PHYTOPLANKTON

Along with bacterioplankton, phytoplankton ("plant" plankton) are at the base of the marine food web. Most biological production begins with transformation of sunlight and nutrients by single celled phytoplankton. There is not enough sunlight to promote rapid plankton growth during the subarctic winter because strong winds over the ocean cause deep circulation of water that takes the phytoplankton cells away from the light. Only when the surface water temperatures warm in spring and vertical circulation is restricted to the surface layers, can phytoplankton grow and multiply. Because of their pigments (e.g. chlorophyll), the colour of the ocean changes with increasing abundance. Since 1978, it has been possible to estimate the amount of chlorophyll at the ocean surface with ocean-colour sensing satellites.

YELLOW SEA / EAST CHINA SEA

There are few time-series to show the interannual variation in the timing and intensity of the seasonal phytoplankton blooms. There is great variation in phytoplankton biomass and primary productivity depending on the particular area and time. For example, primary productivity can range from 11.8 to 3175 mg C m^{-2} d^{-1}.

In tidally mixed zones in shallow water, turbidity is very high and light can be a major limiting factor for phytoplankton growth. Because of high levels of nutrients, diatoms tend to be most abundant when there is adequate light. Species diversity is usually high throughout the year with less conspicuous seasonal patterns. In stratified waters, once blooming condition subside, species diversity can drop quickly. There is also spatial variation in phytoplankton species numbers, decreasing from the East China Sea towards the upper Bohai Sea (Figure 1). About 400 species of phytoplankton have been recorded from this region. More than 90% of these are diatoms and dinoflagellates; the proportion of dinoflagellates increases in stratified water.

In open waters where the water column is seasonally stratified, seasonal phytoplankton blooms occur in spring and autumn. Satellite data indicate that seasonal blooms occur in April and October. During spring, the primary phytoplankton pigment chlorophyll *a* (often used to measure phytoplankton biomass) ranged from 0.4-3.3 mg Chlorophyll *a* m^{-3}, whereas in October it ranged from 0.7-1.2 mg Chlorophyll *a* m^{-3}. Mean values were 0.70, 0.66, and 0.4 mg Chlorophyll *a* m^{-3} in June, August and December, respectively. Primary productivity was the highest in June: 1391 mg C m^{-2} d^{-1}, with estimated annual production of 141 g C m^{-2} yr^{-1}. An estimate of annual production for this entire region would be higher than this value, since the shallow mixed zone has higher production but covers a relatively small area of this region. In shallow tidally-mixed locations, chlorophyll *a* can be very high throughout the year (1.3-22.6 mg Chlorophyll *a* m^{-3}).

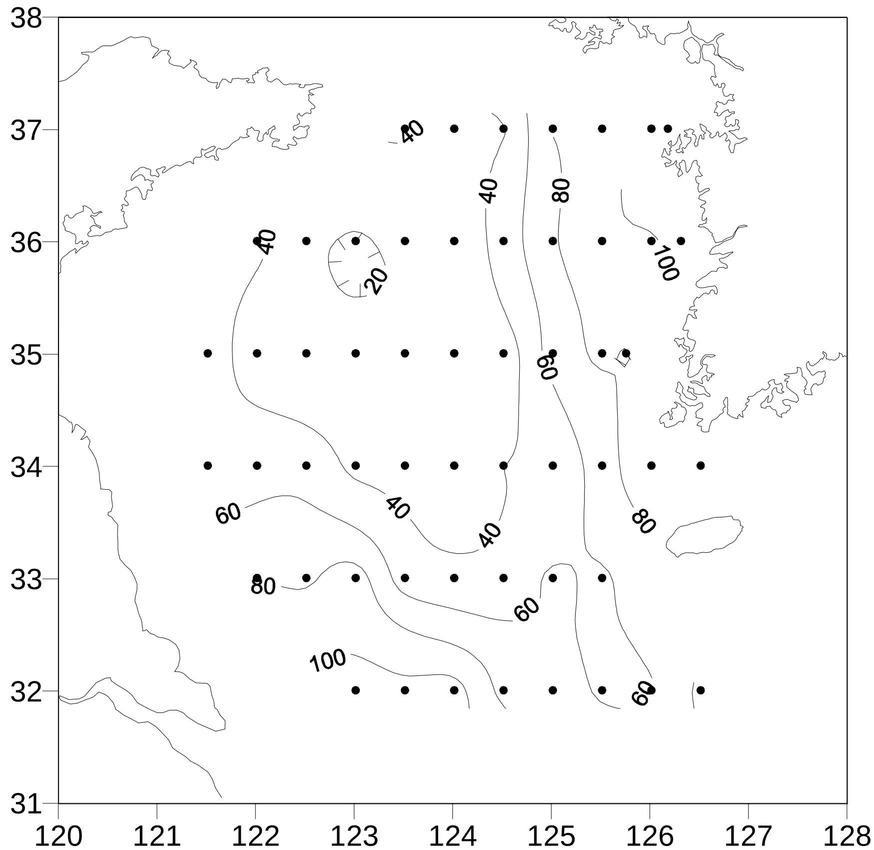

FIGURE 1 DISTRIBUTION OF PHYTOPLANKTON SPECIES NUMBER IN THE YELLOW SEA, SEPTEMBER 1992.

SEA OF OKHOTSK

There is large spatial variability in the biomass of phytoplankton throughout the Sea of Okhotsk, with values ranging from 16,800 mg/m^3 in Kashevarov Bank, to 21,640 mg/m^3 between Shantar and Iona regions, and 902 mg/m^3 in coastal regions. Primary productivity in the Sea of Okhotsk ranges from 101-350 g C m^{-3}. Including phythobenthos, primary production in the Sea of Okhotsk is about 450 g C m^{-2}, or 720,106 t C year^{-1} on an annual basis.

The rate of phytoplankton photosynthetic activity depends on a season, with about 50% of the total annual primary production occurring in spring in the Sea of Okhotsk. The bloom begins in April in the southern areas and in the western Kamchatka shelf, then during May it moves with the retreating ice edge spreading over the northern and northwestern Okhotsk Sea areas.

Phytoplankton species composition varies with season and among regions, with the spring bloom mostly composed of diatoms and dominated by cold-tolerant species. The following early-spring species are highly abundant in the coastal zone: *Thalassiosira nordenskioldii, Th. gravida, Th. decipiensis, Th. hyalina, Bacterosira fragilis, Fragilaria islandica, F. striata, F. oceanica, Thalassiotrix longissima, Coscinodiscus oculus iridis, Detonula confervaceae, Porosira glacialis, Asterionella kariana*. The following late-spring species appear with the seasonal water warming: *Chaetoceros subcecundus, Ch. debilis, Ch. furcellatus, Ch. compressus, Ch. constrictus, Ch. radicans*. Neritic algae species are characterized by wide distribution ranges and can be found in deepwater areas of the Sea of Okhotsk. On the whole, phytoplankton composition there is somewhat different. Other diatoms are predominant within the offshore planktonic algae communities in Okhotsk Sea: *Thalassiosira exentrica,* *Coscinodiscus marginatus, Chaetoceros atlanticus.* *Among the peridinium algae, Peridinium pellucidum, P. pallidum, P. depressum, P. brevipes, Ceratium arcticum* are abundant in spring. During the warm season, algae species composition changes gradually.

OYASHIO/KUROSHIO

Average annual phytoplankton biomass in the Kuroshio region integrated from the surface to about 100 m, as determined using satellites, is 25.6 mg Chlorophyll *a* m^{-2} (Melin and Hoepffner. 2004. EUR 21084 EN). In southern offshore waters, dinoflagellates dominate in the upper layer and small eucaryotic ultraplankton dominate at the depth of the 1% surface light intensity. In the Oyashio region, an extensive phytoplankton spring bloom occurs when the surface water becomes stratified during spring to form a stable, shallow mixed layer replete with nutrients supplied during winter. The main components of the phytoplankton community are large-sized diatoms in spring but small-sized phytoplankton in summer.

WESTERN SUBARCTIC GYRE

The subarctic gyres of the North Pacific are characterised as having high nutrients but low chlorophyll concentrations (called HNLC regions). Very small (nano-sized) phytoplankton dominate throughout year. Average annual chlorophyll biomass integrated from the surface to the bottom of the euphotic zone (70 m) is estimated from satellites to be 33.6 mg m^{-2} (Melin and Hoepffner. 2004. EUR 21084 EN).

BERING SEA

Average annual phytoplankton chlorophyll *a* biomass, integrated from the surface to 50 m, has been estimated using satellites to be 56.0 mg m^{-2} (Melin and Hoepffner. 2004. EUR 21084 EN). There is very strong seasonality, with peak values during spring blooms reaching 2.24 mg chlorophyll *a* m^{-3}. The spring bloom may begin under the ice and as the ice begins to melt, which provides vertical stability to the water column.

Unusual, and sometimes very large, blooms of the coccolithophorid *Emiliana huxleyi* have been observed on the eastern Bering Sea shelf from in 1997 through 2000 but were not observed in 2001 and 2002. The white calcareous liths of these coccolithophores give the seawater a turquoise colour that is best observed by satellite (Figure 2).

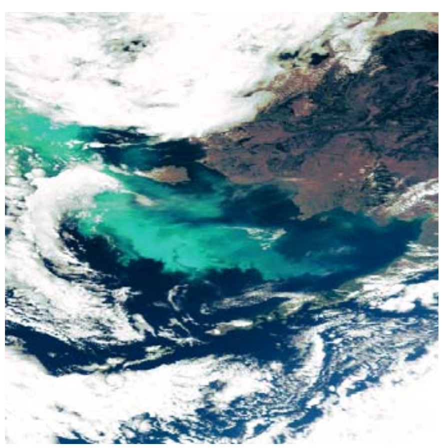

FIGURE 2 COCCOLITHOPHORE BLOOM IN THE BERING SEA (AQUAMARINE REGION) FROM SEA WIFS OCEAN COLOUR ON SEPTEMBER 17, 2000.

GULF OF ALASKA

Average annual phytoplankton biomass, integrated from the surface to a depth of 70 m, has been estimated using satellites to be 30.4 mg m^{-2} **(**MELIN AND HOEPFFNER. 2004. EUR 21084 EN**).** This region is well-known for having very little seasonal variation of phytoplankton biomass. In the central gyre, the growth of large cells (diatoms) is limited by iron in late spring and summer while irradiance is limiting in winter. Annual new production shows large interannual variations and ranges up to approximately 80 g C m^{-2} y^{-1} in the central gyre and as high as 150-200 g C m^{-2} y^{-1} at Ocean Station Papa. Primary productivity at Ocean Station Papa is fuelled by regenerated nitrogen and phytoplankton is dominated by small cells that appear to be primarily controlled by microzooplankton grazers.

In contrast, primary production on the adjacent continental shelf and in coastal embayments shows extreme seasonal variability with high phytoplankton standing stocks, extremely high productivity, and nutrient depletion in the summer. Annual new production on the shelf has been estimated at 300 g C m^{-2} y^{-1}. Productivity and plankton composition is characterized by high spatial variability and strong cross-shelf gradients. Distinct plankton communities populate the inner, middle, and outer shelf with large-celled diatoms and smaller cyanobacteria dominating blooms on the inner and outer shelf, respectively. Microzooplankton are the dominant consumers of phytoplankton and consume much of the production on the shelf. They are in turn consumed by mesozooplankton, such as *Neocalanus*, which serve as important prey for larger zooplankton, fish, seabirds, and marine mammals.

There is evidence that the composition of the phytoplankton community changed between 2000 and 2001. While phytoplankton at OSP is typically dominated by autotrophic flagellates, over 50% of the phytoplankton biomass in spring and summer of 2000 was made up of coccolithophores. Similarly, color satellite data (SeaWIFS) indicates high abundances of coccolithophores in June 2000 throughout the Alaska Gyre, while there was no evidence of coccolithophore dominance in June 2001.

CALIFORNIA CURRENT

Average annual phytoplankton biomass, integrated from the surface to a depth of 85 m, has been estimated using satellites to be 27.4 mg m^{-2} (MELIN AND HOEPFFNER. 2004. EUR 21084 EN). There is some seasonality, but primary productivity remains strong from spring to fall due to the replenishment of surface nutrients resulting from wind-driven upwelling (Figure 3). Diatoms tend to dominate the species composition (by biomass) with a few large species of diatoms (*Coscindiscus, Nitzschia,* and *Tripodonesis*) forming 81% of phytoplankton biomass particularly in upwelling cells of the southern California Current (Longhurst 1998. Ecological Geography of the Sea. Academic Press, San Diego).

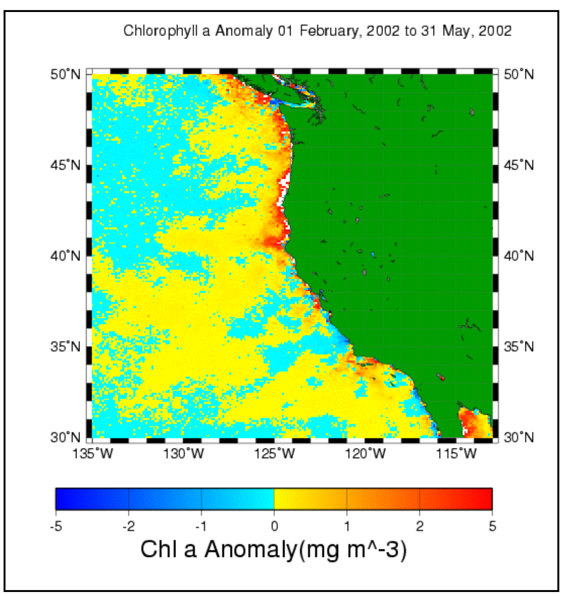

FIGURE 3 CHLOROPHYLL-A ANOMALY FOR SPRING 2002 DERIVED FROM 1998-2002 SEAWIFS OCEAN COLOR DATA.

Gulf of California

Direct observations of phytoplankton in the Gulf of California are scarce and isolated and most of the dynamics are based on satellite-derived information. Average annual phytoplankton biomass, integrated from the surface to a depth of 65 m, has been estimated using satellites to be 42.1 mg m^{-2}, with little seasonality (MELIN AND HOEPFFNER. 2004. EUR 21084 EN). Despite the inherent limitations of this type of information, ocean colour observations from satellite are especially useful in the Gulf of California due to (almost) year-round cloud-free conditions. Estimates of primary production based on the 1996 to 2002 period indicates total annual for the entire Gulf of California is 477 grams of carbon per square metre per year with year-to-year variations of up to 25%. Figure 4 shows average summer (S), autumn (A), and winter (W) primary production for four regions within the gulf.

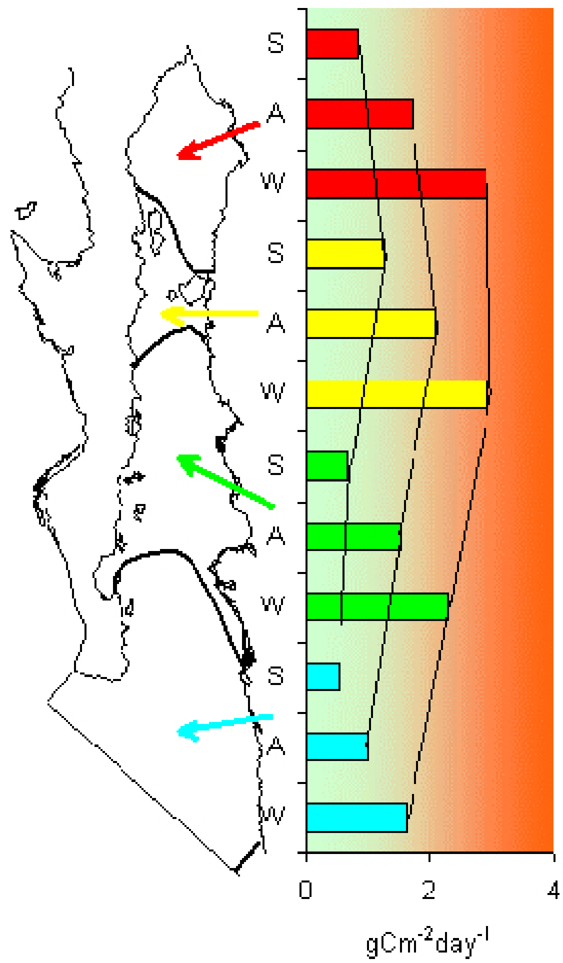

Figure 4 Gulf of California primary production (grams of carbon per metre squared per day) in (S)ummer, (A)utumn and (W)inter by region.

A recent tendency has been the presence of non-native species which cause strong phytoplankton community structure changes in tropical, and temperate, water species (*Pseudonitzchia australis*). *Cochlodinium cf. catenatum*, an ichthiotoxic species, is the most recent introduction of a non-native species which produces huge blooms resulting in mortality of fish along the coasts of Colima, Jalisco, Nayarit, Sinaloa and Baja California Sur.

CENTRAL NORTH PACIFIC TRANSITION ZONE

With limited information available from direct observations, satellite remote sensing of surface chlorophyll-*a* densities provides the best insight into the phytoplankton dynamics of the Transition Zone. In the subtropical central Pacific, surface chlorophyll-*a* concentrations are generally <0.15 mg·m^3 and northward towards the subarctic they are >0.25 mg·m^3. Between these regions of high/low surface chlorophyll lies a sharp basin-wide surface chlorophyll-*a* front, the Transition Zone Chlorophyll Front (TZCF). The TZCF seasonally oscillates north to south about 1000 km with a latitudinal minimum in January-February and maximum in July-August (Figure 5). This biological front also exhibits considerable interannual variations in position, meandering, and gradient strengths.

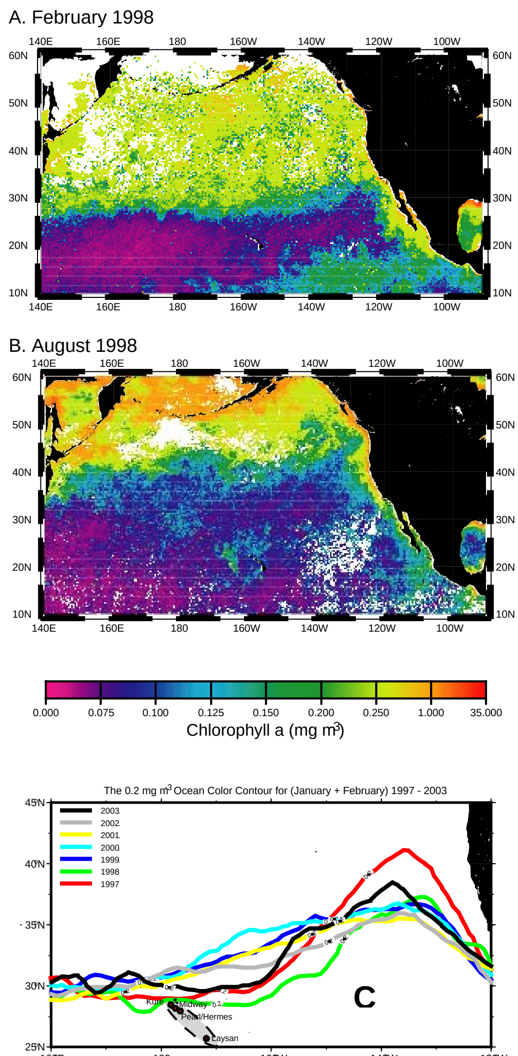

FIGURE 5 SURFACE CHLOROPHYLL DENSITY (MG·M^{-3}) ESTIMATED FROM SEAWIFS OCEAN COLOR FOR (A) FEBRUARY AND (B) AUGUST IN THE NORTH PACIFIC AND (C) THE SOUTHERN MINIMUM OF THE TRANSITION ZONE CHLOROPHYLL FRONT (TZCF) DEFINED AS THE 0.2 MG·M^{-3} CONTOUR FOR 1997-2003.[i]

In stratified, oligotrophic waters such as found during the summer, recycling of nutrients between the grazers and phytoplankton typically maintains primary production at uniform low levels. Transient episodes of upwelled nutrient-rich water from mesoscale events, particularly strong cyclonic eddies and meanders, have been shown to induce ‘new’ production, thus providing a mechanism to shorten the trophic pathway and facilitate energy transfer.

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[i] Polovina, J. J., E. Howell, D. R. Kobayashi, and M. P. Seki. 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. *Progress in Oceanography* 49:469-483.