PICES SPECIAL PUBLICATION 2

Marine Life

in the North Pacific Ocean

the known, unknown and unknowable

PICES Special Publication

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foreword

This report provides an overview of what used to live, what currently lives, and what might yet live in the North Pacific Ocean. It is a contribution to the Census of Marine Life (www.coml.org) and how it might begin to synthesise the results of its large number of regional programs. If you are reading this report electronically, highlighted text is linked to supplemental material on the North Pacific Marine Science Organization (PICES) website located at (www.pices.int/publications/special_publications/). The making of this report has involved the efforts of a large number of people – too many to name individually, but the assistance from all is appreciated. Two specific workshops related to this project were convened in 2003. The first occurred in Seoul, Korea from 9-10 October, focussing on the Yellow Sea and East China Sea. It was convened by Dr. Sinjae Yoo and Dr. Hyung-Tack Huh (Korea Oceanographic Research and Development Institute) and Dr. Ian Perry and Dr. Skip McKinnell (PICES). The second workshop, in Victoria, Canada took place from 17-19 November. Its objective was to build on existing information published by PICES to address what is known, unknown and unknowable about marine life in the North Pacific Ocean. This report would not have been possible without the hard work of the PICES Secretariat. In addition, the project benefitted greatly from the activities of PICES to develop an overview of marine ecosystems of the North Pacific Ocean. Finally, we would like to thank the Census of Marine Life Program, the Sloan Foundation, and Mr. Jesse Ausubel for support and guidance throughout the course of this project.

R. Ian Perry
Chairman, PICES Science Board

Skip McKinnell
PICES Secretariat

The Pacific is the largest ocean in the world and therefore has a significant influence on climate and the functioning of the Earth system. As the terminus of the oceanic "conveyor-belt" circulation system, the North Pacific Ocean contains some of the world's oldest water. This report examines what is "known" about marine life, identifies the critical "unknowns" of marine life, and considers what might be fundamentally "unknowable" about marine life in the North Pacific Ocean. The report was a collaborative effort of the Census of Marine Life (CoML) and the North Pacific Marine Science Organization (PICES). It focuses on "core census" information such as taxonomy, distribution, and abundance, and on "function-related" information such as life histories, productivity, and spatial and temporal variability for several key groups of organisms: bacterioplankton, phytoplankton, zooplankton, unexploited fishes and invertebrates, exploited fishes and invertebrates, seabirds, and marine mammals.

summary

In general, “core census” information is adequate for larger-sized organisms. However, new species have been discovered recently, even among the marine mammals. These discoveries are likely to continue as new methods involving genetics become more widely applied in taxonomy. Three species (Steller’s sea cow, Pallas’ cormorant, and the Japanese sea lion) are known to have gone extinct within the last 300 years. Their larger size makes their absence more obvious. We have no idea about the smaller, more cryptic forms that may have gone extinct over the past few hundred years. Information on the distribution and abundance of fishes, seabirds, and marine mammals is largely adequate, although non-commercial fishes and invertebrates are not so well known as commercially important species. The Yellow Sea and the Sea of Okhotsk appear to have the highest numbers of “unique” finfish species (*i.e.*, species which do not occur in any other marine ecosystem in the North Pacific Ocean). Distributions and abundances of very small organisms such as bacterioplankton are mostly unknown. “Function-related’ characteristics such as life histories, productivity, and seasonal, interannual and spatial variability are more poorly known than “core census” characteristics for all groups. Function-related information for commercial fishes, seabirds, and marine mammal species is somewhat better known than that for other organisms, but large knowledge gaps remain.

Exciting new discoveries have occurred in the North Pacific Ocean and elsewhere in the past few decades, such as a new kingdom of bacterioplankton (the Archaea), deep chemosynthetic ecosystems which derive their energy from minerals and gases vented from the ocean’s crust (hot-vent systems), and deep cold-water coral reefs.

There are at least two “fundamental” unknowables about marine life in the North Pacific Ocean: i) the identification of all species, and ii) the abundances of all species. These are likely to be unknowable because of the difficulties of sampling the vast and deep North Pacific Ocean, and because of major differences in regeneration times (life spans) between bacterioplankton (less than one day) and whales, long-lived rockfishes, and clams (which can be over 100 years). There are also at least two “applied” unknowables about North Pacific Ocean marine life: i) predicting which species is likely to dominate blooms of plankton, and ii) how individual species and therefore, the ecosystem as a whole will respond to changes in natural (*e.g.*, climate) and/or human (*e.g.*, fishing, contaminants) forcing. These are likely to be unknowable because of the complexity and redundancy within marine ecosystems, and our inability to adequately understand and predict how any single species will respond to such changes. Understanding the limits of our knowledge and acknowledging the high levels of uncertainty will provide a more realistic assessment of marine life in the North Pacific, and may reduce the occurrences of “surprises” (*i.e.*, events beyond our narrow expectations) - surprises which seem, all too frequently, to be unpleasant.

The Pacific is the largest ocean on Earth, occupying about one-third of the planet. This large body of water has important influences on, and interactions with, the global climate system. The strongest of these influences originates in the tropics as the El Niño - Southern Oscillation (ENSO). The North Pacific Ocean occupies 20% of the Pacific, with an average depth of 4,270 m and trenches descending to 10,924 m. It is the terminus of the oceanic “conveyor-belt” circulation system that starts in the Northwest Atlantic and winds its way through the Atlantic and Indian Oceans before ending up in the Gulf of Alaska. The result is that the Northeast Pacific Ocean contains some of the oldest water in the world.

introduction

Living marine resources in the North Pacific Ocean have been observed and used by coastal peoples and early seafarers for thousands of years, but (what has evolved to be called) scientific methods of investigation began during the European explorations of the 18th century. Understanding what used to live, what lives now, and what may live in a future North Pacific Ocean is not only critical for sustainable use by humans – but also for sustaining the present functioning of our planet, since the North Pacific Ocean comprises such a large proportion of the Earth's surface. Understanding what lives there is critical to knowing how its ecosystems are structured, how they function, and how they may change in response to stresses – both natural and human-induced.

This report provides a broad overview of what we know, what we do not yet know, and what may be unknowable about marine life in the North Pacific Ocean. Its objectives are to:

- Consider what is "known" about marine life; to provide an overview, rather than a comprehensive inventory;
- Identify the critical "unknowns" of marine life and to assess what might be changed from "unknowns" into "knowns" with appropriate research;
- Consider what might be fundamentally "unknowable" about marine life in the North Pacific Ocean.

Marine life in the North Pacific Ocean can be examined in a number of ways. Size is often the simplest organisational scheme, ranging from smaller to larger organisms, but size is also a good biological scheme since, in general, smaller organisms are eaten by progressively larger organisms in the ocean. The major groups that are considered in this report are listed in Table 1 and are ordered roughly by increasing size. In general terms, "plankton" are organisms that tend to drift with ocean currents, and are divided into three types: bacteria, plant ("phyto") plankton, and animal ("zoo") plankton; "benthos" are organisms that live most of their lives on the sea bottom. An important distinction can also be made between coastal and oceanic regions of the North Pacific Ocean, with "coastal" including organisms that live from the seashore to the edge of the continental shelf (200 m deep).

[Table 1] Major groups of marine life in the North Pacific Ocean.

bacterioplankton
small phytoplankton
large phytoplankton
small zooplankton
large zooplankton
gelatinous plankton
benthos
non-exploited fish & invertebrates
exploited fish & invertebrates
seabirds
marine mammals

To understand what lives where in the North Pacific Ocean and how its ecosystems are changing, information is needed on important characteristics of these major groups. In general terms, the required information can be broadly categorised as either "core census" or "function-related."

"Core census" information

Taxonomy (morphological, genetic, functional)

- have most, if not all, species been described?
- are catalogues, keys, or voucher specimens available?
- are taxonomic relationships among groups known?

Geographic distribution

- are general distributions known for major taxonomic groups (plankton) or for individual species of higher trophic level animals?
- can their general distributions be mapped?
- can their general habitats be described?

Abundance and biomass

- are indicators or estimates of abundance or biomass available?
- are relative abundances of major groups or species known?

"Function-related" information

Life history

- are basic life histories known for major groups or species?
- are estimates of basic life history parameters such as growth and fecundity available for major groups?

Productivity

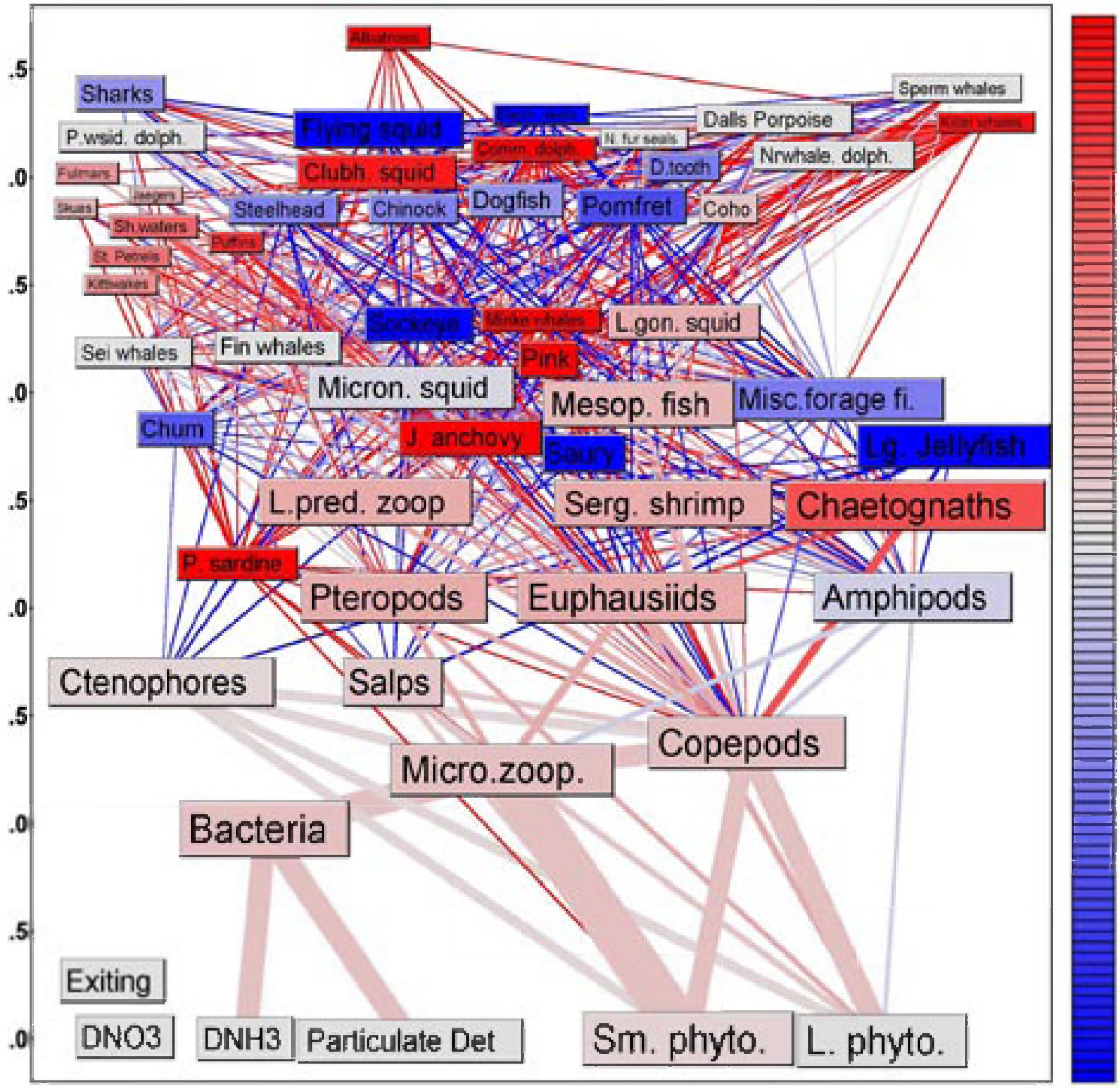
- are estimates of annual production available (e.g., total production for plankton, recruitment and growth for some or most major fish species)?
- are time series of productivity available (estimates or indices of total production, recruitment)?

Variability

- what are the seasonal cycles of biological production, distribution and migration (fishes, mammals, etc.), and growth?
- are there annual estimates of key quantities (production, recruitment, abundance) and are their causes of variability known?
- are spatial patterns in distribution, abundance, productivity sufficiently understood to estimate spatial averages of key quantities?
- is the spatial resolution of data sufficient for management or other purposes?

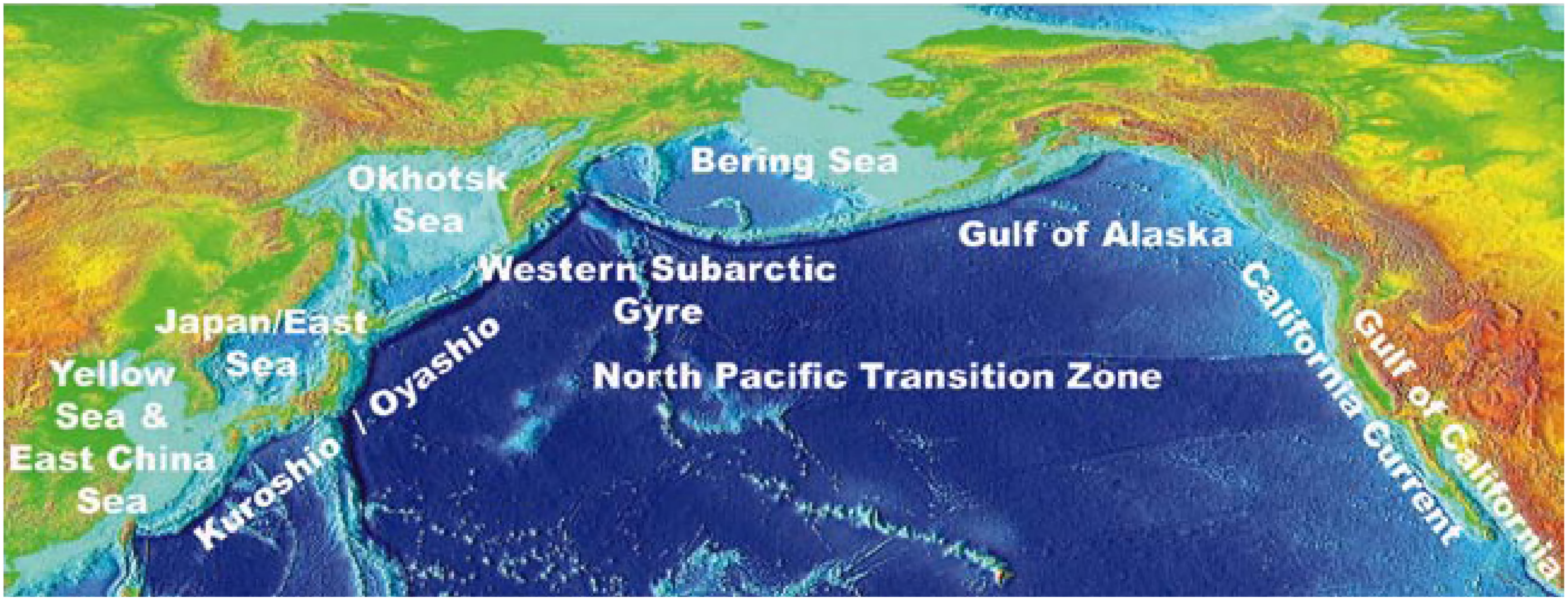
To understand the roles that organisms play in the structure and function of marine ecosystems (*e.g.*, Figure 1), information is needed at the community and ecosystem levels on:

- food web pathways;
- food web efficiencies;
- other food web characteristics;
- species richness, diversity and evenness;
- size / diversity spectra;
- keystone species.



[Figure 1] Simplified food web of the open ocean subarctic North Pacific Ocean. Box sizes are proportional to biomass, and the widths of connecting lines are proportional to fluxes between boxes; red (blue) colours reflect relatively greater importance in the western (eastern) gyres.[2]

[2] Source: Aydin, K.Y., McFarlane, G.A., King, J.R. and Megrey, B.A. 2003. PICES-GLOBEC International Program on Climate Changes and Carrying Capacity. The BASS/MODEL Report on Trophic Models of the Subarctic Pacific Basin Ecosystems. PICES Scientific Report 25, 93p.



[Figure 2] Large marine ecosystems in the North Pacific Ocean provide a geographic basis to describe the trophic levels of the North Pacific Ocean.
(Source of base map: http://ngdc.noaa.gov/mgg/image/2minrelief.html)

For the most part, what is currently known about marine life in the North Pacific Ocean was learned from easily measured aggregate values obtained during limited sampling of coastal regions. Where detailed information is available, it is often related to a commercially valuable species or to the proximity of a vibrant marine science community. Sustained observations of marine life in remote locations are rare. Satellite sensors are providing frequent access to new information over large spatial scales. These new tools are revealing the importance of variability at scales of 10-200 km in the ocean in ways that were not possible previously. Satellites are especially valuable when they are complemented by *in situ* observing systems.

the known

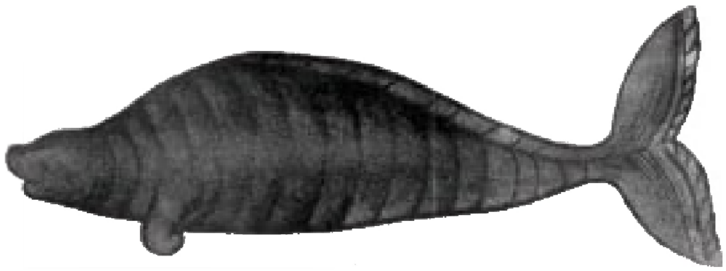
In the mid-1500s in Japan, and the mid- to late 1700s in North America, when Europeans were first exploring the North Pacific Ocean, they encountered people who were highly adapted to an ocean that was rich in natural resources, in particular salmon and marine mammals. Estimates of marine mammal abundance in the North Pacific Ocean prior to industrial exploitation are imprecise, but range from thousands to millions (see Table 2). Living marine resources spurred exploration of the North Pacific Ocean, stimulated commerce with Asia, and greased the wheels of the industrial revolution in Europe.

[Table 2] Estimated abundance of some marine mammals in the North Pacific Ocean prior to industrial exploitation.

Species	Estimated numbers
Blue whale	5,000
Sei whale	63,000
Humpback whale	15,000
Sperm whale	1,250,000
Gray whale	15,000
North Pacific right whale	16,500 – 50,000
Sea otter	300,000
Fur seal (Bering Sea)	3,000,000

Current abundances of many marine mammals are considerably lower than these. Catches of "staple" fish species by indigenous peoples are believed to have been very large in some cases, on both the eastern and western margins of the North Pacific Ocean. For example, along the northwestern coast of North America, annual pre-contact catches are estimated to be 6,500 tonnes of salmon and 1,300 tonnes of halibut.[3] Abundances of near-shore species have suffered declines as human populations, and consequent exploitation of easily accessible marine resources, have grown. Large pelagic fishes, such as tuna are also thought to have been much more abundant prior to the advent, in the 1950s, of large-scale open ocean fishing by industrial fleets.

[3] Source: references cited in Vasconcellos, M. and Pitcher, T. 2002. Fisheries Centre Research Report 10(1): 60-67, University of British Columbia, Vancouver, Canada.



[Figure 3] Sketch of Steller's sea cow.[4]

Extinctions

Species in the North Pacific Ocean that are known to have gone extinct over the past several hundred years are the large, more obvious and visible organisms whose presence in the past, and absence in the present can be determined more easily than most smaller pelagic or cryptic forms. The best known extinction in the North Pacific Ocean is *Hydrodamalis gigas*, the Steller's sea cow (Figure 3), a large herbivorous marine mammal that was related to the dugong of sub-tropical waters. It was known in the western Bering Sea, with the last population discovered by a Russian expedition to Bering Island in 1741. The genus was probably extinct by 1768. Other extinct species from the North Pacific Ocean include:

- Pallas' cormorant (*Phalacrocorax perspicillatus*), which was also restricted to the Bering Island region, appears to have gone extinct about 1850;

- Japanese sea lion (*Zalophus californianus japonicus*), formerly known from marine and coastal waters of the Northwest Pacific where it occurred along the coasts of Japan, the Democratic People's Republic of Korea, and the Republic of Korea. There have been no confirmed reports of this species since the late 1950s.

Bacterioplankton

Bacterioplankton are bacteria that live in large aquatic environments. They are microscopic in size (sometimes at or below the resolution limit of compound light microscopes) and often very abundant. The world ocean contains approximately 3.1 x 10^{28} bacterial cells. There is a fundamental problem with defining "species" of bacteria, since the traditional species concept cannot easily be applied to many marine bacteria. Two "Kingdoms" of heterotrophic bacteria are recognized, based on biochemical and genetic differences: the Archaea and the Eubacteria. Both are abundant in the North Pacific Ocean. In the central North Pacific, from the surface to more than 5000 m depth, Eubacteria are more abundant than the Archaea, although at depths below 150 m their abundances can be similar. The growth of bacterioplankton in the surface waters of the North Pacific Ocean is largely regulated by temperature and the supply of dissolved organic carbon (which often comes from phytoplankton), whereas in the mesopelagic layer (100-1000 m), the growth of bacterioplankton is, to a greater extent, due to the supply of organic carbon. The biomass of bacteria in high latitude seas, such as the Sea of Okhotsk and the Bering Sea, tends to be similar. The biomass of bacteria in warmer seas (Yellow Sea and East China Sea) may be lower than that found in high latitude, colder waters because colder temperatures in higher latitude seas inhibit bacterial recycling so that more organic materials sink, thereby increasing the deep bacterial biomass.

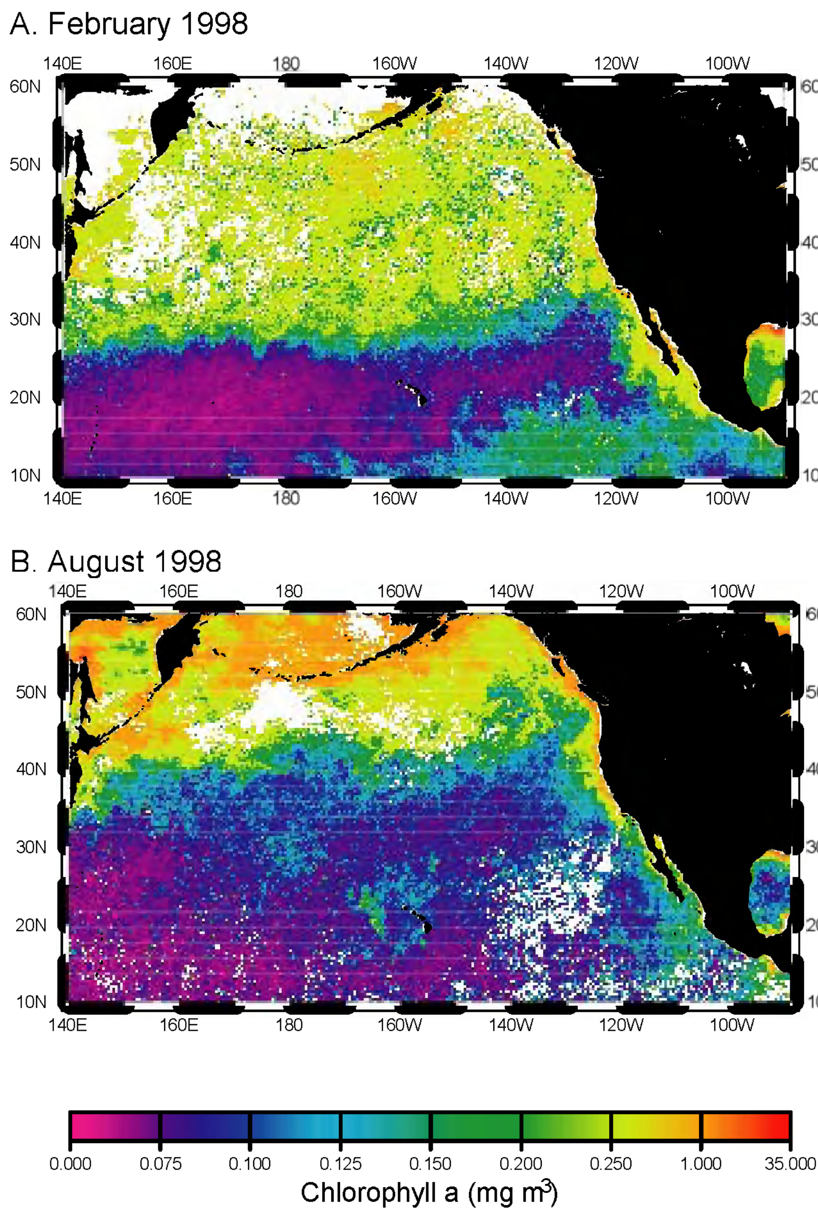
Cyanobacteria such as *Synechococcus* are important organisms in the North Pacific Ocean, although little is known about their distribution and genetic variability. Some species of *Synechococcus* and *Trichodesmium* have the ability to fix nitrogen gas (N_2), so they are important contributors to the geochemical budgets in North Pacific Ocean marine ecosystems, particularly in the central North Pacific Transition Zone where key nutrients, such as nitrate are usually in low concentration. Current understanding of species composition, quantitative estimates of nitrogen fixation, factors influencing nitrogen fixation (phosphate, iron, temperature, etc.), and key genes controlling nitrogen fixation, is limited. Bacteria are important in cycling carbon and nutrients in the ocean and as the source of long food webs. Although difficult to identify, it is important to know which phylogenetic groups of bacteria dominate marine bacterioplankton communities because the abundant groups may have different roles in carbon cycling and other biogeochemical processes.

Viruses also occur in the ocean; some may be specialized to attack phytoplankton, zooplankton, and fishes, etc. but little is known about marine viruses in the North Pacific Ocean.

[4] Source: Taken from "Kamchatka Expedition 1741-1742" by Sven Waxell 1952.

Phytoplankton

Phytoplankton (plant plankton) are also at the base of the marine food web. Most biological production in the ocean begins with the transformation of sunlight and nutrients to organic material by single-celled phytoplankton. During winter, there is not enough sunlight to promote rapid plankton growth and reproduction because strong winds over the ocean cause deep mixing of water that takes phytoplankton cells away from the light. Only when the surface water temperatures warm in spring and vertical mixing is restricted to the uppermost layers can phytoplankton grow and multiply. Because of their pigments (*e.g.*, chlorophyll), the colour of the ocean changes in relation to their varying abundance. Since 1978, it has been possible to estimate the amount of chlorophyll at the ocean surface with ocean-colour sensing satellites (Figure 4). All areas of the North Pacific Ocean have blooms of phytoplankton, *i.e.*, periods of the year when phytoplankton productivity is maximal and the cells



[Figure 4] Surface chlorophyll obtained from SeaWIFS data for February and August 1998.[5]

[5] Source: Polovina *et al*. 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. Progress in Oceanography 49(1-4).

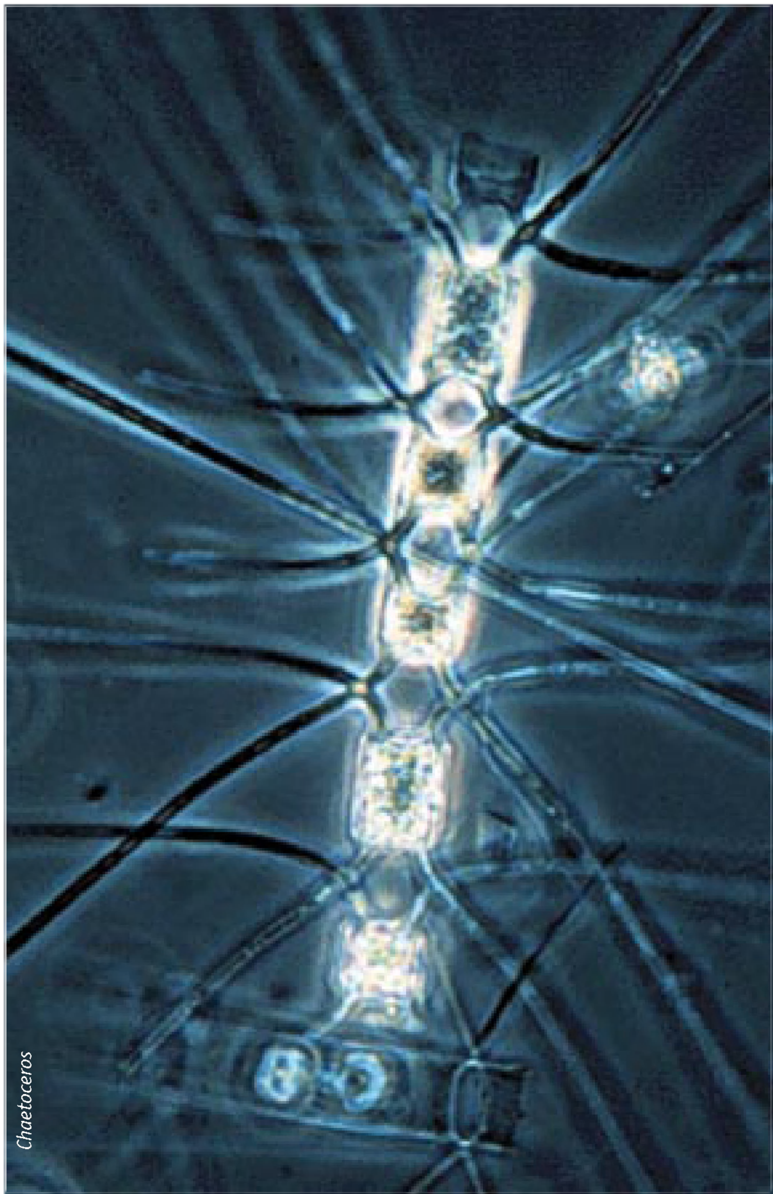
multiply rapidly. Usually, these periods occur in the spring and fall, but at high latitudes and in regions where nutrients are upwelled from deeper waters, these bloom periods may occur in the summer. The most productive regions of the North Pacific Ocean (on an annual basis) are the Yellow Sea and East China Sea (1.08 g C m^{-2} d^{-1}) followed by the coastal regions of the Gulf of Alaska (0.90 g C m^{-2} d^{-1}). The California Current System, where upwelling is a major feature, is less productive (0.61 g C m^{-2} d^{-1}) compared to similar upwelling regions along the coast of South America because of a wider continental shelf off California and differences in wind stress.

Picophytoplankton (less than 2 µm) is distributed throughout the North Pacific Ocean and is the dominant component (in numbers) of the phytoplankton in the subtropical Pacific and central North Pacific Transition Zone. In the subtropical Pacific, *Prochlorococcus* is the most important component of the picophytoplankton, however, they do not occur in the subarctic Pacific. Limited information is available about the northern extent of their range and the factors limiting distribution. Genetic analysis indicates that there are different types of *Prochlorococcus*, each with different vertical distributions and physiologies. Information about the ecological and biogeochemical functions of the various forms of *Prochlorococcus*, as well as the other picophytoplankton, is limited.

Nanophytoplankton (2-20 µm) is also an abundant component of phytoplankton assemblages, especially in the subarctic Pacific (Western Subarctic Gyre, Gulf of Alaska) and central North Pacific Transition Zone. East-west and north-south differences in nanophytoplankton composition have been identified in the North Pacific Ocean based on analyses of marker pigments. Their species composition, genetic variability, nutrient requirements, and roles in marine ecosystems are not well known.

Diatoms are key organisms in marine food webs and biogeochemical cycles. They serve to efficiently package inorganic nutrients and transfer these to higher trophic levels. Diatoms also effectively transfer biogenic elements to the deep ocean, in what is called the "biological pump". In the North Pacific Ocean, diatoms are dominant in coastal waters, but are relatively minor components of the phytoplankton in the open ocean. Their production and biomass in the open ocean is sensitive to environmental conditions, such as ENSO, upwelling and downwelling, sporadic nutrient supply from coastal regions, or wind-driven fluxes of terrestrial dust. Once the factors that limit their growth in the central North Pacific Ocean (*e.g.*, light and iron) are relaxed, diatoms can increase dramatically because they generally are too large to be prey for most zooplankton in this area (except for crustacean zooplankton), and the growth rate of diatoms is much faster than that of crustacean zooplankton. Under optimum conditions of diatom growth, crustacean zooplankton cannot control the biomass of diatoms by grazing, and an intense diatom bloom is the result.

In the Yellow Sea and East China Sea, about 400 species of phytoplankton have been recorded. More than 90% of these are diatoms and dinoflagellates, with the proportion of dinoflagellates increasing in waters that are vertically stratified. The dominant phytoplankton species are *Skeletonema costatum*, *Coscinodiscus* spp., *Melosira sulcata*, and *Chaetoceros* spp.


Chaetoceros

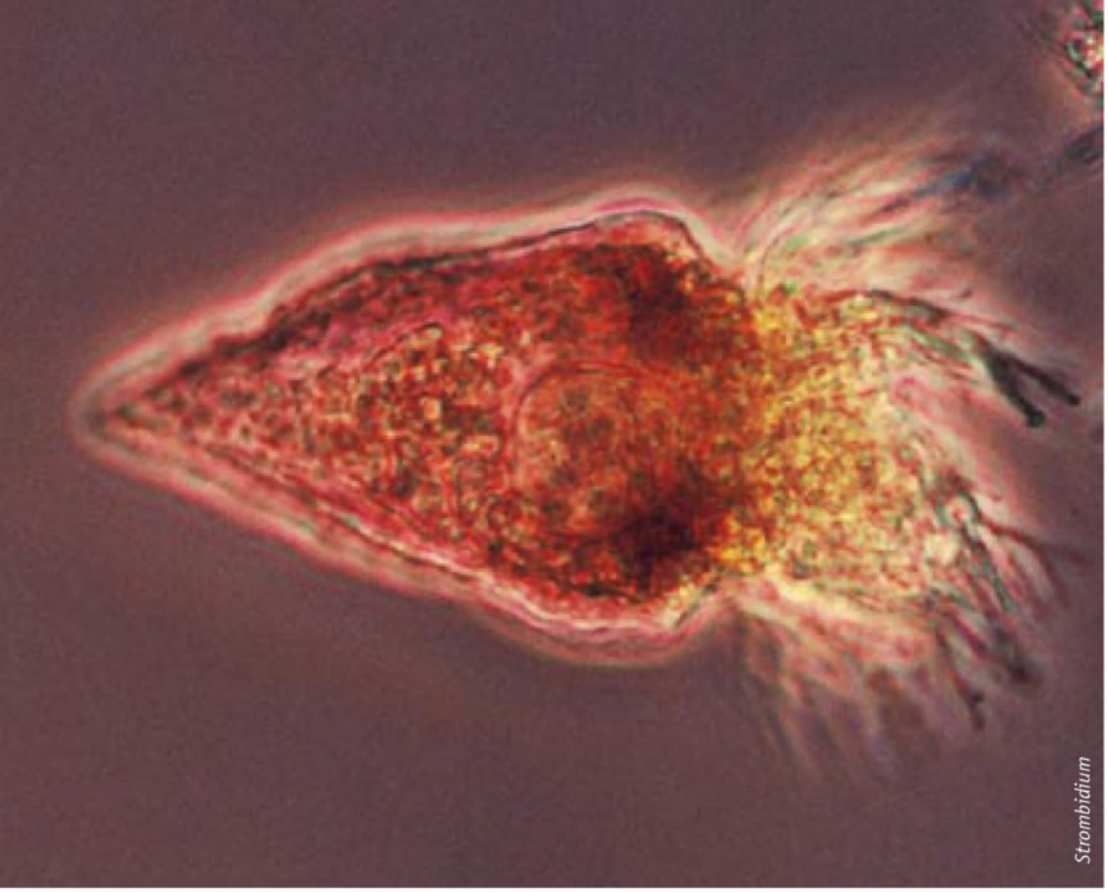
Phytoplankton species composition in the Sea of Okhotsk varies seasonally and among regions, with the spring bloom mostly composed of diatoms and dominated by cold-tolerant species. Early-spring species that are highly abundant in the coastal zone include: *Thalassiosira nordenskioldii*, *T. gravida*, *T. decipiensis*, *T. hyalina*, *Bacterosira fragilis*, *Fragilaria islandica*, *F. striata*, *F. oceanica*, *Thalassiotrix longissima*, *Coscinodiscus oculus iridis*, *Detonula confervaceae*, *Porosira glacialis*, and *Asterionella kariana*. Late-spring species such as *Chaetoceros subcecundus*, *C. debilis*, *C. furcellatus*, *C. compressus*, *C. constrictus*, and *C. Radicans*, appear with seasonal warming. Neritic algae species are characterized by wide distribution ranges and can be found in deepwater areas of the Sea of Okhotsk. Other diatoms that are predominant within the offshore planktonic algae communities in the Sea of Okhotsk are *T. exentrica*, *Coscinodiscus marginatus*, and *C. atlanticus*. *Peridinium pellucidum*, *P. pallidum*, *P. depressum*, and *P. brevipes* are abundant in spring as is *Ceratium arcticum*.

Diatoms tend to dominate the species composition (by biomass) in the California Current System, with a few large species of diatoms (*Coscindiscus*, *Nitzschia*, and *Tripodonesis*) forming 81% of the phytoplankton biomass, particularly in upwelling centres.

Coccolithophores are important organisms in marine ecosystem dynamics and in biogeochemical cycles. Sediment trap experiments and sea water alkalinity studies suggest their production is more important in the central North Pacific Transition Zone and in the Gulf of Alaska than elsewhere in the North Pacific Ocean. Coccolithophores are typically less abundant in the Bering Sea, yet during the extremely warm, low nutrient conditions of the 1997/98 El Niño, their blooms caused significant changes to food web dynamics which persisted for several years (Figure 5). Limited information is available on the distribution, production, and factors initiating blooms of coccolithophores, especially in the open ocean.

[Figure 5] A coccolithophore bloom (milky green waters) in the Bering Sea on April 25, 1998.[6]

[6] Source: Photo provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE at the SeaWIFS Image Gallery.



Zooplankton

Zooplankton ("animal" plankton) provide the food web link between phytoplankton and larger animals (fishes, whales and seabirds). Many zooplankton are herbivorous although they also feed primarily on protist microzooplankton (requiring an extra step in the food web) if the phytoplankton is dominated by very small cells. There are also numerous carnivorous taxa. Many species are small with little ability to swim against ocean currents. They are often categorised by size as micro-zooplankton (20-200 µm), mesozooplankton (0.2-20 mm) and macrozooplankton (2-20 cm). Many species of fish and invertebrate have larval stages that are planktonic for at least part of their lives. The biology and taxonomy of zooplankton in the North Pacific Ocean tend to be better known than for phytoplankton, perhaps because of their larger size. However, the inability to survey zooplankton quickly and remotely, which is currently possible for chlorophyll, means that "function-related" information on zooplankton is quite limited in both time and space.

In the "microbial loop", phytoplankton growth is in balance with the grazing by microzooplankton, so that phytoplankton production is quickly converted back to basic nutrients. However, it is not clear what factors lead to this equilibrium. Limited information is available on microzooplankton species composition in the North Pacific Ocean. Because of the difficulty of identifying pico- and nanophytoplankton, knowledge of prey selection and prey-specific grazing rates of zooplankton (mostly protozoans) is generally lacking. For heterotrophic nanoflagellates, which are the dominant grazers of bacteria and picophytoplankton, understanding of their biomass, species composition, physiology, and ecology is still at a very rudimentary level.

In the Yellow Sea and East China Sea, crustacean copepods are the major zooplankton group, comprising 70.1% of the total zooplankton biomass on average. The remaining biomass includes dinoflagellate pyhtoplankton (5.8%, mostly *Noctiluca*), Cladocera (5.4%), Chordata (5.3%) and Chaetognatha (5.2%). Among the copepods, *Calanus sinicus*, *Paracalanus* spp., *Oithona atlantica*, and *Corycaeus affinis* are dominant through all seasons and occur in most areas, comprising 75.6% of the total copepod biomass. A conspicuous feature of the zooplankton in recent years has been blooms of the large scyphomedusa jellyfish, *Nemopilema nomuri*, in the East China Sea. An unusual bloom was first observed in 2000, and the largest bloom occurred in 2003. Ocean currents are believed to have carried the jellyfish to this region, causing serious problems for marine activities.

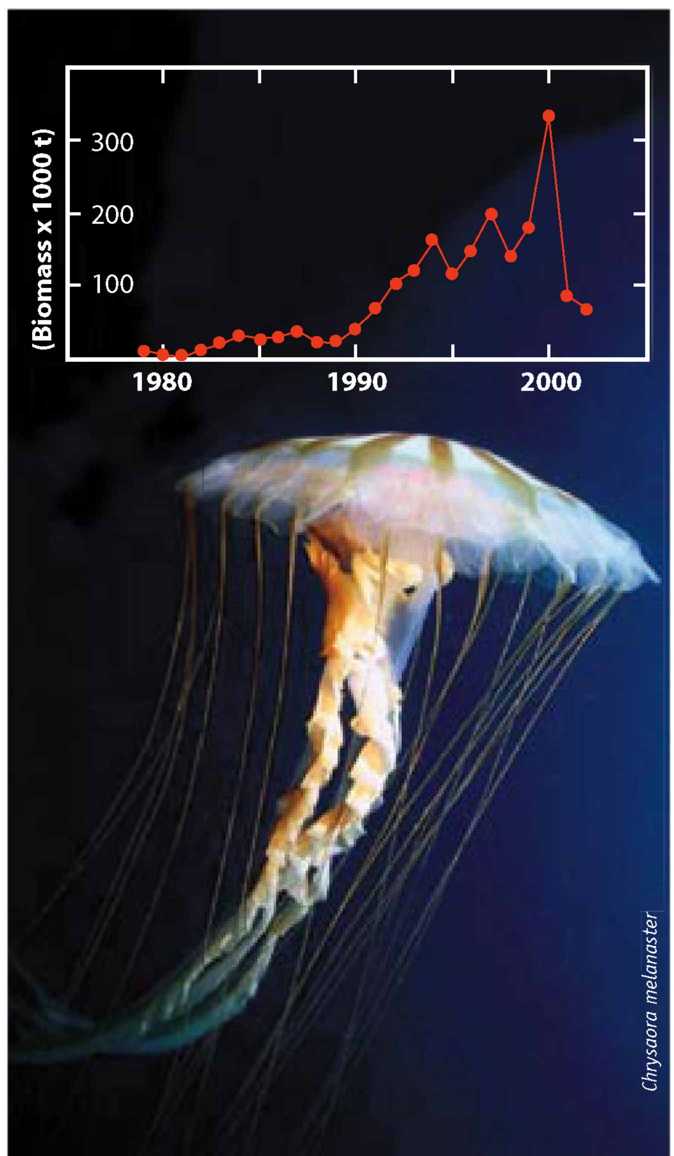
In the Sea of Okhotsk, most of the zooplankton biomass consists of macrozooplankton, particularly euphausiids, copepods, hyperiid amphipods, and chaetognaths. Cold-water species such as *Thysanoessa raschii, Parasagitta elegans, Metridia okhotensis,* and *Pseudocalanus minutus* account for most of the biomass, although in the southernmost parts of this area, warmer water species can be found in small numbers.

In the Oyashio and Kuroshio regions east of Japan, the biomass of zooplankton is well known, but knowledge of species composition or distribution is limited. The copepod fauna is dominated by *Neocalanus cristatus, N. plumchrus, Eucalanus bungii, Metridia pacifica, Pseudocalanus* spp., *Oithona* spp., and *Euchaeta/Paraeuchaeta* species. Copepods of the genus *Neocalanus* are the main components of the mesozooplankton biomass community in this region.

The zooplankton of the shelf regions of the eastern Bering Sea is composed mostly of the smaller continental shelf copepods such as *Calanus pacificus*, *Pseudocalanus* spp. and *Acartia longiremus*. The euphausiid, *Thysanoessa raschii* is also abundant. The zooplankton in deeper waters of the Bering Sea is dominated by the same large, open-water species that are found in the subarctic North Pacific Ocean: *Neocalanus plumchrus*, *N. cristatus*, *Eucalanus bungii*, *Metridia pacifica* (comprising 70-90% of the copepod biomass in the Bering Sea), and other species such as *Pseudocalanus* spp., *Thysanoessa* spp. and *Sagitta elegans*. In the late 1990s, and early in the 21st century, large blooms of jellyfish (mostly the large schyphozoan, *Chrysaora melanaster*) occurred (Figure 6). They are thought to have eaten 5% of the zooplankton and 3% of the young walleye pollock in the region.

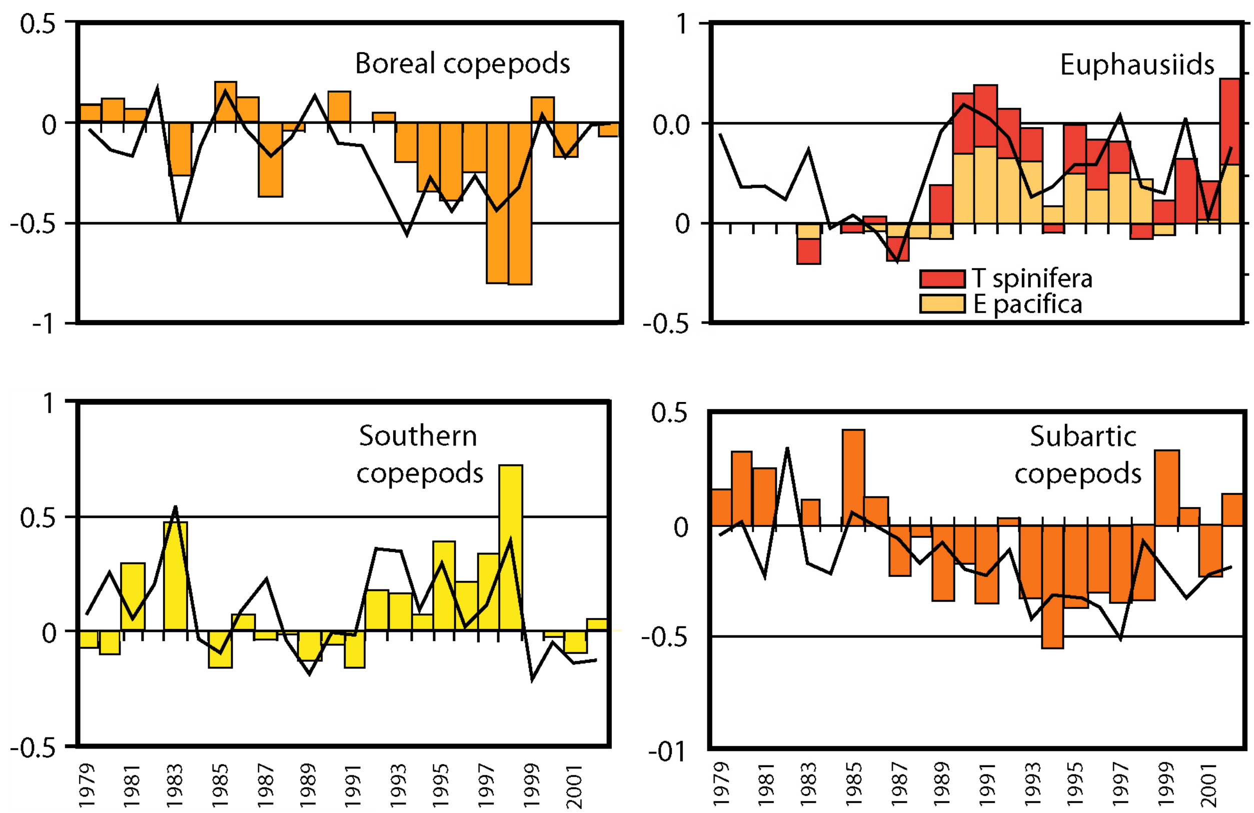
Mesozooplankton composition in the western subarctic Pacific and Gulf of Alaska are similar, although the biomass is higher in the western than in the eastern region. Five subarctic copepods are dominant in these regions: *Neocalanus plumchrus*, *N. cristatus*, *N. flemingeri*, *Eucalanus bungii*, and *Metridia pacifica*. In the western subarctic Pacific, *Neocalanus plumchrus, N. cristatus,* and *Euchaeta bungii* dominate and can constitute 80-95% of total mesozooplankton biomass. Other important non-copepod zooplankton include the chaetognath, *Sagitta elegans*, the euphausiids, *Thysanoessa longipes* and *Euphausia pacifica,* and the mollusks *Limacina helicina*, *Clio pyramidata*, *Clione limacina*. At least 290 species of zooplankton have been reported from the oceanic, shelf, and coastal waters of the northern Gulf of Alaska. Species composition on the continental shelf is characterized by a strong cross-shelf gradient, and considerable cross-shelf exchanges can occur. The zooplankton community on the inner continental shelf and within coastal embayments of the Gulf of Alaska region typically consists of a mix of oceanic (primarily *Neocalanus*) and neritic (*e.g.*, *Pseudocalanus*) species.

[Figure 6] Biomass index of gelatinous zooplankton, primarily *Chrysaora melanaster*, caught in surveys in the eastern Bering Sea.[7]



[7] Source: Photograph courtesy of Kevin Raskoff, Russ Hopcroft & NOAA. Data from Richard Brodeur (NOAA/Fisheries, Northwest Fisheries Science Center)

British Columbia tends to be the northern extent of species that are common in the Oregonian zoogeographic province, and the southern extent of species common in the Aleutian zoogeographic province. The location of this boundary corresponds to the split of the major trans-Pacific ocean current into the northward flowing Alaska Current and the southward flowing California Current. Shifts in zooplankton species composition in the northern areas of the California Current, between large, cold-water zooplankton and small, warmwater taxa, have been dramatic through the 1990s, and were particularly strong in 1998-1999 due to oscillations between warm and cool conditions (Figure 7). Copepod composition is dominated by the relatively large continental shelf species, *Calanus marshallae, Acartia clausii* and *A. longiremis* as well as smaller copepods, such as *Pseudocalanus* spp. and *Oithona similas*. An unusual and important component of the zooplankton in the upwelling areas of southern locations of the California Current is the bright red swimming galatheid crab, *Pleuroncodes planipes*, which can comprise 90% of total zooplankton biomass at these locations.



[Figure 7] Annual zooplankton anomalies averaged across southern Vancouver Island statistical areas and within groups of ecologically similar species (coloured columns). Lines show fits to the zooplankton anomaly time series from stepwise regressions on 1985–1998 time series of environmental indices.[8]

[8] Source: The work of David Mackas and colleagues and reprinted from PICES Special Publication No. 1, 2004.

Unexploited fishes and invertebrates

Fishes and invertebrates that are taken for reasons other than commercial purposes are rarely recorded or assessed in "official" statistics. These include species that are caught incidentally (non-target species) in commercial fishing operations, or species which are caught in "traditional" or artisanal fisheries. They include fish and invertebrates that live on the bottom (benthos), near the bottom (demersal), and/or in the water column (pelagic). Benthic animals are important scavengers and decomposers of organic material that falls to the bottom, and are therefore, important to the recycling of nutrients. They are also important prey for fish which feed on or near the bottom (demersal fish). Many of these unexploited species are relatively small, and are called micronekton. They can also be important links in the food web from smaller zooplankton to large fish, seabirds, and mammals. The fish component of micronekton is called "forage fish" because they are key prey items (forage) for larger fish. They are usually difficult to capture in commercial fisheries, either because they are too dispersed or live in habitats which are too difficult to fish commercially. Along with phytoplankton and zooplankton, unexploited fish and invertebrates include the largest number of undescribed or poorly described and counted species in the North Pacific Ocean. Benthic invertebrates include very small organisms that live within the bottom sediments (the "meiofauna", usually 100-1000 μm in length) and the larger organisms that live on the surface of the sediments (the "macrofauna", greater than 1 mm). Meiofauna include organisms such as nematodes, whereas the macrofauna include invertebrates such as seastars, crabs, etc. As might be expected, more is known about the benthic macrofauna than about the benthic meiofauna, although in the deep ocean, both are relatively unknown and are likely to provide exciting surprises and discoveries of new species. The relatively recent discovery of deep ocean "hot-vent" ecosystems, based on chemosynthetic primary production, is a recent example.

In the northern Yellow Sea, mollusks account for over 55% of the total benthic biomass, with echinoderms, polychaetes and crustaceans accounting for approximately 20, 15, and 10%, respectively; the benthic invertebrate species groups account for the remaining. In the Korean waters of the Yellow Sea, about 500 benthic invertebrate species have been reported, comprising 148 arthropods, 135 mollusks, 87 annelids, 34 cnidarians, 24 echinoderms, and 7 poriferan species.

robust clubhook squid

The dominant unexploited species groups in the open oceanic waters of the subarctic North Pacific Ocean are mostly part of the micronekton - a group of organisms

Chiroteuthis calyx

composed mainly of large-sized euphausiids and shrimps, and small-sized fishes and squids. This group also includes the early life stages of all larger squids such as Japanese common squid and neon flying squid, and finfishes, such as anchovy, sardine, mackerel, albacore tuna, skipjack tuna. The most important mesopelagic fishes in this region are the families Myctophidae and Bathylagidae; they are the most abundant by numbers and biomass (making up from 80 to over 90% of the total micronektonic fish catch). Mesopelagic cephalopods are important components of the micronekton in the subarctic and North Pacific Transition Zone. Micronektonic cephalopods are those species that are less than 60 mm in length, including some adults, but mostly the larval and juvenile stages of larger oceanic cephalopods.

For finfish micronekton in the subarctic North Pacific Ocean:

- taxonomic problems are mostly resolved, particularly for common species; larval taxonomy is known for the common species but relatively few scientists are familiar with their identification; egg taxonomy is not known for most mesopelagic fishes so this limits understanding of spawning seasons and grounds of myctophids;
- zoogeographic distribution patterns are reasonably well-described for adults, but not for many larvae;
- diel migration patterns are known for subarctic and transition zone species;
- life history studies are known for only several dominant species;
- knowledge of the ecological roles of these fishes is restricted to the feeding habits of several dominant species;
- quantitative biomass estimates are available for only a few species because an effective quantitative sampling technique has not yet been established.

For crustacean micronekton in the subarctic North Pacific Ocean, it is known that:

- the distribution and biology of Pacific euphausiids has been well-described, except for several rare meso- and bathypelagic species whose range is unknown;
- mysid biomass is highest (and diversity lowest) in the Bering Sea, while biomass and diversity are similar in both the western and eastern subarctic Pacific Ocean;
- the pelagic crab, *Pleuroncodes planipes* (Galatheidae) is perhaps the only benthopelagic galatheid species of sufficient abundance to be considered an important species in some upwelling regions, and with the potential to support a commercial fishery.

For the cephalopod micronekton in the subarctic North Pacific Ocean there is:

- good understanding of species that are common, and generally coastal, and ecologically important;
- recognition that species-specific life history and ecological information for early developmental stages is generally not available;
- recognition that information is lacking on life history and ecological relationships of the neutrally buoyant cephalopods (such as Histioteuthidae and Cranchiidae).

In the coastal and continental shelf areas of the Gulf of Alaska, common forage fish species include Pacific sandfish (*Trichodon trichodon*), Pacific sandlance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), eulachon (*Thaleichtys pacificus*), gunnels (Pholidae), and pricklebacks (Stichaeidae). Abundances are difficult to assess since these speciesare not retained well by the trawl nets typically used to sample in these areas. Abundance trends for several other groups that are caught in research trawl surveys suggest recent increases in sharks (spiny dogfish, *Squalus acanthias*, and Pacific sleeper shark, *Somniosus pacificus*), skates (Rajidae), grenadiers (primarily *Albatrossia pectoralis*), and yellow Irish lord (*Hemilepidotus jordani*), whereas other sculpins (primarily *Myoxocephalus* sp. and *Hemitripterus bolini*) decreased significantly. Trends in several non-commerical invertebrate groups suggest large increases over time in the frequency of occurrence of seastars, sea urchins, snails, sponges, bryozoans, and other invertebrate groups.

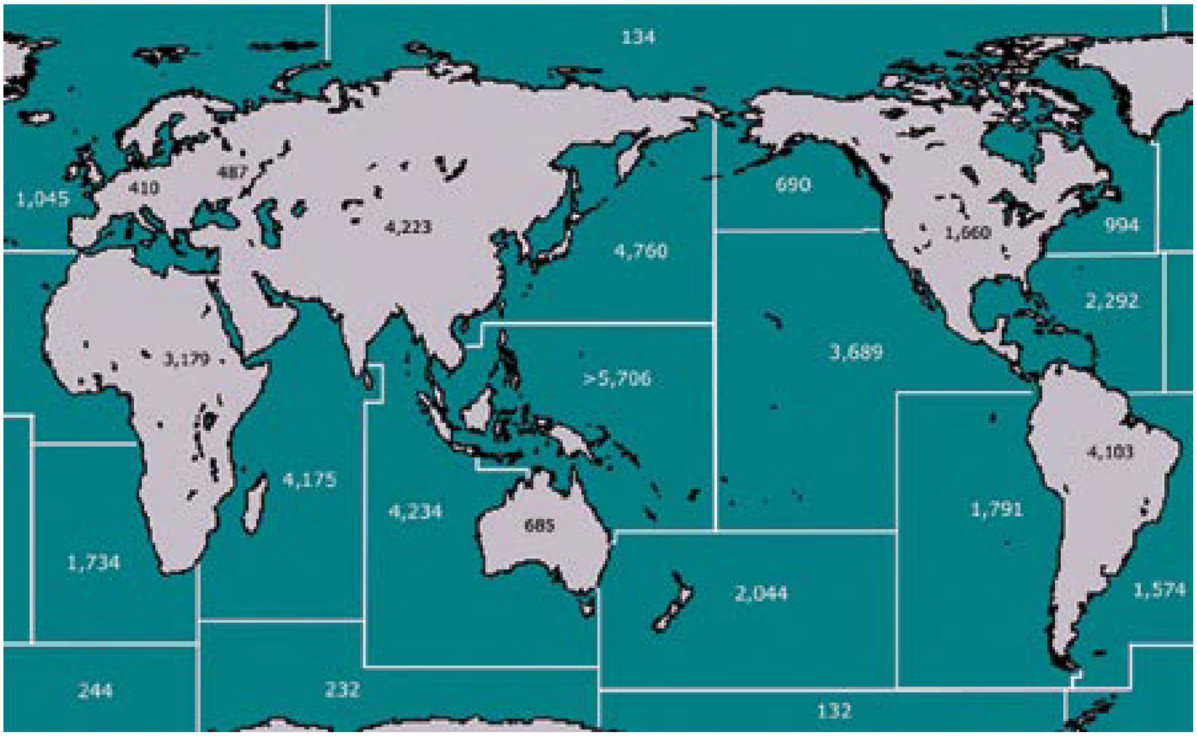
Opah

Commercially important fishes and invertebrates

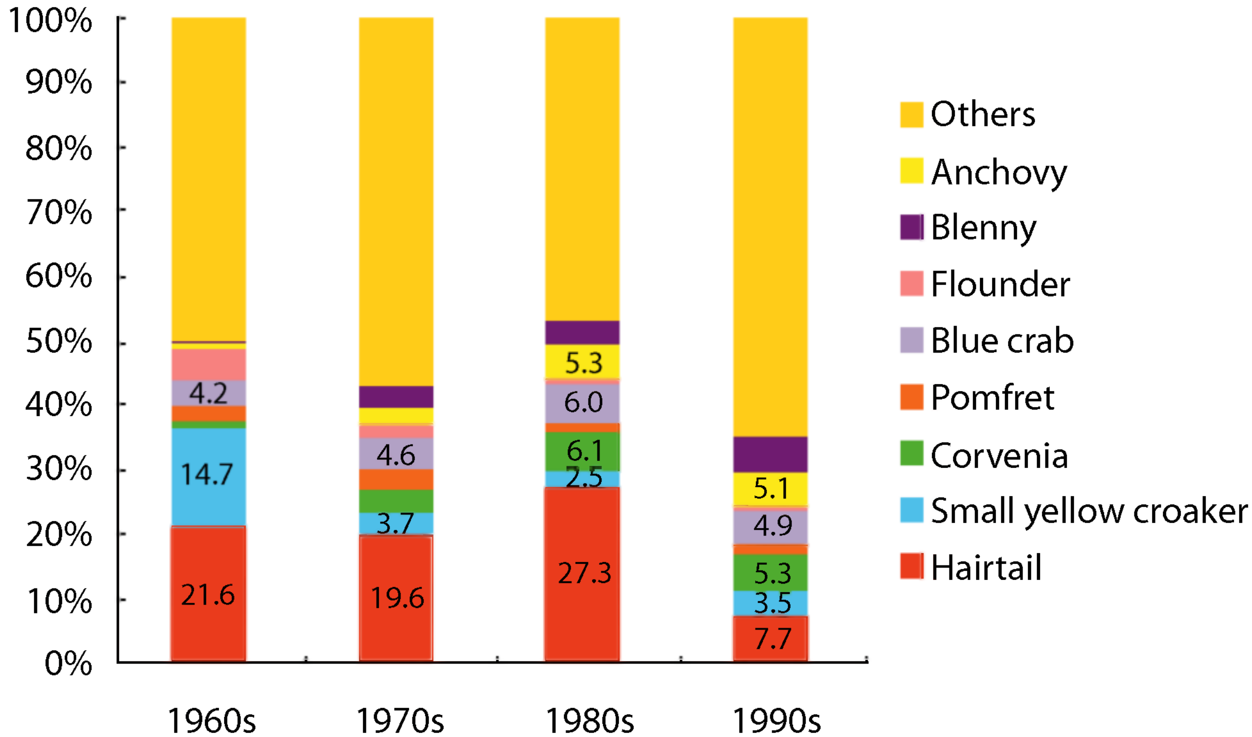
More is known about finfishes than most other species groups because of their generally larger size, and because they are the focus of intense commercial fishing. Statistics on fish catches are reported regularly to the Food and Agriculture Organization (FAO) of the United Nations. These indicate that the number of taxonomic families and species of fish in the North Pacific Ocean are similar to those in other non-tropical waters: 690 finfish species in the Northeast Pacific and 4,760 in the Northwest Pacific including the South China Sea (Figure 8). These species represent 138 finfish families in the Northeast Pacific, and 326 families in the Northwest Pacific.

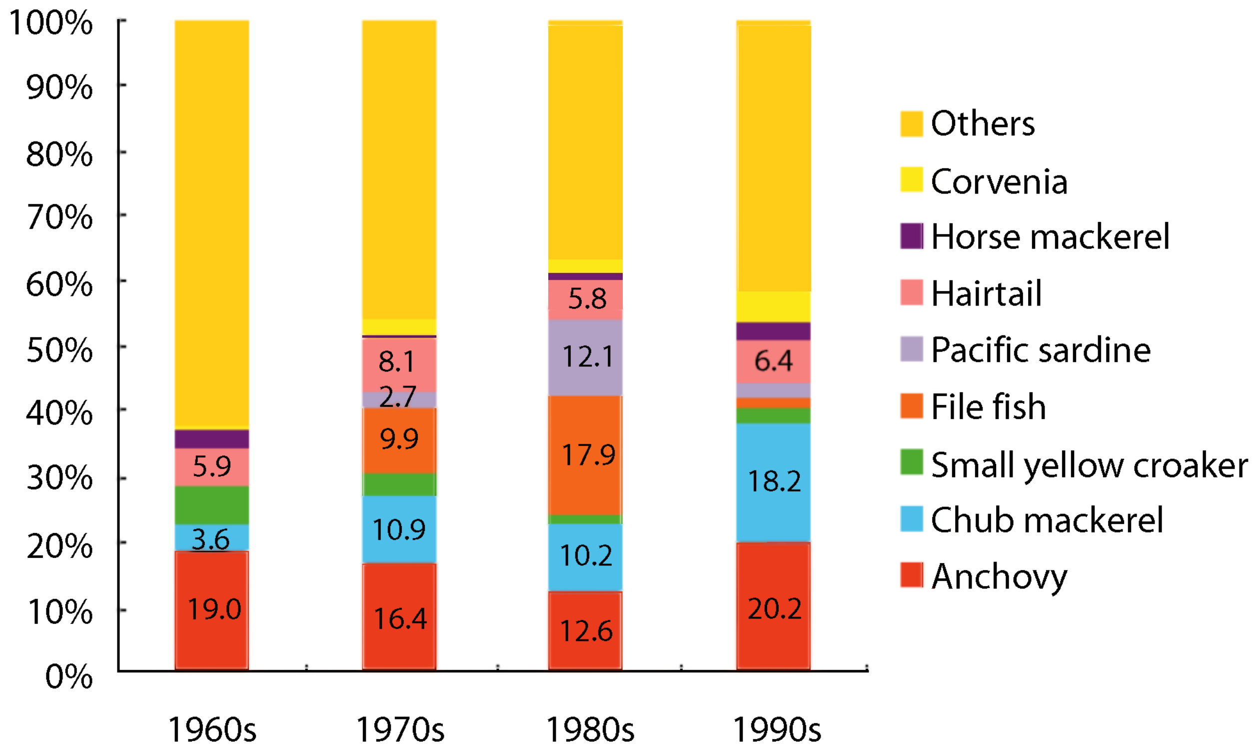
Sixty-two large marine ecosystems (LME) have been defined around the world. They are relatively large (more than 200,000 km^2) regions characterised by distinct bathymetry, hydrographic conditions, productivity, and interacting marine animal populations (http://www.edc.uri.edu/lme). The area, number of finfish species (commercial and non-commercial), temperature (surface and 100 m depth), and primary productivity for each of these regions were estimated by the Fisheries Centre of the University of British Columbia (http://saup.fisheries.ubc.ca/lme/lme.asp). These data indicate that a significant relationship exists between the area (in km^2) of each LME and the number of non-reef finfish species that occur in each LME. However, there is considerable variability in this relationship, and its predictive power is relatively low. The predictive power of this relationship can be increased considerably if temperature is included so that the number of finfish species in any (large) marine region of the world can be predicted from the area of the region and its annual average surface temperature. Warmer waters contain more species than colder waters for the same area, excluding tropical reef species. Including these would increase the number of species in warm waters even more. The number of finfish species that occur in the 11 LMEs of the North Pacific Ocean is what should be expected, based on the global relationships between species number, area, and temperature. However, the number of species in these North Pacific Ocean LMEs can be predicted with better accuracy if other parameters, such as annual primary production and the variability of bottom depth, are included. This relationship has high predictability, explaining 98% of the variability in the data, and can be used to estimate the number of finfish species that can be expected to occur in any (large) area of the North Pacific Ocean.

The number of demersal and pelagic finfish species which have been identified from each of the large marine ecosystems of the North Pacific Ocean are indicated in Table 3. As already noted, more species occur where the temperatures are warmer (compare, for example, the Yellow Sea and East China Sea with the eastern and western Bering Sea), especially the pelagic species.



[Figure 8] Number of finfish species caught in United Nations Food & Agriculture Organization statisical areas.





[Figure 9] Catch percentages by species (1961-2000) in the Yellow Sea (upper) and East China Sea (lower).[9]

[9] Source: PICES. 2004. Marine ecosystems of the North Pacific. PICES Special Publication 1, 280 p.

[Table 3] Number of demersal and pelagic (non-reef) finfish species in large marine ecosystems of the North Pacific Ocean.

LME	Total number of demersal species	Total number of pelagic species
Yellow Sea	570	244
East China Sea	487	258
Kuroshio	232	351
Japan/East Sea	339	91
Oyashio	18	18
Sea of Okhotsk	271	67
Western Bering Sea	215	54
Eastern Bering Sea	161	24
Gulf of Alaska	223	73
California Current	406	308
Gulf of California	186	94

[Table 4] Number of finfish species endemic to each large marine ecosystem of the North Pacific Ocean, and number of finfish species shared with at least one other LME of the North Pacific Ocean.

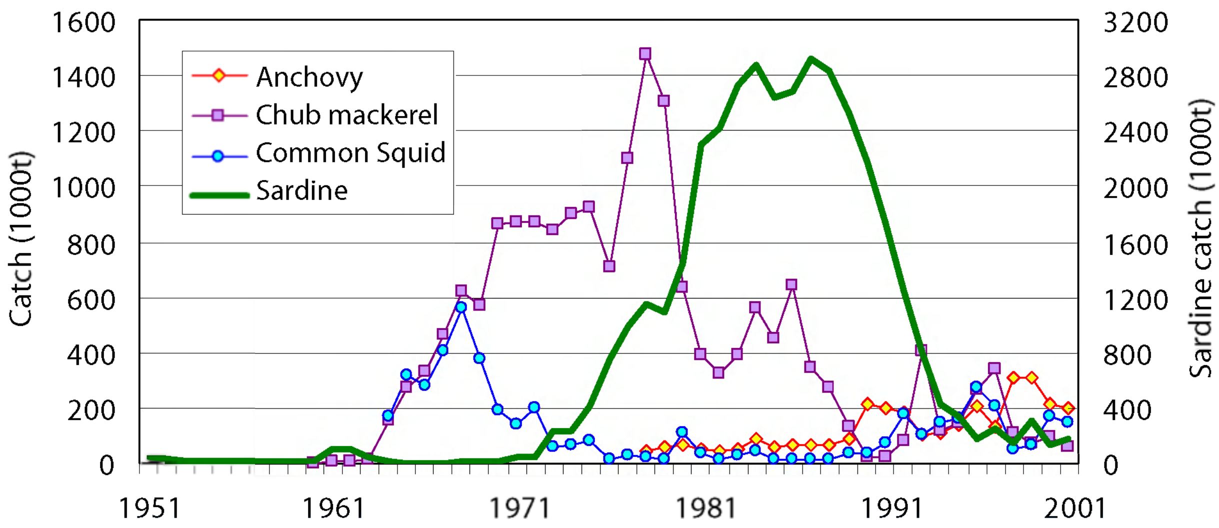
LME	Number of finfish species that occur only in this LME	Number of finfish species that occur in this plus at least one other LME
Yellow Sea	520	1383
East China Sea	271	755
Kuroshio	295	1151
Japan/East Sea	79	419
Oyashio	1	36
Sea of Okhotsk	117	222
Western Bering Sea	26	245
Eastern Bering Sea	10	176
Gulf of Alaska	14	294
California Current	272	449
Gulf of California	229	131

Not surprisingly, there is a high degree of overlap in the numbers of finfish species (including reef-associated species) which occur in the LMEs of the North Pacific Ocean (Table 4). What is more surprising, however, considering the potential for mixing and migrations of fishes among these ecosystems, are the numbers of finfish species which appear to be unique to each of these LMEs. The numbers of finfish species that occur only in the California Current, East China Sea, Gulf of California, and Kuroshio are high (greater than 200 species). However, this analysis considered only those LMEs in the North Pacific Ocean and did not take account of similarities in species composition with adjacent subtropical ecosystems, such as the South China Sea or the Pacific Central-American Coastal System. Since most of the systems with high species "uniqueness" are warmwater systems on the southern edge of the North Pacific Ocean, many of their species will be shared with adjacent subtropical ecosystems. In contrast, the Oyashio ecosystem has the lowest number of unique finfish species; excluding the ecosystems which border on subtropical systems, the highest numbers of unique finfish species occur in the Yellow Sea and the Sea of Okhotsk, both semi-enclosed regional seas having more restricted exchange with adjacent areas than an open offshore system such as the Oyashio.

The ichthyofauna of subarctic coastal systems (eastern Bering Sea, Sea of Okhotsk, parts of the Gulf of Alaska) is dominated by gadids and flatfishes. Walleye pollock (*Theragra chalcogramma*) has been the major species caught but its overall abundance is less now than 15 years ago. In the Bering Sea and the Sea of Okhotsk, various flatfishes such as yellowfin sole (*Limanda aspera*), rock sole (*Lepidopsetta bilineata*), flathead sole (*Hippoglossoides elassodon*), and arrowtooth flounder (*Atheresthes stomias*) are also important, as are the roundfishes Pacific cod (*Gadus macrocephalus*), saffron cod (*Eleginus gracilis*), Pacific ocean perch (*Sebastes alutus*), and Atka mackerel (*Pleurogrammus monopterygius*). Pacific halibut (*Hippoglossus stenolepis*) is the largest flatfish in the world and an important commercial species, particularly in the coastal Gulf of Alaska. Important pelagic species include Pacific herring (*Clupea harengus pallasi*) and capelin (*Mallotus villosus*). The five major species of Salmonidae are also important pelagic species in these open water and coastal systems. Commercially important crab species in these regions include several species of spider crab (Majidae). Typical macrobenthic groups include the Rhizopoda, Spongia, Hydroidea, Priapuloidea, Echiuroidea, Sipunculoidea, Bryozoa, Bivalvia, Cirripedia, Ophiuroidea, Echiuroidea, Holoturoidea, Ascidia, Amphipoda, Gastropoda, Asteroidea, Nemertini, Decapoda, and Anthozoa.

In contrast to the subarctic coastal systems which tend to be dominated by large and long-lived bottom fishes, the coastal and adjacent oceanic systems in temperate mid-latitude regions (Kuroshio/Oyashio, Yellow Sea and East China Sea, California Current system, Gulf of California) have important fisheries for small, short-lived pelagic fishes, in particular Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*). Past abundances of these species have fluctuated widely, often with the replacement of one dominant species by others. In the California Current system, important species include Pacific hake (*Merluccius productus*; also called Pacific whiting), "market" squid (*Loligo opalescens*), dungeness crab (*Cancer magister*), and red sea urchin (*Strongylocentrotus franciscanus*). A total of 276 species of fish have been identified on the Korean side of the Yellow Sea, and approximately 100 species have been utilized as resources. Over 90% of these species are warm or warm-temperate water species. Currently, about 30 species are commercially targeted (Figure 9), including small yellow croaker (*Larimichthys crocea*), largehead hairtail (*Trichiurus lepturus*), chub mackerel (*Scomber japonicus*), and Japanese anchovy (*Engraulis japonicus*). In the Kuroshio region east of Japan, Japanese sardine (*Sardinops melanostictus*), anchovy, chub mackerel and common squid (*Todarodes pacificus*) have constituted the major fraction of commercial landings since the early 20th century (Figure 10). In the Gulf of California, the shrimps (*Farfantepenaeus californiensis*, *Litopenaeus vannamei*, and *Litopenaeus stylirostris*) are among the most important living marine resources for Mexico in terms of income and employment. Small pelagic finfish species are also important commercial resources, including Pacific sardine (*Sardinops caeruleus*), anchovy (*Engraulis mordax*), and thread herring (*Opisthonema libertate*), particularly during El Niño events. Giant squid (*Dosidicus gigas*) are also fished in the Gulf of California.

The subarctic gyres in the western and eastern North Pacific Ocean (western Subarctic Gyre, Gulf of Alaska, and central North Pacific Transition Zone) are dominated year-round by Pacific salmon, and are used as important summer feeding grounds by many warmwater southern species such as Pacific pomfret (*Brama japonica*), Pacific saury (*Cololabris saira*), and various tunas, especially Pacific bluefin (*Thunnus orientalis*) and albacore (*T. alalunga*).



[Figure 10] Japanese catch of sardine, anchovy, chub mackerel, and common squid along the Pacific coast of Japan.

striped marlin with neon flying squid

Seabirds

Marine birds are important components of North Pacific Ocean ecosystems (Table 5). At least 137 seabird species inhabit the North Pacific Ocean, with total abundance estimated to exceed 200 million birds. They are widely distributed including many species which breed in the South Pacific but migrate to the North Pacific Ocean to feed in summer. Sizes of individual birds range from 20 g to over 8 kg. The number of species varies by region. The fewest number of species (24) occurs in the eastern subarctic, whereas the largest number (61) is in the Kuroshio/Oyashio regions. In general, the western Pacific has a higher species richness than the eastern North Pacific Ocean but the difference is only about 10%. Birds of large body mass (greater than 1 kg) predominate in the Bering Sea and California Current regions. Most of these species forage for small fish or macrozooplankton in the upper water column. Small (less than 125 g) marine bird species, such as storm petrels, predominate in the eastern and western subarctic gyres, and in the central North Pacific Transition Zone. These smaller birds forage at the surface, consuming mainly neuston (surface prey) and micronekton. A number of the seabird species are highly migratory, occurring in the North Pacific Ocean during boreal summer, and from the South Pacific to Antarctica during the boreal winter.

[Table 5] Numbers of species of seabirds (excluding shorebirds) by region.

Region	Number of species
East China Sea	25-36
Sea of Okhotsk	42
Kuroshio/Oyashio	54-61
Western Subarctic Gyre	31
Central Transition Zone	35-40
Eastern Bering Sea shelf	37
Gulf of Alaska (offshore)	24-30
Gulf of Alaska (coastal)	38
California Current (north)	52
California Current (south)	49

Marine mammals

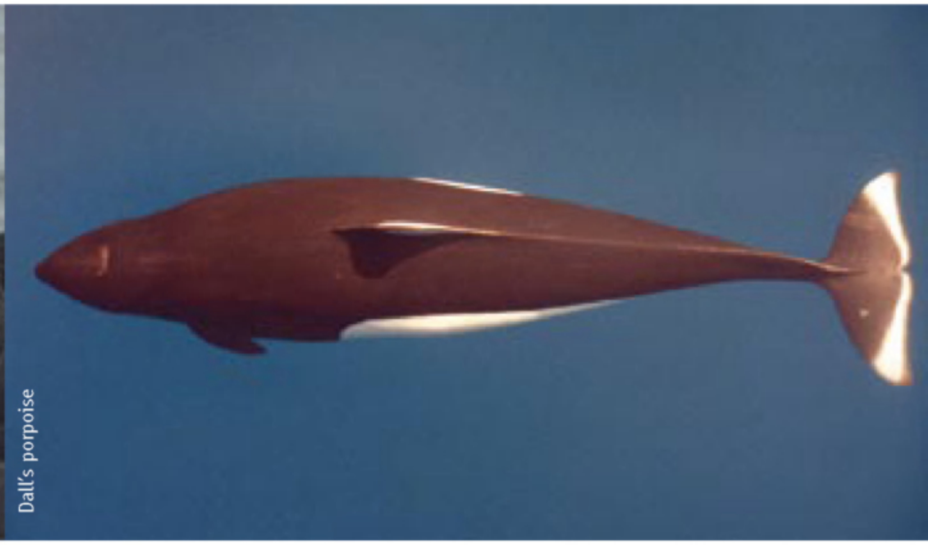
Marine mammals are among the most iconic marine species in the North Pacific Ocean, and the world. They include pinnipeds (seals and sea lions) and two kinds of cetacean; the baleen whales filter zooplankton and small fishes through specialized mouthparts, whereas the toothed whales feed higher in the food web. Although one might think that new marine mammals species are unlikely to be discovered in the North Pacific Ocean (Table 6), it has happened recently, and may happen again. In 2002, a new species of beaked whale, *Mesoplodon perrini*, was discovered using DNA analyses of five animals that were stranded on the coast of California.[10] These animals had initially been confused with a similar-looking species called *Mesoplodon hectori*, but it is now believed that *M. hectori* occurs only in the Southern Hemisphere whereas *M. perrini* is known, so far, only from the North Pacific Ocean. Although existing species vary greatly in abundance, counting individuals of any of the whale species is difficult, considering their wide-ranging open ocean lifestyle. Counting pinnipeds is somewhat easier as many species occupy rookeries to reproduce.

[Table 6] Numbers of marine mammal species by region in the North Pacific Ocean.

Region	Number of species
East China Sea	14
Sea of Okhotsk	19
Kamchatka and Kuril Islands	19
Western Subarctic Gyre	14
Central Transition Zone (west)	27
Western Bering Sea	20
Eastern Bering Sea shelf	22
Gulf of Alaska	18
Eastern Subarctic Pacific	13
California Current (north)	16
California Current (south)	30
Central Transition Zone (east)	27

[10] Source: Dalebout, M.L. et al. 2002. A new species of beaked whale *Mesoplodon perrini* (Cetacea: Ziphidae) discovered through phylogenetic analyses of mitochondrial DNA sequences. Marine Mammal Science 18(3): 577-608.

Northern fur seals



Dall's porpoise

Among the cetacean species recorded in the East China Sea and Yellow Sea, fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutrostrata*), killer whale (*Orcinus orca*), Blainville's beaked whale (*Mesoplodon densirostris*), and finless porpoise (*Neophocaena phocaenoides*) have been observed commonly. In the Changjiang river estuary, in China, two endangered migratory freshwater cetaceans, baiji (*Lipotes vexillifer*) and finless porpoise can be found. The former, listed as a critically endangered species in the International Union for the Conservation of Nature and Natural Resources Red Book, lives only in China. Larga seals (*Phoca larga)*, inhabit many coastal areas of the Yellow Sea.

In the Okhotsk Sea, there are four species of the true seal (Phocidae): ringed seal (*Pusa hispida*), ribbon seal *(Histriophoca fasciata*), bearded seal *(Erignatus barbatus)*, and larga seal; and two species of eared seal: northern fur seal (*Callorhinus ursinus*) and Steller sea lion (*Eumetopias jubatus*). The Kuril Islands are inhabited by the island form of the common seal, the antour (*Phoca vitulina stejnegeri*). Steller sea lions in the Okhotsk Sea are most numerous in the Kuril Islands region.

In the Gulf of Alaska, Steller sea lions are found along the British Columbia coast through to southeastern Alaska, Prince William Sound, Kodiak Island, along the Aleutian Islands and several small islands in the Bering Sea, most notably Bogoslov Island, and along the Commander Islands. Northern fur seals (*Callorhinus ursinus*) also have a similar range. The sea otter (*Enhydra lutris*), gray whale (*Eschrichtius robustus*) and humpback whale (*Megaptera novaeangliae*), and California sea lion (*Zalophus californianus*) occur regularly in the California Current system.

The Gulf of California is a region of high marine mammal diversity (31 species; 4 pinnipeds and 27 cetaceans). During the 1990s, mass mortalities of several marine mammal species occurred here: 367 dolphins (*Delphinus capensis, Tursiops truncatus* and *Stenella coeruleoalba*), 51 California sea lions, and 8 whales (*Balaenoptera physalus, B. acuterorostrata,* and *B. edeni*). In 1997, 168 dolphins (*D. delphis* and *T. truncatus*), 9 California sea lions, 4 whales (*B. physalus*) died, and during 1999, nearly 100 whales died inside the gulf (*Balaenoptera* spp.).

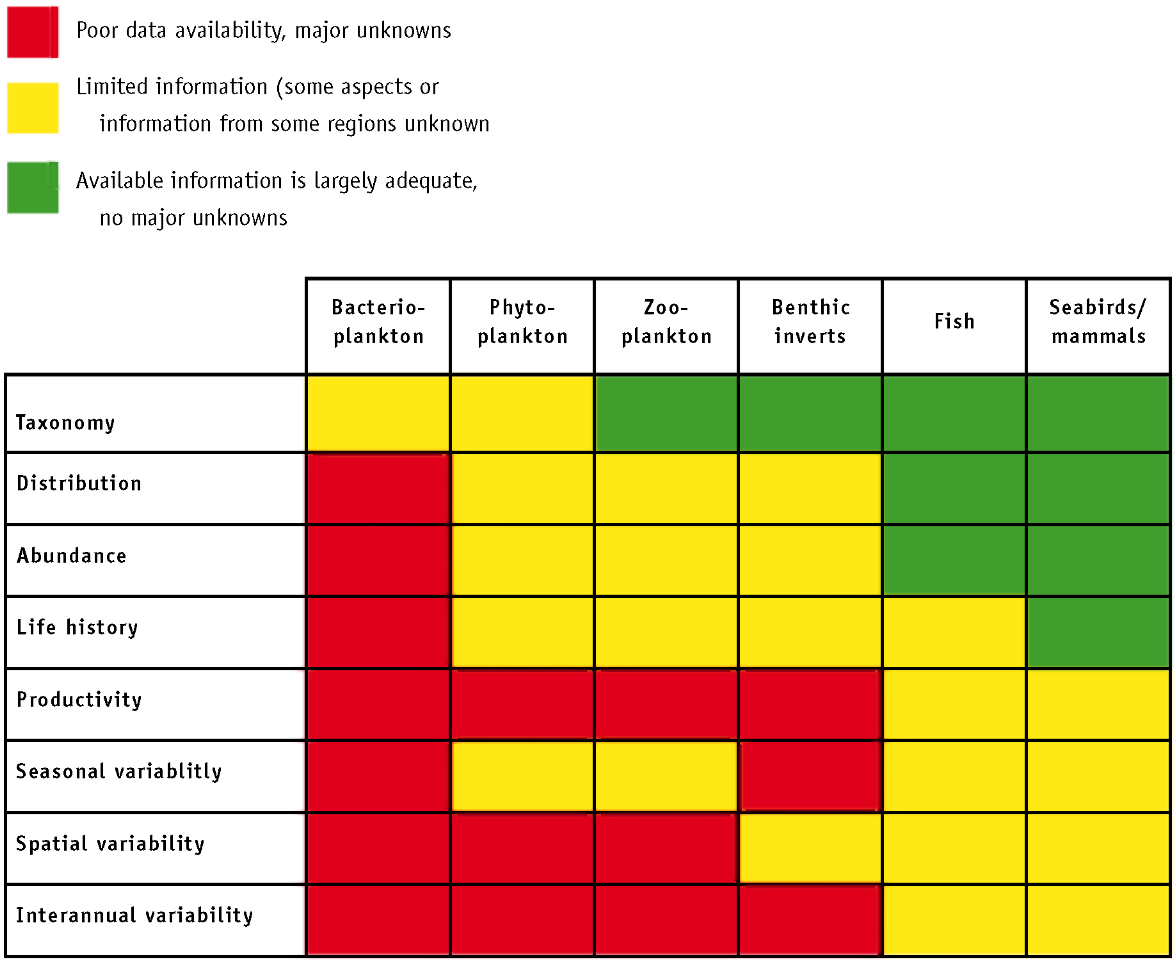
Turtles

Two species of sea turtle are common occupants of the central North Pacific Transition Zone: loggerhead turtles (*Caretta caretta)* and leatherback turtles (*Dermochelys coriacea)*.

Much is known about marine life in the North Pacific Ocean. However, much remains unknown, but could be known if appropriate research were conducted. In addition to items identified as poorly known in the previous section, major questions include:

- what data are available but have not been "converted" to knowledge yet?
- is the particular knowledge relevant and worth knowing?
- why do we need it?
- what / where / when should we monitor?

the unknown



[Figure 11] Summary of unknowns in the North Pacific Ocean.

Figure 11 identifies many of the key unknowns about marine life in the North Pacific Ocean. This graphic provides a snapshot of taxonomic groups for which we have relatively good information (green squares), and those for which we have “relatively” poor information (red squares). Groups for which we have better information are represented by larger-sized taxa where information on individuals (some of the larger zooplankton, fishes, mammals, and seabirds) can be obtained. Taxa with less information tend to be the smaller organisms, and the missing information relates mostly to their ecological roles. By taxonomic group, the major unknowns are listed below.

Bacterioplankton

roles and importance are poorly understood because:

- of limitations of available technologies for identification and sample processing;
- many unknown taxa with the definition of "taxa" often relying on biochemical and genetic methods;
- of basic lack of information on distribution, abundance, and life history;
- estimates of productivity under oceanic conditions are not available;
- there is little or no information on seasonal, spatial, and interannual variability.

Phytoplankton

are somewhat better known, especially the larger forms (larger than 2 µm). However, understanding is lacking for:

- smaller organisms (smaller than 2 µm) in terms of species composition;
- productivity, where estimates are few and/or of poor quality;
- seasonal, spatial, and interannual variability, except in selected regions;
- what controls species composition within phytoplankton blooms (especially harmful algal blooms);
- which species can reach very high abundance while others remain at barely detectable levels;
- species composition of blooms that are detected by remote sensing.

Zooplankton

are generally better known than phytoplankton because of their larger size and longer generation times, but a number of critical unknowns remain:

- distribution and abundance of rare species/taxa;
- few estimates of productivity;
- very limited information on seasonal, spatial, and interannual variability, except in selected regions;
- a need for new sampling devices, *e.g.*, gelatinous zooplankton is difficult to capture and observe;
- limited knowledge of mid-water oceanic shrimps which are likely important components of open ocean food webs;
- limited understanding of very deep oceanic zooplankton.

Benthic invertebrate

taxonomy is reasonably well-known, at least for the macrofauna of the continental shelves. In general, however, many unknowns remain:

- deep-sea benthic invertebrates poorly described, with much of their ecologies and physiologies unknown;
- distribution, abundance, and life histories of many non-commercial groups;
- few estimates of benthic productivity;
- little available information on seasonal, spatial, and interannual variability, except in selected regions.

Fish

taxonomy, distribution, and abundance is reasonably well-described, in particular for those species of commercial interest. However, the roles of these organisms in multi-species assemblages, and in the ecosystem, and for many species, their life history characteristics, are less well-known. Information on non-commercial species is much poorer, to the extent that it is unknown whether or not most species are critical for the functioning of healthy ecosystems. Unknowns include:

- life histories of many species unknown (both commercial and non-commercial species);
- few productivity estimates for non-commercial species;
- limited information on seasonal, spatial, and interannual variability of many groups.

Seabirds and marine mammals

are perhaps best known because individuals can be observed and tracked, and because they must come to the ocean surface at some time to breathe. However, critical unknowns remain:

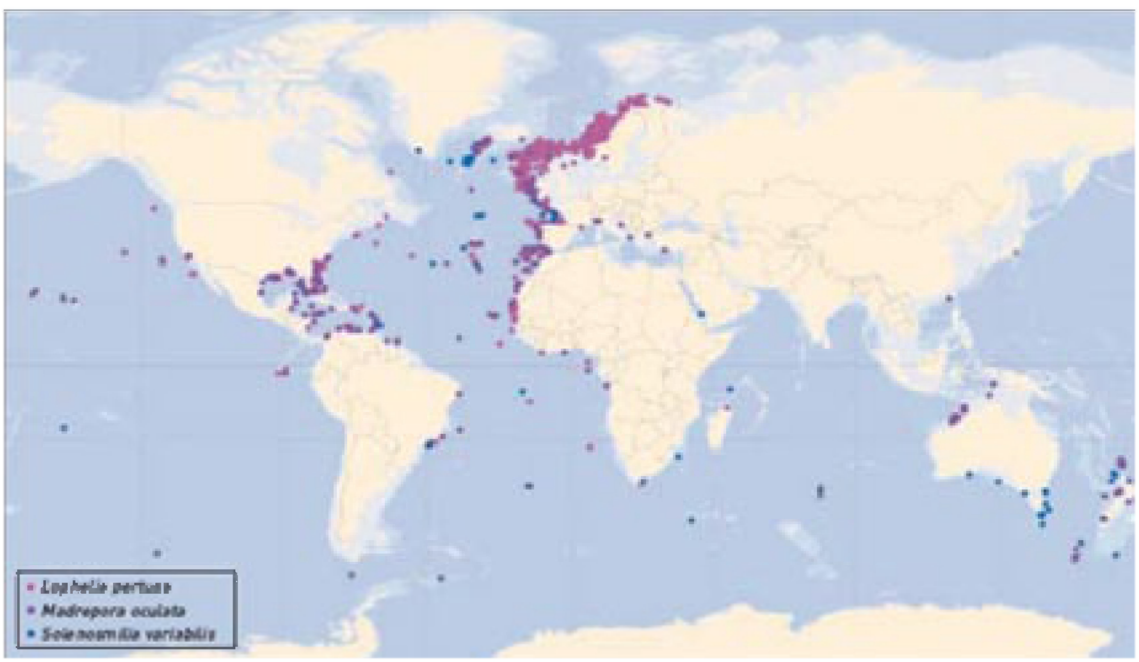
- productivities of many species in most regions;
- on seasonal, spatial, and interannual variability of many groups.

Aurelia aurita

Exciting discoveries

Two of the most exciting and surprising events concerning life in the oceans that have occurred during the past 20 years have been the discovery of deep-vent ecosystems, which derive their energy from chemosynthetic rather than photosynthetic processes, and the discovery of a new Kingdom of bacterioplankton (the Archaea). Such discoveries were unexpected, especially the deep-vent ecosystems. By the very nature of “surprise”, it is unknown whether other ecosystems that exist on non-photosynthetic forms of energy might occur in the ocean. Deep benthic communities are generally poorly known, and it is certain that new species will be found among these communities. The past few years have seen an increase in awareness of deep cold-water corals (Figure 12), and a growing recognition that many of these coral species are undescribed, or have never been seen before. It is likely that are new species of invertebrates to be discovered, living in association with these deep corals – but discovering them is likely to require specialised sampling equipment. Many more deepwater coral aggregations have been found in the North Atlantic than in the North Pacific Ocean, however, this likely reflects a greater effort to sample in the Atlantic Ocean. For example, most deepwater coral reefs in the North Pacific Ocean were discovered from fragments of coral brought to the surface as bycatch in bottom trawling fish boats. There is an obvious need for more study of these ecosystems in the North Pacific Ocean, yet these deep, cold-water corals are increasingly being damaged and destroyed by deepwater trawling for finfishes.

During the past 20 years, there has also been increasing awareness of the importance of very small organisms and the microbial food web – both as a cycle itself, and its relationship to higher trophic levels. Some reports have suggested that a well-developed microbial food web may shunt energy and materials away from the “traditional” food web that leads to higher organisms, thereby decreasing the total productivity of higher trophic levels. Some studies have suggested that gelatinous zooplankton are particularly adapted to feeding on the organisms of microbial food webs, and that there is a dichotomy between diatom and dinoflagellate-based food webs which



[Figure 12] Global distribution of cold-water coral reefs: points on the map indicate observed reefs of varying size and stages of development, but not the actual area covered. The high density of reefs shown in the North Atlantic most probably reflects the intensity of research in this region. Further discoveries are expected worldwide, particularly in the deeper waters of subtropical and tropical regions.[11]

[11] Source: From Freiwald, A., Fosså, J.H., Grehan, A., Koslow, T., Roberts, J.M. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

Pacific white sided dolphin

leads to fish production versus microbial-based food webs that produce jellyfish. Since gelatinous zooplankton are particularly difficult to sample quantitatively, and to capture live for physiological studies, the potentially contrasting importance of finfish versus gelatinous zooplankton food webs remains an important unknown. Resolution of this problem is likely to require new non-destructive, but rapid sampling methods.

An invaluable service that a program like the Census of Marine Life could offer would be to set standards and provide justifications for the development of new sampling systems for marine organisms. The experience of the discovery of the Archaea proves that new sampling systems will lead to new findings. Another activity which would benefit from Census of Marine Life leadership is encouragement to train new taxonomists, for invertebrate plankton and benthos in particular. This should include the use of genomic technologies to "rapidly" distinguish species. Building computer simulation models of food webs and ecosystem structure is also a valuable exercise to synthesise information, and to identify critical information gaps, *e.g.*, in species composition and their roles in ecosystem functioning and stability.

What might be "unknowable" about marine life in the North Pacific Ocean? In fact, "unknowable" is a moving concept, with what might be unknowable today perhaps being unknown tomorrow, but known the day after if the right scientific discoveries and technological developments occur. For example, the human genome was unknowable until methods of gene mapping were developed and resources applied to this problem. Today, the human genome has been mapped, although relating gene sequences to specific traits or actions still lags far behind.

the unknowable

Fundamentally unknowable

Identification of all species

It is unlikely that all species living in the North Pacific Ocean will ever be identified and described. New species are still being discovered, even in terrestrial environments where observations are far easier to make than in the ocean. The area of the globe covered by the North Pacific Ocean, its volume, its three-dimensional environment, and the difficulties of conducting direct observations lead to the conclusion that all species will never be discovered. Nevertheless, there is a hierarchy of discovery: larger species, in particular, those that live near the air-water interface, are more likely to be discovered. All organisms at the lower trophic levels, the smaller benthos (meiobenthos), zooplankton, phytoplankton, and bacterioplankton which are likely to be very speciose, but very difficult to discover, especially in the deep ocean, are those most likely to be unknowable. "Absence of evidence is not evidence of absence" is the appropriate advice here; if we believe we have discovered all species, it will take only one new find to prove us wrong. As for marine life in the North Pacific Ocean in the past, we may never know about all small marine organisms that may now be extinct.

Abundance of all species

For those species that are known to exist, it will be impossible to know the abundance of each. Sampling and time-scale problems are again the issue, since generation times range from less than a day, for bacteria and phytoplankton to decades for seabirds, marine mammals, turtles, and some fish and invertebrates (life spans of some rockfish and clam species in the North Pacific Ocean are known to exceed 100 years). Therefore, it is impossible to know the abundance of all marine organisms at any instant in time. Even "relative" abundances may be unknowable for all species, considering the difficulties of direct sampling and the errors that occur if proxy measures (fishery catches) are used. The difficulties and experiences of estimating the abundances of commercial fish stocks, despite the enormous world-wide resources expended, demonstrate the point.

Applied unknowables

Species dominance

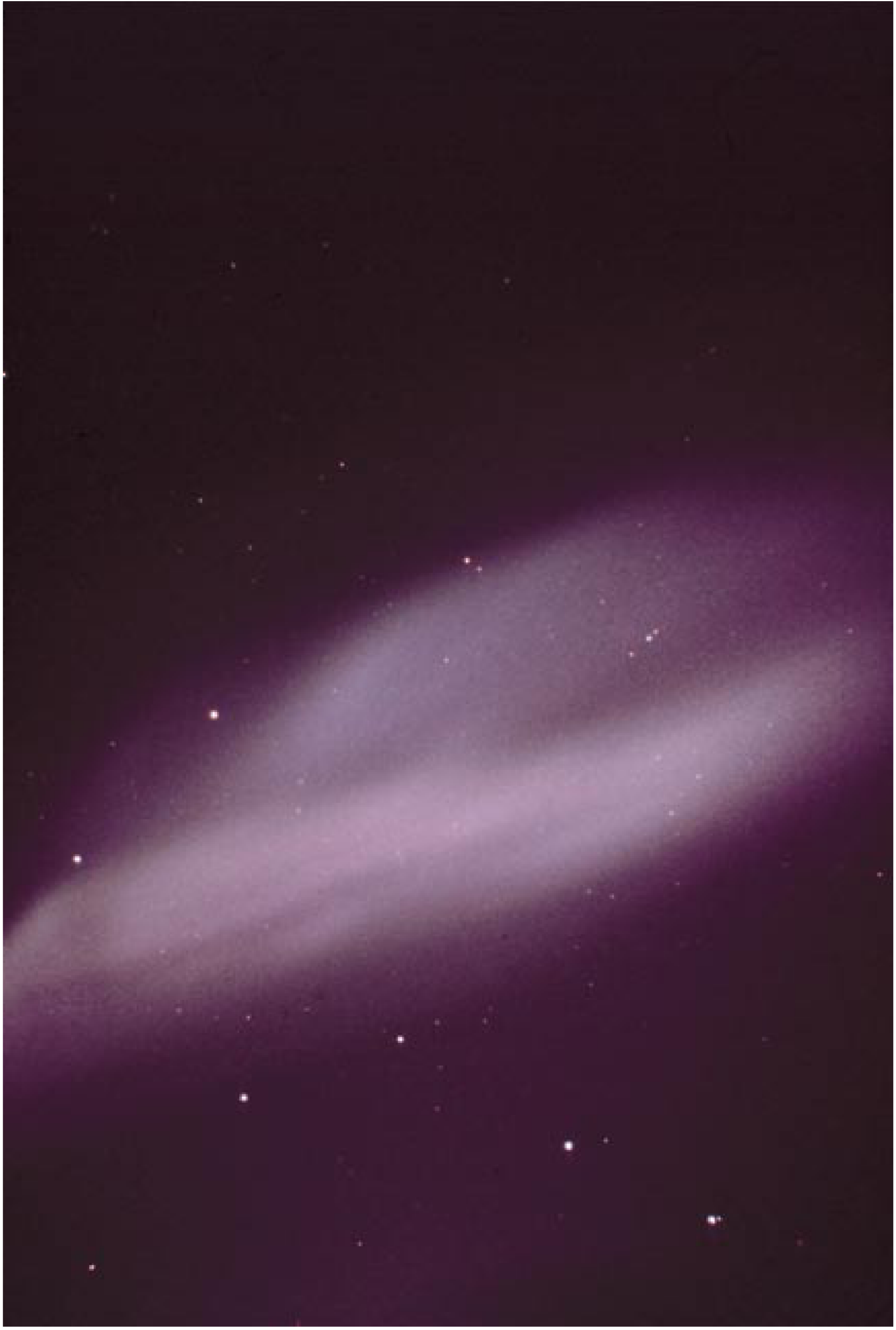
The dominant species of phytoplankton blooms can be predicted in a statistical sense for some locations and seasons. For example, the species of diatoms that will dominate the composition of plankton blooms on the continental shelves of the North Pacific Ocean can be predicted using probabilities developed from observations of past blooms. However, the composition of localized blooms, such as red tides, are much more difficult to predict in space and time; this is particularly true for blooms which produce human neurotoxins such as domoic acid. The unexpected occurrences of coccolithophore and gelatinous zooplankton blooms in the Bering Sea and Gulf of Alaska further illustrate the problem. Computer simulations may be able to model and predict bloom dynamics for the most common phytoplankton, but they are unlikely to predict blooms of previously rare species. Even if the computing power were available to include all rare species, it is unlikely that information on their physiologies and responses to subtle differences in environmental conditions would be available to correctly parameterize the model to simulate the real bloom dynamics.

Response to change

When the complexity of marine ecosystems is considered (Figure 1), the responses of individual species to climatic and anthropogenic change may be unknowable. The response of any species will depend on how the change affects that species directly (*e.g.*, a change in current patterns or water temperature) or indirectly as its predators and prey also respond to change. It will also depend on whether the species has a narrow or wide tolerance to environmental change and the rate of change, whether it has a narrow or wide spectrum of prey to capture and ingest, and whether its predators are selective or generalists. In addition, many marine organisms occupy different trophic niches during their life span and may even prey on their ultimate predators during their early life stages. Many models are available, and more are being developed that simulate marine ecosystem responses to climatic and anthropogenic change. Unfortunately, these models often aggregate many species into single "boxes" (usually species at lower trophic levels such as macrozooplankton) that eliminate differences which may be crucial to understanding the real responses of the ecosystem. This leads to the question of whether or not there are emergent properties of marine ecosystems that are more than the sum of the characteristics of individual species. There are hints that such properties may occur, *e.g.*, biomass-size spectra, but there is an urgent need for the development of macro-ecological theories of marine ecosystem structure and function.

Policy implications of "unknowables"

Each of these unknowables of marine life in the North Pacific Ocean is critically important. The search for new species must continue, both for the excitement and wonder of discovering new organisms, and for the knowledge gained by studying another solution to the struggle for life. The search is also crucial for understanding how ecosystems function and are stabilized against perturbations (*i.e.*, the role of biodiversity in providing ecosystem "goods and services"). Knowing abundances, or at least estimating relative abundances, is therefore essential to understanding the roles of species in a marine ecosystem, and critically important for understanding how humans affect these ecosystems through activities, such as fishing. Knowing species' roles in bloom dynamics and ecosystem responses to changes would also lead to understanding why these systems change in response to both natural and human forcing; these problems are too important to ignore. Nevertheless, we must recognize how much we are likely to know and, most importantly, what we will never know. Analytical methods, predictions, and policy responses to these predictions must consider this uncertainty, and the limits to our knowledge. At the very least, acknowledging the extent of our ignorance and the uncertainties about what can never be known may reduce the occurrences of "surprises", which, all too frequently, seem to be unpleasant.



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Clockwise from left to right:
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Out of camera range: Megrey, Parsons, Bychkov.

Previous PICES Special Publications

1. PICES. 2004.Marine ecosystems of the North Pacific. PICES Special Publication No. 1, 280 p.

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