Swordfish, *Xiphias gladius*, Fisheries of the Eastern North Pacific Ocean

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ABSTRACT

Broadbill swordfish, *Xiphias gladius*, is harvested commercially throughout the area of its distribution, with catches averaging about 78,000 metric tons per yr. In the North Pacific it is harvested in both coastal and high-seas fisheries by numerous nations. This paper provides a description of the swordfish fisheries off the west coasts of the United States and northern Mexico and summaries of other fisheries in the eastern North Pacific.

Introduction

Broadbill swordfish, *Xiphias gladius*, is a large migratory oceanic species widely distributed in all of the world's tropical and temperate oceans and most major seas. It inhabits surface waters above 13°C, but seasonally may enter cooler waters (Nakamura, 1985). The swordfish is known to descend to depths of 300–500 m, where temperatures are 5°–8°C, presumably for feeding (Carey and Robison, 1981; Holts et al.[1]). It is found in greater abundance in areas of rich production where small pelagic prey are plentiful, such as in frontal zones and where water currents merge or where temperature and salinity gradients occur (Sakagawa, 1989; Sosa-Nishizaki and Shimizu, 1991). In the Pacific Ocean there are at least four such areas: the coastal and offshore waters of the California Current, the Kuroshiro Current off Japan, the Peru Current off northern Chile, and the current systems east of Australia.

Swordfish is harvested commercially throughout its area of distribution. It is highly desired, and sold both fresh and frozen in seafood and sushi markets around the world. Individual swordfish may exceed 500 kg in the Pacific. Worldwide landings peaked at 81,000 metric tons (t) in 1988 (Table 1), and currently average about 76,400 t. Total annual catch in the Atlantic Ocean and Mediterranean Sea averages about 44,000 t, representing 56.8% of the world catch. In these areas swordfish production is declining and the stock(s) appear to be overexploited. The International Commission for the Conservation of Atlantic Tunas (ICCAT) therefore set Atlantic quotas in 1991 to gradually reduce catches to below the current estimated maximum sustained yield (MSY). Catches in the Pacific and Indian Oceans, where there is no international management regime, represent 38.7% and 4.5% of world production, respectively (Fig. 1).

The north Pacific swordfish resource was considered stable at the time of the most recent assessments (Sakagawa and Bell, 1980; Bartoo and Coan, 1989; Sakagawa, 1989; Skillman, 1989). However, the data used in these studies were complete only through 1981. The global market and product value have remained steady. In response to continued demand, and reduced supply from the Atlantic, swordfish catches in the Pacific have increased. Data assembled by the Food and Agriculture Organization (FAO) of the United Nations indicate substantial production increases in all three of its eastern Pacific statistical fishery areas (67, 77, and 87), especially from the United States (U.S.), Mexico, Chile,

[1] Holts, D. B., N. W. Bartoo, and D. W. Bedford. 1994. Swordfish tracking in the southern California bight. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., SWFSC Admin. Rep. LJ-94-15, 9 p. Available from SWFCS, NMFS, 8604 La Jolla Shores Dr., La Jolla, CA 92083.

Table 1
Swordfish catch (metric tons) for the eastern Pacific Ocean, entire Pacific, and world (data from Food and Agriculture Organization, 1986–93).

	Eastern Pacific				
Year	Northern Area 67	Central Area 77	Southern Area 87	Pacific total	World total
1970	0	6,000	3,600	9,600	40,500
1971	0	2,800	500	3,300	26,678
1972	0	3,602	800	4,402	28,417
1973	0	4,504	2,600	7,104	32,183
1974	0	2,814	904	3,718	25,911
1975	0	2,697	540	3,237	28,819
1976	0	3,908	544	4,452	31,465
1977	0	3,216	832	4,048	33,380
1978	1	3,760	1,119	4,880	39,864
1979	0	3,215	572	3,787	37,992
1980	0	4,308	896	5,204	37,489
1981	8	5,534	900	6,442	38,663
1982	14	4,926	804	5,744	43,716
1983	26	4,168	1,316	5,510	46,587
1984	35	4,794	1,073	5,902	53,517
1985	162	4,995	688	5,845	59,121
1986	25	4,927	1,239	6,191	61,036
1987	28	5,903	2,662	8,593	67,028
1988	74	5,977	5,508	11,559	81,036
1989	86	5,217	6,318	11,621	78,704
1990	30	8,463	6,072	14,565	76,235
1991	4,004	9,390	8,403	21,797	71,639

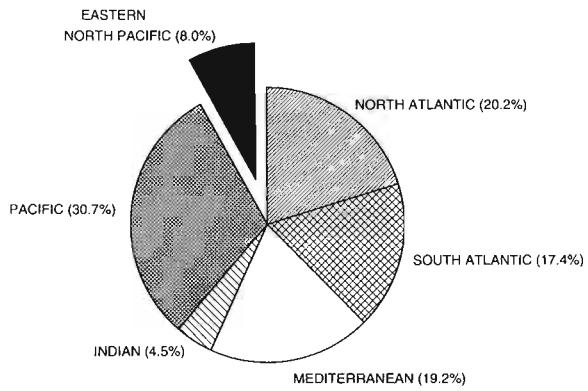

Figure 1
Worldwide swordfish production by major ocean system, 1987–92 (data from Food and Agriculture Organization, 1986–93).

and other Central and South American countries (Food and Agriculture Organization, 1986–93; Table 1). Many U.S. commercial swordfish vessels transferred their operations from the Atlantic and Gulf states to the eastern North Pacific in 1993. This increase in potential production raised fears that the Pacific stock(s) may also be vulnerable to overfishing, and created an urgent need for new assessments utilizing current data (Joseph et al.[2]).

Imports of swordfish into the U.S. have increased from less than 1,000 t prior to 1984, to over 4,000 t per yr in 1985–89. Generally priced well below domestic market prices, imports have continued to increase to more than 7,000 t per yr in recent years (1989–92) with an annual value in excess of $40,000,000 (Jacobson[3]). Imports from the Pacific Ocean are currently about 67% of total U.S. swordfish imports.

This description of the swordfish fisheries off the west coast of the U.S. and Mexico east of 140°W longitude includes the harpoon, driftnet, and longline fisheries operating out of U.S. west coast ports and the driftnet and longline fisheries of Mexico, through the 1993 fishing season (Fig. 2). Summaries of the longline fisheries of Japan, Taiwan, and Korea in the eastern North Pacific and that of Hawaii are also presented.

Fisheries

Japan

Japanese longline vessels began operations in the Pacific in 1952 and were fishing the entire eastern Pacific between 40°S and 35°N by 1968 (Nakano and Bayliff, 1992; Squire and Muhlia-Melo[4]). Directed fishing effort changed seasonally and annually to target the most lucrative species of billfish and tunas available. Japanese Pacific-wide swordfish catches varied between 10,000 and 18,000 t and accounted for at least 80% of Japan's catch of swordfish during 1952–68. The three areas of the eastern Pacific with the highest swordfish catch rates were off northern Mexico, east of 120°W; off northern Chile; and at 10°–15°S and 95°–110°W (Nakano and Bayliff, 1992). Japan has had up to 600

[2] Joseph, J., W. H. Bayliff, and M. G. Hinton. 1994. A review of information on the biology, fisheries, marketing and utilization, fishing regulations, and stock assessment of swordfish, *Xiphias gladius*, in the Pacific Ocean. Inter-Am. Trop. Tuna Comm. Int. Rep. 24, 81 p. Available from IATTC, La Jolla, CA 92037-1508.

[3] Jacobson, R. 1994. Statistics and Market News, Natl. Mar. Fish. Serv., NOAA, Long Beach, CA 90802. Personal commun.

[4] Squire, J. L., Jr., and A. F. Muhlia-Melo. 1993. A review of striped marlin, swordfish, and sailfish fisheries and resource management by Mexico and the United States in the northeast Pacific Ocean. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin Rep. LJ-93-06. 44 p. Available from SWFSC, NMFS, 8604 La Jolla Shores Dr., La Jolla, CA 92038.

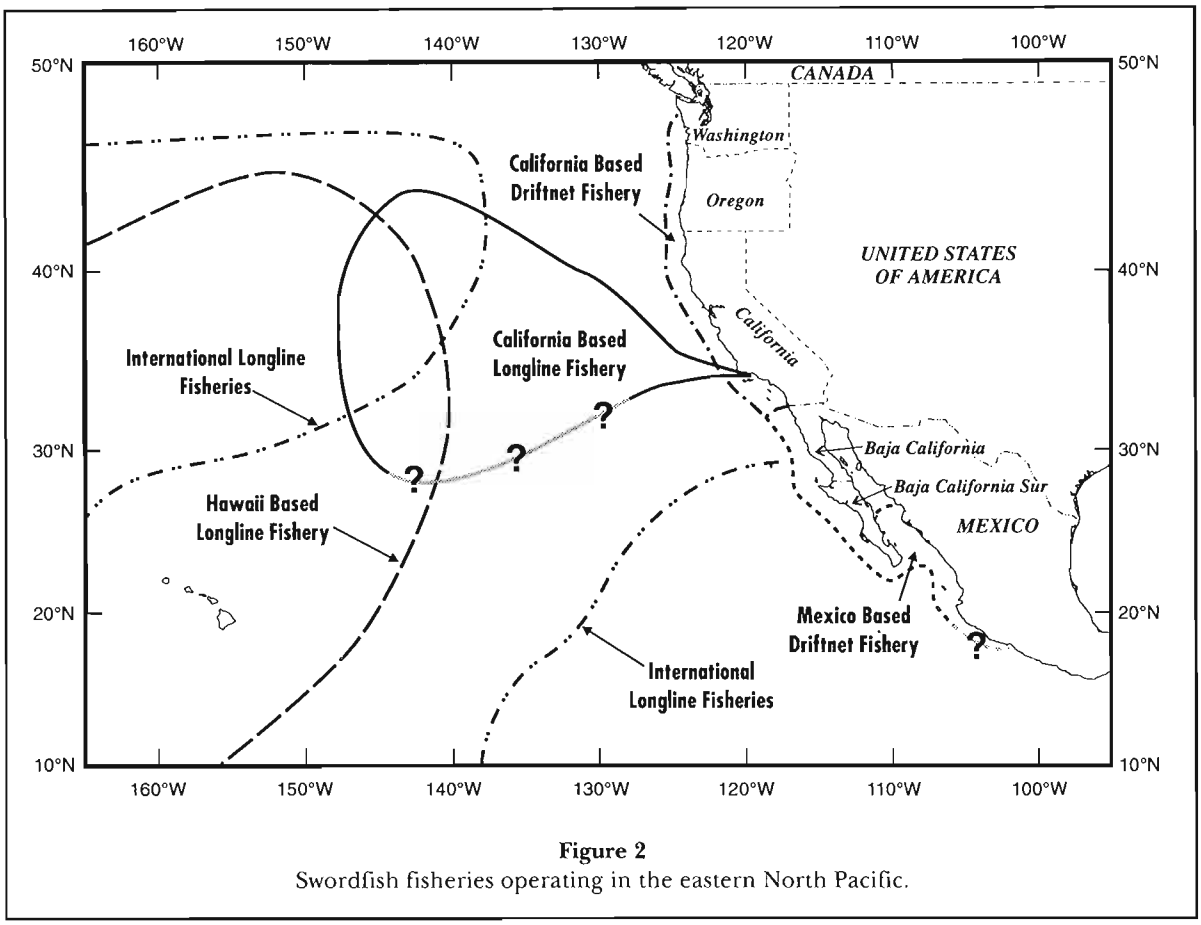

Figure 2
Swordfish fisheries operating in the eastern North Pacific.

longline vessels operating in the eastern Pacific in a single year (Sakagawa, 1989).

Japanese longline fishing effort in the North Pacific increased from 100 million hooks deployed annually in the 1950's to 230 million hooks by 1967, and has remained above 200 million since. Fishing effort in the eastern North Pacific increased from approximately 100,000 hooks during the late 1950's to over 20 million in 1968, and averaged 9.5 million (range 6.4–13.7 million) between 1970 and 1980. This effort was directed primarily at tuna, although striped marlin, *Tetrapturus audax*, and swordfish were targeted around the tip of the peninsula of Baja California, Mexico. During the late 1980's, 49%–58% of Japan's total longline fishing effort in the Pacific was concentrated in the eastern North Pacific, north of 10°N and east of 140°W.

Substantial numbers of Japanese longline vessels fished within 12 nautical miles (n. mi.; 22 km) of the coast of Baja California in 1964, targeting swordfish, marlins, and sailfish. Japan began targeting bigeye tuna, *Thunnus obesus*, in about 1975, using deep longline technology (Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992). That technology employs longer floatlines and fewer floats, increasing the distance between floats and allowing the hooks to fish deeper in the water column where bigeye tuna are more abundant. Deep longlining was more commonly used south of 10°N and was used only about 25%–45% of the time off Baja California.

Conventional Japanese longline fishing effort continued off northern Mexico for swordfish, and the highest catch rates (catch per hundred hooks) were reported from 1975 to 1983 and again in 1986 and 1987 (Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992). Mexico prohibited longline fishing within its Exclusive Economic Zone (EEZ) from late 1984 through most of 1985.

Catch of swordfish north of 10°N and east of 140°W peaked between 1968 and 1973 at an average of nearly 14,200 fish, and represented 9.5% of Japan's total swordfish catch in the Pacific. Between 1974 and 1980, the Japanese catch in the eastern North Pacific declined to 4,400 swordfish (3.1% of their Pacific-wide catch) as a result of targeting on other billfish and tunas. The most recent data available indicate swordfish catches in 1984 and 1985 were the lowest since the early 1960's.

Japanese longline catch rates for swordfish were highest during the mid-1960's from 10°N to 30°N, off Baja

California Sur and Mexico and east of Hawaii. Catch rates were 0.1–0.3 fish per 100 hooks off Baja California in the 1960's and 1970's and fluctuated from <0.1–0.4 as fishermen switched target species between swordfish and other billfish off Baja California in the 1980's (Nakano and Bayliff, 1992). Mexico began enforcing its EEZ in 1978, allowing foreign longline effort within the EEZ on a permit basis only. These permits were limited to joint-venture operations in 1978–91 and were withdrawn for a period in 1984–85. All longline effort, foreign and domestic, was abolished within Mexico's EEZ in 1991. During 1981–87, the greatest Japanese longline catch rates occurred at 30°–35°N and east of 135°W (off Baja California Sur) throughout the year and west of 135°W in the fall and winter.

Considerable variation exists in the length-frequency data. Swordfish less than 80 cm and greater than 200 cm, measured from posterior margin of the eye to fork in tail (EFL), were most common off Baja California Sur. Although clear trends were not identified, recruitment into the longline fishery apparently occurs throughout the year and over a broad area and wide range of sizes (Nakano and Bayliff, 1992).

Japan's high-seas driftnet fleet did not enter the eastern North Pacific, although it did fish for swordfish, billfish, and tunas in the South Pacific in 1972–92.

Taiwan

Taiwan's high-seas longline fleet began fishing in the South Pacific in the 1960's and had expanded into the North Pacific by 1967. Its fishing effort was primarily directed at albacore, *Thunnus alalunga*, and yellowfin tuna, *Thunnus albacares*, in the western Pacific. Taiwan's longline fishing effort exceeded 2 million hooks in 1976, but declined steadily through 1991. Fishing effort in the eastern North Pacific occurred in only two years (1980 and 1987) and was directed toward tunas. Incidental swordfish catches were insignificant.

Korea

Korea's high-seas longline fishery targeted on tropical tunas began in the South Pacific and had expanded into the eastern Pacific by 1975. Fishing effort in the North Pacific averaged 10 million hooks from 1975 to 1987 (range 4.5–21.0 million). Most of this effort targeted tuna between 10°N and the equator. Effort in the eastern North Pacific averaged 1.0 million hooks in 1975–87 (range 0.2–3.5 million). Effort decreased after 1984, possibly because of restrictive licensing agreements within Mexico's EEZ. Catches of swordfish were incidental, averaging only 230 swordfish per year (range 0–1,018).

United States

Harpoon Fishery—Fishing for swordfish with hand-held harpoons began off southern California in the early 1900's. Swordfish (and striped marlin) could be taken by both recreational and commercial fishermen until 1935, when harpooning for sport was banned by the California Fish and Game Commission (CFGC). Harpoon fishing remained the primary fishery for swordfish until 1980, when it was essentially displaced by the driftnet fishery for pelagic sharks and swordfish.

Traditionally the swordfish harpoon fishery extended seasonally north as far as Oregon and south well beyond the U.S.–Mexico border. It was, however, concentrated in warmer waters (18°–22°C) within the Southern California Bight from about Santa Barbara to the Mexican border and out about 60 n. mi. (110 km). The harpoon season peaks in the summer and fall, when generally mild weather conditions exist. Changes in climate and current patterns have influenced the catch distribution (Coan et al., 1998). Fishing vessels search for swordfish "finning" or basking at or near the surface. Because fish are usually sighted from the vessel's mast or from airplanes, calm weather and sea conditions are critical to locating the fish.

Harpoon vessels average about 6–26 m in length, with a bow plank of about 6–8 m. They normally operate with a crew of at least two, who search with binoculars for swordfish. When a swordfish is sighted, one crew member maneuvers the vessel's bow plank over the fish while the other throws the harpoon from the end of the bow plank. The catch is often stored on ice during short trips of a few days.

The number of vessels with harpoon permits remained fairly steady prior to 1970. In 1971, levels of total mercury in swordfish exceeded the allowable level of 0.5 ppm. Local demand dropped for two years, but recovered in 1973. Imports of swordfish were severely restricted for several years, but domestic swordfish, sold locally, was not subject to inspection. The level of methyl mercury legally allowable in swordfish was increased to 1.0 ppm in 1978. With reduced competition from imports and renewed consumer acceptance, the number of permits increased from 150 to over 1,200 by 1980 (Bedford and Hagerman, 1983), although the number of vessels landing harpooned swordfish exceeded 300 only in 1978 and 1980.

Harpoon vessels began using aircraft to assist in locating swordfish at or near the surface in 1970. In 1973, the harpoon was designated the only commercial gear for swordfish by the CFGC. Aircraft proved extremely efficient in locating swordfish and improving catches for those vessels employing their use (Bedford[5]). Air-

[5] Bedford, D. W. 1985. Pelagic shark/swordfish drift gill net fishery. Calif. Dep. Fish Game Manage. Info. Doc., 74 p. Available from CDFG, 1416 Ninth St., Sacramento, CA 95814.

craft use was prohibited for a short time in 1976, but its effectiveness had been demonstrated by both increased catch rates and landings. Use of aircraft was resumed but only to locate areas of fish, and aircraft were required to remain at least 5 mi. from the fishing vessel with which they were working. Legislation was passed in 1980 allowing swordfish taken in the driftnet fishery to be landed and sold in California. Competition between the two fisheries became intense, and harpoon fishers lobbied for and received, in 1984, unrestricted use of aircraft (Squire and Muhlia-Melo[4]).

Many of the owners of harpoon and driftnet vessels obtained dual permits for taking both harpooned and net-caught swordfish during the same trip. These dual permittees set their nets at night and spent their days searching for swordfish to harpoon (Hanan et al., 1993).

Fishing effort for the harpoon fleet peaked in 1979 at nearly 13,000 fishing days, and then fell rapidly in 1980–83 as competition from the driftnet fishery increased. Days fished by the harpoon fleet have averaged about 1,000 per yr since 1989 (Coan et al., 1998).

The first sizable harpoon catch, landed in 1927, was 59 t. Landings fluctuated between 100 and 500 t throughout the 1930's and 1940's, then declined to 10–200 t, where it remained throughout the 1950's and 1960's. Catches averaged about 320 t in 1970–80 and peaked at 1,172 t in 1978 (Table 2). Between 1981 and 1992 catches of harpooned swordfish averaged 92 t, and they increased to 116 t in 1993 with a fleet of less than 40 vessels.

Measured swordfish from the harpoon fishery ranged between 64 and 217 cm alternate length[6] (AL) and averaged 85 kg dressed weight (Coan et al., 1998). Dressed weight of swordfish is estimated at 55% of whole body weight for tax purposes by the California Department of Fish and Game (CDFG, 1995, Chap. 371, p. 2).

Driftnet Fishery—The driftnet fishery off the coast of southern California began in 1978, primarily for pelagic sharks. Major changes have occurred in almost every aspect of this fishery including vessels, gear, fishing techniques, regulations, fishing areas, seasons, and targeted species. By 1980, Pacific broadbill swordfish was the target of the fishery. The early success of the fishery was attributed to the abundance of Pacific swordfish and pelagic sharks (thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus*) in coastal waters, popular consumer acceptance of both swordfish and sharks, and lower operating expenses than in the swordfish harpoon fishery, primarily due to greater fuel efficiency.

Table 2

Reported landings in metric tons by the California swordfish fisheries, 1970–93, by fishery type. DGN=drift gillnet.

Year	Harpoon	DGN	Other	Total
1970	199.3		229.3	428.6
1971	45.2		24.6	69.8
1972	86.4		34.2	120.6
1973	194.9		83.5	278.4
1974	193.7		101.1	294.8
1975	297.8		94.9	392.7
1976	22.4		15.7	38.1
1977	187.1		44.6	231.7
1978	1,171.7		9.2	1,180.9
1979	222.4		43.8	266.2
1980	389.7	110.2	42.9	542.8
1981	178.6	319.7	20.0	518.4
1982	107.6	629.9	29.4	766.9
1983	39.8	922.4	250.9	1,213.1
1984	73.0	1,488.8	430.4	1,992.2
1985	145.0	1,659.4	552.5	2,356.8
1986	162.6	1,169.1	412.4	1,744.2
1987	145.0	895.7	202.4	1,243.0
1988	123.7	759.2	243.6	1,126.5
1989	37.2	730.1	530.1	1,297.5
1990	34.7	717.4	96.8	849.0
1991	11.3	577.8	120.7	709.7
1992	44.2	898.9	110.8	1,053.9
1993	116.1	905.0	67.3	1,088.4

Continued market demand encouraged development, and fishers began exploring new areas farther offshore and as far north as Oregon and Washington, although few landings were made outside California. Both effort and catch expanded, reaching highs in 1984 and 1985.

Several fishery-related conflicts emerged in the early years of this fishery. Commercial swordfish harpoon fishers feared reduced catches of swordfish and lobbied against netting, as did recreational anglers, who were concerned about striped marlin. A related problem was the incidental bycatch of marine mammals (Hanan et al., 1993; Hanan and Scholl[7]; Diamond et al.[8]).

[6] Alternate length (AL) for swordfish is measured from the anterior margin of the cleithrum to the fork of the tail. The regression equation to convert to EFL (length post-orbit to the fork of the tail) in centimeters is EFL = 1.09(AL) + 10.13.

[7] Hanan, D. A., and J. P. Scholl. 1985. Shark drift gill net fishery observation program (May–June, 1983). *In* D. A. Hanan (ed.), California Department of Fish and Game coastal marine mammal study, annual report for the period July 1, 1982–June 30, 1983, p. 10–12. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. LJ-85-10C. Available from SWFCS, NMFS, P.O. Box 271, La Jolla, CA 92038-0271.

[8] Diamond, S. L., D. A. Hanan, and J. P. Scholl. 1986. Drift gill net observations for the 1984–85 fishing season. *In* D. A. Hanan (ed.), California Department of Fish and Game coastal marine mammal study, annual report for the period July 1, 1984–June 30, 1985, p. 9–26 and 45–46. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish Sci. Cent. Admin. Rep. LJ-86-25C. Available from SWFCS, NMFS, P.O. Box 271, La Jolla, CA 92038.

Observer programs were mandated by CDFG in 1980 to address the incidental take of marine mammals. These documented incidental catches during the early years of this fishery. The CDFG observed hauls from 443 net sets during 1980–85. There were no systematic observations during the 1986–89 fishing seasons. As mandated by the U.S. Marine Mammal Protection Act (MMPA), the National Marine Fisheries Service (NMFS) established an observer program in 1990. Data were recorded by observers onboard driftnet vessels during observed net pulls (Hanan et al., 1993; Lennert et al., 1994). Coverage in observed trips has been 10%–14% since 1990.

The incidental catch of marine mammals was considered relatively high in the developing years of the fishery. Time and area closures around the Channel Islands and along the mainland were successful in reducing that bycatch. Currently, the bycatch of marine mammals in this fishery is apparently low and not compromising any stocks (Hanan et al., 1993). Bycatch of other species does not appear to be a problem, except possibly for blue sharks, *Prionace glauca*, which average 10–15 per set. Blue sharks that are not marketable in the U.S. are discarded at sea (Julian and Beeson, 1998).

The first vessels in the driftnet fishery were converted from sea bass and halibut set-net vessels, most of which had wooden or fiberglass hulls. Many harpoon fishers also converted their vessels for driftnet fishing. Effort was concentrated around nearshore banks, canyons, and escarpments, and the offshore islands. As the success of this fishery continued, many of the smaller and older vessels were replaced with larger steel and aluminum vessels with increased speed and range. Fish hold space increased, and cooling capabilities evolved from ice to brine-spray and blast freezers. Several vessels now have large-capacity ice makers and limit the length of trips to less than about 3 wk to obtain the best market price.

As the driftnet fishery prospered, the number of vessels increased and competition for available swordfish became intense. Airplanes were often hired to locate areas of fish and to observe catches of other vessels (Hanan et al., 1993). In 1980, the California legislature made the driftnet fishery a limited-entry fishery, setting the maximum number of permits at 150, but allowing those fishers already involved to continue fishing. The actual number of permits issued reached a high of 300 in 1985. Driftnet vessels landing swordfish in California numbered 173 in 1991, 169 in 1992, and 162 in 1993. There were, however, rarely more than 100 active vessels fishing throughout any one season.

Drift nets are usually fished 4–10 m below the surface to allow small vessels to pass over without entangling them and to avoid catching non-target surface-swimming species. The nets are deployed at sundown and retrieved in the early morning after a soak of 8–12 hr. The length of the drift nets is limited to 1 n. mi. (1.8 km). The nets vary in depth between 50 and 100 meshes, and fish a vertical depth of 15–30 m. The size of each mesh is limited to a minimum of 40 cm (18 in) although 48 cm (22 in) is more common. The fishing season originally started on 1 April and ended on 31 January of the following year. To reduce fishing effort and to protect thresher sharks migrating northward along the California coast, the season start was pushed back to 15 August (Hanan et al., 1993).

Swordfish are removed from the net by first cutting off the bill and removing the fins. Swordfish (and sharks) are dressed (head removed, and eviscerated), unwanted parts discarded, and the carcasses washed with sea water and placed in the hold at just above freezing (0°–2°C) until the vessel returns to port. Most swordfish are sold in local markets (Herrick and Hanan, 1988; Cailliet et al., 1993; Hanan et al., 1993). Ex-vessel price for swordfish has ranged from about $4.40 to $8.50 per kg since 1990.

Hanan et al. (1993) summarized the available driftnet data from the California logbook system, landing receipts, and market sampling program for the 1981–90 fishing seasons. Logbooks collected from driftnet skippers under a mandatory logbook system (Huppert and Odemar, 1986) include catches (number of fish) by species, date, geographical position, gear and set data, and various other information, such as vessel registration and permit numbers. Fishing effort is designated in logbooks as number of sets, a set being one deployment and retrieval of the net.

Landing receipts are collected from commercial fish brokers each time a vessel delivers its catch to a California market. The receipts report landings in pounds, along with location and date of catch and type of fishing gear used. Problems associated with reporting of gear types resulted in the development of criteria to estimate actual landings of the driftnet fishery (Hanan et al., 1993). This convention was used in the determination of 1991–93 effort data in this report. Combined logbook and landing-receipt data provided improved estimates of effort (Julian and Beeson, 1998; Beeson and Hanan[9]) and are used here to estimate effort and catch for the 1991–93 fishing seasons.

Skipper compliance with logbook reporting regulations was estimated to be greater than 90% (Hanan et al., 1993; Miller et al.[10]). The effort data reported in

[9] Beeson, M., and D. Hanan. 1991. Effort estimates of California gill net fisheries: halibut–angel shark set net and shark–swordfish drift net for the 1990–91 fishing year (April 1, 1990–March 31, 1991). Final rep. NA90AA-HFC401 and NA86-ABD-00201 submitted to Natl. Mar. Fish. Serv., Southwest Region, Terminal Island, CA.

[10] Miller, D. J., M. J. Herder, and J. P. Scholl. 1983. California marine mammal–fishery interaction study, 1979–1981. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. LJ-83-13C, 233 p. Available from SWFSC, NMFS, 8604 La Jolla Shores Dr., La Jolla, CA 92038-0271.

Table 3
Reported and estimated swordfish catch and effort in the California driftnet fishery.

	Reported			Estimated	
	Effort (landings)	Effort (sets)	Catch (fish)	Effort (sets)	Catch (fish)
1981	2,388	6,710	3,871		
1982	3,282	10,452	12,925		
1983	3,021	11,160	21,878		
1984	2,912	9,688	25,725		
1985	2,860	9,238	23,062		
1986	2,411	11,243	23,454		
1987	2,258	8,382	12,690		
1988	1,572	6,047	11,289		
1989	1,376	6,028	11,511		
1990	1,545	4,392	9,367	4,504	15,211
1991	1,335	4,643	7,771	4,752	11,517
1992	1,119	3,898	10,460	4,504	16,360
1993	1,305	5,380	11,680	5,380	13,706

logbooks were therefore assumed accurate. The annual distribution of effort in the driftnet fishery shifted geographically from nearshore southern California to northward and offshore. Prior to 1982, fishing effort during spring was concentrated on sharks in the Southern California Bight, then shifted northward and offshore, targeting swordfish as the season progressed. During the height of the fishery, effort was concentrated around the offshore seamounts of central and northern California, and northward to Oregon and Washington. Most effort off Oregon and Washington was directed at thresher sharks, and few swordfish were caught. Because most of these vessels were based in California, their catches were likewise landed in California.

Total reported annual driftnet effort nearly doubled in the first 5 yr to a high of 11,243 sets in the 1986 fishing season, and subsequently declined to a low of 3,898 sets in the 1992 season. This effort increased in 1993 to 5,380 sets. The decline in effort resulted from increasing regulations and laws governing the fishery. Concern about possible overfishing of some pelagic sharks resulted in the fishing season being shortened in 1985 to 15 August–30 January, and in prohibition of sets within 75 n. mi. (139 km) of the coast and nearby islands to avoid the directed spring thresher shark fishery. Effort decreased almost 60% by 1993, corresponding to decreased total landings. Reported driftnet landings increased to a high of 3,500 in the 1983 season, then decreased steadily to a low of 1,500 in the 1990 season, and have averaged 1,223 during the 1991–93 seasons. Estimates of effort that incorporate NMFS observer data closely correspond to reported effort for the 1990–93 fishing seasons (Table 3).

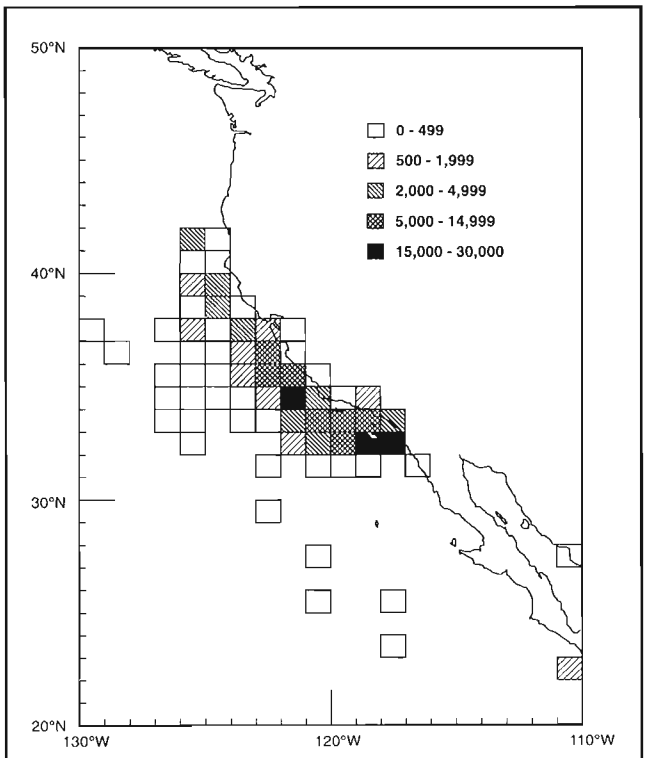

Figure 3
Geographical distribution of swordfish catch (number of fish) reported in CDFG logbooks for the California driftnet fishery, 1981–93 fishing seasons.

The driftnet fishery catches swordfish mostly in waters off San Diego to San Francisco, and within 500 km of shore. Catches of swordfish usually peak in October and November and taper off in December and January. During the 1981 and 1982 seasons, the areas of highest catch were in the Southern California Bight. Small numbers of swordfish were also caught between San Francisco and the California–Oregon border and within 200 km of shore. As effort expanded, good catches were taken offshore of Monterey and San Francisco. Few catches of swordfish occurred north of Oregon (Fig. 3).

Logbook data closely followed landings data, showing a peak catch of 25,725 swordfish in the 1984 season followed by a decrease to 7,771 swordfish in the 1991 season and then an increase to 11,680 in 1993 (Table 3). Mean annual landings were 898 t of swordfish for the 1981–93 seasons. Average landings for 1990–93 were 775 t, with improved landings in 1992 and 1993 (Table 2). Estimates that incorporate NMFS observer data indicate that swordfish catch may be under-reported from 15% in 1993 to 38% in 1990 (Julian and Beeson, 1998).

Swordfish dominated driftnet landings during 1983–93. Swordfish landings increased from 110 t in the

1980's to a high of 1,659 t in the 1985 season, and then declined to 578 t by 1991. Landings subsequently increased to 941 t and 897 t in 1992 and 1993, respectively. Shark landings are a significant product of this fishery, and actually dominated the catch prior to 1983. Shark landings have decreased steadily from a high of 1,000 t in 1981 to about 500 t in recent years (Hanan et al., 1993).

The CDFG market sampling program began in 1981 (Bedford, 1987). Market samplers made routine visits to primary California fish markets in San Diego, San Pedro, Santa Barbara, Ventura, Morro Bay, Monterey, Moss Landing, and the San Francisco Bay area. They recorded weight and AL for swordfish carcasses delivered for sale.

Swordfish sampled during the 1981–93 seasons (24,401 fish) measured 37–250 cm AL (mean 144 cm). Annual mean ranged from 128 to 152 cm (Fig. 4). Larger swordfish (150–160 cm AL) tended to be caught off northern California, north of 35°N, with smaller fish (130–145 cm AL) taken farther south (Hanan et al., 1993). At-sea measurements by NMFS observers between 1990 and 1993 indicate that fish caught north of 35°N averaged 8.6–17.5 cm AL longer than those caught south of 35°N. CDFG market samplers measured fewer swordfish after 1991, while measurements by NMFS observers increased (Fig. 4). A large proportion of swordfish measured by NMFS observers between 1990 and 1993 were caught north of 35°N. Coverage rates for NMFS observation averaged 5%–28% of reported trips.

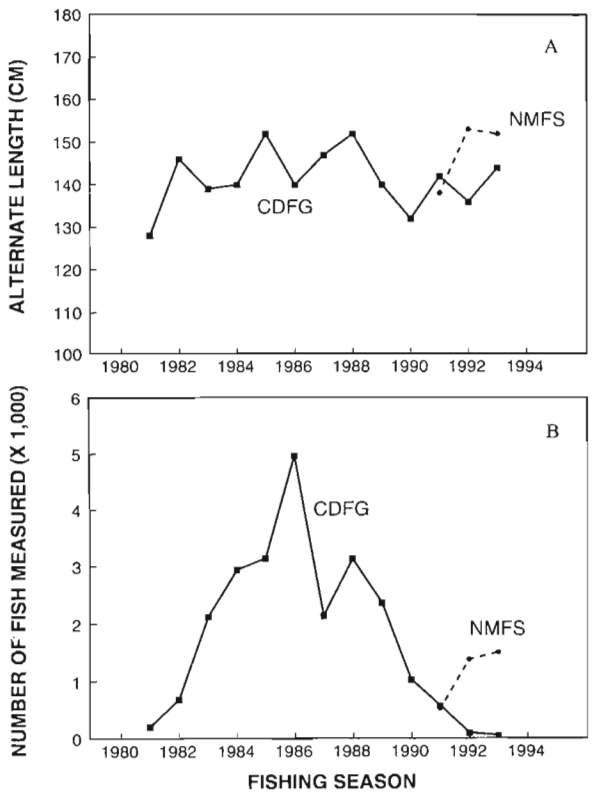

Figure 4
(A) Mean alternate length of swordfish and (B) smaller coverage in number of swordfish measured by CDFG market samplers and NMFS observers, 1981–93.

Longline Fishery—Traditionally there has been little longline effort for swordfish along the west coast of the U.S. and only moderate effort in waters around Hawaii. In California, only harpoon and driftnet fishing for swordfish were allowed within the EEZ. Catches of swordfish taken by high-seas longlining started arriving in southern California in 1991. Swordfish are rarely landed by any fishery in Oregon or Washington.

Longline vessels based in Hawaii have fished for a variety of tunas and billfish since the 1950's. In the beginning, this was primarily a near-shore, daytime tuna fishery. In 1987 the Hawaii-based fishery expanded with technology adapted from the successful longline swordfish fishery in the Atlantic Ocean, employing night fishing with chemically-activated light sticks attached near each baited hook. Expansion was encouraged by new export markets for fresh tuna in Japan and for swordfish in the U.S.

This fishery mostly operates west of 140°W, although some fishing occurs to the east. By 1990, annual swordfish landings in Hawaii had jumped from <40 t to >1,600 t (Boggs and Ito, 1993), greatly exceeding landings on the west coast of the U.S. In 1991, the longline catch of swordfish totaled 4,500 t and represented 68% of total landings in Hawaii. Landings exceeded 6,000 t in 1993 and were valued in excess of US$27 million (Ito et al., 1998; Skillman, 1998).

Hawaii-based longline vessels targeting only swordfish deployed 6–7 million hooks annually between 1991 and 1993. As the fishery expanded farther than 200 n. mi. (370 km) from Hawaii, higher catch rates were obtained to the north and east. Swordfish CPUE varied between 10 per 1,000 hooks in the most productive areas to less than 4 per 1,000 hooks nearer the Islands.

Longlining for swordfish in waters off California and Mexico began prior to 1950. This daytime effort met with little success, and was banned within California by the CFGC in 1971, when harpoons were designated the only legal commercial fishing gear for swordfish in California.

In the fall of 1993, four longliners arrived in Ventura, California, from the U.S. east-coast swordfish fishery and began longline operations for swordfish in the waters beyond 200 n. mi. They ranged north to 42°N and west to at least 135°W (Vojkovich and Barsky, 1998). These vessels had encouraging catches, and by the spring

of 1994 another 15–20 vessels had departed the swordfish fisheries in the Atlantic and Gulf of Mexico for the west coast. A few local vessels also converted to longline gear, and by late 1994 nearly 30 California-based longline vessels were fishing swordfish. They set from 300 to 1,300 hooks per set, depending on location and sea-surface conditions. Like the Hawaiian fishery, they set at night with light sticks and used large squid for bait.

In 1994 it was legal to land longline-caught swordfish in California only if taken outside the EEZ. Preliminary data indicate catch was 100 t for the last part of 1993 and nearly 543 t for 1994 (Barsky[11]). These fish ranged between 73 and 226 cm AL, and averaged 63 kg dressed weight (Vojkovich and Barsky, 1998).

In 1994 the CFGC approved a regulation to require all longline vessels operating beyond the EEZ from California ports to complete and submit logbooks of daily fishing activity to the CDFG.

Recreational Fishery—The California recreational fishery for swordfish developed along with that for striped marlin in southern California about the turn of the century. Because of the size and strength of swordfish, anglers still consider them one of the finest of all trophy game fish. Although highly prized by the recreational community, catch is insignificant compared to the commercial catch in the same areas (Bedford and Hagerman, 1983).

Swordfish in California was first listed as a game fish in 1931, and required a sport fishing license issued by the CDFG. Recreational anglers were allowed the use of hand-held harpoons as well as sport rod-and-reel fishing tackle until 1971, when the CFGC restricted harpooning to the commercial fishery.

The rod-and-reel season for swordfish can begin as early as May and continue through December, although most fish are taken from July to September. Fishing occurs from about Santa Barbara south at least to the U.S.–Mexico border, and out to about 100 km. Most fishing is done during the day from private boats targeting striped marlin. Swordfish is a minor component of the sport catch of billfish in California, equalling only 1% or less of total marlin catch. Swordfish commonly fin or bask at or near the water's surface in the area between the Channel Islands and the coast of southern California. When anglers sight swordfish, they will offer them live bait or artificial lures, although swordfish are usually not receptive to bait presented while basking.

Catch records of swordfish are kept by the various sportfishing clubs in California. The Balboa Angling Club, San Diego Marlin Club, and the Tuna Club (Avalon) are three of the major clubs where anglers have their swordfish catches recorded and weighed. Catches have averaged 3–4 fish per yr, except for 1969–80, when they averaged 30.5 fish, and peaked in 1978 with 127 swordfish reported (Fig. 5). The increased catches in 1969–80 corresponded to a similar increase in landings from California's harpoon fishery, and may have reflected a generally higher abundance of swordfish in southern California waters during that time. Higher abundances were also reported for the northern anchovy, *Engraulis mordax*, and bluefin tuna, *Thunnus thynnus*, during the same period (Squire, 1993). There were four El Niño episodes during this time, and it is possible that increased catches occur in the years following El Niño events (Coan et al., 1998).

The whole weight of recreationally-caught swordfish is less than the weight of fish taken in the harpoon fishery. Of 45 swordfish weighed at major sport fishing clubs between 1981 and 1992, the average whole body weight was 107.5 kg (range 58.5–177 kg).

The only estimate of recreational fishing effort for swordfish is from the NMFS's Billfish Angler Survey (Squire and Muhlia-Melo[4]; SWFSC[12,13]). The survey requests individual angler data on fishing effort and catch of all billfish and swordfish in the Pacific Ocean. The survey cannot, however, identify effort directed specifically at swordfish. Effort is primarily directed at striped

[11] Barsky, K. 1994. Marine Resources Div., CDFG, 530 E. Montecito St., Ste. 104, Santa Barbara, CA 93103. Personal commun.

[12] Southwest Fisheries Science Center (SWFSC). 1994. 1993 Billfish Newsletter. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., SWFSC, 9 p. Available from SWFSC, NMFS, 8604 La Jolla Shores Dr., La Jolla, CA 92083.

[13] Southwest Fisheries Science Center (SWFSC). 1995. 1994 Billfish Newsletter. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., SWFSC, 12 p. Available from SWFSC, NMFS, 8604 La Jolla Shores Dr., La Jolla, CA 92083.

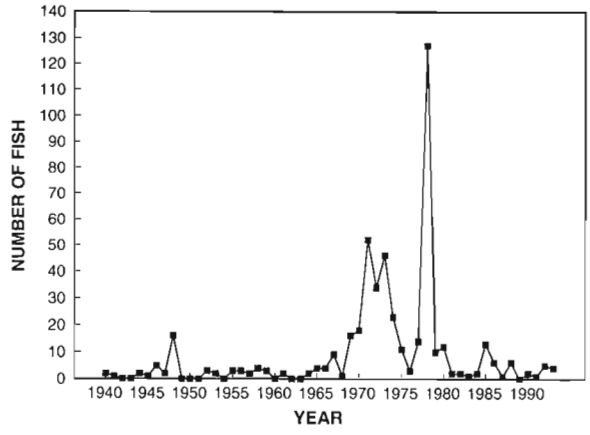

Figure 5
Recreational swordfish catch by southern California anglers, as reported by major sportfishing clubs, 1940–93.

Table 4
Reported swordfish effort and catch from the Japanese longline fishery within the Mexican EEZ, 1961–85.

Year	Hooks	Catch (number of fish)
1961	74,700	36
1962	429,198	62
1963	502,124	76
1964	10,502,535	20,624
1965	12,797,567	12,235
1966	8,524,654	10,722
1967	7,169,512	6,363
1968	14,393,695	14,770
1969	7,679,938	10,667
1970	7,754,116	14,490
1971	7,269,733	12,092
1972	8,453,797	16,575
1973	8,883,135	12,593
1974	8,365,245	6,214
1975	4,316,486	5,749
1976	7,405,134	11,441
1977	1,844,845	2,997
1978	287,515	115
1979	699,044	233
1980	2,676,935	1,790
1981	1,569,164	3,657
1982	4,601,736	9,275
1983	3,538,430	4,537
1984	1,899,067	1,994
1985	62,984	7

marlin in southern California, and is directed at all billfishes in Mexico. Effort estimates (catch per angler day) for swordfish are therefore very low. Anglers fishing in southern California and northern Mexico reported swordfish catches of 0–0.002 fish per day in 1990–93.

Mexico

Longline Fishery—In 1967, the Mexican government increased its Exclusive Fishing Zone from 9 to 12 n. mi. (from 17 to 22 km). Prior to this, foreign commercial fishing for swordfish, billfish, and tunas was essentially unrestricted beyond 17 km from the coast. Between 1967 and 1976, Mexico issued permits to Japan's longline fleet to fish for swordfish, billfish, and tunas off northern and central Mexico, 22 km and further from the coast. Fishing effort averaged 8.2 million hooks and catch averaged over 11,000 swordfish per yr during that 10-yr period (Table 4).

Mexico established its EEZ in 1976 and withheld all longline permits for swordfish, billfish, and tuna between 1977 and 1980, although some fishing continued. Between 1980 and 1984, only vessels registered in Mexico and joint-venture longline vessels fished coastal waters. Fishing effort increased within Mexico's EEZ, averaging 2.4 million hooks in 1981–83. In 1983, a 50-n. mi. (93-km) sportfishing-only zone was established along the coast of Mexico to protect billfish, swordfish, and other popular species and to manage them for the recreation and tourist industries. Longline permits were not issued from mid-1984 until late 1985, and effort decreased (Table 4). Longline permits were again issued in 1987 under stricter regulations, allowing only about 15 fishing vessels within the EEZ. Operating under new permits, the Japanese/Mexican joint-venture fleet increased fishing effort to 2.3 million hooks between 1986 and 1988 (Squire and Muhlia-Melo[4]). All longline permits for swordfish, billfish, and tunas within Mexico's EEZ were repealed in 1990. Longline fishing operations have not been conducted since.

Table 5
Reported swordfish landings and catch rates for fishing vessels landing swordfish in the driftnet fishery of Mexico, 1985–93.

Year	Landings (metric tons)	Mean catch (kg/day)	Vessels
1986	286		2
1987	471		3
1988	385	88.8	11
1989	407	250.9	14
1990	661	287.6	21
1991	831	215.5	28
1992	552	115.6	29
1993	372	105.7	31

Most of the swordfish and marlin catches from the joint-venture vessels were shipped to Japan and the U.S., while other catches were canned or used in domestic markets. The most productive area was 20°–27°N, east of 115°W.

Longline catches from Mexico's joint-venture fisheries peaked in 1982 with 9,275 swordfish (after a low of 115 in 1978). Catches of swordfish subsequently increased to at least 5,000 through 1988, before being terminated in 1990 (Squire and Muhlia-Melo[4]). CPUE fell dramatically in 1983 and 1984, possibly due to the prohibition of fishing within the 50-n. mi. sportfishing-only zone.

Driftnet Fishery—In 1986 a small fleet of driftnet vessels appeared in northern Baja California. This fishery was stimulated both by the reduction in longline permits and by the local abundance of swordfish and other marketable bycatch products, including several species of large pelagic sharks. The number of vessels had grown to 20 by 1990, and to 31 by 1993 (Table 5). These vessels operate out of Ensenada and are similar in de-

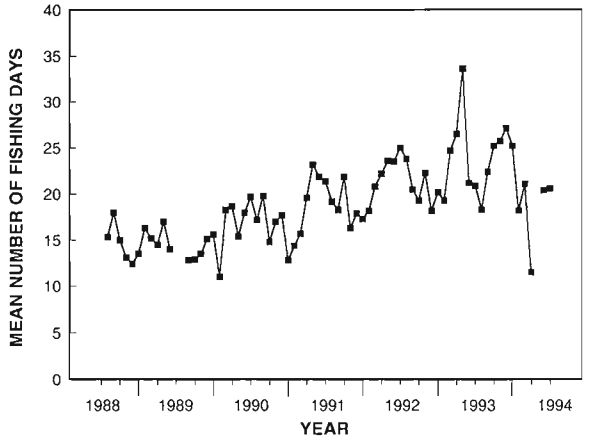

Figure 6
Total reported fishing effort for the driftnet fishery in Mexico, 1988–94.

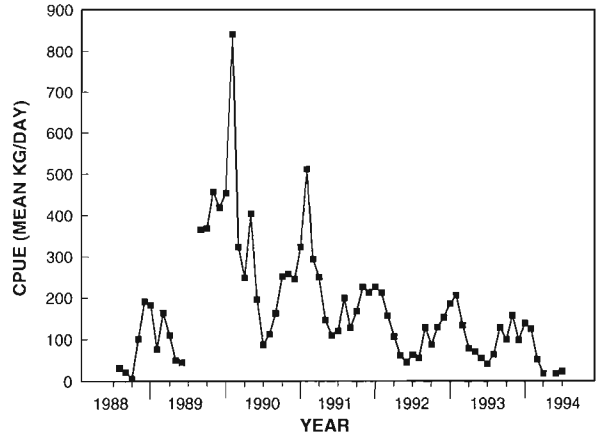

Figure 7
CPUE by month for the driftnet fishery in Mexico, 1988–94. The break in 1989 represents missing data.

sign and size (18–25 m) to the U.S. driftnet vessels operating just 100 km to the north. The nets are similar in design to the U.S. drift nets, although they may be up to 4.5 km long, whereas U.S. nets are limited to 1 n. mi. (1.8 km). Operational procedures are virtually identical to those in the U.S.

The fishing season usually begins in the waters off Ensenada in the fall and moves south to central Baja California between 25° and 27°N during December and January.

Swordfish landings from Mexican driftnet vessels were first reported in 1986. They increased steadily to a high of 831 t in 1991, and averaged 535 t in 1988–93 (Table 5). The low catch in 1993 forced some fishing vessels to look for alternate resources including coastal and pelagic sharks in the Gulf of California. The number of vessels driftnetting for swordfish in the first half of 1994 fell to 16.

Total driftnet fishing effort for swordfish increased from about 15 days per mo in 1989 to 20–30+ days per mo in 1993 (Fig. 6). CPUE increased from about 100 kg/day in 1989 to over 800 kg/day by the end of 1990, but has generally declined through 1994 (Fig. 7). The best catches occur in the winter months of October–February (Fig. 8)

A coperative program was established by commercial driftnet fishermen operating out of Ensenada and scientists at Centro de Investigación Cientifica y de Educación (CICESE), Ensenada, Mexico in 1992. Crew members and scientists measured 1,412 swordfish during the 1992 and 1993 seasons (Sosa-Nishizaki et al., 1993). Most fish were taken from the southern Baja California peninsula between 25° and 28°N. Mean length (EFL) was 164 cm and fish length ranged from 60 to

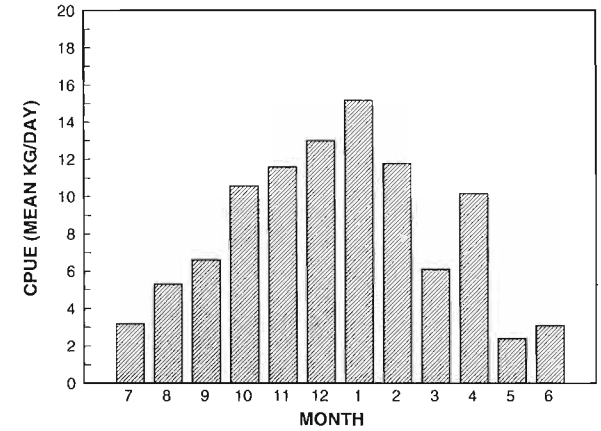

Figure 8
CPUE by month for the driftnet fishery in Mexico, 1988–94.

245 cm. Larger fish were reported taken during March and October, mostly in waters off Baja California Sur (Sosa-Nishizaki et al., 1993).

Recreational Fishery—Recreational fishing for marlin around the Baja California peninsula is extremely popular world-wide. Angling for swordfish in these waters is opportunistic and incidental to the large marlin catch. Although the recreational catch of swordfish is unreported, the greatest catches of swordfish appear to be off Guaymas and Mazatlan. Swordfish, like marlin, are included under the existing regulations which allow a maximum catch of one billfish per day.

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Papers from the International Symposium on Pacific Swordfish, Ensenada, Mexico, 11–14 December 1994

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