Chapter 36C. North Pacific Ocean

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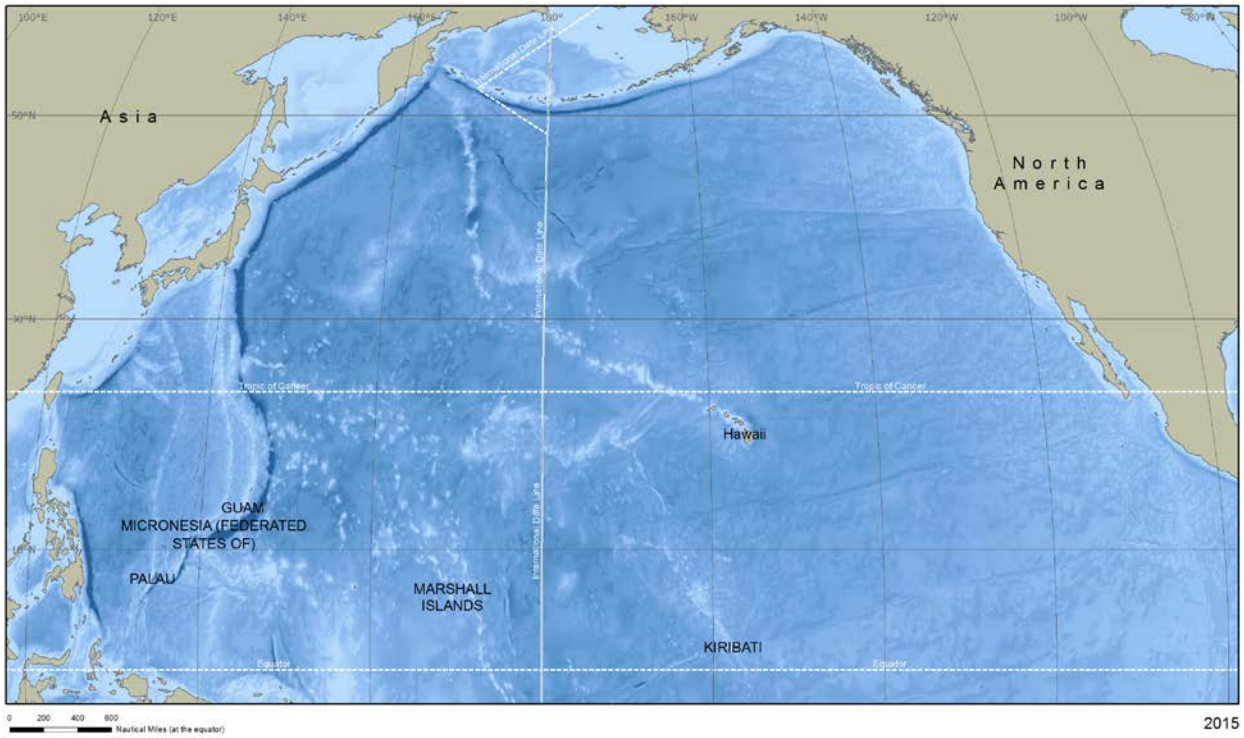
1. Introduction

The Pacific is the largest division of the World Ocean, at over 165 million km^2, extending from the Arctic Ocean in the north to the Southern Ocean in the south (Figure 1). Along the western margin are several seas. The Strait of Malacca joins the Pacific and the Indian Oceans to the west, and the Drake Passage and the Strait of Magellan link the Pacific with the Atlantic Ocean to the east. To the north, the Bering Strait connects the Pacific with the Arctic Ocean (International Hydrographic Organization, 1953). The Pacific Ocean is further subdivided into the North Pacific and South Pacific; the equator represents the dividing line. The North Pacific includes the deepest (and, until recently, the least explored) place on Earth, the Mariana Trench, which extends to almost 11 km below the ocean's surface, although the average depth of the North Pacific is much less, at approximately 4.3 km. Thus, the North Pacific encompasses a wide variety of ecosystems, ranging from tropical to arctic/sub-arctic with a wide diversity of species and habitats. Further, the volcanism that creates the "rim of fire" around the Pacific has resulted in unique undersea features, such as hydrothermal vents (including the Endeavor Hydrothermal Vents) and seamount chains (including the Hawaiian-Emperor Seamount Chain). Both create unique habitats that further enhance biodiversity in the North Pacific. The continental shelves around the North Pacific tend to be very narrow with highly variable productivity, with the exception of the continental shelf of the Bering Sea, which is one of the largest and most productive in the World Ocean (Miles et al., 1982). Further influencing productivity and biological diversity in the North Pacific is a series of large-scale oceanic currents on both sides of the basin, especially the Kuroshio and Oyashio Currents on the western side and the Alaska and California Currents on the eastern side. Also, the North Pacific Transition Zone (NPTZ) is an oceanographic feature of special importance to the biology of many species in the North Pacific Ocean. This 9,000 km wide upper water column oceanographic feature is bounded by thermohaline fronts thereby establishing a highly productive habitat that aggregates prey resources, attracts a number of pelagic predators, and serves as a migratory corridor. Ocean climate indices, such as the Pacific Decadal Oscillation (PDO), reflect spatial and temporal variability observed in the North Pacific (Mantua and Hare, 2002). For example, the PDO tends to indicate that a cool eastern North Pacific is associated with a warmer central and western North Pacific and *vice versa,* thereby contributing to spatial and temporal variability in ecosystem productivity and shifting patterns of biological diversity. The density of human habitation around the North Pacific is more concentrated in southern latitudes and on the western side of the basin.

This in turn influences the anthropogenic stressors affecting biodiversity and productivity.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1. Sources: Bathymetry extracted from the GEBCO Digital Atlas (GDA): IOC, IHO and BODC, 2003. Centenary Edition of the GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans, British Oceanographic Data Centre, Liverpool, U.K. More information at http://www.gebco.net/data_and_products/gebco_digital_atlas/
Ocean and Sea names extracted from ESRI, DeLorme, HERE, GEBCO, NOAA, National Geographic, Geonames.org, and other contributors More information at http://www.arcgis.com/home/item.html?id=0fd0c5b7a647404d8934516aa997e6d9. With the kind assistance of the FAO.

2. Coastal Areas of the North Pacific

Like other oceanic basins, the coastal areas of the North Pacific encompass a wide variety of complex habitat patches, each with different levels and types of biological diversity. Spalding et al. (2007) identify at least 50 ecoregions around the North Pacific, based in part on their relatively homogenized biological diversity and differentiation from adjacent areas, but status and trend information for biodiversity is not available even at this intermediate spatial scale. Limited information is derived from localized, smaller-scale studies conducted for specific habitat patches (e.g., coral reefs, estuaries, etc.) or fish stocks, but synthesis at the basin scale remains a critical gap for coastal areas of the North Pacific. For example, Japan has established a programme to track community-structure changes at 1,000 monitoring sites (both terrestrial and marine) and many countries around the North Pacific conduct stock assessments for major commercial species, but higher-level synthesis remains a gap. Furthermore, coastal systems are under different pressures in different parts of the basin, which will only complicate higher-level synthesis of status and trends.

2.1 Biodiversity status and trends

2.1.1 Primary producers

Climatic variability continues to increase in the North Pacific Ocean, especially in the eastern part of the basin, where both extreme warm and cool events have occurred in the Gulf of Alaska , the California Current and equatorial waters in recent years (Sydeman et al., 2013). At finer spatial scales, eddies and current meanders are important determinants of ecosystem productivity. For example, in the Gulf of Alaska region, eddies influence nutrients, phytoplankton, and even higher trophic levels (Ream et al., 2005). In the California Current, chlorophyll concentrations have increased (Kahru et al., 2009), but this has resulted in a shift to a community more dominated by dinoflagellates, at least in Monterey Bay, that has resulted in significant ecosystem changes, including impacts at higher trophic levels. In the Kuroshio Current region, the species-composition time-series is limited, hence it is not possible to identify trends in biomass, but the dominant taxa have been highly variable with an obvious diatom spike in 2004, possibly due to the meandering of this current (Sugisaki et al., 2010; Figure 2). In general, large-scale, taxonomically diverse time series for phytoplankton are lacking.

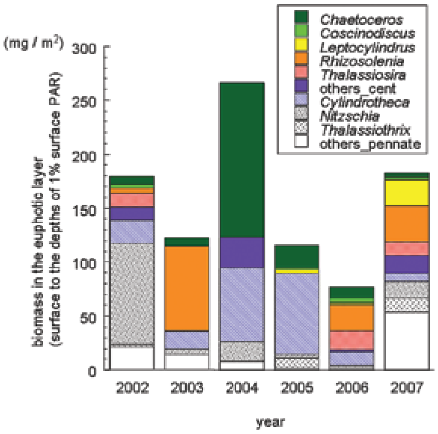


Figure 2. Composition of diatoms in the euphotic zone at Station B03 (34°N 138°E) in May (from Sugisaki et al., 2010).

2.1.2 Zooplankton communities

One of the most significant biological changes in the North Pacific is the explosion of gelatinous macrozooplankton in the western portion of the basin, especially the Yellow Sea, where medium to large jellyfish have become overly abundant in recent years and have resulted in increased reports of impacts (Purcell et al., 2007; Figure 3). This increase in jellyfish has had unforeseen biological (e.g., effects on productivity and diversity) and economic consequences (e.g., effects on fisheries, industry, and tourism) with resulting impacts to ecosystem and human services.

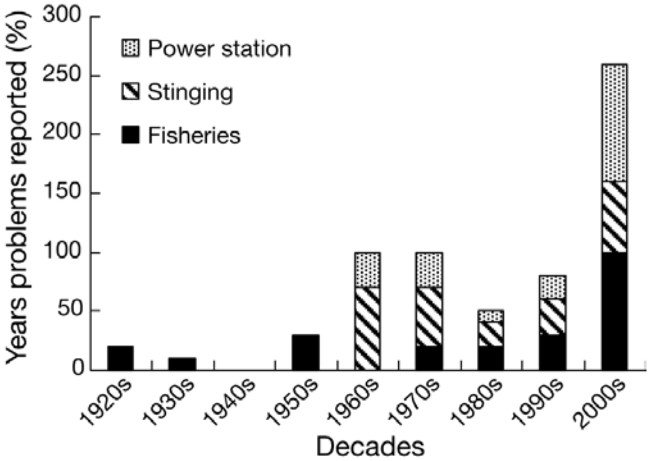


Figure 3. Percentage of years in each decade with reports of human problems with jellyfish in Japan (from Purcell et al., 2007).

Studying the California Current system Chelton et al. (1982) showed a strong correlation between zooplankton biomass anomalies and temperature anomalies. Thus, it is not surprising that recent changes between warm and cool periods in the eastern North Pacific coincided with large-scale changes in zooplankton community composition and abundance. Cool periods favour northern copepod species that tend to be larger and energy rich, making them good prey items while warm periods favour southern copepod species that tend to be smaller and energy poor making them less suitable prey (McKinnell et al., 2010; Figure 4). Anomalously strong upwelling further influences the zooplankton community composition and abundance in the California Current system. On the western side of the North Pacific, the hydrography of the Kuroshio Current acts to differentiate zooplankton biomass and diversity between the onshore and offshore sides and main stream of this current. Further, copepod biomass varies interannually with different seasonal peaks but the overall trend remains relatively constant (Sugisaki et al., 2010). Large-scale, taxonomically diverse time series are lacking for other important zooplankton species (e.g., arrow worms, pteropods, salps, krill).

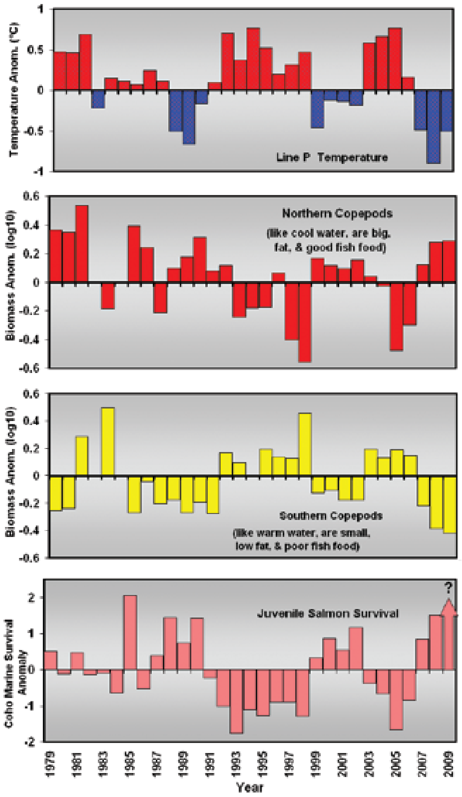


Figure 4. Northeast Pacific anomaly time series for upper ocean temperature, biomass of "Northern" and "Southern" copepods, and marine survival of coho salmon relative to ocean entry year (from McKinnell et al., 2010).

2.1.3 Benthic communities

Although cold, deep-water corals and sponges have received some attention in recent years (and some have been afforded special protection at regional or local scales), our understanding of the diversity and distribution of these organisms at larger spatial scales is very incomplete, making inferences about status of and trends in diversity impossible. Given their very slow growth rates and long regeneration times, they are particularly sensitive to disturbances, such as bottom-contact fishing gear, harvesting, natural resource exploration and extraction, submarine cable/pipelines, climate change, ocean acidification, and invasive species (Hourigan et al., 2007). Corals and sponges are not the only benthic taxa but no large-scale synoptic information was identified on status and trends in the diversity of other benthic communities in the coastal areas of the North Pacific. However, Kodama et al. (2010) and Kodama and Horiguchi (2011) document periods of defaunation in Tokyo Bay for macrobenthic and megabenthic communities, suggesting there have been decreases in benthic community diversity at least at local scales around the North Pacific (beyond the scope of this Assessment).

2.1.4 *Higher trophic levels*

McKinnell et al. (2010) provide the only intra-basin comparison of changes in key fish and invertebrate stocks between 1990-2002 and 2003-2008. In this study many taxa in the Sea of Okhotsk and Oyashio regions increased and many taxa in the California Current, Yellow Sea, and East China Sea decreased (Table 1). In addition to changes in abundance, distributional shifts occurred, related at least in part to changing ocean conditions; these shifts can have ecological and economic consequences on ocean services (e.g., Mueter and Litzow, 2008).

In the eastern North Pacific, a mid-water trawl survey for the California Current system provides evidence that the forage fish community of this ecosystem tends to alternate between a less productive warm community and a more productive cool community in response to widely recognized regime shifts in oceanic conditions (NOAA's Southwest Fisheries Science Center (SWFSC) in Bograd et al., 2010). Similarly, on the western side of the basin in the Kuroshio-Oyashio system, where a strong latitudinal gradient in annual productivity (Pope et al., 1994) exists, evidence of decadal-scale changes in fish communities or "species replacements" linked to regime shifts have been observed (Chiba et al., 2010; Figure 5).

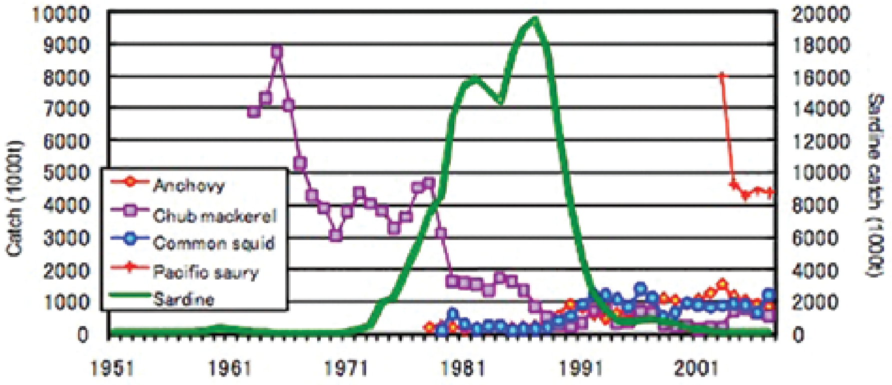


Figure 5. Biomass of sardine, anchovy, chub mackerel, Pacific saury and common squid (winter spawning stock) along the Pacific coast of Japan (from Chiba et al., 2010).

Pacific salmon are an economically and culturally important species in the North Pacific. Marine survival for over 40 coho salmon stocks has decreased substantially in the California Current system since the early 1970s, due at least in part to poor marine survival (Bograd et al., 2010; Figure 6); extremely low survival corresponds to the 2005 smolt entry year; this trend is also detected in marine birds (see 2a (v) below). Similarly, masu salmon (*Oncorhynchus masou*) in Japan have experienced significant declines in returns over the same period (Chiba et al., 2010). Additional higher trophic level species in the North Pacific include a variety of fish and invertebrate species, including: small pelagic species (e.g., anchovy, sardine, saury, mackerel, squid); large pelagic species (e.g., tuna, shark, billfish, ray); benthopelagic species (e.g., rockfish, croaker, cod); and demersal species (e.g., pollock, flatfish, crab), some of which may have experienced population declines at regional or sub-regional scales.

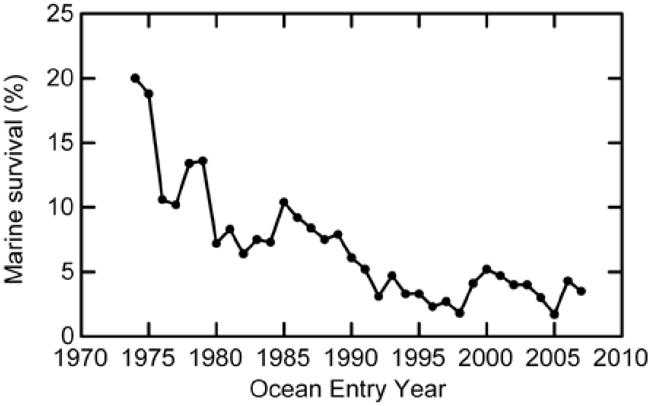


Figure 6. Average marine survival of up to 45 coho salmon (*O. kisutch*) stocks in the northern California Current region by year of ocean entry (from Bograd et al., 2010).

For Pacific salmon spawning in Canadian waters, the Canadian Department of Fisheries and Oceans has provided outlooks since 2002. In the most recent iteration, 91 stocks were assessed and an outlook provided for 84, of which 28 were linked to a conservation concern, despite 21 units showing improvement, compared to 9 that have worsened since the previous period (DFO, 2014). In the United States, the National Oceanic and Atmospheric Administration (NOAA) reports on the status of 480 managed stocks and stock complexes, including rockfishes, flatfishes, and gadoids, relative to fishing mortality and biomass reference points. Several of these stocks from the Pacific Ocean have been identified as overfished, but all domestic stocks are rebuilding and one stock (Sacramento River Fall Chinook) was recently removed from this list (NOAA, 2013). No domestic stocks in the Pacific currently are experiencing overfishing, although several stocks of highly migratory species are under international management and two species (Pacific bluefin tuna and striped marlin) were added to the list of overfished stocks in 2013 (NOAA, 2013).

2.1.5 Other biota

At least eleven species of marine birds and nine species of marine mammals designated as being at risk by the IUCN are found in the North Pacific; overall, it does appear that populations are either stable or increasing. Only planktivorous auklets in the Sea of Okhotsk appear to be the exception for marine birds (McKinnell et al., 2010; Table 3); Steller sea lions and harbour seals in the central and western Aleutian Islands, northern fur seals from the Pribilof Islands, and potentially harbour seals in Prince William Sound, Alaska, are the exceptions for marine mammals (McKinnell et al., 2010; Table 4) have experienced population declines. Additional species that are critically endangered in the North Pacific include the vaquita (*Phocoena sinus*) which is on the verge of extinction: only 241 animals were estimated in 2008 (Gerrodette et al., 2011) and Hawaiian monk seals (*Monachus schauinslandi*). Additional marine birds and mammals may be considered at-risk at regional or sub-regional scales that are beyond the scope of this Assessment.

In the California Current, increased variability has resulted in significant responses at higher trophic levels, including marine birds and mammals, and the cumulative effects of human-mediated stressors on marine predators can be difficult to unravel (Maxwell et al., 2013). For example, Cassin's auklets experienced an almost complete breeding failure in 2005-2006, due to changes in upwelling phenology that affected euphausiid prey populations (Sydeman and Thompson, 2010). Also, the California sea lion (*Zalophus californianus*), where the number of pups produced at the Channel Island reference site has shown a quadratic increase since the mid-1970s (Bograd et al., 2010), has experienced a recent decline in abundance and poor pup health. The spotted seals of the Yellow Sea also have decreased precipitously since the 1960s, due to overharvesting and habitat destruction; this has resulted in local extirpation and some rookeries support fewer than 150 individuals.

2.2 Major pressures in the coastal area and major groups affected by the pressures

In addition to global climate change impacts, including ocean acidification, there are a large number of coastal pressures affecting the North Pacific, similar to other coastal marine ecosystems, due largely to the diverse human-mediated activities in these environments. These include, but are not limited to: habitat loss; over-exploitation and fishing impacts; shipping; energy development/exploration; aquaculture; pollution (both direct and indirect), eutrophication and resulting impacts (pathogenic bacteria, harmful algal blooms; hyp/anoxia); species introductions/invasions; watershed alteration and physical alterations of coasts; tourism; and marine litter. None have been quantified at the scale of the North Pacific, but some regional patterns can be highlighted. Studies such as by Halpern et al. (2008) demonstrate that coastal area can be severely affected by human activities, including those in the western North Pacific. Furthermore, the Yellow and East China Seas area is one of the most densely populated areas of the world; approximately 600 million people inhabit this area, resulting in immense anthropogenic stressors on this coastal system. Urbanization in Asia is not unique and other coastal areas of the North Pacific also have experienced increased urbanization and an increase in a wide variety of ecosystem stressors.

Runoff from the Fraser and Columbia Rivers in the California Current region, the Amur River in the Sea of Okhotsk, the Changjiang River in the East China Sea, and the Pearl River and Mekong River in the South China Sea all play important roles in driving coastal processes and resulting ecosystem services. The Changjiang River is the world's third-longest river; its watershed of approximately 1.8 million km^2 encompasses about one-third of China's population and 70 per cent of its agricultural production. The widespread use of fertilizers for agricultural production has resulted in increased nutrient discharge to the coastal environment, causing increased eutrophication since the early 1970s. As a result, in the Yellow Sea, nitrogen:phosphorus and nitrogen:silicon ratios have been increasing basin-wide for decades (Yoo et al., 2010; Figure 7). This in turn has resulted in an increase in the frequency and intensity of harmful algal bloom events and a shift in the phytoplankton community from diatoms to dinoflagellates that have affected ecosystem services and increased the severity of hypoxic events in the estuary (Yoo et al., 2010). A related anthropogenic activity that could significantly alter riverine discharges is large-scale water diversion projects that would result in less discharge to coastal environments around the North Pacific. For example, much of the flow of the Columbia and Fraser Rivers is used for agricultural production that can result in less discharge reaching ocean in some years. This can result in reduced nutrient inputs, which in turn lowers productivity, and that reduction adversely affects the diversity that depends on it. As increased climate variability intersects with growing human populations and increased irrigation demands in coastal environments, reduced river discharges could have profound impacts on coastal productivity and biodiversity.

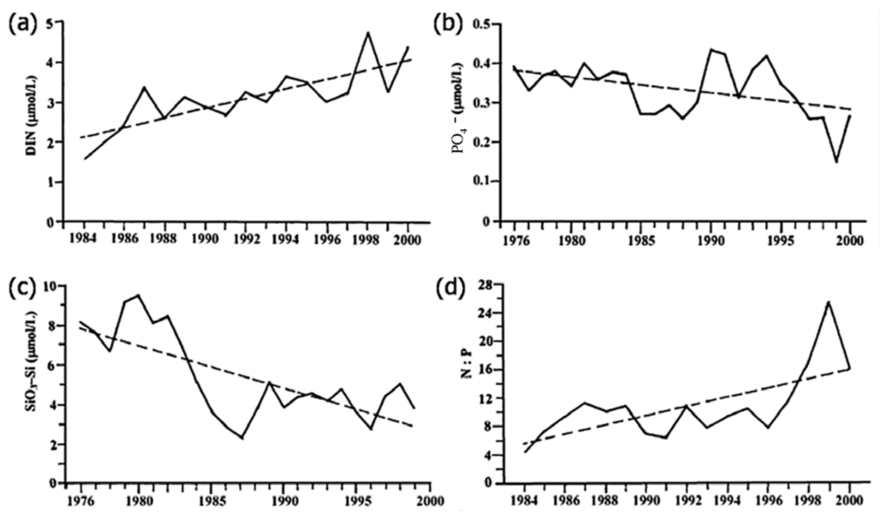


Figure 7. Long-term trend in the nutrients along a transect across 36°N in the Yellow Sea. (a) Dissolved Inorganic Nitrate (DIN), (b) phosphates, (c) silicates, (d) N:P ratio (from Yoo et al., 2010, and modified from Lin et al., 2005).

The introduction of non-indigenous species continues to result in economic and ecological consequences, including negative impacts on native biodiversity (Sala et al., 2000). In the first synoptic study of non-indigenous species in the North Pacific, Lee II and Reusser (2012) identified 746 species that were present in, but not native to, at least one ecoregion in the North Pacific. Of these, 32 per cent were native elsewhere in the North Pacific, 48 per cent were native to regions outside the North Pacific, and 20 per cent were cryptogenic (of unknown origin). Furthermore, the Hawaiian and Northeastern Pacific regions had considerably more introduced species than the Northwestern Pacific (Lee II and Reusser, 2012; Figure 8). Given the continued increase in global trade, it is expected that the number of species that will be introduced to new environments also will increase. Combined with the high species richness and density of non-indigenous species already reported for many regions that have significantly altered population, community, and ecosystem processes (Ruiz et al., 1997), additional, cumulative consequences of these invasions should be expected.

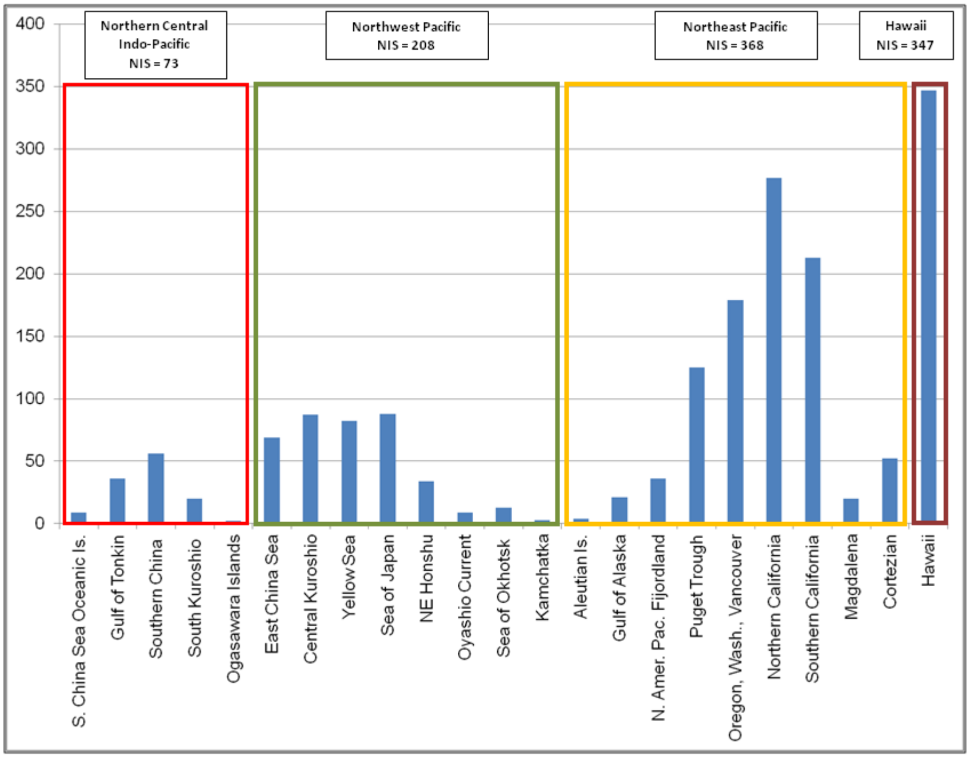


Figure 8. Number of non-indigenous species in central/northern North Pacific marine ecoregions (from Lee II and Reusser, 2012).

Other major stressors in the North Pacific include hypoxia, habitat destruction, pollution, and overfishing. However, none of these have been quantified at the scale of the North Pacific. Ocean acidification has dramatically impacted some calcifying organisms such as pteropods (Orr et al., 2005). Hypoxia has not only increased in the Yellow Sea, but continues to be a major pressure on coastal ecosystems in the eastern North Pacific, including off Oregon, with lethal consequences for benthic species (Grantham et al., 2004) and the western North Pacific, including Tokyo Bay where there has been a reduction in nutrient recycling (Kodama and Horiguchi, 2011). Further, the shoaling of this continental hypoxic zone has reduced habitat for several species, including some commercially important ones, which could alter ecosystem services. Habitat destruction is the leading cause of biodiversity loss (Sala et al., 2000). Many forms of habitat destruction and/or degradation are occurring around the North Pacific, including shoreline hardening/development and land creation, but quantifying the amount of habitat lost or impaired at the scale of the North Pacific remains a gap. Overfishing continues to be a major pressure in some coastal areas of the North Pacific. For example, in the Yellow Sea, overfishing has contributed to trophic cascades, resulting in fishing down the food chain. In addition, Hutchings (2000) has shown that most stocks are very slow to recover from overfishing; this has consequences for ecosystem services and can adversely affect biodiversity. However, it should be noted that some managed fisheries systems in the North Pacific are doing well (Hilborn et al., 2005).

2.3 Major ecosystem services being affected by the pressures

2.3.1 Ecosystem services being lost

Although it is expected that ecosystem services being lost in coastal areas of the North Pacific would be consistent with those affected by these pressures globally, these data are lacking at the scale of the North Pacific. Worm et al. (2006) showed that reduced biodiversity increased the rate of resource collapse and decreased recovery potential, stability, and water quality; in contrast, restoration of biodiversity increased productivity and decreased variability. Furthermore, Francis et al. (1998) document the ecological consequences of major species re-distribution in the northeast Pacific following the major regime shift in 1977. Species invasions (and extinctions) also reorganize coastal ecosystems; Hooper et al. (2005) show that this has altered ecosystem goods and services in many well-documented cases and that most are difficult, expensive, or impossible to reverse.

The Pacific Ocean has the largest pool of low-oxygen water in the global ocean and in recent decades this pool has been expanding, with reduced oxygen concentrations observed both on the western and eastern sides of the basin (Ono et al., 2001; Emerson et al., 2004; Bograd et al., 2008). Generally, global climate models predict that global warming will lead to deoxygenation of the deep ocean because warmer surface waters will hold less oxygen and will be more stratified, resulting in less ventilation of the deep ocean (Sarmiento et al., 1998; Keeling et al., 2010). This will adversely affect benthic and pelagic ecosystems (Levin et al., 2009; Stramma et al., 2010; Koslow et al. 2011). Koslow et al. (2011) showed decreased mid-water oxygen concentrations were correlated with the decline of 24 mid-water fish taxa from eight families. Extended to larger scales, this could have significant adverse ecological and biogeochemical effects.

2.3.2 Human services being lost

Changes to marine biodiversity in coastal systems, and hence in ecosystem structure and function, can result from both direct impacts (e.g., exploitation, pollution, species invasion, and habitat destruction), or indirect impacts, via climate change and related perturbations of ocean biogeochemistry (e.g., acidification, hypoxia); these can have severe consequences on human services. Although no basin-scale studies quantifying these impacts were found, smaller-scale examples can highlight what might be expected. Myers and Worm (2003) demonstrated a dramatic decline in large predatory fish globally while Ovetz (2007) showed how industrial longline fishing has extensive negative economic and social consequences for coastal communities, especially those heavily reliant on fish protein, as biomass/species changes resulted in cascading effects, some of which were not predicted.

Also, Schroeder and Love (2002), who compared rockfish assemblages among three differently fished areas, showed large differences in fish density, size structure, and species composition. Only the protected area had both higher density and larger fish and greater species composition. Finally, Jackson et al. (2001) highlight how overfishing that precedes other forms of human disturbance to coastal ecosystems (pollution, degradation of water quality, and anthropogenic climate change) has resulted in ecological extinctions, especially of large vertebrate predators, with significant ecological and economic consequences.

In the western North Pacific, increased jellyfish blooms have had both direct and indirect negative impacts on human services. These blooms have reduced tourism, affected fishing and aquaculture and increased industrial costs, by, e.g., clogging the cooling-water intake screens of power plants (e.g., Purcell et al., 2007). Furthermore, blooms of gelatinous zooplankton have indirect effects on fisheries by feeding on zooplankton and ichthyoplankton; thus they are predators on and potential competitors with fish. Similarly, Cooley et al. (2009) showed that ocean acidification could affect a range of ecosystem services, such as fishery/aquaculture harvests, coastal protection, tourism, cultural identity, and ecosystem support, by adversely affecting calcifying marine organisms; they also showed that these impacts are expected to be greater in developing countries. Thus, more research is needed to understand how pressures are affecting services at the basin scale.

Coastal eutrophication is a growing concern, especially in the western North Pacific, where increases in nutrient loading have been linked with the development of large biomass blooms and harmful algal blooms, resulting in anoxia and toxic/harmful impacts on fisheries, aquaculture, ecosystems, human health and recreation (see Anderson et al., 2002; McKinnell and Dagg, 2010).

3. Oceanic Areas of the North Pacific

Unlike the coastal realm, where Spalding et al. (2007) proposed marine ecoregions, the oceanic realm of the North Pacific does not have a similar delineation scheme. Longhurst (2007) identifies zones in the North Pacific, but these are delineated more on the basis of oceanographic conditions and have relatively little weighting based on differences in biological diversity, species composition and productivity. It is probable that biological diversity in the oceanic North Pacific is also patchy, but the nature and scale of this patchiness needs to be determined.

3.1 Biodiversity Status and Trends

3.1.1 Primary producers

Using SeaWiFS satellite data, it is possible to detect large-scale changes in chlorophyll concentrations between 1998-2002 and 2003-2007. During this period, average chlorophyll decreased in parts of the eastern North Pacific (with the exception of the California Current region) and increased in the western North Pacific (McKinnell et al., 2010; Figure 9). Also of note is the significant decline in average chlorophyll across the entire tropical/subtropical zone from Indonesia to Baja California, Mexico. However, at finer spatial and temporal scales, interannual variations in the location, timing, and magnitude of surface chlorophyll levels can be considerable around the North Pacific (Yoo et al., 2008). The general trend towards increased sea surface temperatures has resulted in an expansion of the low surface-chlorophyll extent in the subtropical North Pacific (Polovina et al., 2008). The areal increase in these low-chlorophyll waters of the central North Pacific from 1998 to 2006 is about 2 per cent per year (Batten et al., 2010); much of this expansion is eastward. The expansion of low surface-chlorophyll waters is consistent with increased vertical stratification due to ocean warming; this situation also has been identified in the South Pacific, North Atlantic, and South Atlantic (Polovina et al., 2008). Two satellite-derived time series exist for chlorophyll estimates (SeaWiFS and MODIS) for three major domains in the North Pacific (Batten et al., 2010; Figure 10). Both the central subarctic Pacific (CSP) and eastern subarctic Pacific (ESP) are completely oceanic; the western subarctic Pacific (WSP) does infringe upon the coastal environment and thus is subject to potential biases in spring-bloom characteristics (both concentration and seasonal variability were greatest for this domain). The spike in 2008 is obvious in both the ESP and CSP series. As noted above, the NPTZ is a key feature of the oceanic realm of the North Pacific and the transition-zone chlorophyll front (TZCF), which indicates a strong meridional gradient in surface chlorophyll at the boundary of the subarctic and subtropical gyre, migrates from south to north over 1,000 km annually (Polovina et al., 2001). Ocean productivity estimates derived from models and satellite observations (Behrenfeld and Falkowski, 1997) indicate high annual average phytoplankton production throughout the NPTZ, in particular in the west, related to the Kuroshio Extension region. Surface chlorophyll concentrations in the subtropical gyre are usually <0.15 mg/m^3, whereas in the subarctic gyre and NPTZ they can be >0.25 mg/m^3. Further, the expansion of the subtropical central gyre appears to have resulted in a change in primary productivity from a nitrate-limited, diatom-dominated phytoplankton community to one that is dominated by the N_2-fixing *Prochlorococcus* (Karl, 1999; Karl et al., 2001).

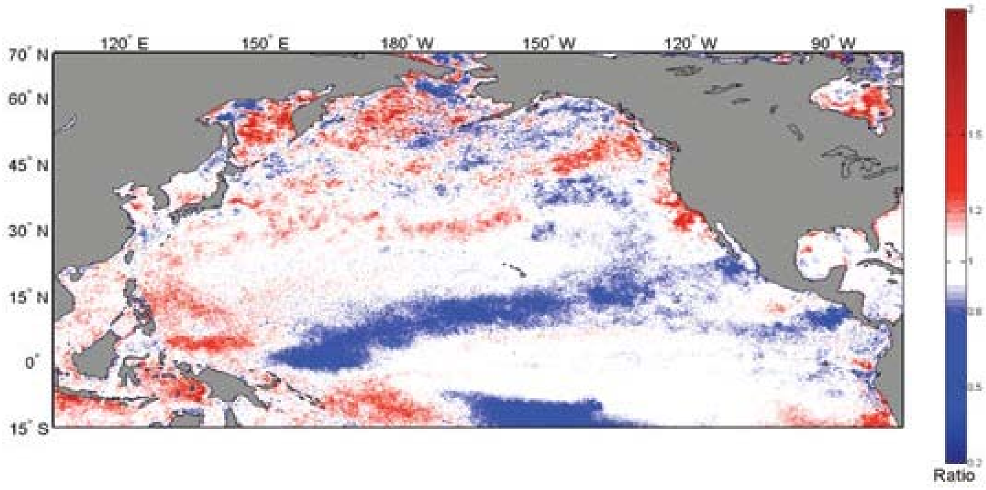


Figure 9. Ratio of mean chlorophyll a between 1998-2002 (denominator) and 2003-2007 periods. White colour indicates minimal change between the two periods (ratios = 0.9-1.1) (from McKinnell et al., 2010).

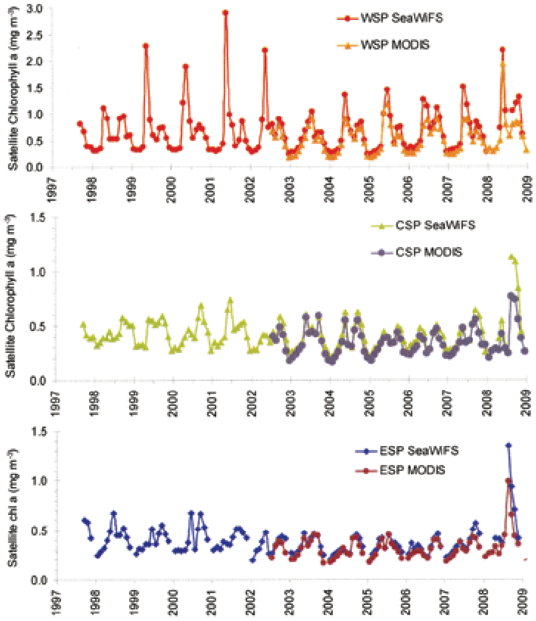


Figure 10. Chlorophyll a concentration for three regions (western subarctic Pacific (WSP), 155-172°E, 45-53°N; eastern subarctic Pacific (ESP), 140-155°W, 49.5-57°N; and central subarctic Pacific (CSP), 45-51°N 160-180°W) estimated from ocean colour-sensing satellites (from Batten et al., 2010).

3.1.2 Zooplankton communities

The NPTZ supports higher secondary productivity with respect to zooplankton biomass (McKinnell and Dagg, 2010) relative to other areas of the North Pacific, but no single comprehensive index exists for mesozooplankton time-series trends in the North Pacific.

Efforts at sub-basin scales are focused on the Alaska Gyre (Continuous Plankton Recorder (CPR) Survey, Line P), near Hawaii (Hawaii Ocean Time Series), and in the western Pacific along 155^{o}E (Hokkaido University T/S *Oshoro Maru*). The Weathership surveys provided a zooplankton time series within the Alaska Gyre along Line P off the West Coast of Vancouver Island from 1956-1980 (see Fulton, 1983) but only intermittent sampling was conducted opportunistically, until more regular surveys were initiated in 1997 (Mackas and Galbraith, 2002). In addition, a CPR survey has provided additional zooplankton productivity and diversity measures since 2000 (Batten et al., 2010). Although zooplankton taxa are similar between nearshore and offshore stations, the dominance hierarchies differ between the shelf margin (Mackas et al., 2001) and the oceanic zone, (Mackas and Galbraith, 2002) where "subarctic oceanic" copepod species dominate. These species have distributions that span the Pacific basin north of the subarctic front and their interannual variability has been attributed both to temperature variability and increased transport by the North Pacific Current; this could result in re-distribution of other marine species (Batten et al., 2010; Figure 11). Zooplankton time-series information also exists for station ALOHA, due to survey efforts by the Hawaii Ocean Time Series programme showed an increase in biomass between 1994 and 2004, after which it either stabilized or decreased slightly (Sheridan and Landry, 2004; Batten et al., 2010). The sampling along the 155^{o}E transect provides an opportunity to look at productivity and diversity along a north:south gradient that encompasses the subarctic front, transition domain, subarctic boundary and subtropical current system. Batten et al. (2010) demonstrate that zooplankton biomass tends to be higher in the transition domain, and during the unprecedented warm year of 2008, this transition domain extended north into the historical zone of the subarctic front. Furthermore, taxonomic composition differs along this latitudinal gradient, with small and large copepods most prevalent at the subarctic front and transition domain; amphipods, euphausids, chaetognaths, and copepods are represented in the subarctic boundary and subtropical current system.

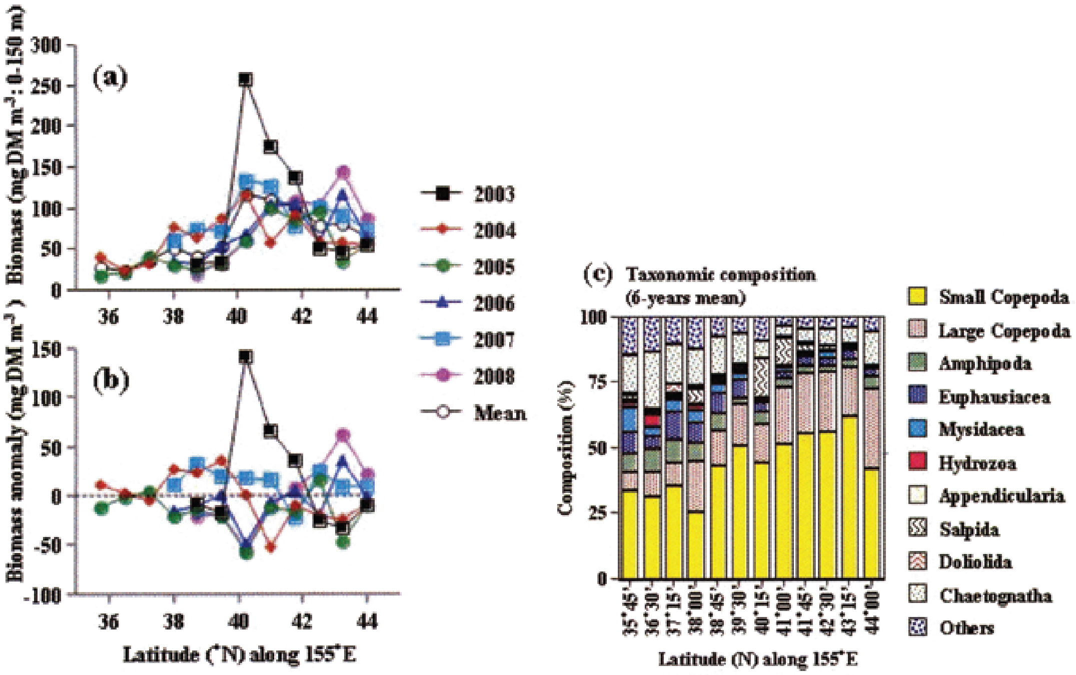


Figure 11. (a) Zooplankton dry biomass at 35°45'N-44°00'N along 155°E in the western North Pacific between 10-20 May, 2003-2008. (b) biomass anomalies compared to a 6-year mean, (c) and the taxonomic composition (from Batten et al., 2010).

3.1.3 Benthic communities

Perhaps with the exception of the limited snap-shot surveys of hydrothermal vent and seamount chain communities, no large-scale synoptic information is available on status of and trends in the diversity of benthic communities in the oceanic realm of the North Pacific. Much of this area is extremely deep, making survey efforts virtually impossible until recently, leaving much to be explored and characterized. The limited studies of vent communities in the North Pacific suggest high levels of endemism and diversity, especially within microbial communities that have different physiologies/metabolisms and thermal and salinity tolerances (e.g., Hedrick et al., 1992; Tunnicliffe et al., 1993). Furthermore, for these unique systems, the chemosynthesis that forms the basis of these deep-water food webs is critically important (Zhou et al., 2009). Stone and Shotwell (2007) have identified at least 140 coral species associated with seamounts in Alaska, representing at least six major taxonomic groups.

3.1.4 Higher trophic levels

Taxonomic diversity in both the eastern and western divisions of the North Pacific contains a mix of subtropical, temperate, subarctic and arctic species. The eastern North Pacific shows a gradient in diversity from east to west (Mueter and Norcross, 2002), with most fish biomass (and exploited stocks) on the continental shelf or coastal nearshore areas. Relatively little is known about the demersal species in the oceanic realm due to the great depths. Some exploitation of species associated with seamounts occurs in the Gulf of Alaska and along the west coast of North America, for species such as sablefish (*Anaplopoma fimbria*), but within exclusive economic zones (EEZs), most seamounts have some level of protection due to restrictions on bottom-contact fishing gear and seamounts have been identified as Ecologically and Biologically Significant Areas (CBD, 2014). Furthermore, limited surveys/data mean that no time series are available.

The NPTZ once supported large-scale squid (*Ommastrephes bartrami*) driftnet fisheries, until a United Nations General Assembly ban on this gear was imposed in 1992 (see resolution 46/215) (PICES, 2004). Now the NPTZ supports the pelagic longline fishery based in Hawaii, with many vessels targeting tunas (including albacore, *Thunnus alalunga*), billfish, and squid. Albacore tuna is an economically important and widely distributed species in the North Pacific. Reported catches for albacore have been variable over time, but peaked in 1976 and 1997, and were rather depressed until the early 1990s, in part due to overfishing and below average recruitment (Cox et al., 2002; Batten et al., 2010; Figure 12). The catch of other tuna species, especially skipjack and yellowfin, has increased substantially since the 1950s (Sibert et al., 2006). However, Sibert et al. (2006) found that, although biomass was lower than that predicted in the absence of fishing (and perhaps higher than management targets), a reduction in the proportion of large fish, and the decreased trophic level of the catch suggest fisheries impacts on these top-level predators.

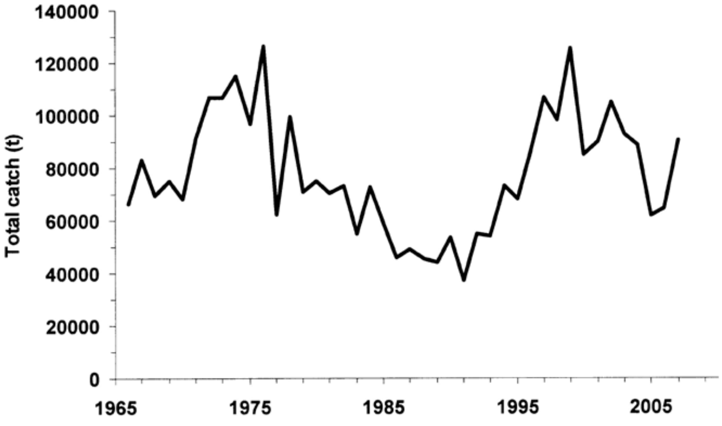


Figure 12. Total annual catch (tons reported) of North Pacific albacore tuna by all nations, 1966-2007 (from Batten et al., 2010, with data taken from ISC, 2008).

3.1.5 Other biota

As noted in 2(a) above, at least eleven species of marine birds and nine species of marine mammals designated as being at risk by the IUCN are found in the North Pacific. Although it appears that some populations are either stable or increasing, significant threats remain. No additional entirely oceanic organisms are known to be designated as being at risk for the North Pacific.

3.2 Major pressures in the oceanic area and major groups affected by the pressures

It appears that the open oceanic area of the North Pacific is significantly less affected than coastal areas, where multiple point-source stressors are routinely encountered. However, the large-scale stressors that are affecting this oceanic area will require substantial international efforts to mitigate: specifically the climate impacts that have resulted in changes to both the physical and biogeochemical properties of the ocean. For example, global climate change is altering temperature, salinity, mixed-layer depth, and pCO_2 (acidification) in the open ocean. It has been demonstrated that marine organisms have shifted their distributions in response to changing marine conditions and this can result in local extinctions or incursions (Cheung et al., 2009). Furthermore, Cheung et al. (2009) suggest that under certain climate change scenarios up to 60 per cent of current biomass could be affected, and disrupt existing ecosystem services.

In addition to climate change, overfishing, illegal, unreported and unregulated fishing, and commercial shipping are major pressures in the oceanic North Pacific. Other major pressures in the oceanic areas of the North Pacific include ocean dumping and increased UV-B radiation (Gray, 1997). However, time series are unavailable for these oceanic stressors at the scale of the North Pacific and require more study.

A rather unique but more localized feature of the North Pacific that could be affecting the open-ocean environment is the Pacific garbage patch. Day and Shaw (1987) have shown that the amount of plastic material in the oceans has increased over historical levels, and as oceanic eddies represent favourable locations for accumulation of floating debris like plastic, it should not be surprising that Moore et al. (2001) found the highest concentrations of plastic recorded in the Pacific within the North Pacific Subtropical Gyre. Also, mesopelagic fish species such as myctophids, have been shown to ingest microplastics in both the eastern (Davison and Asch, 2011) and western (Van Noord, 2013) parts of the basin. Thus, there are potential implications of this microplastic on a variety of organisms and on ecosystem structure and function although the specific effects are less clear.

3.3 Major ecosystem services being affected by the pressures

3.3.1 Ecosystem services being lost

It has been shown that zooplankton on both sides of the North Pacific respond strongly to regime shifts and hence should be expected to respond similarly to climate change. Thus, if the results of the study by Beaugrand et al. (2010) for the North Atlantic translate to the reorganization of the planktonic ecosystem towards smaller organism dominance that affects carbon flows, there could be adverse effects. As in coastal ecosystems, oceanic fishing operations can cause different types of ecological impacts, including bycatch of non-target species, habitat damage, mortality caused by lost or discarded gear, pollution, generation of marine debris, etc. Understanding the specific ecosystem services lost due to these activities will require more study.

3.3.2 Human services being lost

As in the coastal areas, changes to marine biodiversity (and hence to ecosystem structure and function) in oceanic systems also can result from direct impacts (e.g., fishing, pollution, and habitat destruction), and indirect impacts via climate change and related perturbations of ocean biogeochemistry (e.g., acidification) and these can have severe consequences on human services. As with the coastal areas, no basin-scale studies quantifying these impacts have been found and the lack of smaller-scale examples from oceanic areas of the North Pacific suggest that significant gaps exist. Although some studies have suggested fisheries targeting top predators have resulted in fewer large fish available for fishermen (Myers and Worm, 2003), other impacts on human services are less clear, suggesting that additional research is needed.

Historically, plastic debris was seen as a major concern for organisms that became entangled in or were ingesting it, especially marine mammals, seabirds, turtles, and fish (Laist, 1987). More recently, Boerger et al. (2010) showed that 35 per cent of the planktivorous fish sampled in the North Pacific Gyre (Garbage Patch) had ingested plastics; with this increased recognition of microplastics in the marine environment, the potential services being lost could be greater than initially thought, suggesting that more research is warranted.

4. Specific Areas of the North Pacific

The Bering Sea is a semi-enclosed subarctic sea that connects the North Pacific and Arctic Oceans and is bounded to the north by the Bering Strait and to the south by the Aleutian Archipelago. The deep central basin of this sea is bordered by a western shelf that extends from the Gulf of Anadyr along the Kamchatka Peninsula and a very broad eastern shelf extending from Alaska to the Russian Federation. Sea ice is important for determining the extent of the cold pool and regulates the timing of the spring bloom that has important cascading effects on ecosystem productivity and biological diversity (Stabeno and Hunt, 2002; Stabeno et al., 2007). Similarly, sea ice is a critical component of the structure and function of the Sea of Okhotsk. As with the Bering Sea, the Sea of Okhotsk has a relatively large shelf zone covering approximately 40 per cent of the basin (Udintsev, 1957). Predictions of potential impacts of global climate change are expected to be more severe at higher latitudes, suggesting native biodiversity could be adversely affected.

The South China Sea is a tropical system that includes diverse habitats such as mangrove forests, seagrass beds, and coral reefs. It lies within the Tropic of Cancer and has an area of 3.5 million km^2, of which 30 per cent is relatively deep sea with an average depth of about 1,400 m. The unique feature of this sea includes the effect of a monsoonal climate and complex surface-current patterns (Huang et al., 2010 and references therein). The complex surface-current system greatly influences the structure of the marine ecosystem, which is a mixture of tropical and subtropical communities. In addition, the Pearl and Mekong rivers discharge a huge amount of nutrients into the South China Sea. These characteristics support very diverse fauna and flora, with over 2,300 fish species (Caihua et al., 2008), 58 cephalopod species, and many other invertebrates (Jia et al., 2004). However, the dramatic expansion of fishing effort and improved fishing technology (Pang and Pauly, 2001) resulted in over-exploitation of fisheries resources here (Cheung and Sadovy, 2004).

Two additional semi-enclosed seas around the North Pacific deserve attention, due to increased human population growth and anthropogenic stress (e.g., urbanization, pollution, fisheries, and invasive species). On the eastern side of the basin is the Salish Sea; this relatively large estuarine system extends from the Strait of Georgia/Desolation Sound in the north to Puget Sound in the south and the Strait of Juan de Fuca to the west. With over seven million people living in the basin, the number of anthropogenic stressors is large with many having the potential to adversely affect biodiversity and ecosystem structure and function. Similarly, on the western side of the basin is the Seto Inland Sea, which serves as an important transportation link between the Pacific Ocean and the adjacent sea and between industrial centres around Japan. Many unique species call the Seto Inland Sea home, but anthropogenic impacts have been severe. For example, increased frequency of red tide (HAB) events and jellyfish blooms, possibly due to changes in nutrients in recent years, have resulted in significant losses to fisheries and aquaculture production.

A number of major rivers terminate in the North Pacific, but the ones that empty into semi-enclosed basins can result in unique attributes there. For example, the Colorado River, that discharges into the upper portion of the Gulf of California, results in biophysical features and oceanographic characteristics (strong tidal mixing, significant freshwater influx) that has resulted in a high level of endemism, such as the vaquita (a critically endangered porpoise; Gerrodette et al., 2011). In addition, other marine megafauna, such as the totoaba (*Totoaba mcdonaldi*) and the curvina golfina (*Cynoscion othonopterus*) have disjointed distributions in the upper Gulf of California.

The Emperor Seamount Chain and Hawaiian Ridge extends over 3,000 km from the Aleutian Trench to the Hawaiian Islands and seamounts outside of the United States EEZ were identified as meeting the criteria for Ecologically and Biologically Significant Areas (CBD, 2014). Hart and Pearson (2011) identified 49 fish species associated with this seamount chain and commercial fisheries targeting North Pacific armorhead (*Pseudopentaceros wheeleri*) and Splendid alfonsin (*Beryx splendens*) have operated since the late 1960s. Further, Japanese surveys have identified a variety of coral species inhabiting this chain including; Gorgonaceans (8 families, 24 genera), Alcyonaceans (6 families, 7 genera), Antipatharians (4 families, 5 genera) and Scleractinians (6 families, 16 genera). Also, the more productive surface waters provide good foraging environments for a variety of seabird species, including albatrosses.

Other specific areas in the North Pacific include the Mariana Trench and deep-sea hydrothermal vents. The Mariana Trench is unique in being the deepest location known on Earth. Relatively few studies exist; most characterize or describe the unique bacterial communities inhabiting this environment. Globally, hydrothermal vents are relatively rare and a unique geological feature associated with the spreading of tectonic plates. These sites support chemosynthetically driven ecosystems that support a diverse array of unique organisms (see Chapter 45).

5. Special conservation status issues

5.1 Taxonomic groups

Corals are often identified as a taxonomic group requiring special conservation consideration. In the North Pacific, approximately 30 per cent of the world's coral reefs are located in Southeast Asia; Wilkinson et al. (1993) suggest that more than half are already destroyed and being destroyed by sedimentation, overexploitation (including by dynamite and chemicals), and pollution. In addition to these warm-water corals, a growing number of cold-water corals and sponges also should be considered (e.g., Stone and Shotwell, 2007). Both warm- and cold-water corals are covered in more detail in Chapters 43 and 42, respectively.

Pacific salmon (*Oncorhynchus* species) are ecologically, commercially, and culturally important around the North Pacific. As anadromous species they require both freshwater and marine habitats for their continued survival and productivity but increased human activities have reduced productive habitat (in both freshwater and marine environments) and resulted in a number of additional stressors. The unique homing nature of salmon has resulted in a high degree of stock differentiation. For example, Slaney et al. (1996) identified 9,662 anadromous salmon stocks in British Columbia and the Yukon, including 866 Chinook, 1,625 Chum, 2,594 Coho, 2,169 Pink, 917 Sockeye, 867 Steelhead and 612 sea-run Cutthroat trout stocks. Maintaining genetic diversity will be important for maintaining productive Pacific salmon stocks; a goal of Canada's Wild Salmon Policy (DFO, 2005).

Other taxonomic groups often identified for special conservation status include many large or apex predators, such as tunas, sharks, billfish, and sea turtles, including Loggerhead (*Caretta caretta*) and Olive Ridley (*Lepidochelys olivacea*) sea turtles often found associated with the NPTZ (Polovina et al., 2004), because of their vulnerability to overexploitation and their role in ecosystem structure and function. Each of these is considered in more detail in Chapters 37-41.

5.2 Habitats

Much remains to be discovered with respect to biodiversity in the North Pacific, but additional conservation measures could be considered for several habitats, including hydrothermal vents, seamounts, large river deltas, kelp forests, mangroves, and coastal lagoons. In general, seamounts are often highly productive ecosystems that can support high biodiversity (Pitcher et al., 2007; Chapter 51), especially where their summit reaches into the euphotic zone and can be utilized by pelagic species, including marine birds and mammals. However, they can be susceptible to overfishing (see Douglas, 2011). Closer to the equator, coastal habitats, such as mangroves and coastal lagoons, are important habitats supporting relatively higher levels of biodiversity where degradation and/or complete destruction are significant concerns (see Chapters 48 and 49).

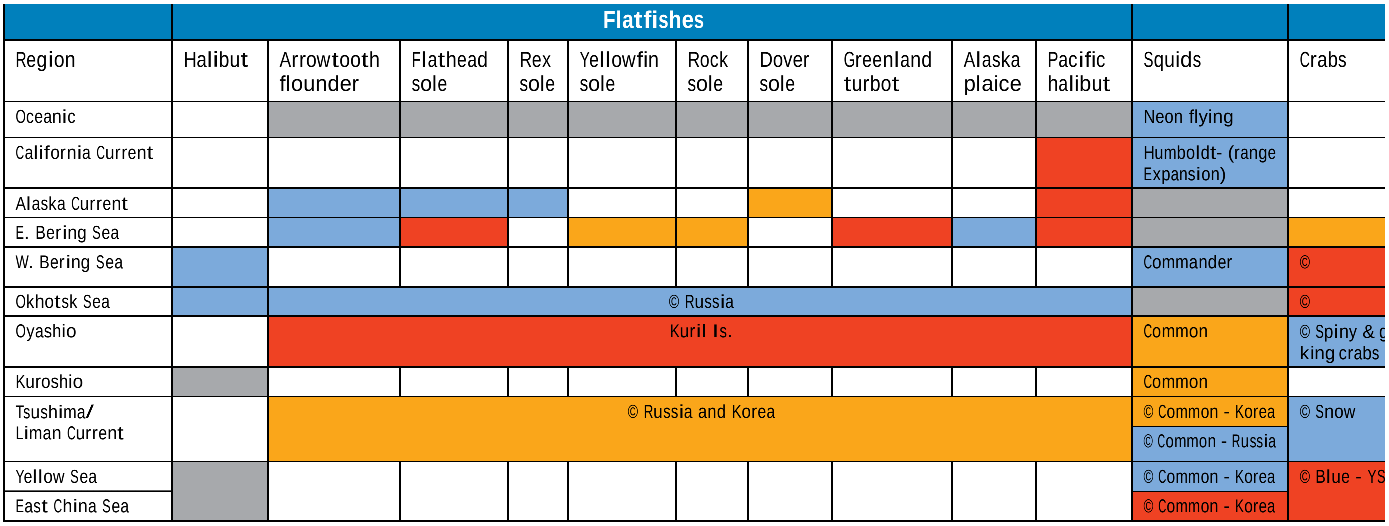
6. Factors for sustainability

It is clear that the maintenance of biodiversity contributes to ecosystem stability and sustainability and, like the other world oceans, the North Pacific is not unique in being under a barrage of anthropogenic stressors, that threaten the biodiversity and the sustainability it provides both for ecosystem services and human well-being. However, these stressors are not uniformly distributed across the North Pacific, with many more stressors noted for coastal ecosystems relative to the oceanic North Pacific. Furthermore, as research expands into the realm of how multiple stressors interact to affect biodiversity and ecosystem structure, function, and productivity, evidence is mounting that ecosystems are responding in complex, non-linear, non-additive - but cumulative - ways. Understanding and managing human activities to maintain or enhance biodiversity will make a substantial contribution to ecosystem sustainability globally (e.g., Hughes et al., 2005) and in the North Pacific specifically. However, as human populations, many of which are dependent on coastal or oceanic ecosystems for their existence, continue to expand around the North Pacific, there will be challenges.

Table 1. Interregional comparison of levels in biomass or abundance indices of fishes and invertebrates since 2003 compared to 1990-2002. Colour codes are: blue (increase), red (decrease), orange (change <|10%|), grey (not relevant to the region), and white (no data). The symbol © indicates that the evaluation for that taxon/region is based on catch data. In some regions, flatfish data were not reported by species, so any trends that are indicated apply only to the aggregate of flatfish species caught in that region, and not necessarily to the individual species listed in the column headers (from McKinnell et al., 2010).

	Salmonidae					Small					Mackerels		
Region	Pink	Chum	Sockeye	Coho	Chinook	Herring	Capelin	Sardine	Anchovy	Others	Chub	Spanish	Yellowtail
Oceanic						▨	▨				▨	▨	▨
California Current	🟥	🟧	🟥	🟥	🟦	🟥 Georgia St.	▨	🟧	🟧	🟥		▨	▨
Alaska Current	🟧	🟧	🟦	🟦	🟧	🟧 SE Alaska 🟥 PWS					▨	▨	▨
E. Bering Sea	🟥	🟧	🟧	🟥	🟥	🟧 Togiak		▨		🟧	▨	▨	▨
W. Bering Sea						🟥 ©5-fold ▼	🟧	▨	🟥 Range decline No fishery	🟦	▨	▨	▨
Okhotsk Sea	🟧 Japan	🟦 Japan				🟦 ©Russia		▨	🟦		▨	▨	▨
Oyashio	🟥	🟧						🟥	🟦		🟦	▨	▨
Kuroshio	▨	▨	▨	▨	▨	▨	▨	🟥	🟦		🟦		
Tsushima/ Liman Current	🟥 Japan	🟦 Japan	▨	▨	▨	🟧 ©	🟧	🟥	🟦	🟥 © Saury (K) 🟦 © Sandfish (K)	Present in Russia	🟦 ©	🟦 ©
Yellow Sea	▨	▨	▨	▨	▨				🟦 Korea				
East China Sea	▨	▨	▨	▨	▨				🟧 Korea		🟥 Korea		

							Gadidae						
Region	Hairtail	Tuna Billfish Sharks	Rockfish	Sablefish	Atka mackerel	Walleye pollock	Giant grenadier	Pacfic hake	Pacific cod	Saffon cod	Longfin codling	Goosefish	Small yellow croake
Oceanic	▨	🟥 Hawaii	▨	▨	▨	▨	🟧 ©	▨		▨	▨	▨	▨
California Current	▨		🟥	▨	▨	▨	▨	🟥		▨	▨	▨	▨
Alaska Current	▨		🟦 POP 🟥 Northern 🟦 Dusky 🟧 Rougheye	🟧		🟥	▨	▨	🟥		▨	▨	▨
E. Bering Sea	▨		🟦 **POP** 🟧 Northern	▨	🟥 **Aleutian**	🟥	▨	▨	🟧			▨	▨
W. Bering Sea	▨		🟥 ©	▨	🟦	🟥 ©	▨	▨	🟥 ©	🟥 ©		▨	▨
Okhotsk Sea	▨	🟦	🟥	▨	▨	🟧	▨	▨	🟥 ©	🟥 ©		▨	▨
Oyashio	▨		🟧 Northern 🟧 Thornyheads		🟦 Kuril Is.	🟧	▨	▨	🟧		🟦	▨	▨
Kuroshio				▨	▨	▨					▨	▨	▨
Tsushima/ Liman			🟧 Russia	▨	🟦 Arabesque greenling	🟥	▨	▨	🟦 Korea	🟦 Russia	▨	🟦 Korea	▨
Yellow Sea	🟥 Korea			▨	▨						▨	🟦 Korea	🟧 Korea
East China Sea	🟧 Korea			▨	▨						▨		



	Flatfishes											
Region	Halibut	Arrowtooth flounder	Flathead sole	Rex sole	Yellowfin sole	Rock sole	Dover sole	Greenland turbot	Alaska plaice	Pacific halibut	Squids	Crabs
Oceanic		▨	▨	▨	▨	▨	▨	▨	▨	▨	🟦 Neon flying	
California Current										🟥	🟦 Humboldt- (range Expansion)	
Alaska Current		🟦	🟦	🟦			🟧			🟥	▨	
E. Bering Sea		🟦	🟥		🟧	🟧		🟥	🟦	🟥	▨	🟧
W. Bering Sea	🟦										🟦 Commander	🟥 ©
Okhotsk Sea	🟦	🟦 © Russia	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	▨	🟥 ©
Oyashio		🟥 Kuril Is.	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧 Common	🟦 © Spiny & g king crabs
Kuroshio	▨										🟧 Common	
Tsushima/ Liman Current		🟧 © Russia and Korea	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧 © Common - Korea 🟦 © Common - Russia	🟦 © Snow
Yellow Sea	▨										🟦 © Common - Korea	🟥 © Blue - YS
East China Sea											🟥 © Common - Korea	

Table 2. Status of commercial fishery stocks in the North Pacific.

Stock	Status	Region	Source
Bigeye tuna	Overfishing	Pacific/Western Pacific	NOAA (2013)
Pacific bluefin tuna	Overfishing	Pacific/Western Pacific	NOAA (2013)
Striped marlin (Central Western Pacific)	Overfishing	Western Pacific	NOAA (2013)
Blue king crab (Pribilof Islands)	Overfished	North Pacific	NOAA (2013)
Canary rockfish	Overfished	Pacific	NOAA (2013)
Pacific ocean perch	Overfished	Pacific	NOAA (2013)
Yelloweye rockfish	Overfished	Pacific	NOAA (2013)
Striped marlin (Central Western Pacific)	Overfished	Western Pacific	NOAA (2013)
Seamount groundfish complex (Hancock Seamount)	Overfished	Western Pacific	NOAA (2013)
Pacific bluefin tuna (Pacific)	Overfished	Pacific and Western Pacific	NOAA (2013)

Table 3. Trends in the numbers or productivity of planktivorous species of marine birds and baleen whales. [CA= California, USA; BC=British Columbia, Canada; PRBO= Point Reyes Bird Observatory in California, K = carrying capacity] (from McKinnell et al., 2010)

Location	Species	Metric	Dates used	Trend	Reference
California Current					
Farallon Is., CA	Cassin's auklet	Population trend	1998 - 2008	No trend	PRBO - pers. comm.
Farallon Is., CA	Cassin's auklet	Productivity	2002 - 2008	Down	PRBO - pers. comm.
California & Oregon	Blue whale	Population trend	1991 - 2008	Up <3% y^{-1}	Calambokidis 2009
California, Oregon & Washington	Blue whale	Population trend	2001 - 2005	No trend	Caretta et al. 2009
California, Oregon & Washington	Fin whale	Population trend	2001 - 2005	No trend	Caretta et al. 2009
California & Oregon	Humpback whale	Population trend	1990 - 2008	Up 7.5% y^{-1}	Calambokidis 2009
California, Oregon & Washington	Humpback whale	Population trend	1999 - 2003	Up	Caretta et al. 2009
British Columbia and Southeast Gulf of Alaska					
Triangle Is., BC	Cassin's auklet	Population trend	1999 - 2009	No trend	Hipfner, pers. comm.
Triangle Is., BC	Cassin's auklet	Productivity	1998 - 2006	No trend	Hipfner, pers. comm.
British Columbia	Humpback whale	Population trend		Up 4.1%	Ford et al. 2009
Northern and western Gulf of Alaska					
Northern Gulf of Alaska	Humpback whale	Population count	1987 - 2003	Up 6.6% y^{-1}	Allen & Angliss 2009
Shumagin-Kodiak areas	Fin whale	Population count	1987 - 2003	Up 4.8% y^{-1}	Allen & Angliss 2009
Sea of Okhotsk					
Talan Island	Crested auklet	Population count	1989 vs 2008	Down	Andreev et al., In Press
Talan Island	Ancient murrelet	Population count	1989 vs 2008	Down	Andreev et al., In Press
Talan Island	Parakeet auklet	Population count	1989 vs 2008	Down	Andreev et al., In Press
Western North Pacific					
Asia stock	Humpback whale	Population count	1991-93 vs. 2004-06	Probably Up	Allen & Angliss 2009

Table 4a. Piscivorous species in the North Pacific [PRBO= Point Reyes Bird Observatory in California, USA; K= carrying capacity; CA= California, USA; WA= Washington State, USA; BC= British Columbia, Canada; GOA= Gulf of Alaska; DFO= Canadian Department of Fisheries & Oceans] (from McKinnell et al., 2010)

Location	Species	Metric	Dates used	Trend	Reference
California, Oregon & Washington	California sea lion	Population trend	2000 - 2006	No trend	Caretta et al. 2009
San Miguel Is., CA	Northern fur seal	Population trend	1998 - 2005	Up	Caretta et al. 2009
San Miguel Is., CA	Northern fur seal	Pup production	1972-76 vs 2002-06	Up - interrupted by El Niño	Olesiuk 2009
Channel Islands, CA	California sea lion	Population trend	2004 - 2008	Up	Bograd et al. 2010
Channel Islands, CA	Northern elephant seal	Population trend	2000 - 2005	Up	Caretta et al. 2009
Farallon Is. CA	Common murre	Population trend	1998 - 2008	Up	PRBO – pers. comm.
Farallon Is., CA	Common murre	Productivity	2002 - 2008	No trend	PRBO – pers. comm.
Farallon Is, CA	Rhinoceros auklet	Population trend	1998 - 2008	Unknown	PRBO – pers. comm.
Farallon Is., CA	Rhinoceros auklet	Productivity	2002 - 2008	No trend	PRBO – pers. comm.
Farallon Is. CA.	California sea lion	Population trend	1998 - 2008	No trend	PRBO – pers. comm.
Farallon Is., CA	Northern fur seal	Population trend	1998 - 2008	Up	PRBO – pers. comm.
Farallon Is., CA	Northern elephant seal	Population trend	1998 - 2008	No trend	PRBO – pers. comm.
Central California	Steller sea lion	Non-pup count	1996 - 2004	No trend	Caretta et al. 2009
Northern California & Oregon	Steller sea lion	Non-pup count	1996 - 2002	No trend, at K	Caretta et al. 2009
California	Harbour seal	Population trend	1995 - 2004	No trend, at K	Caretta et al. 2009
Oregon & Washington	Harbour seal	Population trend	1995 - 2004	No trend, at K	Caretta et al. 2009
Tatoosh Is., WA	Common murre	Productivity	1998 - 2008	Up	Parrish, pers. comm.
Triangle Is., B.C.	Rhinoceros auklet	Population trend	1999 - 2009	Up ?	Hipfner, pers. comm.
Triangle Is., B.C.	Rhinoceros auklet	Productivity	1998 - 2007	Up ?	Hipfner, pers. comm.
British Columbia	Steller sea lion	Pup count	1980s - 2006	Up 7.9% y^{-1}	DFO, 2008
British Columbia	Steller sea lion	Non-pup count	1998 - 2002	Up	Allen & Angliss 2009
St. Lazaria Is., E GOA	Rhinoceros auklet	Population trend	1994 - 2006	Up	Slater, pers. comm.
St. Lazaria Is., E GOA	Rhinoceros auklet	Population trend	1998 - 2006	Up 5% y^{-1}	Dragoo, pers. comm.
St. Lazaria Is., E.GOA	Rhinoceros auklet	Productivity	2002 - 2006	Up ?	Dragoo, pers. comm.
St. Lazaria Is., E GOA	Unid. murre	Population trend	1998 - 2006	No trend	Dragoo. pers. comm.
St. Lazaria Is., E GOA	Unid. murre	Population trend	1994 - 2006	Down	Slater & Byrd 2009
St. Lazaria Is., E GOA	Unid. murre	Population trend	2001 - 2006	No trend	Slater & Byrd 2009
Southeast Alaska	Steller sea lion	Pup counts	1996 - 2009	Up 5.0% y^{-1}	DeMaster, 2009
Southeast Alaska	Harbour seal	Population trend	1990s - 2002	Variable no trend	Allen & Angliss 2009
Eastern GOA	Steller sea lion	Pup count	2001 - 2009	No trend	DeMaster 2009
Central GOA	Steller sea lion	Pup count	1994 - 2009	Down 0.6% y^{-1}	DeMaster 2009
Middleton Is., GOA	Unid. murre	Population count	1998 - 2007	Down	Hatch, pers. comm.
Middleton Is., GOA	Rhinoceros auklet	Population count	1998 - 2007	Up	Hatch, pers. comm.
Middleton Is., GOA	Black-legged kittiwake	Population count	1998 - 2007	Down	Hatch, pers. comm.
Western GOA	Steller sea lion	Pup count	1998 - 2009	Up 2.6% y^{-1}	DeMaster 2009
Prince William Sound	Harbour seal	Population trend	1984 - 1997	Down	Allen & Angliss 2009
Kodiak Region, GOA	Harbour seal	Population trend	1993 - 2001	Up 6.6% y^{-1}	Allen & Angliss 2009
Semidi Is, W GOA	Black-legged kittiwake	Population trend	1998 - 2007	No trend	Dragoo, pers. comm.
Semidi Is., W GOA	Common murre	Population trend	1999 - 2007	No trend	Dragoo, pers. comm.

Table 4b. Piscivorous species in the eastern Bering Sea and Aleutian Islands (from McKinnell et al., 2010)

Location	Species	Metric	Dates Used	Trend	Reference
St. Paul Is., E Bering	Black-legged kittiwake	Population trend	1999 - 2008	No trend	Dragoo, pers. comm.
St. Paul Is., E. Bering	Common murre	Population trend	1999 - 2008	No trend	Dragoo, pers. comm.
St. George Is., E. Bering	Black-legged kittiwake	Population trend	1999 - 2008	No trend	Dragoo, pers. comm.
St. George Is., E. Bering	Common murre	Population trend	1999 - 2008	No trend	Dragoo, pers. comm.
Pribilof Is., Bering Sea	Northern fur seal	Pup count	1972 - 76 vs. 2002 - 06	Down 2.7% y^{-1}	Olesiuk 2009
St. Paul Is., Pribilofs	Northern fur seal	Pup count	1998 - 2006	Down 6.1% y^{-1}	Allen & Angliss 2009
St. George Is., Pribilofs	Northern fur seal	Pup count	1998 - 2006	Down 3.4% y^{-1}	Allen & Angliss 2009
Bogoslof Is., Bering Sea	Northern fur seal	Population trend	1972 - 76 vs. 2002 - 06	Rapid growth	Olesiuk 2009
Bogoslof Is., Bering Sea	Northern fur seal	Pup count	2005 - 2007	Up	Allen & Angliss 2009
Bering Sea	Harbour seal	Population trend	1980s - 1990s	Probably down	Allen & Angliss 2009
Aiktak Is., Eastern Aleutian Islands	Unidenitified murre	Population trend	1998 - 2007	No trend	Dragoo, pers. comm.
Eastern Aleutian Islands	Steller sea lion	Pup count	1998 - 2009	Up 4.2% y^{-1}	DeMaster 2009
Eastern Aleutian Islands	Harbour seal	Population trend	1977 - 82 vs. 1999	Down 45%	Allen & Angliss 2009
Koniuji Is., C. Aleutian Islands	Black-legged kittiwake	Population trend	1998 - 2007	No trend	Dragoo, pers. comm.
Koniuji Is., C. Aleutian Islands	Unidentified murre	Population trend	2001 - 2007	No trend	Dragoo, pers. comm.
Ulak Is., C. Aleutians	Unidentified murre	Population trend	1998 - 2008	Up 6.2% y^{-1}	Dragoo, pers. comm.
C. Aleutian Islands	Harbour seal	Population trend	1977 - 82 vs. 1999	Down 66%	Allen & Angliss 2009
Buldir Is., W. Aleutians	Black-legged kittiwake	Population trend	1998 - 2007	No trend	Dragoo, pers. comm.
Bering Sea Stock	Harbour seal	Population trend	1980s - 1990s	Probably down	Allen & Angliss 2009
Western Aleutian Islands	Harbour seal	Population trend	1977 - 82 vs. 1999	Down 86%	Allen & Angliss 2009
Aleutian Islands	Steller sea lion	Pup count	1994 - 2009	Down 1.6% y^{-1}	DeMaster 2009
Western Aleutian Islands	Steller sea lion	Pup count	1997 - 2008	Down 10.4% y^{-1}	DeMaster 2009

Table 4c. Piscivorous species in the western Pacific, including western Bering Sea, Sea of Okhotsk, Oyashio, and Yellow Sea (from McKinnell et al., 2010).

Location	Species	Metric	Dates Used	Trend	Reference
E. Kamchatka	Steller sea lion	Non-pup count	2001 – 2008	No trend	Burkanov et al. 2009
Commander Islands	Steller sea lion	Non-pup count	2000 - 2008	No trend	Burkanov et al. 2009
Commander Islands	Northern fur seal	Pup production	1972 - 76 vs. 2002 - 06	No trend	Olesiuk 2009
Kuril Islands	Northern fur seal	Pup production	1972 - 76 vs. 2002 - 06	Up, 3% y^{-1}	Olesiuk 2009
Robben Is., Okhotsk	Northern fur seal	Pup production	1972 - 76 vs. 2002 - 06	No trend	Olesiuk 2009
Kuril Islands	Steller sea lion	Non-pup count	2000 – 2007	Up	Burkanov et al. 2009
N. Okhotsk	Steller sea lion	Non-pup count	1996 – 2006	Up	Burkanov et al. 2009
Sakhalin Island, Okhotsk	Steller sea lion	Non-pup count	2000 – 2009	Up	Burkanov et al. 2009
Talan Is., Okhotsk	Horned puffin	Population count	1989 vs 2008	Up	Andreev et al., In Press
Talan Is., Okhotsk	Black-legged kittiwake	Population count	1989 vs 2008	Up	Andreev et al., In Press
Talan Is., Okhotsk	Unidentified murre	Population count	1989 vs 2008	No trend	Andreev et al., In Press
Teuri Is., W. Hokkaido	Japanese cormorant	Nest count	2007 - 2008	No trend	Watanuki, pers. comm.
Teuri Is., W. Hokkaido	Rhinoceros auklet	Population count	1985 -1997	Up	Watanuki, pers. comm.

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