XIV NORTH EAST PACIFIC

XIV-44 California Current LME
XIV-45 East Bering Sea LME
XIV-46 Gulf of Alaska LME
XIV-47 Gulf of California LME
XIV-48 Pacific Central-American Coastal LME

XIV-44 California Current LME

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The California Current LME is bordered by the USA and Mexico, between subtropical and subarctic LMEs. It has a surface area of around 2.2 million km², of which 1.31% is protected, and it contains 0.01% of the world's coral reefs and 1.04% of the world's sea mounts (Sea Around Us 2007). The LME shoreline is more than two thousand miles long. The LME features more than 400 estuaries and bays, including the Columbia River, San Francisco Bay and Puget Sound, which constitute 61% of the estuary and bay acreage. This LME is characterised by its temperate climate and strong coastal upwelling. Book chapters and articles pertaining to this LME include MacCall (1986), Mullin (1991), Bakun (1993), Bottom *et al*. (1993), McGowan *et al*. (1999), Brodeur *et al*. (1999) and Lluch-Belda *et al*. (2003). Additional information on this well-studied LME is available from the Pacific Marine Environmental Laboratory at< www.pmel.noaa.gov>.

I. Productivity

The effects of coastal upwelling, ENSO and the Pacific Decadal Oscillation (PDO) result in strong interannual variability in the productivity of the ecosystem and, consequently, of the catch levels of different species groups (Bakun 1993). ENSO events are characterised locally by an increase in temperature, a rise in coastal sea level, diminished upwelling and increased coastal rainfall (Bakun 1993). Miller (1996) reports a significant deepening of the thermocline off California, which he attributes to a weakening of the Aleutian Low (decadal scale), and to waves propagating through the ocean from the tropics (interannual scale). There is speculation as to what causes changes in the eastern bifurcation of the Subarctic Current into the California Current, and the possible effects of these changes on biological production in this LME.

The CCLME is one of the world's five LMEs that undergo seasonal upwellings of cold nutrient rich water that generate localised areas of high primary productivity that support fisheries for sardines, anchovy, and other pelagic fish species. (e.g. California Current, Canary Current, Guinea Current, Benguela Current, and Humboldt Current LMEs). The California Current LME can be considered a Class III, low productivity ecosystem (<150 $gCm^{-2}yr^{-1}$) (Figure XIV-44.3). The Pacific Decadal Oscillation (PDO) is a 20-30-year cooling and warming cycle between a cool and productive ocean regime and a warm and unproductive ocean regime. The latest warm regimes were in 1977-1998 and 2003-2006. Apparent biological consequences of these regime shifts are changes in primary and secondary production and changes in the abundance of eastern Pacific fish stocks. For example, there was a sharp decline in primary and secondary production following the 1977 regime shift (CalCOFI Atlas 35, 2002). The California Cooperative Oceanic Fisheries Investigations (CalCOFI) programme has sampled zooplankton biomass almost continuously from 1951 to present. Observed decline in zooplankton abundance related to water column stratification has been described by Roemmich & McGowan (1995a and 1995b), Haywood (1995), and McGowan *et al*. (1999). These biomass changes appear to be inversely related to those occurring in the Gulf of Alaska LME to the north (Brodeur & Ware 1995, Brodeur *et al*. 1999). For a study of interannual variability impacts on the LME, see Lluch-Belda *et al*. (2003), Peterson and Schwing (2003), and Hooff and Peterson (2006). There is a need to better understand the role of climate and seasonal change in the energy flow and population dynamics of species inhabiting the LME. For an analysis of chlorophyll and sea surface temperature changes during the El Niño/La Niña period of 1998/1999, see Kahru & Mitchell (2000). For an article on observing and modelling the California Current system, see Miller and Schneider (2000). Information on the U.S. GLOBEC Northeast Pacific Programme is available at: http://globec.coas.oregonstate .edu/

Oceanic fronts (Belkin et al. 2008): The California Current Front (CCF) separates relatively cold, low-salinity waters of the southward California Current from warmer and saltier waters inshore (Hickey 1998) (Figure XIV-44.1). The Subarctic Front (SAF) separates the northward Subarctic Current from inshore waters. On the inshore side of the California Current, upwelling fronts develop in summer (Belkin & Cornillon 2003, Belkin *et al*. 2003). Offshore frontal filaments, sometimes a hundred km long, carry the upwelled cold, nutrient-rich water across the entire LME (Belkin & Cornillon 2003). In winter, a second and seasonal poleward current develops over the shelf and slope, giving rise to the seasonal Davidson Current Front (DCF) between warm saline subtropical waters inshore and colder, fresher temperate waters offshore. This front can be traced from off southern California (35°N) to the northern Washington coast (48-49°N).

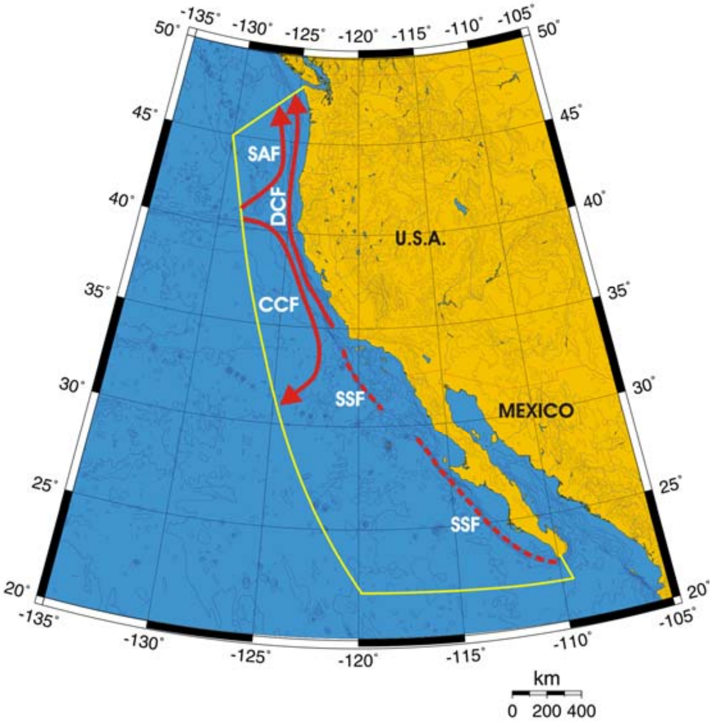

Figure XIV-44.1. Fronts of the California Current LME. CCF, California Current Front; DCF, Davidson Current Front (winter only); SAF, Subarctic Front; SSF, Shelf Slope Front; Yellow line, LME boundary. After Belkin et al. (2008).

California Current LME SST (Belkin 2008)(Figure XIV-44.2).
Linear SST trend since 1957: 0.32°C.
Linear SST trend since 1982: -0.07°C.

Like the East Bering Sea and Gulf of Alaska LMEs, the California Current cooled dramatically, by nearly 2°C, from 1958 to 1975, then warmed in 1977 as a result of the North Pacific regime shift (Mantua et al., 1997), and remained relatively warm in 1998. Cooling was again observed from 1999-2002, then warming in 2003-2006. The absolute minimum of 1975 was synchronous with the absolute minima in two other LMEs of the East Pacifi, the Gulf of California and Pacific Central American. The absolute maximum of 18.3°C in 1997 is attributable to El Niño, whereas the dramatic 1.8°C cooling in 1999 was associated with La Niña. The California Current LME and the Humboldt Current LME have experienced a slight cooling over the last 25 years. Both LMEs are situated in similar oceanographic regimes of East Pacific wind-induced coastal upwelling systems. These regimes feature strong and persistent alongshore winds directed towards the Equator, causing Ekman offshore transport of warm surface waters and upward flux of cold subsurface waters (coastal upwelling). The above-noted long-term cooling in these areas is suggestive of a long-term increase in the upwelling intensity, which in turn may have resulted from a long-term increase in the strength and/or persistence of upwelling-favorable along-coast winds. This hypothesis is supported by observed data and numerical modeling experiments (Schwing and Mendelsson, 1997; and GLOBEC at www.usglobec.org). There is no significant time lag between major thermal events in the California Current, Gulf of Alaska and East Bering Sea LMEs. The observed synchronicity among these regions suggests ocean-scale – if not global – forcing in the Northern and Northeast Pacific. The North Pacific regime shifts of 1976-1977 and 1999-2002 were broad scale events.

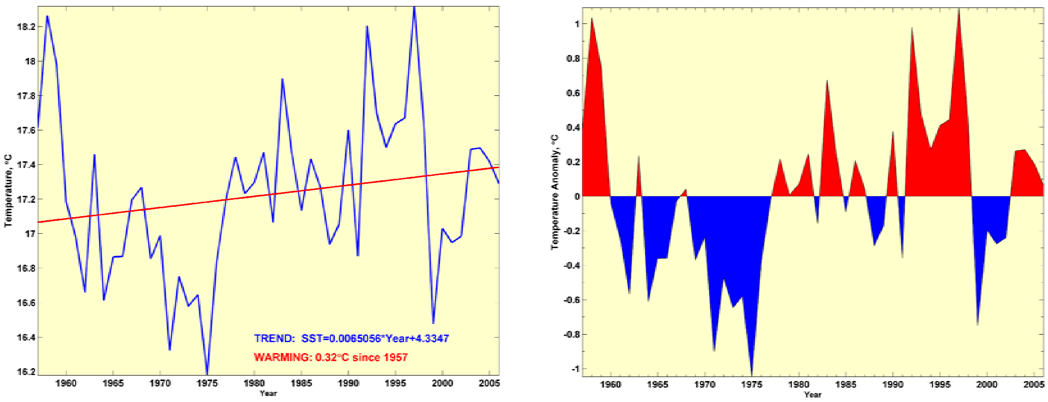

Figure XIV-44.2 California Current LME annual mean SST (left) and SST anomalies (right) based on Hadley climatology. 1957-2006. After Belkin (2008).

California Current LME Chlorophyll and Primary Productivity: The California Current LME is a Class III, low productivity ecosystem (<150 gCm^{-2}yr^{-1})(Figure XIV-44.3).

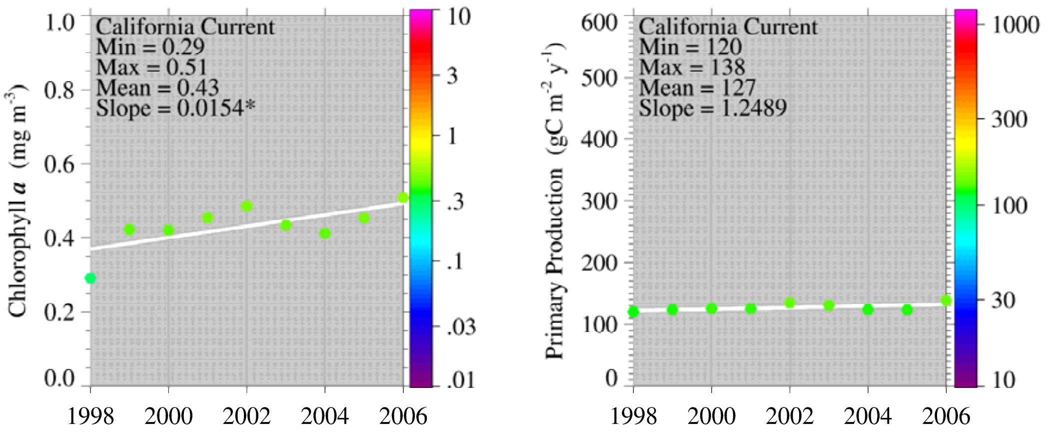

Figure XIV-44.3. California Current LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume..

II. Fish and Fisheries

Fisheries resources in the California Current LME include salmon, pelagic fisheries, groundfish, and invertebrates. Salmon fisheries harvest 5 species of salmon (Chinook, coho, sockeye, pink, and chum). The abundance of salmon stocks fluctuates considerably. Chinook and coho are harvested recreationally and commercially in Puget Sound and in freshwater rivers. Fisheries management for salmon is complex, with conflicting jurisdictions and salmon originating from several rivers. For all salmon species there is excess fishing power and overcapitalization of the fishing fleet. For coho and Chinook there is a sharp decline in abundance that has led to the closure of all salmon fisheries off the coasts of Oregon and California. Small pelagic resources in the LME are Pacific sardine, northern anchovy, jack mackerel, chub (Pacific) mackerel, and Pacific herring. Sardine, anchovy and mackerel are mostly harvested off California and Baja California. Sardine and anchovy fluctuate widely in abundance (NMFS 2009). Natural environmental change and intensive fishing are causing long-term shifts in their abundance in this LME. The CalCOFI programme was initiated to examine the reasons for the decline of the Pacific sardine and to study its physical and biotic habitat (CalCOFI 1990 results at www.calcofi.org). The collapse of the Pacific sardine has had cascading effects on other ecosystem components including marine birds. The variability in abundance levels of sardine and anchovy spawning biomass from 1930 to 1985 is analysed in MacCall (1986). Sardine catches declined after World War II, and the stock collapsed in the late 1950s. The sardine crash is one of the earliest well documented major fishery crashes (Radovich 1982) and is attributed to overfishing that accelerated a long term pattern of natural decline. Sardines today are taken for human consumption, bait, and aquaculture feed. Consumer demand for canned anchovy is low. Anchovy are harvested for reduction into fishmeal, bait, human consumption and oil. In recent years, low prices and market problems continue to prevent a significant anchovy fishery. The endangered brown pelican depends on anchovy as an important food source, and the wellbeing of the ecosystem is an important factor in resource management. Mackerel supported a major fishery in California but the stock collapsed in the 1970s. It has since reopened under a quota system. Sardine, anchovy, and mackerel are transboundary stocks exploited by both US and Mexican fleets. Squid is an important fishery in California in terms of revenue and tons landed. The vast majority is frozen for human consumption and exported to China, Japan and Europe. Landings depend on cyclical oceanographic regimes, with increases when relatively warm water events are displaced by cool water. Herring landings declined with an El Niño episode. Groundfish fisheries include sole, thornyheads, sablefish, rockfish, ligcod and cabezon, flatfish, and Pacific hake. Harvest rates have been reduced in recent years and gear designs to reduce bycatch. Nearshore fisheries are for invertebrate species including crabs, shrimps, abalones, clams, scallops and oysters (NMFS 2009). A recent compilation of species inhabiting the nearshore California Current LME can be reviewed at the California Department of Fish and Game site at: www.dfg.ca.gov/mrd/.

Total reported landings peaked at 710,000 tonnes in 1987 (Figure XIV-44.4). The value of reported landings peaked in 1970 at US$540 million (in 2000 US dollars) with a similar level recorded in 1988 (Figure XIV-44.5). The major commercial fish species are Pacific salmon, hake, albacore tuna, Pacific sardine (also known as South American pilchard), northern anchovy, jack mackerel, chub (Pacific) mackerel, Pacific herring, and Pacific halibut. Shrimp, squid, crab, clam and abalone have high commercial value.

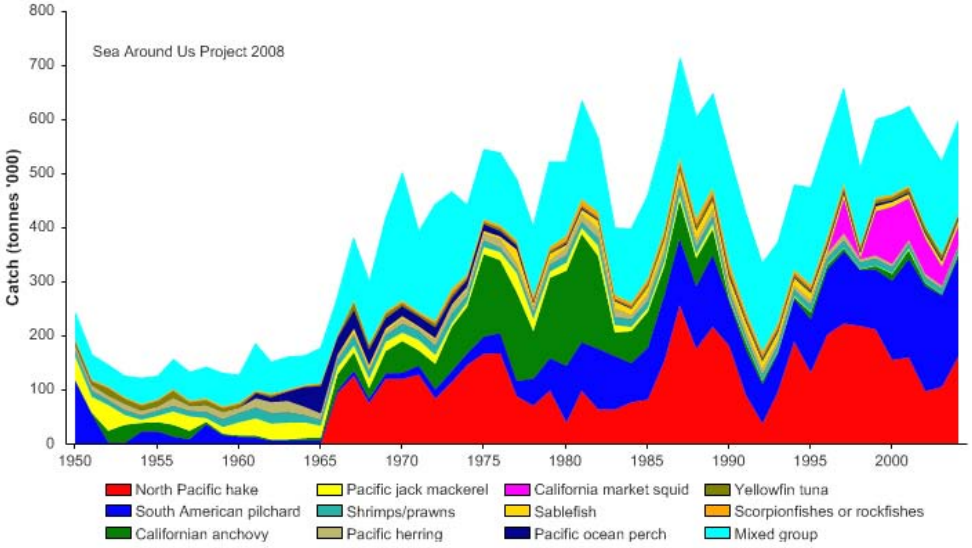

Figure XIV-44.4. Total reported landings in the California Current LME by species (Sea Around Us 2007).

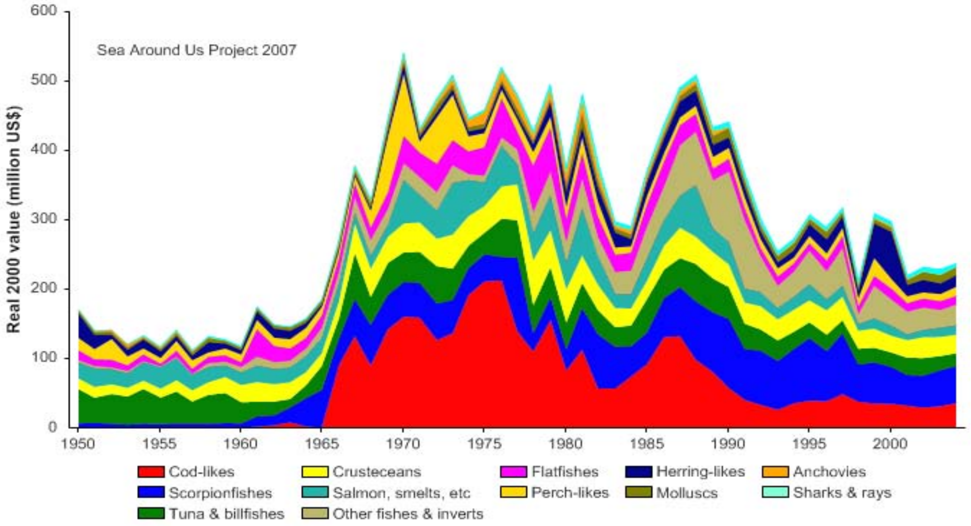

Figure XIV-44.5. Value of reported landings in the California Current LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR) (Pauly & Christensen 1995) to sustain reported landings in this LME reached 16% of the observed primary production in the late 1980s, and has fluctuated between 7 to 15% in recent years (Figure XIV-44-6). The USA has the largest share of the ecological footprint in the LME.

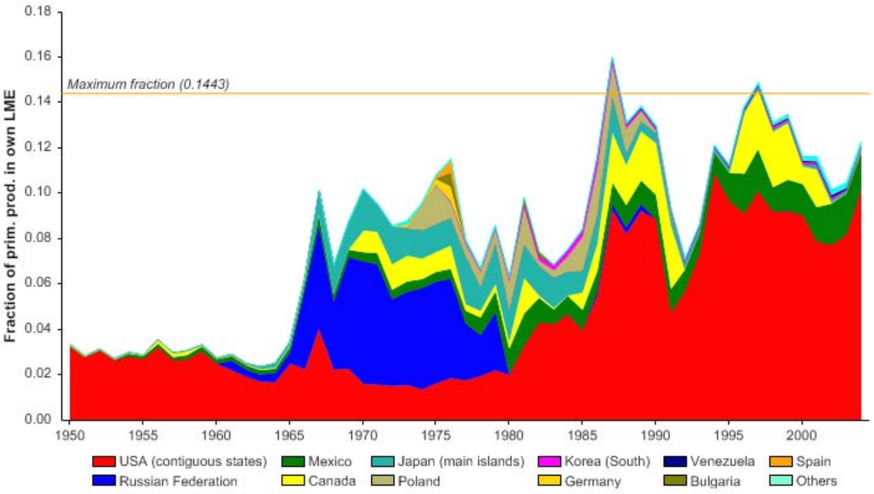

Figure XIV-44.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the California Current LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

Both the mean trophic level of the reported landings (Pauly & Watson 2005; figure XIV-44.7, top) and the Fishing-in-Balance index (Figure XIV-44.7, bottom) show considerable fluctuation over the reported period with no clear trend, except for the initial increase in the FiB index corresponding to a growth in fisheries during the 1960s.

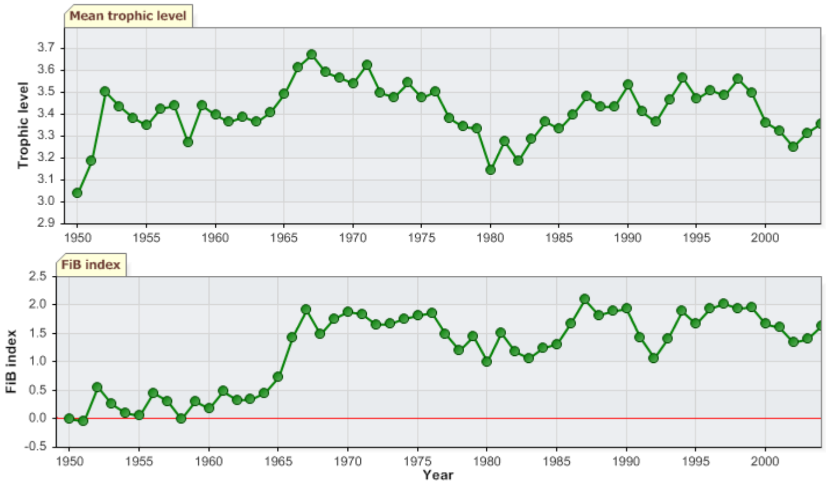

Figure XIV-44.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the California Current LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that over 80% of the stocks in the LME have collapsed or are currently over-exploited (Figure XIV- 44.8, top). Half of the reported landings biomass is still supplied by fully exploited stocks (Figure XIV-44.8, bottom). The US National Marine Fisheries Service (NMFS) includes "overfished" but not "collapsed" in its stock status categories. Currently overfished are Chinook and coho salmon, thought to be impacted by environmental conditions resulting in poor ocean survival. The other salmon species are considered fully exploited. Six other overfished species are among groundfish stocks. Hake and lingcod have been rebuilt to target levels. Jack mackerel and northern anchovy are underutilized species (NMFS 2009).

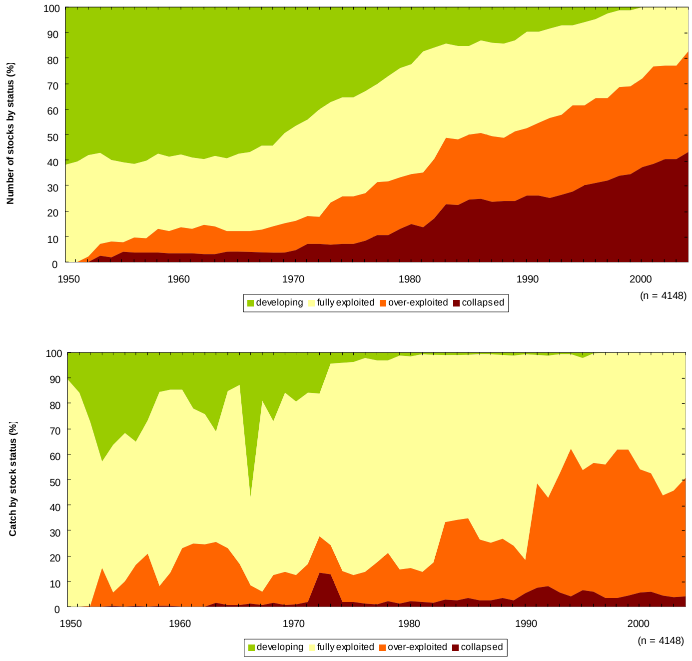

Figure IV-44.8. Stock-Catch Status Plots for the California Current LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only includes taxonomic entities at species, genus or family level. Higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

Comprehensive plans for the management of marine resources in this LME are being developed. Efforts are underway to implement ecosystem management in this LME. There is a need to know more about competitive and predatory interactions, and about climate effects on the fish stocks.

III. Pollution and Ecosystem Health

The major stressors in this LME are the effects of shifting oceanic climate regimes, the intensive harvesting of commercial fish, releases of captive-bred salmon, and low-level, chronic pollution from multiple sources (Bottom *et al*. 1993). Population growth rates suggest that human pressures on coastal resources will increase substantially in many coastal areas (EPA 2004). Hypotheses concerned with the growing impacts of pollution, overexploitation and environmental changes on sustained biomass yields are under investigation. Pacific salmon in the California Current LME depend on freshwater habitat for spawning and rearing of juveniles. There are concerns about the interactions of hatchery and natural wild salmon regarding the genetic integrity of native stocks and productivity levels. The quality of freshwater habitat is largely a function of land management practices. Coastal habitat degradation and shoreline alteration have resulted from dam construction, logging, agriculture, increased urbanisation, grazing and atmospheric pollution. In 1990-2000, the coastal areas experienced a loss of 1720 acres, a low figure compared with other regions of the country but high in relation to existing wetlands in the California Current LME. Ecological conditions in West Coast estuaries, a valuable resource in this LME, are considered fair to poor (EPA 2004). Eighty seven percent of estuaries assessed are impaired by some form of pollution or habitat degradation. Some estuaries have extensive areas with elevated phosphorus concentrations and decreased water clarity. Considerable areas have poor light penetration. DIN concentrations in estuaries are rated good. Summer wind conditions result in an upwelling of nutrient rich deep water that enters estuaries during flood tides (EPA 2004). DIP concentrations in estuaries are rated fair. Chlorophyll a concentrations in estuaries are rated good.

The EPA rated water clarity and dissolved oxygen as good, benthos and fish tissue as fair, and coastal wetlands, eutrophic condition and sediment as poor in this LME (EPA 2001). In 2004 the EPA assessed the water quality index as fair, the sediment quality index slightly improved, and the coastal habitat index and fish tissue index as poor (EPA 2004). The primary problem in California Current estuaries continues to be degraded sediment quality, with 14% of estuaries exceeding thresholds for sediment toxicity or sediment contaminants. Seventeen different contaminants were responsible for fish advisories in this LME in 2002. Toxic sediments in Puget Sound were contaminated with DDT and metals. For a study of water quality and one on sediment contamination in Puget Sound, see EPA 2004. High concentrations of metals and PAHs were observed in the Los Angeles harbour. The potential for benthic community degradation and fish contamination is increasing. A decline in seabirds such as the sooty shearwater has been observed. The LME contains a large seabird and marine mammal population (Bakun 1993) that includes sea lions and elephant seals. Since the late 1970s, pinnipeds have been increasing and are consuming large quantities of fish (DeMaster 1983; California Department of Fish and Game 2005). For more information on marine mammals as indicators of LME health, see NOAA (1999, p. 238). Of 274 coastal beaches, 178 were closed or under an advisory for some period of time in 2002.

IV. Socioeconomic Conditions

Three major estuaries, the San Francisco Bay, the Columbia River and Puget Sound, contribute to the local economy and enhance the quality of life of the inhabitants. Human population pressures are increasing in Puget Sound, the Seattle-Tacoma region, San Francisco Bay and southern California. California's population approached 37.7 million persons on January 1, 2007 (www.dof.ca.gov), up almost 3.8 million persons from the 2000 census. The coastal population increased by 45% between 1970 and 1980 (U.S. Census Bureau 1996). Forty seven coastal and estuarine countries bordering the California Current LME increased their population by 13% between 1990 and 2000 (U.S. Census Bureau 2001). In 2008 the combined population increase of San Diego, San Bernardino, Orange and Riverside counties in California was estimated at 12 percent of the total U.S. coastal population increase (www.oceanservice.noaa.gov). These pressures require continued environmental monitoring to ensure that environmental indicators currently demonstrating fair condition do not deteriorate. The California Current LME supports important commercial and recreational fisheries. All salmon species are harvested by Native American tribes for subsistence and ceremonial purposes. The value of recreational catches is not easily measured. Recent prices for salmon have declined due to market competition from record landings of Alaskan salmon and increasing aquaculture production. Northern anchovy landings fluctuate more in response to market conditions than to stock abundance. Commercial fishing is heavily regulated in an effort to achieve sustainability. In 1998 there were 9,843 commercial fishermen licensed to fish in California waters, down from 20,363 in 1980-1981. In 2006, there were 6,354 commercial fishing licenses purchased (California Department of Fish and Game Statistics, online at <www.dfg.ca.gov/licensing/statistics>). Recreational fishing in California generates US$4.9 billion and supports 43,000 jobs paying US$1.2 million in salaries and wages (Bacher 2007). An increase in the demand for oil, gas and mineral resources (e.g., chromite-bearing black sands and titanium sands off the Oregon and Washington coasts; sand and gravel dredging) has stimulated an exploration of the non-living resources of the LME.

V. Governance

Some critical issues requiring management include wild salmon stocks and significant loss of their spawning and nursery habitats (EPA 2001, p.153). The Pacific Fishery Management Council (PFMC) is responsible for managing fisheries off the coasts of California, Oregon and Washington, with cooperation form states and tribal fishery agencies. Within Puget Sound and the Columbia River, fisheries for Chinook and coho salmon are managed by the states and tribes. The Pacific Salmon Commission, the State of Washington, and tribal fishery agencies manage fisheries for pink, chum, and sockeye salmon. All species of pink salmon have been listed as threatened or endangered under the US Endangered Species Act. There is a legally mandated tribal allocation of Coho salmon. The Pacific Salmon Treaty with Canada determines the share of Canada and the US in the transboundary stock (NMFS 2009). There are more than 80 species managed under the Pacific Coast Groundfish Fishery Management Plan (FMP) of the PFMC, no less than eight of which have been declared overfished. Many groundfish stocks have geographic ranges that extend beyond the US EEZ into Canada and Mexico. Groundfish stocks support many commercial, recreational, and Indian tribal fishing interests in state and Federal waters off the coasts of Washington, Oregon, and California. Groundfish are also caught incidentally in other fisheries, such as the trawl fisheries for pink shrimp and ridgeback prawns. Current management measures include trip limits, bag limits size limits, time/area closures, and gear restrictions. A trawl permit buy-back program was implemented in 2003 to reduce the capacity of the groundfish fishery. NOAA Fisheries Service, in cooperation with the PFMC, is assessing the impacts of groundfish fisheries on the human, biological and physical environment. A preliminary set of alternatives will be developed to take into account new stock assessments for 23 of the groundfish species managed under the FMP (NOAA Fish News 2005). For information concerning the San Francisco Bay Estuary Project, see www.abag.ca.gov/. In Northern California, commercial, recreational, and Native American fishermen have recently targeted both State and Federal water management on the Klamath River and in the California Delta charging that historic fish runs in Northern California have been destroyed by illegal pumping in the Delta area and by hydroelectric dams (Bacher, 2007).

Since the passage of the Marine Mammal Protection Act in 1972, populations of seals and sea lions have increased. Killer whales are listed as an endangered species. In the south, the Mexican portion of the LME has minimal fisheries regulation, with limited fauna and marine mammal protection. The Mexican part of this LME falls within a non-UNEP administered Regional Seas Programme, the North-East Pacific Region, which covers 8 central American countries (Colombia, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama). The Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the North-East Pacific (Antigua Convention) was signed in 2002. The governments also approved an Action Plan detailing how the countries concerned will improve the environment of the North-East Pacific for the benefit of people and wildlife. The Action Plan's secretariat is COCATRAM (Central America Marine Transport Commission). For information on PICES, see the East China Sea LME (Chapter X). The States of California, Oregon, and Washington are developing and implementing a network of marine protected areas.

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XIV-45 East Bering Sea LME

M.C. Aquarone and S. Adams

The East Bering Sea LME is characterised by an extremely wide, gradually sloping shelf, and by a seasonal ice cover that in March extends over most of this LME. The LME is bounded by the Bering Strait to the North, by the Alaskan Peninsula and Aleutian Island chain to the South, and by a coastline to the east that is thousands of miles in length. The surface area is about 1.4 million km², of which 0.87% is protected. It contains 0.07% of the world's sea mounts. This LME receives freshwater discharge from major rivers including the Yukon and Kuskokwim (Sea Around Us 2007). Book chapters and articles pertaining to this LME include Incze & Schumacher (1986), Carleton Ray & Hayden (1993), Livingston *et al*. (1999) and Schumacher *et al*. (2003).

I. Productivity

Temperature, currents and seasonal oscillations influence the productivity of this LME. For information on oceanographic and climate forcing in the East Bering Sea ecosystem, and the recruitment responses of many Bering Sea fish and crabs linked to decadal scale patterns of climate variability, see EPA (2004) and PICES (2005). The East Bering Sea LME is a Class II, moderately high productivity ecosystem (150-300 gCm^{-2}yr^{-1}). This LME is undergoing a climate driven change in species dominance and species abundance in some ecological groups (PICES 2005). On the temporal variability of the physical environment over the LME, see Stabeno et al., 2001. There is much to understand about its carrying capacity during the present period of climate change. For example, there have been nearly ice-free conditions in the mid shelf from January to May in 2000-2004. Accompanying this change are shifts in the trophic structure with walrus populations moving northward with the ice, and Alaska pollock moving east.

Oceanic fronts: Five major fronts can be found over the East Bering shelf and slope (Belkin et al., 2003; Belkin & Cornillon 2005; Belkin et al., 2008). The Coastal Front consists of three segments, the Bristol Bay Front (BBF), the Kuskokwim Bay Front (KBF), and the Shpanberg Strait Front (SSF), all extending approximately parallel to the Alaskan Coast at a depth of 10 to 20 meters (Figure XIV-45.1). Farther offshore, the Inner Shelf Front (ISF) is located at a depth of 20 to 40 meters while the Mid-Shelf Front (MSF) is found at 40 to 60 meters. These two fronts are also approximately isobathic. The most distant offshore fronts, the Outer Shelf Front (OSF; 60-100-m depth) and the Shelf-Slope Front (SSF; 100-200-m depth within this LME) are not isobathic. They extend from relatively shallow depths in the east, off Bristol Bay, to significantly greater depths in the west, where the SSF crosses the shelf break and slope to continue over the deep basin as it leaves the East Bering Sea LME and enters the West Bering Sea LME.

East Bering Sea SST (Belkin 2008)(Figure XIV-45.2)
Linear SST trend since 1957: 0.46°C.
Linear SST trend since 1982: 0.27°C.

The annual mean SST averaged over the East Bering Sea increased by 0.46°C between 1957 and 2006. The 50-year warming was not uniform: instead, the time span included two periods with opposite SST trends. In 1957 the average Bering Sea SST reached a maximum that has not been surpassed until recently (Niebauer et al., 1999). From 1957 to 1971, the SST decreased by 1.3°C. The SST drop was especially abrupt in the late 1960s-early 1970s; in 1969-71 SST decreased from 5°C to 4°C. The cold spell lasted through 1976. In the winter of 1976-77, the East Bering Sea underwent an abrupt regime shift to warm conditions, with the SST rising by 1°C in a single year and remaining relatively high through 2006. The 1°C SST jump from 4.1°C to 5.1°C between 1976-77 was a regional manifestation of a trans-North Pacific "regime shift" that occurred during the winter of 1976-77, caused by a major shift of the North Pacific atmospheric pressure pattern captured in three indexes, ENSO, PDO, and the Aleutian Low index (Mantua et al., 1997; Hare and Mantua, 2000). This has helped species such as salmon stocks rebound from previous low years of abundance. The atmosphere-ocean system shift was followed by an ecosystem shift around and across the entire North Pacific. For some species, the effects of this ecosystem shift were beneficial, for others they were detrimental. The most recent cold episode, in 1999, was short-lived. The East Bering Sea has returned to warm conditions.

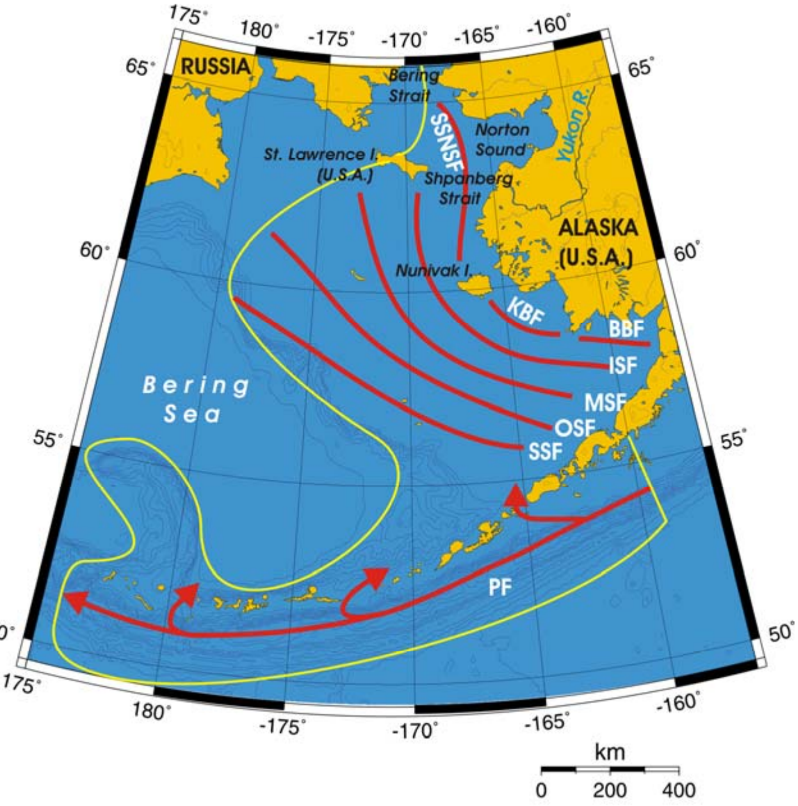

Figure XIV-45.1. Fronts of the East Bering Sea LME. BBF, Bristol Bay Front; ISF, Inner Shelf Front; KBF, Kuskokwim Bay Front; MSF, Mid-Shelf Front; OSF, Outer Shelf Front; PF, Polar Front; SSF, Shelf-Slope Front; SSNSF, Shpanberg Strait-Norton Sound Front. Yellow line, LME boundary. After Belkin *et al.* (2008).

The bathymetry of this LME is critically important while analyzing the area-averaged SST time series. The most important feature is the presence of two different oceanographic regimes within this LME, namely an extremely wide, nearly horizontal continental shelf and a deep-sea basin. This co-existence of shallow shelf and deep sea might explain the observed discrepancy between the LME-averaged SST time series and the SST observations over the East Bering Sea Shelf alone. Indeed, the most recent observations over the southeastern Bering Sea Shelf revealed a dramatic summertime warming by 3°C in the 2000s, likely caused by a synergy of several mechanisms, including (a) persistent northward winds since 2000; (b) a later fall transition combined with an earlier spring transition that resulted in a shorter sea ice season; (c) an increased flux of warm waters from the Gulf of Alaska LME through Unimak Pass; and (d) the feedback mechanism between warm summertime oceanic temperatures and the wintertime southward advection of sea ice (Stabeno et al., 2007).

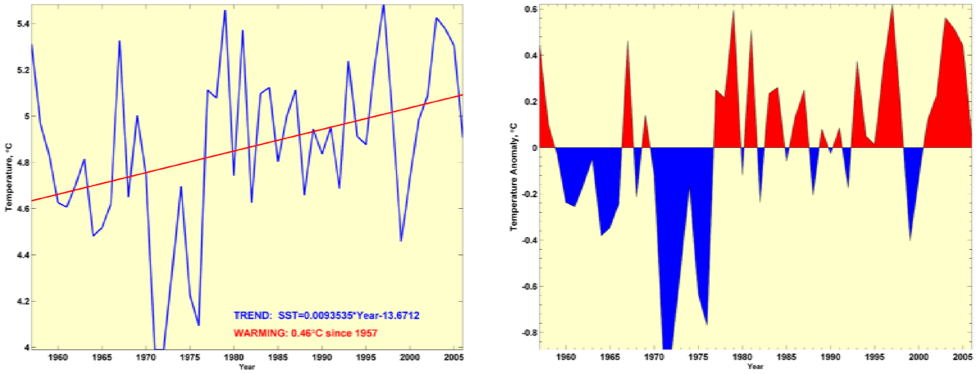

Figure XIV-45.2. East Bering Sea LME annual mean SST (left) and annual SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

East Bering Sea LME Chlorophyll and Primary Productivity: The East Bering Sea LME is a Class II, moderately high productivity ecosystem (150 – 300 gCm^{-2}yr^{-1})(Figure XIV-45.3).

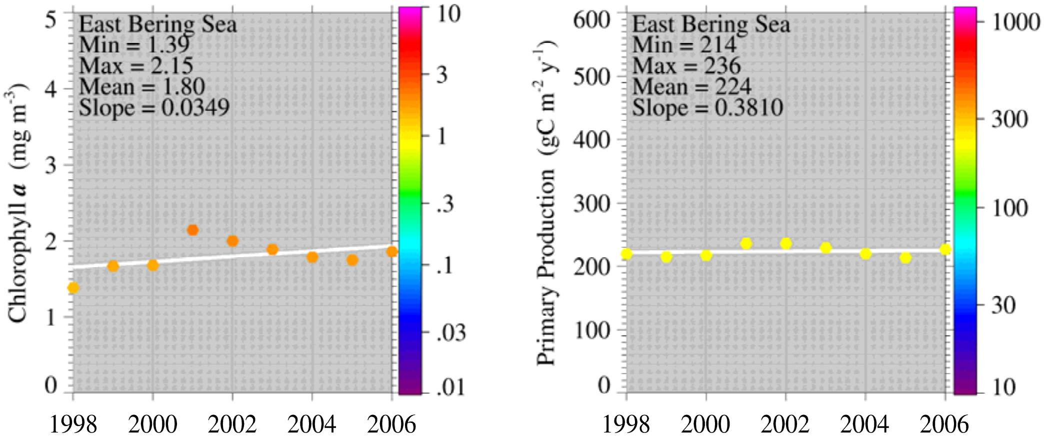

Figure XIV-45.3. East Bering Sea LME trends in chlorophyll-*a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The LME's thousands of miles of coastline support populations of five species of salmon (pink, sockeye, chum, Coho and Chinook). The high abundance of salmon is due to a number of factors including favourable ocean conditions that promote high survival rates of juveniles, hatchery production, and reduction of bycatch (EPA 2004). Sockeye salmon (in Bristol Bay, Alaska Peninsula and Aleutian Islands) is the most valuable of the salmon species but has had recent declines, along with chum salmon. In some years, significant numbers of chum salmon are caught as bycatch in fisheries that target pollock and other groundfish. Despite relatively stable Chinook stocks there is concern over abundance trends. A quota under the provisions of the Pacific Salmon Treaty regulates the Chinook salmon harvest in this LME. Coho salmon is the most popular recreational species. Salmon bycatch in US groundfish fisheries continues to be a problem in fisheries management (NMFS 2009). Groundfish (Pacific halibut, Walleye pollock, Pacific cod, flatfish, sablefish, and Atka mackerel) are the most abundant fisheries resource off the East Bering Sea LME. The dominant species harvested are pollock and cod. Catch quotas have been capped at 2 million tons for groundfish in the fishery management plan for the East Bering Sea and Aleutian Islands. Reported annual landings of Alaska pollock (*Theragra chalcogramma*), the largest catch of any species harvested in the US EEZ, now range between 1.0 and 1.5 million tonnes, a level thought to be sustainable. Pollock has fluctuated in the past decades as a result of variable year classes. Other commercially valuable species include herring, rockfish, skate, Greenland turbot, sole, plaice and crab. The centers of abundance for pelagic herring are in northern Bristol Bay and Norton Sound (EPA 2004). This fishery occurs within state waters and is managed by the Alaska Department of Fish and Game. From catch records it is clear that herring biomass fluctuates widely due to the influence of strong and weak year-classes. Species such as herring, pollock and Pacific cod show interannual variability in recruitment that might be related to climate variability (EPA 2004). Herring biomass fluctuates widely due to strong and weak year classes. Years of strong onshore transport, typical of warm years in the East Bering Sea, correspond with strong recruitment of Pollock (NMFS 2009). Annual summaries of pollock catches and other groundfish, flatfish and invertebrates in the Eastern Bering Sea from 1954 to 1998 are presented in Schumacher *et al*. (2003).

Major shellfish fisheries in the LME are king and snow crab. King and Tanner crab fisheries are managed by the state of Alaska with advice from federal fisheries. Crab resources are fully utilized. Catches are restricted by quotas, seasons, size and sex limits. Shrimp are also managed by the state of Alaska. For biomass trends of crab species from 1979 to 1993, and for finfish fishery exploitation rates compared with crab recruitment in this LME, see Livingston *et al*. (1999). Nearshore fishery resources are those coastal and estuarine species found in the 0-3 nautical mile zone of coastal state waters. Pollock is targeted in the ‘Donut Hole’ that exists in the high seas area outside of the U.S. and Russian EEZs.

Historical catches in this area were very high and unsustainable. Since 1999, however, there has been evidence of increased abundance of Alaska pollock in the Donut Hole, coincident with the reduction of annual sea-ice cover (Overland *et al*. 2005). Another species that appears to be increasing in abundance in response to warming conditions in this LME is pink salmon (Overland *et al*. 2002 and 2005, Overland & Stabeno 2004), whose catches were about 100 thousand tonnes in 2003 and 2004. Patterns of production for salmon are inversely related to those in the California Current LME.

Total reported landings experienced a historic high of over 2.5 million tonnes between 1995 and 1990 (Figure XIV-45.4), with Alaska pollock dominating. In that period, the ex-vessel value of the catches from the East Bering Sea LME was US$2.5 billion (Figure XIV-45.5). The value of the salmon catch has declined due to a number of complex worldwide factors (see IV. Socioeconomic Conditions).

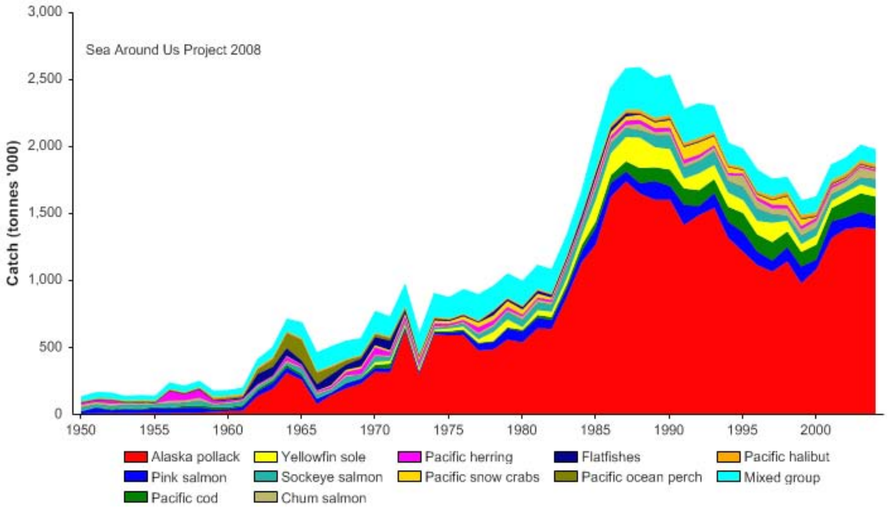

Figure XIV-45.4. Total reported landings in the East Bering Sea LME by species (Sea Around Us 2007).

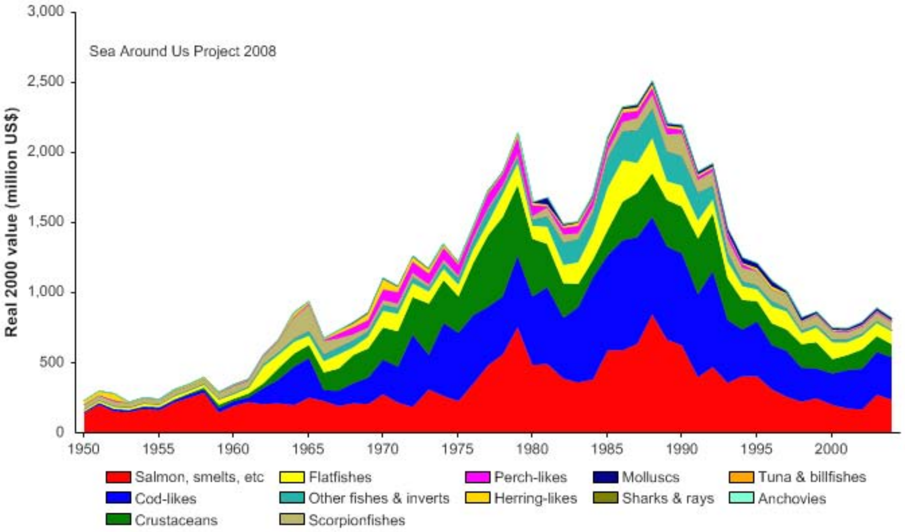

Figure XIV-45.5 Value of reported landings in the Eastern Bering Sea LME by commercial groups (Sea Around Us 2007)

The primary production required (PPR) (Pauly & Christensen 1995) to sustain the reported landings in this LME exceeded 45% of observed primary production in the late 1980s, and has remained around 40% in recent years (Figure XIV-45.6). The USA has the largest share of the ecological footprint in this LME. The mean trophic level of the reported landings (i.e., the MTI, Pauly & Watson 2005) declined from the 1950s to the early 1970s, but has since leveled off at around 3.5 due to the high catch of Alaska pollock. (Figure XIV-45.7, top). The geographic expansion which led to this dominance of Alaska pollock is represented by the increase of the FiB index from the mid 1970s to the mid-1980s (Figure XIV-45.7 bottom). The system appears sustainable according to these two indices, although it must be stressed that such an interpretation is based on the overwhelming effect of a single species.

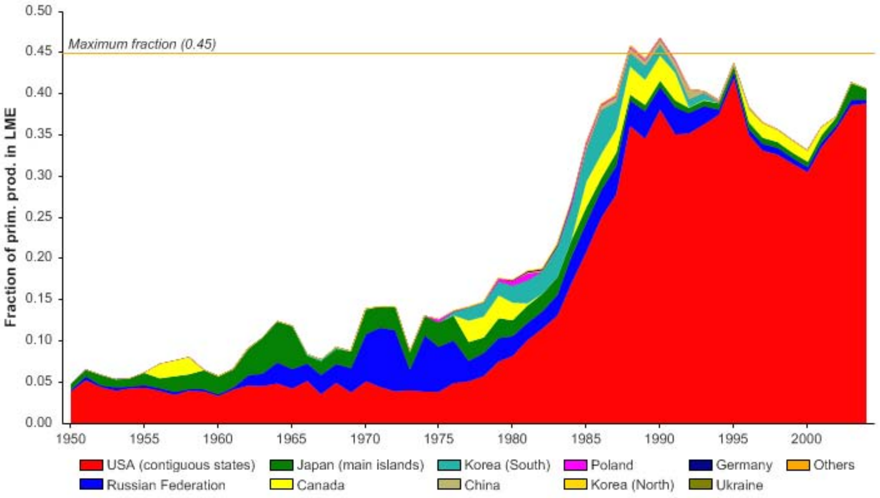

Figure XIV-45.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the East Bering LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

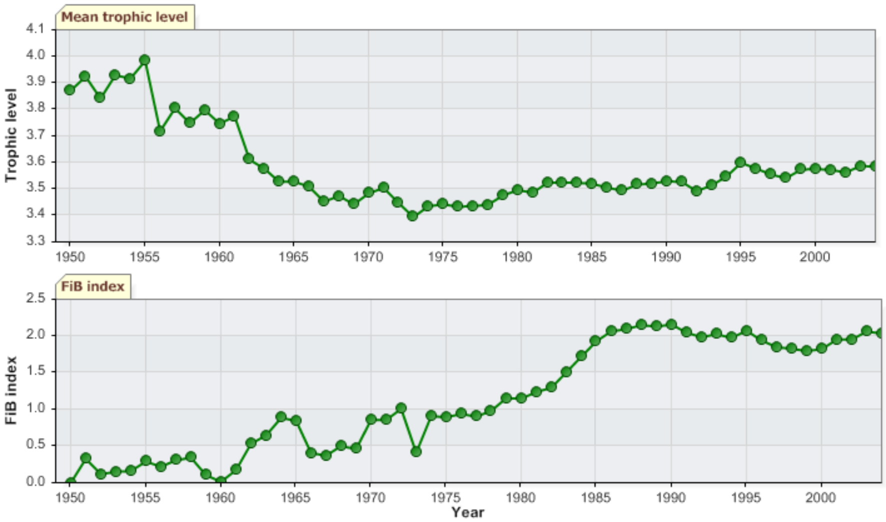

Figure XIV-45.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the East Bering Sea LME (Sea Around Us 2007)

The Stock-Catch Status Plots indicate that over 70% of the commercially exploited stocks are now generating catches of 10% less than the historic maximum, corresponding to the 'collapsed' status in Figure XIV-45.8 (top). This is in line with the findings of Armstrong *et al.* (1998), who reported, for an area immediately adjacent to the one considered here, on serial depletion of the (frequently small) stocks of commercial invertebrates. However, the overwhelming bulk of the reported landings for this LME is supplied by fully exploited stocks of Alaska pollock (Figure XIV-45.8, bottom). The US National Marine Fisheries Service (NMFS) includes "overfished" but not "collapsed" in its stock status categories. All five species of Alaska salmon are fully utilized, and stocks in the LME have rebuilt to near or beyond previous high levels. There is concern for some salmon stocks (especially Chinook and chum salmon) along the East Bering Sea LME, due to overfishing, incidental take of salmon as bycatch in other fisheries, and loss of freshwater spawning and rearing habitats. There is however growing evidence of population increases of pink salmon in Norton Sound and Kotzebue Sound, due perhaps to climatic changes. The halibut fishery is not subject to overfishing. A Pacific halibut cap constrains these fisheries. The Walleye Pollock stock in the LME is considered fully utilized and is well managed for bycatch and other issues which include minimizing impacts on Steller sea lion populations. Flatfish species are underutilized. The sablefish stock is fully utilized and is harvested under an IFQ system. Skates and squids are underutilized. Alaska crab resources are fully utilized (NMFS 2009). The difference between the two panels of Figure XIV-45.8 is the greatest of all LMEs included in this volume. It illustrates the contrast between the effect of prudent management in a few abundant stocks (bottom), combined with serial depletion of what might be seen as minor stocks (top).

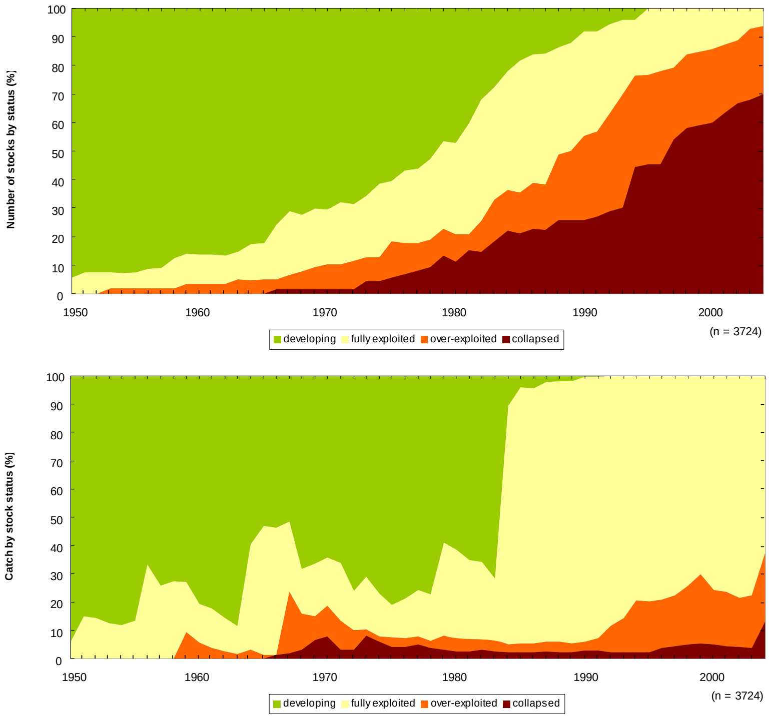

Figure XIV-45.8. Stock-Catch Status Plots for the East Bering Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

The management regime annually updates fishing quotas based on biomass estimates, including those for Alaska pollock. Because of the Steller sea lion interaction with pollock, research is underway to study the dynamics and distribution of Steller sea lion prey and predators, and to evaluate the connection with commercial fishing (www.etl.noaa.gov/). An ecosystem approach is being implemented for the assessment and management of fisheries biomass yields in the East Bering Sea LME. The basic ecosystem consideration is a precautionary approach. All groundfish stocks are considered healthy, providing sustained yields of approximately 2 mmt annually. Actions are taken by the North Pacific Fisheries Management Council to annually cap a total groundfish TAC based on NOAA-Fisheries survey operations (Witherell et al. 2000).

III. Pollution and Ecosystem Health

The coastal resources in this LME are generally in pristine condition. Coastal habitats are favourable to, for instance, the high abundance of salmon and with minimal impact from extensive development. Salmon being anadromous depend on freshwater streams, rivers and lakes. Their health is directly influenced by land management practices. The conservation of the region's salmon resource requires the conservation of the thousands of miles of riparian habitat that support salmon production. Competing uses for this habitat include logging, mining, oil and gas development, and industrial and urban development. Contaminant levels are consistently below the EPA's level of concern (EPA 2001 and 2004). Hypotheses concerned with the growing impacts of pollution, overexploitation and environmental changes on sustained biomass yields are under investigation. Concerns for the health of this LME focus on petroleum hydrocarbons found in the tissue of marine mammals, and the effects of the growing industrialisation of the region. Population levels of marine mammals in the coastal areas are low compared to other shallow seas. For statistics concerning the harbour seal, Beluga whale and harbor porpoise, see NOAA (1999, p. 231). Current regulations restrict the Aleutian Islands pollock quota due to concerns over food competition with Steller sea lions in this area, which contains critical habitat for the species. Marine mammal interactions with fish and fisheries are a major concern in fishery resource management in this LME. Fisheries compete for prey items that marine mammals and seabirds depend on for food and are a major factor in the decline of sea lion populations. The Steller sea lion is listed as threatened under the Endangered Species Act.

The East Bering Sea LME has low levels of toxic contaminants, but these have been rising over the last 50 years due to increased human activities (mining, fishing and oil exploration). This increase is linked to the long-range transport of contaminants through the ocean and atmosphere from other regions. Cold region ecosystems such as the East Bering Sea LME are more sensitive to the threat of contaminants than warmer regions because the loss and breakdown of these contaminants are delayed at low temperatures. Also, animals high in the food web with relatively large amounts of fat tend to accumulate organic contaminants such as pesticides and PCBs (EEA 2004). This causes concerns for human health in the region, particularly for Alaska natives, including the Aleut community, who rely on marine mammals and seabirds as food sources. The EPA and Indian Health Service contribute $20 million annually for water and sanitation projects now underway in rural Alaska so that 85% of all Alaska households will have access to safe water and basic sanitation (www.dced.state.ak.us.AEIS).

IV. Socioeconomic Conditions

The Alaskan coast east of the LME has a low population relative to its size and is distant from major urban or industrial areas. More than 65,000 Native Americans live on the shores of the East Bering Sea LME, with a long tradition of relying on salmon and other marine resources for economic, cultural and subsistence purposes. Pacific salmon plays an important and pivotal role, along with mining, timber, and furs, keystone natural resources that led to the settling and development of the US's 49th state by non-native peoples. Many Alaskans still depend heavily on salmon for recreation, food, and industry. Recent declines in chum and sockeye salmon runs have added to the hardships experienced by fishermen in Bristol Bay. The value of the salmon catch has declined over the past decade, along with a rising trend in total worldwide salmon production with the rapid growth of farmed salmon especially in Norway, Chile and the United Kingdom. Nearshore fishery resources provide important subsistence and recreational fishing opportunities for Alaskans of the East Bering Sea LME. Subsistence fishing is distributed all along the coastline of the LME. The East Bering Sea herring fishery began in the late 1920s, with a small salt-cure plant in Dutch Harbor in the Aleutian Islands. Commercial harvesting and processing, along with rapidly growing tourism and sport fishing, provide the region with big employment opportunities (NMFS 2009). According to statistics from the State of Alaska Department of Labor and Workforce Development in 2005, nearly 80% of the private sector population was engaged in fish harvesting or seafood processing in the Aleutian Islands. In the Bristol Bay Region, 75%, of which 40% were non-residents, were employed in the regional seafood industry (harvesting or processing). In the Yukon Delta Region, about 28%.were engaged in fish harvesting or seafood processing. Recreational fishing continues to grow due to an increase in guided fishing trips for visitors and tourists.

The East Bering Sea is home to a valuable offshore fishing industry. The interests of US factory trawlers differ markedly from those of small fisheries. Much of the groundfish catches are exported, particularly to Asia. This trade is a major source of revenue for US fishermen. For an article on the political economy of the walleye pollock fishery, see Criddle & Mackinko (2000). There are increasing demands from extractive industries to log and drill for oil and gas development. Climate change is having and is expected to have a profound influence on the socioeconomics of natural resources, goods and services of the East Bering Sea LME. The U.S. National Science Foundation supports studies of the physical, chemical and biological processes and human impacts to be expected by the reduction of sea ice in the East Bering Sea (BEST 2003).

V. Governance

The East Bering Sea LME is bordered by the USA (State of Alaska). The Alaska Board of Fisheries deals with the allocation of fish resources and quotas among various fisheries. The North Pacific Fishery Management Council (NPFMC) has primary responsibility for groundfish management within the US Exclusive Economic Zone (3 to 200 nautical miles) off the coasts of the East Bering Sea and Aleutian Islands, with the goal of maintaining stable yields by regulating harvest allocations among species. It is addressing the issue of salmon bycatch through time-area closures and bycatch limits set for different gear types in groundfish fisheries. The Alaska native populations benefit from individual fishing quotas or IFQs. There are also community development quotas (CDQs). Pelagic and salmon fisheries occurring within 3 miles are managed by the Alaska Department of Fish and Game. Improved management of the salmon fishery by state and federal agencies has contributed to the high abundance of Pacific salmon. High seas drift net fisheries by foreign nations for salmon has been eliminated through UN Resolution 46/215. The management of high seas salmon is under the North Pacific Anadromous Fish Commission. Initial signatories of the Commission are Canada, Japan, Russian Federation, Korea, and the United States. The Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean has eliminated a former high seas salmon fishery by Japan. An area involving salmon and negotiations with Canada concerns the stocks and fisheries of the 2,000 mile long Yukon River system. The agreement sets harvest quotas for Chinook and chum salmon stocks. The Magnuson-Stevens Fishery Conservation and Management Act extended federal fisheries management jurisdiction to 200 nautical miles and stimulated the growth of a domestic Alaskan groundfish fishery that rapidly replaced foreign fisheries. The former unregulated pollock fishery in the “Donut Hole” now comes under the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea. The Convention has been signed by the Russian Federation, Japan, Poland, China, Korea, and the United States. A moratorium on pollock fishing was voluntarily imposed in 1993 (NMFS 2009). The Bureau of Indian Affairs has responsibility to protect and improve trust assets of Alaska natives. Alaska has a Department of Environmental Conservation (ADEC) responsible for assessing and controlling potential environmental degradation.

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XIV-46 Gulf of Alaska LME

M.C. Aquarone and S. Adams

The Gulf of Alaska LME lies off the southern coast of Alaska and the western coast of Canada. It is separated from the East Bering Sea LME by the Alaska Peninsula. The cold Subarctic Current, as it bifurcates towards the south, serves as the boundary between the Gulf of Alaska and the California Current LME. For a description of the Gulf of Alaska's major currents, see www.pmel.noaa.gov/np/. The LME has a sub-Arctic climate and is subject to interannual and interdecadal climate variations (Brodeur *et al*. 1999). The area of this LME is about 1.5 million km², of which 1.50% is protected, and includes 0.52% of the world's sea mounts (as defined in Sea Around Us 2007 and Kitchingman et al. 2007). There are 14 estuaries and river systems, including the Stikine River, Copper River, and Chatham Sound (Skeena River). A book chapter pertaining to this LME is by Brodeur *et al*. (1999).

I. Productivity

The Gulf of Alaska LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$). The LME's cold, nutrient-rich waters support a biologically diverse ecosystem. Large-scale atmospheric and oceanographic conditions affect the productivity of this LME. Changes in zooplankton biomass have been observed in both the Gulf of Alaska LME and the adjacent California Current LME. These biomass changes appear to be inversely related to each other (Brodeur *et al*. 1999). A well-documented climatic regime shift occurring in the late 1970s caused the Alaska gyre to be centred more to the east (Lagerloef 1995, Anderson & Piatt 1999). Brodeur and his co-authors suggested a possibility of increases in the future production of salmon as a consequence of long-term oceanographic shifts resulting in increases in plankton biomass in the last decade. More information is available on climate variability and its effect on the abundance and production of marine organisms in this LME (Hollowed *et al*. 1998). For more information on the production dynamics of Alaska salmon in relation to oscillating periods of 'warm' and 'cool' regimes, see Francis (1993), Francis & Hare (1994), and Hare & Francis (1995).

Oceanic Fronts (Belkin et al. 2008): The Polar Front (PF) exists year-round in the western part of the Gulf (Belkin *et al*. 2002) (Figure XIV-46.1). This front is associated with the Subarctic Current that crosses the North Pacific from Hokkaido to the Gulf of Alaska where it retroflects and flows along the Aleutian Island Chain, branching first into the Eastern Bering Sea, then into the Western Bering Sea. Several fronts develop in summer over the Alaskan Shelf (Belkin & Cornillon 2003, Belkin *et al*. 2003). The conspicuous Kodiak Front (KF) is observed east and south of Kodiak Island, where its quasi-stable location is controlled by local topography. The Inner Passage Front (IPF) is located in a strait between the Queen Charlotte Islands and the British Columbia coast.

Gulf of Alaska LME SST (Belkin 2008)(Figure XIV-46.2)
Linear SST trend since 1957: 0.38°C.
Linear SST trend since 1982: 0.37°C.

Temporal SST variability in the Gulf of Alaska (GOA) LME is strong (Figure XIV-46.2). In 1957-2006, three successive regimes were: (1) rapid cooling by nearly 2°C from the sharp peak of 1958 until 1971; (2) a cold spell in 1971-1976; (3) a warm epoch, from 1977 to the present. These epochs are best defined in the central GOA and off the Queen Charlotte Islands (Mendelssohn et al., 2003, and Bograd et al., 2005). The transition from the cold spell to the present warm epoch occurred during the North Pacific regime shift of 1976-77 (see East Bering Sea LME). In general, the SST history of the GOA is very similar to the East Bering Sea (EBS). In particular, SST swings in 1996-2006 were synchronic, from the absolute maximum in 1997 to a 1.4°C drop in 1999, to a maximum in 2003-2005, followed by a drop in 2006. The observed synchronicity between the GOA and EBS is suggestive of large-scale forcing that spans the eastern North Pacific.

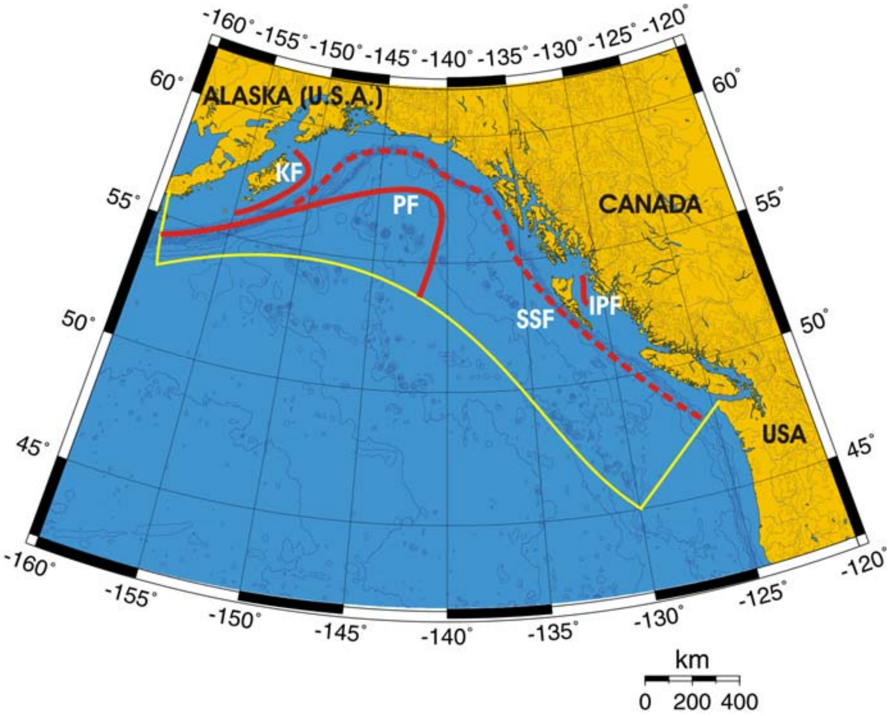

Figure XIV-46.1. Fronts of the Gulf of Alaska LME. IPF, Inner Passage Front; KF, Kodiak Front; PF, Polar Front; SSF, Shelf-Slope (most probable location). Yellow line, LME boundary. After Belkin et al. (2008).

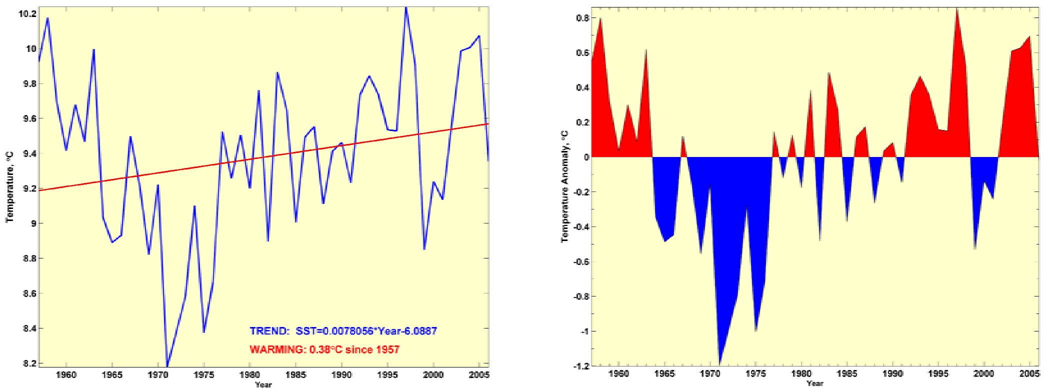

Figure XIV-46.2. Gulf of Alaska LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

Gulf of Alaska LME Chlorophyll and Primary Productivity: The Gulf of Alaska LME is a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$)(Figure XIV-46.3).

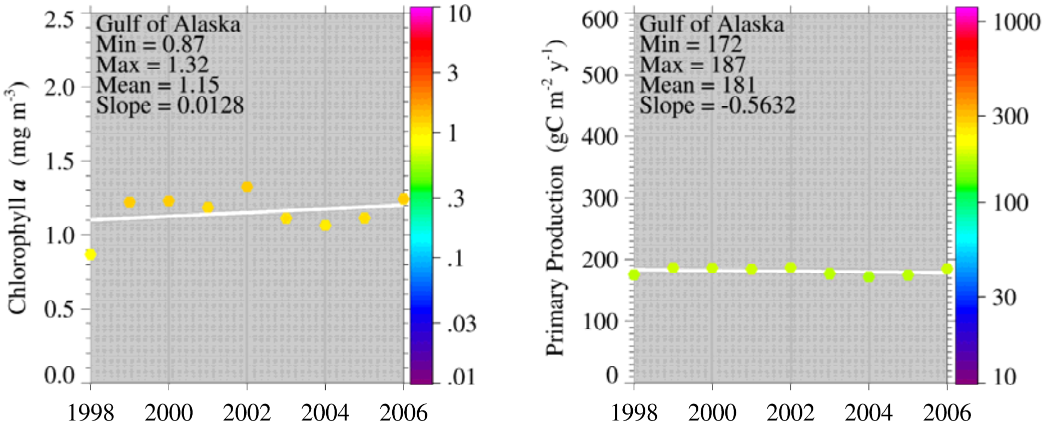

Figure XIV-46.3. Trends in Gulf of Alaska LME chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

This LME supports a number of commercially important fisheries for crab, shrimp, scallops, walleye pollock, Pacific cod, rockfishes, sockeye salmon, pink salmon and halibut. For information on salmon, pelagic, groundfish, shellfish and nearshore fisheries in Alaska, see NMFS (1999). The largest fisheries for sockeye salmon, the salmon species of highest commercial value in the US portion of the LME, occur in Cook Inlet, Kodiak Island, and Prince William Sound. Chum salmon hatcheries produce a significant portion of the catch. A quota, under the provisions of the Pacific Salmon Treaty between Canada and the US, regulates the Chinook salmon harvest in this LME. Pacific herring is the major pelagic species harvested in the LME. In Alaska, spawning fish concentrate in Prince William Sound and around the Kodiak Island-Cook Inlet area (EPA 2004). The groundfish complex (walleye pollock, Pacific cod, flatfish, sablefish, rockfish, and Atka mackerel) is an abundant fisheries resource in the Gulf of Alaska LME but less so than in the neighboring East Bering Sea LME. The extreme variation in pollock abundance is primarily the result of environmental forcing. For information on abundance of larval pollock, see Duffy-Anderson et al., 2002. Pollock are carefully managed due to concerns about the impact of fisheries on endangered Steller sea lions for which pollock is a major prey. Sea lion protection measures include closed areas and determinations of the acceptable biological catch. The western part of the Gulf (Kodiak Island and along the Alaska Peninsula) is a major area of operation for the shrimp fishery. Shrimp landings rose and are now declining. King crab catches peaked in the mid 1960s. Almost all Gulf of Alaska king crab fisheries have been closed since 1983. Dungeness crabs are harvested in the Yakutat and Kodial areas of the Gulf of Alaska. Most nearshore fisheries take place in the Gulf of Alaska LME near population centers (NMFS 2009). Current information regarding US fisheries in the GOA is available from the NMFS Alaska Region (www.fakr.noaa.gov), the Alaska Fisheries Science Center (www.afsc.noaa.gov), and the Alaska Department of Fish and Game (www.cf.adfg.state.ak.us). Current information regarding Canadian fisheries is available from Fisheries and Oceans, Canada, Pacific Region (www.pac.dfo-mpo.gc.ca).

Total reported landings in this LME is in the order of 600 to 700 thousand tonnes, with a peak of 800 thousand tonnes in 1993 (Figure XIV-46.4). The value of the reported landings peaked in 1988 at nearly US$1.2 billion (calculated in 2000 US dollars) but has since declined to about US$500 million in 2004 (Figure XIV-46.5).

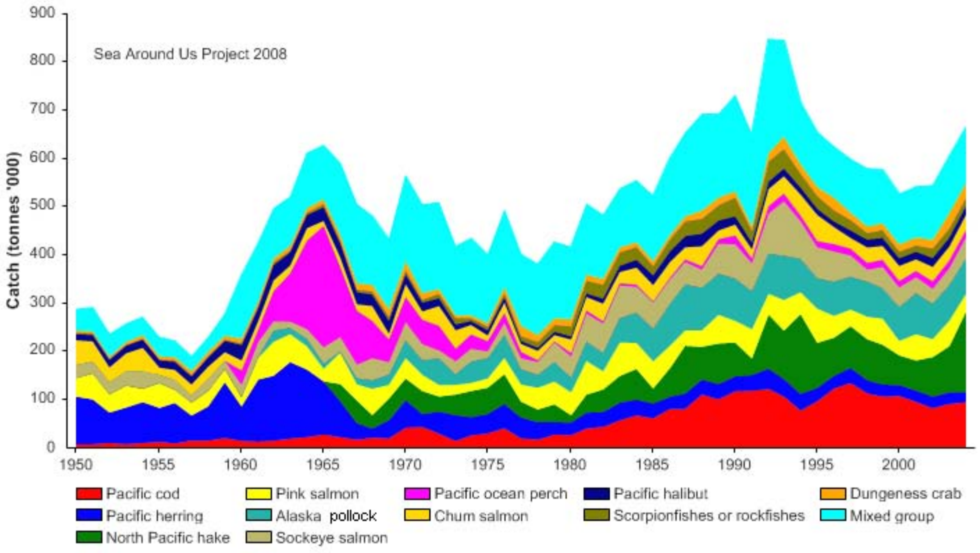

Figure XIV-46.4. Total reported landings in the Gulf of Alaska Sea LME by species (Sea Around Us 2007)

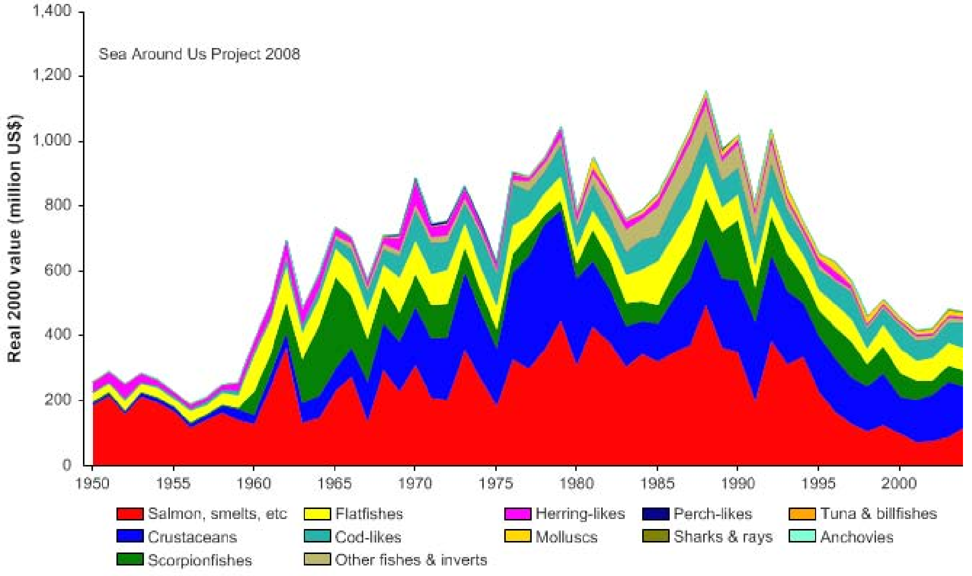

Figure XIV-46.5. Value of reported landings in the Gulf of Alaska LME by commercial groups (Sea Around Us 2007)

The primary production required (PPR) (Pauly & Christensen 1995) to sustain the reported landings in this LME reached over 25% of the observed primary production in the late 1980s, but leveled off at around 20% in recent years (Figure XIV-46.6). The USA and Canada now account for all landings (i.e. ecological footprint) in this LME.

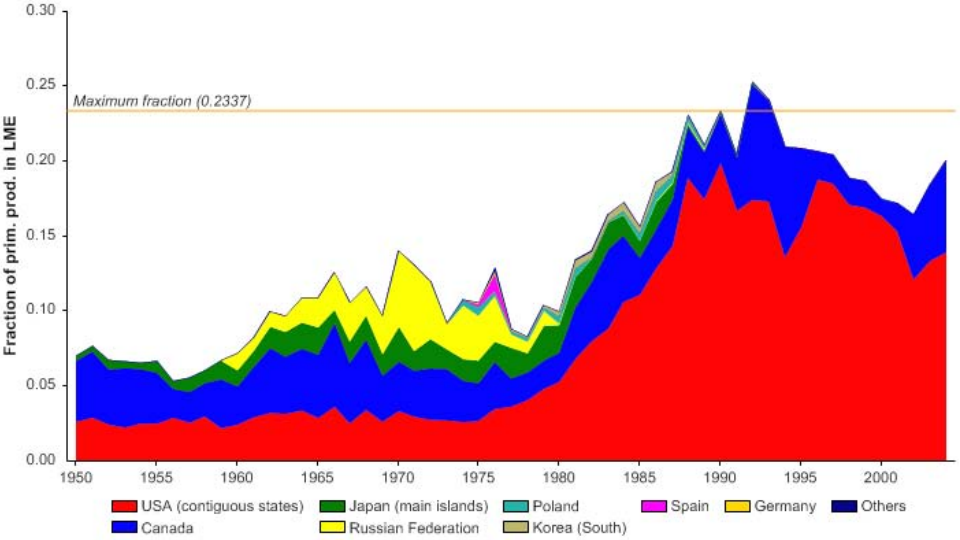

Figure XIV-46.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Gulf of Alaska LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the fisheries landings (MTI) (Pauly & Watson 2005) is rather high, especially in recent years (Figure XIV-46.7 top), while the increase in the Fishing-in-Balance index in the early 1980s reflects the increased landings reported during that period (Figure XIV-46.7 bottom).

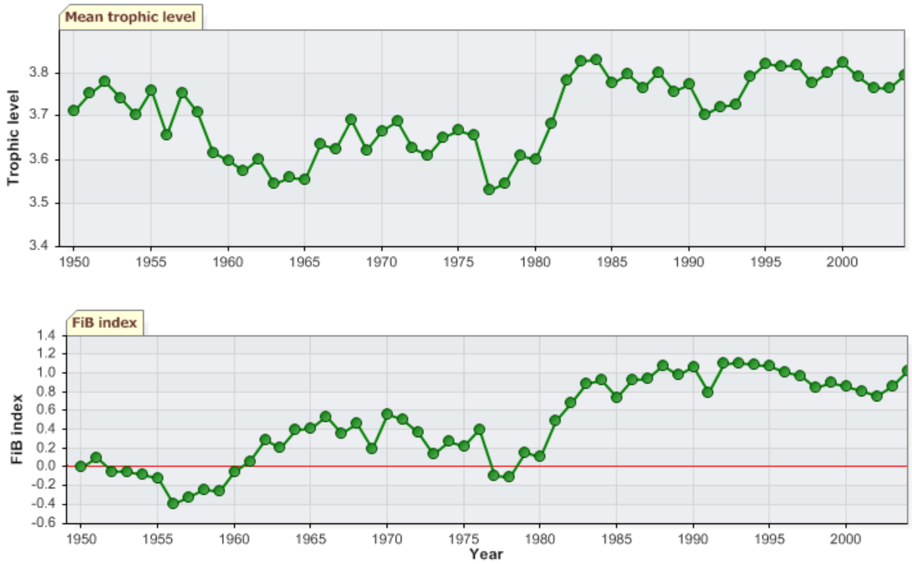

Figure XIV-46.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Gulf of Alaska LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that over 30% of the commercially exploited stocks are now generating catches of 10% or less than the historic maximum, corresponding to the 'collapsed' status (Figure XIV-46.8, top). Another 40% are generating catches from 50 to 10%, corresponding to the 'overexploited ' status (see Pauly et al. this vol.). This is explained by Armstrong *et al.* (1998), who reported on the serial depletion of (frequently small) stocks of commercial invertebrates. However, 80%. (in bulk) of the reported landings in the Gulf of Alaska LME are contributed by fully exploited (i.e., not overexploited) stocks. (Figure XIV-46.8, bottom), thus confirming the positive assessment also suggested by Figure XIV-46.7. The US National Marine Fisheries service (NMFS) includes "overfished" but not "collapsed" in its stock status categories. NMFS 2009 lists no overfished species. Several groundfish are presently underutilized and cannot be fully harvested without exceeding the bycatch limits for Pacific halibut. Gulf of Alaska groundfish stocks in the US are considered to be in a healthy condition as a result of ecosystem-based management actions by the North Pacific Fishery Management Council, which include public participation, reliance on scientific assessments, conservative catch quotas built around annually determined overall fisheries biomass yield catch, and total allowable catch levels for key species with the objective of long term sustainability of fisheries stocks (Witherell et al, 2000; North Pacific Management Council, 2002).

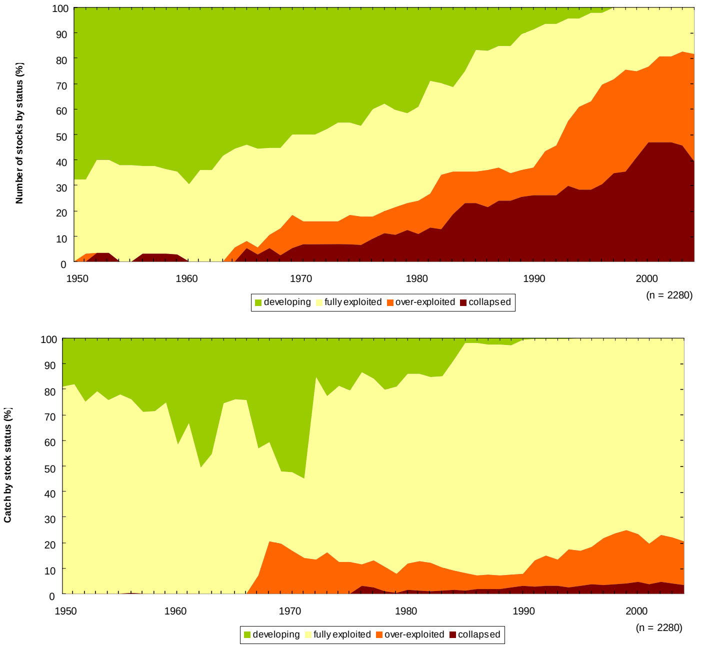

Figure XIV-46.8. Stock-Catch Status Plots for the Gulf of Alaska LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

III. Pollution and Ecosystem Health

Because salmon are anadromous and spend a portion of their lives in freshwater streams, rivers, and lakes, the health of salmon populations in this LME is directly influenced by land management practices in both countries and the loss of freshwater spawning and rearing habitats. Competing uses for the salmon habitat include logging, mining, oil and gas development, and industrial and urban development. Prince William Sound is an area of concern where large returns of hatchery pink salmon mix with lower numbers of wild fish. The Gulf of Alaska Ecosystem Monitoring and Research Program is a long-term effort to gather information about the physical and biological components of the marine ecosystem, the cooperation of agencies, public involvement and access to informative data. For pollution issues, see <www.evostc.state.ak.us/>. For information on coastal condition for all of Alaska, see EPA 2001 and 2004. A sampling survey of the ecological condition of Alaska's estuarine resources in the south-central region of the state of Alaska was completed in 2002 (EPA 2004), with data collected from 55 sites. Prince William Sound and Cook Inlet are major estuaries. The total allowable catch for pollock in the Alaska is apportioned to accommodate Steller sea lion concerns, as pollock are the major prey of Steller sea lions in the Gulf of Alaska. For information on clean water assessments in Alaska, see EPA (2004). For statistics on harbour seals and harbour porpoises in this LME, see NMFS (1999). Audubon red listed Alaskan seabirds include Steller's eider, Spectacled eider, Sooty grouse, Laysan albatross, Black-footed albatross, Short-tailed albatross, Pink-footed shearwater, Eskimo curlew, Rock sandpiper, Buff-breasted sandpiper, Ivory gull, and murrelet.

Problems affecting the LME include predation by invasive species, discharges of oil products, and industrial and agricultural contaminants that enter the LME through a variety of pathways (ocean currents, prevailing winds). Prince William Sound is routinely crossed by large oil tankers. In 1989, the *Exxon Valdez* spilled 11 million gallons of North Slope crude oil off the Port of Valdez, the terminal of the Trans-Alaskan Pipeline. This was the largest tanker oil spill in U.S. history and it contaminated over 2,000 km of the Gulf of Alaska's coastline. The livelihood of 70,000 full-time residents living in the area was directly affected by the Exxon Valdez oil spill. They had to overcome the effects of the oil-related fish mortalities. Others using the area seasonally for work or recreation were also seriously affected. There remain concerns about the lingering effects of the oil spill and the pockets of residual oil in the environment, especially in the Western portion of Prince William Sound. The effects of the oil spill interact with the effects of other kinds of changes and perturbations in the marine ecosystem. More common than spills, however, are smaller discharges of refined oil products, crude oil and hazardous substances.

IV. Socioeconomic Conditions

The LME coastal population is low relative to the length of the coastline, with the exception of the city area of Vancouver in the Canadian province of British Columbia. Native peoples have a long and rich tradition of relying on salmon for economic, cultural, and subsistence purposes. The coastal native communities rely for their subsistence largely on hunting and the harvesting of marine resources. The economy of the coastal communities is based on commercial fishing of pink and red salmon, fish processing, timber, minerals, agriculture and tourism. Pacific salmon has played a pivotal role in the history of the region. Although commercial salmon harvests are at high levels, the value of the catch has declined due to a number of world wide reasons, one of which is a rising trend in salmon farmed production in Norway, Chile, and the United Kingdom. Alaska's herring industry began in the late 19th century and expanded rapidly, with markets shifting from salt-cured herring to reduction products for fishmeal and oil (NMFS 2009). Shellfish fisheries developed in the 1960s in the Gulf of Alaska (NMFS 1999). US groundfish catches are exported to Asia, which constitutes a major source of revenue for US fishermen. The estuarine resources of Prince William Sound and Cook Inlet in Alaska are of major importance for the local and state economy. Conflicts have emerged between coastal and offshore interests. In addition to jobs in fishing and fish processing, people in Gulf of Alaska communities work in government, military (Kodiak U.S. Coast Guard base), logging, mining and tourism. In 1998, there was an increase of visitors to over 1 million a year in Alaska. Colt et al. (2007) estimate summer 2005 revenue from nature-based tourism activities in Chichagof Island alone at $15.5 million.

V. Governance

The Gulf of Alaska LME is bordered by the U.S. and Canada, each with separate government actions and management plans. In 2004, Amendment #66 to the Halibut and Sablefish program became a law that allowed eligible coastal communities in Alaska to purchase halibut and sablefish quota shares. The North Pacific Fishery Management Council, in conjunction with NOAA, produces a Gulf of Alaska Groundfish Fishery Management Plan for Alaska. The Gulf of Alaska Coastal Communities Coalition has identified 42 communities within Alaska eligible to participate in a program to form a CQE (Community Quota Entity), a non-profit corporation for the purchasing of quota shares (www.goac3.org). The program helps compensate for the negative impacts of Individual Fishing Quotas (IFQs) on subsistence fishers. The transboundary management of Pacific salmon (sockeye, chum, pink, chinook, coho and steelhead salmon) is conducted under the Pacific Salmon Treaty (www.oceanlaw.net), signed in 1985 by Canada and the US. The Treaty is intended to facilitate the management of these salmon stocks by preventing overfishing and providing for optimum production and equitable sharing of the salmon catch. Catch quota levels since 1999 are subject to fluctuations of salmon abundance from year to year. Major transboundary concerns between the two countries are: Chinook salmon catches in southeastern Alaska where Canadian salmon are caught along with other non-Alaska US stocks; fisheries in the Dixon Entrance where each country catches salmon originating in the other nation; transboundary river stocks associated primarily with the Taku and Stikine Rivers; Canadian fisheries off the west coast of Vancouver Island; and Strait of Juan de Fuca fisheries for salmon bound for the Fraser River in Canada (NMFS 2009). The North Pacific Anadromous Fish Commission (NPAFC) manages the salmon harvest in the high seas. Signatories are Canada, Japan, Russian Federation, United States and Korea. The Convention prohibits high seas salmon fishing and trafficking of illegally caught salmon. United Nations Resolution 46/215 bans large scale pelagic driftnet fishing in the world’s oceans. The Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean seeks to control the interception and incidental take of the LME’s salmon resources. Pacific Halibut is also a target of transboundary management. The resource is managed by a bilateral treaty between the US and Canada, with recommendations coming from the International Pacific Halibut Commission. Both Canada and Alaska have moved to regulating halibut fisheries subareas through catch quotas, time-area restrictions, and by individual fishing quotas (IFQs). Under the IFQ system there has been a decline in the overall size of the fishing fleet.

In the aftermath of the Exxon Valdez oil spill, the US Congress crafted the Oil Pollution Act of 1990 (OPA 90). Under OPA 90, two Regional Citizen Advisory Councils were created, one for Prince William Sound, and one for Cook Inlet (EPA 2004). In the US, the Magnuson-Stevens Fishery Conservation and Management Act extended federal fisheries management jurisdiction to 200 nautical miles and stimulated the growth of a domestic Alaskan groundfish fishery that rapidly replaced the foreign fisheries. Pacific ocean perch was intensively exploited by foreign fleets in the 1960s. Inshore groundfish resources are managed by the Alaska Department of Fish and Game.

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XIV-47 Gulf of California LME

S. Heileman

The Gulf of California LME (also known as the Sea of Cortez) is a long (1,130 km) and narrow (80-290 km), semi-enclosed LME bordered by the Baja California Peninsula and mainland Mexico. It has a surface area of about 221,600 km^2, of which 3.64% is protected, and includes 0.11% and 0.06% of the world's coral reefs and sea mounts, respectively (Sea Around Us 2007). The Gulf is one of the youngest ocean bodies and was formed by the separation of the North American Plate and the Pacific Plate by tectonic movement (Rusnak *et al*. 1964). Several deep basins (up to 3,600 m deep) occur in the southern part of the Gulf, including the Guaymas Basin. The northern part of the Gulf is shallower, due to the large amount of siltation produced over the years by the Colorado, the major river entering this LME. There are 898 islands of all sizes within the Gulf, included in the 'Area de Protección de Flora y Fauna Islas del Golfo de California' (Islands of the Gulf of California Flora and Fauna Protection Area) (SEMARNAP 1999). A report pertaining to this LME is UNEP (2004).

I. Productivity

Surface winds have an average direction that generally follows the axis of the Gulf (Marinone *et al*. 2004). Tropical storms and hurricanes can cause heavy rainfall and intensified water and sediment runoff. SST seasonality is very conspicuous. Highest annual SST is observed during August and September (30-31º C south of the islands). Between October and December, the SST of the northern Gulf falls by almost 20° C and of the central and southern by about 7º C. Intense tidal mixing and upwelling maintain minimum SSTs around the mid-gulf islands throughout the year (Marinone & Lavín 2003). The largest interannual variability signal in the Gulf SST is due to El Niño-La Niña. The largest SST positive anomaly in the satellite records is that of 1997-1998, 3º C over the seasonal climatology, while the largest negative anomaly is associated with the 1988-1989 La Niña (4ºC below the climatological mean). SST anomalies due to El Niño tend to be strongest in the region just south of the mid-gulf islands (Soto-Mardones *et al*. 1999, Lavín *et al*. 2003).

The Gulf has unique oceanographic characteristics because of its long axis and the Baja California Peninsula limit moderating influences from the Pacific Ocean circulation. Water circulation varies in time from two main influences: diurnal, semidiurnal, and fortnightly tidal cycles, and annual and semiannual seasonal changes. The tides, which co-oscillate with those of the Pacific Ocean, are mixed semi-diurnal tides, with one of the greatest tidal ranges on Earth. For instance, maximum registered spring tidal range at San Felipe is 6.95 m (Gutierrez & González 1999), with even larger amplitudes at the entrance to the Colorado Delta. The best-documented features of Gulf of California circulation are large-scale seasonally reversing gyres in the northern Gulf. A cyclonic gyre lasts approximately from June to September, and an anticyclonic gyre from November to April. Estimates from ship drift and the distributions of temperature and salinity indicate surface outflow during winter and inflow during summer, with mass conservation requiring a compensating flow at depth (Lavín *et al*. 1997, Berón-Vera & Ripa 2002, Castro 2001, Palacios-Hernández *et al*. 2002, Marinone & Lavín 2003, Lluch-Cota *et al*. 2004).

The LME is a Class I, highly productive ecosystem (>300 gCm^{-2}yr^{-1}), and is one of the five marine ecosystems with high productivity (Enríquez-Andrade *et al*. 2005). The northern Gulf has two main natural fertilisation mechanisms: one is the year-round tidal mixing around the large islands leading to an area of strong vertical mixing and continuous flow of cool nutrient-rich water into the euphotic layer, providing a thermal refuge for temperate species during the warmer periods (Lluch-Belda *et al*. 2003); the second is wind-induced upwelling along the eastern central gulf, enriched waters from the islands and the east coast reaching the peninsular side and remaining trapped, contributing to higher primary production per unit area. Also, because this enrichment system operates only during winter, there is a strong annual gradient of pigment concentration in most of the Gulf (Lluch-Cota *et al*. 2004, 2007).

The Guaymas Trench has volcanic and hydrothermal vents, with biotic communities supported by chemosynthesis using hydrogen sulfide, rather than photosynthesis (Teske *et al*. 2002). One of the most diverse biological communities in the world is found in this LME, with 4,852 species of invertebrates, excluding copepods and ostracods, (767 endemic), 891 species of fish (88 endemic) and 222 species of non-fish vertebrates, (four endemic) (Enríquez-Andrade *et al*. 2005). An outstanding diversity of marine mammal species is also found in the LME: 36 species, including 4 pinnipeds, 31 cetaceans and one bat (Aurioles-Gamboa 1993, Brusca *et al*. 2004). This LME is also the habitat of one of the world's most endangered cetaceans, the Vaquita porpoise (*Phocoena sinus*), endemic to the upper Gulf and the world's smallest and rarest porpoise. The blue, fin and grey whales are also found in this LME. The high primary productivity supports sardine and anchovy, which are the main prey of large quantities of squid, fish, seabirds and marine mammals.

Oceanic Fronts: This is one of the smallest LMEs, located between Baja California and Mexico's mainland. The temperature contrast between the northern and southern Gulf is 2ºC to 3ºC, depending on the season. This gradient is enhanced along a bathymetric step in the middle of the Gulf, where a thermal front is observed (Inner Gulf Front, IGF) (Figure XIV-47.1).

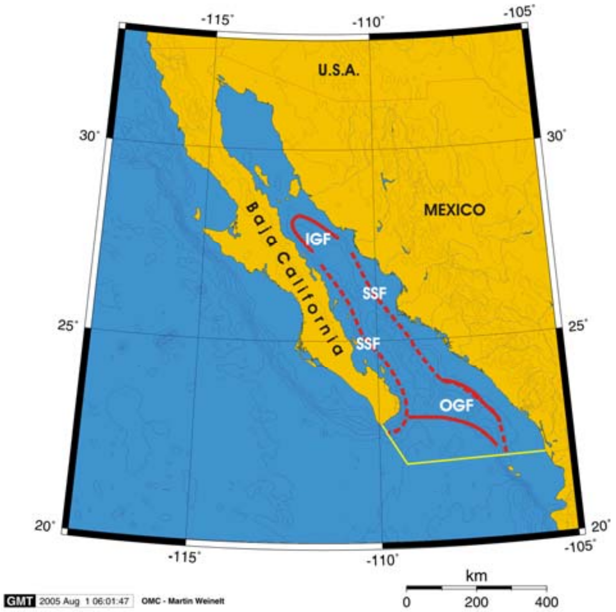

Figure XIV-47.1. Fronts of the Gulf of California LME. IGF, Inner Gulf Front; OGF, Outer Gulf fronts; SSF, Shelf-Slope Front (most probable location). Yellow line, LME boundary. GMT 2005 August 1 06:01:47. OMC Martin Weinelt. Courtesy of I. Belkin October 2005.

Other fronts form between Mexico's mainland and Baja California where Pacific inflow waters meet resident waters of the Gulf of California (Outer Gulf fronts (OGF) (Belkin *et al*. 2005). The Pacific and resident waters have different salinities and different temperatures; the salinity differential is the main factor responsible for the maintenance of this front.

Gulf of California SST

Linear SST trend since 1957: 1.24°C.
Linear SST trend since 1982: 0.31°C.

The semi-landlocked Gulf of California shares some similarities with the California Current. The global cooling of the 1960s-1970s manifested here as a 2.2°C drop from 1958 to 1975. After a 2.8°C rebound in 1979-1983, the Gulf of California remained warm until the present. The sharp SST peak of 1983 attributed to a major El Niño 1982-1983 was synchronous with similar peaks in the California Current LME, the Central American Pacific LME and the Humboldt Current LME. Since 1983, the Gulf of California thermal history is strongly correlated with the California Current LME, including major events (peaks) of 1992 and 1997, associated with major El Niño events.

The relatively small warming of 0.31°C over the last 25 years is misleading since the transition from the cold epoch to the warm occurred in the late 1970s. Regardless of the exact timing of the breakpoint between the cold and warm epochs (1975 or 1979), the overall warming since then exceeded 1.5°C, which would put the Gulf of California into the league of fast-warming LMEs. The absolute minimum in 1975 was synchronous with absolute minima in both adjacent LMEs, the California Current LME and Central-American Pacific LME.

The Gulf of California is considered to be a primary source of moisture for the North American or Mexican monsoon, "the most regular and predictable weather pattern in North America" (Mitchell et al., 2002, p.2261), therefore warmer surface temperatures are expected to increase evaporation from the Gulf, which in turn would fuel stronger Mexican monsoons.

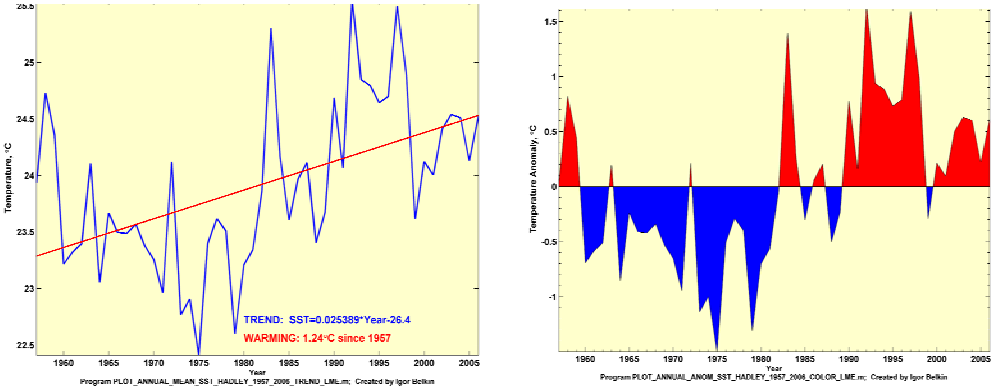

Figure XIV-47.2. Gulf of California annual mean SST and annual SST anomalies, 1957-2006. After Belkin 2008.

Gulf of California Chlorophyll and Primary Productivity: The LME is a Class I, highly productive ecosystem (>300 $gCm^{-2}yr^{-1}$),

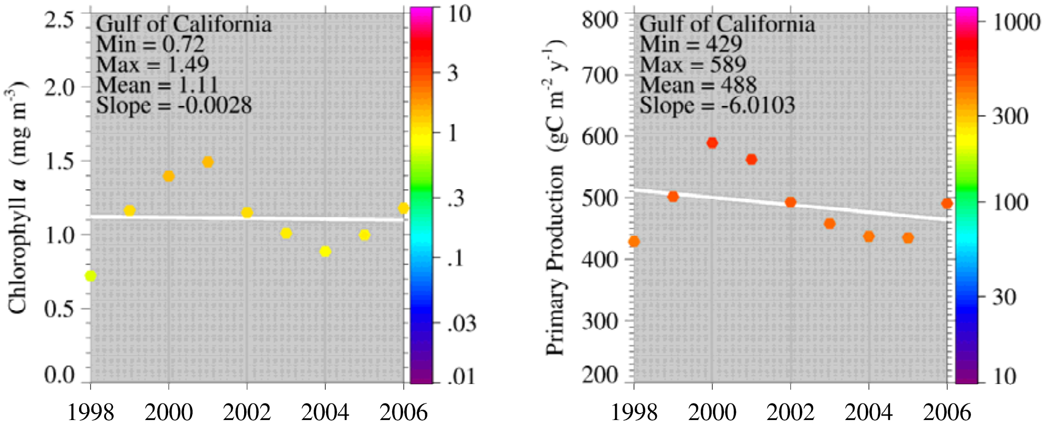

Figure XIV-47.3. Gulf of California trends in chlorophyll a and primary productivity, 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Historically, the LME has supported numerous fisheries of commercially valuable species. Fisheries resources in the Gulf are targeted by the commercial, artisanal, and recreational fishing sectors. In terms of weight caught, the major fisheries are dominated by small pelagic fish, primarily Californian anchovy (*Engraulis* mordax) and South American pilchard (*Sardinops sagax* [formerly known as Pacific sardine, *Sardinops caeruleus*]), as well as penaeid shrimps (blue, white and brown shrimp, *Litopenaeus stylirostris*, *Litopenaeus vannamei*, *Farfantepenaeus californiensis*, respectively, together with other less important species). Californian anchovy (*Engraulis mordax*) undergoes major scale abundance fluctuations related to environmental variation (Nevárez-Martínez *et al*. 2001). Jumbo squid (*Dosidicus gigas*), also a highly variable resource, is a major constituent in recent years (Nevárez-Martínez *et al*. 2000; Lluch-Cota 2007)). At a lower level of abundance, but much more consistent, are larger pelagic tuna-like fishes (mostly yellowfin and skipjack tuna) representing important commercial fisheries. The total annual catch of tuna-like resources increased rapidly from the late 1970s to peak in the mid 1980s. This increase was followed by a general downward trend until 1995, when catches began to increase again. The trend in catch of tuna-like species is mirrored by that of small pelagic fish.

Due to difficulties in separating landing from the Mexican State of Baja California Sur into components from the Gulf of California and those from the Pacific coast (and belonging mainly to the California Current LME), the values presented in Figure XIV-47.4 are only indicative of the magnitude of the catches in this small, yet highly productive LME, In particular, they differ from catch series (1980-2002) for 'sardines', jumbo squids', and 'shrimps' (though they match for tuna) presented in the review by Lluch-Cota *et al.* (2007, Fig. 5), which was not available when Figure XIV-47.4 and derived graphs (Figures XIV-47.5-10) were obtained. However, these graphs can still be expected to give a general impression of the fisheries and their status in the Gulf of California LME. [See www.seaaroundus.org for updated version on these graphs]

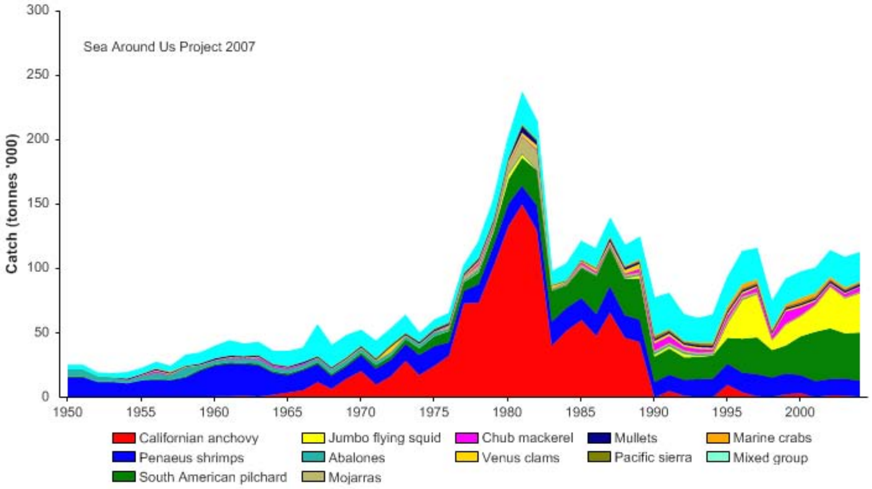

Figure XIV-47.6. Total reported landings in the Gulf of California LME by species (Sea Around Us 2007); see www.seaaroundus.org for a corrected update.

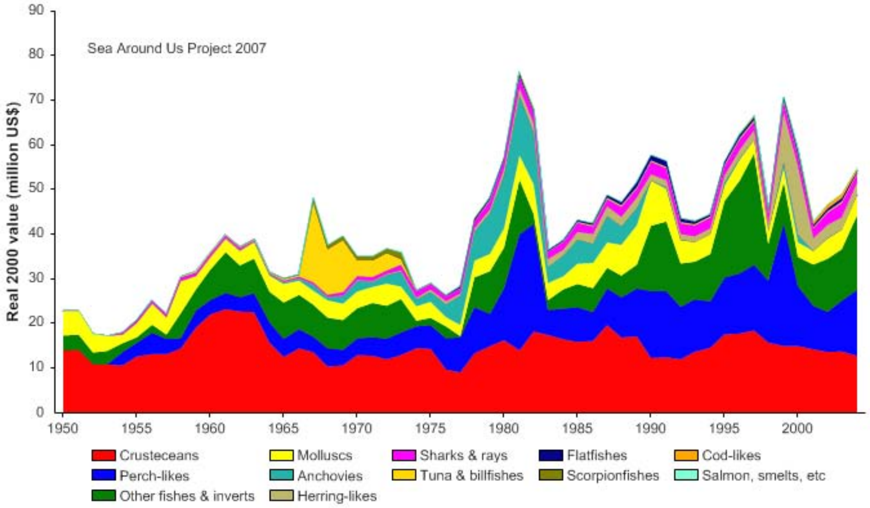

Figure XIV-47.7. Value of reported landings in the Gulf of California LME by commercial groups (Sea Around Us 2007); see www.seaaroundus.org for a corrected update.

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings reached 10% of the observed primary production in 1996 and has fluctuated between 5 to 9% in recent years (Figure XIV-47.6). Accounting for the catches in Fig. 5 of Lluch-Cota *et al.* (2007) would increase this figure to 15% at most. Since the mid 1970s, Mexico has been the only country fishing in this LME and hence accounts for all of the ecological footprint.

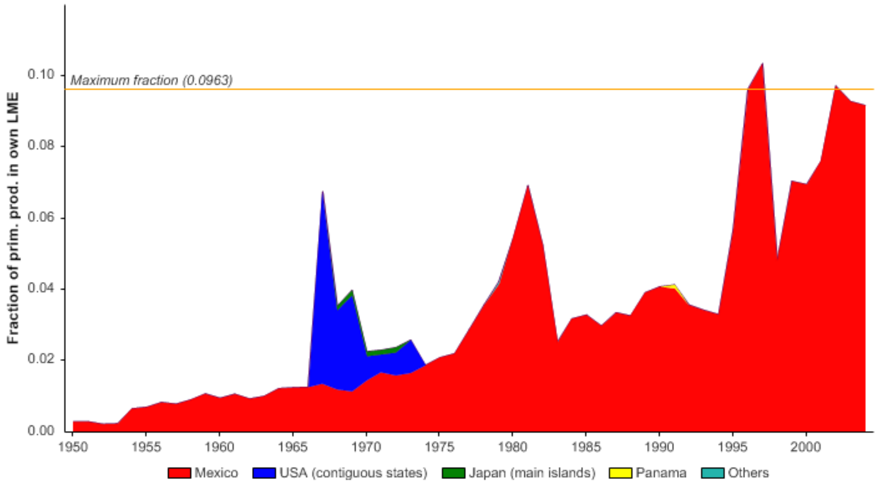

Figure XIV-47.8. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Gulf of California LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values; see www.seaaroundus.org for a corrected update.

The mean trophic level of the reported landings (MTI; Pauly & Watson 2005), has increased from 1950 to the early 1970s, and remained relatively steady thereafter, except for a more recent increase (Figure XIV-47.7 top). The FiB index suggests a spatial expansion of the fisheries until the early 1980s, and has remained relatively level since, suggesting that natural limits may have been reached (Figure XIV-47.7 bottom).

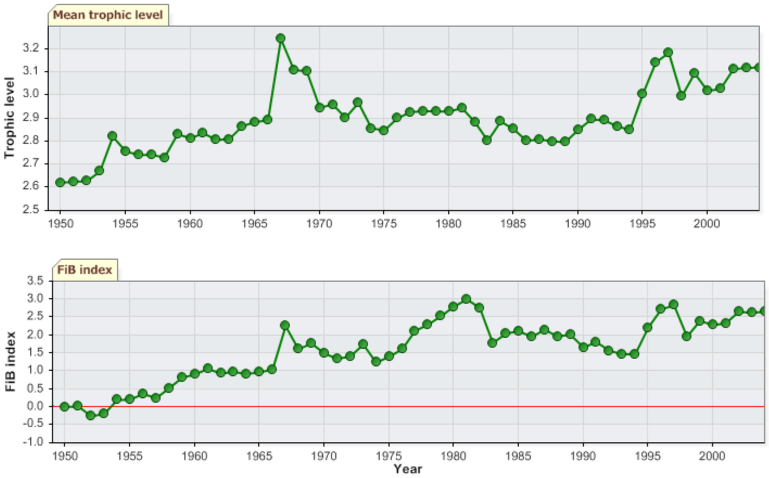

Figure XIV-47.9. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Gulf of California LME (Sea Around Us 2007); see www.seaaroundus.org for a corrected update.

A decline in trophic levels in the coastal food webs of this LME was reported by Sala *et al*. (2004), based on interviews with fishers, fisheries statistics and field surveys. According to Sala and colleagues, the decline in fish stocks has been accompanied by a marked shift in the species composition of the coastal fisheries and a decrease in the maximum individual length of fish catches by approximately 45 cm in 20 years. Large predatory fishes were among the most important catches in the 1970s, but became rare by 2000. Moreover, species that were not targeted in the 1970s have now become common in the catches. These findings contradict the conclusion of Pérez-España (2004) who, strangely, failed to find evidence of ‘fishing down the food web’ in this LME. The work of Saenz-Arroyo *et al.* (2005a, 2005b, 2006), and of Lozano-Montes *et al.* 2008) should, in any case, lay this controversy to rest as these authors not only demonstrated massive changes in the catch composition of the Gulf of California fisheries, but also that the bulk of these changes occurred before the period covered here, which, put them before the cognitive reach of researchers using based only on official catch statistics (Pauly 1995).

The Stock-Catch Status Plots indicate that the number of collapsed and overexploited stocks have been increasing in the LME, to about 70% of the commercially exploited stocks (Figure XIV-47.10 top). These stocks supply half of the reported landings (Figure XIV-47.10, bottom).

Several authors have suggested that the LME’s fish resources are overexploited and regard the impacts of overfishing as severe, at least in the upper Gulf (Brusca *et al*. 2001). Distinct areas of concern include: impacts of fishing on shrimp populations, impacts of shrimp fishing on non-targeted populations (mostly the bycatch issue) and on the physical habitat, and catch of fish for bait and in sport fisheries.

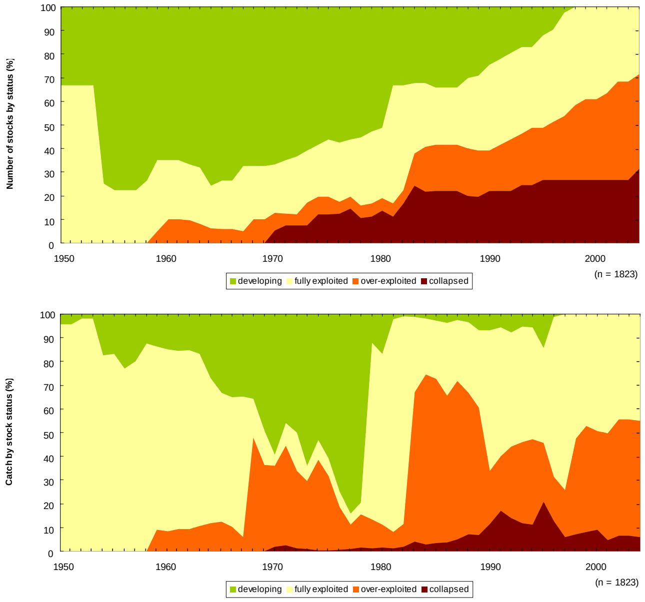

Figure XIV-47.10. Stock-Catch Status Plots for the Gulf of California LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of ‘stocks’, i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

The abundance and availability of small pelagic fish fluctuate mostly because of natural environmental variations at various interannual scales, as shown by several studies including paleosedimentary evidence for the last 250 years (Holmgren-Urba & Baumgartner 1993, Cisneros-Mata *et al*. 1995a, Lluch-Cota *et al*.1999, Nevárez *et al*.

2001). The sudden collapse of the sardine population during the 1991-1993 fishing seasons was related to overfishing and natural variation (Cisneros-Mata *et al*. 1995a, Nevárez *et al*. 1999), and resulted in the closure of more than 50% of the fish plants. However, the industry and governmental and research agencies together agreed on time and area closures, a reduction of the fishing fleet by 50% and a programme of research cruises to monitor recruitment. The fishery fully recovered after three years. No major concerns seem to be related to the fisheries for jumbo squid and tuna-like fishes.

The shrimp fishery, which has been assessed since the 1970s, was found to be overfished as a result of excessive fishing effort and small mesh size in the trawl nets. Since then, fishing effort has increased further with the increase in the number of large boats and their fishing power, but most of all, with the number of outboard powered *pangas* now fishing for offshore shrimp. According to data in Páez *et al*. (2003), total shrimp catch has been declining by an average of 600 tonnes per year in the period 1980-2001, while shrimp aquaculture has increased by 30% per year since 1990 and now exceeds the catch. Natural variation may further impact shrimp abundance, as suggested several decades ago (Castro-Aguirre 1976). Galindo-Bect *et al*. (2000) found a significant correlation between total shrimp catch in the upper Gulf and the rate of freshwater discharge by the Colorado River. Although the damming of the Colorado River may have been the principle cause of the decline in the shrimp fishery, the escalation in the number of fishing vessels and fishing gear types could have also contributed to this decline (UNEP 2004). Catches of offshore shrimp could improve substantially both in volume and individual sizes if fishing effort were to be reduced to adequate levels and mesh sizes regulated for optimum selectivity. While it would appear that the trend has been to allow more fishers to participate as a means of further distributing the benefits, it is becoming increasingly clear that such a process has involved extra financing through tax exemptions and subsidies and is no longer viable.

Conservation International Mexico (2003) has estimated that each kilogramme of shrimp caught in the commercial fishery is accompanied by at least 10 kg of bycatch. (Tis bycatch is not included in catch statistics, but should be). Estimates for the Gulf of California LME have ranged from 1:2 up to 1:10 (Rosales 1976) and larger at times. This proportion is similar to those reported for shrimp fisheries in tropical areas around the world, i.e., 1:10 (Cascorbi 2004). The magnitude of bycatch is highly variable, depending on area and season. At the beginning of the shrimp season the proportion may be lower; bycatch tends to increase towards the end of the season, when shrimps have been fished out. The National Fisheries Institute of Mexico (INP) began developing fish excluders together with Conservation International in 1992, particularly directed to the protection of totoaba *Cynoscion macdonaldi* (Balmori *et al*. 2003). Such efforts have continued with the FAO on an international project to develop suitable excluders.

Some species, such as juveniles of totoaba, a large endemic species that was heavily fished during the 1930s-1940s, and marine turtles, both vulnerable to trawl nets, are of particular concern. Cisneros-Mata *et al*. (1995b) estimated that an average of 120,300 juvenile totoaba was killed by shrimp vessels each year from 1979 to 1987. Other icon species, such as dolphins, are rarely killed by these gears. Vaquitas and sea turtles are incidentally captured in gill nets. The total estimated incidental mortality caused by the fleet of El Golfo de Santa Clara was 39 Vaquitas per year, over 17% of the most recent estimate of population size (D'Agrosa *et al*. 2000). The vaquita population is estimated to be less than 600 (Jaramillo-Legorreta *et al*. 1999). Therefore, considering normal replacement rates (maximum rate of population growth for cetaceans is of 10% per year), this incidental loss is unsustainable. Although turtle-excluder devices are mandatory for industrial fishing vessels, poaching of sea turtles is still a problem throughout western Mexico.

The impacts of the trawl fishery on the ecosystem are a major concern. Anecdotal information suggests that sweeping changes in benthic community structure have taken place over the past 30 years of these disturbances. Commercial shrimp trawling exacts a harsh toll on the Gulf's marine environment, as more than a thousand shrimp trawlers annually rake an area of sea floor equivalent to four times the total size of the Gulf. This constant bottom trawling is considered to damage fragile benthic habitats and non-commercial, small invertebrate species (Brusca *et al*. 2001). However, this area of research is in need of attention since data are not sufficient to evaluate the extent of this damage in the LME.

UNEP (2004) recalls that the American Fisheries Society's official list of marine fish at risk of extinction includes six species of large groupers and snappers, four of which are endemic to the Gulf of California and adjacent areas. Of these, two are regarded as endangered, while the remaining four are considered as vulnerable, given the fact that these species are sensitive to overfishing because of late maturity and the formation of localised spawning aggregations (Musick *et al*. 2001). The effect of fishing is particularly evident in large, slow-growing fish, and includes a decrease in abundance and in the average individual size, where both are unavoidable consequences when aiming at maximizing yield. What occurs in the Gulf of California LME is similar to what occurs in Puget Sound, Florida and the southern Gulf of Mexico, the other 'hot spots' described by Musick *et al*. (2001). Of particular concern has been the totoaba. Although overfishing has been blamed for the early decline of the fishery, the reduction in the flow of the Colorado River may have been a major cause of depletion through the alteration of the estuarine habitat of the river delta, its normal spawning and nursery area (UNEP 2004). The totoaba fishery declined since 1970 due to declining populations and to restrictions imposed (in 1975) when catch levels threatened the population. Despite closures, the totoaba gill net fishery continues on a small-scale.

The tremendous diversity and complexity of the fisheries within the Gulf of California LME and the large size of the basin make it a difficult area to manage. This is aggravated by the lack of sufficient resources for implementing and enforcing management decisions and federal laws, inadequate knowledge about the ecology of exploited species, and insufficient past efforts to actively involve fishing communities in management decision-making. However, current efforts are succeeding in conserving the natural resources upon which a large number of people depend, and an improvement in terms of overexploitation is expected in the future (UNEP 2004).

III. Pollution and Ecosystem Health

Pollution: A sizeable portion of the eastern coast of the Gulf of California LME is subject to pollution from industrial and human wastes, agricultural run-off and aquaculture residues. Other pollution threats include sedimentation from deforestation, bilge water from ships, the construction of tourist marinas in sensitive coastal areas, and the risk of oil spills from a steady traffic of oil tankers. While pollution was found to be generally slight, it is more serious in some localised coastal areas (UNEP 2004). Beman *et al*. (2005) have reported eutrophication episodes caused by agricultural irrigation in the coastal area off the Yaqui Valley. A long time series of data related to eutrophication and HABs available from Mazatlán showed an increase in the number of toxic species as well as in the length and frequency of HABs events. Mortalities of marine mammals, birds, and fish in 1995, 1997 and 1999 were related to HABs (Sierra-Beltrán *et al*. 1998, 1999). Except for La Paz Bay and Los Cabos areas, the west coast of the Gulf is nearly pristine. In the few places where towns or villages do exist, some pollution occurs. Agricultural pesticides used in the Mexicali Valley and in Sonora and Sinaloa States have led to concerns since the early 1970s about the possibility of pesticide transport into the Upper Gulf of California. Pesticides have been found in organisms of the Mexicali Valley irrigation canals as well as the Upper Gulf of California (García-Hernández *et al*. 2001). For instance, DDE, DDT and DDD were detected in fish and invertebrate sampled from the delta wetlands even though such pesticides have been banned (Mora & Anderson 1995). Preliminary findings indicate high concentrations of zinc and lead in Navachiste Bay, Sinaloa (Orduña-Rojas *et al*. 2004).

Habitat and community modification: The delta wetlands and marine areas provide unique and valuable habitats for a large number of invertebrates, marine mammals, birds and commercial species of fish (Alvarez-Borrego 1983). These habitats are, however, being altered by various human activities, the impacts of which are magnified by the semi-enclosed nature of the Gulf. The most notable human activity to impact the upper Gulf has been the damming of the Colorado River, which has significantly modified the environment in this area. The river supplied freshwater, silt and nutrients to the delta, and helped to create a complex system of wetlands that provided feeding and nesting grounds for birds, and spawning and nursery habitat for fishes and crustaceans (Glenn *et al*. 1996). The reduced freshwater input has drastically changed what used to be an estuarine system into one of high salinity. It has also reduced the influx of nutrients to the sea and critical nursery grounds for many commercially important species such as the totoaba, Gulf curvina, and brown shrimp (Aragón-Noriega & Calderon-Aguilera 2000).

In terms of vegetation cover, the degree of mangrove deterioration in Mexico is not as evident as in other countries (Páez-Osuna *et al*. 2003). However, on a regional scale, there is evidence of mangrove destruction mainly in Sinaloa (Ceuta and Huizache-Caimanero coastal lagoons) and Nayarit (Marismas Nacionales). The drying out of lagoons in the Huizache-Caimanero system caused a 20% reduction in water surface area from 1973 to 1997 and an increase in adjacent seasonal salt pans (Ruiz-Luna & Berlanga-Robles 1999). The Huizache-Caimanero coastal lagoon supports an important shrimp fishery. Until the 1980s, this system had yields up to 1,500 tonnes (de la Lanza & García-Calderón 1991) and provided the highest yields per unit area for shrimp fisheries in coastal lagoons in Mexico. During the last decade, yields notably decreased (Zetina-Rejón *et al*. 2003). Rogerío-Poli & Calderón-Pérez (1987) considered that the changes in postlarvae density were mainly due to changes in water temperature. On the other hand, Ruiz-Luna & Berlanga-Robles (1999) suggested that the loss of freshwater, which changed the salinity in this lagoon, was a consequence of the removal of deciduous tropical forest for agricultural purposes and a 50% decrease of mangrove forests between 1973 and 1997. In addition to the elevated rate of mangrove deforestation (1.9% per year), mangrove coverage for this zone is scarce and with patchy distribution that aggravates an unstable condition (Páez-Osuna *et al*. 2003). Carrera & de la Fuente 2001 reported that in Marismas Nacionales about 1,500 hectares of wetlands have been replaced by shrimp farming. Nonetheless, DeWalt (2000) considered that shrimp aquaculture in Mexico has thus far developed largely without the major detrimental environmental effects seen in other countries and has found little evidence of mangrove destruction.

IV. Socioeconomic Conditions

The Gulf of California LME is a very economically active zone. Overall, the region accounts for approximately 10% of Mexico's GDP, with a human population of about 8.6 million. Approximately 40% of Mexico's agricultural production comes from the region, mainly from the States of Sonora, Sinaloa and Nayarit. Because of the richness of the marine basin and a very particular social-geographic situation (border with the U.S.), key productive activities have been increasing along the littoral areas, driving an uncontrolled coastal population growth (WWF Mexico 2005). Port activities and marine traffic represent a fundamental support for agriculture, industry, mining and fishing. The region is considered a natural port for international traffic routes and tourism development. The Mexican government and the Fondo Nacional de Fomento al Turismo (FONATUR) have announced plans to proceed with a project called Escalera Nautica, or Nautical Ladder, consisting of at least 22 yachting marina resorts placed strategically along the coast. The project also contemplates new and improved highways, airports, airstrips, and the development of hotels, golf courses, etc. (Enríquez-Andrade *et al*. 2005).

An increase in the demand for oil, gas and mineral resources has stimulated the exploration of the non-living resources of the EEZ. The LME's fisheries are an important source of food and income for Mexicans (Enríquez-Andrade *et al*. 2005). Major resources are small pelagic fishes, jumbo squid, tuna-like fishes and shrimp. Shrimp production continues to be of important value, despite the decline in offshore shrimp catches in the upper Gulf in the late 1980s-early 1990s.

V. Governance

The LME is governed by Mexico. Fisheries regulations are numerous and complex, responding to the diverse array of natural resources. All fisheries resources in the country are managed by the Federal Government through the Ministry of Agriculture, Livestock, Fisheries and Food, by the National Commission of Aquaculture and Fisheries (CONAPESCA), while the environment is under the responsibility of the Ministry of Environment and Natural Resources. CONAPESCA has a technical branch, the National Fisheries Institute (INP), which conducts regular assessments and evaluations of the status of fisheries resources.

Several natural protected areas have been established in the region, including five biosphere reserves (among them the Upper Gulf of California and the Colorado River Delta, the coast of the Reserva de la Biosfera del Vizcaíno and the San Pedro Mártir Island), five marine parks (including the Bay of Loreto and Cabo Pulmo), three wildlife reserves (including Cabo San Lucas and all of the Islands of the Gulf of California) and three areas with other protection status. In addition, two new marine parks are being considered for decree (Enríquez-Andrade *et al*. 2005). There are 16 areas designated as 'priority' by the National Commission of Biodiversity. Protected areas are managed by the National Commission of Protected Areas (CONANP), reporting to Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). After several years of relatively uncoordinated efforts by several NGOs, a Coalition for the Sustainability of the Gulf of California was created in December 1997 in an attempt to integrate available information and generate broad consensus on conservation priorities for the region (Enríquez-Andrade *et al*. 2005). At present there is an ongoing process to develop an Ecological Ordering of the Gulf of California, started June, 2004. This is a coordinated effort of the Federal Government through SEMARNAT, SAGARPA, the Ministry of Communications and Transportation (SCT), Ministry of Tourism (SECTUR), Ministry of the Interior (SEGOB) and the Ministry of the Navy (SEMAR). At the same time, SEMARNAT, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA) and Secretaría de Turismo de México (SECTUR) signed an agreement with the governments of the states of Baja California, Baja California Sur, Sonora, Sinaloa and Nayarit to develop the ecological ordering of the terrestrial components of the coastal areas.

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XIV-48 Pacific Central-American Coastal LME

S. Heileman

The Pacific Central-American Coastal LME extends along the Pacific Coast of Central America, from 22ºN off Mexico down to 4ºS. It is shared by Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia and Ecuador. The LME covers a surface area of nearly 2 million km^2, of which 1.42% is protected, and includes 0.22% of the world's coral reefs and 0.78% of the world's sea mounts (Sea Around Us 2007). Re-circulating coastal currents and milder temperatures than those of the adjacent California Current and Humboldt Current LMEs characterise this LME (Bakun *et al*. 1999). Much of the Pacific Central-American Coastal LME is influenced by the seasonal movements of the Inter-tropical Convergence Zone (Bakun *et al*. 1999). The region is vulnerable to the ENSO phenomenon, which affects productive activities, infrastructure, natural resources and the environment in general. The climate varies from tropical to temperate, with a dry period during the winter months. During the rainy season from May to September, rivers discharge significant volumes of freshwater and suspended solids into the coastal areas of this LME (Windevoxhel *et al*. 2000). Extreme ocean depths are reached very close to the coast due to a narrow and steep continental shelf. Book chapters and reports on this LME are by Bakun (1999), Bakun *et al*. (1999), Lluch-Belda (1999) and UNEP (2006).

I. Productivity

The Pacific Central-American Coastal LME could be considered a Class I, high productivity ecosystem (>300 gCm^{-2}yr^{-1}). Several mechanisms, other than the classic eastern ocean upwelling produced by Ekman transport, are important sources of nutrient enrichment in this LME. The mechanisms include equatorial upwelling, open ocean upwelling driven by wind stress curl, and episodic downwind coastal upwellings forced by mountain gap winds from the Caribbean, as well as the mechanism underlying the Costa Rica Dome structure (Bakun *et al*. 1999). In addition, nutrient inputs also come from river run-off along the tropical areas of this LME (FAO 1997). Upwelling plumes extending offshore are located off the three major mountain ranges of the region (Bakun *et*. *al*. 1999). An extensive minimum oxygen layer exists off Mexico and Central America (Wyrtki 1965, Bianchi 1991), with oxygen levels low enough to have major effects on the composition and migration of the biological communities (Bakun *et al*. 1999). The large-scale monthly mean ocean temperatures remain above 26ºC throughout the year and, as a consequence, the marine fauna of this LME is tropical and distinctly different from the predominantly temperate fauna of the California and Humboldt systems (Bakun *et al*. 1999). Threatened species such as turtles and sharks are of particular concern in the region.

Oceanic Fronts (Belkin and Cornillon 2003; Belkin et al. 2008): Most fronts within this LME (Figure XIV-48.1) are generated by coastal upwelling. Some fronts off the Pacific coast of Central America originate from quasi-regular bursts of topographically generated winds blowing from the Caribbean across Central America toward the Pacific Ocean. Local orography tends to channel these winds and make their direction exceptionally stable and predictable, especially in the Gulf of Tehuantepec where these winds result in formation of upwelling zones and fronts that bound them extending far offshore (Belkin & Cornillon 2003). This is the only place in the World Ocean where such fronts are observed.

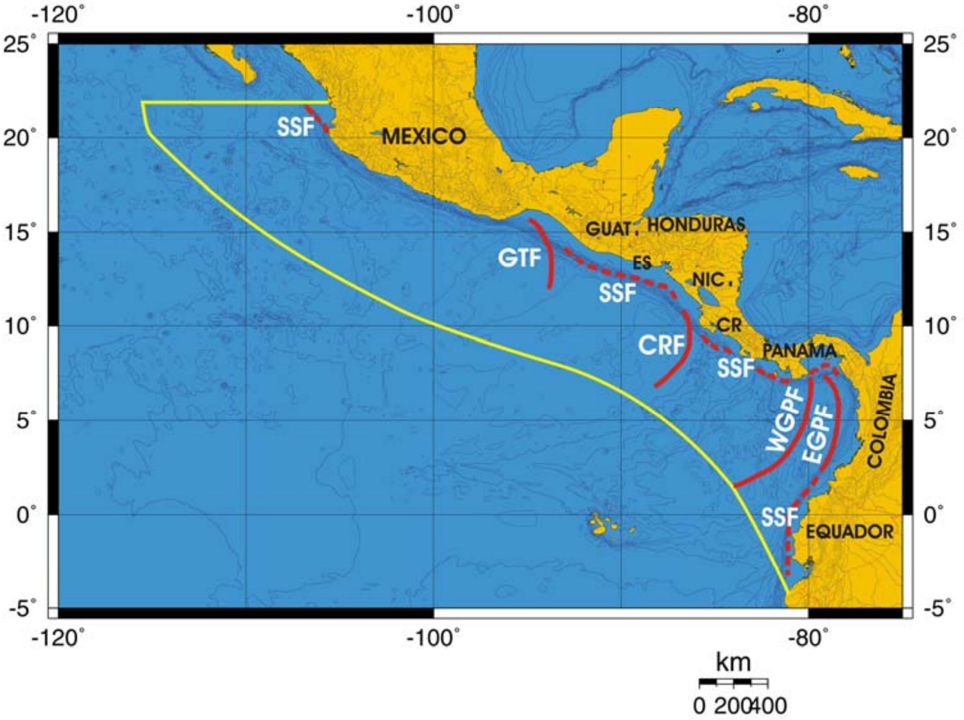

Figure XIV-48.1. Fronts of the Pacific Central-American Coastal LME. CR, Costa Rica; CRF, Costa Rica Front; EGPF, East Gulf of Panama Front; ES, El Salvador; GTF, Gulf of Tehuantepec Front; GUAT, Guatemala; NIC, Nicaragua; SSF, Shelf-Slope Front (most probable location); WGPF, West Gulf of Panama Front. Yellow line, LME boundary. After Belkin et al. (2008).

Pacific Central-American Coastal LME SST (Belkin 2008)(Figure XIV-48.2)
Linear SST trend since 1957: 0.29°C.
Linear SST trend since 1982: 0.14°C.

The Central-American Pacific LME experienced moderate warming over the last 50 years. However, the thermal history of this LME was non-monotonous. The cooling phase culminated in the two minimums, in 1971 and 1975, both associated with major La Niñas ((National Weather Service/Climate Prediction Center, 2007), after which the SST rose by approximately 1°C over the next 30 years. The absolute minimum of 1975 was synchronous with absolute minima in two other East Pacific LMEs: California Current LME and Gulf of California LME. The minimum also was roughly synchronous with the absolute minimum of 1974-1976 on the other side of the Central American Isthmus, in the Caribbean LME. The warming phase was accentuated by two sharp peaks, in 1983 and 1997, both associated with major El Niños (National Weather Service/Climate Prediction Center, 2007). Similar peaks (warm events) were also observed in other East Pacific LMEs, namely the Humboldt Current, Gulf of California, and California Current. The warm event of 1992, concurrent with a strong El Niño, was less conspicuous in this LME compared with other East Pacific LMEs. In general, all significant maxima and minima of SST observed in this LME are associated with El Niños and La Niñas respectively (National Weather Service/ Climate Prediction Center, 2007). This strong correlation is not surprising giving the location of this LME in the Eastern Tropical-Equatorial Pacific, where El Niños' and La Niñas' effects are most conspicuous.

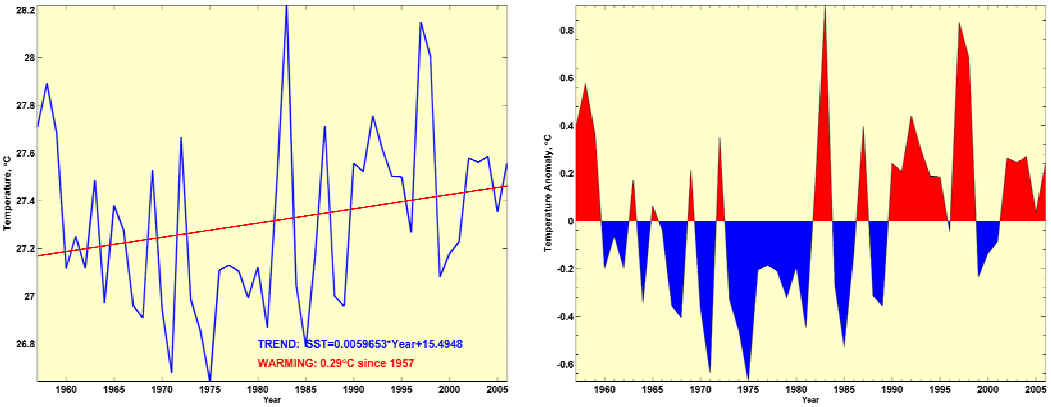

Figure XIV-48.2. Pacific Central-American Coastal LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

Pacific Central-American Coastal LME Chlorophyll and Primary Productivity: The Pacific Central-American Coastal LME is a Class I, high productivity ecosystem (>300 gCm^{-2}yr^{-1})(Figure XIV-48.3).

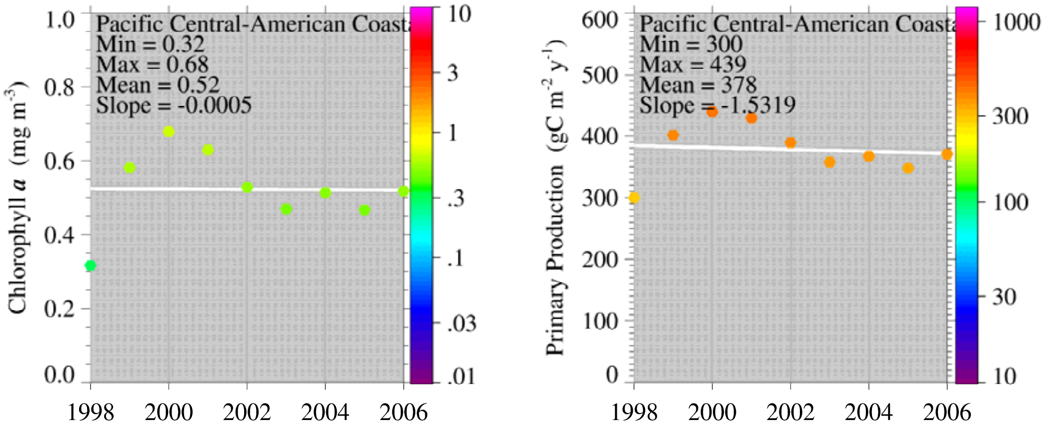

Figure XIV-48.3. Pacific Central-American Coastal LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hude. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The Pacific Central-American Coastal LME is rich in both pelagic and demersal fisheries resources. The most valuable fisheries in the region are offshore tunas and coastal penaeid shrimps. More than 50% of the shelf catches consists of small coastal pelagic species such as anchoveta (*Engraulis ringens* and *Cetengraulis mysticetus*), South American pilchard (*Sardinops sagax*) and the Pacific thread herring (*Opisthonema libertate*), most of which are used for fish meal and fish oil. Artisanal shark fisheries also operate in El Salvador and Guatemala. In addition to the capture fisheries, aquaculture of penaeid shrimp is an important economic activity.

Total reported landings have risen, with some fluctuations, to peak landings of 730,000 tonnes in 1994 (Figure XIV-48.4). The species composition of the landings has also fluctuated, particularly between anchovies and South American pilchard. These fluctuations coincide with the most important El Niño events and are related to the dramatic and simultaneous inter-decadal regime shifts in marine fish populations in other Pacific LMEs associated with El Niño (Bakun 1999, Lluch-Belda 1999). Fluctuations in the value of the reported landings correspond with the landings, with a peak of US$548 million (in 2000 US dollars) recorded in 1994 (Figure XIV-48.5).

It should be cautioned, however, that the underlying landing statistics in this LME, particularly those reported by the countries south of Mexico, strongly underestimate the true catch (see, e.g., Wielgus et al. 2007 for Columbia) and represent, in several instances, a bias toward landings of exported species (e.g., lobsters, shrimps), while those sold on local markets by artisanal fishers are often ignored (see also Bakun *et al*. 1999).

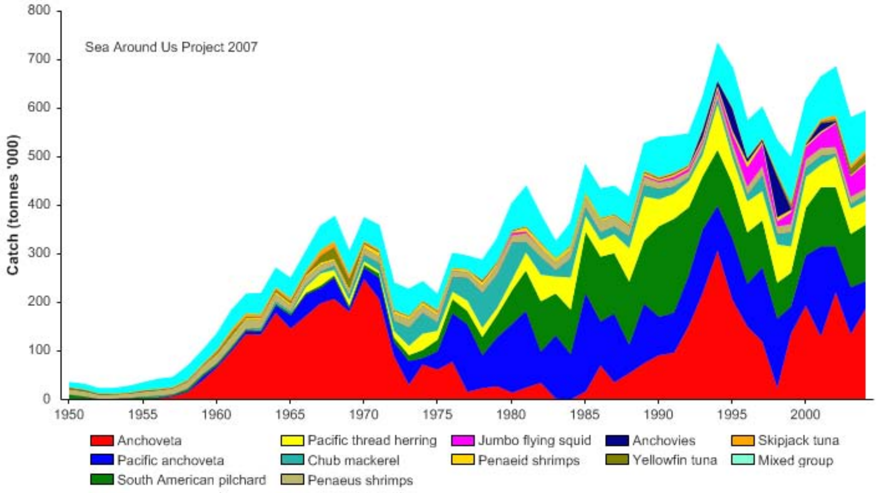

Figure XIV-48.4. Total reported landings in the Pacific Central-American Coastal LME by species (Sea Around Us 2007).

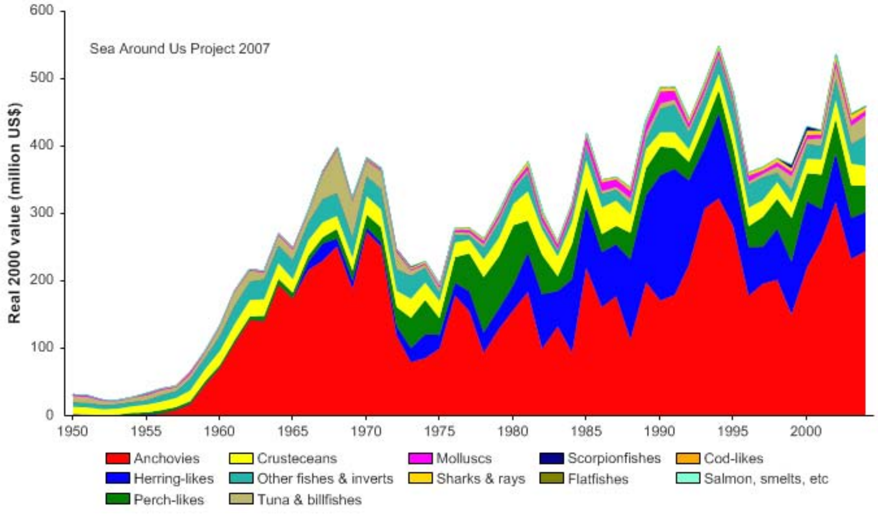

Figure XIV-48.5. Value of reported landings in the Pacific Central-American Coastal LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 5% of the observed primary production in 2002 (Figure XIV-48.6). Mexico, Ecuador, El Salvador, Peru and Panama account for most of the ecological footprint in this LME.

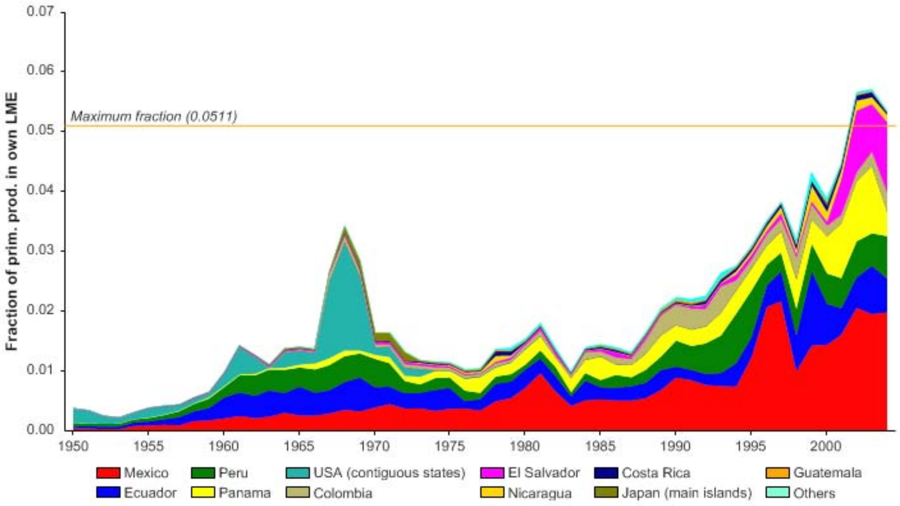

Figure XIV-48.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Pacific Central-American Coastal LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) is relatively low, and shows a declining trend until the mid 1980s, after which a slight increasing trend became apparent (Figure XIV-48.7 top). The FiB index has increased, indicating that whatever 'fishing down' (Pauly *et al*. 1998) that may be occurring in the LME would be masked by either the geographic (offshore) expansion of the fisheries (Figure XIV-7.7 bottom) or the incompleteness of the underlying statistics as indicated above.

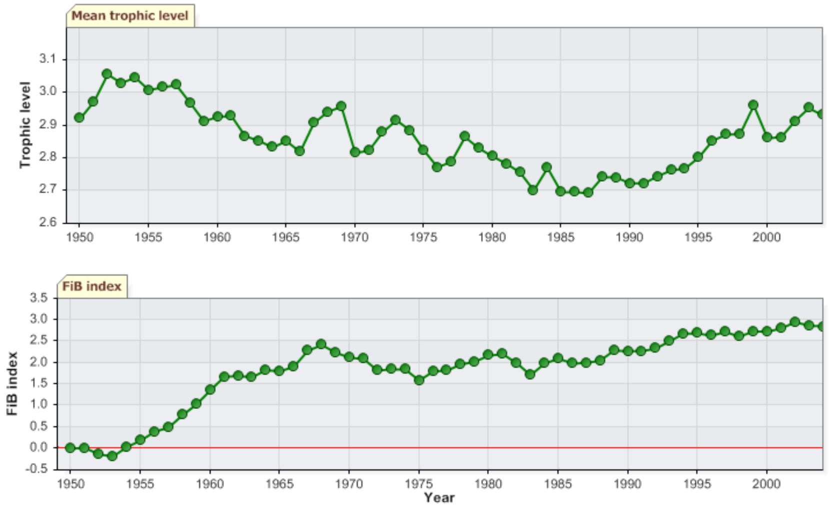

Figure XIV-48.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Pacific Central-American Coastal LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that the number of collapsed and that overexploited stocks are rapidly increasing in the LME (Figure XIV-48.8 top). Approximately 40% of the reported landings are supplied by fully exploited stocks (Figure XIV-48.8 bottom).

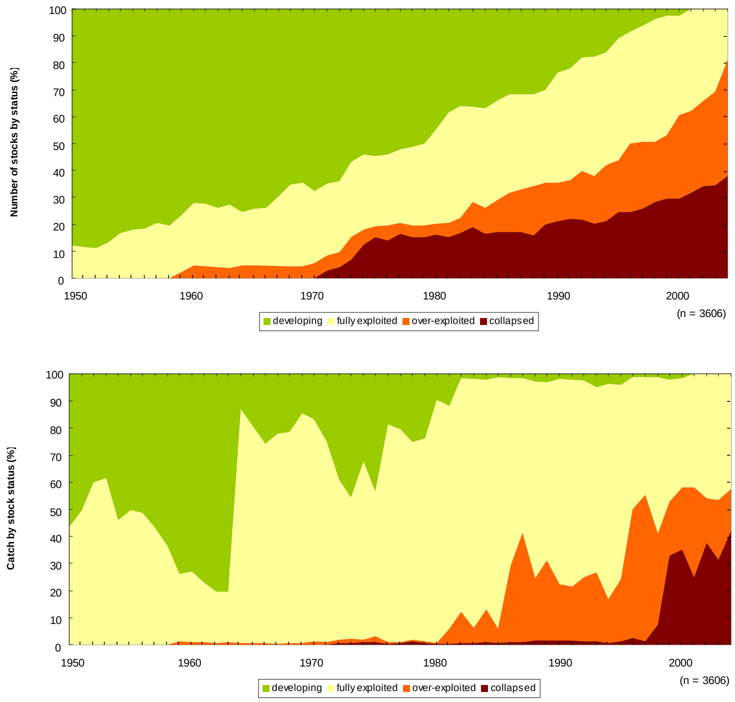

Figure XIV-48.8. Stock-Catch Status Plots for the Pacific Central-American Coastal LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

In general, overexploitation was found to be moderate in this LME, although it was severe in Colombian waters (UNEP 2006), with several traditionally fished stocks showing signs of overfishing. For example, most of the shrimp stocks are considered to be overexploited (Bakun *et al*. 1999, FAO 2005a), although the reported landings of shrimp trawlers have not substantially declined. In Costa Rica, the landings of the shrimp trawler fleet increased between 1993 and 2002. However, closer examination reveals that the increase was due to larger catches of finfish, suggesting that when the shrimp stocks were reduced, greater fishing effort was focused on high-value fish (FAO 2005a). Fishery resources in the Gulf of Nicoya have come under heavy pressure from the rapid growth of the small-scale fleet in the past 20 years. As a result, there has been a reduction in the catch per unit effort of the most valuable species and the sizes of fish and shrimp caught.

Numerous species of demersal fish are under heavy fishing pressure from the shrimp fisheries, in which they are commonly taken as bycatch (Bakun *et al*. 1999). The shark stocks in the Gulf of Fonseca are also showing signs of depletion. Other overexploited stocks include several species of Lutjanidae, Sciaenidae, Centropomidae and Serranidae (CCAD/IUCN 1999). In the Gulf of Fonseca, some molluscs and crustacean species are overexploited by the artisanal fishery and several others such as the tropical rocky oyster (*Ostrea iridescens),* green lobster (*Panulirus gracilis*) and crab (*Menipe frontalis*) are fully exploited (CCAD/IUCN 1999).

Likewise, the level of bycatch and discards and the use of destructive fishing practices were assessed as generally moderate, but severe in Colombian waters (UNEP 2006). Several hundred species of demersal fish, especially early life history stages, are taken as bycatch in the shrimp trawl fishery, which also has the highest rate of discards. Many of these bycatch species have potential economic value, but do not sustain major commercial fisheries in the region (Bakun *et al*. 1999). Nonetheless, their effective level of exploitation could be high as a result of pressure from the shrimp fishery, which probably inhibits the development of fisheries for these species (Bakun *et al*. 1999). Furthermore, the juveniles of about 30 different groups are discarded during the catching of shrimp larvae for aquaculture in the Gulf of Fonseca (CCAD/IUCN 1999). This is of particular concern since it is likely affecting the recruitment of several commercial species and threatening the long-term sustainability of both aquaculture and artisanal fisheries. No assessment of marine mammal bycatch has been conducted, although Palacios and Gerrodette (1996) suggested that the rate could be as high as that in other parts of the Pacific coast of South America.

The current level of fisheries exploitation is unsustainable, and overexploitation is expected to worsen (UNEP 2006) as a result of increasing coastal populations and further increases in fishing effort in the traditional fisheries. However, there is a potential for the development of fisheries for other species such as mid-sized pelagics and other oceanic species as well as deepwater shrimps (Bakun *et al*. 1999). Among the most pressing needs is the development of systems for improved data collection and monitoring, since the fisheries catch statistics in the bordering countries are generally poor and unreliable (Bakun *et al*. 1999). Future conditions will depend on the effective implementation of conservation and development projects directed towards the environmental sustainability of the region.

III. Pollution and Ecosystem Health

Pollution: Population growth, poorly planned urban development, tourism and industrial and agricultural activities exert significant pressures on the Pacific Central-American Coastal LME, partly as a result of the associated discharges of waste into the aquatic environment (IDEAM 2002). Although pollution was found to be generally moderate in this LME, it was assessed as severe in some localised areas, including in the transboundary Gulf of Fonseca (UNEP 2006). Land-based pollution is potentially more damaging in the coastal waters because of the numerous sheltered bays and gulfs in which pollutants are not easily dispersed. About 95% of the wastewater produced in the bordering countries is untreated and reaches the Pacific Ocean with high loads of organic matter, nutrients and other pollutants (PNUMA 2001). The limited available information indicates accumulation of pesticides, heavy metals and other pollutants in coastal areas, with unknown impacts on the marine biota. High concentrations of pathogenic micro-organisms have been recorded in some areas (CPPS 2000). For example, in Puntarenas, Costa Rica, total coliform bacteria concentrations between 16 - 20 million MPN[1]/100 ml and between 2 - 9.2 million MPN/100 ml for faecal coliforms have been reported (Wo-Ching & Cordero 2001).

Wastewater discharges and agriculture run-off are the main source of anthropogenic nutrient enrichment in the LME. Fertiliser consumption increased from 76 kg ha^{-1} in 1990 to about 131 kg ha^{-1} in 2000 in the countries in the central part of the LME. It is

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[1] MPN: Most Probable Number

estimated that the coastal waters in the region receive 120,300 tonnes nitrogen yr^{-1} and around 14,500 tonnes phosphorus yr^{-1} (PNUMA 2001). The high rate of deforestation, poor agricultural practices and associated increase in erosion and runoff also contribute to elevated nutrient levels to this LME (PNUMA 2001). As a consequence, eutrophication is evident in coastal areas of e.g. Panama (Panama Bay), Nicaragua (Corinto, El Realejo, Estero Chocolate, La Esparta, El Real), El Salvador (Jiquilisco Bay) and Costa Rica (Gulf of Nicoya) (PNUMA 2001). Harmful algal blooms (HABs) associated with eutrophication have also been observed (Rubio *et al*. 2001). These factors combined with the input of wastewater, are producing a significant amount of suspended solids and high sedimentation in some coastal areas (CCAD/IUCN 1999, Rubio *et al*. 2001, Sánchez 2001).

Chemical contamination is highly concentrated in some areas of the Pacific coast (Jameson *et al*. 2000). Heavy metals such as lead, copper and chromium have been reported in sediments and surface waters in several countries of the region, especially in Panama, Nicaragua and Costa Rica (Sánchez 2001, Wo-Ching & Cordero 2001). Discharges from agricultural areas are a major source of pollution by persistent toxic substances. The level of pesticides used in the region is one of the highest in Latin America, and their presence has been reported in discharges of several rivers (Rubio *et al*. 2001, Wo-Ching & Cordero 2001). Pesticides have been found in fish, crustacean and mollusc tissue in some areas (Rubio *et al*. 2001).

Over 15 million tonnes of solid waste are produced annually in the region, about 44% of which originates in coastal settlements (PNUMA 2001). However, the collection of solid waste is generally inadequate, or it is disposed of in inappropriate sites or discharged directly into water bodies. Litter accumulation has reduced the aesthetic value of coastal areas and presents a permanent risk for fishing and maritime traffic in the region. Most oil spills are chronic and occur in ports and storage sites. The heavy traffic on the shipping lanes to North and South America and Asia, which parallel almost the entire length of the coastline, increases the threat of oil spills in the LME. Another potential source of oil pollution is the trans-isthmus oil pipeline (PNUMA 1999). Small spills also come from the cities when oils and other hydrocarbons are eliminated through the sewerage system and finally disposed of in coastal areas.

Habitat and community modification**:** The LME's coast is characterised by its many peninsulas, gulfs and bays, as well as extensive intertidal areas, barriers and well developed coastal lagoons. An important geographic feature is the transboundary Gulf of Fonseca, which is shared by Nicaragua, Honduras and El Salvador. Poorly planned urbanisation and economic development along the Pacific coast is leading to the accelerated degradation and destruction of economically and ecologically important habitats. Habitat modification was found to be moderate in this LME (UNEP 2006). Even protected areas are being affected, with about 35% of protected areas showing some type of deterioration in 2001 from various causes such as sedimentation, mangrove destruction, pollution and overfishing (PNUMA 2001).

Of the coastal habitats in the LME, mangroves are the most affected by human activities and there are reports of mangrove destruction throughout the region (CCAD/IUCN 1999, Rubio *et al*. 2001, Sánchez 2001). Mangrove forests have been cleared for several purposes including aquaculture, agriculture, urban development, firewood, building material and tannin production. Conversion to aquaculture ponds is, however, a major cause of mangrove loss in the region. At least 90% of the shrimp farms have been constructed on former mangrove or salt pond areas. All mangroves in the transboundary Gulf of Fonseca have been affected (CCAD/IUCN 1999). The mangrove area in the Gulf was reduced from 1,049 km^2 in 1976 to 691 km^2 in 1997. In addition, the Gulf is also polluted by run-off from extensive banana plantations in the coastal areas. In the central parts of the LME, only a small proportion of the mangrove area is relatively stable, the remaining areas being considered vulnerable (wet Pacific coast), in danger (Gulf of Fonseca and the northern dry coast), or critical (the southern part of the dry coast) (PNUMA 2001). About 98% of the estuaries are estimated to be affected by sedimentation, wastewater and agro-industrial residuals. The effects of mangrove destruction include an increase in coastal erosion, higher penetration of the saline wedge in some estuaries, soil salinisation and decrease of biological productivity with direct effects on artisanal fisheries.

The LME's coral reefs have been affected by sedimentation, oil spills, pesticides and trawling activities (Escobar 1996, PNUMA/IUCN 1998). Also, some reefs were severely impacted by the 1982-1983 El Niño event, which caused mass coral bleaching and mortality in all areas (Spalding *et al*. 2001). In Costa Rica, recovery has generally been good and, despite repeated bleaching in 1992 and 1997-1998, coral cover remains high in most areas. In contrast, recovery on many reefs in Panama has been poor. Pollution and habitat and community modification are expected to increase in the future, if the growth of poorly planned coastal urbanisation and development continues (UNEP 2006). This could be compounded by lack of adequate sanitation service and waste treatment and disposal facilities, and requires an increase in the provision of sanitation services as well as the strengthening of measures to prevent and control pollution and habitat degradation in the region. The crucial nature of transboundary issues within this region are demonstrated by the situation in the transboundary Gulf of Fonseca (Bakun *et al*. 1999). Threats to the finely structured habitats of this LME pose important concerns for biodiversity preservation and resource sustainability.

IV. Socioeconomic conditions

In 2002, the total population of the Pacific Central-American Coastal LME region was about 180 million, 80% of which is found in Colombia and Mexico (WRI 2004). Within these countries, some of the most impoverished people have migrated to the coast where they manage to make a meagre living from subsistence fishing and farming. The main economic activities in the coastal zone are tourism, fisheries, aquaculture and agriculture, as well as shipping and industrial activities (Bakun *et al*. 1999). Fish export value is substantial for Mexico, Nicaragua, Panama and Ecuador and the export of frozen crustaceans represents a significant source of foreign exchange. In 2001, the export value of frozen crustaceans was US$281 million in Ecuador, US$450 million in Mexico, US$33 million in Nicaragua and US$80 million in Panama (FAO 2005b). This LME is located on the intercontinental maritime route with intensive commercial exchange and tourist activity through the region. The most important site of maritime traffic is the Panama Canal, with an annual average of 14,300 ships (1990-1998) and income of US$420 million (PNUMA 2001).

Overexploitation, pollution and habitat modification have moderate socioeconomic impacts in the bordering countries (UNEP 2006). Fishing is of high social and economic significance for coastal populations, being a major source of protein, employment and income. However, total catches do not satisfy the local demand because investments are directed towards international markets. This has a direct impact on coastal populations by affecting social stability and creating food insecurity. About 28% of children below five years of age have nutritional problems. A study has shown that the number of artisanal fishers has increased but fish production has decreased (CCAD/IUCN 1999). This is producing lower incomes from fishing and an increase of the population living in extreme poverty. In the Gulf of Fonseca, the increasingly restricted and scarce marine resources associated with ongoing economic activities have had negative social impacts by further marginalising traditional human users of mangroves, wetlands and marine resources (DANIDA 1997).

Pollution and eutrophication in coastal areas also threaten the food security of the coastal communities by affecting the harvesting of shellfish and other living resources. Available information indicates the accumulation of pesticides, heavy metals and other pollutants in coastal areas. Coastal water pollution also has negative impacts on commercial fisheries and tourism and endangers the health of swimmers. A growing number of environmental refugees are encroaching on sensitive areas in need of protection.

V. Governance

The Pacific Central-American LME coastline is shared by Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia and Ecuador. Each of these countries has laws and institutions related to management of the marine environment and its resources at the national level. However, there is need for the strengthening of local administrations for effective monitoring and management as well as for improved data collection (Bakun *et al*. 1999). Greater awareness is also required among local people and governments of the importance of preserving ecosystem integrity, especially for key coastal habitats like mangrove swamps and coral reefs. The marine environmental initiatives in the region are partly governed by international conventions such as UNCLOS, the UN Fish Stocks Agreement and the FAO Code of Conduct for Responsible Fisheries.

Regional initiatives include the Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the Northeast Pacific (Antigua/Guatemala Convention), which was signed by Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama in 2002. Key parts of this convention address the high levels of sewage and other pollutants being discharged from urban areas into the Pacific Ocean. Another priority is the assessment of risks from oil pollution and a strategy to deal with such events including an evaluation of the region's access to clean-up equipment and personnel. The Northeast Pacific Regional Seas Programme includes Colombia, Costa Rica, El Salvador, Guatemala, Honduras and Panama and is based on the Antigua/Guatemala Convention. The Central American Commission for Maritime Transportation acts as secretariat for the Northeast Pacific Regional Seas Programme. El Salvador, Honduras, Nicaragua are preparing the project 'Integrated Ecosystem Management of the Gulf of Fonseca' for GEF support. The development objective of the proposed project is to prevent the degradation and maintain the ecosystem integrity of the Gulf of Fonseca through an integrated approach to managing its land and water resources and promoting their sustainable use. The project's global objective is to implement a regional cooperative framework for the management of the Gulf that will result in enhanced environmental protection of international waters and strengthen the conservation of globally significant coastal and marine habitats.

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