X-23 Kuroshio Current: LME #49

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The Kuroshio Current LME extends from the Philippines to the Japanese Archipelago's northernmost island, Hokkaido. It has a surface area of about 1.3 million km^2, of which 0.33% is protected, and contains 1.29% of the world's coral reefs, 0.99% of the sea mounts, and 9 major estuaries (Sea Around Us 2007). Among its other underwater features are the Japan Trench, Ryukyu Trench, and Okinawa Trough. The Kuroshio (Black Current in Japanese) is a warm (24° C, annual mean sea surface temperature) current about 100 km wide that flows in a north-easterly direction along Japan's east coast. Northeast of Taiwan, the Tsushima Current branches off towards the Sea of Japan/East Sea. A rich variety of marine habitats results from the LME's wide latitudinal expanse. The region has a generally mild, temperate climate. Natural hazards in this region are active volcanoes, frequent earthquakes, tsunamis and typhoons. One of the first multi-chapter volumes in English devoted to the Kuroshio was by Marr (1970). Terazaki (1989) presented a book chapter on this LME.

I. Productivity

Small-and meso-scale eddies have been observed in the coastal regions of the Kuroshio Front, which separates the Kuroshio Current from the East China Sea LME. There are indications that these eddies contribute to the retention and subsequent survival of fish larvae transported by the Kuroshio Current. The Kuroshio Current LME is considered a Class II, moderately high (150-300 $gCm^{-2}y^{-1}$) productivity ecosystem (Figure X-23.3). Plankton biomass fluctuates from year to year, and is usually highest in the eddy area of the Kuroshio's edge. In the outer area, plankton distribution is low. Of the 66 species in 15 genera of diatoms commonly distributed in Kuroshio waters, 12 species in 5 genera are purely neritic cold water forms (Terazaki, 1989). The spring zooplankton biomass is much greater than in winter (Kozasa 1985). The LME is an important spawning and nursery ground for many important pelagic fishes such as clupeoids, horse mackerel, scomber and saury. In the southern part of this LME, the Ryukyu Archipelago has a tropical environment characterised by coral reefs, mangrove swamps and many diverse marine organisms. Field studies of the ocean environment in relation to biological production in the Kuroshio/Oyashio transitional region have been conducted through GLOBEC (Global Ocean Ecosystems Dynamics) and JGOFS (Joint Global Ocean Flux Study). NOAA has a moored buoy in the Kuroshio Current, providing surface data on winds, air temperature, relative humidity, rain rate, downwelling solar and longwave radiation, SST and salinity. The data are used in studies of climate change effects on the mass transport of the Kuroshio Current LME. Seasonal variations in temperature and nutrients were measured in Sagami Bay in the northern section of this LME (Terazaki 1989).

Oceanic fronts (Belkin and Cornillon 2003; Belkin et al. 2009): The Kuroshio Current is associated with two parallel fronts, with the stronger front along the inshore boundary of the Kuroshio Current and the weaker front along the Kuroshio's offshore boundary (Figure X-23.1). This double Kuroshio Front (KF) forms a large meander that emerges and disappears quasi-periodically off Japan, downstream of Izu Ridge. Its emergence is linked to inter-annual fluctuations in the Kuroshio transport and is ultimately related to the Pacific Decadal Oscillation (PDO) and El-Niño-Southern Oscillation (ENSO). The Kuroshio Front leaves the coast of Japan off Cape Inubo where it forms two quasi-stationary meanders, the so-called First and Second Meanders of the Kuroshio. These meanders often spawn extremely energetic anticyclonic warm-core rings that exist for many months in a transition zone between the Kuroshio Front and the Oyashio Front (OF).

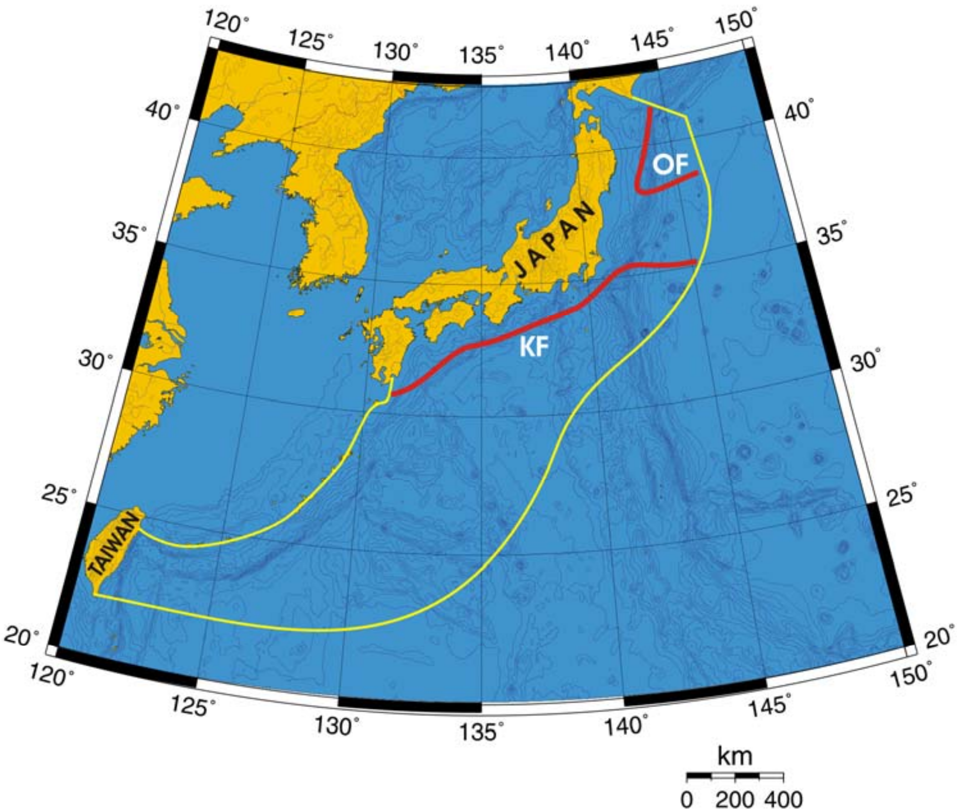


Figure X-23.1. Fronts of the Kuroshio Current LME. F, Oyashio Front; KF, Kuroshio Front. Yellow line, LME boundary. After Belkin et al. (2009).

Kuroshio Current SST (Belkin, 2009)(Figure X-23.2)
Linear SST trend since 1957: 0.65°C.
Linear SST trend since 1982: 0.75°C.

The Kuroshio Current thermal history is similar to the East China Sea LME. Since the Kuroshio flows over the East China Sea shelf, this current is likely affected by the East China Sea. During the 1950s-1970s, SST was rather stable, and then rose rapidly. After the all-time maximum of 1998 caused by the El Niño 1997-98, SST dropped to 23°C, still more than 0.5°C above the average level of the 1960s. Over the last 50 years, the North Pacific experienced several "regime shifts" that affected ocean stratification and all trophic levels (Chiba et al. 2008; Overland et al. 2008). These regime shifts have been shown to correlate with the Pacific Decadal Oscillation (PDO), El-Nino-Southern Oscillation (ENSO), Artic Oscillation (AO), North Pacific Index (NPI) and other atmospheric indices (Minobe 1997; Mantua et al. 1997; Mantua and Hare 2002). The North Pacific regime shift of 1976-77 (Mantua et al. 1997; Hare and Manthua 2000) did not transpire in the Kuroshio Current (although it affected the Oyashio Current). The Kuroshio Current LME shifted to warmer conditions after 1986, the last cold year on record, and experienced another shift to even warmer conditions, around 1997-1998. The shift of 1986-88 could be tentatively associated with the North Pacific regime shift of 1989 documented, among others, by Hare and Mantua (2000).

The shifts of 1987-88 and 1997-98 affected the abundance and biological indices of Pacific saury (Tian et al., 2004). The saury abundance and indices have been found to correlate with two wintertime parameters: SST in the NW Kuroshio waters and surface current velocity in the Kuroshio axis. As Tian et al. (2004, p. 235) pointed out: “These correlations suggest that winter oceanographic conditions in the Kuroshio region strongly affect the early survival process and determine the recruitment success of Pacific saury. The abundance of other major small pelagic species also changed greatly around 1989, suggesting that the regime shift in the late 1980s occurred in the pelagic ecosystem basin. We concluded that Pacific saury could be used as a bio-indicator of regime shifts in the northwestern subtropical Pacific.”

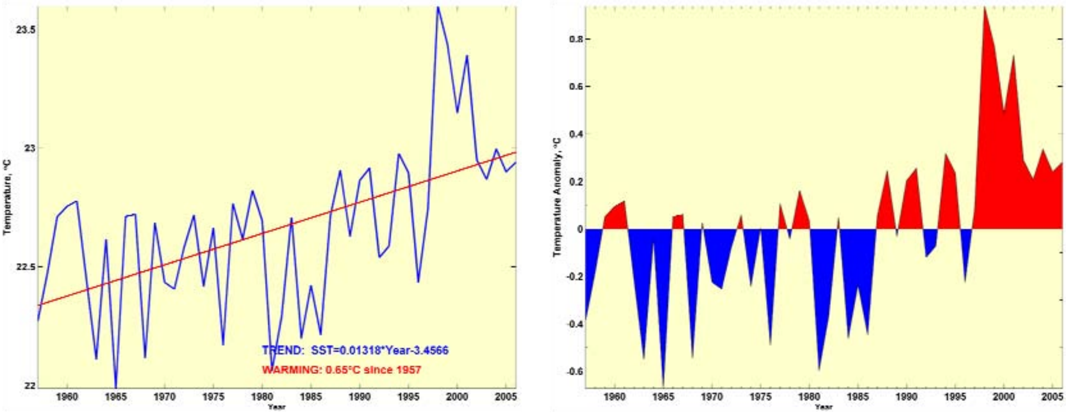


Figure X-23.2. Kuroshio Current LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

Kuroshio Current LME Chlorophyll and Primary Productivity: The Kuroshio Current LME is considered a Class II, moderately high (150-300 $gCm^{-2}y^{-1}$) productivity ecosystem.

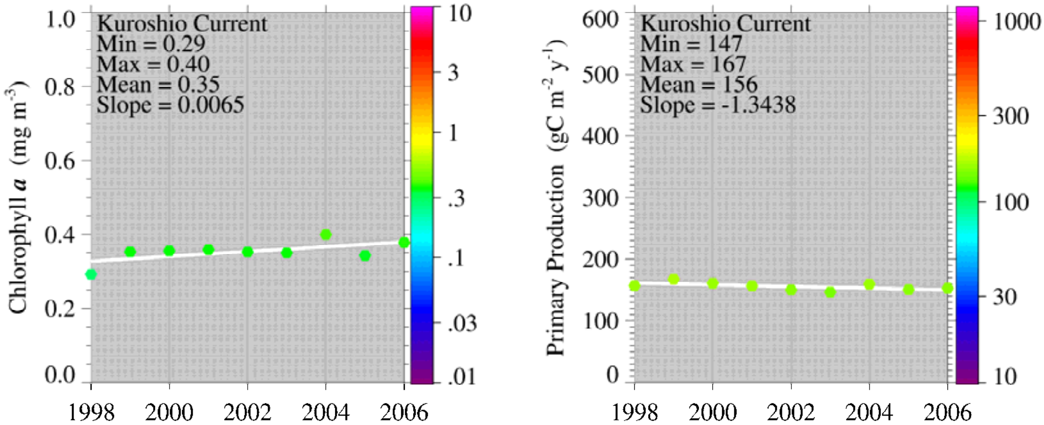


Figure X-23.3. Kuroshio Current LME trends in chlorophyll a (left) and primary productivity (right), 1998 – 2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O’Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Total reported landings in this LME reached 2.5 million tonnes in 1986, but the total has been on a decline following the collapse of the South American pilchard fisheries which dominated the landings in the 1980s (Figure X-23.4). The value of the reported landings peaked at nearly US$4.6 billion (in 2000 US dollars) in 1980 but has declined along with the reduced landings (Figure X-23.5).

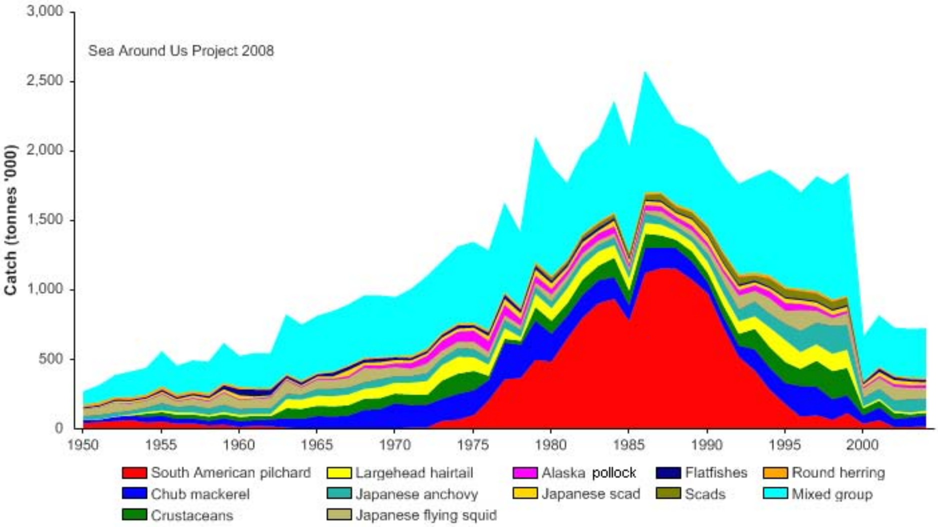


Figure X-23.4. Total reported landings in the Kuroshio Current LME by species (Sea Around Us 2007).

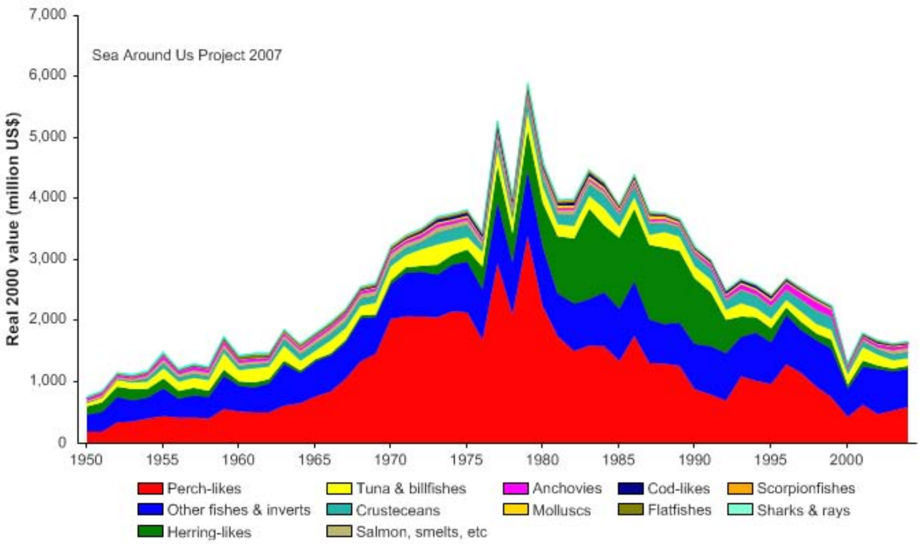


Figure X-23.5. Value of reported landings in the Kuroshio Current LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in the LME reached 70% of the observed primary production in the late 1990s, (Figure X-23.6). Two likely explanations for the extremely high level of PPR recorded in the 1980s and 1990s are the over-reporting in the underlying landings statistics by China (Watson & Pauly 2001) and the shift in the distribution of South American pilchard beyond the LME boundary (Watanabe *et al.* 1996) which resulted in possible misreporting of some of the South American pilchard landings as being caught within the LME. Japan and China account for the largest share of the ecological footprint in the LME, though the extremely large size of the Chinese footprint must be questioned.

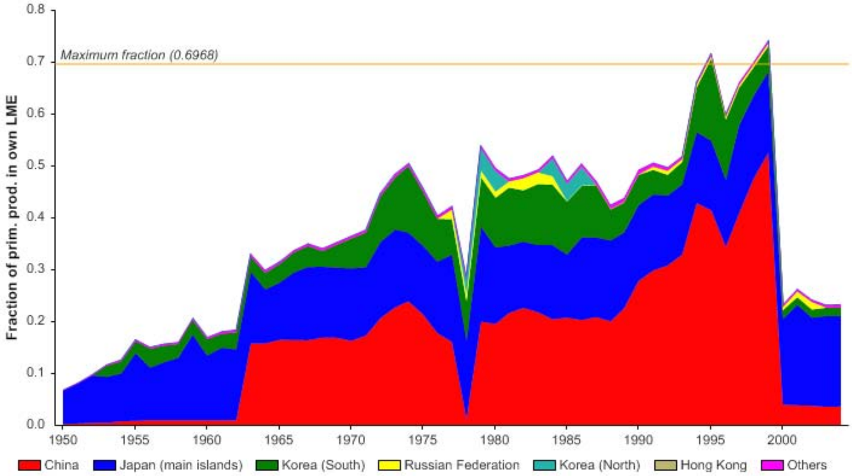


Figure X-23.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Kuroshio Current LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e. the MTI; Pauly & Watson 2005) shows a series of large fluctuations, reflecting the cyclic nature in the relative abundance, and hence the landings, of the low-trophic South American pilchard in the LME (Figure X-23.7 top). The FiB index shows a period of expansion in the 1950s and 1960s, after which the index levels off, indicating that the decrease in the mean trophic level resulting from the high proportion of South American pilchard catches in the 1980s was compensated for by its large landings (Figure X-23.7 bottom).

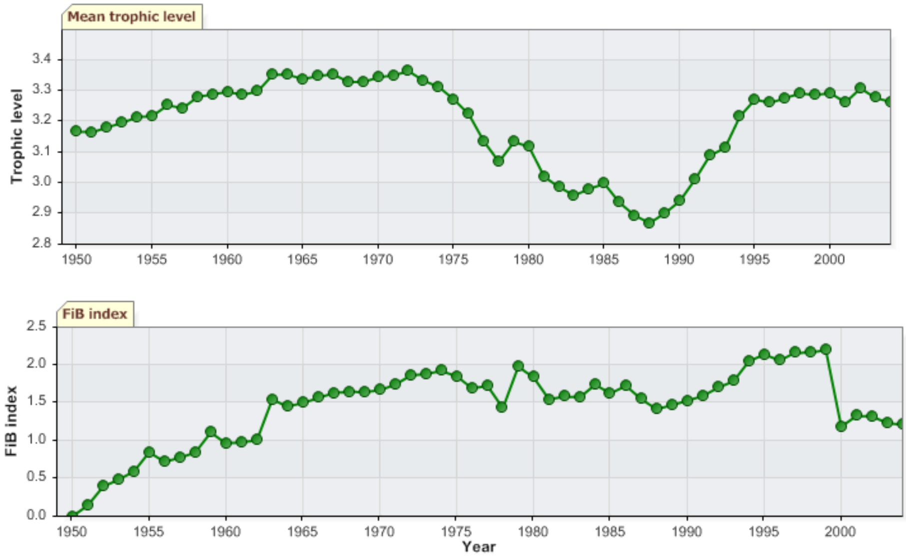
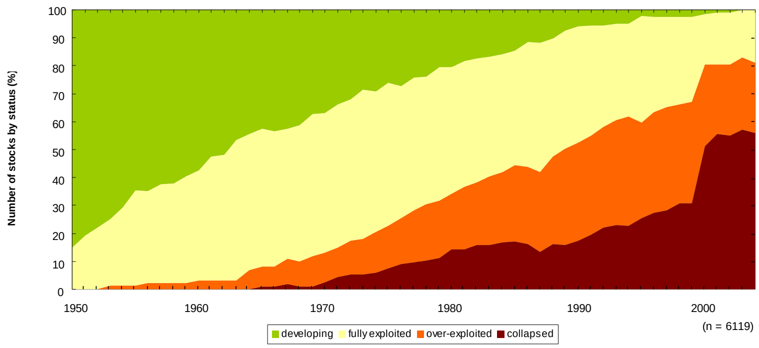


Figure X-23.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Kuroshio Current LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that the number of collapsed and overexploited stock has been on a rise, accounting for 80% of the commercially exploited stocks by 2004 (Figure X-23.8, top) with only half of the reported landings supplied by fully exploited stocks (Figure X-23.8, bottom, and see Figure X-23.6). This is in line with the landings trends, which are declining since the mid-1980s (Figure X-23.4).



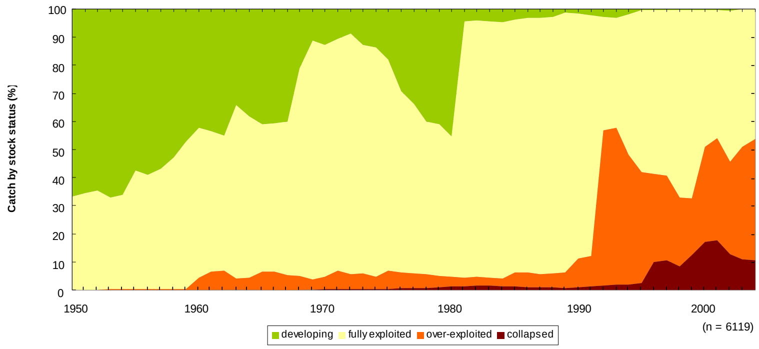


Figure X-23.8. Stock-Catch Status Plots for the Kuroshio LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', 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 biomass of fish stocks depends on the biomass of lower trophic levels (prey), primary production, and also directly on oceanic and atmospheric conditions. The fish catches in the Kuroshio-Oyashio region strongly depend on two oceanographic patterns related to (1) Oyashio's southward intrusions (OSI) or meanders east of Honshu, and (2) Kuroshio's Large Meander (KLM) south of Honshu. Typically, there are two quasi-stationary southward meanders of the Oyashio east of Honshu (Qiu, 2001). Their southward limits SL01 and SL02 correlate with temperature and salinity in the Oyashio LME since the Oyashio meanders contain subarctic water that is markedly colder and fresher than resident water east of Honshu. The OSI strongly affect recruitment, biomass, and catch of such species as pollock, sardine and anchovy. The years when the OSI are well developed and protruded southward are cold years favorable for sardine because sardine uses these meanders as feeding grounds. The KLM development correlates with sardine recruitment and catch owing to the proximity of the KLM to the southern spawning and fishing grounds of sardine (Sakurai, 2007).

Various conceptual hypotheses have been put forth to relate ocean-atmosphere variability to fish catch. For example, Tian et al. (2003) related the abundance of Pacific saury to remote large-scale forcing originated as far away as the equatorial Pacific and the Arctic. Yatsu et al. (2008) linked stock fluctuations of the Pacific stock of Japanese sardine to the Aleutian Low intensification, Oyashio expansion, and mixed layer depth deepening and lower SST in the Kuroshio Extension - as well as less arrival of the two most important predators, skipjack tuna and common squid.

Multi-decadal fluctuations of, and strong correlation between, sardine and anchovy catches that fluctuate out-of-phase is well-known, although the mechanisms behind this phenomenon remain poorly understood (e.g. Chavez et al., 2003). The most recent results by Takasuka et al. (2008) shed a new light on this enigmatic pattern as they found that sardine and anchovy statistical distributions with regard to temperature are distinctly different. In the NW Pacific, they found anchovy to be warm and eurithermal, whereas sardine is cold and stenothermal. In the NE Pacific (California Current), this pattern is reversed.

III. Pollution and Ecosystem Health

Japan's rapid economic development after World War II impacted its marine environment. Rivers have been polluted. On the Pacific side there is air pollution from power plant emissions, resulting in acid rain. Lakes and reservoirs are acidified, resulting in a decrease in water quality and a threat to aquatic life. In the 1960s, heavy industries concentrated along the Japanese coast caused severe water pollution linked to red tides. Strict laws and standards established in the 1970s have improved the quality of coastal waters, although eutrophication in areas such as Tokyo Bay is still serious despite the development of sewage treatment systems. In the Tokyo/Yokosuka area, sewage pollution, habitat destruction and non-biodegradable pollution are considered the most serious problems. Further north, in the Hakodate/Otsuchi area, non-biodegradable pollution is also seen as the most serious problem, followed by sewage pollution and oil pollution. The numbers of reported marine pollution incidents for the coastal areas of Japan appear high. There have been oil spills and incidents caused by land-based activities. A marine environmental monitoring plan for coastal Japan is available online. Table 1-3-4 in the Report on the Environment in Japan (www.env.go.jp/en/focus/080704.html) indicates the number of marine pollution incidents caused by drifting oil and wastes, red tide, and blue tide (in Japanese: Aoshio; this phenomenon is caused by upwelling of blue-green oxygen-depleted turbid waters; observed in Tokyo Bay from early summer to autumn) in sea areas surrounding Japan in the past five years. In 2002, there were 516 occurrences, an increase of 30 occurrences over 2001. Oil spills from ships accounted for the majority of marine pollution, with 231 incidents reported in 2002.

IV. Socioeconomic Conditions

The wide latitudinal extension of the Kuroshio Current LME helps sustain regions varied in culture and economic development. The Japanese Archipelago is comprised of 4 main islands and 200 smaller islands, including those of the Amami, Okinawa, and Sakishima chains of the Ryukyu Islands, all linked by an efficient transport system. Fisheries are a major economic activity in Japan, which relies on the sea for its supply of fish, seaweed and other marine resources. Japan maintains one of the world's largest fishing fleets and accounts for nearly 15% of the global catch. According to the Japan Fisheries Agency report of 1997 (http://www.jfa.maff.go.jp/jfapanf/english/index.htm), Japan produced 7.4 million tons of fishing products in 1996. By 2007, fisheries production is reported at 5.70 million tons (www.stat.go.jp/english/data/handbook/c05cont.htm). The Japan Fisheries Market Report, issued by the Commercial Section of the Canadian Embassy, Tokyo for May 2002 states that Japan’s imports of fish and fisheries products recorded a high in

2001 of 3.823 million metric tons then valued at US$14.21 billion. Of Japan's 2,944 fishing ports, the main Pacific ports are Hachinohe, Shimizu, Tokyo and Tomakomai.

V. Governance

Japan is involved in the governance of this LME. As a country with major interests in fisheries, Japan has formulated and implemented conservation and management measures. In 1971, it established an Environment Agency. Since 1975, the Agency has been conducting annual surveys of marine pollution in LMEs adjacent to Japan including this LME. Another marine research programme, initiated in 1995, evaluates the effects of pollution on marine organisms and of air pollution on the marine environment. Internationally, Japan plays a central role supporting high seas fisheries for salmon, tuna, and bill fish. In order to cope with the changing economical and social situation, in 1997 the Fisheries Agency was reorganized into a four-department system; Fisheries Policy Planning Department, Resources Management Department, Resources Development Department, and Fishing Port Department (www.jfa.maff.go.jp/). The Fisheries Agency attempts to ensure a stable supply of marine products to the people and promotion of the marine products industry in Japan.

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