad-scale line-transect aerial surveys (1982-91, 2008-2019; Clarke et al. 2020). Bowhead and gray whales were occasionally sighted near Herald Shoal in previous years, but balaenopterid sightings were rare and included only one minke whale in September 2016. In 2019, 26 total humpback, fin, and minke whales were sighted on Herald Shoal (Clarke et al. 2020). These sightings of fin whales were the farthest north fin whale visual detections recorded in the Pacific Arctic.

The underlying causes for this anomalous bowhead whale migration and the unusual distribution of balaenopterid whales are presently topics of investigation. The Pacific Arctic is a region with dynamic ecosystems that are undergoing unpredictable and rapid changes. During 2019, in addition to record low summer and winter sea ice extents in the Alaska Arctic, other extreme environmental variables were recorded, including warmer surface air and sea surface temperatures, lower snow cover, thawing permafrost, and decreased sea ice thickness (Richter-Menge et al. 2019). The effects of these physical changes undoubtedly cascaded throughout ecosystems, affecting primary and secondary productivity, transport from the Bering Sea, and freshwater runoff, among other factors. In the western Beaufort Sea, very few bowhead whale aggregations (an indication of feeding) were observed and feeding behavior was conspicuously absent (Clarke et al. 2020), suggesting that krill and other bowhead whale prey were mostly absent or only present in much lower densities. Autumn winds near Point Barrow were not conducive to upwelling (Clarke et al. 2020, Ashjian et al. 2021). The presence of killer whales in the western Beaufort Sea (Clarke et al. 2020) also may have influenced the distribution of bowhead whales (Willoughby et al. 2020).

We aim to further investigate patterns in the ASAMM 2019 data for large cetaceans and their association with remotely sensed physical and biological environmental data. The

ASAMM's unusual observations in 2019. We have three primary objectives. First, to compile year-round monthly composites of remotely sensed environmental data from 2014 to 2019; input the data into a GIS; and generate maps for each combination of environmental variable, month, and year, using a standardized color scale for each environmental variable. Second, to generate maps for each species, month, and year for ASAMM bowhead, gray, humpback, fin, and minke whale sighting and sighting rate data from 2014 to 2019. Third, we summarize published literature to create a conceptual model explaining the ecological mechanisms that shape the spatiotemporal variability in the bowhead whale autumn migration across the western Beaufort Sea.

## **Methods**

Remotely sensed satellite data were collected for sea ice, sea surface temperature (SST), chlorophyll a (chl a), and net primary productivity of carbon. Table 1 lists each environmental variable, temporal resolution, spatial resolution, data source (url), dataset name, data format, and reference for each dataset used. Datasets for each environmental variable were chosen to maximize coverage of the Pacific Arctic region (110°-180°W, 50°-90°N) and provide monthly composites for every month from 2014 to 2019 in a file format that could be easily and efficiently input into ArcGIS for mapping. In this case, netCDF (.nc) files were chosen. SST, chl a, and primary productivity data were accessed and downloaded from Environmental Research Division's Data Access Program (ERDDAP), developed by the Southwest Fisheries Science Center. Sea ice data were accessed and downloaded from the National Snow and Ice Data Center (NSIDC). Within the NSIDC dataset, NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 3, there were four ice concentration data products. The product, "goddard bt seaice conc monthly" was available for years 2012-2018, and "seaice\_conc\_monthly\_cdr" was available for 2019, except December 2019, which was missing. Data were then imported into ArcGIS (ArcMap version 10.8).

Maps of remotely sensed variables were standardized to allow direct comparison of the color scale across all years and months for each variable. This involved setting four parameters for the color scale on each map: minimum, maximum, mean, and standard deviation. For each variable, the minimum scale parameter for all maps was set to the overall minimum value across all years and months. The maximum scale parameter was derived using analogous methods. The mean scale parameter for each variable was computed using a three-step process: 1) find the set of months that had the greatest range between the minimum and maximum values; 2) compute the mean of all cells for each combination of month and year for the set of months identified in step 1; and 3) assign the mean scale parameter for all maps to the mean of the values derived in step 2. The standard deviation scale parameter was computed similarly: 1) compute the standard

deviation of all cells for each combination of month and year for the same set of months used to compute the mean scale parameter; and 2) assign the standard deviation scale parameter for all maps to the mean of the values derived in step 1. For SST, summer (July-Aug.) was chosen for parameterizing the color scale because we expected the greatest variability to occur when there is a combination of heating from the sun and surface cooling from upwelling. The greatest range and largest maximum values for chl a and primary productivity occurred from late spring through early fall. To parameterize the color scale for these variables, May-October was chosen for chl a and April-September for primary productivity. For sea ice, because the data ranged 50°-90°N, the minimum and maximum scale parameters were set to 0 and 100, respectively, for each month; all months/years were used to compute the mean and standard deviation.

The ASAMM study area (140°-169°W, 67°-72°N) was divided into 10 depth zones in three regions: the Chukchi Sea subarea (157°-169°W, 67°-72°N), Beaufort Sea West subarea (154°-157°W, shore to 72°N), and Beaufort Sea East subarea (140°-154°W, shore to 72°N) (Fig. 2). Clarke et al. (2020) comprehensively details aerial survey methodology. Bowhead, gray, humpback, fin, and minke whale sighting rates (number of whales per oneffort km flown, where "on-effort" refers to transect and CAPs adjusted; Clarke et al. [2020]) were computed for each depth zone in the three regions. These large whale sightings and sighting rates were mapped for each region.

### Results

Remotely sensed satellite data for sea ice are shown in Appendix A, SST in Appendix B, chl a in Appendix C, and primary productivity in Appendix D.

Bowhead whale sighting and sighting rates are shown in Appendix E. In the Beaufort Sea West subarea, 724 bowhead whales were sighted on effort in all months and years; in 2019, only 7 (1%) bowhead whales were sighted in this area. In the Beaufort Sea East subarea, 2,036 bowhead whales were sighted on effort in all months and years; in 2019, 236 (12%) bowhead whales were sighted in this area. In the Chukchi Sea subarea, 318 bowhead whales were sighted on effort in all months and years; in 2019, only 2 (<1%) bowhead whales were sighted in this area. Out of all months and years examined, sighting rates were highest in the Beaufort Sea West subarea in the 0-20 m zone in September 2015, in the eastern Beaufort Sea subarea in the 0-20 m zone in August 2016, and in the Chukchi Sea subarea in the 50-200 m north zone in October 2017.

Gray whale sightings and sighting rates are presented in Appendix F. For all years and months pooled, sighting rates were highest in the Chukchi Sea subarea (0.0784 whales/km compared to 0.0013 whales/km in the Beaufort Sea West subarea and 0.00005 whales/km in the Beaufort Sea East subarea). This pattern of sighting rates per subarea

was similar in 2019, with 98% of gray whales sighted in the Chukchi Sea subarea. Out of all months and years examined, sighting rates were highest in the Chukchi Sea subarea in the 50-200 m south zone in August 2014, in the Beaufort Sea West subarea in the 20-50 m zone in July 2019, and in the Beaufort Sea East subarea in the 20-50 m zone in July 2016.

Humpback whale sightings and sighting rates are shown in Appendix G, fin whales in Appendix H, and minke whales in Appendix I. All humpback, fin, and minke whale sightings were in the Chukchi Sea subarea. In 2019, the highest sighting rates for humpback whales were in September in the 50-200 m south zone, in the same zone for fin whales in October, and in the 0-35 m north zone for minke whales in September. Out of all months and years examined, the highest sighting rates for humpback and fin whales were in the 0-35 m south zone in September 2018, and for minke whales were in the 0-35 m south zone in September 2014.

### Discussion

The ASAMM 2019 surveys revealed surprising and unprecedented changes in the eastern Chukchi and western Beaufort seas, including the anomalous bowhead whale autumn migration and frequent sightings of humpback, fin, and minke whales in an area where ASAMM has never detected them before.

Our primary goal was to conduct a preliminary investigation of patterns between ASAMM large cetacean sightings and remotely sensed physical and biological variables to better understand the ecological linkages causing spatiotemporal variability in the bowhead whale autumn migration across the western Beaufort Sea. We focused our investigation at a temporal resolution of one month, temporal extent of six years (2014-2019), spatial resolution of 1-25 km², and spatial extent encompassing the Pacific Arctic (U.S. Bering, U.S. Chukchi, and U.S. and Canadian Beaufort seas). Due to persistent cloud cover in the Pacific Arctic region and the inability for satellites to sense SST and ocean color through clouds, our investigation was limited to a minimal temporal resolution of one month.

Based on visual inspection of the sea ice maps, there appears to be an association between spring sea ice coverage in the Chukchi Sea and bowhead whale sighting rates in the Beaufort Sea West subarea. These associations between the bowhead whale sighting data and spring sea ice coverage in the Chukchi Sea correspond to the ecological mechanisms described in Berline et al. (2008), Ashjian et al. (2010, 2021), Woodgate et al. (2018), and Okkonen et al. (2019). We summarize these ecological linkages in Figure 3. During the period from 2014 to 2019, it appears that the lowest spring sea ice coverage in the Chukchi Sea occurred in 2019; 2017 and 2018 also had low spring sea ice coverage in the Chukchi Sea. Bowhead whales often aggregate and feed during late summer and

autumn in the 0-20 m zone in the Beaufort Sea West subarea (Ashjian et al. 2010); however, in August-October 2019, bowhead whales were not sighted in this area. Bowhead whales were sighted in this area in autumn 2017 and 2018, with low to moderate sighting rates. Based on visual examination of the sea ice maps, the highest spring sea ice coverage in the Chukchi Sea occurred in 2014 and 2015. The highest bowhead whale sighting rates in the Beaufort Sea West subarea occurred in August and September 2015 in the 0-20 m zone, with low sighting rates in this area in October of every year. In 2014, no bowhead whales were sighted in this area in August, and sighting rates were low in September and October. Hence, observations from 2014 and 2015 do not provide evidence of a consistent association between spring sea ice coverage in the Chukchi Sea and bowhead whale sighting rates in the Beaufort Sea West subarea.

In contrast to the sea ice results, we did not find consistent relationships between the ASAMM bowhead whale data and the remotely sensed SST, chl a, and primary productivity data at the monthly resolution. This result is consistent with the specific findings of Ashjian et al. (2010, 2021), Okkonen et al. (2011, 2018, 2020), and Ferguson et al. (2021), which highlight mesoscale oceanographic features such as upwelling zones and fronts as the main local drivers of spatiotemporal variability in bowhead whale density in the Point Barrow region. The relevant time scales for identifying these mesoscale features range from days to weeks. More generally, this result is consistent with Mannocci et al. (2017):

"We posit that animal associations with fine-scale and ephemeral features are best modelled with instantaneous covariates. Associations with large scale and persistent oceanographic features are best modelled with climatological covariates. Associations with mesoscale features are best modelled with instantaneous or contemporaneous covariates if ephemeral processes are present or interannual variability occurs, and climatological covariates if seasonal processes dominate and interannual variability is weak."

We suspect that patterns in SST, chl a, and primary productivity do relate to observed patterns in bowhead whale density, however, the ecological variables need to be sampled at a finer temporal resolution than monthly for such patterns to be evident (Ashjian et al. 2010, Okkonen et al. 2018). Therefore, further investigation into associations between the in situ ecological data from cruises or biophysical moorings hold promise (e.g., Okkonen et al. 2018).

Because the Chukchi Sea represents the northern distribution of humpback, fin, and minke whales, ASAMM surveys have encountered relatively few sightings of each of these species and much less is known about their ecology in the ASAMM study area. Our investigation did not reveal clear patterns in the distribution and density of these species with respect to the environmental variables that we considered. Nevertheless, we suspect

to find associations between biophysical forcing and the spatiotemporal variability in the density of these species with additional years of monitoring, which would increase the temporal extent over which to examine patterns and would likely increase the number of sightings in the database, providing more strength to investigate ecological linkages. This may be particularly important as climate change continues to warm the Arctic because consecutive years with higher than average temperatures and less sea ice may have cumulative effects on the spatiotemporal variability of these species.

Although not directly examined in the maps generated for this investigation, winds also influence the spatiotemporal variability in the autumn bowhead whale migration via both remote and local forcing. Seasonally averaged regional winds are correlated with the timing and pattern of sea ice retreat across the Chukchi Sea (Okkonen et al. 2019) and the transport of krill to the Utqiaʻgvik region (Okkonen et al. 2020; Ashjian et al. 2021). At smaller spatial and temporal scales, the strength and direction of winds in the western Beaufort Sea influence coastal circulation patterns, including upwelling and convergence of water masses. Ashjian et al. (2010) found that the mean size of bowhead whale groups off Point Barrow was significantly larger following a 2- to 3-day period of upwelling favorable winds. Similarly, Okkonen et al. (2018) found that bowhead whale group sizes in the central Alaskan Beaufort Sea during September 1997 and 2014 were larger when upwelling winds occurred within the preceding 5-day period. Local and regional winds are essential to understanding the spatiotemporal variability in the bowhead whale autumn migration.

In conclusion, future investigations into the ecological mechanisms shaping interannual variability in the bowhead whale autumn migration and the density and distribution of humpback, fin, and minke whales in the Pacific Arctic should incorporate the dynamic influences of processes such as advection and climate warming acting over long periods (months and years) and broad scales (the extent of the Pacific Arctic region, hundreds to thousands of kilometers), in addition to mesoscale processes such as upwelling and convergence that occur over days and weeks across distances spanning tens to hundreds of kilometers (Haury et al. 1978; Moore et al. 2018; Ashjian et al. 2021).

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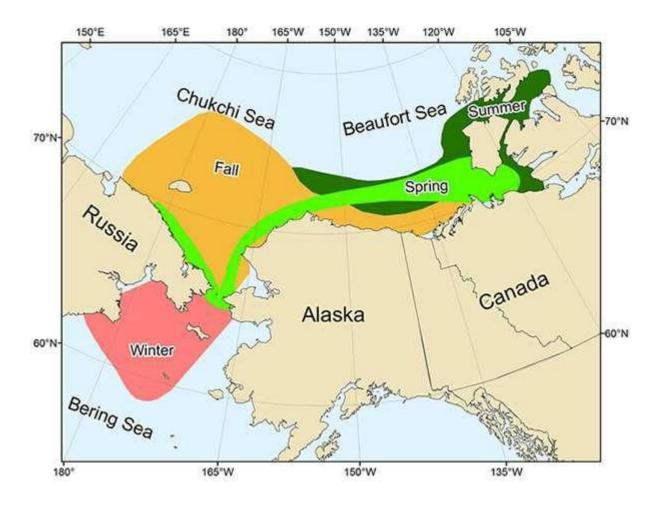


Figure 1. -- Seasonal migration of the Bering-Chukchi-Beaufort Seas population of bowhead whales. *Note:* From "Satellite Tracking of Bowhead Whales, Movements and Analysis from 2006 to 2012 Final Report," by Quakenbush et al. (2013), U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, AK. OCS Study BOEM 2013-01110. 60 p. + appendices.

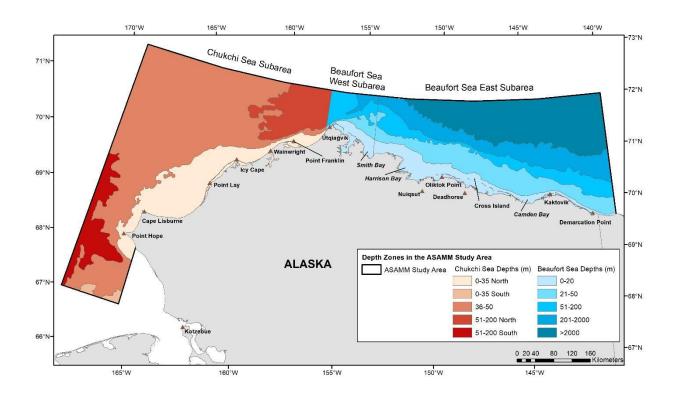


Figure 2. -- Depth zones for the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas in the ASAMM study area.

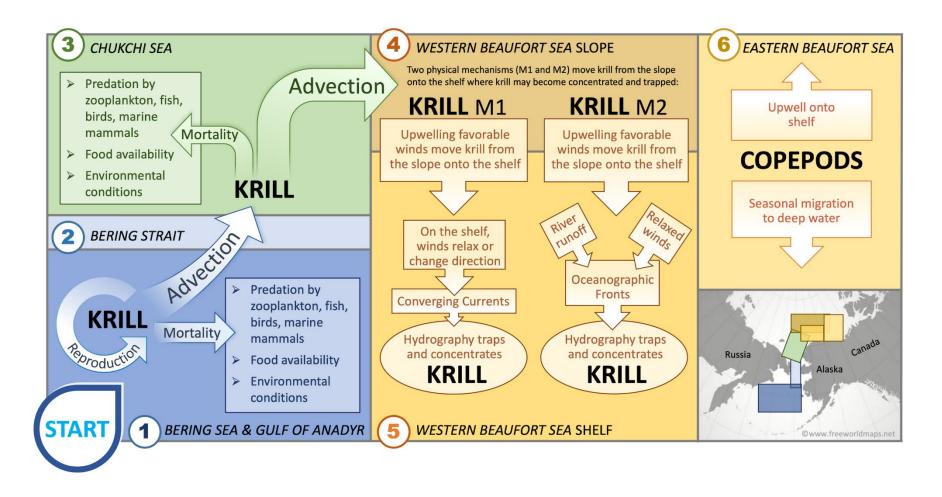


Figure 3. -- Mechanisms driving krill characteristics near Point Barrow, Alaska, during late summer and autumn that relate to bowhead whale feeding opportunities. The narrative for Figure 3 is below.

# Figure 3 -- Narrative:

# 1. Bering Sea and Gulf of Anadyr

Krill (euphausiids) are bowhead whales' primary prey during late summer and autumn near Point Barrow. Both Thysanoessa raschii and T. inermis have been identified in bowhead whale stomachs taken from the area during autumn subsistence whaling (Lowry et al. 2004). Both species are not believed to reproduce near Point Barrow; rather, they spawn during spring (Siegel 2000) in the Bering Sea and Gulf of Anadyr (Berline et al. 2008). Survivors (recruits) transition through multiple life history stages that can be broadly categorized as larvae, juveniles, and adults (Siegel 2000). Adults of these species may reach a maximum age of 2-3 years (Siegel 2000). Krill survival (recruitment success) may be affected by factors such as predation, food availability, and environmental conditions. Since 2000, the Bering Sea has alternated between multi-year periods of cold states or warm states (Stabeno et al. 2012). The abundance of krill and other large zooplankton is typically higher during cold states than warm states (Coyle et al. 2011; Eisner et al. 2014). Some of these krill are advected northward by currents from the Bering Sea and Gulf of Anadyr to the Chukchi Sea, Beaufort Sea, East Siberian Sea, and Arctic Ocean basin (Berline et al. 2008). These emigrants from the Bering Sea and Gulf of Anadyr are thought to be larvae in the furcilia developmental stage; Ashjian et al. (2021) refers to a "furcilia front" that advances northward.

# 2. Bering Strait

Krill from the Bering Sea and Gulf of Anadyr must transit through Bering Strait to reach Arctic waters farther north. The volume transport through Bering Strait varies across seasons and years (Woodgate et al. 2018). Furthermore, Woodgate et al. (2018) found long-term trends in water transported through Bering Strait based on a time series of mooring data spanning 1990–2015: the volume transport through the strait during summer months increased, resulting in a reduction in the flushing time of the Chukchi Sea from ~7.5 months to 4.5 months. They attributed the changes to far-field (Pacific-Arctic "pressure head") forcing rather than to local winds. This temporal variability in water transport from the Bering to Chukchi seas affects krill in a number of ways, including the route and transit time through the Chukchi Sea, and the species composition and population structure near Point Barrow in late summer and autumn (Ashjian et al. 2021), as described in (3) Chukchi Sea.

### 3. Chukchi Sea

Many krill that enter the Chukchi Sea through Bering Strait will eventually reach the Point Barrow region (Berline et al. 2008). Far-field forcing factors ultimately influence krill's route and transit time through the Chukchi Sea, and the species composition and population structure near Point Barrow in late summer and autumn (Ashjian et al. 2021). Specifically, sea level pressure patterns over the Chukchi and Beaufort seas in autumn of the previous year and late spring of the subsequent year affect the strength, variability, and

direction of the seasonally-averaged regional winds and the late-spring sea ice extent in the Chukchi Sea (Okkonen et al. 2019; Ashjian et al. 2021).

In one scenario, a strong Beaufort Sea High (BSH) sea level pressure field that occupies the western Beaufort Sea during the preceding autumn and subsequent spring generates stronger, persistent easterly winds (from the east/northeast). Theses easterlies drive a more rapid rate of sea ice retreat during spring and older, larger krill who overwintered on the Chukchi shelf are simultaneously exported northward into the Arctic basin. As a consequence, there is more open water, less late season melt water (LMW), and a predominance of small young-of-the-year krill in the furcilia life stage near Point Barrow in late summer and autumn (Okkonen et al. 2019; Ashjian et al. 2021).

In contrast, a weaker BSH located in the eastern Beaufort Sea during the preceding autumn and subsequent spring generates weaker, variable winds, resulting in a slower rate of spring sea ice retreat and greater retention of large overwintering krill on the Chukchi shelf. Accordingly, there is less open water, more LMW, and a predominance of juvenile and adult krill near Point Barrow in late summer and autumn (Okkonen et al. 2019; Ashjian et al. 2021). The number of krill that reach the Point Barrow region is also affected by mortality, which may be a function of predation, food availability, and environmental conditions.

# 4. Western Beaufort Sea Slope

Krill that reach the western Beaufort Sea from the Chukchi Sea tend to transit along the upper slope at flow depths of  $\sim$ 50-150 m.

### 5. Western Beaufort Sea Shelf

Two physical mechanisms are known to concentrate krill on the western Beaufort Sea shelf, resulting in feeding habitat where bowhead whales may aggregate in high densities. One mechanism (M1), known as the krill trap (Ashjian et al. 2010; Okkonen et al. 2020) involves a two-step process: 1) easterly winds cause water and krill from the slope to upwell to shallower depths on the shelf; and 2) subsequent relaxation or change in the direction of winds cause the westward-flowing Beaufort Sea shelf currents to converge with the northeastward-flowing Alaskan Coastal Current, creating a hydrographic trap that retains and concentrates krill on the shelf. The second mechanism (M2) involves upwelling-favorable winds blowing across the western Beaufort Sea that transport krill from deeper slope waters to shelf waters, where hydrographic fronts created by freshwater runoff from rivers concentrate and trap krill. These hydrographic fronts become more pronounced when river discharges are high and relaxed winds allow these riverine fronts to intensify (Okkonen et al. 2018).

### 6. Eastern Beaufort Sea Shelf

In the eastern Beaufort Sea, the shelf waters located north and northwest of the Tuktoyaktuk Peninsula, Northwest Territories, Canada, represent a bowhead whale coreuse area (an area of concentrated use) from early May to mid-October, with peak use typically spanning mid-July to late September (Citta et al. 2015). In this area, calanoid copepods may be upwelled onto the shelf, producing an efficient foraging area for bowhead whales (Walkusz et al. 2012). In late summer and autumn, these copepods migrate to greater depths, making them less likely to be upwelled onto the shelf. The majority of bowhead whales begin their return migration towards the west when the availability of copepods declines in the eastern Beaufort Sea. During years in which the winds in the eastern Beaufort Sea are not conducive to upwelling, bowhead whales begin their westward migration earlier in the summer (Ferguson et al. 2021).

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Table 1. -- Remotely sensed satellite data for the Bering, Chukchi, and Beaufort seas and Amundsen Gulf.

Date Type	Temporal Resolution	Spatial Resolution	Data Source (includes URL)	Dataset Name	Data Format	References
Sea Ice	1978-2019, monthly average	25 km x 25 km	National Snow and Ice Data Center (NSIDC): nsidc.org/data/search/# keywords=sea+ice/sortK eys=score,,desc/facetFilte rs=%257B%257D/pageN umber=1/itemsPerPage= 25	NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 3	netCDF (.nc file)	Peng, G., W.N. Meier, D. Scott, and M. Savoie. 2013. A long-term and reproducible passive microwave sea ice concentration data record for climate studies and monitoring, Earth Syst. Sci. Data. 5. 311-318. doi.org/10.5194/essd-5-311-2013
Sea Surface Temperature	2002- present, monthly composite	0.01 degrees (1.1 km)	NOAA SWFSC Environmental Research Division's Data Access Program (ERDDAP): coastwatch.pfeg.noaa.gov /erddap/index.html	Multi-scale Ultra- high Resolution (MUR) SST Analysis fv04.1, Global, 0.01°, 2002-present, Monthly	netCDF (.nc file)	JPL MUR MEaSUREs Project. 2015. GHRSST Level 4 MUR Global Foundation Sea Surface Temperature Analysis. Ver. 4.1. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at doi.org/10.5067/GHGMR-4FJ04. Accessed June 2020.
Chlorophyll	2012- present, monthly composite	4 km	NOAA SWFSC Environmental Research Division's Data Access Program (ERDDAP): https://coastwatch.pfeg.n oaa.gov/erddap/index.ht ml	VIIRSN, Suomi-NPP, Level-3 SMI, NASA, Global, 4km, Chlorophyll a, OCI Algorithm, R2018, 2012-present, Monthly	netCDF (.nc file)	NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Visible and Infrared Imager/Radiometer Suite (VIIRS) {Dataset Name} Data; NASA OB.DAAC, Greenbelt, MD, USA. doi: {DOI}. Accessed July 2020.
Primary Productivity	2003- present, monthly composite	0.0125 degrees (1.4 km)	NOAA SWFSC Environmental Research Division's Data Access Program (ERDDAP): coastwatch.pfeg.noaa.gov /erddap/index.html	Primary Productivity, Aqua MODIS, NPP, Global, 2003-present, EXPERIMENTAL (Monthly Composite)	netCDF (.nc file)	Citation not available on website. Data Creator is NOAA NMFS SWFSC ERD, pfeg.noaa.gov, erd.data@noaa.gov. Accessed July 2020.

# **APPENDIX A: SEA ICE CONCENTRATION**

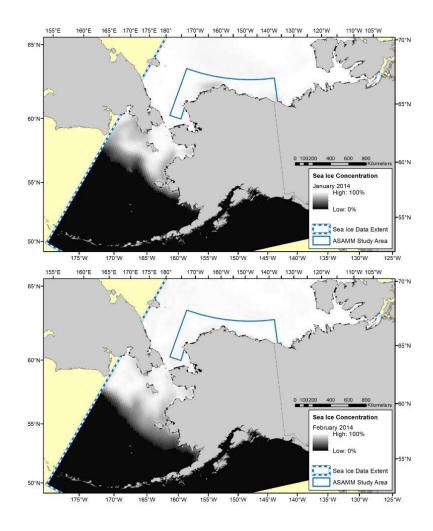


Figure A-1. -- Sea ice concentration in the Pacific Arctic, January-February 2014.

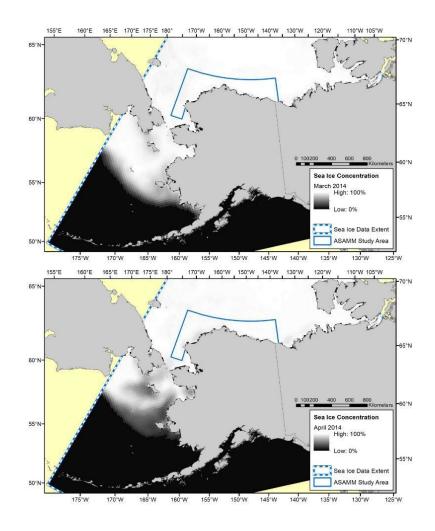


Figure A-2. -- Sea ice concentration in the Pacific Arctic, March-April 2014.

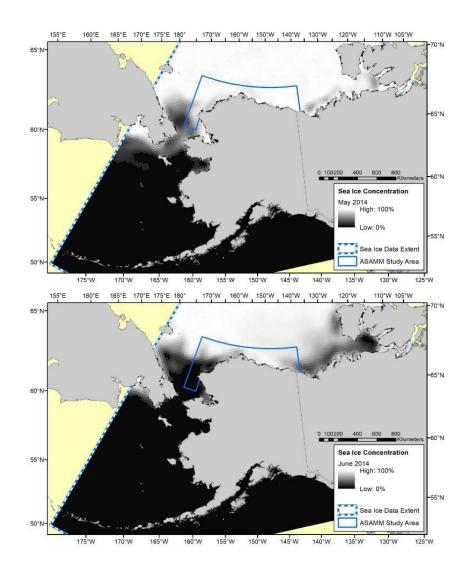


Figure A-3. -- Sea ice concentration in the Pacific Arctic, May-June 2014.

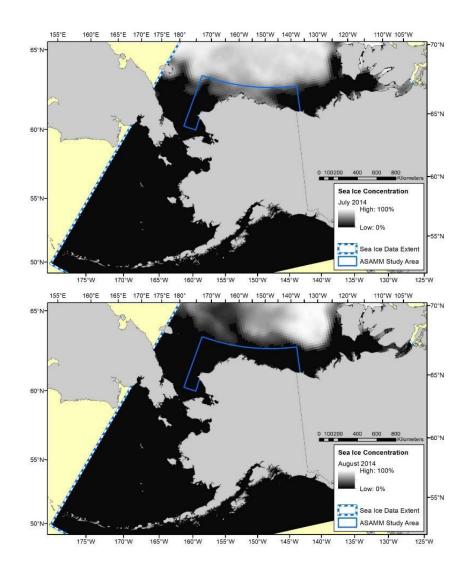


Figure A-4. -- Sea ice concentration in the Pacific Arctic, July-August 2014.

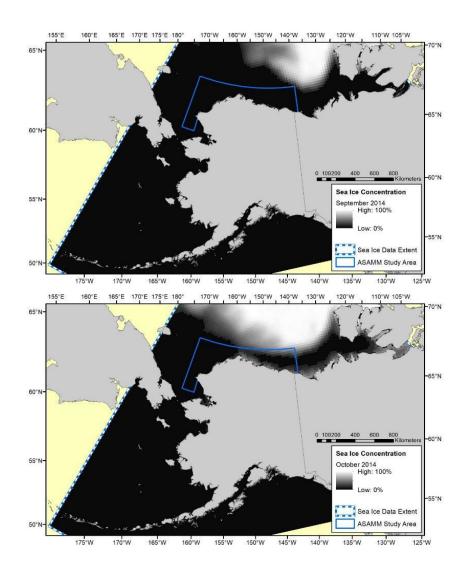


Figure A-5. -- Sea ice concentration in the Pacific Arctic, September-October 2014.

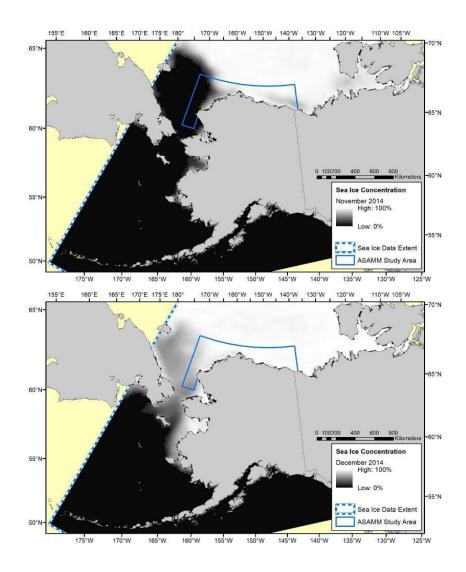


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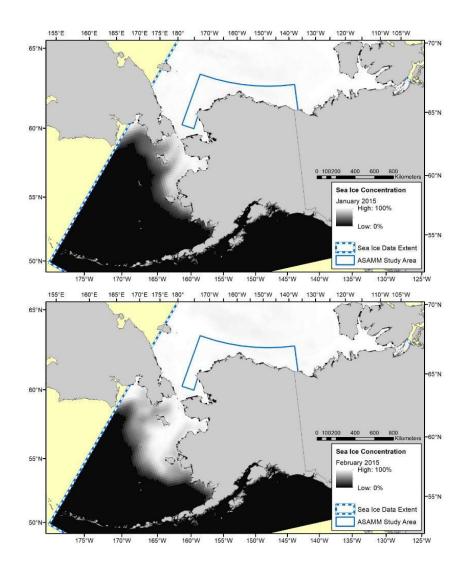


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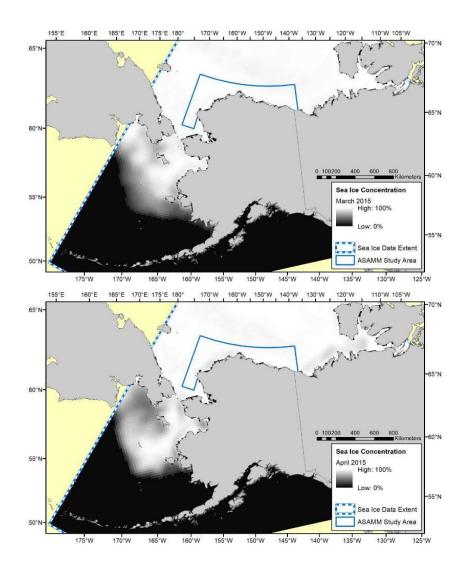


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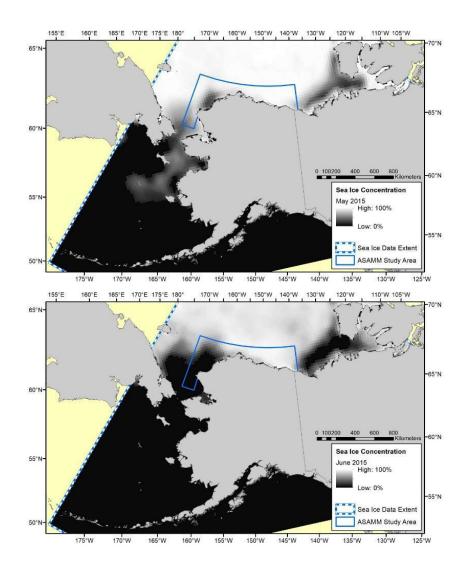


Figure A-9. -- Sea ice concentration in the Pacific Arctic, May-June 2015.

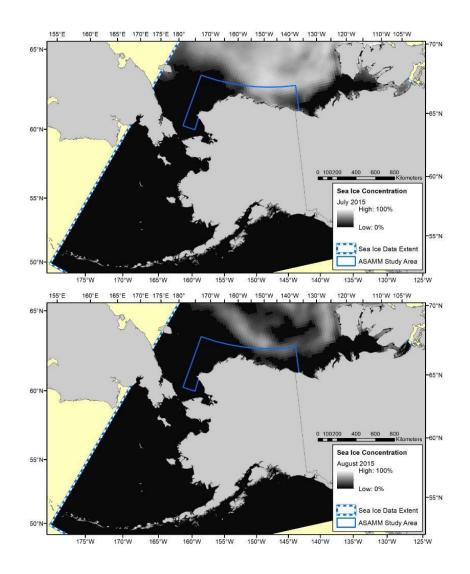


Figure A-10. -- Sea ice concentration in the Pacific Arctic, July-August 2015.

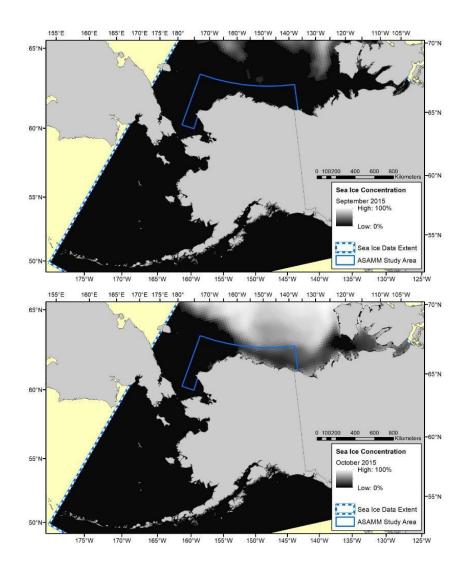


Figure A-11. -- Sea ice concentration in the Pacific Arctic, September-October 2015.

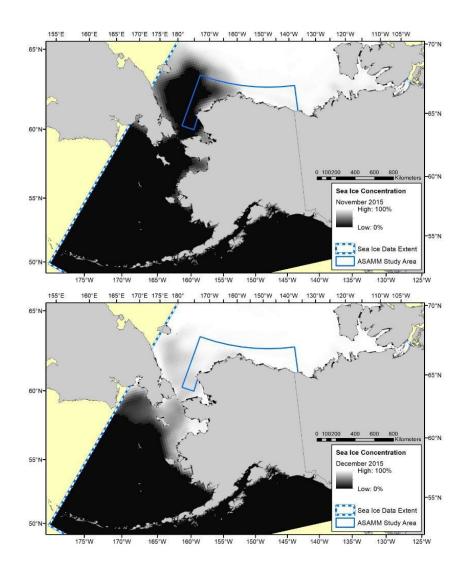


Figure A-12. -- Sea ice concentration in the Pacific Arctic, November-December 2015.

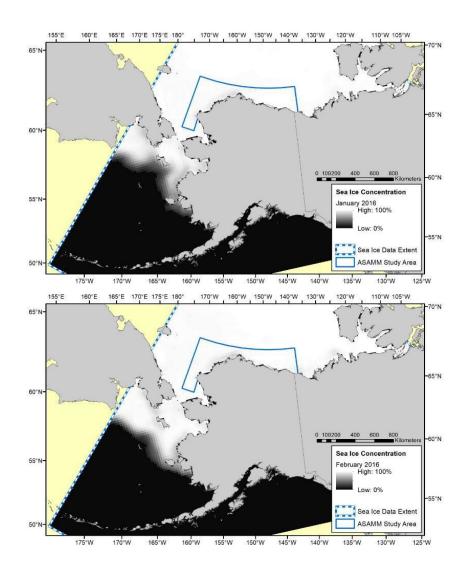


Figure A-13. -- Sea ice concentration in the Pacific Arctic, January-February 2016.

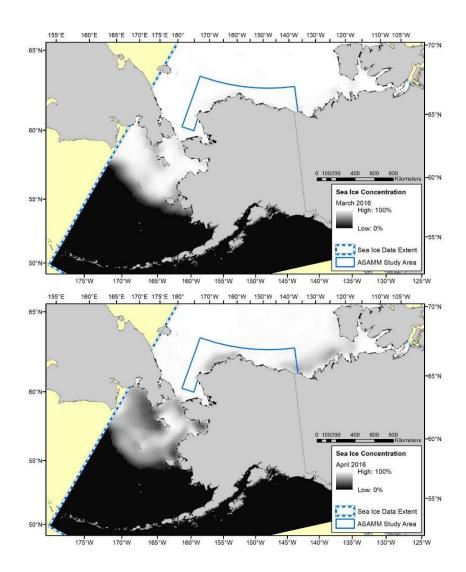


Figure A-14. -- Sea ice concentration in the Pacific Arctic, March-April 2016.

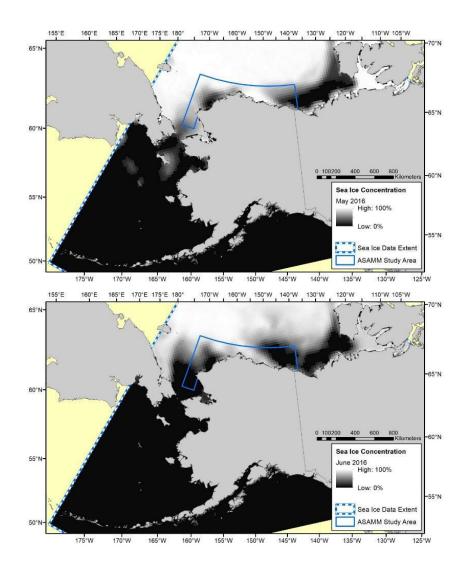


Figure A-15. -- Sea ice concentration in the Pacific Arctic, May-June 2016.

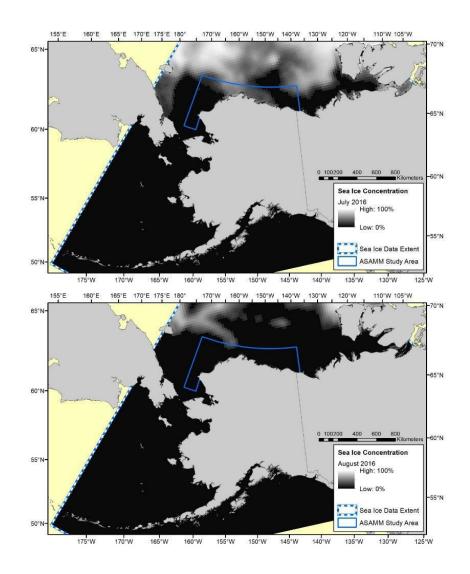


Figure A-16. -- Sea ice concentration in the Pacific Arctic, July-August 2016.

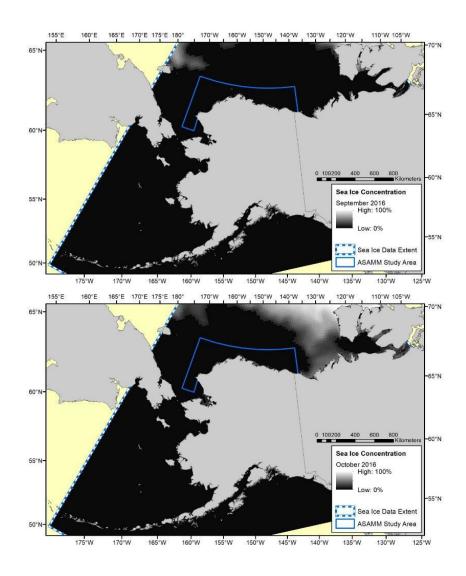


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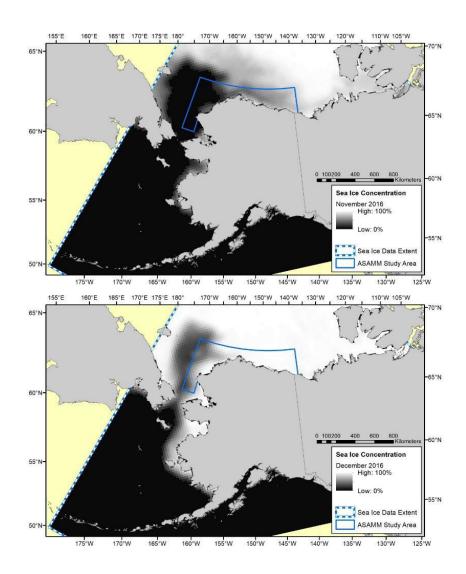


Figure A-18. -- Sea ice concentration in the Pacific Arctic, November-December 2016.

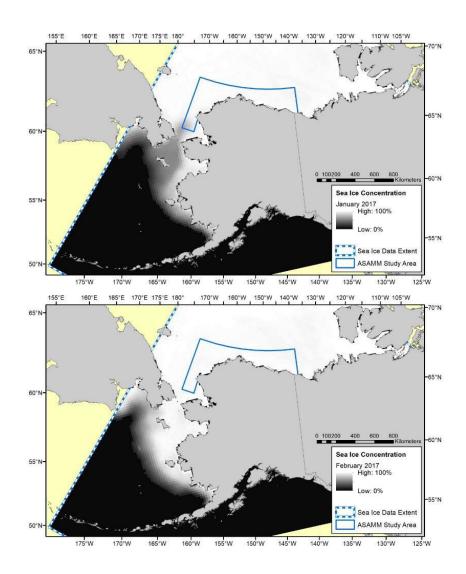


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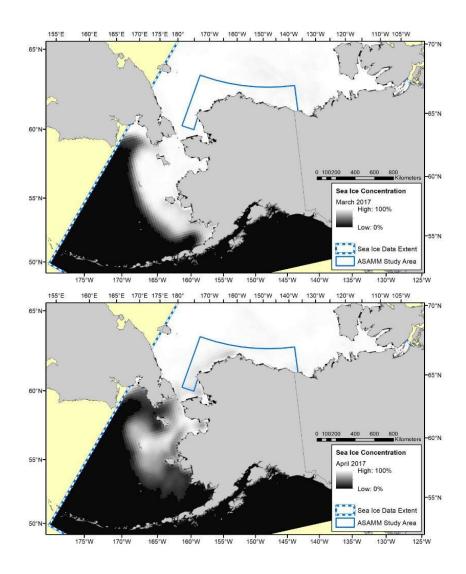


Figure A-20. -- Sea ice concentration in the Pacific Arctic, March-April 2017.

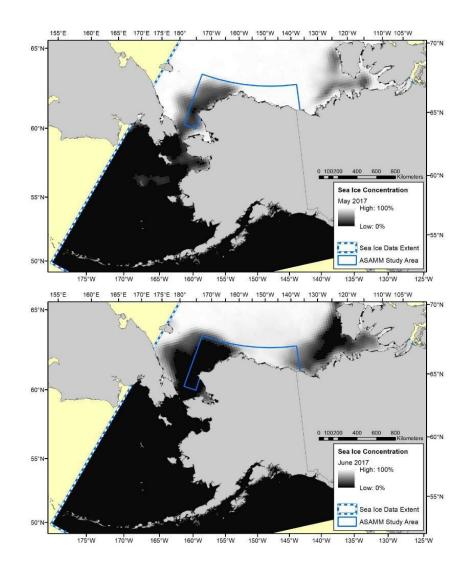


Figure A-21. -- Sea ice concentration in the Pacific Arctic, May-June 2017.

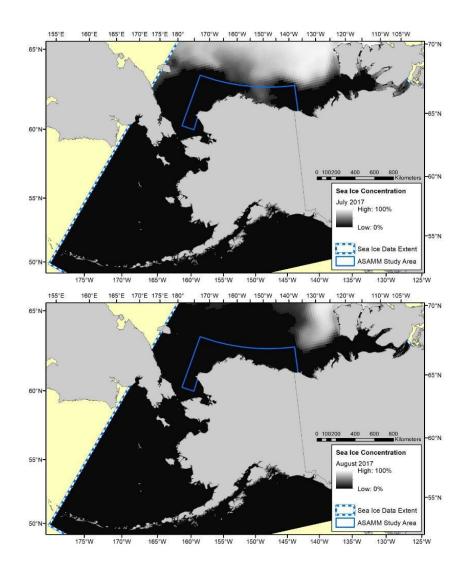


Figure A-22. -- Sea ice concentration in the Pacific Arctic, July-August 2017.

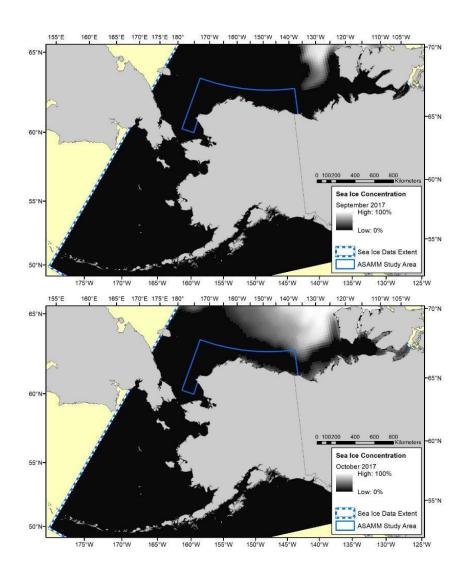


Figure A-23. -- Sea ice concentration in the Pacific Arctic, September-October 2017.

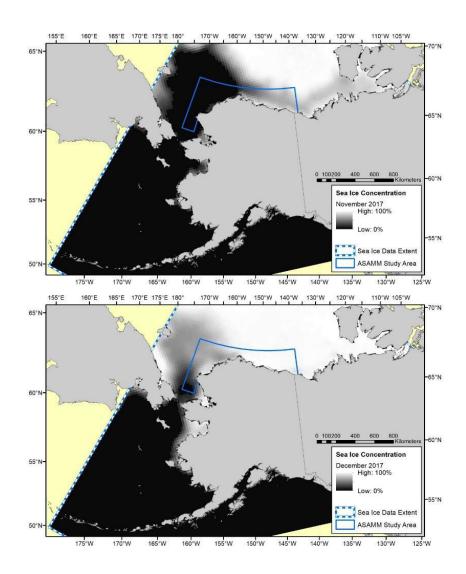


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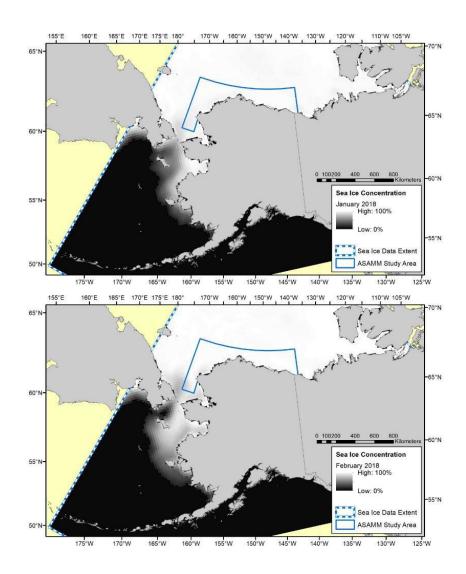


Figure A-25. -- Sea ice concentration in the Pacific Arctic, January-February 2018.

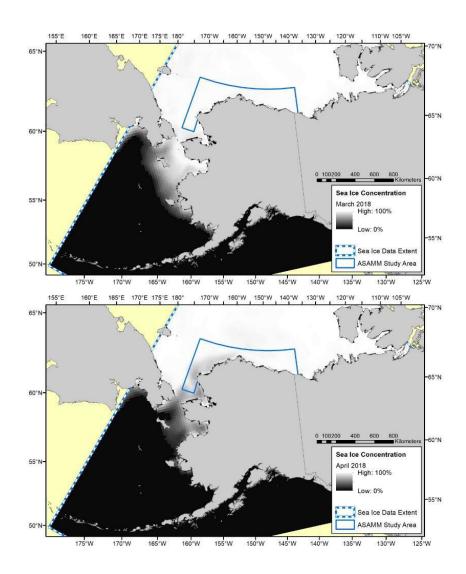


Figure A-26. -- Sea ice concentration in the Pacific Arctic, March-April 2018.

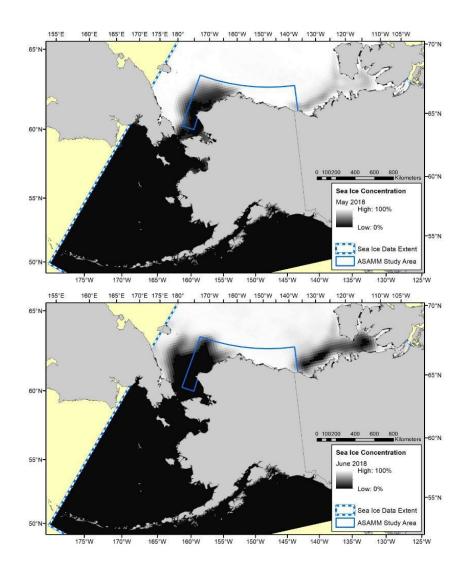


Figure A-27. -- Sea ice concentration in the Pacific Arctic, May-June 2018.

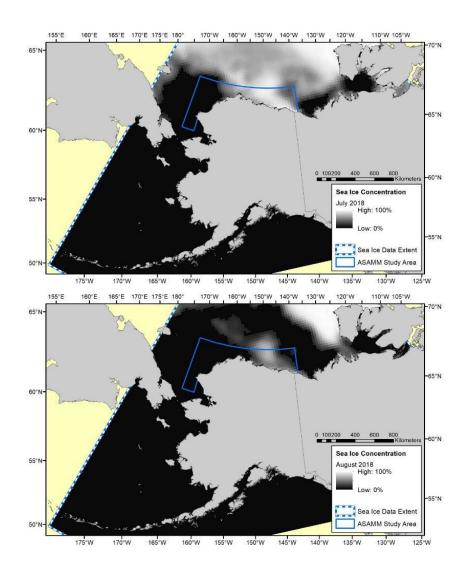


Figure A-28. -- Sea ice concentration in the Pacific Arctic, July-August 2018.

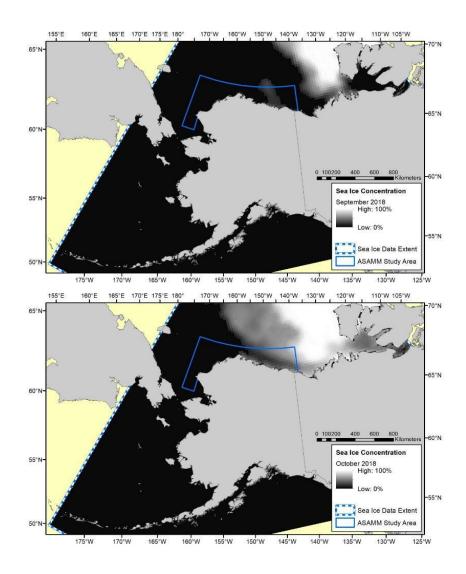


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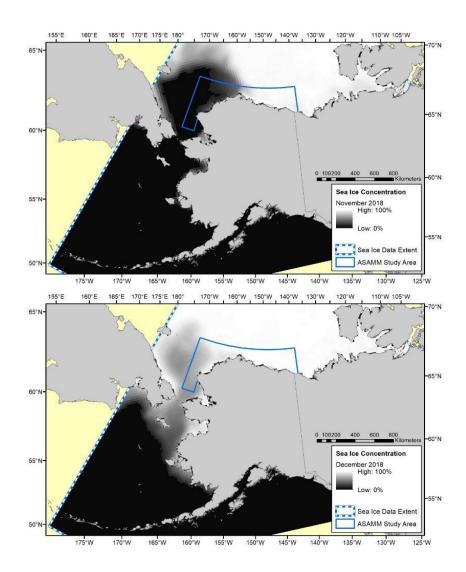


Figure A-30. -- Sea ice concentration in the Pacific Arctic, November-December 2018.

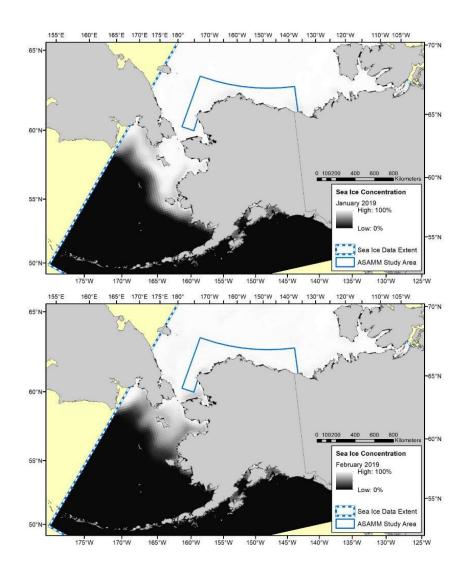


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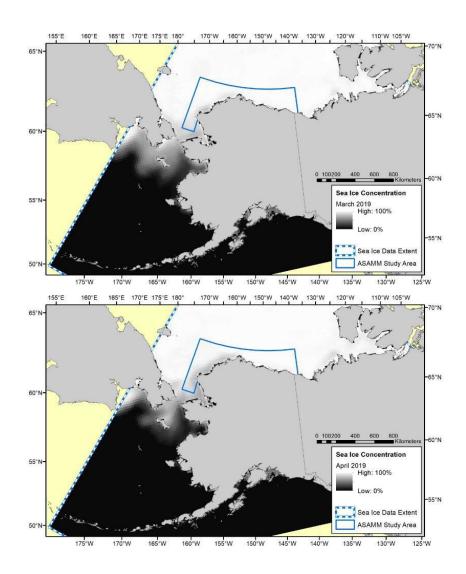


Figure A-32. -- Sea ice concentration in the Pacific Arctic, March-April 2019.

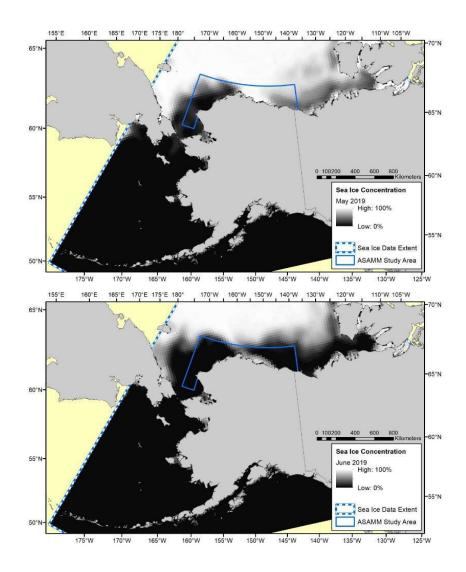


Figure A-33. -- Sea ice concentration in the Pacific Arctic, May-June 2019.

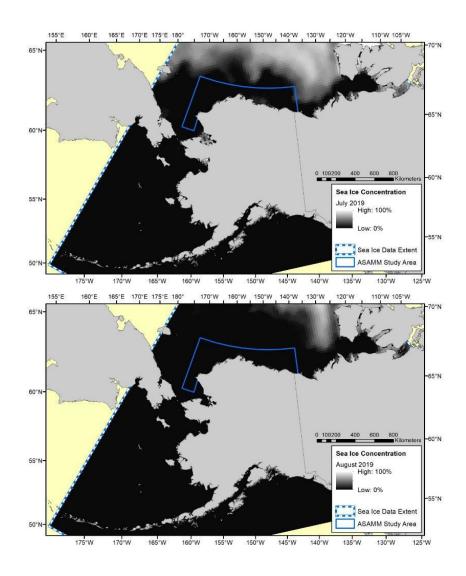


Figure A-34. -- Sea ice concentration in the Pacific Arctic, July-August 2019.

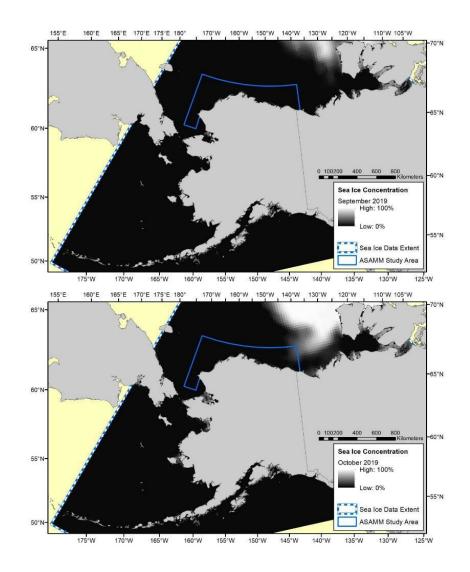


Figure A-35. -- Sea ice concentration in the Pacific Arctic, September-October 2019.

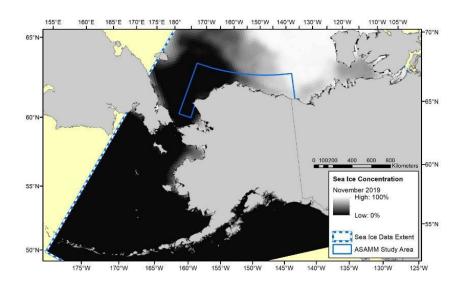


Figure A-36. -- Sea ice concentration in the Pacific Arctic, November 2019. December 2019 data were not available.

## APPENDIX B: SEA SURFACE TEMPERATURE

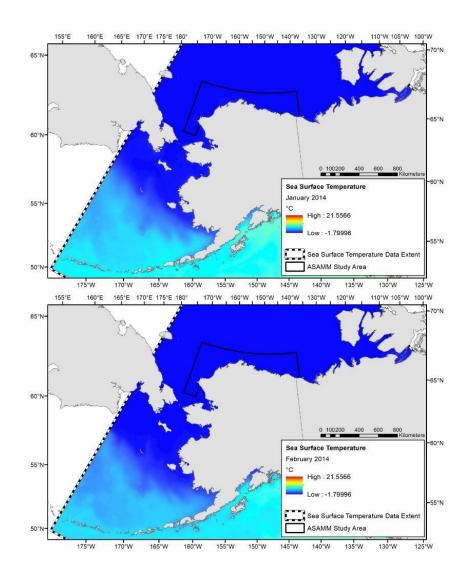


Figure B-1. -- Sea surface temperature in the Pacific Arctic, January-February 2014.

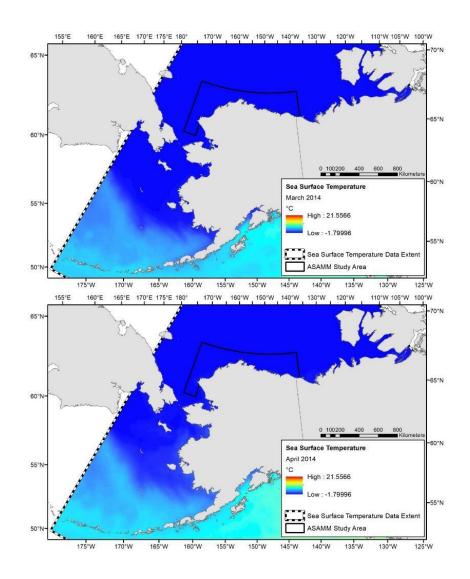


Figure B-2. -- Sea surface temperature in the Pacific Arctic, March-April 2014.

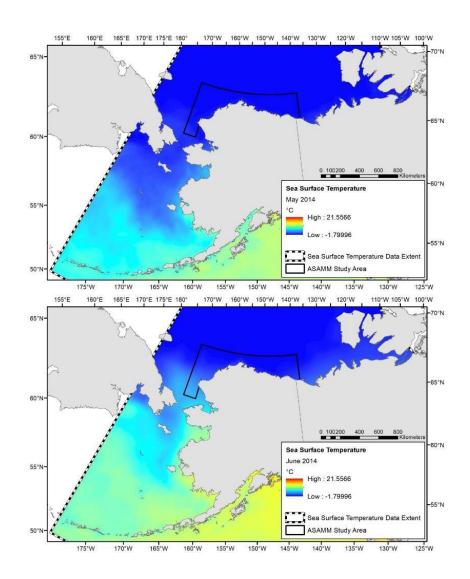


Figure B-3. -- Sea surface temperature in the Pacific Arctic, May-June 2014.

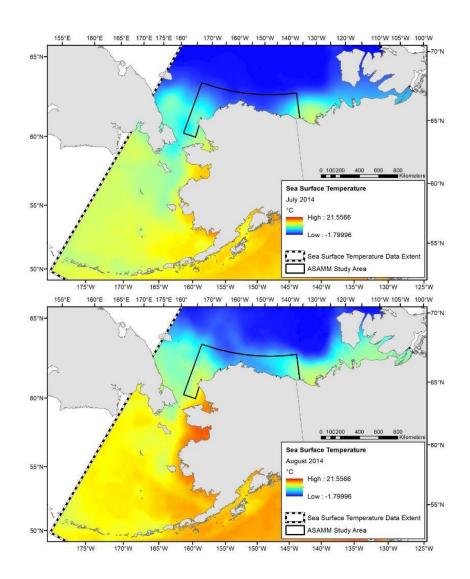


Figure B-4. -- Sea surface temperature in the Pacific Arctic, July-August 2014.

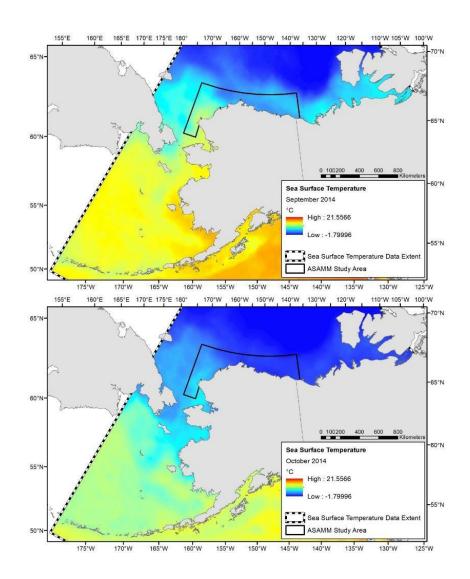


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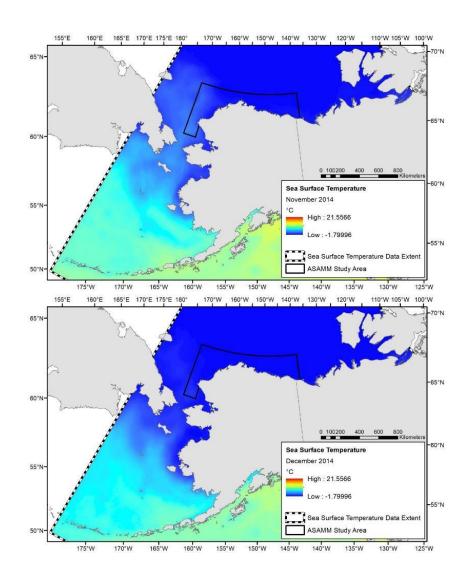


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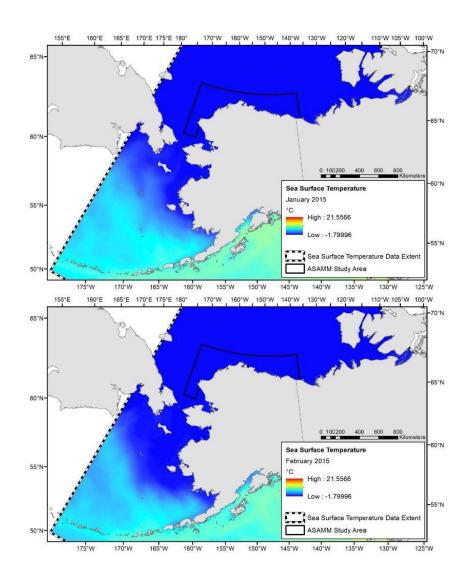


Figure B-7. -- Sea surface temperature in the Pacific Arctic, January-February 2015.

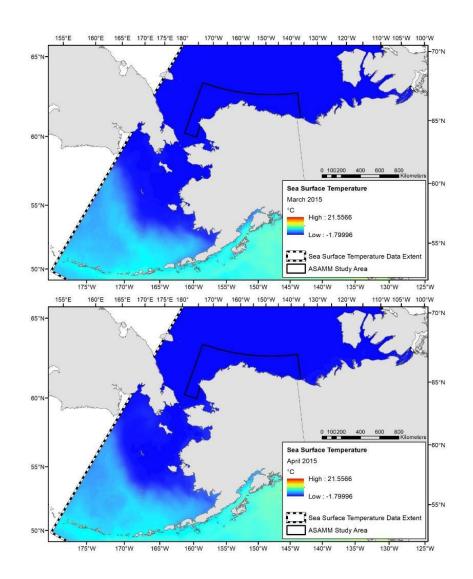


Figure B-8. -- Sea surface temperature in the Pacific Arctic, March-April 2015.

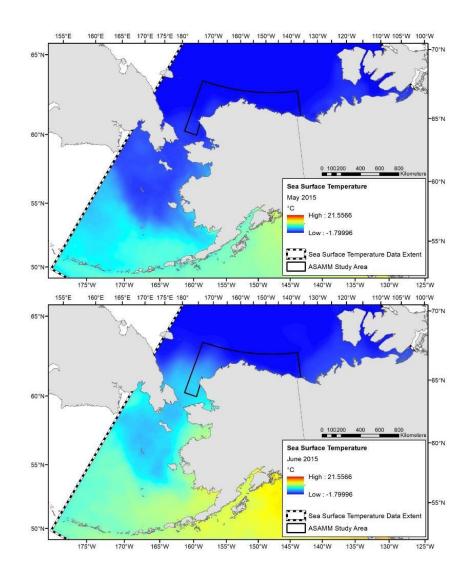


Figure B-9. -- Sea surface temperature in the Pacific Arctic, May-June 2015.

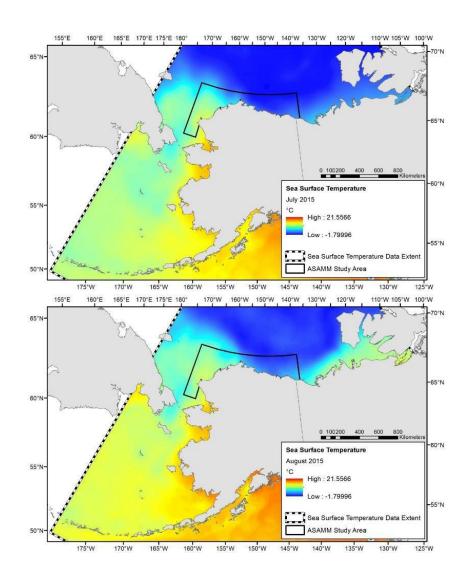


Figure B-10. -- Sea surface temperature in the Pacific Arctic, July-August 2015.

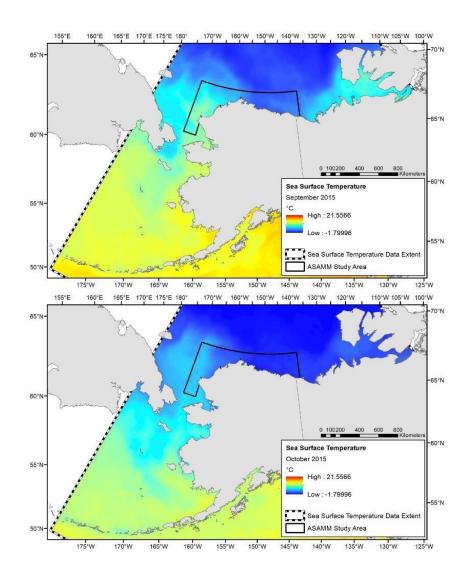


Figure B11. -- Sea surface temperature in the Pacific Arctic, September-October 2015.

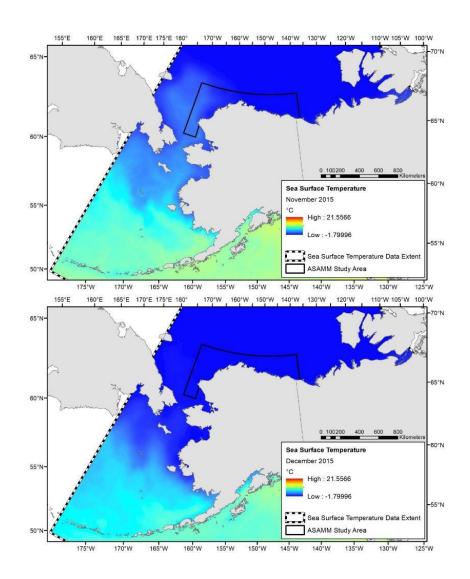


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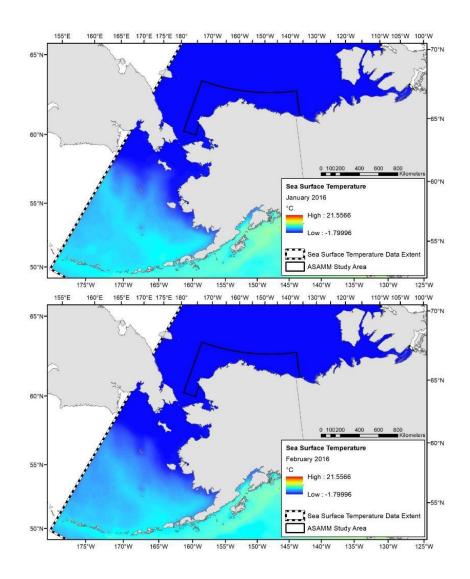


Figure B-13. -- Sea surface temperature in the Pacific Arctic, January-February 2016.

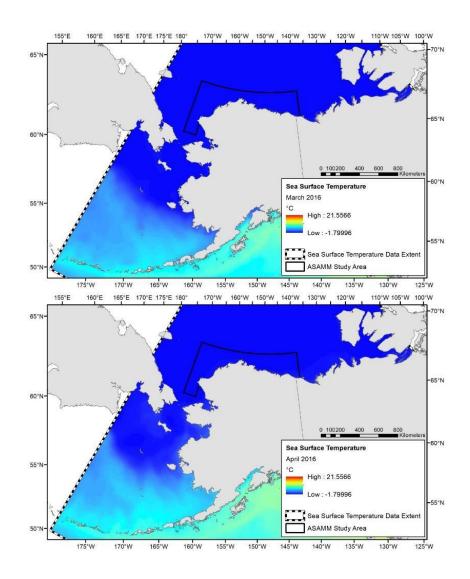


Figure B-14. -- Sea surface temperature in the Pacific Arctic, March-April 2016.

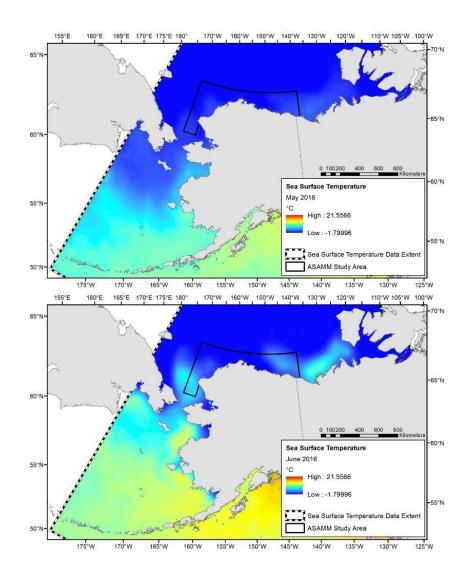


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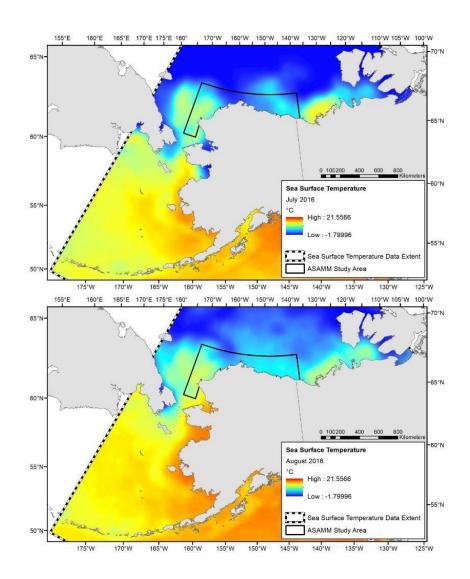


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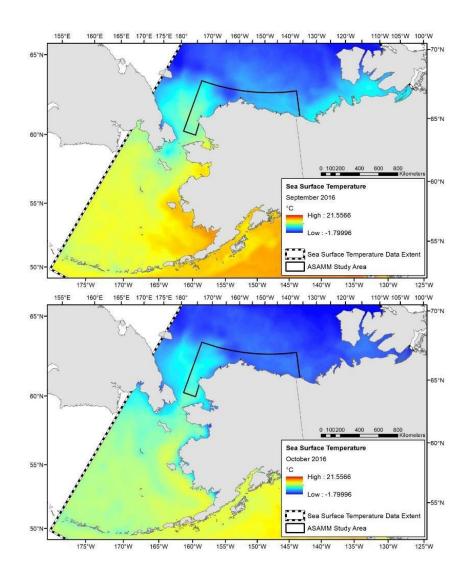


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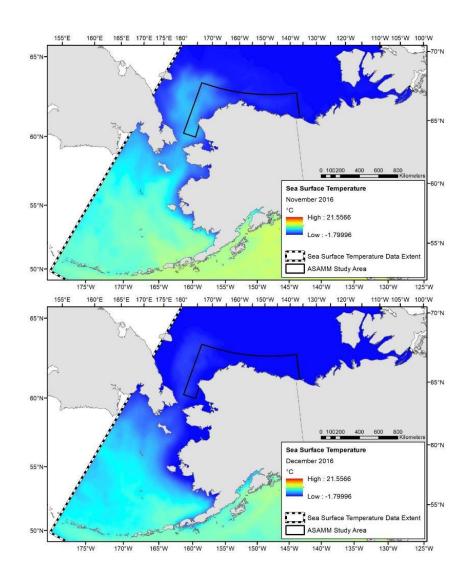


Figure B-18. -- Sea surface temperature in the Pacific Arctic, November-December 2016.

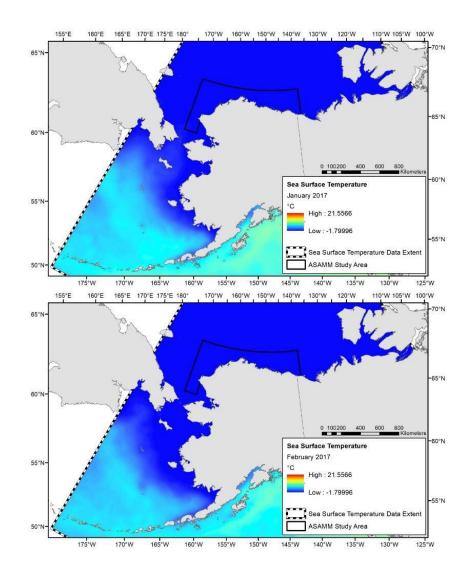


Figure B-19. -- Sea surface temperature in the Pacific Arctic, January-February 2017.

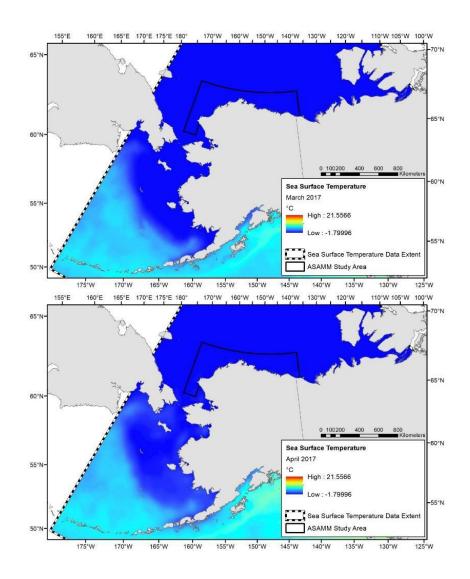


Figure B-20. -- Sea surface temperature in the Pacific Arctic, March-April 2017.

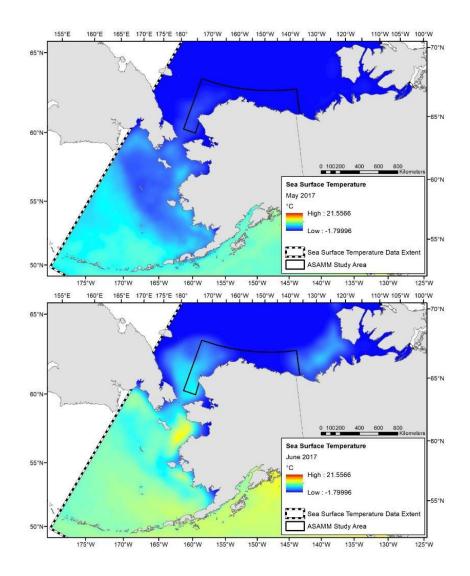


Figure B-21. -- Sea surface temperature in the Pacific Arctic, May-June 2017.

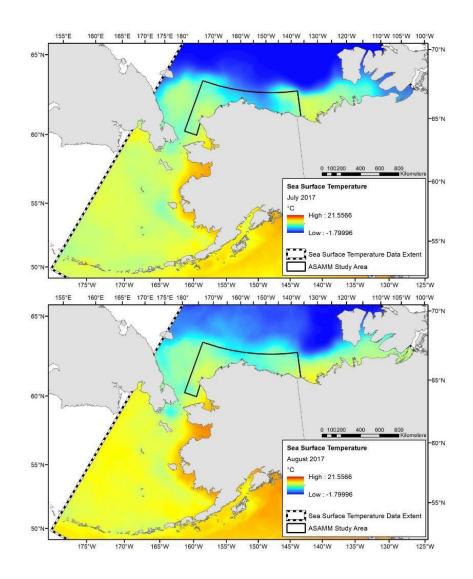


Figure B-22. -- Sea surface temperature in the Pacific Arctic, July-August 2017.

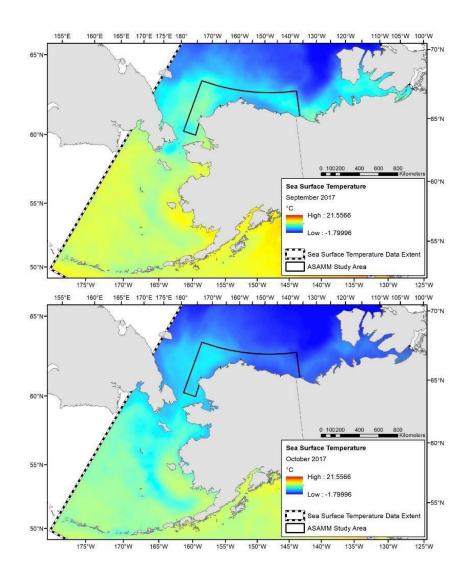


Figure B-23. -- Sea surface temperature in the Pacific Arctic, September-October 2017.

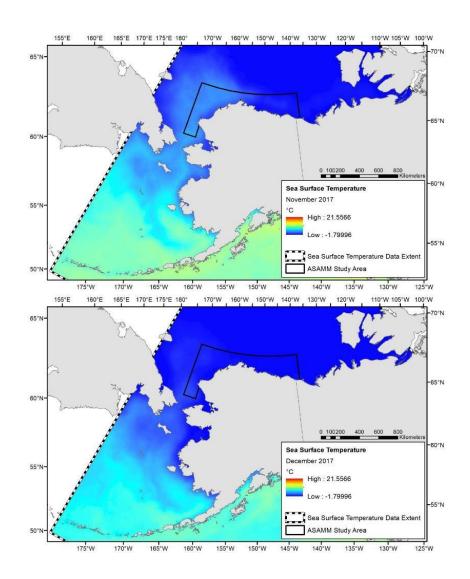


Figure B-24. -- Sea surface temperature in the Pacific Arctic, November-December 2017.

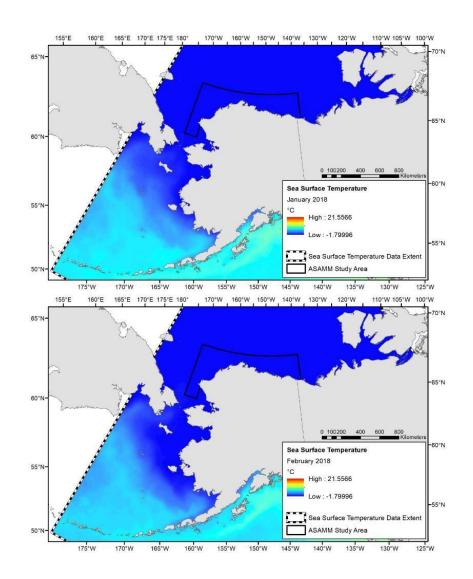


Figure B-25. -- Sea surface temperature in the Pacific Arctic, January-February 2018.

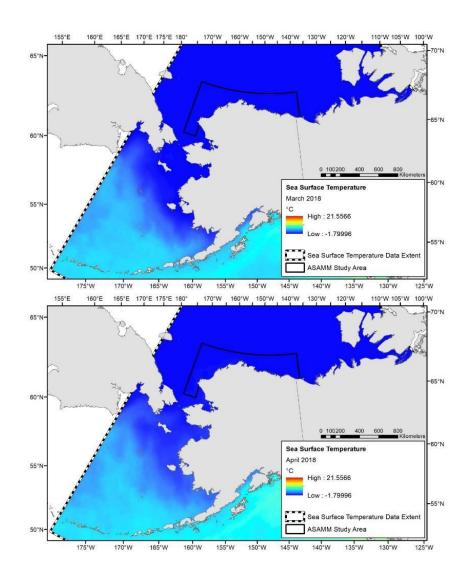


Figure B-26. -- Sea surface temperature in the Pacific Arctic, March-April 2018.

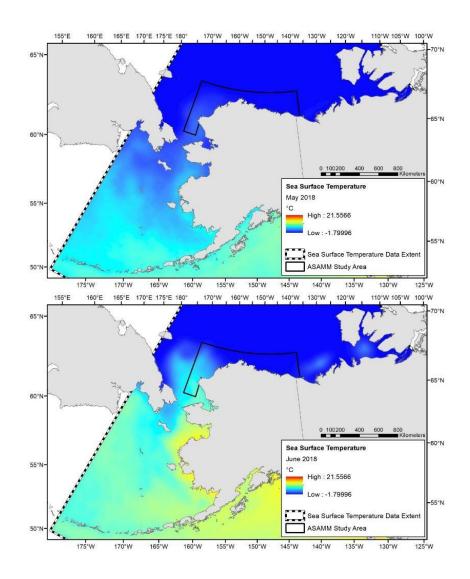


Figure B-27. -- Sea surface temperature in the Pacific Arctic, May-June 2018.

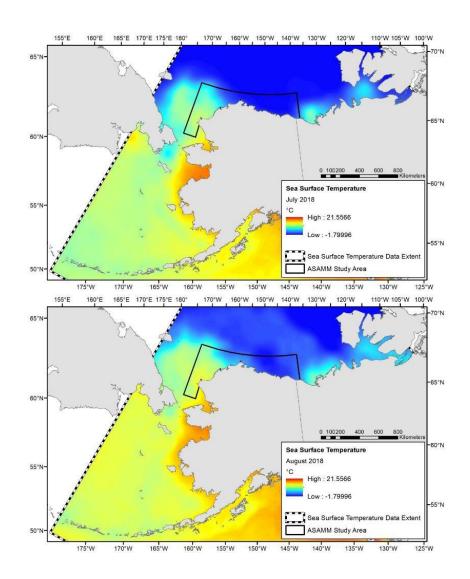


Figure B-28. -- Sea surface temperature in the Pacific Arctic, July-August 2018.

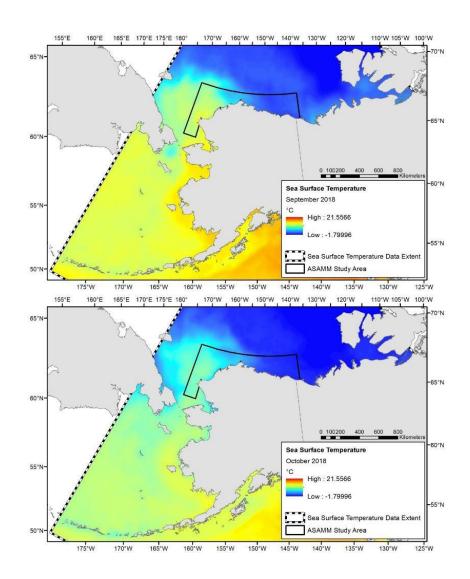


Figure B-29. -- Sea surface temperature in the Pacific Arctic, September-October 2018.

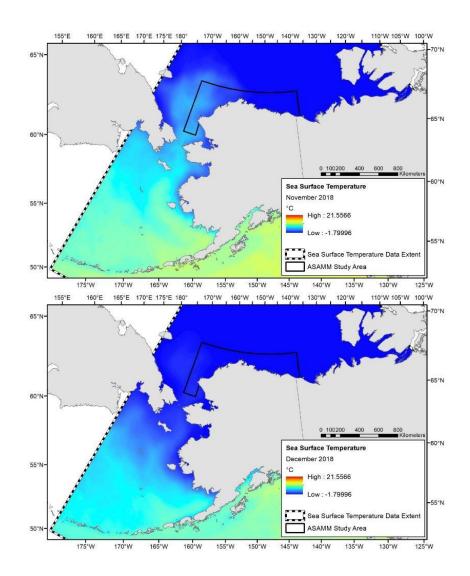


Figure B-30. -- Sea surface temperature in the Pacific Arctic, November-December 2018.

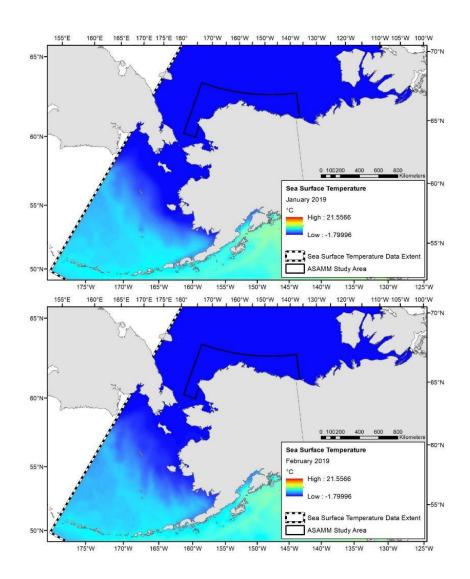


Figure B-31. -- Sea surface temperature in the Pacific Arctic, January-February 2019.

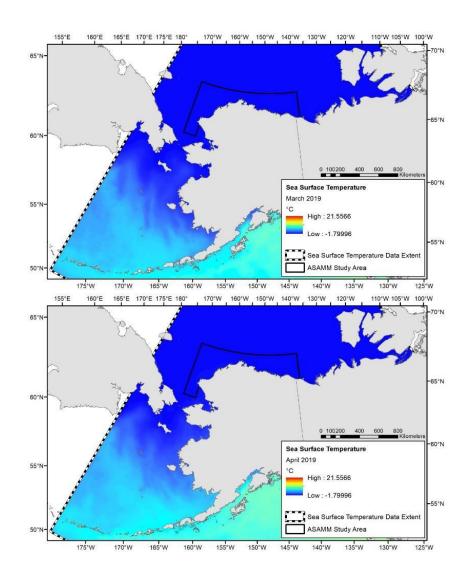


Figure B-32. -- Sea surface temperature in the Pacific Arctic, March-April 2019.

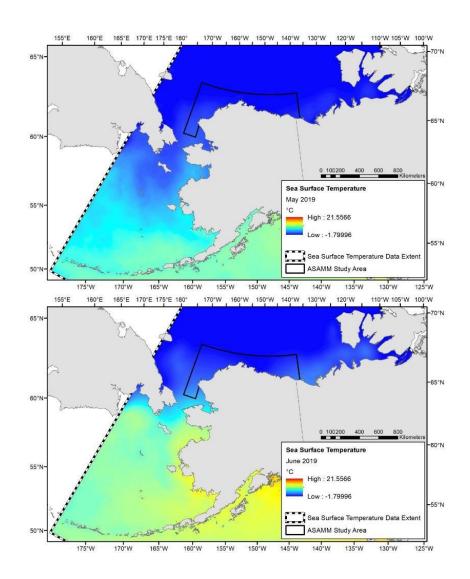


Figure B-33. -- Sea surface temperature in the Pacific Arctic, May-June 2019.

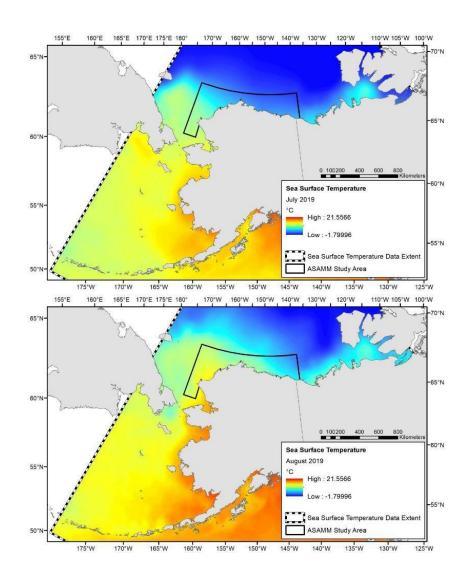


Figure B-34. -- Sea surface temperature in the Pacific Arctic, July-August 2019.

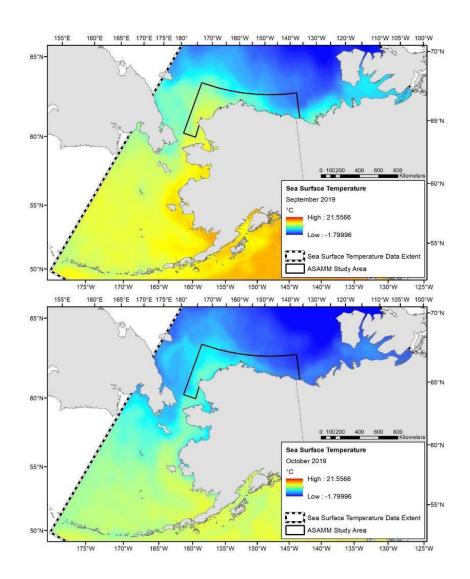


Figure B-35. -- Sea surface temperature in the Pacific Arctic, September-October 2019.

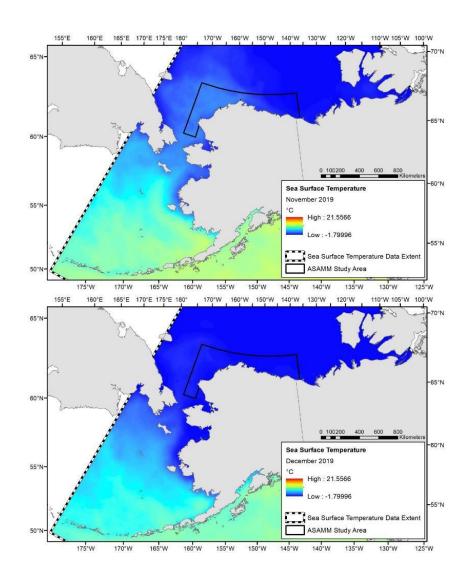


Figure B-36. -- Sea surface temperature in the Pacific Arctic, November-December 2019.

## APPENDIX C: CHLOROPHYLL A CONCENTRATION

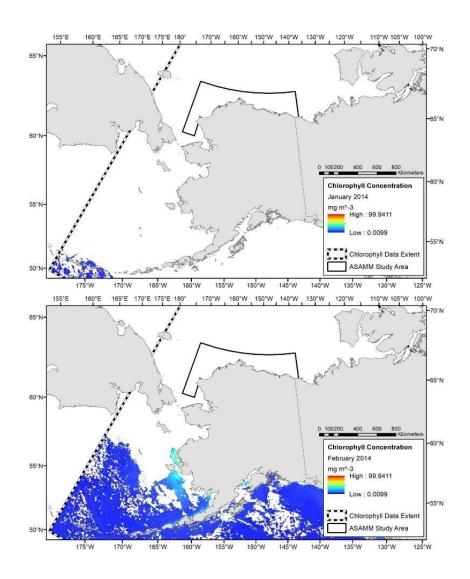


Figure C-1. -- Chlorophyll a concentration in the Pacific Arctic, January-February 2014.

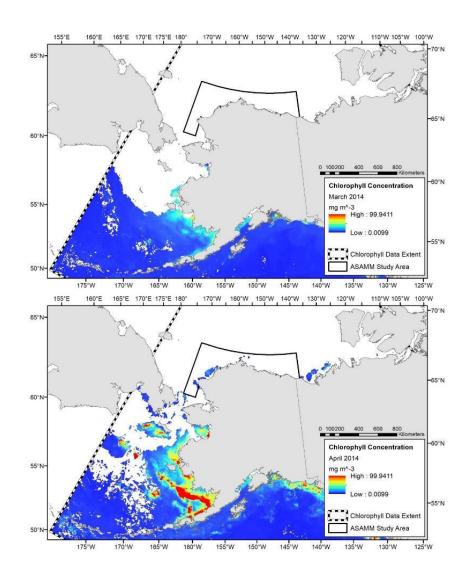


Figure C-2. -- Chlorophyll a concentration in the Pacific Arctic, March-April 2014.

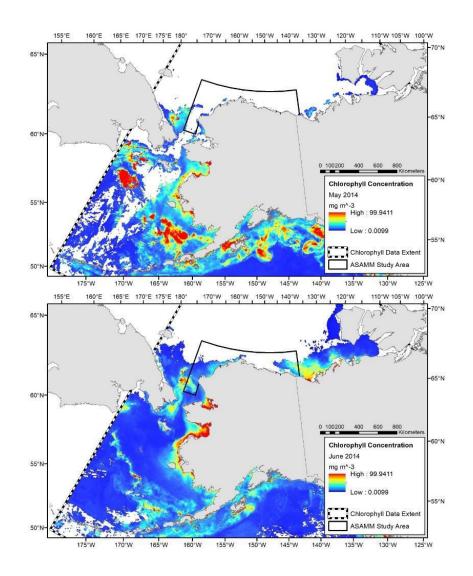


Figure C-3. -- Chlorophyll a concentration in the Pacific Arctic, May-June 2014.

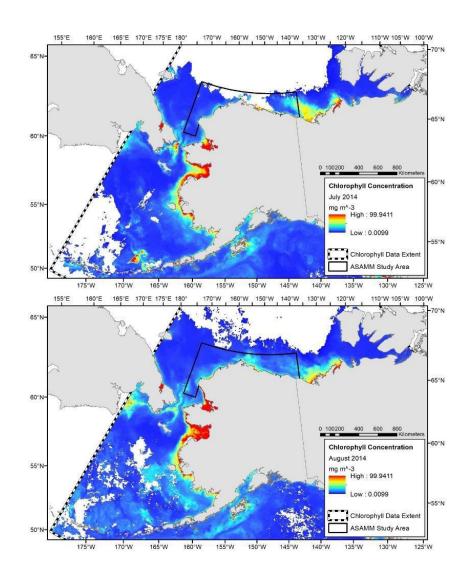


Figure C-4. -- Chlorophyll a concentration in the Pacific Arctic, June-August 2014.

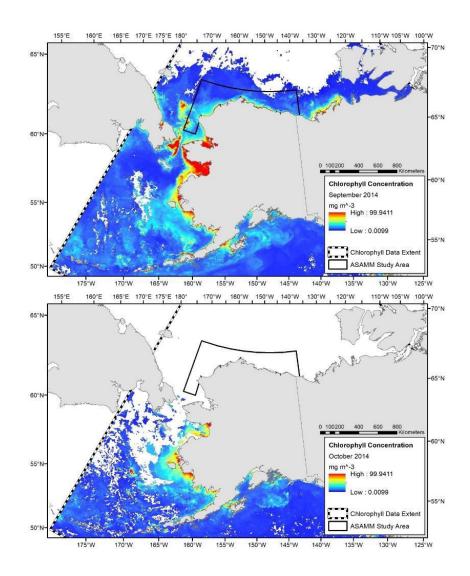


Figure C-5. -- Chlorophyll a concentration in the Pacific Arctic, September-October 2014.

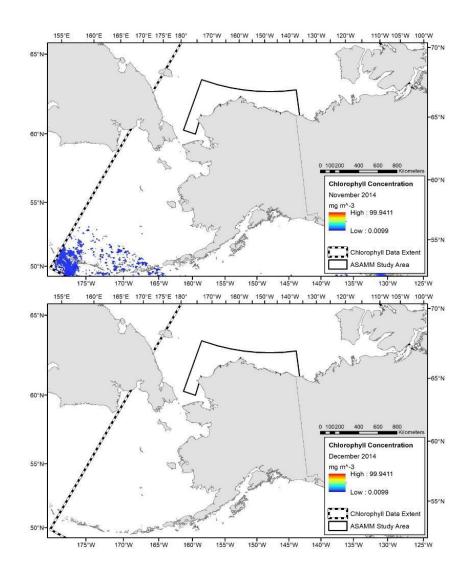


Figure C-6. -- Chlorophyll a concentration in the Pacific Arctic, November-December 2014.

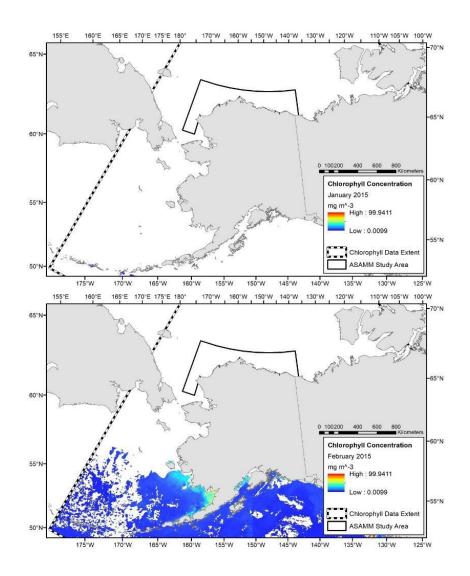


Figure C-7. -- Chlorophyll a concentration in the Pacific Arctic, January-February 2015.

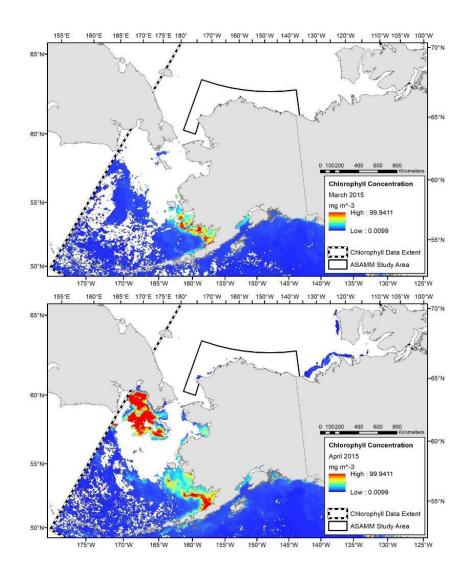


Figure C-8. -- Chlorophyll a concentration in the Pacific Arctic, March-April 2015.

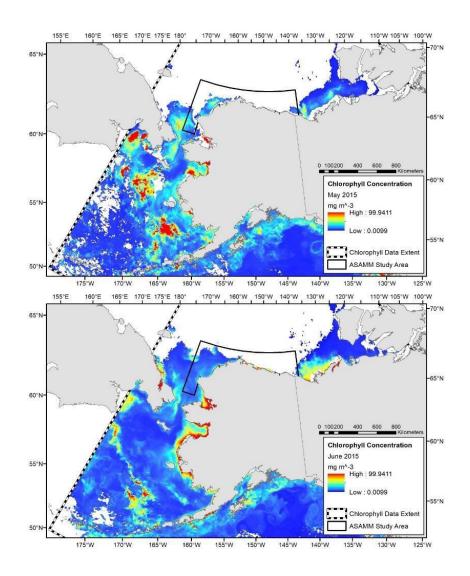


Figure C-9. -- Chlorophyll a concentration in the Pacific Arctic, May-June 2015.

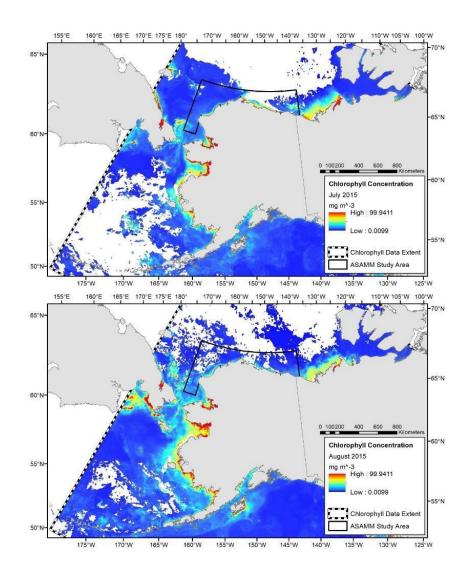


Figure C-10. -- Chlorophyll a concentration in the Pacific Arctic, July-August 2015.

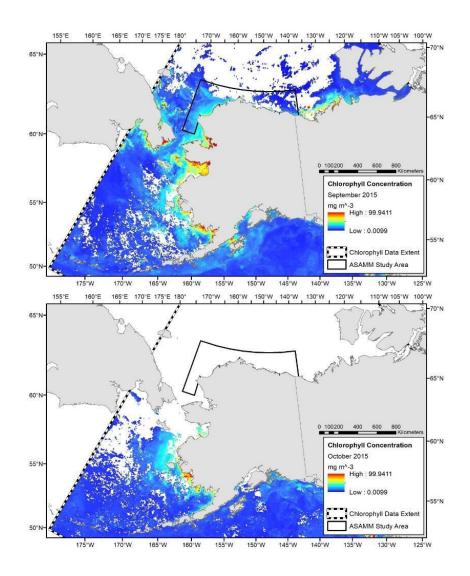


Figure C-11. -- Chlorophyll a concentration in the Pacific Arctic, September-October 2015.

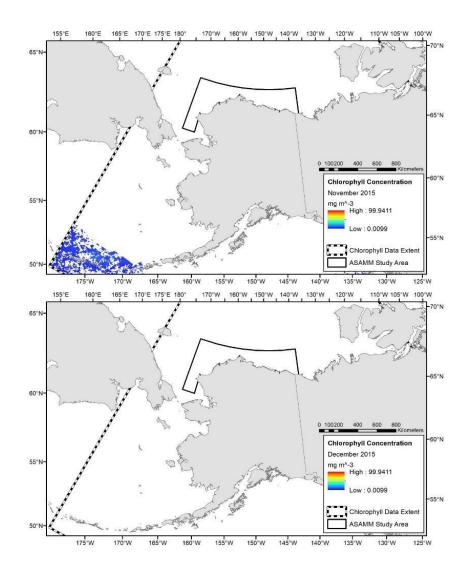


Figure C-12. -- Chlorophyll a concentration in the Pacific Arctic, November-December 2015.

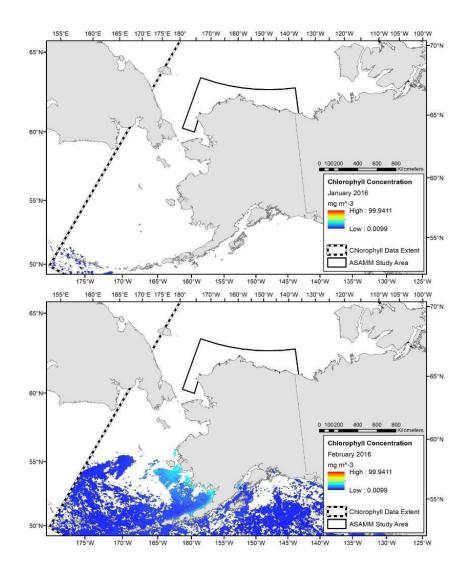


Figure C-13. -- Chlorophyll a concentration in the Pacific Arctic, January-February 2016.

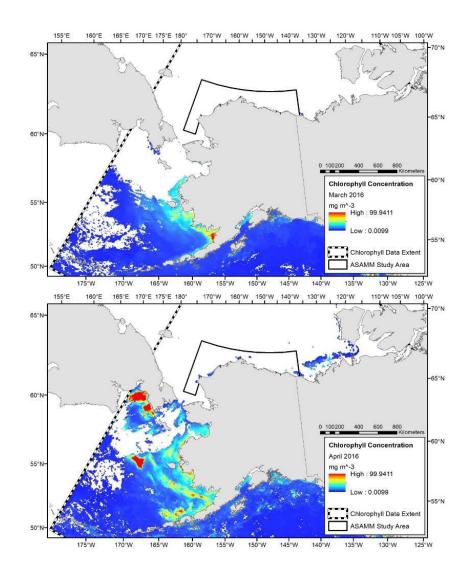


Figure C-14. -- Chlorophyll a concentration in the Pacific Arctic, March-April 2016.

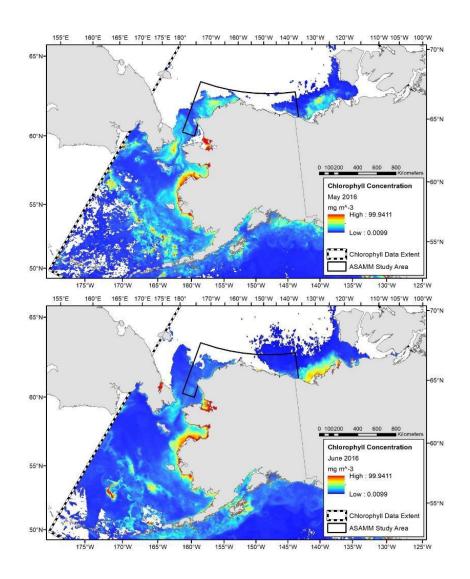


Figure C-15. -- Chlorophyll a concentration in the Pacific Arctic, May-June 2016.

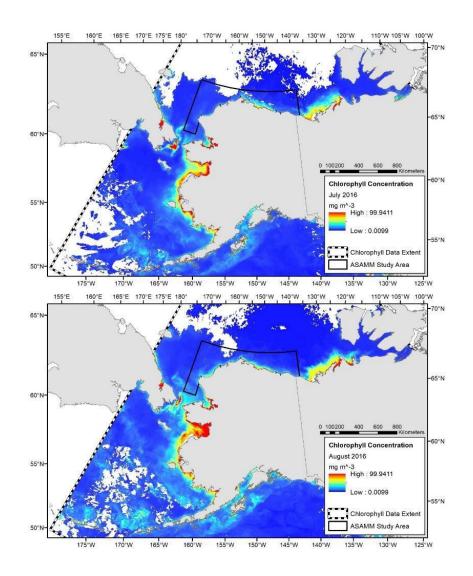


Figure C-16. -- Chlorophyll a concentration in the Pacific Arctic, July-August 2016.

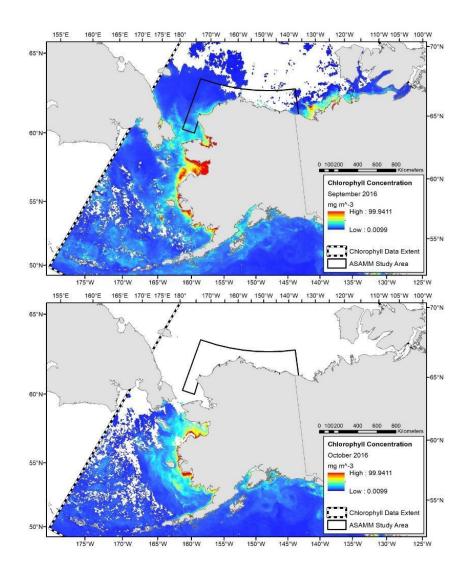


Figure C-17. -- Chlorophyll a concentration in the Pacific Arctic, September-October 2016.

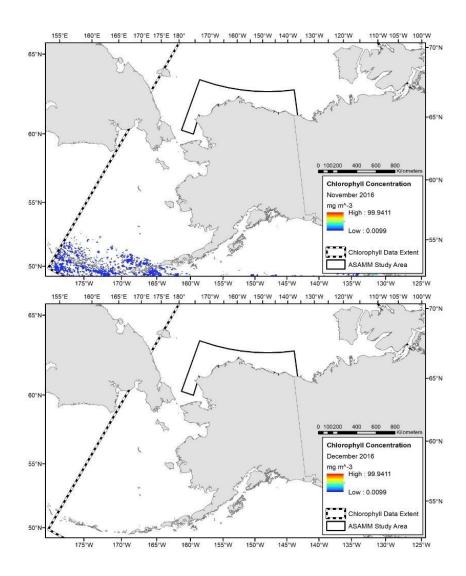


Figure C-18. -- Chlorophyll a concentration in the Pacific Arctic, November-December 2016.

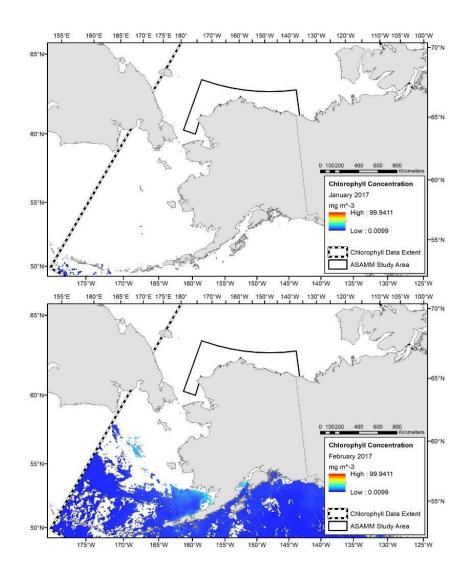


Figure C-19. -- Chlorophyll a concentration in the Pacific Arctic, January-February 2017.

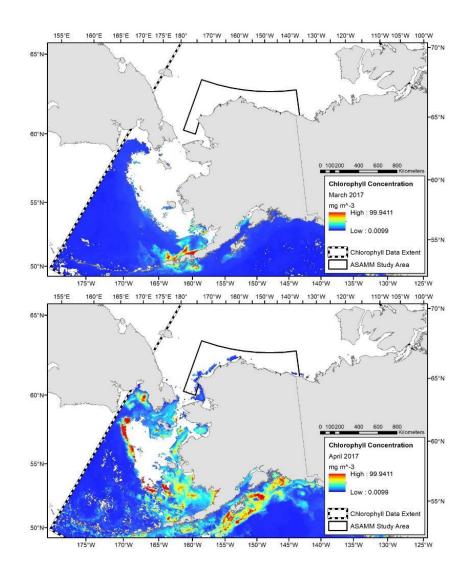


Figure C-20. -- Chlorophyll a concentration in the Pacific Arctic, March-April 2017.

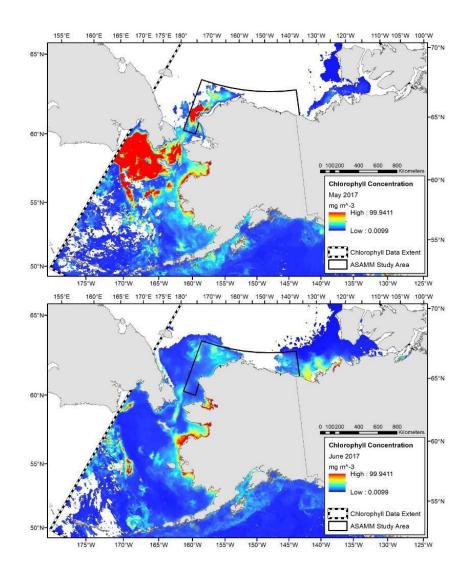


Figure C-21. -- Chlorophyll a concentration in the Pacific Arctic, May-June 2017.

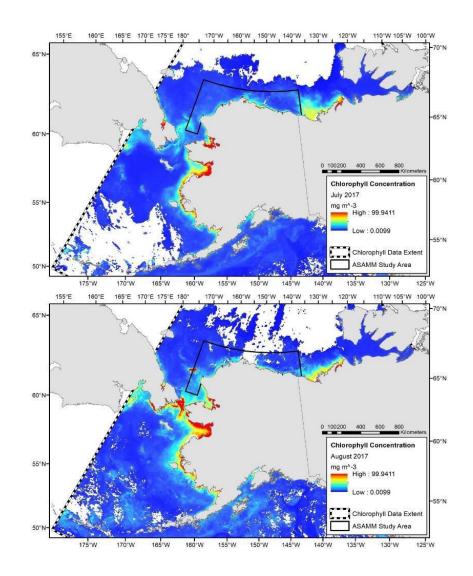


Figure C-22. -- Chlorophyll a concentration in the Pacific Arctic, July-August 2017.

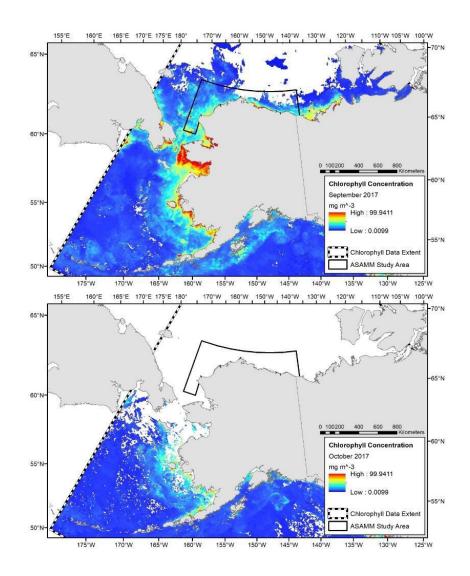


Figure C-23. -- Chlorophyll a concentration in the Pacific Arctic, September-October 2017.

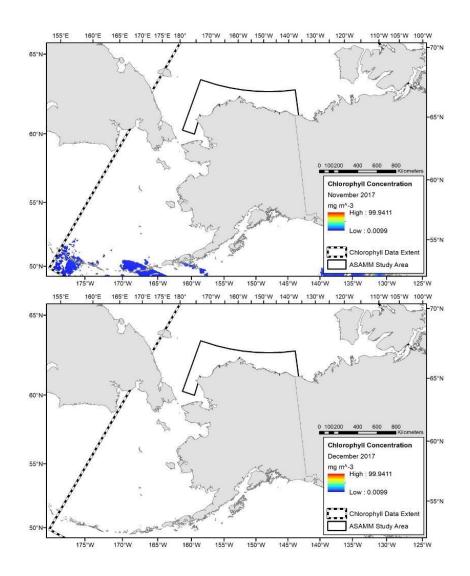


Figure C-24. -- Chlorophyll a concentration in the Pacific Arctic, November-December 2017.

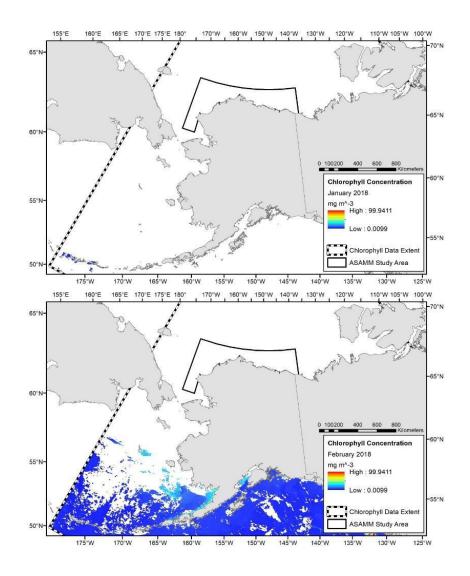


Figure C-25. -- Chlorophyll a concentration in the Pacific Arctic, January-February 2018.

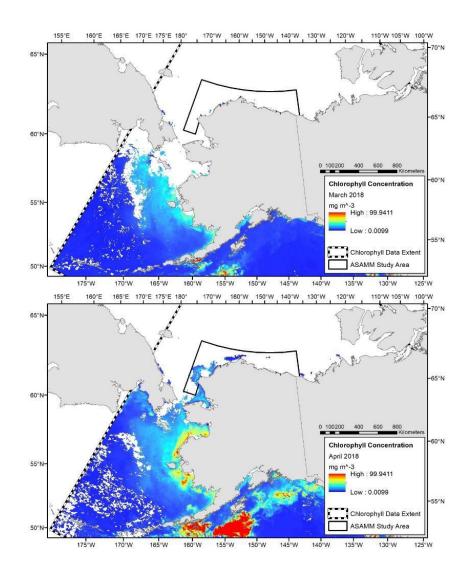


Figure C-26. -- Chlorophyll a concentration in the Pacific Arctic, March-April 2018.

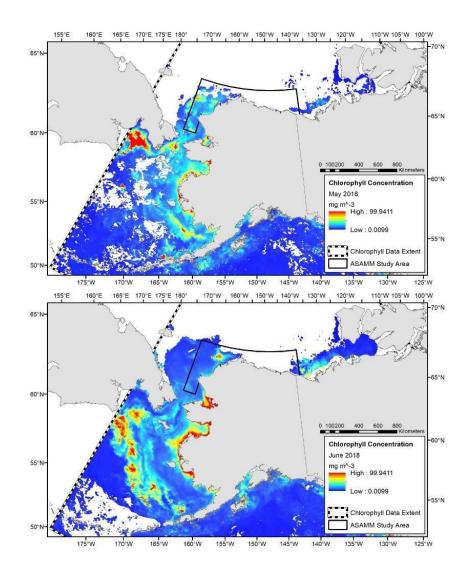


Figure C-27. -- Chlorophyll a concentration in the Pacific Arctic, May-June 2018.

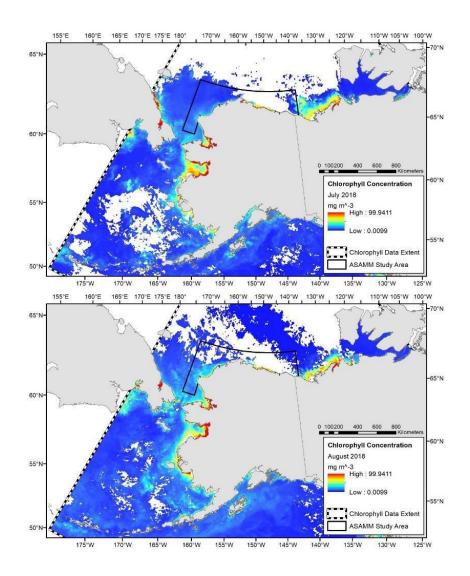


Figure C-28. -- Chlorophyll a concentration in the Pacific Arctic, July-August 2018.

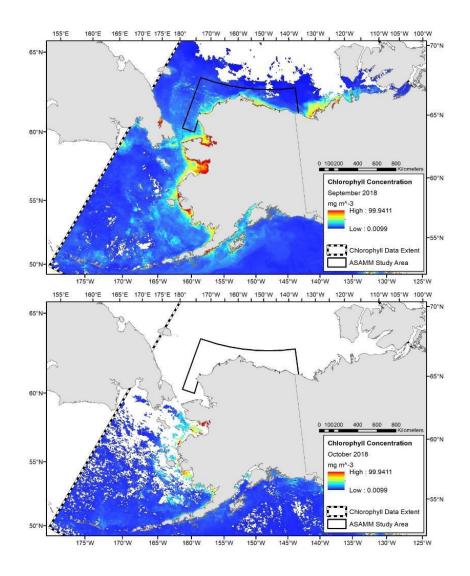


Figure C-29. -- Chlorophyll a concentration in the Pacific Arctic, September-October 2018.

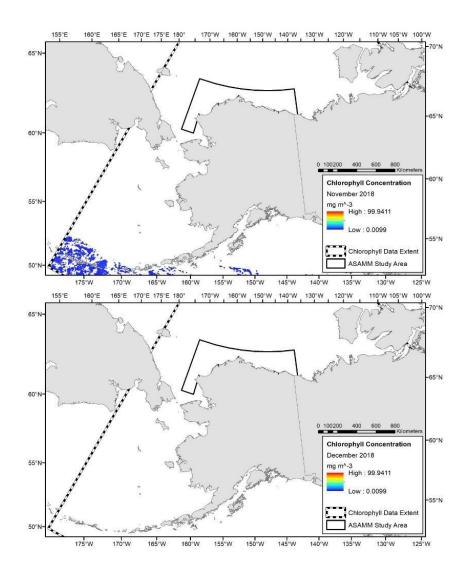


Figure C-30. -- Chlorophyll a concentration in the Pacific Arctic, November-December 2018.

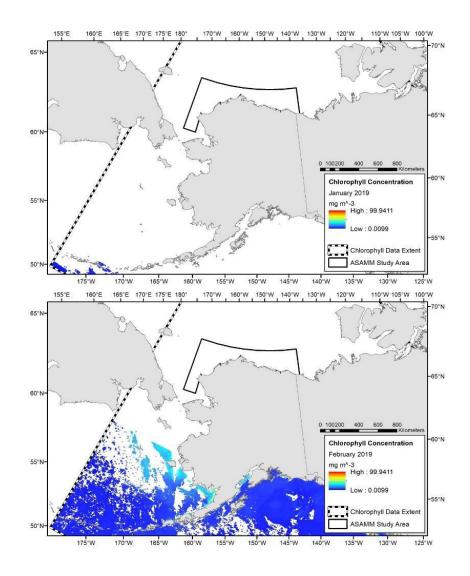


Figure C-31. -- Chlorophyll a concentration in the Pacific Arctic, January-February 2019.

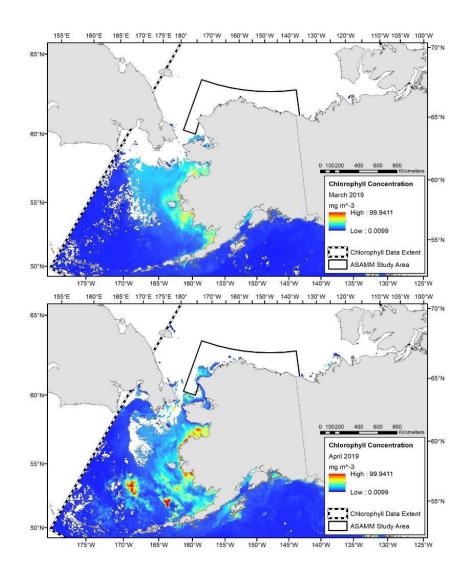


Figure C-32. -- Chlorophyll a concentration in the Pacific Arctic, March-April 2019.

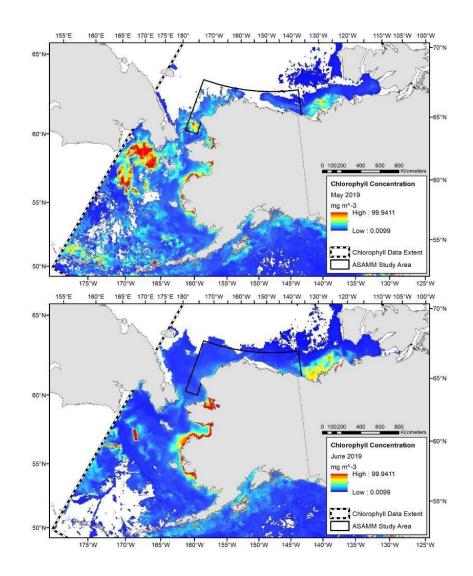


Figure C-33. -- Chlorophyll a concentration in the Pacific Arctic, May-June 2019.

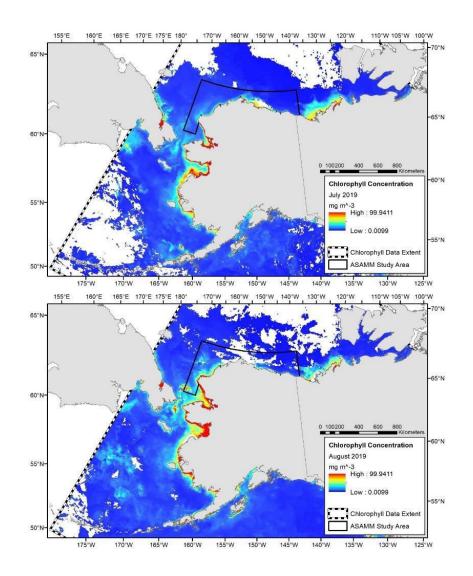


Figure C-34. -- Chlorophyll a concentration in the Pacific Arctic, July-August 2019.

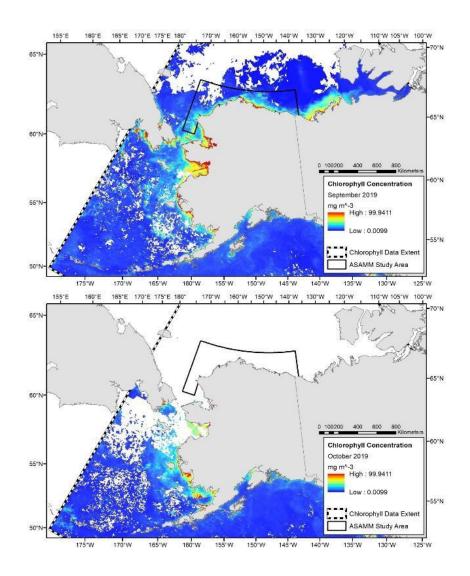


Figure C-35. -- Chlorophyll a concentration in the Pacific Arctic, September-October 2019.

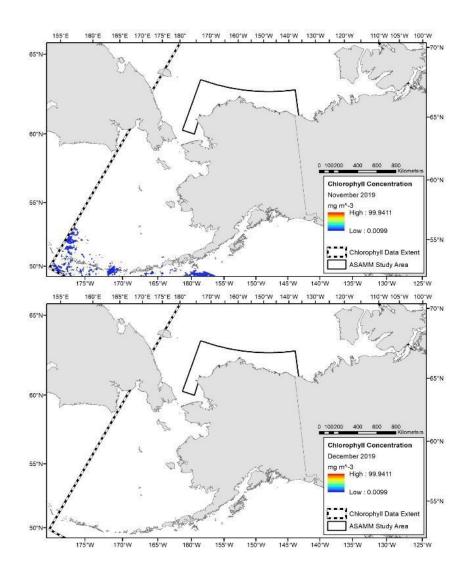


Figure C-36. -- Chlorophyll a concentration in the Pacific Arctic, November-December 2019.

## APPENDIX D: NET PRIMARY PRODUCTIVITY OF CARBON

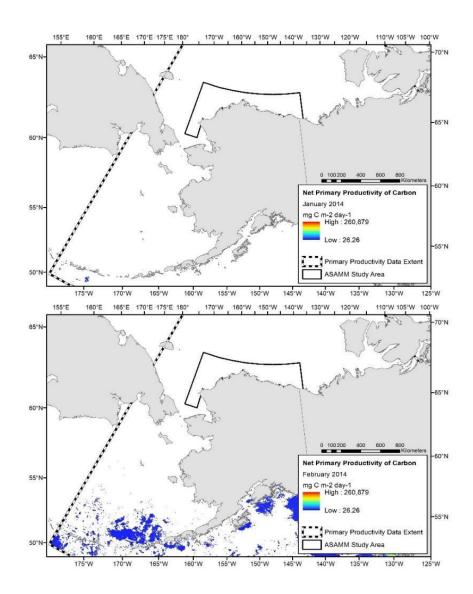


Figure D-1. -- Net primary production of carbon in the Pacific Arctic, January-February 2014.

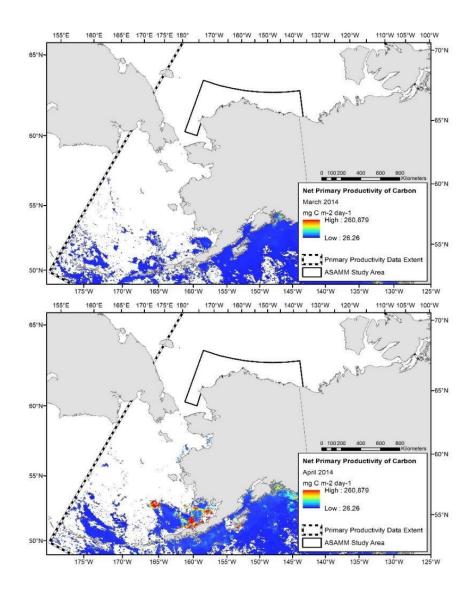


Figure D-2. -- Net primary production of carbon in the Pacific Arctic, March-April 2014.

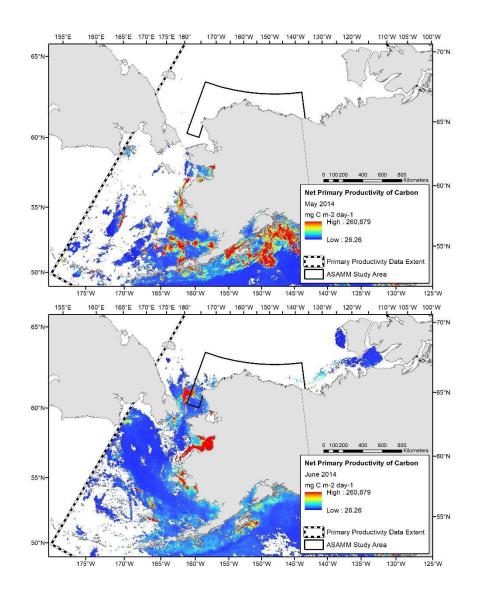


Figure D-3. -- Net primary production of carbon in the Pacific Arctic, May-June 2014.

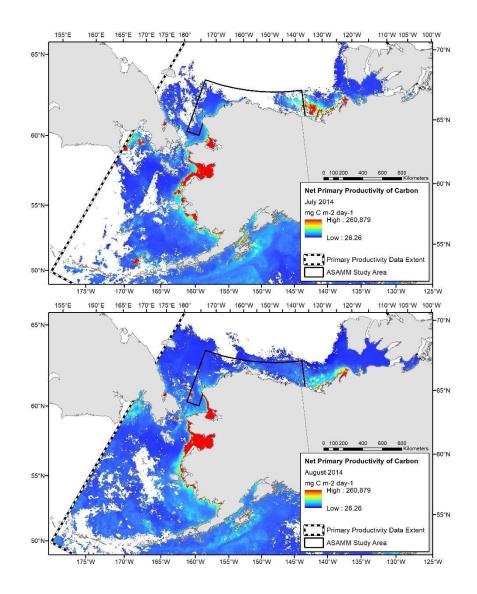


Figure D-4. -- Net primary production of carbon in the Pacific Arctic, July-August 2014.

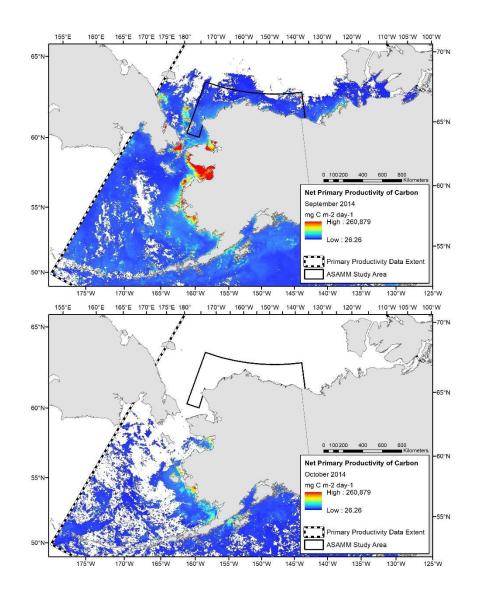


Figure D-5. -- Net primary production of carbon in the Pacific Arctic, September-October 2014.

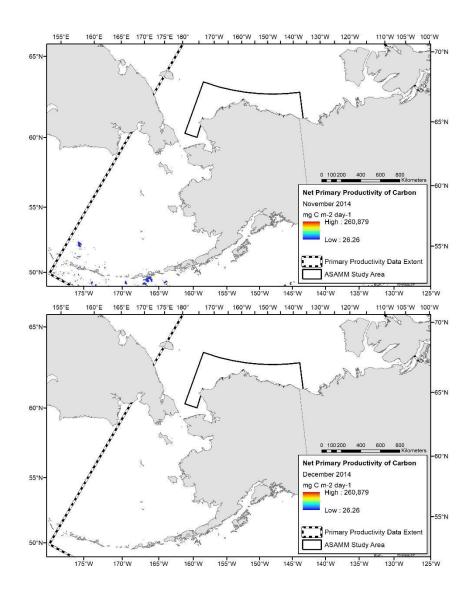


Figure D-6. -- Net primary production of carbon in the Pacific Arctic, November-December 2014.

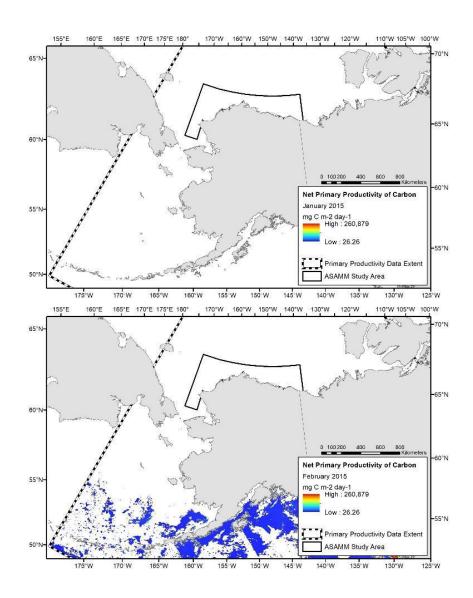


Figure D-7. -- Net primary production of carbon in the Pacific Arctic, January-February 2015.

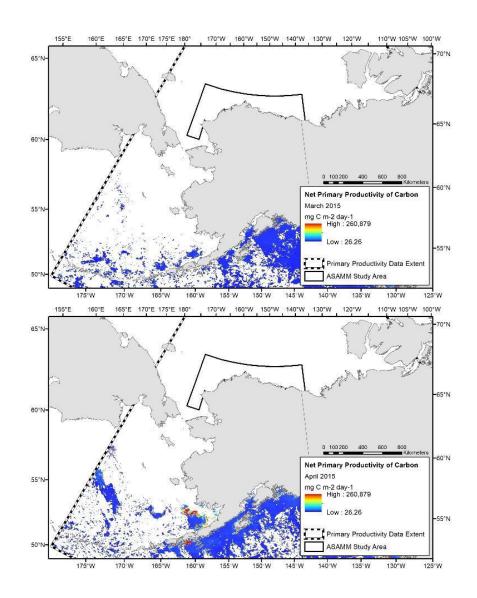


Figure D-8. -- Net primary production of carbon in the Pacific Arctic, March-April 2015.

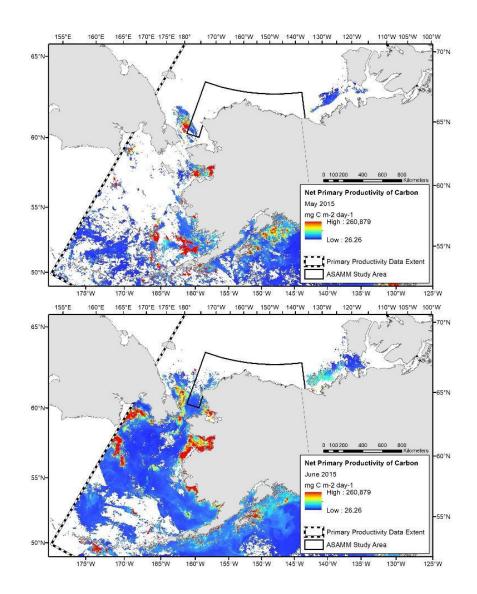


Figure D-9. -- Net primary production of carbon in the Pacific Arctic, May-June 2015.

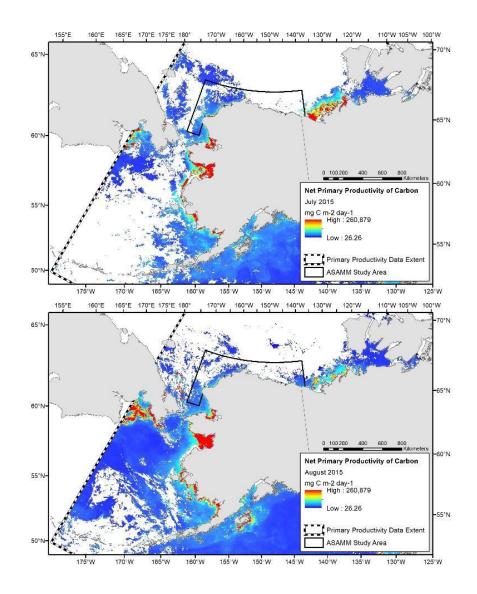


Figure D-10. -- Net primary production of carbon in the Pacific Arctic, July-August 2015.

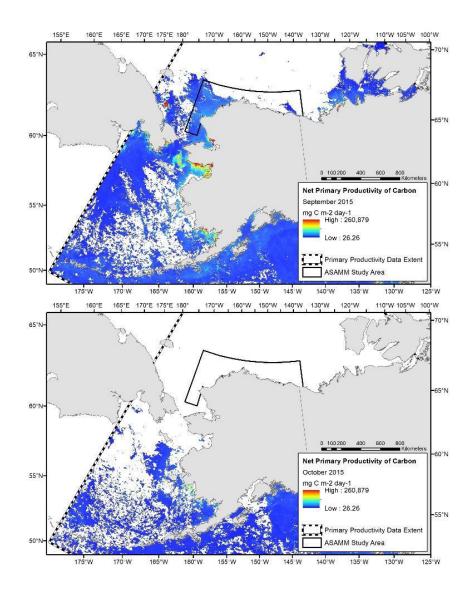


Figure D-11. -- Net primary production of carbon in the Pacific Arctic, September-October 2015.

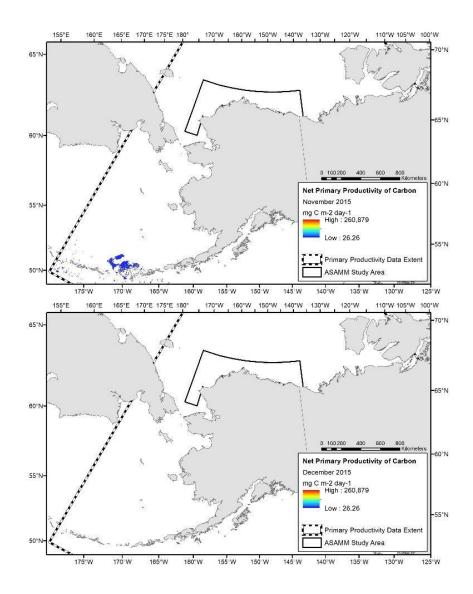


Figure D-12. -- Net primary production of carbon in the Pacific Arctic, November-December 2015.

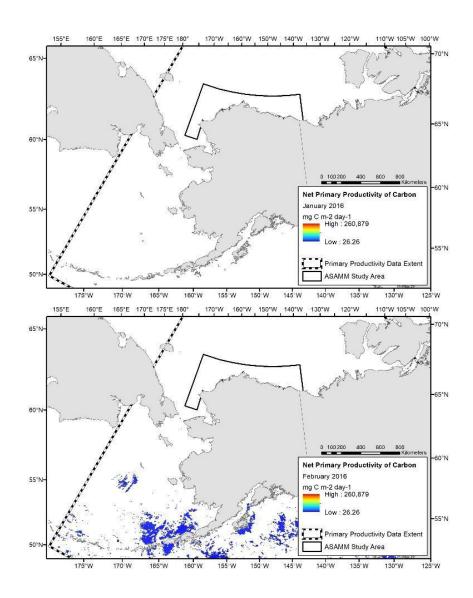


Figure D-13. -- Net primary production of carbon in the Pacific Arctic, January-February 2016.

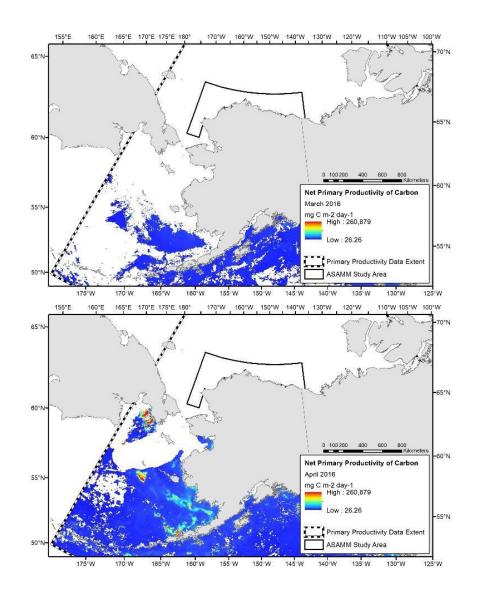


Figure D-14. -- Net primary production of carbon in the Pacific Arctic, March-April 2016.

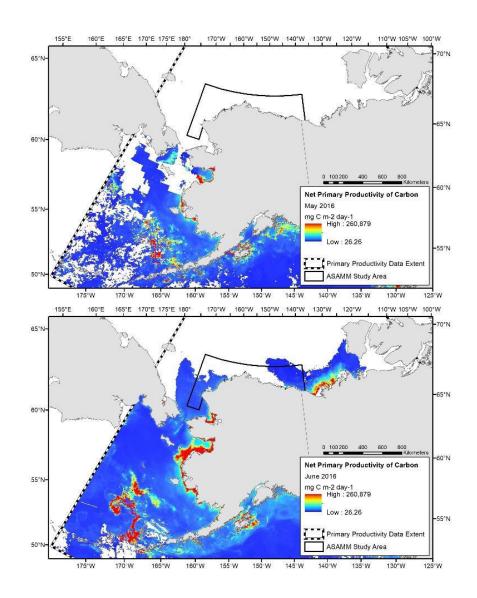


Figure D-15. -- Net primary production of carbon in the Pacific Arctic, May-June 2016.

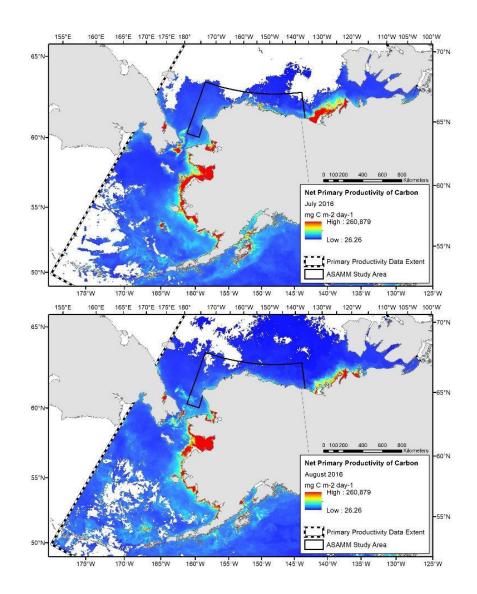


Figure D-16. -- Net primary production of carbon in the Pacific Arctic, July-August 2016.

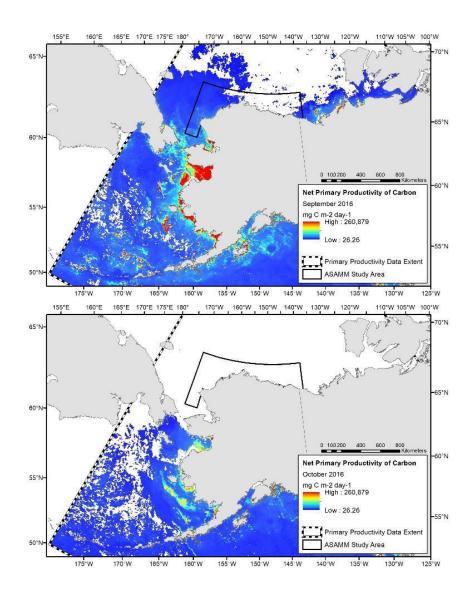


Figure D-17. -- Net primary production of carbon in the Pacific Arctic, September-October 2016.

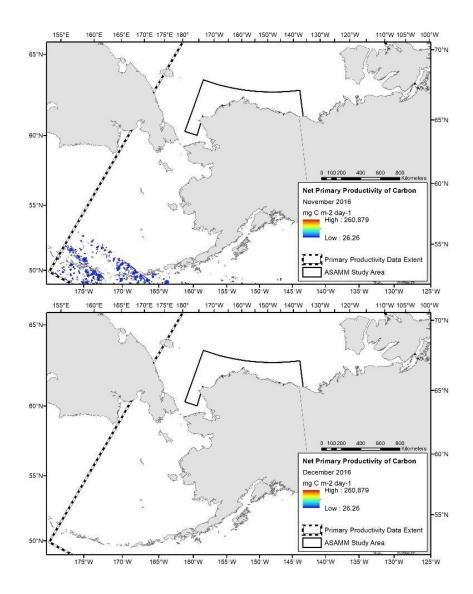


Figure D-18. -- Net primary production of carbon in the Pacific Arctic, November-December 2016.

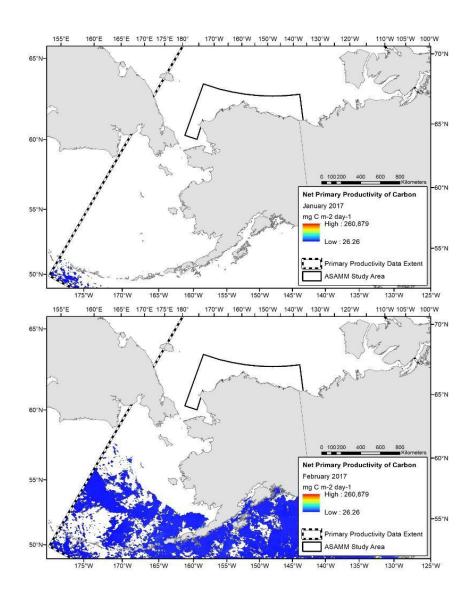


Figure D-19. -- Net primary production of carbon in the Pacific Arctic, January-February 2017.

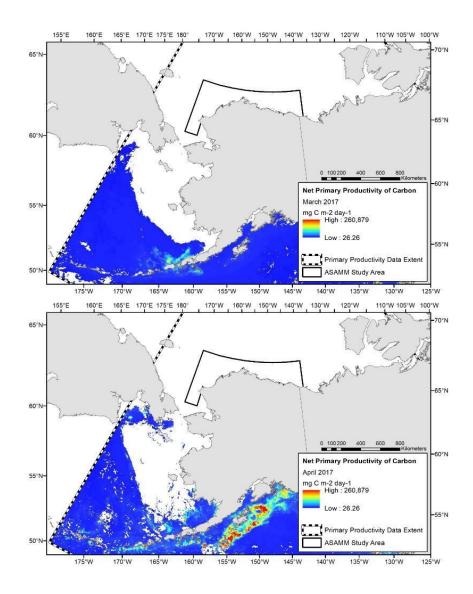


Figure D-20. -- Net primary production of carbon in the Pacific Arctic, March-April 2017.

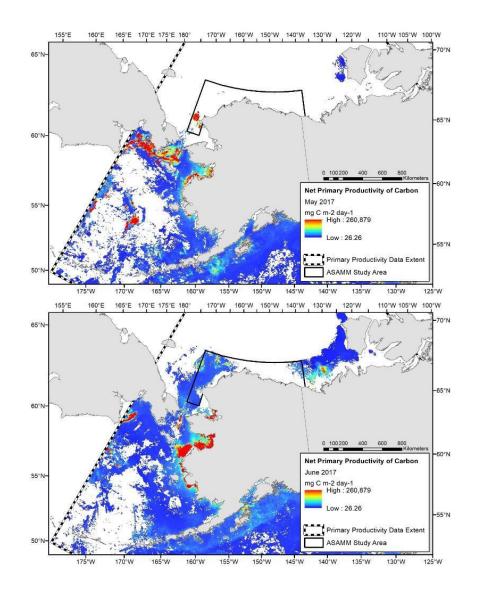


Figure D-21. -- Net primary production of carbon in the Pacific Arctic, May-June 2017.

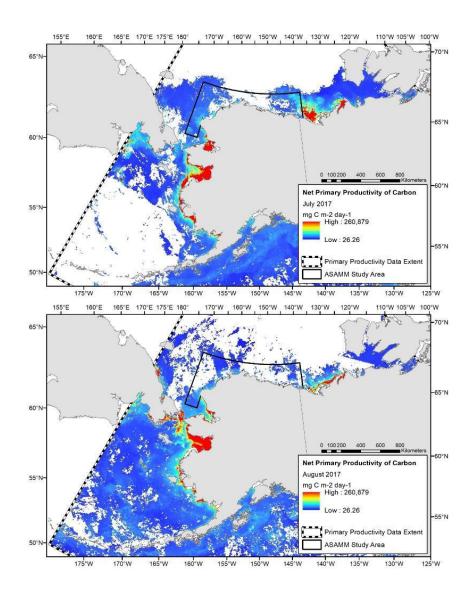


Figure D-22. -- Net primary production of carbon in the Pacific Arctic, July-August 2017.

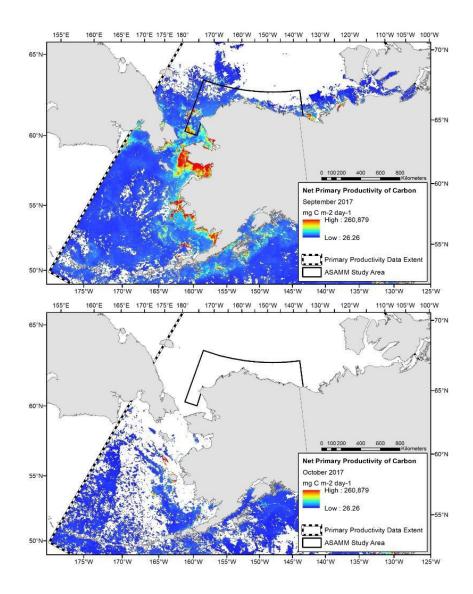


Figure D-23. -- Net primary production of carbon in the Pacific Arctic, September-October 2017.

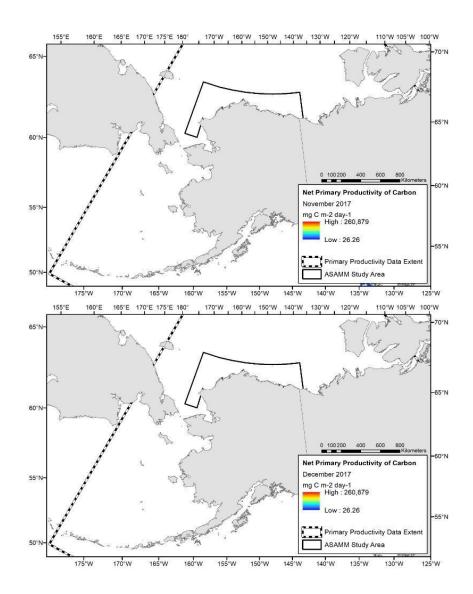


Figure D-24. -- Net primary production of carbon in the Pacific Arctic, November-December 2017.

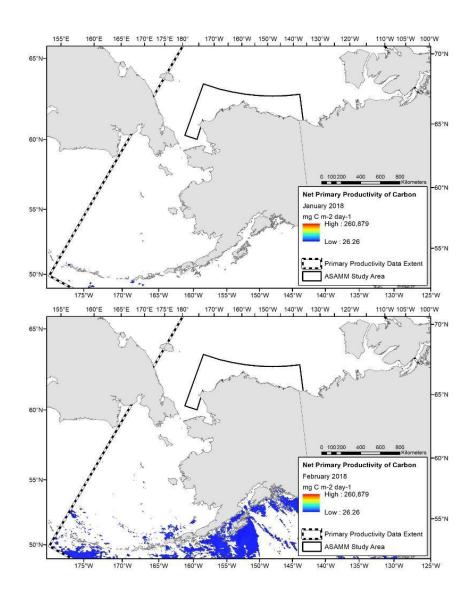


Figure D-25. -- Net primary production of carbon in the Pacific Arctic, January-February 2018.

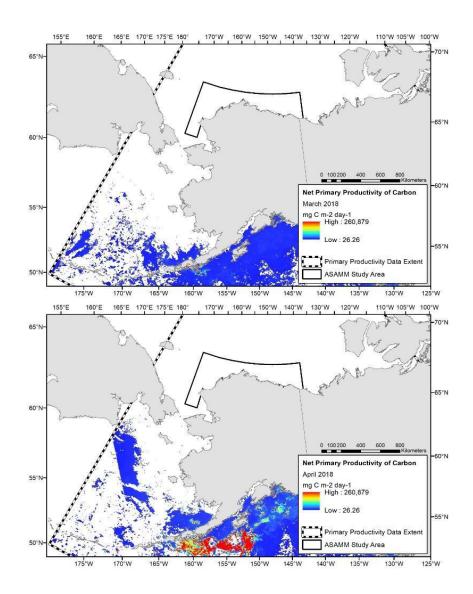


Figure D-26. -- Net primary production of carbon in the Pacific Arctic, March-April 2018.

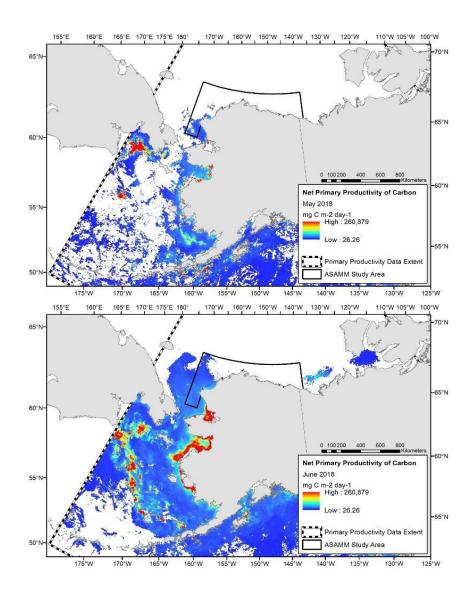


Figure D-27. -- Net primary production of carbon in the Pacific Arctic, May-June 2018.

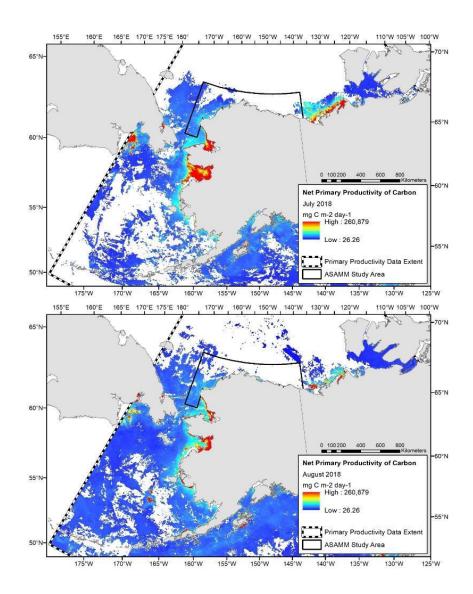


Figure D-28. -- Net primary production of carbon in the Pacific Arctic, July-August 2018.

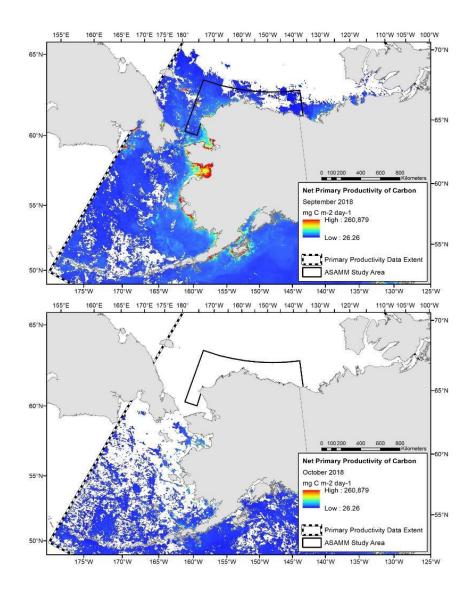


Figure D-29. -- Net primary production of carbon in the Pacific Arctic, September-October 2018.

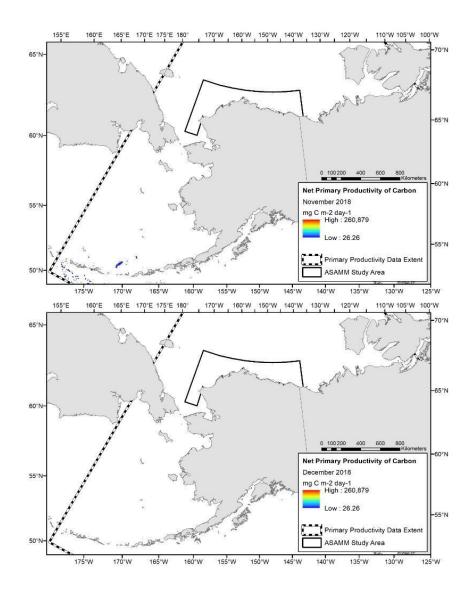


Figure D-30. -- Net primary production of carbon in the Pacific Arctic, November-December 2018.

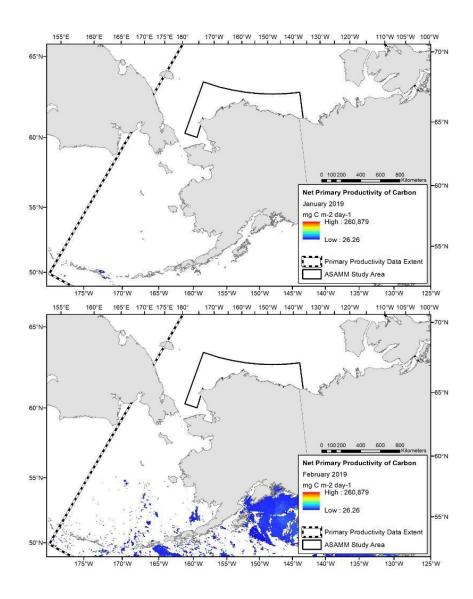


Figure D-31. -- Net primary production of carbon in the Pacific Arctic, January-February 2019.

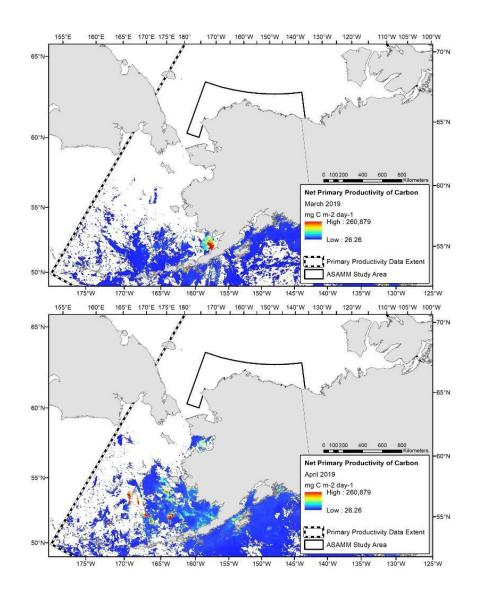


Figure D-32. -- Net primary production of carbon in the Pacific Arctic, March-April 2019.

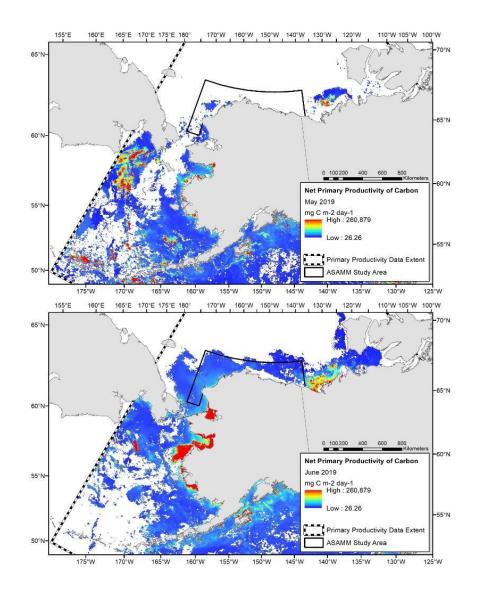


Figure D-33. -- Net primary production of carbon in the Pacific Arctic, May-June 2019.

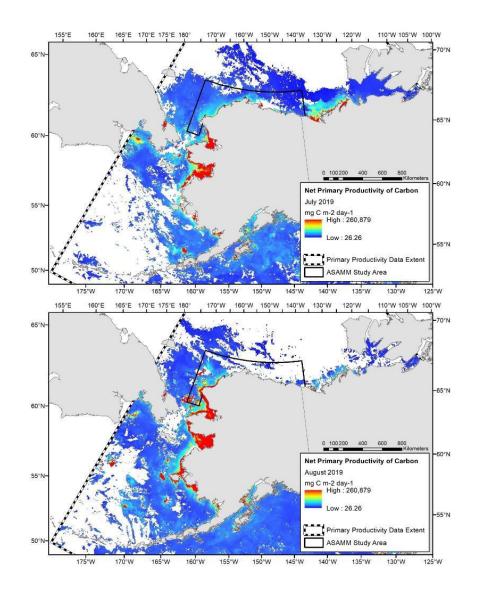


Figure D-34. -- Net primary production of carbon in the Pacific Arctic, July-August 2019.

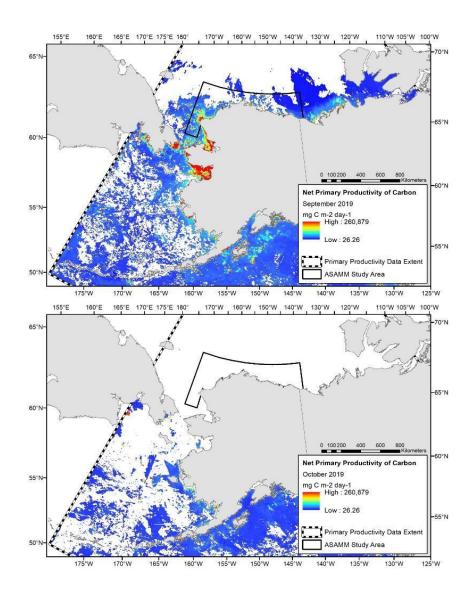


Figure D-35. -- Net primary production of carbon in the Pacific Arctic, September-October 2019.

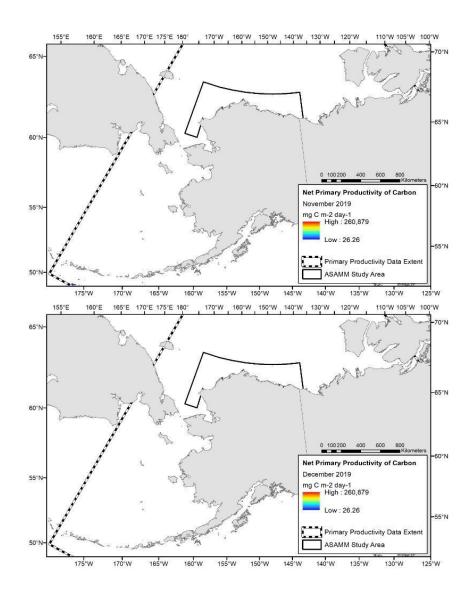


Figure D-36. -- Net primary production of carbon in the Pacific Arctic, November-December 2019.

## APPENDIX E: BOWHEAD WHALE SIGHTINGS AND SIGHTING RATES

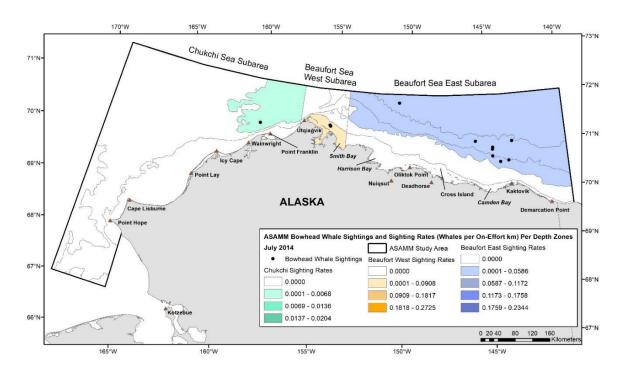


Figure E-1. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2014.

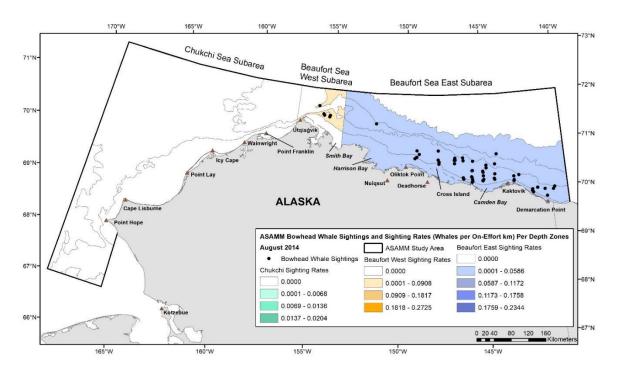


Figure E-2. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2014.

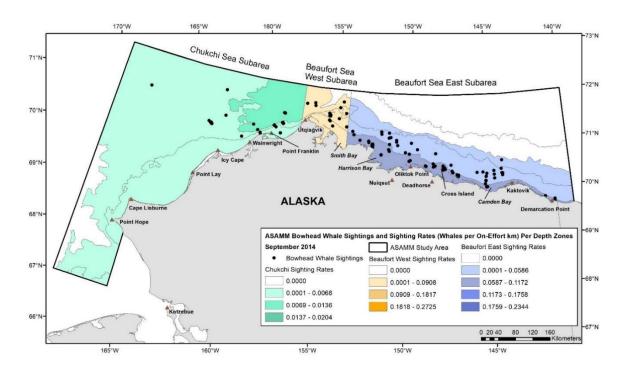


Figure E-3. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2014.

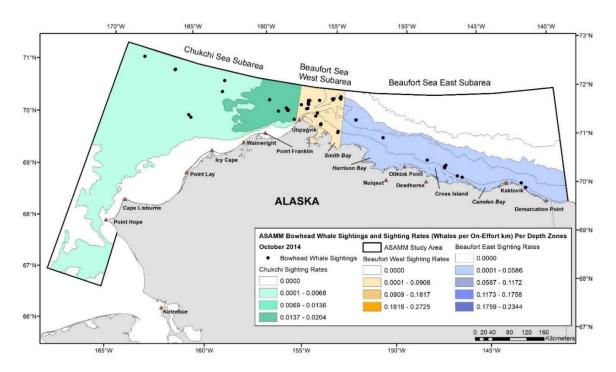


Figure E-4. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2014.

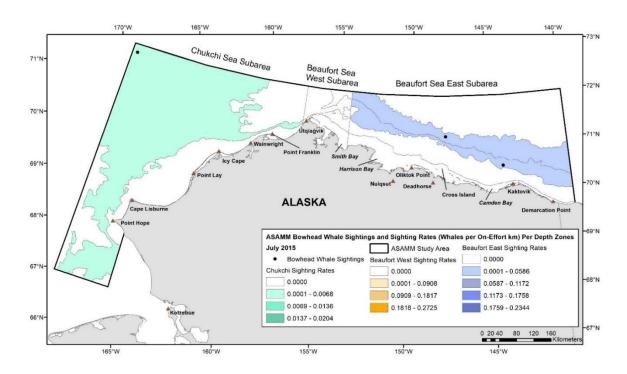


Figure E-5. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2015.

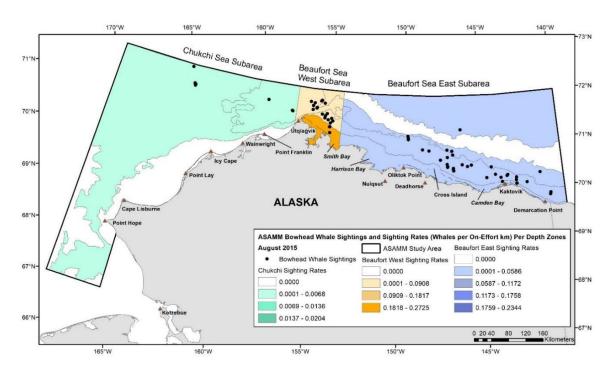


Figure E-6. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2015.

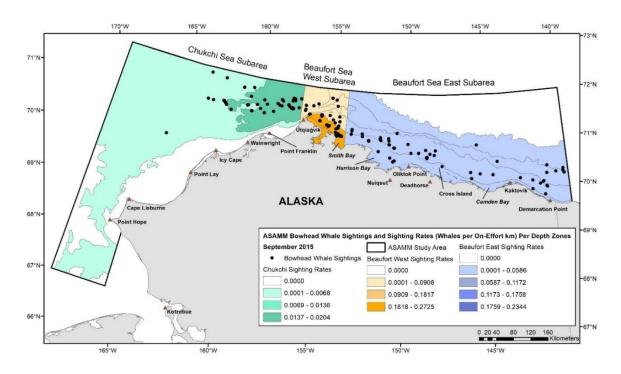


Figure E-7. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2015.

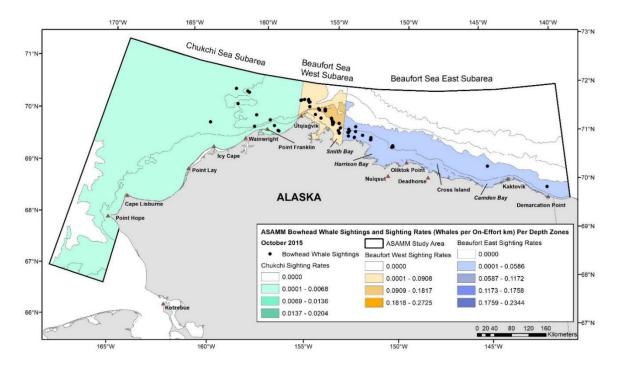


Figure E-8. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2015.

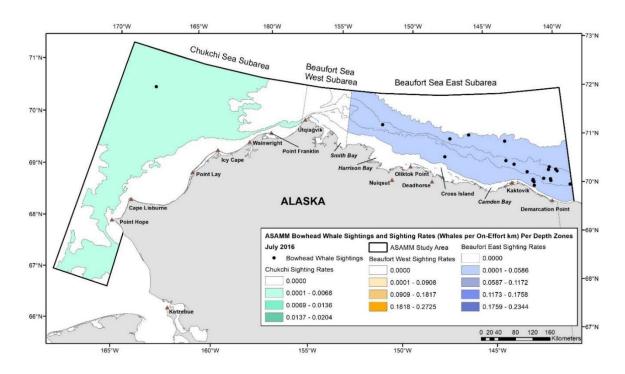


Figure E-9. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2016.

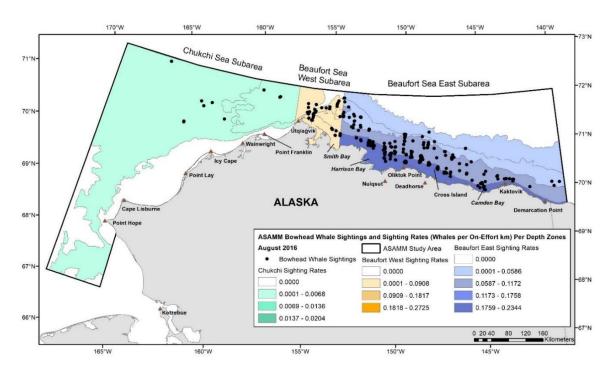


Figure E-10. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2016.

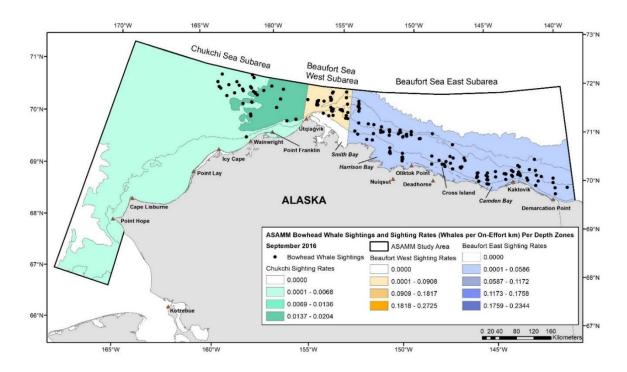


Figure E-11. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2016.

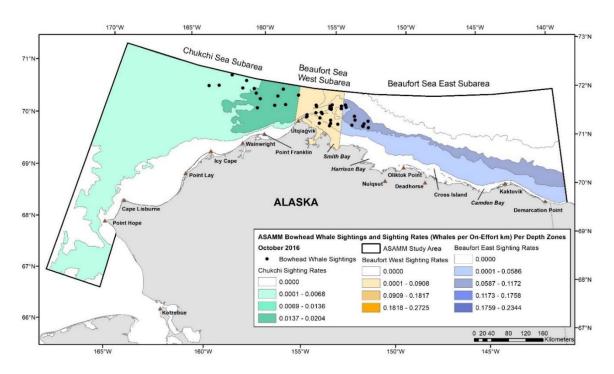


Figure E-12. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2016.

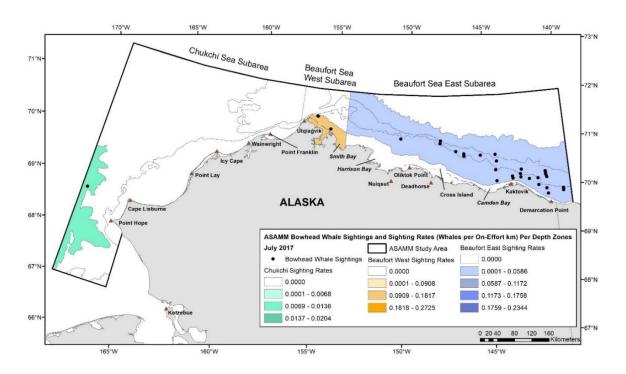


Figure E-13. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2017.

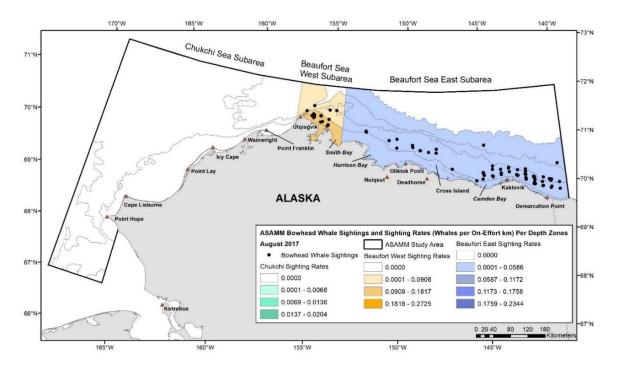


Figure E-14. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2017.

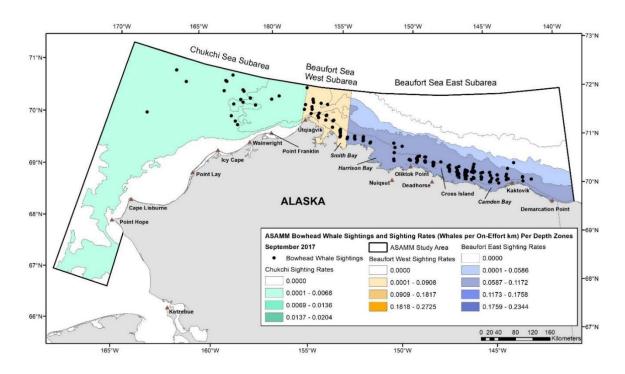


Figure E-15. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2017.

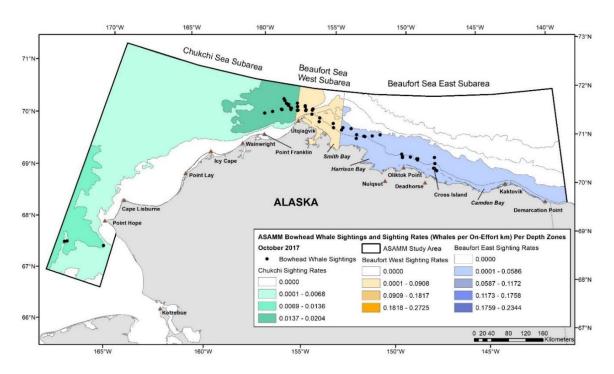


Figure E-16. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2017.

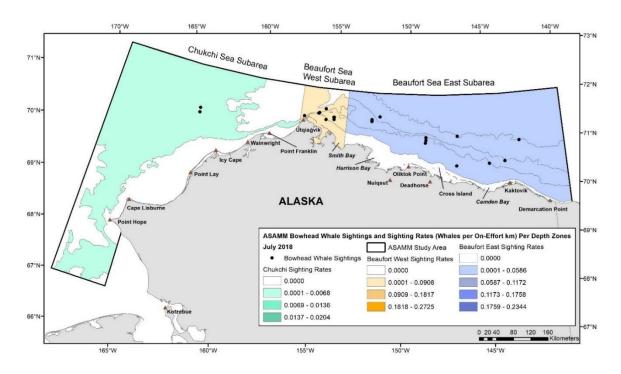


Figure E-17. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2018.

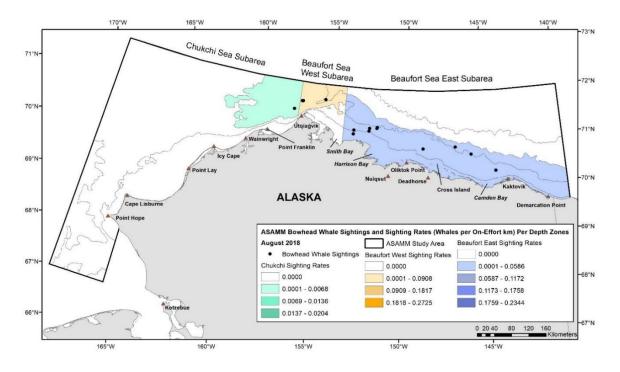


Figure E-18. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2018.

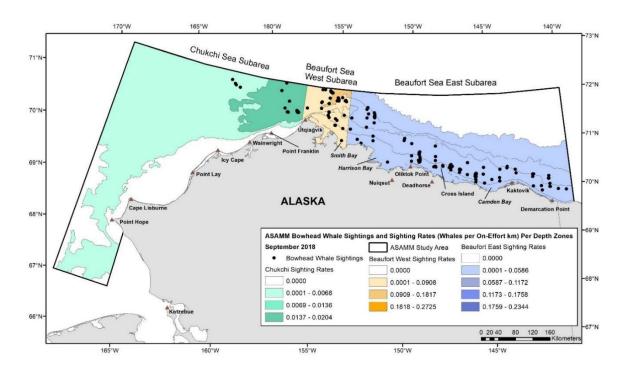


Figure E-19. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2018.

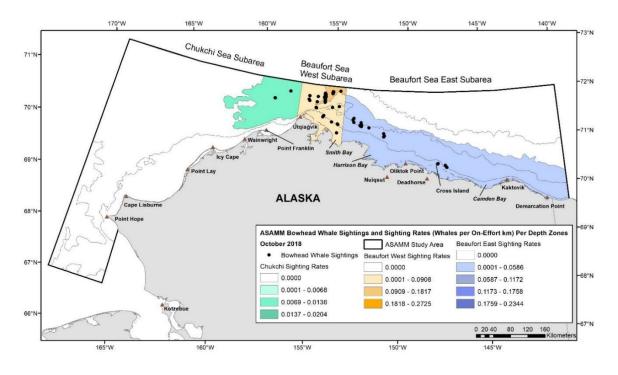


Figure E-20. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2018.

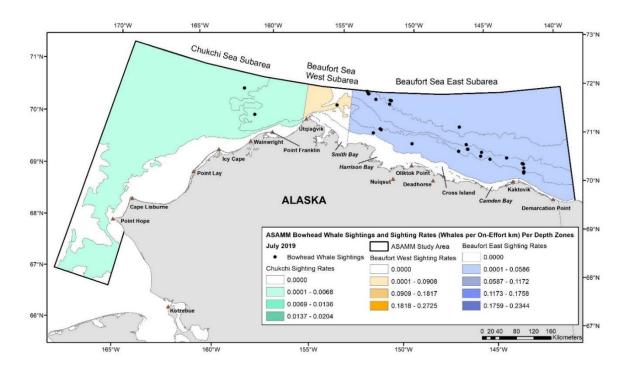


Figure E-21. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2019.

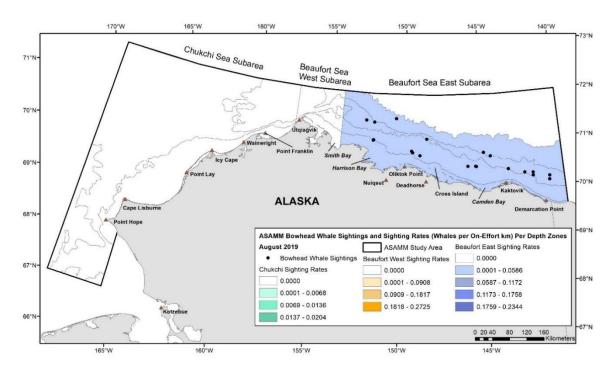


Figure E-22. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2019.

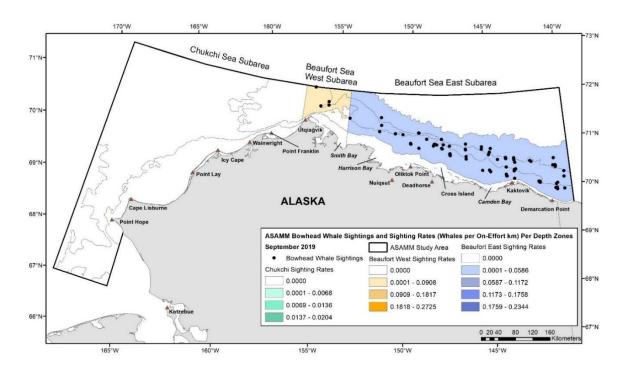


Figure E-23. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2019.

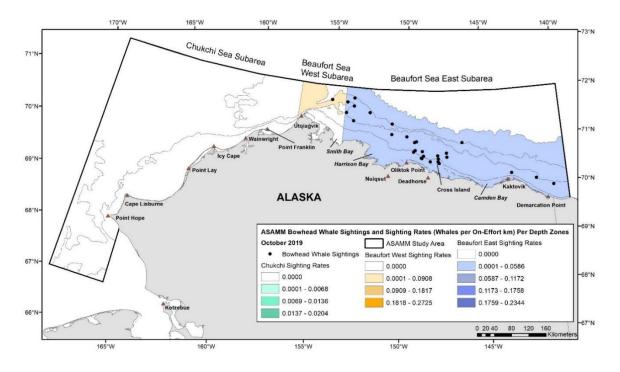


Figure E-24. -- ASAMM bowhead whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2019.

## APPENDIX F: GRAY WHALE SIGHTINGS AND SIGHTING RATES

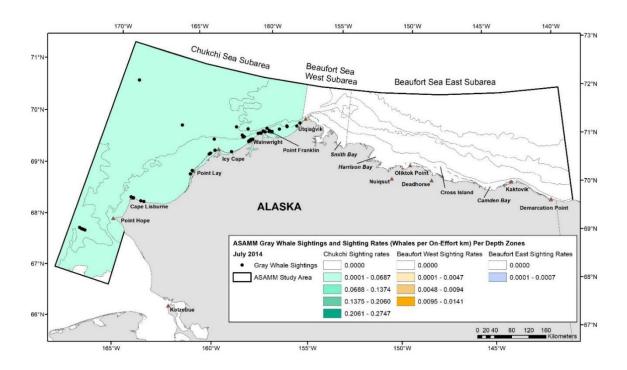


Figure F-1. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2014.

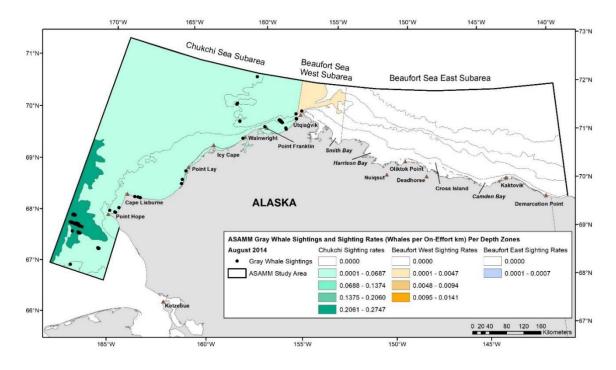


Figure F-2. -- ASAMM gray whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2014.

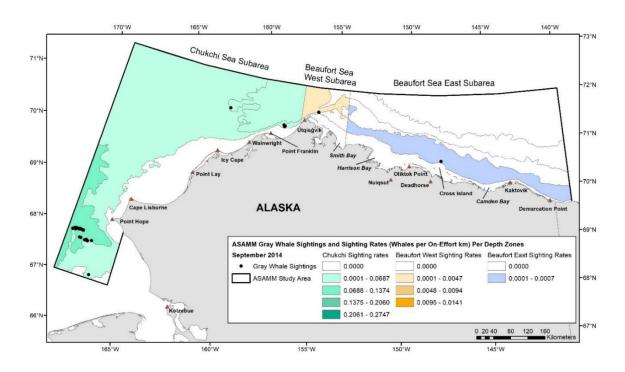


Figure F-3. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2014.

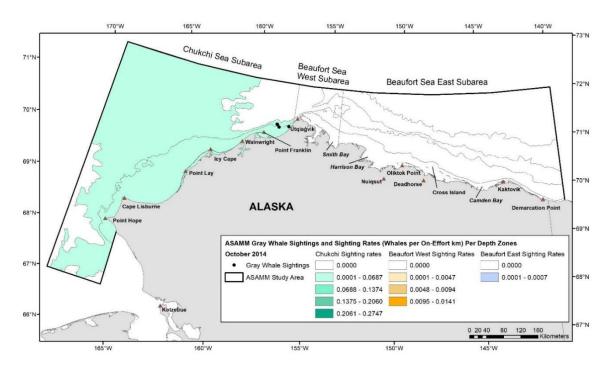


Figure F-4. -- ASAMM gray whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2014.

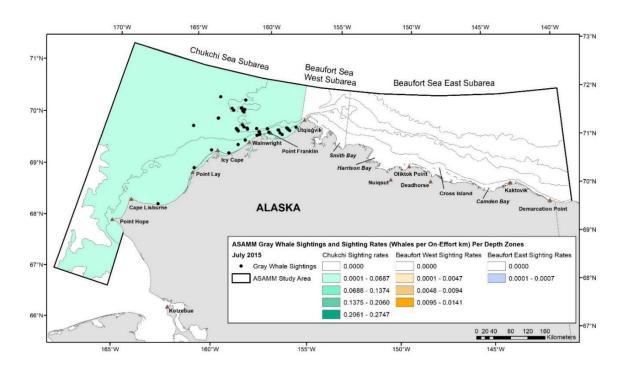


Figure F-5. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2015.

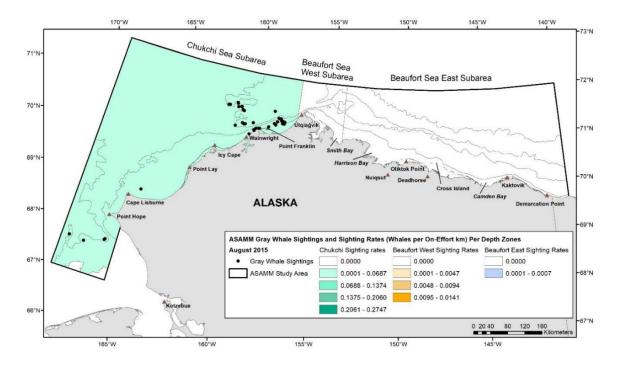


Figure F-6. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2015.

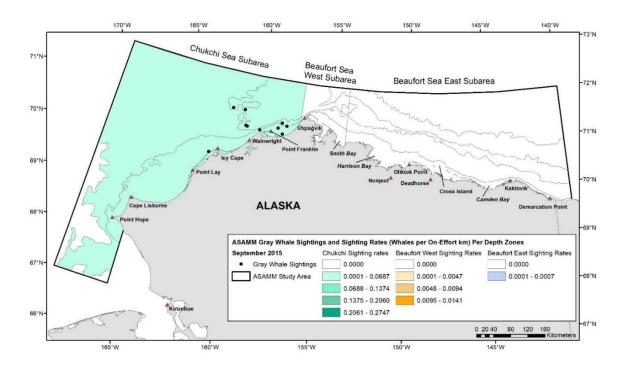


Figure F-7. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2015.

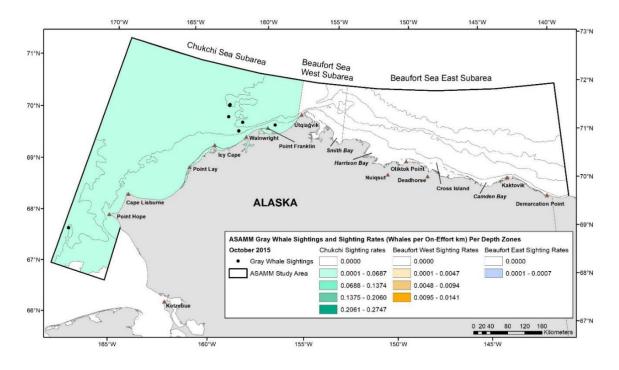


Figure F-8. -- ASAMM gray whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2015.

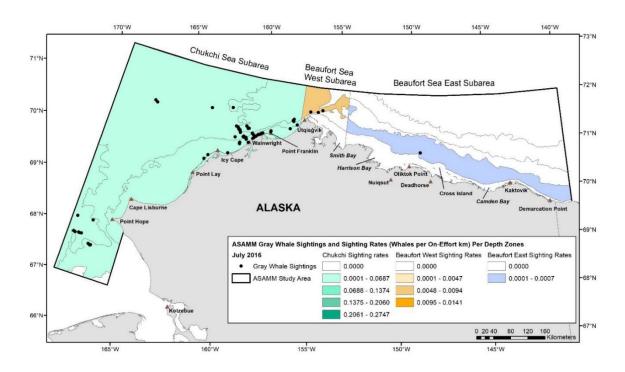


Figure F-9. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2016.

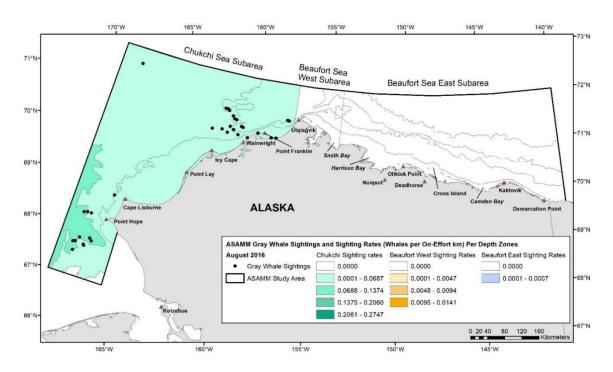


Figure F-10. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2016.

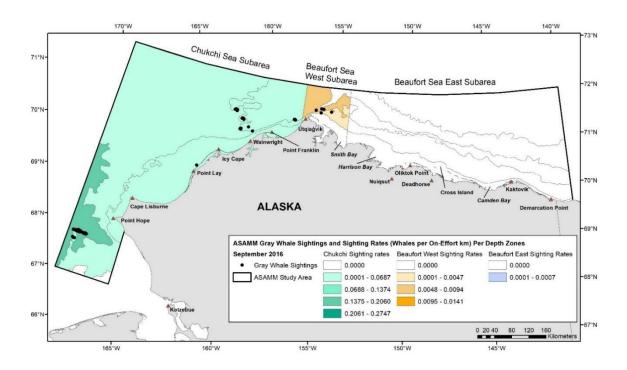


Figure F-11. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2016.

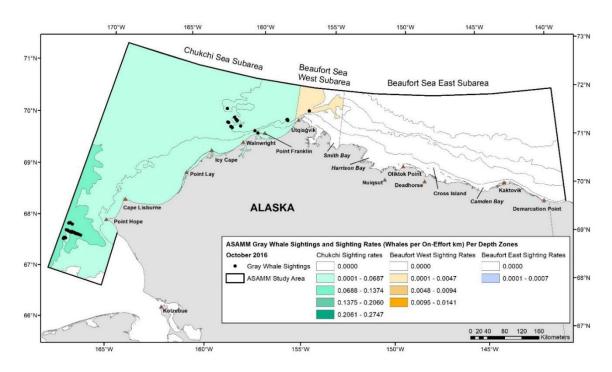


Figure F-12. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2016.

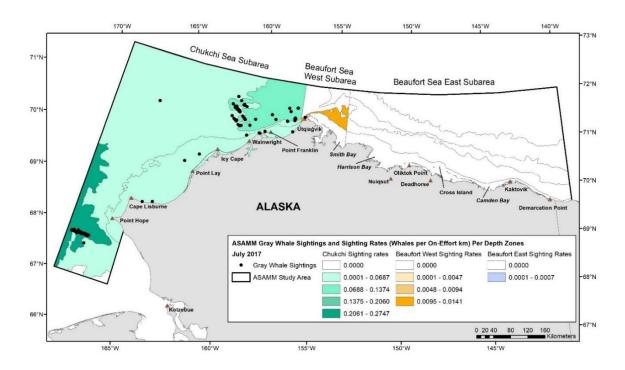


Figure F-13. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2017.

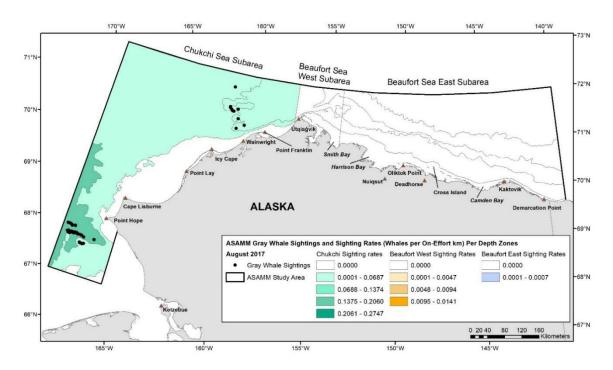


Figure F-14. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2017.

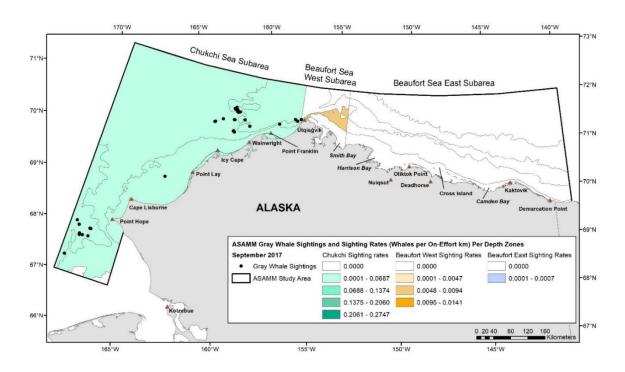


Figure F-15. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2017.

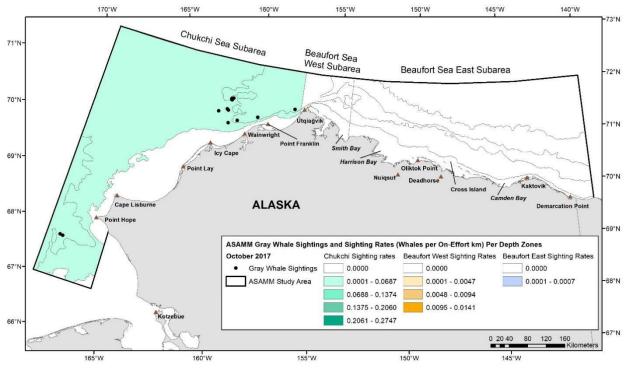


Figure F-16. -- ASAMM gray whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2017.

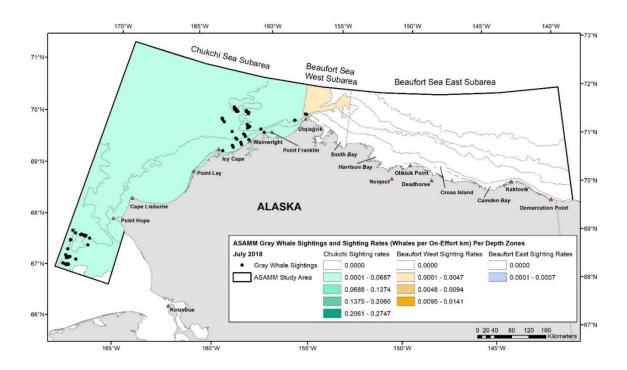


Figure F-17. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2018.

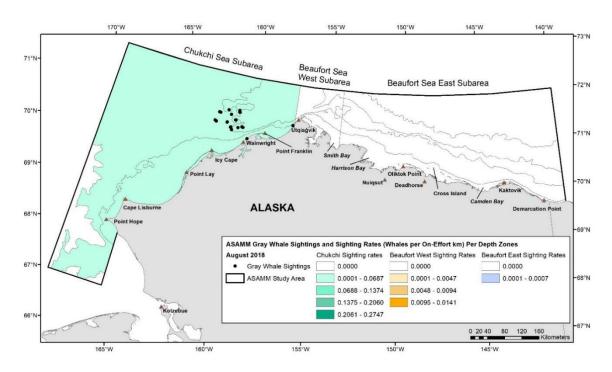


Figure F-18. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2018.

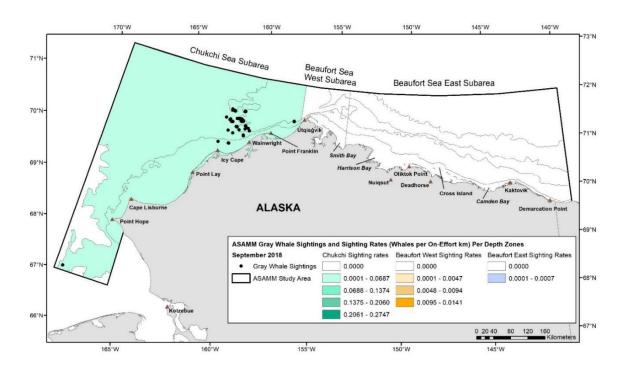


Figure F-19. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2018.

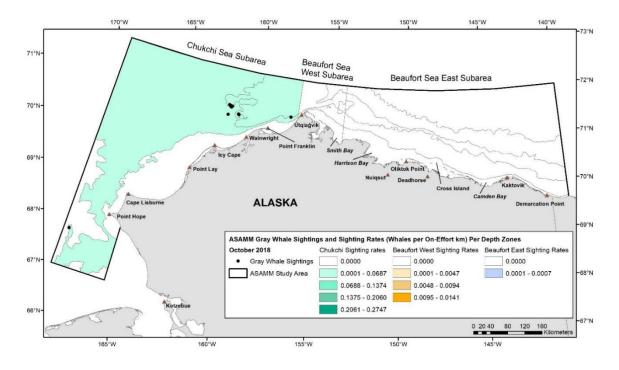


Figure F-20. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2018.

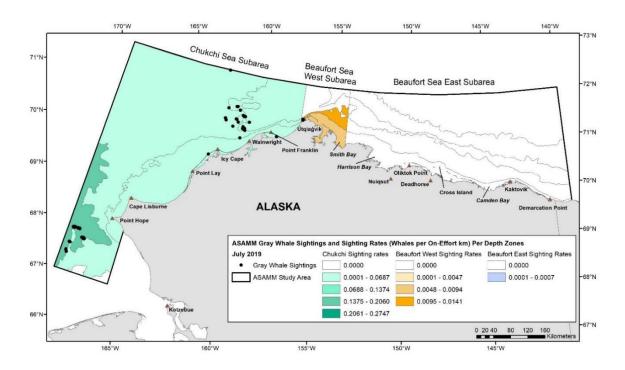


Figure F-21. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, July 2019.

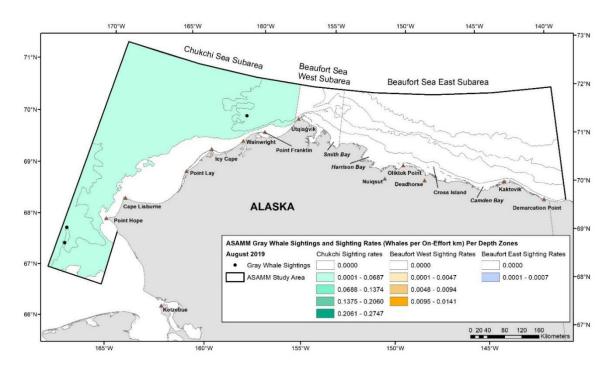


Figure F-22. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, August 2019.

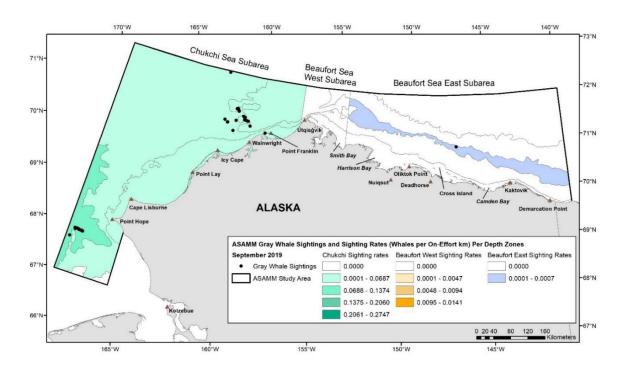


Figure F-23. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, September 2019.

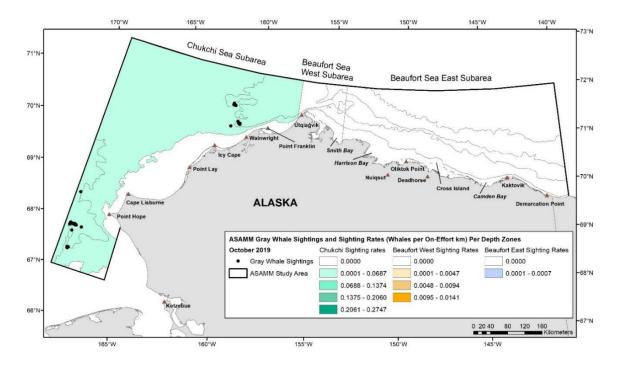


Figure F-24. -- ASAMM gray whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, Beaufort Sea West, and Beaufort Sea East subareas of the ASAMM study area, October 2019.

## APPENDIX G: HUMPBACK WHALE SIGHTINGS AND SIGHTING RATES

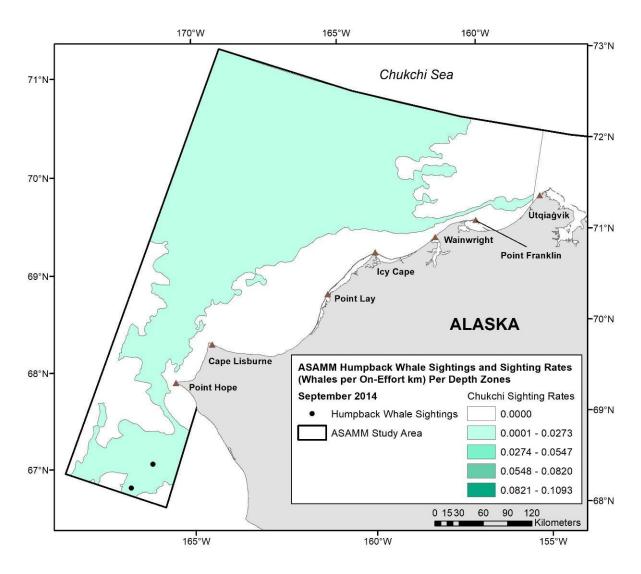


Figure G-1. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, September, 2014. Humpback whales were not observed by ASAMM in any other months in 2014.

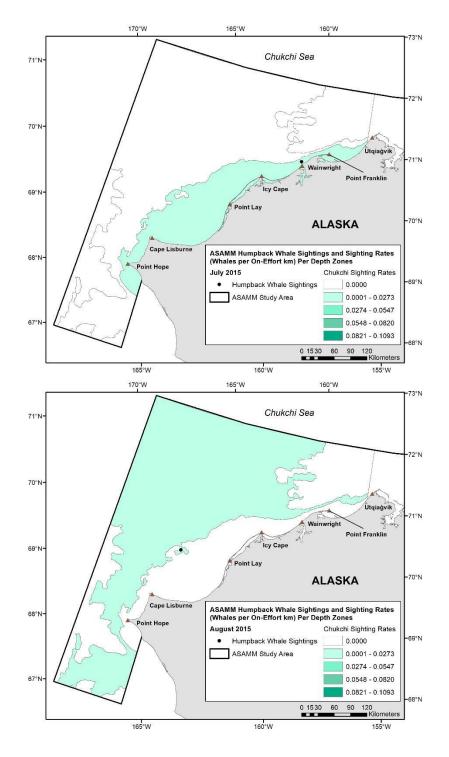


Figure G-2. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, July and August 2015.

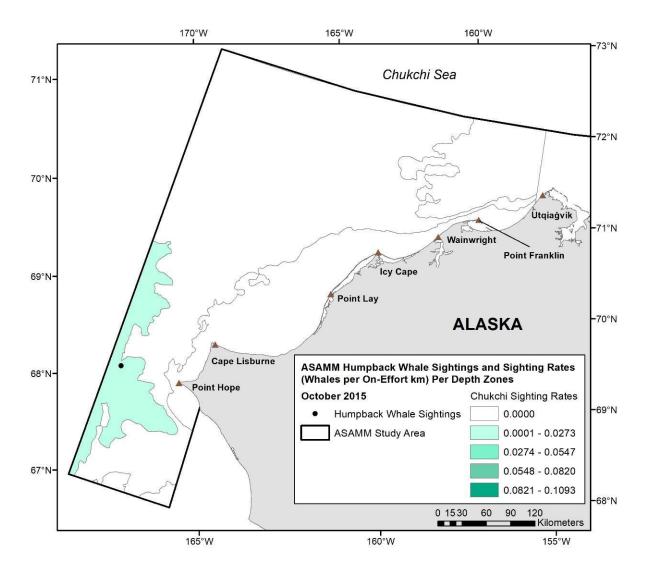


Figure G-3. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, October, 2015. Humpback whales were not observed by ASAMM in September 2015.

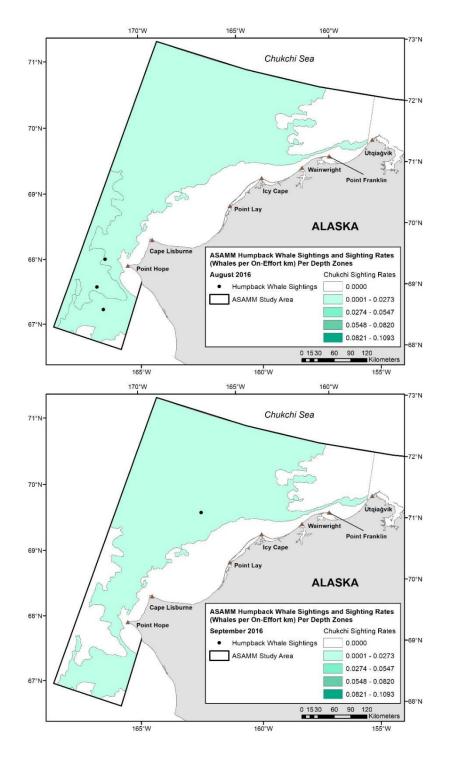


Figure G-4. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, August and September, 2016. Humpback whales were not observed by ASAMM in July and October 2016.

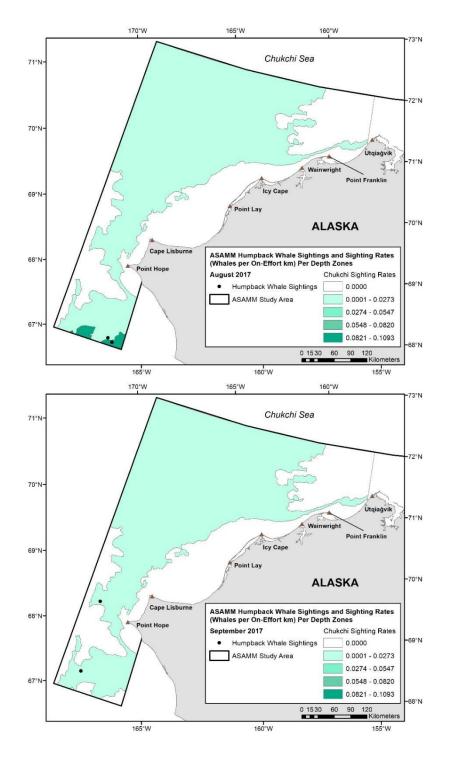


Figure G-5. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, August and September 2017. Humpbacks were not observed by ASAMM in July 2017.

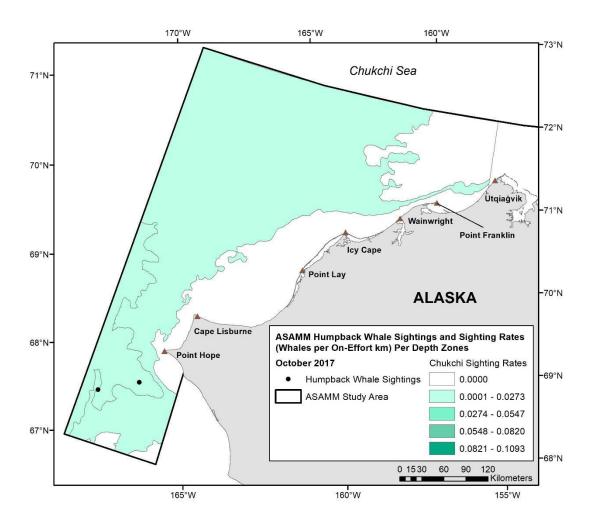


Figure G-6. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, October 2017.

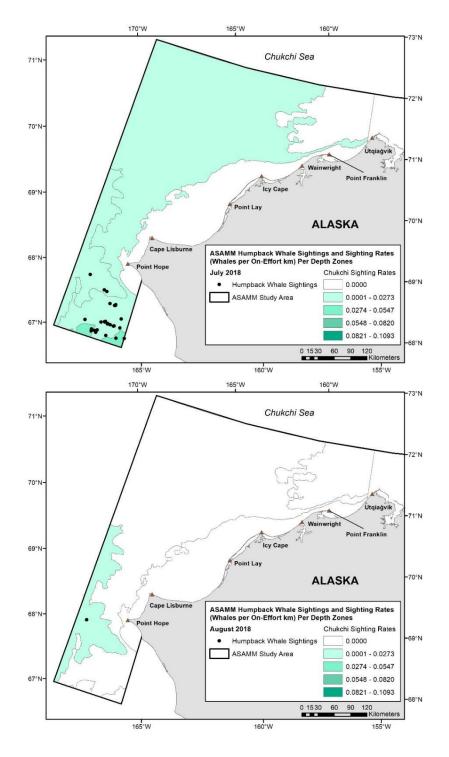


Figure G-7. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, July and August 2018.

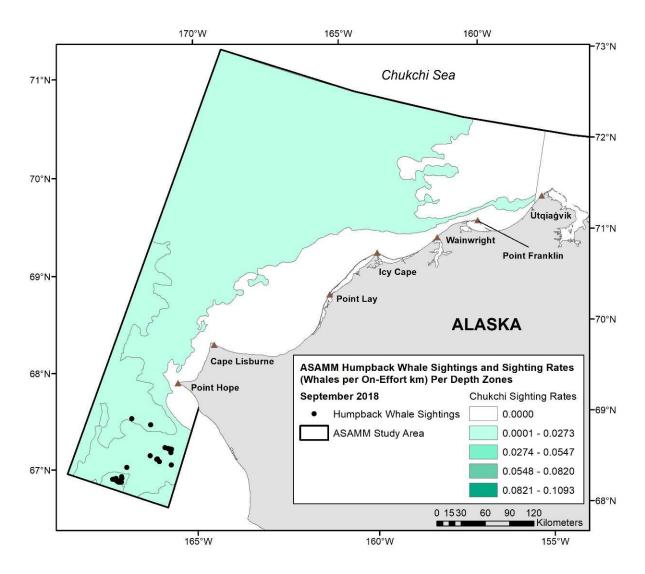


Figure G-8. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, September, 2018. Humpback whales were not observed by ASAMM in October 2018.

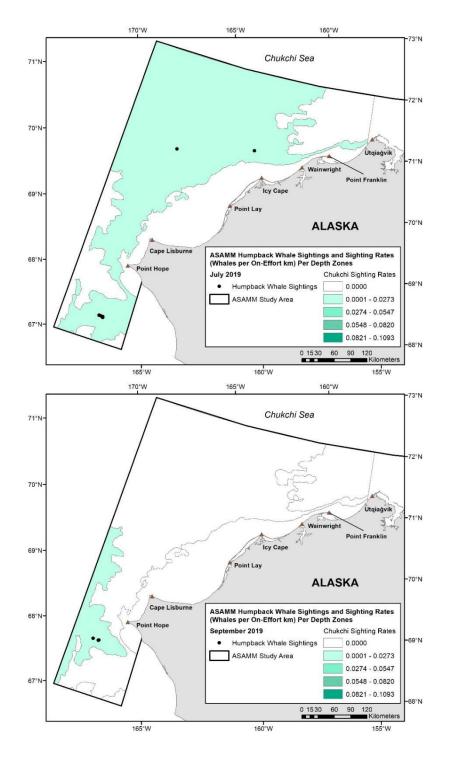


Figure G-9. -- ASAMM humpback whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, July and September, 2019. Humpback whales were not observed by ASAMM in August and October 2019.

## APPENDIX H: FIN WHALE SIGHTINGS AND SIGHTING RATES

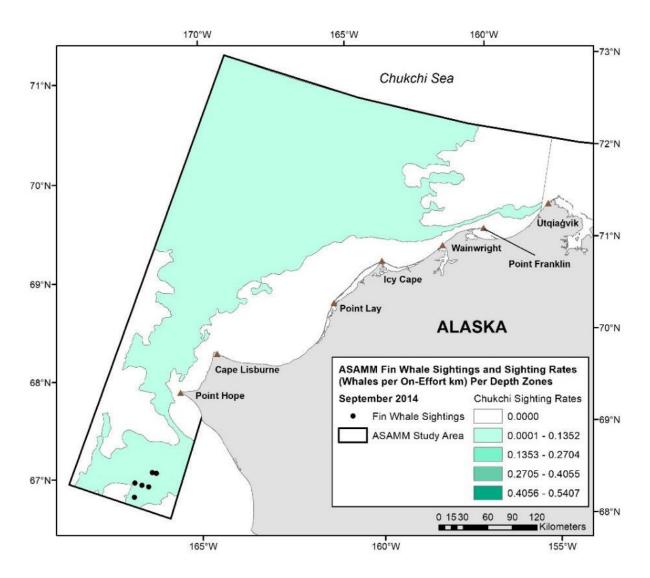


Figure H-1. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, September 2014. Fin whales were not observed by ASAMM in any other month in 2014.

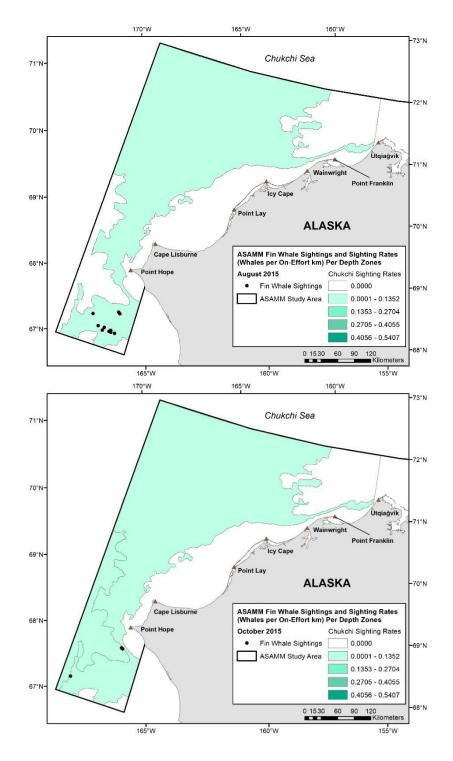


Figure H-2. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, August and October 2015. Fin whales were not observed by ASAMM in July and September 2015.

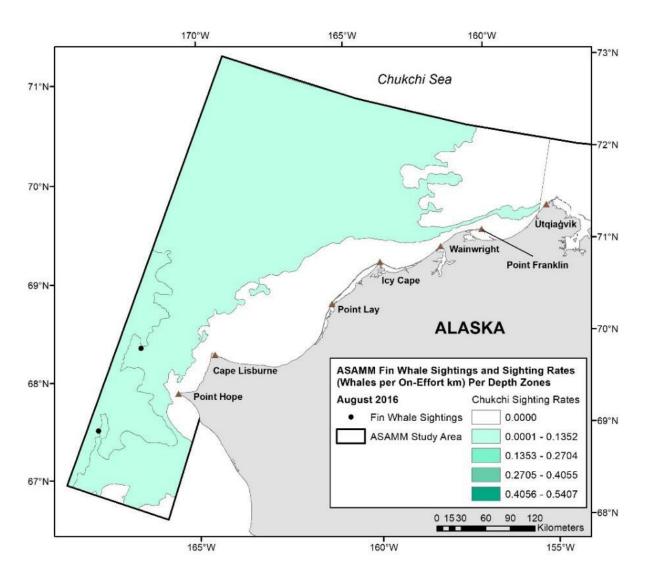


Figure H-3. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, August 2016. Fin whales were not observed by ASAMM in any other month in 2016.

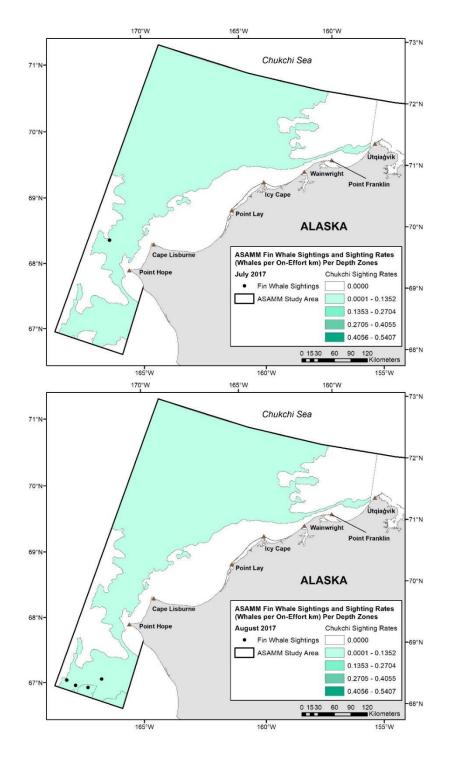


Figure H-4. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, July and August 2017.

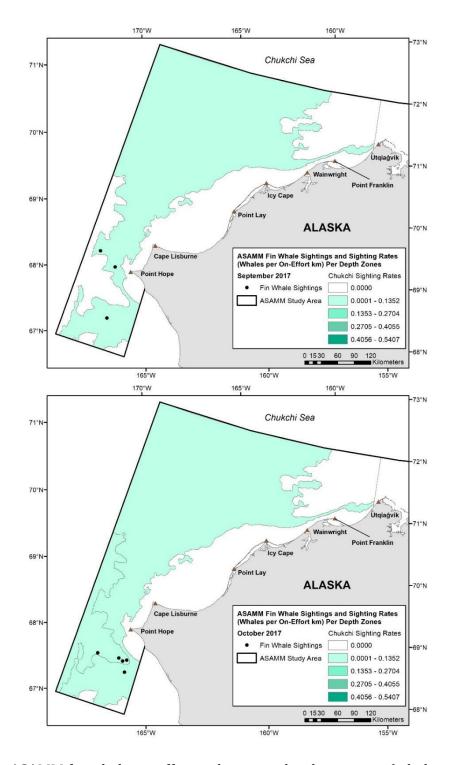


Figure H-5. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, September and October 2017.

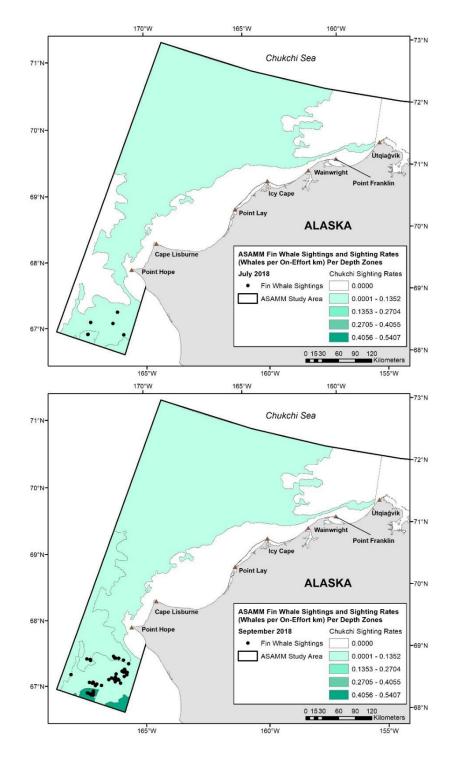


Figure H-6. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, July and September 2018. Fin whales were not observed by ASAMM in August 2018.

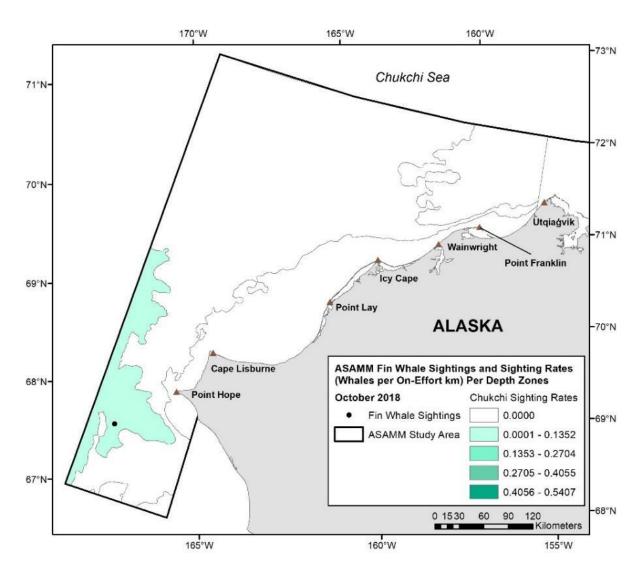


Figure H-7. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, October 2018.

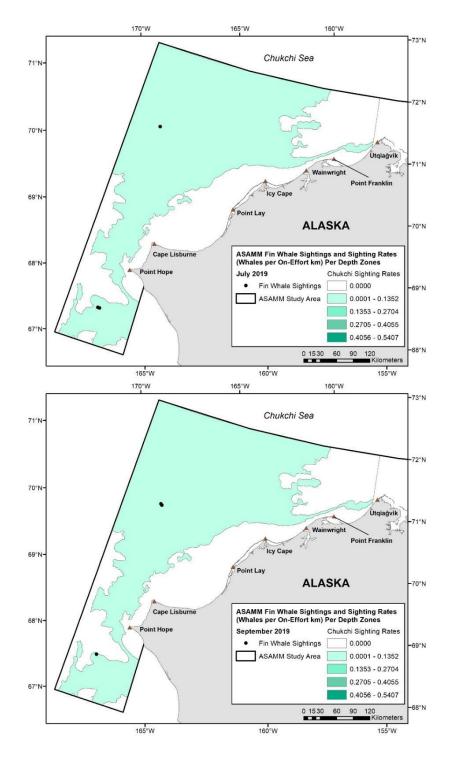


Figure H-8. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, July and September 2019. Fin whales were not observed by ASAMM in August 2019.

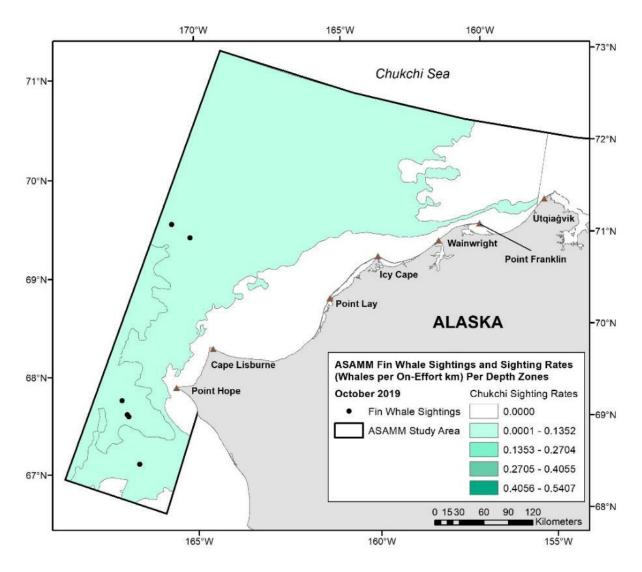


Figure H-9. -- ASAMM fin whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, October 2019.

## APPENDIX I: MINKE WHALE SIGHTINGS AND SIGHTING RATES

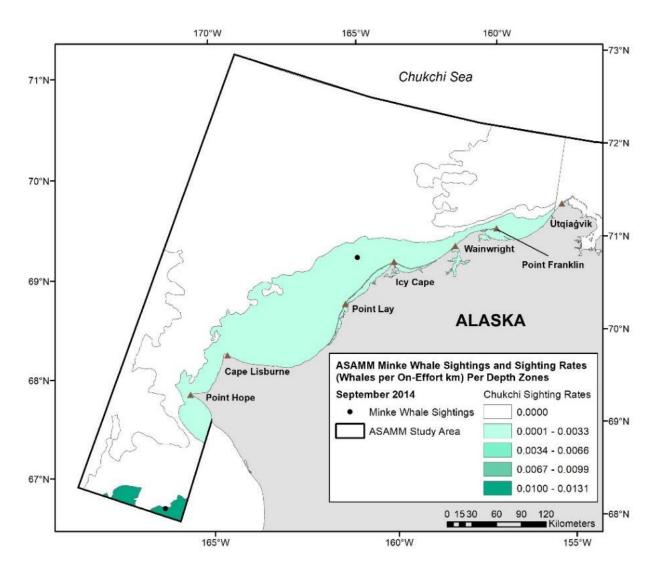


Figure I-1. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, September 2014. Minke whales were not observed by ASAMM in any other month in 2014.

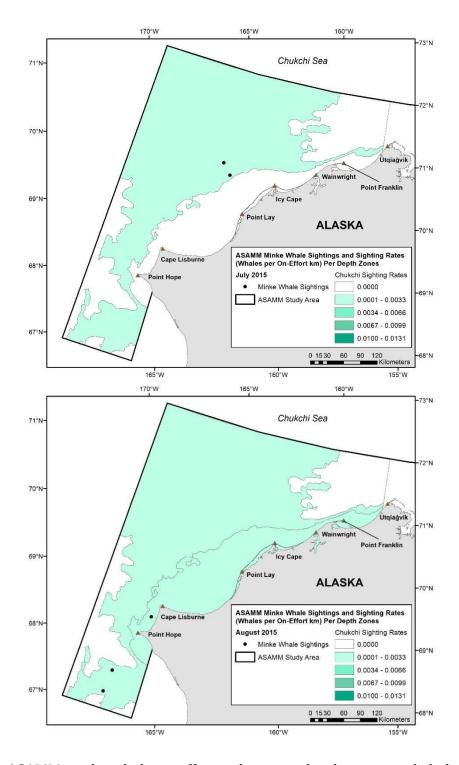


Figure I-2. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, July and August 2015.

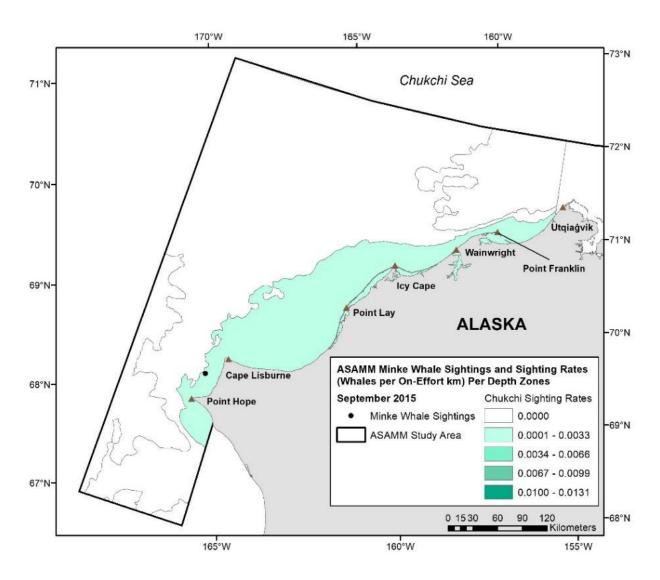


Figure I-3. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, September 2015. Minke whales were not observed by ASAMM in October 2015.

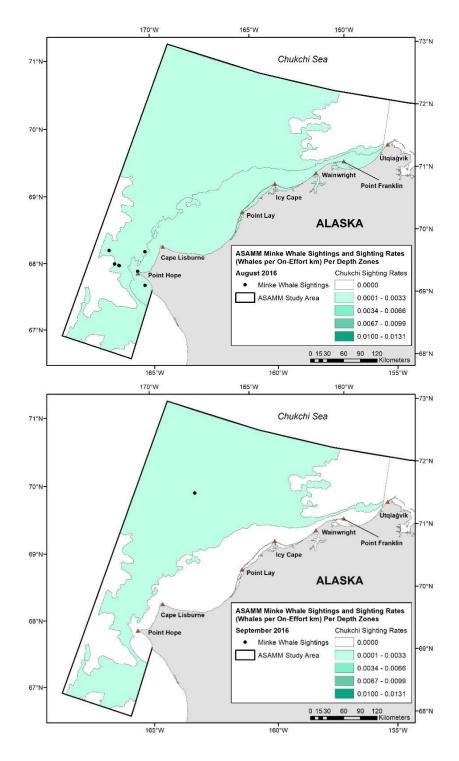


Figure I-4. -- ASAMM minke whale on-effort sightings and sighting rates (whales per on-effort km) in the Chukchi Sea, August and September 2016. Minke whales were not observed by ASAMM in July and October 2016.

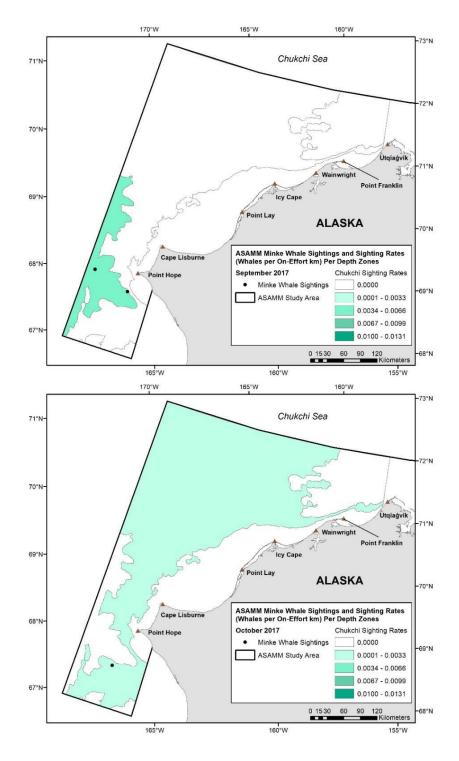


Figure I-5. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, September and October 2017. Minke whales were not observed by ASAMM in July and August 2017.

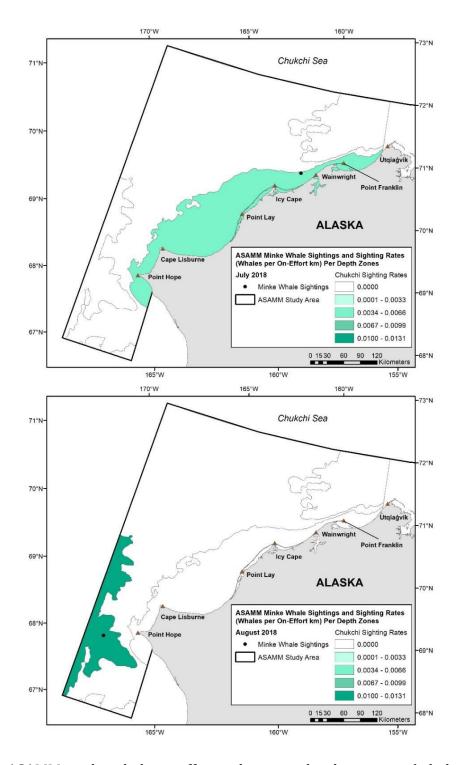


Figure I-6. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, July and August 2018.

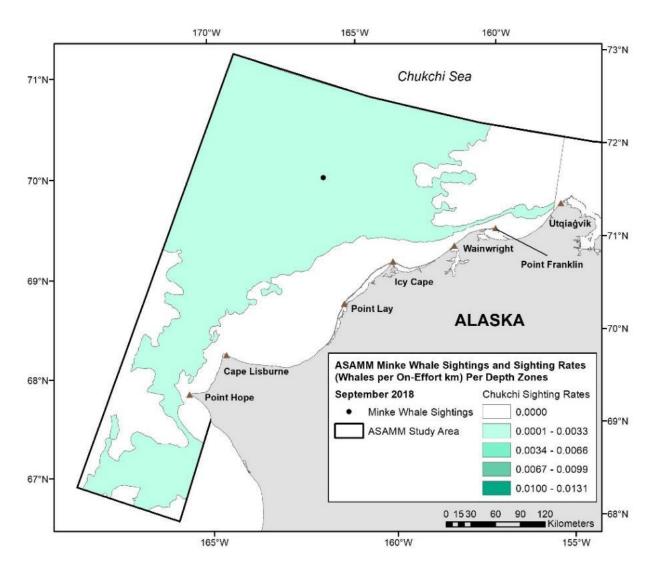


Figure I-7. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, September 2018. Minke whales were not observed by ASAMM in October 2018.

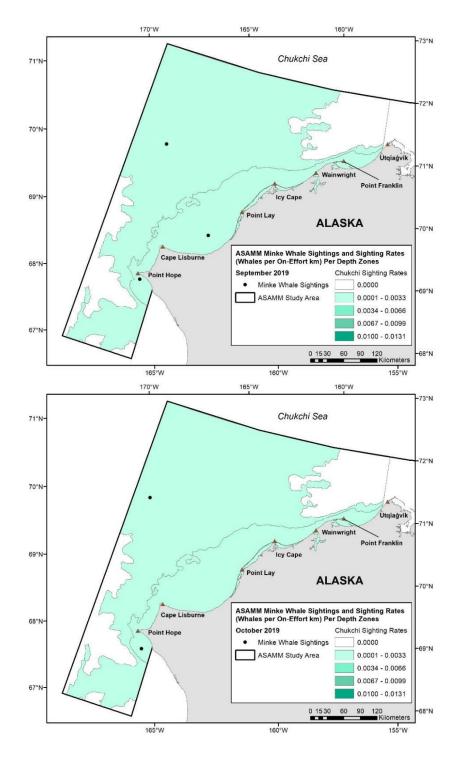


Figure I-8. -- ASAMM minke whale on-effort sightings and sighting rates (whales per oneffort km) in the Chukchi Sea, September and October 2019. Minke whales were not observed in July and August 2019.



U.S. Secretary of Commerce Gina M. Raimondo

Under Secretary of Commerce for Oceans and Atmosphere
Dr. Richard W. Spinrad

Assistant Administrator, National Marine Fisheries Service. Also serving as Acting Assistant Secretary of Commerce for Oceans and Atmosphere, and Deputy NOAA Administrator

Janet Coit

June 2022

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