WATER COLUMN AND BENTHIC LIFE
**CHLOROPHYLL-A**

**Description**
Phytoplankton are microscopic plants, which are the basic building block of the marine food web. Chlorophyll is the green pigment found in plant matter, including phytoplankton and ice-algae.

Chlorophyll absorbs light in the blue and red portions of the spectrum while reflecting green light. Reflectance values collected by the Aqua MODIS sensor measure chlorophyll-a biomass as a proxy to indicate areas that tend to be high in primary productivity at the surface of the ocean.

A study in the nearshore Beaufort Sea suggests that ice-algae provides about two-thirds and phytoplankton provides about one-third of the spring primary production (Horner and Schrader 1982). A second Arctic-wide study found that ice algae makes up on average 57% of the water column and sea ice productivity (Gosselin et al. 1997). On the map, areas of higher productivity are shown in green, yellow, and brown. Bering Strait, Norton Sound, Kotzebue Sound, and MacKenzie Bay are the most productive waters in the project area.

Variation in ice cover is the dominant factor in the spatial pattern of primary production from phytoplankton (Wang et al. 2005). In the northern Bering and Chukchi seas, chlorophyll-a and primary productivity are tightly coupled with benthic biomass (Grebmeier et al. 1988; Springer and McRoy 1993; Dunton et al. 2005; Grebmeier et al. 2006a). Chlorophyll-a and primary productivity in the Beaufort Sea are less closely linked, except around Barter Island where both relatively high biomass and chlorophyll-a are found (Dunton et al. 2005; Grebmeier and Harvey 2005).

Grebmeier et al. (2006b) show that the northern Bering and Chukchi seas are shifting away from tight coupling of pelagic-benthic productivity, coinciding with lower benthic prey populations, higher pelagic fish populations, reduced sea ice, and increased air and ocean temperatures. They state that “the vulnerability of the ecosystem to environmental change is thought to be high, particularly as sea ice extent declines and seawater warms.” Climate change may potentially break this short link between primary productivity and the benthos, converting the area to a pelagic- rather than benthic-oriented system (Grebmeier et al. 2006a; Grebmeier et al. 2006b).

Understanding the relationship between ice cover and productivity is essential in understanding Arctic marine ecology under reduced ice thickness and extent (Stockwell 2008).

See related maps and descriptions of Bathymetry, Ecoregions, Ocean Circulation, Sea Ice Dynamics, Sea Surface Temperature, Observed Climate Change, Net Primary Productivity, Zooplankton, and Benthic Biomass.

**Data Compilation and Mapping Methods**
Data for all open water months (May to October) were collected for five years, from 2004 to 2008. Chlorophyll-a measurements were collected by the Aqua MODIS satellite and served through the NASA Ocean Color website as monthly 4-km raster grids (Feldman and McClain 2009). Some southern areas were ice-free for all six months, and northern areas were ice-free for only one month per year. Chlorophyll-a grids were summed from May to October, indicating the total available primary productivity over the course of the ice-free season. Last, the five years were averaged, for a final result
reflecting the average yearly mean chlorophyll-a during ice-free months.

Data Quality
This map has a data quality rating of good because it provides a complete geographic picture of chlorophyll-a over the entire project area at a consistent 4-km resolution. Primary productivity within the sea ice and potential changes in primary productivity caused by climate change are known data gaps.

The data are limited in that production throughout the water column and in the bottom of the sea ice are not picked up by satellite sensors. The data presented here uses chlorophyll-a biomass as a proxy to indicate areas that tend to be high in primary productivity at the surface of the ocean. Few studies have directly measured water column productivity, which would permit regional and seasonal differences to be derived; productivity is highly sensitive to sea ice dynamics, which are the result of regional climate patterns (Stockwell 2008). These patterns are constantly changing, such that field studies that sample a small portion of the project area for only one week or month per year will never be able to capture the fully dynamics of the system. This makes study of remotely sensed information highly desirable even with its known limitations.

Taking into consideration the limitations described above, remotely sensed chlorophyll-a data are of high quality. The data are available daily, or in weekly, monthly, seasonal, or annual averages, beginning in July 2002. No data areas existed in the original data because of either cloud cover or sea ice cover. It was assumed that ice-covered areas had no chlorophyll production. For cloud cover, although data may not be available for a number of days because of cloud cover, when the available data are averaged over a month, and those months are averaged over a year, and those years are averaged as well, the data gap of missing days tends to be minimized. There were no concerning data gaps in the remotely sensed information presented in the map.

Summary and Synthesis
Areas of high productivity indicate important biological hotspots for multiple trophic levels in the marine ecosystem—these areas provide the basic building blocks of the food web which flow throughout the food chain. Monitoring of chlorophyll-a through satellite imagery should be continued. This information provides a baseline from which climate changes can be measured. Such long-term, consistent data at a good resolution with complete geographic coverage are very rare for the Arctic.

Text Citations


Map Data Sources

**Net Primary Productivity**

**Description**
The total amount of productivity in a region is its gross primary productivity. Some of the energy captured in photosynthesis goes to growth, which is available energy to water column grazers, and the other portion is used up by the primary producers themselves. Net primary productivity is the productivity available to support consumers and the benthos in the sea. It is the total growth of phytoplankton, including reproduction. In the Arctic, this productivity is primarily from phytoplankton and ice-algae. This map is similar to the preceding chlorophyll-a map, which is a related method for estimating primary productivity. Reflectance values collected by the Aqua MODIS sensor measure chlorophyll-a biomass as a proxy to indicate areas that tend to be high in primary productivity at the surface of the ocean. Chlorophyll-a data were combined with other information to model net primary productivity throughout the euphotic zone (the area with sufficient light for photosynthesis). Net primary productivity is highest in Norton Sound, Kotzebue Sound, MacKenzie Bay, Bering Strait, and the Chirikov and Hope basins.

See related maps and descriptions of Bathymetry, Ecoregions, Ocean Circulation, Sea Ice Dynamics, Sea Surface Temperature, Observed Climate Change, Chlorophyll-a, Zooplankton, and Benthic Biomass.

**Data Compilation and Mapping Methods**
Data for all months from January 2003 to December 2007 were collected from Oregon State University’s Ocean Productivity website (2009). The website data is based on the Vertically Generalized Production Model (Behrenfeld and Falkowski 1997). A chlorophyll-based model, it estimates net primary productivity by relating chlorophyll, available light, temperature, and photosynthetic efficiency (Oregon State University 2009). The model used MODIS chlorophyll-a and sea surface temperature data, SeaWiFS Photosynthetically Active Radiation data, and euphotic zone (1% light level) depth based on a model by Morel and Berthon (1989).

Net primary productivity grids were summed from May to October, indicating the total available productivity over the course of the ice-free season. This calculation was performed for each of five years from 2003 to 2007. Those years were then averaged, for a final result reflecting the average rate of net primary production during the ice-free season.

**Data Quality**
This map has a data quality rating of good because it provides a complete geographic picture of net primary productivity over the entire project area at a consistent 7.5-km resolution. Primary productivity within the sea ice and potential changes in primary productivity caused by climate change are known data gaps.

These data are limited in that production throughout the water column and in the bottom of the sea ice is not picked up by satellite sensors. The data presented here use chlorophyll-a as a surrogate for primary productivity at the surface of the ocean. Few studies have directly measured water column productivity for use in deriving regional and seasonal differences; productivity is highly sensitive to sea ice dynamics, which are the result of regional climate patterns (Stockwell 2008). Because these patterns are constantly changing, field studies that sample a small portion of the project area for only one week or month per year will never be able to
capture the full dynamics of the system. Consequently, study of remotely sensed information is highly desirable even with its known limitations.

Taking into consideration the limitations described above, modeled net primary productivity data are of good quality. The data from Oregon State University (2009) was available in monthly grids beginning in 2003. There is an odd data gap in Long Strait, between Wrangel Island and the northern Chukotkan coast. Persistent sea ice cover explains the lack of remotely sensed net primary productivity in the Canada Basin, but the same is not true for Long Strait. It is not known why this area appears to have no productivity.

Summary and Synthesis
Areas of high productivity indicate important biological hotspots for multiple trophic levels in the marine ecosystem—these areas provide the basic building blocks of the food web which flow throughout the food chain. Monitoring of chlorophyll-a through satellite imagery and modeling of net primary productivity should be continued. This information provides a baseline from which we can measure climate changes. Such long-term, consistent data at a good resolution with complete geographic coverage are very rare in the Arctic.

Text Citations


Map Data Sources


ZOOPLANKTON

Description
Zooplankton are a key component in marine ecosystems. The seasonal success of zooplankton communities affects related species at higher trophic levels, such as fish, seabirds, and whales (Hopcroft 2008). These small planktonic animals vary in size from microscopic to several feet long. The spatial distribution of zooplankton communities in the Chukchi Sea is strongly tied to water masses and circulation patterns (Springer et al. 1989; Plourde et al. 2005; Hopcroft 2008). Zooplankton is carried to the Chukchi Sea through the Bering Strait, so that both communities are Pacific-influenced; the Beaufort Sea in contrast is primarily Arctic in terms of species composition (Hopcroft 2008). In both areas Calanus and Pseudocalanus species of copepods appear to dominate zooplankton biomass and/or abundance (Horner and Murphy 1985; Springer et al. 1989; Ashjian et al. 2003; Plourde et al. 2005; Lane et al. 2008; Hopcroft et al. in press), and less abundant euphausiids are also important prey for whales, birds, and fish (Hopcroft 2008). Other important and less known groups include chaetognaths, amphipods, ctenophores, and cnidarians (Horner and Murphy 1985; Hopcroft 2008). They are a highly important string in the marine food web, and yet little cohesive data exists on the distribution and abundance of species, or seasonal and annual variation.

Areas of very high primary productivity, such as Anadyr waters north of the Bering Strait, produce more biomass than can be consumed by zooplankton (Springer et al. 1989). This excess biomass creates a benthic-driven marine system, as excess nutrients fall to the seafloor, feeding the benthos. This contrasts with the southern Bering Sea, where zooplankton consume a greater amount of the primary production, creating a pelagic-driven system. Changes in temperature, circulation, and ice cover due to climate change may alter plankton dynamics in the Chukchi and Beaufort seas; the effects of such changes, which are not well understood, may have significant implications for the ecology of the Arctic marine system (Lane et al. 2008; Hopcroft et al. in press).

See related maps and descriptions of Ecoregions, Ocean Circulation, Observed Climate Change, Chlorophyll-a, Net Primary Productivity, Capelin, Pacific Herring, Saffrod Cod, Pink Salmon, Chum Salmon, Kittlitz’s Murrelet, Ivory Gull, Northern Fulmar, Short-Tailed Shearwater, Bowhead Whale, Gray Whale, Human Impact, and Predicted Climate Change.

Data Compilation and Mapping Methods
Zooplankton data were digitized from a georeferenced TIFF image in NOAA’s Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones Strategic Assessment Data Atlas (1988).

Data Quality
This map has a data quality rating of poor because it provides an incomplete geographic picture of zooplankton distribution and abundance. No data are available for large portions of the project area, and those areas for which data are available are mapped at a low resolution. It is unclear why some areas are lacking information altogether. The information shown here is more than 20 years old and does not have enough detail for useful application in research or planning.

These data should be critically examined and updated. Current knowledge of zooplankton is fragment and incomplete (Hopcroft 2008). Although a large number of surveys have collected data, such as those available on the Arctic Ocean Diversity website, those surveys did not use consistent methodologies
or provide comparable results. “It is essential that we collect and collate detailed and extensive baseline information on these communities as our current knowledge is fragmented and incomplete...we still lack unbiased and comprehensive estimates of the abundance, biomass, and composition of the zooplankton in the Chukchi and Beaufort seas, due to sampling inadequacies of the past” (Hopcroft 2008).

Summary and Synthesis
Hopcroft (2008) recommends establishing long-term repeated measurements, annual, year-round sampling at a series of fixed locations and transects, and sampling in Russian waters, as well as compiling and consolidating existing data into a central database. An understanding of the role of zooplankton in Arctic marine food webs is critical to comprehend ecosystem structure and functioning, and how climate change is affecting the region.

Text Citations


Map Data Sources
BENTHIC BIOMASS

Description
Benthic organisms live on, in, or just above the seafloor. The combined weight, or biomass, of these organisms indicates potential forage for benthic-feeding bird and mammal species. Hotspots of benthic food resources are shown in yellow, orange, and red. The map indicates that the Bering Strait region, including the Chirikov and Hope basins, plus Hanna Shoal, Prudhoe Bay, Stefansson Sound, and waters around Barter Island are rich in benthic biomass, and are potentially important foraging areas for mammals and birds. Benthic organisms are less affected by seasonal and annual variability, so that high biomass sites indicate areas that likely have persistently high nutrients from the water column (Bluhm et al. 2008).

Sediment heterogeneity, type, and structure (how well sorted, grain size, etc.), along with temperature, salinity, and ice gouging, are major regulating factors on benthic community structure and diversity (Grebmeier et al. 1989; Barber et al. 1994; Bluhm et al. 2008). The Chukchi Sea and Kotzebue Sound epibenthos (organisms on or just above the sea floor) are dominated in abundance by echinoderms, crustaceans, polychaetes, and bivalve mollusks (mainly Macoma calarea) (Gagaev 2007; Bluhm et al. 2009), and in biomass by echinoderms (mainly sea stars) (Feder et al. 2005). Close to 1,200 species have been identified in the Chukchi Sea, dominated by amphipods, clams, and polychaetes; the most important prey species may be Macoma bivalves for walrus and benthic amphipods for gray whales and bearded seals (Bluhm et al. 2008).

Differences between benthic systems in the Chukchi Sea are attributed to water mass flow patterns. Areas of very high primary productivity, such as Anadyr waters north of the Bering Strait, produce far more biomass than is consumed by zooplankton (Springer et al. 1989). This excess biomass falls to the seafloor, becoming nutrients for the benthos (Gagaev 2007; Bluhm et al. 2008). Epibenthos sampling between the 1970s and 1990s reveals increased abundance and biomass for the Chukchi and northeastern Bering seas (Feder et al. 2005; Feder et al. 2007). Range expansions of warm-water Pacific species are probably indicative of climate change (Gagaev 2007).

See related maps and descriptions of Bathymetry, Ecoregions, Sea Ice Dynamics, Sea Floor Substrate, Observed Climate Change, Chlorophyll-a, Net Primary Productivity, Opilio Crab, Spectacled Eider, Steller's Eider, King Eider, Common Eider, Long-Tailed Duck, Pacific Walrus, Bearded Seal, Gray Whale, Energy Development And Protected Areas, and Predicted Climate Change.

Data Compilation and Mapping Methods
Benthic biomass samples were interpolated using the natural neighbor methodology available in ESRI's Spatial Analyst extension. Other methods such as kriging, spline, and inverse distance weighted did not appear to represent the data as well as the natural neighbor methodology. Sample locations are denoted by a diamond so that the map reader can see where data gaps exist.

Data Quality
This map has a data quality rating of fair. It provides a partially complete geographic picture of benthic biomass. Data across the project area are variable—some portions of the map are represented by reliable, high-quality data and data for other portions are outdated or are missing altogether. Sampling locations are a collection of 50 years worth of
data, and large areas have not been sampled at all. Although this map is a very informative and important snapshot, mapping temporal or seasonal change is not possible, and more sampling should be done.

Sample locations are indicated on the map, revealing large tracts of seafloor that have not been sampled, including the Russian Chukchi Sea and the Canada Basin. Although surveys have taken place on the Beaufort Sea shelf, those measurements were not made in comparable units and could not be integrated into our analysis.

It is not yet known how climate change will affect the Arctic marine system. Although it is known that water temperatures are rising, evidence about whether benthic biomass will increase or decrease on the whole in a warming climate is not conclusive at this point. However, climate change is hypothesized to weaken the short link between primary productivity and the benthos, converting the area to a pelagic-rather than benthic-oriented system (Grebmeier et al. 2006).

Summary and Synthesis
Repeated benthic sampling should occur at established points every one to three years (Bluhm et al. 2008). Dunton et al. (2003) suggest that sampling stations should be placed 50 to 100 km apart for optimum results; however, such a grid may not provide enough resolution to understand ecological processes and effects at the fine scale used in project planning efforts. Areas of the highest biomass, which are likely key foraging habitats for birds and marine mammals, should be priority areas for protections. Some such areas include Chirikov Basin, Bering Strait, Hope Basin, Long Strait, Hanna Shoal, Herald Shoal, Peard Bay, Stefansson Sound, and waters around Barter Island.

Text Citations


coupling on the shelf of the northern Bering and Chukchi seas – II: benthic community structure. Marine Ecology-Progress Series 51:253-269.


Map Data Sources


OPILIO (TANNER OR SNOW) CRAB
Chionoecetes opilio

Description
Opilio crab, also known as snow crab or tanner crab, is a key commercial species in Alaskan waters, especially the Bering Sea. Currently no commercial fishery exists in the Chukchi or Beaufort seas, although a small number of crabs of commercial size were recently found in a survey north of Barrow (NOAA and MMS 2008). Essential Fish Habitat for adults and juveniles is defined as bottom habitats to 100-m depth south of Cape Lisburne, wherever there are substrates consisting mainly of mud (North Pacific Fishery Management Council [NPFMC] 2009). Those areas are outlined in yellow on the map.

Opilio crabs mature between seven and nine years of age (NPFMC 2009), and weigh one to two pounds (Alaska Department of Fish and Game [ADFG] 1994). Eggs incubate in the female for a year before hatching during April to June, often coinciding with the spring plankton bloom (ADFG 2009). In the larval stage they feed on plankton and are preyed upon by pelagic fishes. Juveniles feed on diatoms and detritus, and adults feed on benthic organisms, including crustaceans, bivalves, brittle stars, worms, and fish (National Research Council [NRC] 1996). Both juvenile and adults crabs are prey for demersal fish, seals, and humans (ADFG 1994).

The Arctic Fishery Management Plan (NPFMC 2009) indicates that biomass for this species is estimated at 66,000 metric tons on the Alaskan Chukchi Sea shelf and 30,000 metric tons in the surveyed portion of the Beaufort Sea. Of the Beaufort Sea biomass, approximately 6,500 metric tons are estimated to be of commercial size. Bluhm et al. (2009) found the Opilio crab in high abundance at sample locations throughout the American and Russian Chukchi Sea.


Data Compilation and Mapping Methods
Data were digitized from three sources, each showing Opilio crab present in its research area. One source was NOAA’s Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones Strategic Assessment Data Atlas (1988), which indicated that Opilio crabs were found only as far north as the Bering Strait. Paul and Paul (1997) indicated that these crabs were found in the northwestern Chukchi Sea as well. Finally, surveys by NOAA and MMS (2008) indicate that Opilio crabs live north of Barrow in the Beaufort Sea.

The map has a data quality rating of poor because it provides an incomplete geographic picture of Opilio crab distribution and abundance. No data are available for large portions of the project area, and the data for those areas provide only rudimentary estimates of abundance and size.

Data Quality
Areas not indicating the presence of this species are likely due to no data rather than an actual absence of Opilio crab. Data from NOAA and MMS (2008) and Paul and Paul (1997) indicate the species is present throughout their research areas in high abundance. Information on concentration areas for larvae, juvenile, and adult crabs is lacking.
Summary and Synthesis

Although the Arctic is closed to commercial harvest, the Opilio crab, an important prey species, could be targeted in the future. Knowledge of its abundance, distribution, concentration areas, and role in the ecosystem is rudimentary and should be further studied.

Text Citations


NPFMC. 2009. Fishery management plan for fish resources of the Arctic Management Area.


Map Data Sources
