Trends in Fisheries for Swordfish in the Pacific Ocean

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The broadbill swordfish, *Xiphias gladius* (Fig. 1), is largely distinguishable from other billfishes by the absence of pelvic fins. It is a large pelagic species that attains a maximum size of 540 kg (1,190 lb) and is found in tropical, subtropical and temperate waters of the world's oceans and adjacent seas (Nakamura 1985, Palko et al 1981). It has been a favorite food fish in many countries since antiquity, esteemed for its white firm flesh, mild flavor, and high flesh-to-bone ratio.

Beside being esteemed as a food fish, the swordfish is a prized game fish. It is a difficult game fish to catch with rod and reel, so is pursued by only the most dedicated anglers. Trolling is the traditional method used, although this is done only after the swordfish is visually sighted basking at the surface.

In 1976, drift fishing for swordfish with baited lines and light sticks at night proved successful off Florida. This method quickly spread to other places along the Atlantic and Gulf of Mexico coasts of the United States (Palko et al *op. cit.*). The nominal sport catch, however, has remained small, amounting to no more than a few hundred swordfish per year.

The commercial fisheries produce more than 50,000 mt annually and are by far the major producers of swordfish. They are the focus of this chapter, which begins with a discussion of the markets, or forces that directly influence the level of commercial fishing for swordfish. This is followed by a review of the world catch and a description of the major fisheries in the Pacific Ocean, and concludes with a discussion of trends and outlook for the Pacific fisheries.

Global Markets

Commodity markets for swordfish are forces behind production. As a food fish having a high market value and ability to hold quality when frozen for long-distance shipment, swordfish is produced and traded on an international scale. It is sold fresh or frozen as steaks, fillets, and for raw consumption. The major markets are western Europe, Japan, and the U.S. Collectively, they account for an estimated 87% of the annual consumption.

Europe

The western European market is the largest, estimated to consume about 35% of the annual world supply of swordfish, principally for steaks and fillets. Consumption is concentrated in the Mediterranean countries, particularly Italy and Spain. This market depends largely on swordfish caught by the Spanish, Italian, and Greek fleets fishing on stocks in the Atlantic Ocean and Mediterranean Sea (ICCAT 1988).

Japan

The second largest market for swordfish is Japan. Consumption is estimated to be about 30% of the annual world supply. This market is primarily for high-quality fish, eaten raw as "sashmi" and "sushi." The product must be fresh or, if frozen, kept at low temperatures ($-50°$ to $-60°$C, or $-58°$ to $-76°$F) for retention of desired qualities. Average ex-vessel price was approximately $4.70/kg ($2.13/lb) in 1986 (Yao 1988).

A world-wide Japanese fleet of longliners is largely the source of fish for this market. About 70% to 80% of the supply is from swordfish stocks in the Pacific Ocean and the remainder is evenly divided from stocks in the Atlantic and Indian oceans.

United States

The U.S. market currently consumes about

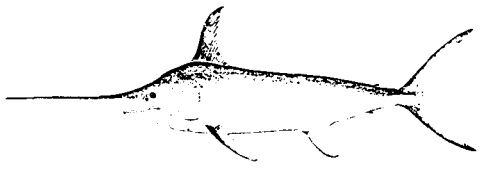

Figure 1. Broadbill swordfish with distinguishing characteristics, including absence of pelvic fins (from Nakamura 1985).

12,000 mt annually, or 22% of the world supply of swordfish. Products are in the form of fresh and frozen steaks and fillets. This market is growing at an estimated annual rate of 5% to 7% (Lipton 1986).

About half of the U.S. supply comes from the U.S. fleet and half from foreign fleets operating in the Atlantic and Pacific oceans. Canada, Spain, and Taiwan currently are the major sources for U.S. imports. In 1986, the average ex-vessel price for U.S.-caught swordfish was $6.95/kg ($3.15/lb); for foreign-caught fish, it was $5.65/kg ($2.56/lb).

The U.S. market has evolved in phases. Before 1971, the market was almost completely dependent on imports, mainly from Canada and Japan (Fig. 2). The discovery in 1970 of high levels of mercury residue in swordfish steaks (Peterson et al 1973), in excess of established health safety margins, reversed this picture.

In 1971, the U.S. strictly enforced a regulation on the permissible level (0.5 ppm) of mercury in imported fish. Consumers stopped buying swordfish, supplies quickly dried up and the market collapsed (Lipton *op. cit.*). A slow recovery began in 1973, with U.S. consumers cautiously returning to the market as fears of mercury poisoning faded. U.S. fishermen increased their efforts to fill the supply lines since they were largely exempt from the mercury regulation that had virtually stopped the entry of imports. They captured over 90% of the market and began establishing new fisheries to meet the increasing demand. Production increased slowly at first, and grew. By 1978, it had grown sufficiently to attain the levels that were consumed before the mercury scare of 1971, and was increasing in line with renewed market growth. In 1985, however, domestic production showed signs of leveling off at 7,500 mt (Fig. 2).

In 1979 the mercury regulation was revised to allow a higher level of 1.0 ppm. In combination with rising value of the dollar relative to foreign currencies and, foremost, exponential growth in U.S. consumption of swordfish, this revision allowed imports to be more competitive (Lipton *op. cit.*). Significant amounts of foreign-caught swordfish began reappearing in 1981. Imports captured 10% of the market share that year and grew in subsequent years. The largest increase occurred in 1985, when domestic production leveled off while consumption continued upwards. Imports captured 35% of the market in 1985, increasing further to 44% in 1986.

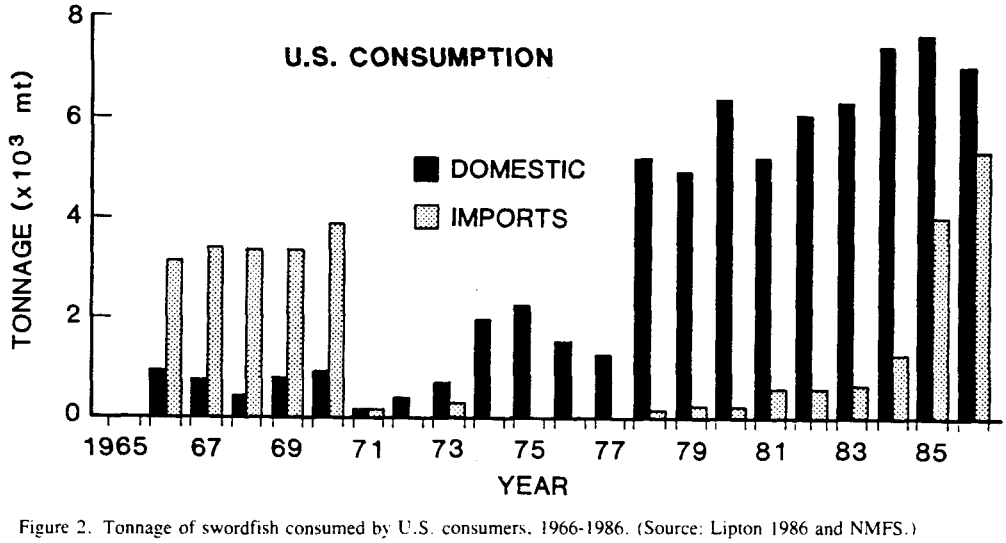

Figure 2. Tonnage of swordfish consumed by U.S. consumers, 1966-1986. (Source: Lipton 1986 and NMFS.)

Global Production

Identifying trends in the catch of swordfish on a world-wide basis is difficult, owing to changes in data gathering and reporting procedures over time, inaccurate reporting of some statistics, and non-reporting for some fisheries. Nonetheless, by piecing together recent estimates from several sources, particularly from ICCAT (*op. cit.*) and FAO (ms), the global catch appears to be increasing — from a low of about 27,000 mt in 1972 to a high of approximately 56,000 mt in 1986.

The major increases have been in the Atlantic Ocean and Mediterranean Sea although the trend has also been upward in the Pacific Ocean. In 1972, the Pacific catch was 12,600 mt or about 47% of the total global catch; in 1986, it was about 21,000 mt and only 37% of the global catch (Fig. 3).

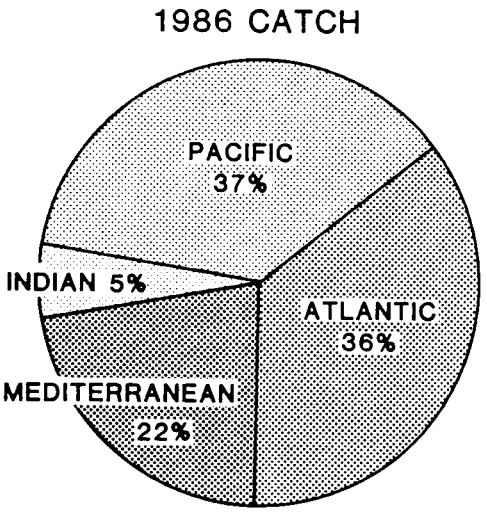

Figure 3. Proportion of swordfish catch by ocean, 1986.

The Pacific catch has shown an increasing trend since 1972, although remaining below the peak of 24,300 mt recorded in 1961 (Fig. 4). The stocks are considered to be in good condition (Bartoo and Coan 1989) and able to sustain increased catches. Comparison of Pacific catches with those of the Atlantic or Mediterranean, and relative sizes of the areas where they are made, suggest that there is considerable opportunity for increased production of swordfish from the Pacific Ocean.

Nations participating in the Pacific fisheries include: United States (harpoon and drift gillnet fisheries off California); Chile, Mexico, and Peru (coastal handline, gillnet and longline fisheries); Japan (Pacific-wide longline fishery and a coastal, mainly drift gillnet fishery off Honshu); the Philippines (coastal handline fisheries); Taiwan (Pacific-wide longline fishery and coastal, primarily longline and harpoon fisheries); and Republic of Korea (Pacific-wide longline fishery).

Pacific Fisheries

The geographic distribution of swordfish varies with seasonal changes in water temperature, but can extend from 50°N lat to 50°S lat. Preferred water temperature for swordfish is 18° to 22°C (64° to 72°F) (Nakamura *op. cit.*) and varies with size of the animal. Juveniles prefer warm water and are found only in the tropical region. Adults have a wider temperature tolerance and occupy the full distributional range, spawning in the tropics and feeding in the temperate regions. Females reach a larger maximum size than males, and can tolerate colder water and occupy the highest latitudes. The smaller adult males generally remain in warmer water close to the equator.

Adult swordfish are found throughout the year in most parts of their distributional range, except in the extreme sub-polar latitudes during the winter. They concentrate in areas where food is abundant, commonly along frontal zones where ocean currents or water masses intersect to create turbulence and sharp gradients of temperature and salinity. The fisheries for swordfish occur in these regions of frontal zones.

In the Pacific Ocean, there are five frontal zones (Sverdrup et al 1942) where swordfish are found in fishable concentrations (Fig. 5): (1) in the northwestern Pacific (Huang 1974, Sakagawa and Bell 1980), where the warm Kuroshiro Current meets the coastal waters of Taiwan and Japan, and where the Kuroshiro Extension Current meets the Oyashio Current to the north; (2) off southeastern Australia (Sakagawa and Bell *op. cit.*), where the warm East Australian Current meets intrusions of the cold Southern West Wind Drift Current; (3) off northern New Zealand (Bailey and Ross 1987), where the warm South Equatorial Current intersects with intrusions of the cold Southern West Wind Drift Current; (4) in the eastern tropical Pacific (Squire and Au 1989), where the warm

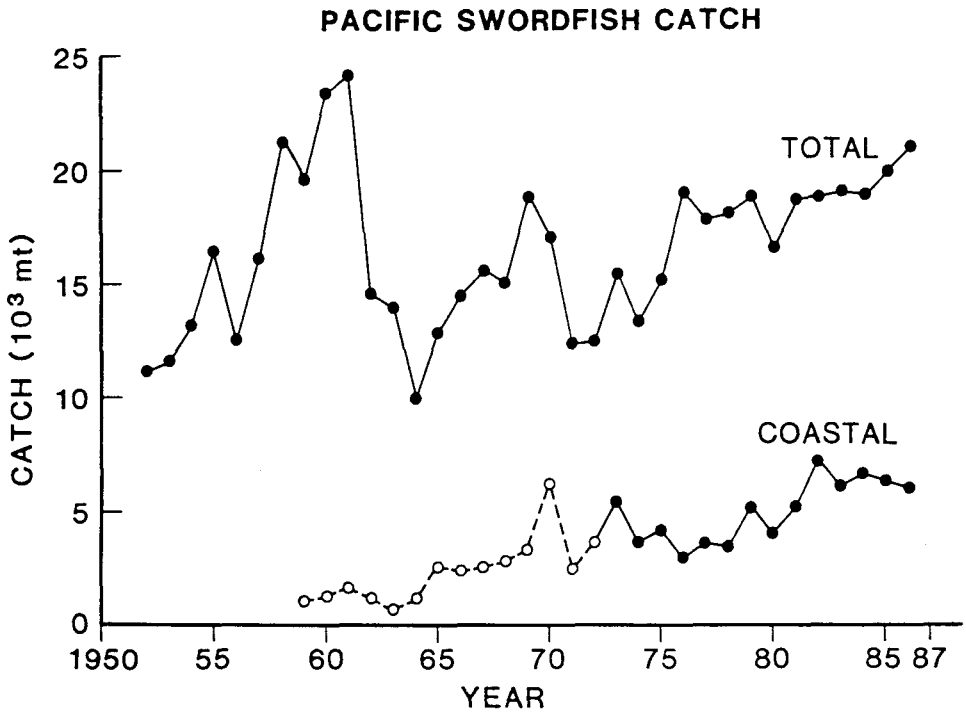

Figure 4. Total catch of swordfish from the Pacific Ocean, 1952-1987. Catches by gears, such as harpoon, drift gillnet, and longlines in coastal waters are labeled "coastal". High seas longline catches are not labeled. Open circles are estimated catches. (Source: FAO ms.)

Equatorial Counter Current intersects with the colder Peru Current; and (5) along Baja California, Mexico, and California, U.S.A. (Bedford and Hagerman 1983, Squire and Au 1989), where the cool offshore California Current intersects with intrusions along the coast of warmer water from the south.

Swordfish are caught in artisanal and other small-scale fisheries but mostly by fisheries that are large-scale commercial operations. Because swordfish forage in the surface waters during the night, inhabiting deeper depths during the day (Carey ms), catches are made principally during the night. Most of the Pacific catch of swordfish is taken incidental to fishing for other species, such as tunas, which are fished during the day. Typically, fisheries that catch significant quantities of swordfish, even incidentally as a complex of target species, are arbitrarily designated as swordfish fisheries.

This review, employed this procedure and applied it to the fisheries of Japan, Taiwan, and the U.S. The fisheries were further separated by major gear: longline, drift gillnet, and harpoon.

Japanese Fisheries

The Japanese fisheries, with total production of 14,300 mt in 1986, or 68% of the total Pacific production, are by far the most important in the Pacific Ocean. The fisheries can be separated into longline, drift gillnet, and harpoon. Each is actively managed by the Japanese government through a complex system of vessel licenses, gear limitations, and area-time regulations to reduce gear conflicts and to enhance economic viability of the fisheries. Over the years 1972 and 1985, the contribution of each fishery to the total catch has changed, with the drift gillnet fishery contributing a greater proportion, and the longline and harpoon fisheries contributing smaller proportions (Fig. 6).

Longline Fishery

The Japanese longline fishery is conducted

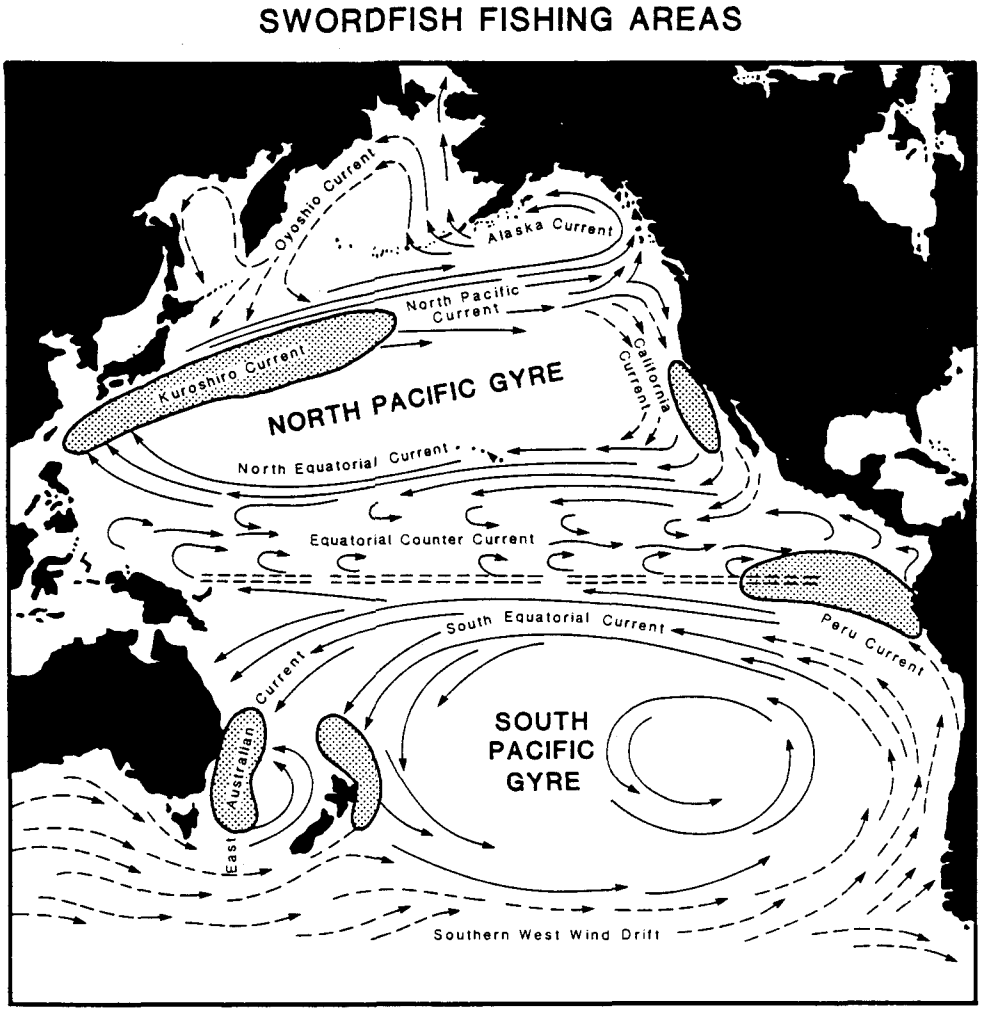

Figure 5. Location of major swordfish areas (stippled) in the Pacific Ocean. The areas correspond to zones of high production of food organisms and where major ocean currents meet.

on the high-seas using vessels of 50+ gross tons and in near-shore and coastal waters of Japan using vessels of less than 50 gross tons. The fleet consists of approximately 1,200 vessels of which about 600 may be deployed in the Pacific during a single fishing season.

The gear used by the vessels is the longline, consisting basically of a main line with float lines and branch lines with baited hooks. For the large high-seas vessels, the main line is set over a distance of 25-75 km (14-40 nmi) and fishes about 2,000 hooks during a single set.

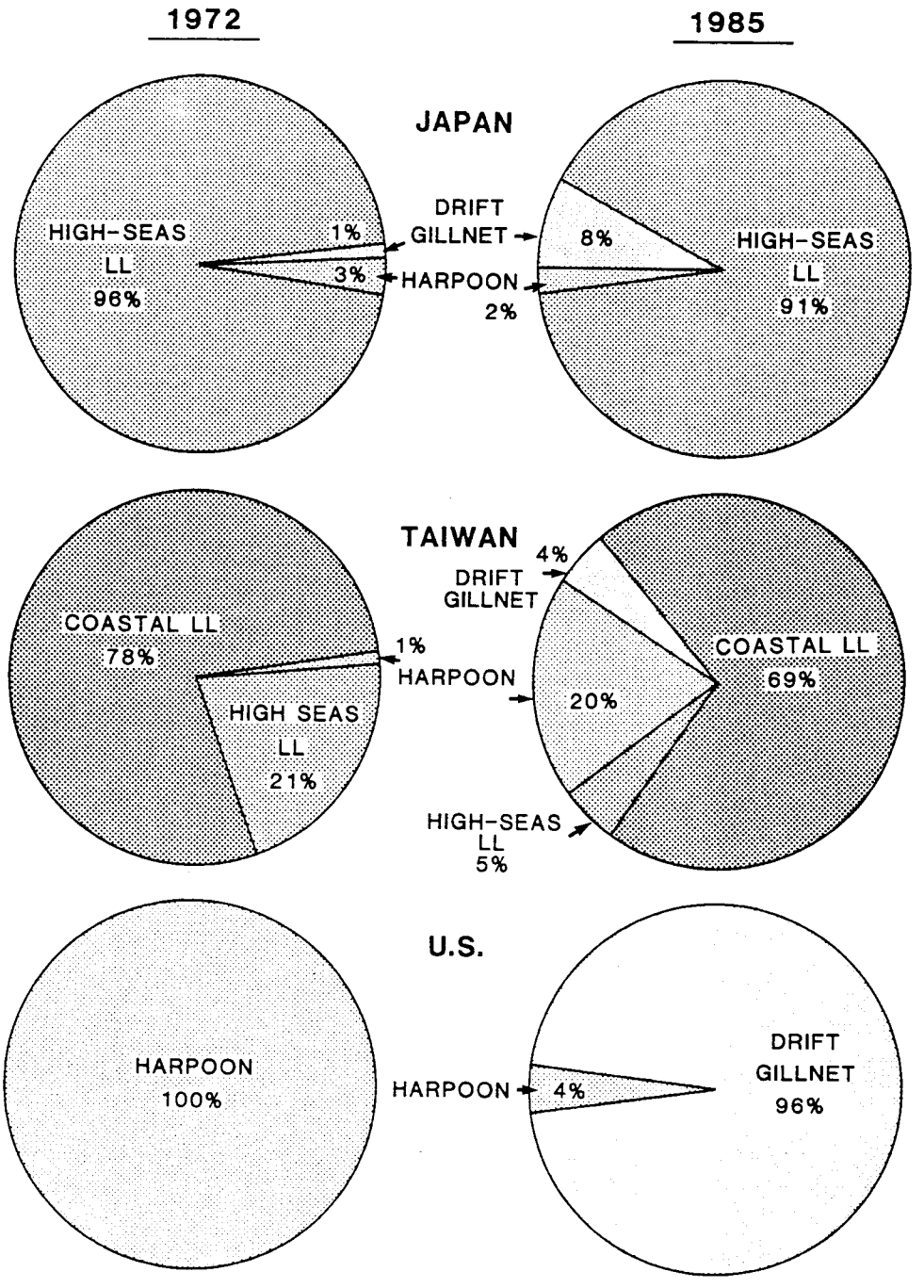

Figure 6. Comparison of percent swordfish catch by fisheries for 1972 and 1985.

Float lines are attached to the main line to regulate fishing depth, a maximum of 170 m (557 ft) for standard sets and about 300 m (984 ft) for deep sets (deep longlining). A set is normally deployed early in the morning and retrieved beginning around noon, frequently ending after midnight (Ueyanagi 1974).

Deep longlining is a relatively recent innovation that was introduced to catch the deep-swimming bigeye tuna, *(Thunnus obesus)*. Deployment started by the Japanese in about 1974 in the equatorial regions of the Pacific and Indian oceans (Suzuki et al 1977, Suzuki and Kume 1982). It spread gradually to all oceans and to other longline fleets, i.e., those of Korea and Taiwan. Because it fishes deeper, deep longlining is less efficient in catching the more shallow-swimming species — albacore *(T. alalunga)*, yellowfin tuna, *(T. albacares)*, and swordfish — than is the standard longline gear. The incidental catches of swordfish by this latter gear are probably largely made as the gear is being retrieved during the night hours.

Swordfish is not currently the primary target species of this fishery and the catch is a small proportion of the total longline catch (less than 5%). Tunas are the target species and the catch amounted to about 190,000 mt in 1986 (Sakagawa et al 1987). In past years, this was not the case as swordfish was a target species in certain areas of the Pacific Ocean and made up more than 50% of the catch in some 5×5 degree fishing areas (Bartoo and Coan 1989). In recent years, some vessels continue to target on billfishes, such as striped marlin *(Tetrapturus audax)*, and/or swordfish in limited areas off Mexico (Squire and Au 1989), New Zealand (Bailey and Ross *op. cit.)*, and in the Kuroshio Extension Current (Bartoo and Coan 1989).

During the period 1952 through about 1962, swordfish were specifically targeted, along with albacore, by the Japanese longline fleet. Night fishing at shallow depths with squid as bait was used in certain areas (Ueyanagi *op. cit.)*. The longline catch during that period reached a record high of 22,000 mt of swordfish in 1961 (Fig. 7). Since then the fishery changed to primarily day operations, using a mixture of bait types and emphasizing catching tunas for the sashimi market; swordfish catches slipped to a lower level, averaging 12,300 mt (1966-1969). In 1971, catches decreased again owing to the mercury scare and collapse of the U.S. market. Since 1975, catches have rebounded to an average of about 11,000 mt (Fig. 7).

The areal distribution of the swordfish catches for 1976 shows that swordfish were taken mostly in the northwestern region, along the edge of the Kuroshio and Kuroshio Extension Currents, off the Mexican coast, and off southeastern Australia (Fig. 8, panel B). In 1980, fishing effort was more widely distributed and for the most part targeted for bigeye tuna (Fig. 8, panel A). Significant amounts of swordfish continue to be taken in the northwestern region and in other areas where major frontal systems are located (Fig. 8, panel C). The eastern tropical Pacific, in particular, shows significant recent catches by this fishery.

Drift Gillnet Fishery

The Japanese drift gillnet fishery lands swordfish as a by-catch of fishing for other pelagic species in the northwestern Pacific Ocean. More than 1,600 vessels of varied sizes, 10 to 250 gross tons, participate in this fishery (Yonemori and Honma ms). Generally, the larger vessels operate on the high-seas and target pelagic species such as squid *(Ommastrephes bartrami)*, salmon *(Oncorhynchus* sp.), pomfret *(Brama japonica)*, and albacore. The smaller vessels operate closer to the coast off northern Honshu Island, primarily from July to October, and switch to other fisheries during the off-season (Anon 1978). This coastal component targets primarily striped marlin but also catches yellowfin tuna, skipjack tuna *(Katsuwonus pelamis)*, mahimahi (i.e., dolphin, *Coryphaena hippurus)*, sharks and swordfish (Anon *op. cit.)*. Fishing success of this fleet is largely dependent on oceanographic conditions associated with the meandering of the Kuroshio Current off Japan.

The gear used is multifilament netting of about 9 m (30 ft) deep and 18 cm (7 in) mesh size (Yonemori and Honma ms). The net is fished at the surface and a set can extend up to 12 km (6.5 nmi). Sets are usually made in the afternoon, allowed to drift during the night, and retrieved beginning before dawn.

This fishery began recording significant catches of swordfish in the mid-1970s (Fig. 7). Catches increased sharply to a peak of 3,500 mt in 1976, declined to 1,000 mt in 1979 and remained fairly level since then.

Harpoon Fishery

The Japanese harpoon fishery targets striped marlin and takes blue marlin *(Makaira nigri-*

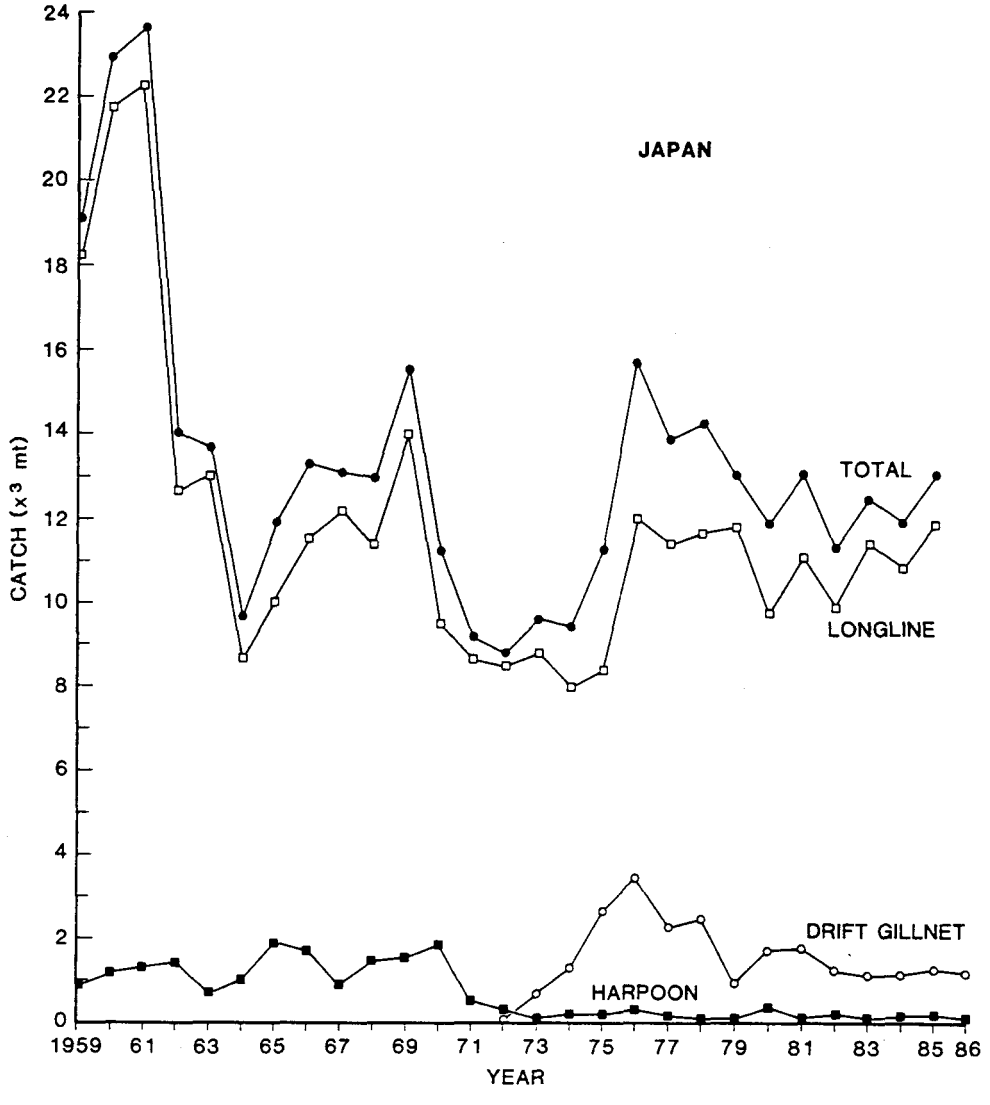

Figure 7. Catch of swordfish by gear for the Japaneses fisheries, 1959-1986. (Sources: FAO ms, Y. Watanabe pers. comm.)

cans), and swordfish incidentally. Because fishing with harpoons requires calm seas for visually sighting the basking fish, and for positioning the vessel within striking distance of the fish, oceanographic conditions, particularly associated with the Kuroshio Current, dictate the fishing season (Sawadaishi 1985). Typically, this fishery is active from December to May. The fishing areas are in the Bonin and Izu Islands (south of Tokyo) and off the northern coast of Honshu Island (off Miyako).

About 100 boats of less than 20 gross tons (mainly 3 to 15 gross tons) participate in this fishery. Most boats are active in harpooning only during December to May, squid jig fishing during the rest of the year (Y. Watanabe pers. comm.).

The gear used is a three-prong electric-dart

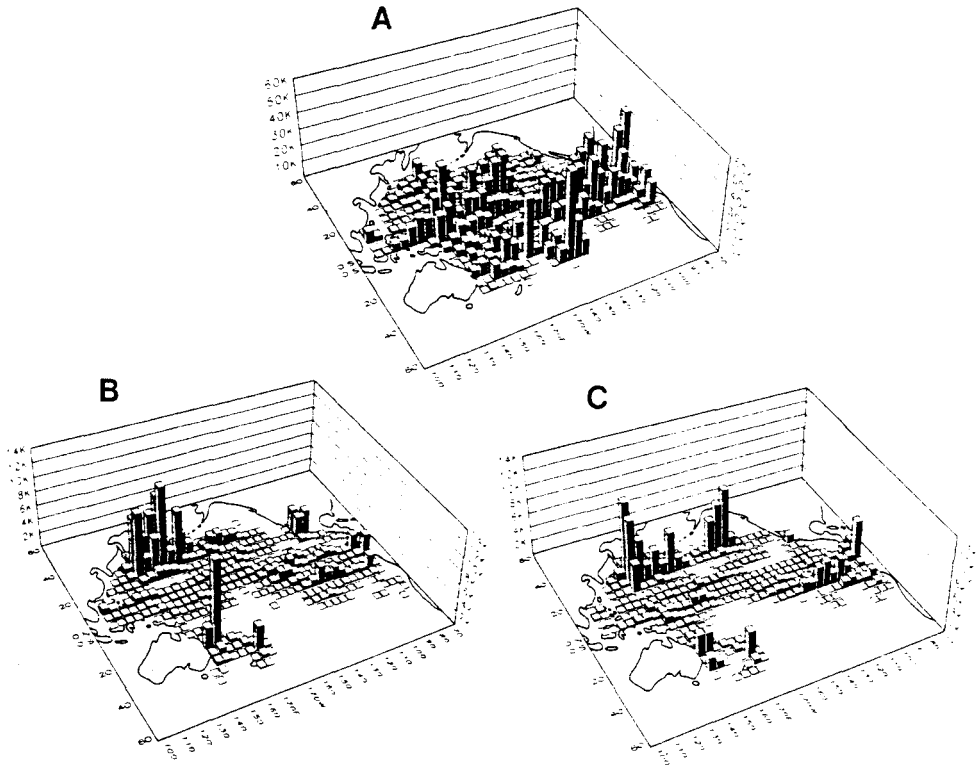

Figure 8. Areal distribution of catches (in numbers) for the Japanese longline fishery in the Pacific Ocean. Panel A is catches of bigeye tuna, the principal target species for 1980. Panel B is catches of swordfish for 1976, a year of exceptional high catches. Panel C is catches of swordfish for 1980, a recent year.

harpoon (Sawadaishi *op. cit.*). The pole is 5 m (16 ft) long and 4 cm (1.6 in) in diameter, of oak or reinforced plastic. Fastened to the tip of the pole is a steel attachment with three prongs, each holding a removable dart. The dart is 8 to 12 cm (3.1 to 4.7 in) long, arrow shaped and made of steel. Holes in the shank of the dart allow attachment of electrical wiring and the main line of 4 to 5 mm (0.16 to 0.2 in) diameter rope. The opposite end of the electrical wire is attached to a storage battery located in the engine room of the vessel.

Operationally, fish are sighted from the crow's nest. The vessel maneuvers to the target, and the harpooner on the bow plank is positioned. The harpooner throws the harpoon by hand. The harpoon tips embed in the fish and separate from the pole while the main line, with electrical wire, is played out as the fish tries to escape. The electrical shock is administered and the dead fish is retrieved.

The swordfish catch of this fishery ranged from a high of 1,700 mt in 1970 to a low of about 100 mt in 1986 (Fig. 7). In 1971, the catch fell substantially (-71%) and has not recovered. Because this low catch corresponds to the period of increased activity of the drift gillnet fishery, the harpoon fishery appears to compete directly with the drift gillnet fishery for available swordfish in the coastal waters.

Taiwanese Fisheries

Taiwanese fisheries contributed an estimated 700 mt, or 3% to the total Pacific swordfish catch in 1986. They are not major fisheries, but are reviewed here because Taiwan is a major exporter of swordfish to the U.S. market and Taiwan has a major world-wide longline fleet. Taiwanese fisheries that catch significant amounts of swordfish are the high-seas longline, coastal longline, and harpoon fisheries.

Between 1972 and 1985, the contribution of each of these fisheries to the total Taiwan catch of swordfish changed markedly. Most significant has been the decreased percentage contribution by the longline fisheries and increased percentages by the harpoon fishery and by the emerging drift gillnet fishery (Fig. 6). Swordfish catches in this latter fishery are not yet large enough to be considered significant.

High-Seas Longline Fishery

The high-seas longline fleet of Taiwan consists of vessels larger than 50 gross tons. This fleet numbered more than 200 vessels in the Pacific in the 1970s, but have been reduced to fewer than 100 in 1984. Fishing effort (number of hooks) for this fleet likewise decreased by 80% between 1980 and 1985 (Tuna Research Center 1986).

Like the Japanese longline fleet, the Taiwanese vessels operate on the high-seas in pursuit of large tunas. Albacore is the principal target species (Sakagawa et al *op cit.*), making up 88% of the tuna catch of 7,000 mt in 1985. Recently, modern longliners have been added to this fleet for catching large tunas, principally yellowfin and bigeye, for the Japanese sashimi market.

Swordfish is an incidental species caught by the vessels. The catch has been less than 300 mt and, since 1980, it has decreased to a low level of 40 mt in 1985 (Fig. 9). Catches have been small because fishing is principally in the southwestern region of the Pacific and for albacore (Fig. 10). The area fished also appears to have a low density of swordfish. Highest catches of swordfish occur off southeastern Australia and northern New Zealand.

Coastal Longline Fishery

Taiwan has a large number of longline vessels (2,080 registered in 1986) that fish the nearshore and coastal waters of Taiwan. Most are of 20 to 50 gross tons and operate off eastern Taiwan along the edge of the Kuroshio Current in pursuit of large tunas (Huang *op. cit.*). This

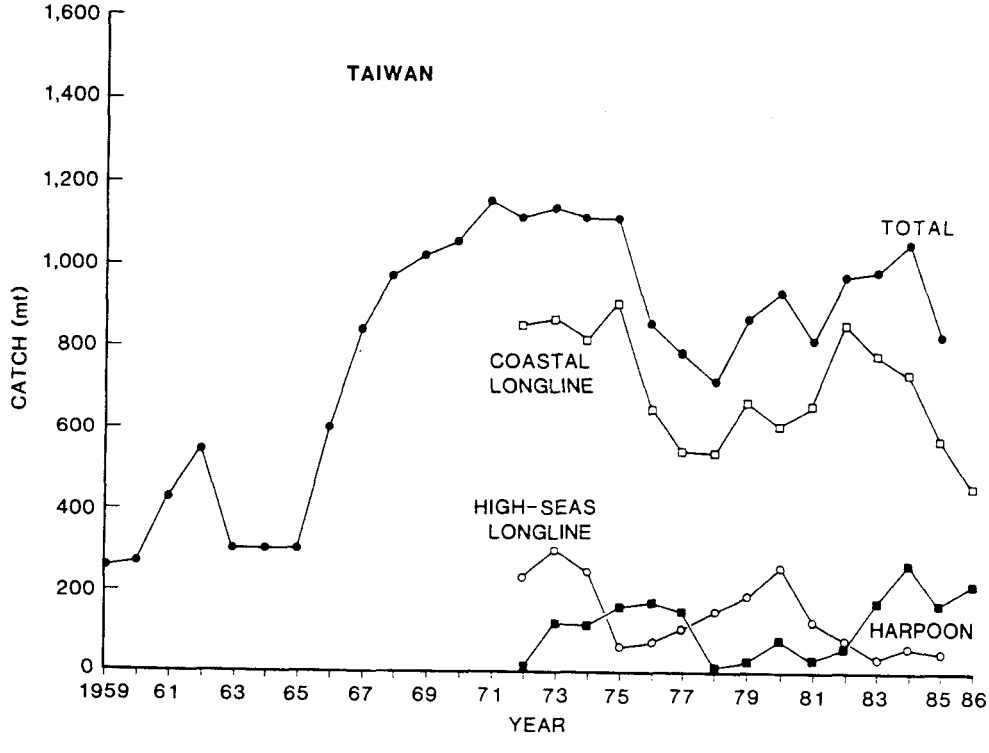

Figure 9. Catch of swordfish by gear for the Taiwanese fisheries, 1959-1986. (Sources: Tuna Research Center 1986, FAO ms, H.C. Liu, pers. comm.)

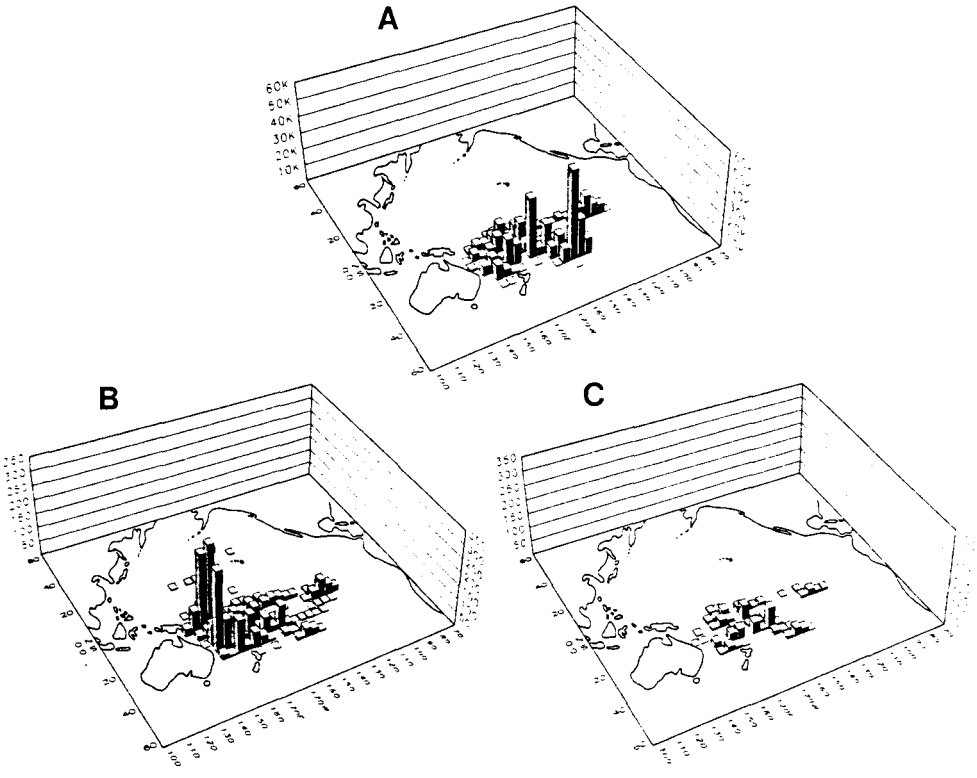

Figure 10. Areal distribution of catches (in numbers) for the Taiwanese longline fishery in the Pacific Ocean. Panel A is catches of albacore, the principal target species for 1985. Panel B is catches of swordfish for 1977, a year of exceptionally high catches. Panel C is catches of swordfish for 1985, a recent year.

fleet catches significant amounts of billfishes, including swordfish, and other large pelagic species as a by-catch.

The swordfish catch of this coastal longline fishery has fluctuated between 500 mt and 900 mt (Fig. 9). Since 1982, the trend has been downward, with the catch reaching a record low of 500 mt in 1986. Among the billfishes caught in this fishery, swordfish ranks low at 14%, behind blue marlin at 35%, and sailfish *(Istiophorus platypterus)* at 24% (Table 1).

Harpoon Fishery

Harpoon fishing for billfishes was introduced into Taiwan by the Japanese in 1913 (Huang *op. cit.*). In 1986, a total of 390 vessels participated in this fishery. They operated primarily in the eastern region of Taiwan, from the southern ports of Kaohsiung and Taitung and from the northern port of Keelung.

Unlike the Japanese harpoon fishery, this fishery appears to target a complex of billfishes, with swordfish ranking low (Table 1). Blue marlin, sailfish, and black marlin *(Makaira indica)* are principal target species. Catches of swordfish were low during 1978-1982, at less than 100 mt annually (Fig. 9). Since then, it appears to have stabilized at the 200 mt level.

Table 1. Average (1980-1985) catches of billfishes by species in the billfish catch of Taiwanese fisheries. (Source: H.C. Liu pers. comm.)

	Billfish species					
Fishery	Swordfish	Striped marlin	Blue marlin	Black marlin	Sailfish (others)	Total
High-seas longline						
Catch (mt)	94	145	236	19	15	509
Percentage	18	29	46	4	3	100
Coastal longline						
Catch (mt)	699	524	1,695	773	1,144	4,835
Percentage	14	11	35	16	24	100
Harpoon						
Catch (mt)	120	147	585	524	554	1,930
Percentage	6	8	30	27	29	100
Total						
Catch (mt)	913	816	2,516	1,316	1,713	7,274
Percentage	12	11	35	18	24	100

United States Fisheries

U.S. fisheries for Pacific swordfish are centered in the coastal waters off southern California. In 1986, the fisheries produced about 2,100 mt of swordfish, representing 10% of the total swordfish catch from the Pacific. Management of the fisheries is largely by state agencies through limits on number of fishing licenses, design of the gear, and fishing season and area (Squire ms).

The U.S. fisheries can be divided into two: drift gillnet and harpoon. The drift gillnet fishery is relatively new, started in the late 1970s. It currently is the dominant fishery (Fig. 6). The harpoon fishery, in contrast, dates back to the turn of the century (Bedford and Hagerman *op. cit.*) and is on the decline.

Drift Gillnet Fishery

During 1977 and 1978, southern California fishermen discovered that drift gillnets set for common thresher shark *(Alopias vulpinus)* and shortfin mako *(Isurus oxyrinchus)*, resulted in incidental catches of the more valuable swordfish. This discovery, along with development of a market for fresh shark fillets, led to rapid improvements in the gear and in the number of fishermen using the gear; many were swordfish harpoon fishermen, as well. By 1980, a full-fledged modern drift gillnet fishery targeting sharks, with significant catches of swordfish, was in operation.

Opposition mounted to this new fishery (Herrick and Hanan 1988). Opposition forces were concerned with the adverse effects on other commercial and recreational fisheries as well as protection of marine mammals and seabirds that get entangled in the gear. As a result, a series of laws was enacted by California to control the drift gillnet and other similar net fisheries.

Most significant of the new laws was one requiring revocable, nontransferable permits for all drift gillnet fishermen, and which specified qualifications for obtaining them. It also required permit holders to submit logbooks and to allow observers on fishing trips.

Another significant piece of legislation was passed in 1982 in recognition of the significant amounts of swordfish taken in drift gillnets and concern over excessive effort on the shark resource (Herrick and Hanan *op. cit.*). The legislation allowed for targeting swordfish with drift gillnets and placed a limit on number of licenses. This transformed the fishery overnight. Swordfish became the target species and sharks the secondary species. A target of no more than 150 permits was put into effect (Herrick and Hanan *op. cit.*). Because there were about 200 fishermen with drift gillnet gear at that time, all were issued permits and a moratorium placed on new issues until the number drops below 150. Since then, the number has remained relatively stable at about 200 to 225 permits (Fig. 11).

The drift gillnet used is constructed of nylon twine and with large mesh, 20.3 to 50.8 cm (8 to 20 in) (Bedford and Hagerman *op. cit.*). It is approximately 18 to 37 m (60 to 120 ft) deep and 1,829 m (6,000 ft) long. It is fished at night one meter to 2.7 m (3 to 9 ft) beneath the surface. Fishing depth is controlled by suspended float lines at about 18 m (60 ft) intervals along the length of the net. The net drifts with one end attached to the vessel and the other attached to a buoy, which contains a strobe light and radar reflector.

Before 1982, the U.S. drift gillnet fishery operated in an area south of Point Conception, California, to the Mexican border and within about 92 km (50 nmi) of the coast (Fig. 12). This is the same fishing area used by the older harpoon fishery for swordfish. Beginning in 1982, the fishery expanded northward about to San Francisco and, in some years, even farther northward to waters off Oregon and Washington (Fig. 13). Fishing in the most northern part is almost exclusively for sharks and only rarely results in swordfish catches; hence, swordfish fishing by the fleet can be considered limited to waters off California.

The fishing season is regulated and extends from May to February. Within this season, the distribution of fishing effort is bimodal, May and October (Fig. 14). Approximately 80% of the fishing takes place, however, during August through January, when 99% of the catch is made.

Most of the catch (75%) is made in the area south of Point Conception, with exceptional catches made off San Diego, between Catalina Island and the mainland (off Los Angeles), and southeast of Anacapa Island in the Santa Barbara Channel Islands (Fig. 15). North of Point Conception, the catch is relatively small (about 6,000 fish in the 1984-1985 season) and there is only one exceptionally high catch area, off San Francisco. Fishing effort is also reduced in this northern area owing to poor ocean condi-

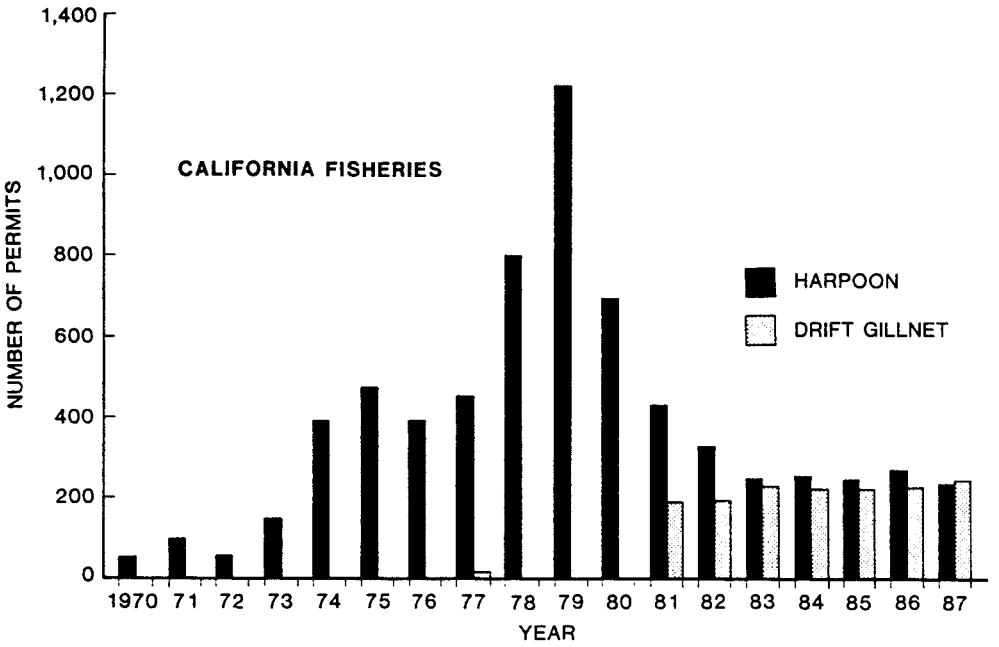

Figure 11. Number of permits issued by California for fishing with harpoon and drift gillnet.

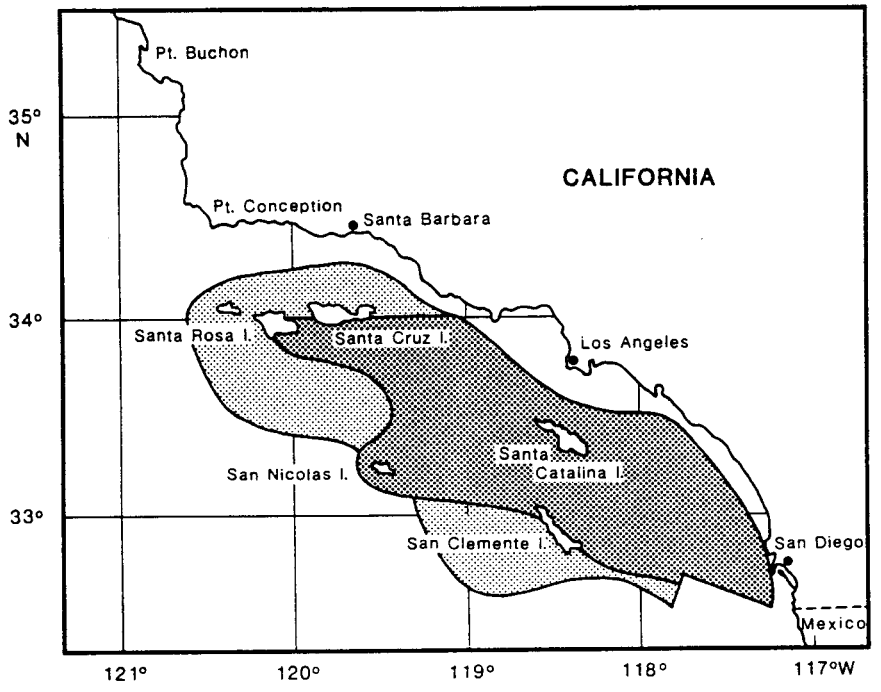

Figure 12. Location of fishing areas of the U.S. harpoon fishery (dark stipple) and drift gillnet fishery (light stipple) for swordfish off California.

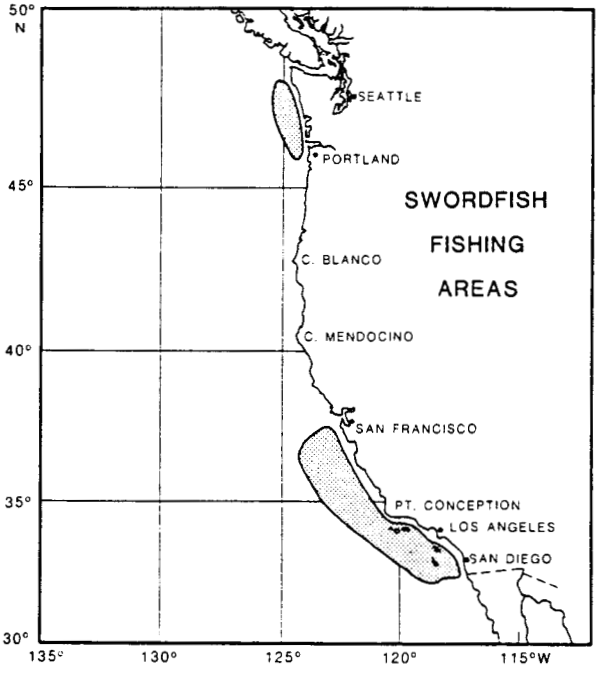

Figure 13. Location of fishing areas (stippled) of the U.S. drift gillnet fishery for swordfish and sharks.

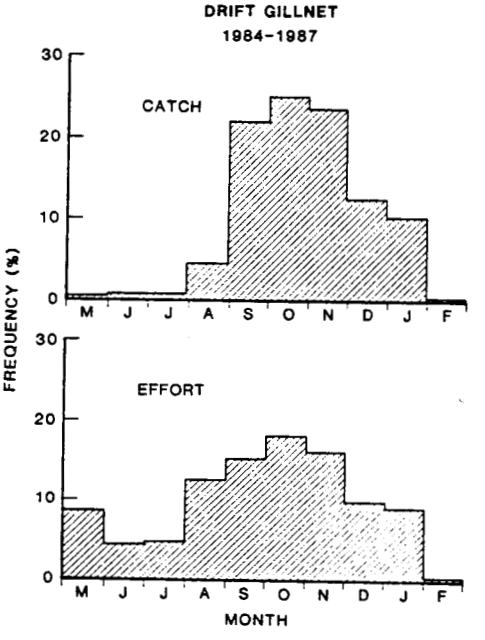

Figure 14. Seasonal distribution of swordfish catch and fishing effort for the U.S. drift gillnet fishery. (Source: D. Bedford pers. comm.)

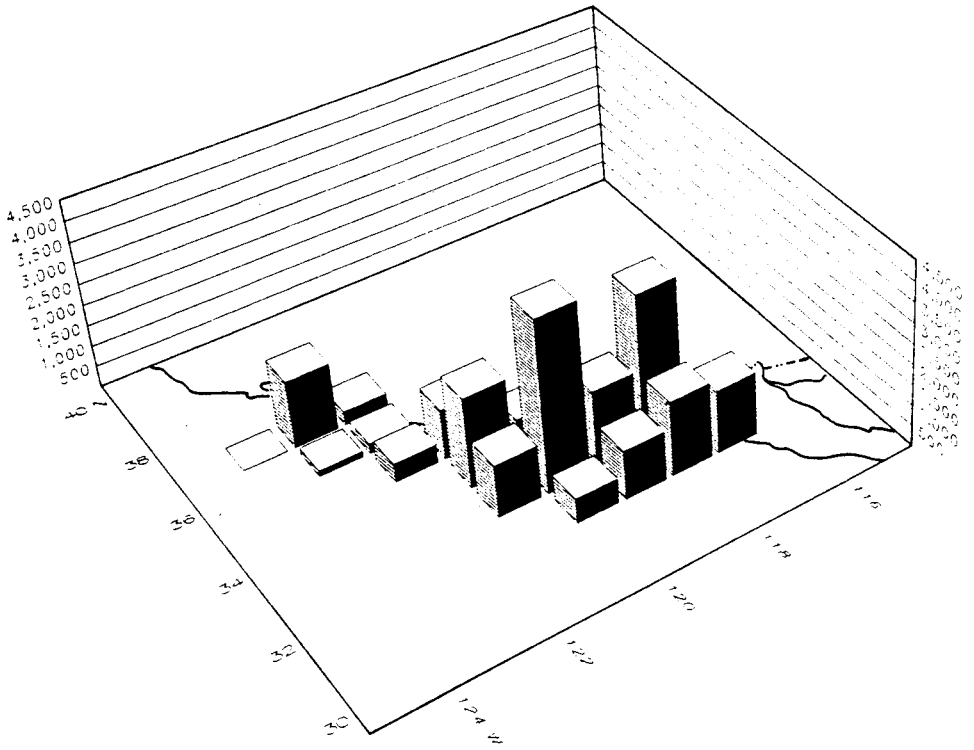

Figure 15. Areal distribution of swordfish catches (in numbers) for the U.S. drift gillnet fishery off California, 1985.

tions and weather for drift gillnet fishing during most of the fishing season (Bedford and Hagerman *op. cit.*).

The total catch in this fishery increased steadily from 1980 to 1985, recording an impressive 890% increase (Fig. 16). Since then, the catch has fallen sharply to 1,900 mt in 1986 and to 1,400 mt in 1987, despite stable fishing effort of approximately 10,000 days fished per season. The average size of fish caught has not been affected and has remained stable[1].

Harpoon Fishery

The oldest U.S. fishery for Pacific swordfish is the harpoon fishery off California. The fishery began at the turn of the century and grew in response to consumer demand for swordfish. It is exclusively devoted to catching swordfish during a season that extends from about June to December and peaks in August or September (Fig. 17).

The heyday for this fishery was in the 1970s. The U.S. mercury regulation cut off foreign supplies and prices rose. This encouraged participation and innovation in the fishery. One innovation was the use of airplanes to locate swordfish more efficiently, and for directing the harpoon vessel. This innovation proved so successful that a flood tide of new participants entered the fishery and as many as 20 airplanes were engaged full time by the fleet (Bedford and Hagerman *op. cit.*). Before 1974, less than 150 persons held permits for swordfish fishing with harpoons in California waters (Fig. 11). In 1974, the number more than doubled to about 400.

Fierce competition and conflicts among the harpoon fishermen resulted from the fact that the fishing area is limited to a small region south of Santa Barbara to the Mexican border and within 92 km (50 nmi) of the coast (Fig. 12). To reduce the conflict, beginning in 1976, restrictions were placed on the use of aircraft for

[1] Available data on dressed length of swordfish average about 1.5 m (5 ft) annually in 1984 to 1988 (D. Bedford pers. comm.).

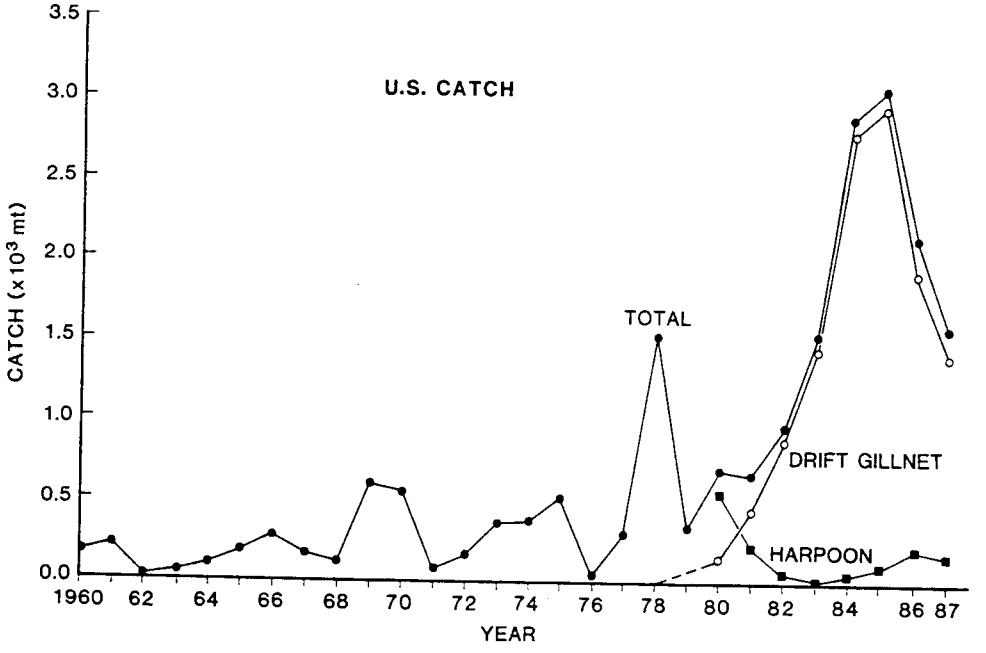

Figure 16. Catch of swordfish by gear for the U.S. fisheries, 1960-1987.

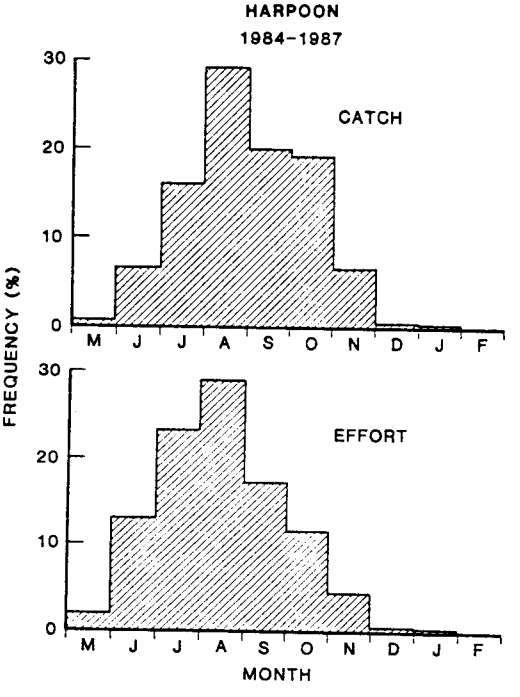

Figure 17. Seasonal distribution of swordfish catch and fishing effort in the U.S. harpoon fishery. (Source: D. Bedford pers. comm.)

assisting swordfish fishermen (Bedford and Hagerman *op. cit.*). Despite the restrictions, the number of participants continued to grow, peaking at 1,200 permits in 1979 before declining (Fig. 11). Currently, only about 225 permits are outstanding in this fishery.

This reduction in the number of participants can be attributed largely to keen competition from the drift gillnet fishery. The drift gillnet fishery, largely of full-time fishermen, operates in the same fishing area and competes with the harpoon fishery. In the 1970s, when there was no drift gillnet fishery, most of the harpoon permit holders were part-time fishermen, attracted to the fishery that required modest investment. For example, in 1974-1978, only 52% of the harpoon permit holders actually fished for swordfish, about 34% caught swordfish, and 12% landed 50% of the total harpoon catch (Bedford and Hagerman *op. cit.*). Currently, only the more serious and skilled fishermen remain in the harpoon fishery.

Vessels engaged in swordfish harpooning are mostly between 6 and 15 m (20 and 49 ft) long (Weber ms). Each is equipped with a crow's nest and a "plank" that extends 6 to 9 m (20 to 30 ft) from the bow (Bedford and Hagerman *op. cit.*). The harpooner stands at the tip of the plank in a "pulpit" and throws the harpoon by hand at the target.

The harpoon consists of a pole of tubular steel construction with an attachment at one end for holding a removable brass or bronze arrow-shaped dart of about 10 cm (4 in.). Holes in the shank of the dart allow attachment of the main line of nylon rope. About 91 m (300 ft) of main line are used, with several neoprene floats or solid PVC balls and a marker-flag attached at the end.

When a fish is harpooned, the main line, floats, and marker-flag are thrown overboard. The fish is allowed to tire from dragging the line, floats, and marker flag, while the vessel pursues other targets. After about 2 to 3 hours, the vessel returns to retrieve the line and fish (Weber ms). The catch is dressed — gutted, head removed back of the cleithrum, and fins trimmed — and stored on ice at sea. Similar dressing of the catch at sea is done by the drift gillnet fishermen.

The catch of the harpoon fishery was at a high point of 600 mt in 1969 and 1970 just before the mercury scare (Fig. 16). The catch collapsed to less than 100 mt in 1971. Recovery followed as demand and prices increased. The catch built back up to 500 mt by 1975. Restrictions on the use of airplanes in 1976 — first as a total ban but, by the end of the year, relaxed to searching outside of 8 km (5 mi) radius of the fishing vessel — disrupted the fishery and the catch fell to only 50 mt. The catch improved the following year as the fishery adjusted to the airplane restrictions. It continued upward, reaching a record of 1,500 mt in 1978. From this peak, it declined sharply to 30 mt in 1983 as the drift gillnet fishery developed and recovered to 160 mt in 1987. Recovery was aided in 1985 by lifting of the restriction on use of aircraft for directing harpoon vessels to swordfish.

Trends and Outlook

The trend of swordfish catches from the Pacific Ocean in recent years is upward (Fig. 4.). Projecting this trend to the future is risky without considering several factors, namely the global market for swordfish, the condition of the stocks, and developments in the longline fisheries.

The world market for swordfish is strong, so prices should remain high. If the market grows at a modest rate of say 5% over 3 years, it will require approximately 1,000 mt of additional swordfish per year, above the 56,000 mt caught worldwide in 1986, to meet the demand.

The Pacific Ocean stocks are in sufficiently good condition (Bartoo and Coan *op. cit.*) to contribute to such an increase. Other major stocks, such as those in the Atlantic Ocean and Mediterranean Sea, are not as healthy. They are showing signs of overfishing, with large numbers of small fish making up the catch (ICCAT *op. cit.*). These stocks, therefore are not likely to contribute substantially to future increased world supply. In fact, total yield from them could decrease in the long run if stock conditions worsen and the fleets remove smaller fish. Such a decrease will exert pressure on the Pacific fisheries to make up the shortfall.

Except for some coastal fisheries, such as the U.S. fisheries, the Pacific fisheries generally do not target swordfish. Most of these fisheries target tunas and take swordfish as a by-catch; consequently, the markets for tuna will dictate how these fisheries operate and the level of by-catch. The U.S. fisheries target swordfish, and production and catch per unit of effort are declining owing largely to the limited area for suitable operation of the gears and fishing restrictions.

The outlook for coastal fisheries for swordfish is not good, judging from experiences with similar coastal fisheries in the Atlantic Ocean (Caddy 1976). Production is likely to decrease or stall at current levels unless the fisheries expand and exploit additional segments of the stock outside the traditional fishing areas. This will be difficult to do because the fishable areas where the gears are most effective are limited.

In contrast, the longline fisheries of the Pacific have the greatest potential for improved catches of swordfish. Longline fishing effort currently targets the more abundant tunas for the high-value markets, particularly the Japanese sashimi market. This Japanese sashimi market is limited and undergoing strains because of oversupply and instability of prices (Yamashita ms). Discussions among the major suppliers, i.e., Japan, Korea, and Taiwan, are being held to bring stability to the market. If successful, longline fishing effort on tunas could be cut back and the excess effort directed towards other species such as swordfish. Targeting longline effort to swordfish can be easily done by night fishing in certain areas.

As for the outlook of U.S. production of Pacific swordfish, the trend is downward or leveling off. Production is severely limited because the current gears, drift gillnets and harpoon, are effective only in a limited coastal area. Although current state laws allow for experimental gear permits, the restrictions on them and on use of alternative gears, including longlines, and on incidental catches, discourage innovation in catching and landing swordfish (Squire ms). Lacking modification of these restrictions, there is little incentive for investment in new ways to expand the fisheries and increase U.S. production of swordfish from the Pacific Ocean.

Summary

Swordfish are caught in significant amounts only by commercial fishermen. In the Pacific, the catch peaked at 24,300 mt in 1961. The discovery in 1970 of high levels of mercury in swordfish steaks resulted in reduced consumer demand and the catch declining to 11,000 mt in 1971. This decline was short lived, however, as demand returned and production increased to 21,000 mt in 1986.

Approximately 70% of the Pacific swordfish catch is taken with longline gear that is directed at catching tunas, while 30% is taken by surface fishing gears, such as harpoon, drift gillnets, and handlines, directed at catching large pelagic species. Hence, there is little directed fishing for swordfish except for the U.S. fisheries. Both drift gillnets and harpoons are used in the U.S. fisheries off southern California to target swordfish. The total catch for these fisheries was 2,600 mt in 1986 and 1,600 mt in 1987. About 96% of this catch is made by the drift gillnet fishery.

The outlook for the Pacific fisheries is mixed. The world market for swordfish is strong, so prices should remain high. Greater yields appear to be available from the Pacific swordfish stocks as they are in good condition. Increased production by coastal fisheries operating in traditional areas, however, appears unlikely owing to limitations of the gears and suitable fishing areas. In contrast, longline fisheries have considerable potential for increased catches of swordfish. The current fisheries are largely day-fishing operations and directed at catching tunas. They can be redirected to night-fishing operations in certain regions to target swordfish.

For the U.S., the outlook is not good. Pacific swordfish production is severely limited because the gears used are effective only in a limited coastal area. Furthermore, government restrictions on use of alternative gears and on incidental catches discourage efforts to expand the fisheries and increase production.

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