The California Harpoon Fishery for Swordfish, *Xiphias gladius*

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ABSTRACT

We review and analyze fishery data collected from the California harpoon fishery for swordfish, which began in the early 1900's. Landings data for 1969–93, logbook data for 1974–93, and size composition data for swordfish landed in 1981–93 are analyzed. Swordfish landings peaked in 1978 (1,172,000 kg) and decreased to a record low (11,000 kg) in 1991. Landings were less than 200,000 kg in most years. Swordfish landed averaged 149 cm in length (cleithrum to fork) or 85 kg dressed weight in 1981–93.

The harpoon fishing season, typically May–December, usually concentrates in the Southern California Bight off San Diego early in the season and then shifts as far north as Oregon. Swordfish are usually sighted while basking at the surface in water of 12°–26°C. Fishing effort peaked in 1979 (12,700 days fished), decreased in 1991 (700 days), and rebounded slightly in 1993. Catch per day fished fluctuated between 0.14 and 0.93 during 1974–93, and peaked in 1974, 1978, 1985, and 1993, usually 1–2 yr after an El Niño event.

Introduction

In North America, harpoon fishing dates to the use of harpoons by Indians to catch swordfish, *Xiphias gladius,* off the California coast almost 3,000 yr ago (Kronman, 1988). Their vessels were 6.1-m (20-ft) driftwood canoes, and their gear consisted of a 1.8-m (6-ft) foreshaft tipped with a carved wooden harpoon which bore a stone point on one end and a curved barb of deer bone behind (Kronman, 1988).

California's modern-day harpoon fishery for swordfish developed in the early 1900's. The fishery was modeled after the East Coast harpoon fishery, which began almost 70 yr earlier. Vessels were small sail-powered sloops or schooners. The harpoon gear was 4.6–5.5 m (15–18 ft) in length, fashioned from hickory and tipped—with a bronze dart (Kronman, 1988). The bronze dart was backed by a tapered socket and a 0.6-m (2-ft) metal shank attached to the end of a wooden handle. The design of harpoon gear has remained unchanged except for minor modifications in the metal used in the shank.

Harpoon fishing continued as the only commercial fishery that harvested swordfish within 200 mi of the California coast until 1980, when drift gill net fishing started in waters off California. The competition from the more-efficient drift gill nets proved too great for the harpoon fishery, and many vessels converted to drift gill net gear or obtained permits to use both types of gear. Today, harpoon and drift gill net are the only commercial fishing gears operating on swordfish in the area, and only a handful of vessels continue to participate in the harpoon fishery.

This paper reviews and analyzes data collected from the California harpoon fishery. Landings data are reviewed for 1969–93, logbook data for 1974–93, and size composition of swordfish catches for 1981–93.

Data and Methods

Landings, logbook, and size composition data for California's harpoon fishery have historically been collected by California Department of Fish and Game (CDFG) biologists at landing ports as vessels returned from fishing trips. Locations of landings, logbook catches, and measured fish were recorded by CDFG blocks, which are usually 10-minute quadrangles. These were converted to latitude and longitude and summed to 1-degree quadrangles for the purposes of this report.

Landings

Swordfish landings data have been collected since the early 1900's (Bedford and Hagerman, 1983). This study includes landings data for 1969–93, to match the existing logbook and size-composition data sets. This period includes all of the 1970's, a period of relatively high catches and increased regulations that significantly impacted the harpoon fishery.

The landings data were compiled from CDFG landing receipts. Commercial fish buyers are required to fill out a landing receipt for each landing purchased in California (Hanan et al., 1993) and submit these receipts to CDFG. Therefore, coverage is very close to 100% for all landings sold commercially. Landings kept for private consumption are not recorded in the landing totals. A small number of swordfish landings may also escape the landing receipt system. The landing receipts contain information on species landed, weight landed, price paid, and fishing gear used. Other information, such as area of catch, may be included but in many circumstances is left blank.

Data for 1969–79 include landings reported as catches by harpoon, spear, and unknown fishing gear (Table 1). Data from 1980 to 1993 include only those landings specifically designated as caught with harpoon or spear gear. Landings with unknown fishing gear were included before 1980 because harpoon was the prevalent gear used during that time. After 1979, drift gill net gear accounted for a significant number of swordfish landings, and unknown gear could no longer be assumed to be harpoon.

Landings other than sharks were not included as harpoon incidental catches (Table 1). Albacore, *Thunnus alalunga*; yellowfin tuna, *Thunnus albacares*; mackerel, Scombridae; rockfishes, *Sebastes* spp.; and other species were often recorded as harpoon landings. These entries were considered errors in gear-type coding; the catches were most likely made with troll fishing gear while searching for swordfish.

Logbooks

CDFG implemented a mandatory permit and logbook system in 1974 (Bedford and Hagerman, 1983). The original logbook provided space for recording information about a single fishing day on each line. Requested information included name of skipper and boat; swordfish permit number and CDFG boat number; date (month and day) of each entry; CDFG block number; whether an aircraft was used; whether the fish was sighted underwater, finning, or jumping; whether the fish was harpooned; whether it was landed; and estimated dressed weight in pounds. Space was also included for any other pertinent remarks.

The original logbook was later modified so that each page represented a single day of fishing (Fig. 1). Fields were added to record starting and ending times of fishing, time of each entry on the form, sea-surface temperature, whether sighted fish were pursued, other CDFG blocks searched, and weather conditions, sea state, and sea color.

Size Composition

Landings of swordfish have been sampled for length since 1981 under a program originally designed to monitor gill net landings (Odemar[1]). Samples were taken by CDFG biologists as fish were unloaded at various fish markets throughout the state (Hanan et al., 1993). No formal constraints on sample size were established, and samplers selected as many fish and vessels to sample as time permitted. Since swordfish were always landed gutted, headed, and with the dorsal fins and the posterior portions of the tail fins removed, samplers recorded the cleithrum length (CL), the straight length from the anterior margin of the cleithrum to the fork of the tail. Lengths were recorded to the nearest millimeter. The samplers, whenever possible, recorded information on the weight in pounds of each fish measured, date measured, boat name and number, port and market of

[1] Odemar, M. 1982. Inventory of California marine fisheries port sampling activities. Calif. Dep. Fish Game internal report, 157 p. CDFG, 1416 Ninth St., Sacrament, CA 95814.

Table 1
California harpoon fishery landings (kg). Landings for 1969 to 1979 include landings reported as unknown fishing gear. Unid. indicates sharks not identified to species.

		Sharks						
Year	Swordfish	Thresher	Mako	Blue	Hammerhead	Soupfin	White	Unid.
1969	459,748	0	0	0	0	0	0	5,230
1970	421,933	0	53	0	0	0	0	0
1971	68,215	0	0	0	0	0	0	0
1972	118,223	0	0	0	0	0	0	0
1973	274,779	0	0	0	0	0	0	382
1974	279,649	0	0	0	0	0	0	1,974
1975	383,658	44	0	0	0	0	0	124
1976	28,936	0	17	0	0	0	0	83
1977	219,055	1,024	192	0	0	0	0	2,839
1978	1,171,655	951	565	0	27	0	0	2,275
1979	226,625	11,857	311	348	0	0	0	4,936
1980	389,722	2,915	1,486	0	0	0	0	4,336
1981	178,660	0	157	15	69	161	0	1,184
1982	107,580	122	621	0	0	0	0	297
1983	39,796	0	82	0	93	0	0	187
1984	72,992	22	269	0	0	28	0	238
1985	145,154	0	203	0	55	0	0	0
1986	162,634	55	549	0	43	289	61	69
1987	144,954	0	1,506	0	0	0	227	39,009
1988	123,757	12	1,121	0	61	0	0	22
1989	37,197	0	404	0	0	0	0	0
1990	34,726	33	892	0	70	0	0	0
1991	11,362	29	540	0	0	0	0	0
1992	44,285	30	1,991	0	0	0	0	0
1993	116,058	0	403	0	0	0	0	0

landing, CDFG block number, and landing weights (Childers and Halko[2]). No sampling bias by vessel, market, area, or month was detected.

Vessels, Gear, and Fishing Strategies

Vessels that participate in the harpoon fishery are quite variable but very distinctive. They are usually 6–26 m (20–87 ft) in length (Holt[3]), with hold capacities up to 100 metric tons (110 short tons) and main engines of 25–1,300 horsepower. The vessels are equipped with high masts of 5–12 m (18–40 ft; Kronman, 1988) and a plank extending 6–9 m (20–30 ft) beyond the bow. The crow's nest at the top of the mast is usually equipped with controls to steer the vessel during the pursuit of swordfish. The planks, while originally made of wood, are now aluminum or steel conduit and can be raised during travel and lowered when in pursuit. At the end of the plank is a pulpit consisting of a metal stand and railing against which the harpooner can lean.

Harpoon fishing gear has changed little since the early 1900's. Current harpoon gear consists of a handle made of metal or wood and approximately 3–5 m long (10–16 ft), attached to a metal shank approximately 0.6 m long (2 ft), and tipped with a 10-cm (4-inch) bronze or iron dart. One end of a mainline, 15–46 m (50–150 ft) in length, is attached to the middle of the dart, and floats and a marker flag are attached to the other end.

Harpoon vessel fishing trips usually are from 3 to 10 days in length and vary according to fishing success, fish carrying capacity, and preservation capability. Fishing starts with the search. Fish are sighted either finning or jumping at the surface or swimming just beneath the surface. Sightings are made by the vessel's crew using binoculars or by assisting aircraft. Since sightings are of fish on or near the surface, good weather conditions

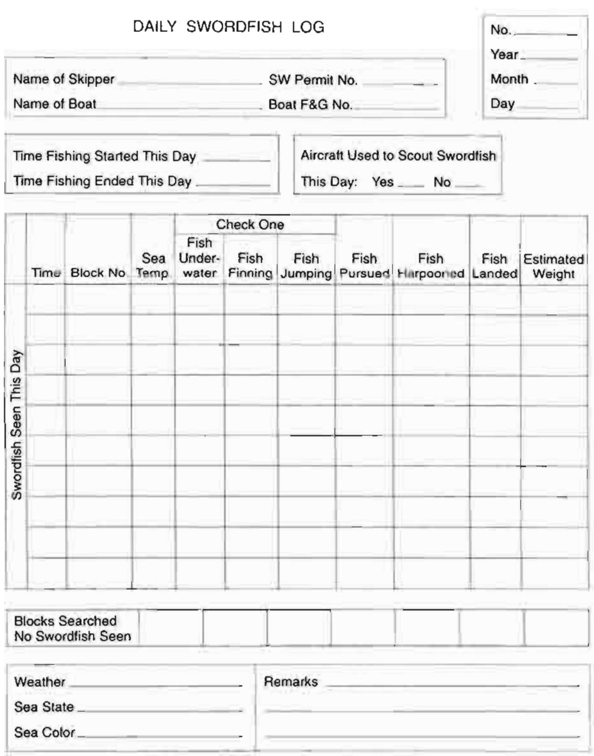
[2] Childers, J., and L. Halko. 1994. Length-frequency database description: California Department of Fish and Game gill net market samples. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Center Admin. Rep. LJ-94-01, 46 p.

[3] Holt, S. 1978. Economic analysis of the swordfish harpoon fishery. Pacific billfish management plan, 47 p. Prepared under contract no. 78-20 for PFMC. Available from Pac. Fish. Manage. Counc., 45 S.E. 82nd Dr., Ste. 100, Gladstone, OR 97027-2522.

and calm seas favor fishing. Swordfish are found in sea-surface temperatures of 12°–26°C (64°–72°F), and vessels usually start their search in areas where temperatures are within this range.

After a fish is sighted, the vessel's plank is maneuvered over the fish and the striker harpoons the fish. The handle is pulled free from the dart, the mainline, marker flag, and floats are thrown overboard, and the fish is left to tire itself. The vessel is then able to pursue other fish. After the fish has tired (approximately 2 hr) the vessel returns to retrieve it. The fish is dressed (headed, gutted, and fins removed) and stored in ice for transport to shore. During the early years of the harpoon fishery, the livers were sometimes kept for sale because of their vitamin A and D content (CDFG, 1949); this practice is no longer followed as other sources of vitamin A and D have been developed.

The use of airplanes to assist in the sighting and harpooning of swordfish started in the early 1970's. Airplanes both spot the fish and guide the vessels to the fish. Because conflicts arose between commercial fishermen who used airplanes and sportsmen and other commercial fishermen who did not use airplanes, a series of regulations was enacted to limit their use.


DAILY SWORDFISH LOG

No. ____ Year ____ Month ____ Day ____

Name of Skipper ____ SW Permit No. ____

Name of Boat ____ Boat F&G No. ____

Time Fishing Started This Day ____

Time Fishing Ended This Day ____

Aircraft Used to Scout Swordfish This Day: Yes ____ No ____

	Time	Block No.	Sea Temp.	Check One: Fish Under-water	Check One: Fish Finning	Check One: Fish Jumping	Fish Pursued	Fish Harpooned	Fish Landed	Estimated Weight
Swordfish Seen This Day										

Blocks Searched No Swordfish Seen

Weather ____

Sea State ____

Sea Color ____

Remarks ____

Figure 1
A page from the current California harpoon fishery logbook.

Modern-day harpoon vessels have added new technology and fishing strategies as they became available, to increase fishing efficiency. Some vessels employ state-of-the-art navigation equipment, sea-surface-temperature recorders, and sounders to help locate fish. Some have also been known to use satellite imagery to identify fishing areas. Harpoon vessel operators have also obtained multiple permits that allow them to fish both gill net and harpoon fishing gears, and have also been known to troll jigs between sightings to increase catches of swordfish and other commercial species of fish.

Regulations

Over time, several regulations have been imposed that directly or indirectly affect the California harpoon fishery (California Fish and Game Code and Title 14 Regulations; Squire and Muhlia-Melo[4]; Sakagawa[5]). The major regulations are:

1935 Swordfish may be taken with hook-and-line and harpoon gear.

1971 U.S. Food and Drug Administration (FDA) begins to enforce guideline of 0.5 ppm of mercury in swordfish.

1973 A permit is required to take swordfish commercially. California Legislature gives regulative authority over the swordfish fishery to the State Fish and Game Commission (F&GC).

1974 F&GC adopts commercial swordfish regulations including specific permit qualifications, a logbook requirement, and the notification that airplanes cannot be used to assist a vessel in capturing swordfish after 28 June 1976.

1976 F&GC allows airplane use in locating swordfish, but not within an 8-km (5-mi) radius of a vessel operated by a swordfish permittee.

1977 F&GC extends the airplane operating radius to beyond 16 km (10 mi) of a vessel operated by a swordfish permittee.

1978 FDA changes limit of total mercury in swordfish to 1.0 ppm.

[4] Squire, J. L., and A. F. Muhlia-Melo. 1993. A review of striped marlin (*Tetrapturus audax*), swordfish (*Xiphias gladius*), and sailfish (*Istiophorus platypterus*) 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 Fisheries Science Center Admin. Rep. LJ-93-06, 44 p. (in Engl. and Span.). SWFSC, NMFS, NOAA, P.O. Box 271, La Jolla, CA 92038-0271.

[5] Sakagawa, G. T. 1994. Supply of swordfish, *Xiphias gladius*, for the United States consumer market. International Symposium on Pacific Swordfish, 11–14 December 1994, Ensenada, Mexico. Available from G. T. Sakagawa, Southwest Fisheries Science Center, NMFS, NOAA, P.O. Box 271, La Jolla, CA 92038-0271.

1980 F&GC prohibits swordfish harpoon permittees from possessing a gill net on board except for set gill nets with mesh sizes of 20 cm (8") or less if they declare on their swordfish permit that they intend to use such gear.

1984 F&GC allows unlimited airplane use to directly assist a permittee in the taking of any species of fish while operating under a swordfish harpoon permit. FDA changes its regulation to limit methyl mercury content in swordfish to 1.0 ppm.

1985 F&GC allows swordfish harpoon permittees to have set gill nets of any mesh size aboard if they declare on their swordfish harpoon permit application that they intend to use such gear.

1987 F&GC allows swordfish harpoon permittees to have drift gill nets aboard in addition to set gill nets, if they also possess a valid permit to use drift gill nets.

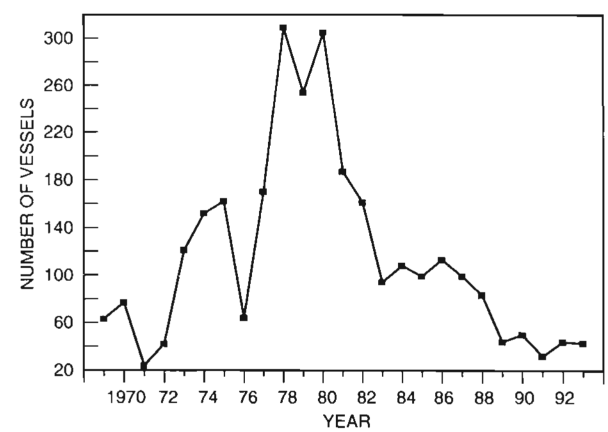


Figure 2
Number of California harpoon fishing vessels landing swordfish during 1969–93.

Numbers of Vessels and Landings

The number of California harpoon vessels landing swordfish increased from 63 in 1969, to 309 in 1978 (Fig. 2), decreased to 32 in 1991, and then increased slightly to 43 in 1993. A sharp decline in 1971 in the number of vessels participating in the fishery was probably due to the collapse of the swordfish market in that year as a result of the mercury scare—publicity about the high levels of mercury in swordfish and health problems from ingestion of mercury, which discouraged consumers from buying swordfish—and the FDA's subsequent strict enforcement of the 0.5-ppm mercury limit. The decline in 1976 was probably due to the ban on aircraft use, and the general decline since 1980 has been primarily due to increased competition from drift gill net operations.

The number of vessels landing swordfish is indicative of the harpoon fishery fleet size. CPUE during this time was relatively stable at 0.1–0.9 fish per day, and the number of harpoon permits showed a trend similar to that in number of vessels landing swordfish: 164 permits in 1984, decreasing to 43 in 1993.

Harpoon fishery landings in California have been recorded since 1918 (CDFG, 1949). Records for 1918–37 combined striped marlin, *Tetrapturus audax*, and swordfish landings, since no requirements were in place to separate the two species. Commercial landings of striped marlin in California have been prohibited since the late 1930's.

Records for 1938–68 contained swordfish landings only and are assumed to be from harpoon gear, although small amounts of catch from other fishing gears are probably included. Landings averaged approximately 330,000 kg in 1938–48 and declined to approximately 110,000 kg in 1949–68. Landings increased dramatically in 1968 to 460,000 kg, and reached a record high of 1,172,000 kg in 1978 (Table 1). After 1978, landings decreased to a record low of 11,000 kg in 1991 and rebounded slightly to 116,000 kg in 1993. In general, landings seem to be lower during El Niño events (1972–73, 1976–77, 1982–83, 1991–92) and peak 1–2 yr thereafter. The same regulations that affected vessel participation in the harpoon fishery, mentioned above, also affected annual landings.

The most prevalent incidental landings of sharks identified to species were thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus* (Table 1). The most thresher sharks landed in a year was 12,000 kg in 1979; the most shortfin mako sharks landed was approximately 1,500 kg in 1980 and 1987. Other sharks landed by harpoon gear include blue, *Prionace glauca*; hammerhead, *Sphyrna* spp.; soupfin, *Galeorhinus zyopterus*; and white, *Carcharodon carcharias*. The most reported landings of unidentified sharks occurred in 1987 when 39,000 kg were landed.

Logbook Records

Coverage Rates

Annual logbook coverage rates were calculated as the total annual weight of swordfish reported in logbooks, divided by yearly swordfish landing weights as given in Table 1 (Fig. 3). Total annual swordfish weight reported in logbooks was calculated as the total number of fish reported in logbooks, multiplied by the average weight (85 kg) of fish recorded in market sampling of harpoon catches during 1981–93. Annual average

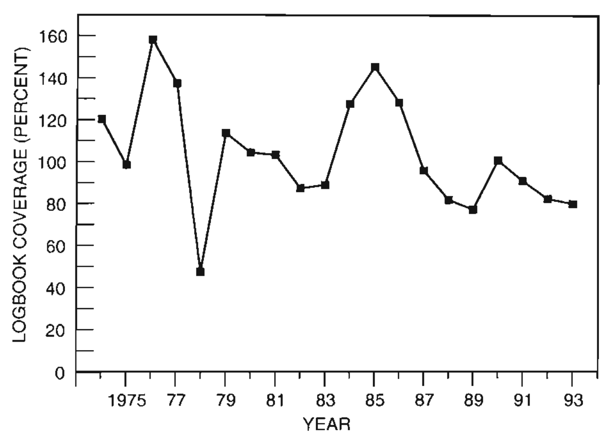


Figure 3
California harpoon fishery logbook coverage rates (logbook catch in weight divided by landed weight) for 1974–93.

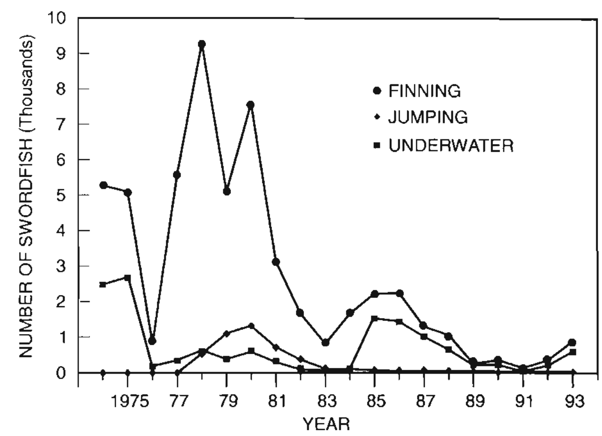


Figure 4
Number of swordfish sighted at the sea surface finning, swimming, jumping, or swimming just under the surface (underwater) by California harpoon fishery vessels and reported in logbooks for 1974–93.

weights were not used because of the low sample sizes in some years. Logbook-estimated weights were not used because they were missing for as many as 100 landings per yr, combined processed and total weights, which were difficult to separate, and produced estimates significantly higher than those produced by using average weights from port sampling.

Coverage rates were greater than 120% in 1976, 1977, and 1984–86; between 80% and 120% in 1979–83 and 1987–92; and less than 50% in 1978 (Fig. 3). Since the logbook program was mandatory during this time, vessel coverage rates should have been 100%. Coverage rates not equal to 100% can be attributed to several factors: 1) use of an average weight to convert numbers of fish to catch in weight of fish may overestimate or underestimate actual logbook catches; 2) landings underestimated due to some being classified as unknown gear; 3) fish kept for personal consumption; and 4) confusion at markets between gill net landings and harpoon landings, especially when a permittee had both drift gill net and harpoon permits. The extremely low coverage rate in 1978 is difficult to explain and may be due to a deliberate misreporting of drift gill net catches as harpoon landings, in an effort to circumvent the prohibition of drift gill net swordfish landings (Bedford, 1987).

Data on Sightings

Swordfish initially sighted by harpoon fishery vessels or spotter airplanes were reported in logbooks as either finning at the surface, swimming just below the surface, or jumping. An average of 74% of fish sighted during 1974–93 were finning at the surface (Fig. 4). The next most prevalent type of sighting was of fish just under the surface (19%), except in 1979–82, when jumping fish were sighted more often (6%). Fish were sighted finning in especially dominant numbers compared to fish seen underwater and jumping during 1976–84, when spotter airplanes were banned. Before 1976 and in 1984–88, the numbers of finning and underwater sightings were comparable, and in 1989–92 were virtually the same, probably due to the increased ability to spot fish just under the surface from airplanes.

Harpoon vessel captains recorded sightings of swordfish in three types of water color, blue/green, blue, and green. Swordfish were found most often in blue/green water in 1974–79, and in blue water in 1980–87 (Fig. 5). During 1988–93, swordfish were found with the same frequency in water of all three colors. Blue/green water is usually associated with high primary production; the records for this color water seem to parallel increased swordfish catches and abundance levels of other species of fish in the Southern California Bight during 1974–79 (Squire, 1993).

Swordfish caught in the California harpoon fishery were found in surface water temperatures of 12°–26°C (54°–79°F; Fig. 6). Over 50% of the fish were found in temperatures of 19°–22°C (66°–71°F). In El Niño years, the range of water temperatures in which the majority of swordfish are sighted narrows and favors warmer temperatures of 20°–22°C (68°–71°F). This was very evident during the strong El Niño of 1982–83 (Fig. 6). In non-El Niño years, swordfish are sighted in a broader range of water temperatures, and more are caught in colder water. This is consistent with oceanographic conditions in the Southern California Bight, where the California Current extends farther south during non-El Niño years (Miller[6]). This extension of the California Current would result in more mixing of colder water in the area and, therefore, more days when swordfish would be sighted in cooler water.

Success and Effort

When a swordfish is pursued by a harpoon fishing vessel, the fish often escapes being harpooned or, if harpooned, may never be landed. In order to measure the success of each swordfish encounter, vessel captains recorded, for each fish, whether it was pursued, subsequently harpooned, and landed. Logbook records show that when swordfish were pursued, on average 74% were actually harpooned (Fig. 7). Of those that were harpooned, 91% were actually landed. The best ratios of pursuit to landing success occurred in 1986 and 1989–92 when more than 75% of pursued fish were actually landed.

Annual harpoon fishing effort, as reported in logbooks, increased from 3,500 days fished in 1976 to a record high of almost 13,000 days in 1979, then declined to a low of approximately 700 days in 1991 (Fig. 8). Airplane-assisted fishing effort accounted for less than 30% of the total effort during 1974–79, and dropped to 0% in 1980 and 1983. Between 1984 and 1986, airplane-assisted effort increased rapidly to a peak of over 1,600 days fished (39%) in 1986, probably in response to the restoration of unlimited airplane use in 1984. The numbers of assisted and unassisted days fished since 1989 were approximately the same.

Annually, harpoon fishing effort usually peaked in August, with high levels of effort extending into the last quarter of the year (Fig. 9). In El Niño years, fishing effort peaked and concentrated in July and August, with less effort in the last quarter. Over 70% of fishing effort was expended between July and October and concentrated in the Southern California Bight during 1974–93 (Fig. 10). Fishing effort usually started in waters off San Diego early in the season, and progressed to waters sometimes as far north as Oregon later in the season. During El Niño years, fishing effort tended to compress spatially and concentrate in the Southern California Bight. In non-El Niño years, fishing effort extended to areas off Oregon, but with relatively little success. This extension of the fishery is consistent with temperature regimes during non-El Niño years, when cooler water mixes throughout the area.

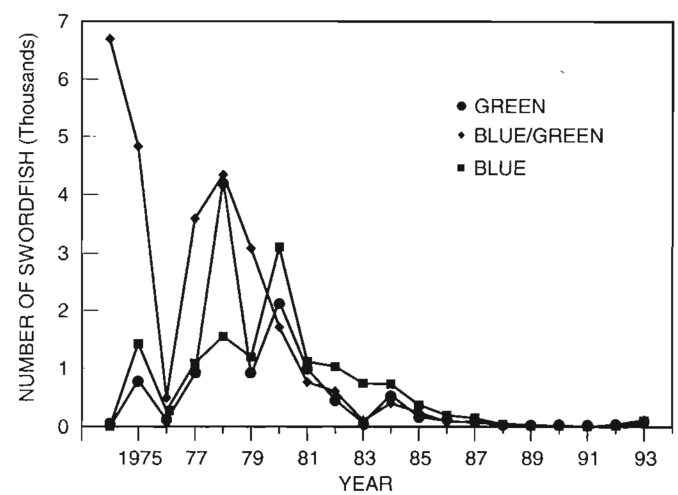


Figure 5
Number of swordfish sighted in blue/green, green, and blue water by California harpoon fishery vessels and reported in logbooks for 1974–93.

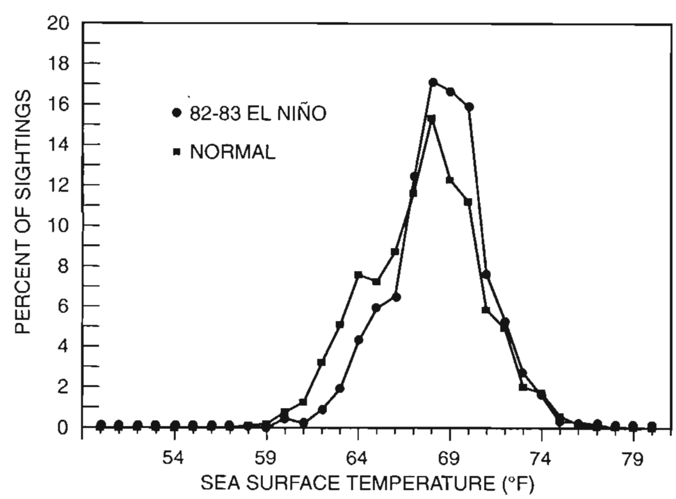


Figure 6
Proportion of swordfish sightings made at different sea-surface water temperatures (°F) from California harpoon fishery vessels and reported in logbooks for 1974–93. Normal includes all non-El Niño years. 82-83 El Niño indicates the effect of a strong El Niño on swordfish sightings.

[6] Miller, F. 1994. Inter-American Tropical Tuna Comm., 8604 La Jolla Shores Dr., La Jolla, CA 92037-1508. Pers. commun.

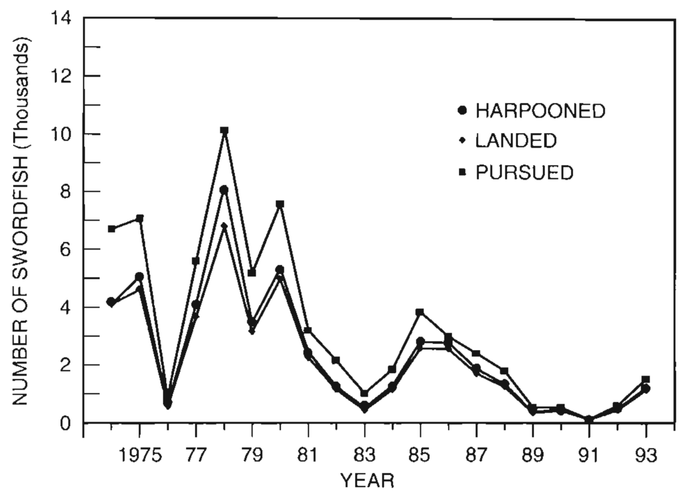


Figure 7
Number of swordfish pursued, harpooned, and landed by California harpoon fishery vessels, as reported in logbooks for 1974–93.

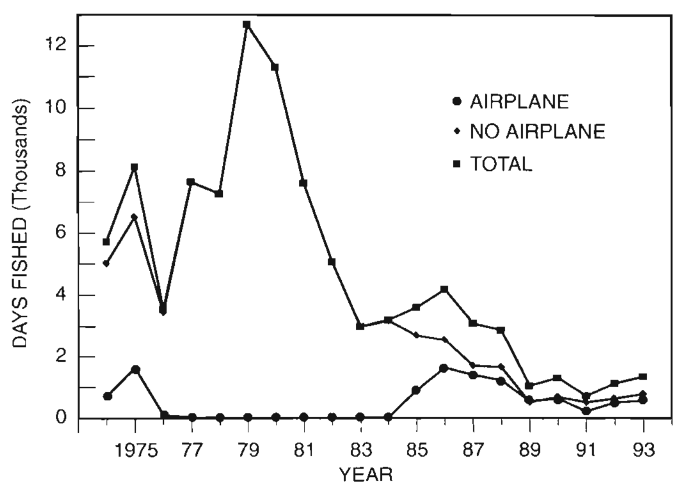


Figure 8
Total fishing effort in number of days fished, and fishing effort with and without the use of airplanes by California harpoon fishery vessels, as reported in logbooks for 1974–93.

Catches and CPUE

Trends in annual catch (in number of fish, as recorded in logbooks) closely followed trends in annual landings, with low catches of approximately 500 fish in 1976 and 1983 and a record low of 120 fish in 1991. The highest recorded catch (nearly 7,000 fish) was in 1978 . Recorded fishery catches, like effort, were also highest in the Southern California Bight, especially in waters between the California coast and San Clemente and Santa Catalina Islands (Fig. 11). Catches tended to concentrate in the Southern California Bight in El Niño years and extend farther north during non-El Niño years. Unlike fishing effort, which generally peaked in August, swordfish catches usually peaked in October, with over 70% of the catch made between July and October (Fig.

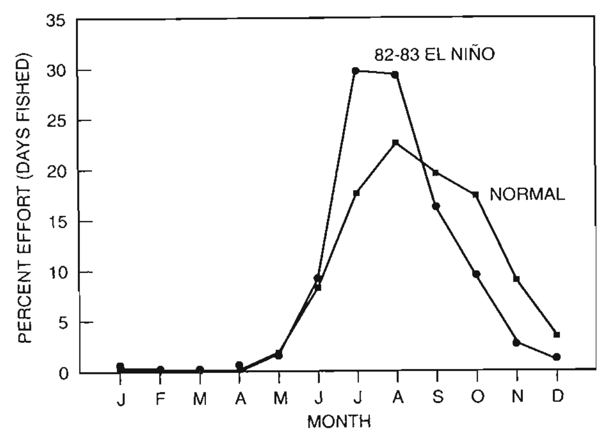


Figure 9
Proportion of fishing effort by month by California harpoon fishery vessels and reported in logbooks for 1974–93. Normal indicates fishing effort in non-El Niño years, and 82-83 El Niño indicates fishing effort during the strong El Niño of 1982–83.

12). During El Niño years, swordfish catches tended to peak earlier in the year, in July and August, with less catch in the last quarter of the year.

Catch-per-unit effort (CPUE, in number of fish per day fished) was calculated from logbook statistics for days with airplane assistance, days without airplane assistance, and for total days (Fig. 13). Airplane-assisted CPUE was higher than airplane-unassisted CPUE except in 1978–83, a period when airplane-assisted effort was less than 10 days per yr. Combined CPUE fluctuated between 0.14 and 0.93 swordfish per day fished. The trends in all estimates of CPUE were very similar: decreasing from 1978 to 1983, increasing to a peak in 1985, decreasing again until 1991, and then increasing in 1993. CPUE tended to increase 1–2 yr after an El Niño event. In comparison, drift gill net catch rates, in the same areas, ranged from 1 to 3 fish per day.

Size Composition

Sampling coverage (number of fish sampled, divided by the number of fish recorded in logbooks) for size composition of swordfish catches from the harpoon fishery sold at fish markets ranged between 0.2% and 7.0% during 1981–93 (Fig. 14). The low sampling coverage was probably due to the higher priority given to sampling gill-net-caught fish, combined with a low overall monitoring effort which did not adequately cover the various ports where harpoon vessels landed. The largest number of fish sampled was in 1984 (about 80 fish) and the smallest in 1990 (only one fish). Because of the low coverage rates, estimates of length distributions of swordfish by month and by latitudinal band could not be made. However, because of the close temporal and spatial proximity of this fishery to its drift gill net counterpart, the tendency seen in the drift gill net fishery for larger fish to be caught farther north and later in the season (Hanan et al., 1993) probably also applies to the harpoon fishery.

Average CL was calculated for each year and shows a slight increasing trend, from 140 cm in 1981 to approximately 183 cm in 1990 (Fig. 14). However, because of the small number of individuals sampled, the estimates are highly suspect during 1989–92. Fish sampled from harpoon fishery catches during 1981–93 ranged from approximately 62 to 217 cm CL (Fig. 15), with an average of about 149 cm. In comparison, fish caught in the California gill net fishery, as expected, were slightly smaller, averaging only 141 cm.

Discussion

The data collected from the California harpoon fishery are valuable for monitoring the fishery. While the data are generally of high quality, some problems can be identified and improvements made.

Landings data can be affected by various problems associated with reporting. Reported landings of fish that would be impossible to catch with a harpoon indicate a problem in the reporting of gear type used to catch those fish and possibly also swordfish. Also, since some vessels may have both harpoon and gill net per-

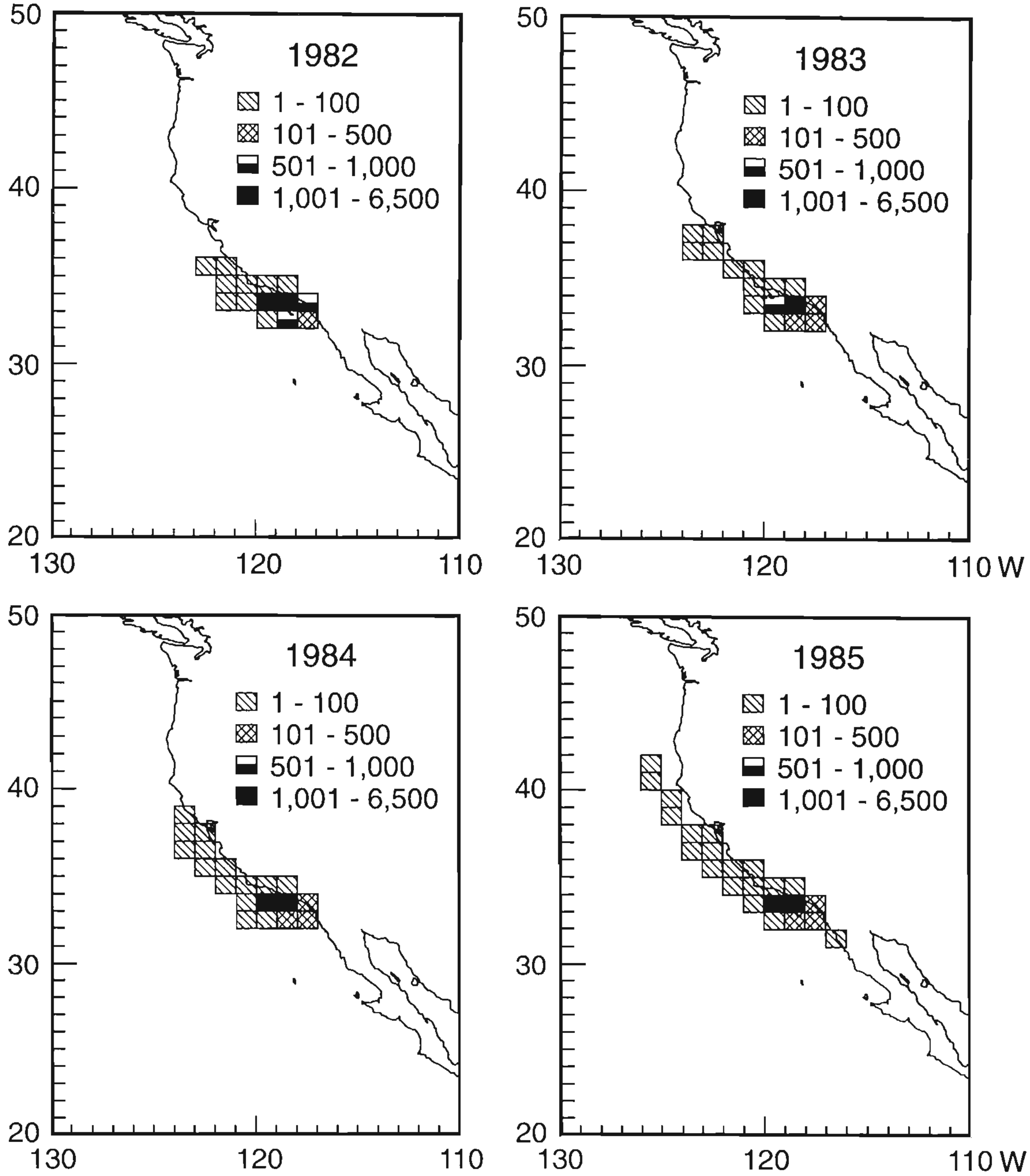


Figure 10

Typical spatial distribution of fishing effort by California harpoon fishery vessels reported in logbooks during normal fishing years, 1984 and 1985, and during a strong El Niño, 1982 and 1983. Spatial distribution of fishing effort for other years in which logbooks were collected was very similar.

mits onboard during a fishing trip, there will probably be problems in reporting of the appropriate gear. These problems could be especially frequent during periods when drift gill net swordfish landings were not allowed to exceed shark landings. Many of these problems could be alleviated and the quality of the landing statistics improved if buyers more carefully verified gear types used to capture purchased fish.

Rates of logbook data coverage are very high and therefore can be used to monitor catch rates, seasonal

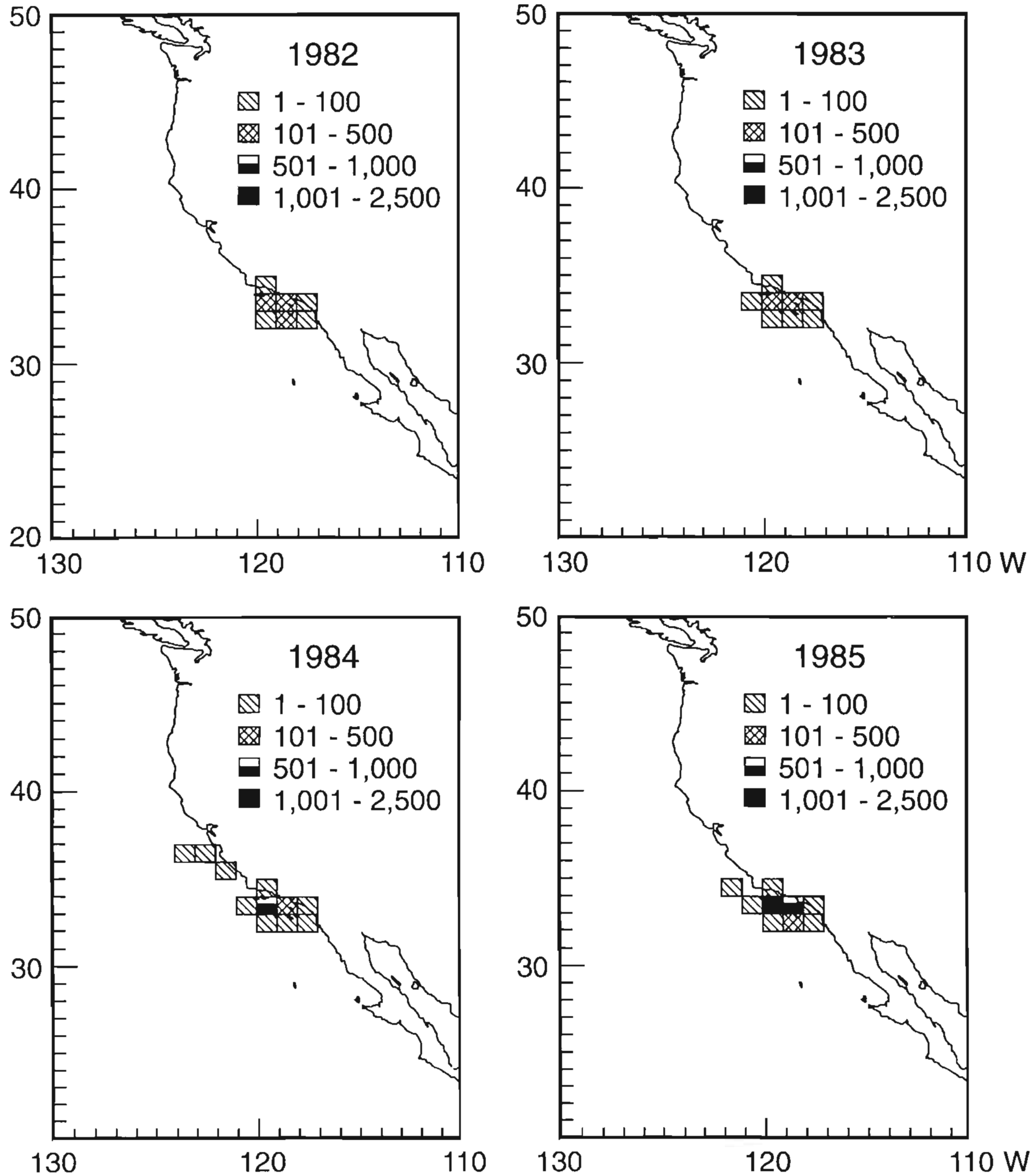


Figure 11
Typical spatial distribution of catches by California harpoon fishery vessels reported in logbooks during normal fishing years 1984 and 1985 and during a strong El Niño, 1982 and 1983. Spatial distribution of catches for other years in which logbooks were collected was very similar.

and spatial positioning of the harpoon fishery, and some environmental conditions that affect fishing success. Some confusion was noted in the reporting of weights associated with landed fish. While the vessel captains were instructed to enter their best estimates of dressed weight for each landed fish, many times these were unreasonably high and probably actually represented estimates of whole fish weight. A possible solution to this type of confusion would be to distribute an instruction section with the logbooks. An improvement in logbook recording of weights of fish landed would augment and/or verify market sampling results.

Market sampling coverage of harpoon-caught swordfish is low and leads to questions concerning the utility of size data from the sampling program. The quality of these data could be improved by establishing a formal sampling plan that began by establishing sample sizes necessary to predict lengths of swordfish caught by year, season, and geographic area.

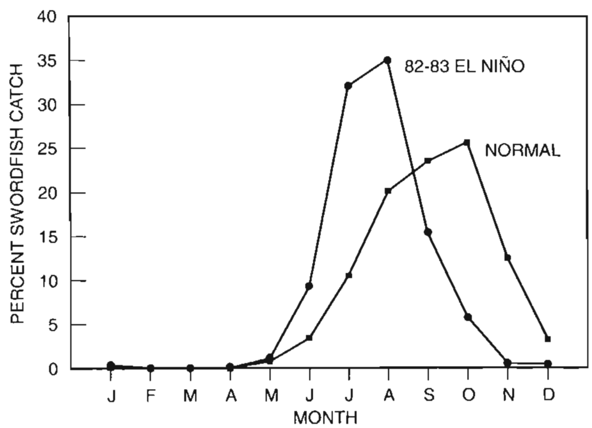


Figure 12
Proportion of swordfish catch (number of fish) by month for California harpoon fishery vessels, as reported in logbooks for 1974–93. Normal indicates fishing effort in non-El Niño years and 82-83 El Niño indicates fishing effort during the strong El Niño of 1982–83.

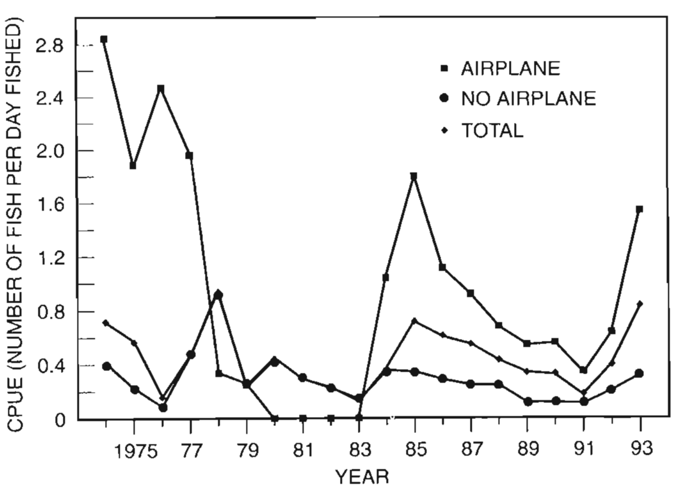


Figure 13
Catch per unit of effort (CPUE) in number of swordfish caught per day fished and per days fished with (AIRPLANE) and without (NO AIRPLANE) airplanes by California harpoon fishery vessels, as reported in logbooks for 1974–93.

The harpoon fishery is largely confined to a relatively small area, the Southern California Bight, which leaves it vulnerable to changing environmental conditions and competition from other fishing gears. The effects of environmental changes were most evident during El Niño events and resulted in decreasing catches and CPUE. Competition from the drift gill net fishery since 1980 has resulted in decreases in harpoon catches and effort. Catch rates in the drift gill net fishery are 2–3 times higher than in the harpoon fishery, drift gill net vessels use less fuel in finding and pursuing their catch, and drift gill net vessels can supplement swordfish catches with catches of sharks. It remains to be seen what effects recent increases in offshore longline fisheries will have on the harpoon fishery. Therefore, major concerns for the remaining harpoon fleet will probably be the continued availability of the resource in the Southern California Bight, and the effects of interactions between fisheries and the environment.

Because of the harpoon fishery's inability to move to other areas and increased competition from other gears, the outlook for a resurgence of the harpoon fishery seems unlikely. Recent increases in swordfish catches by the California harpoon and drift gill net fisheries (Holts and Sosa, 1994) indicate that the swordfish population may be able to support an even higher catch. However, due to the low catch rates in the harpoon fishery and the greater efficiency of the drift gill net fishery, increases in the harpoon fleet size or catch do not seem feasible (Sakagawa, 1989). Therefore, harpoon fishing will probably continue in the Southern California Bight, but as a form of fishing practiced by a handful of fishers who continue to pursue the thrill of the one-on-one hunt for swordfish.

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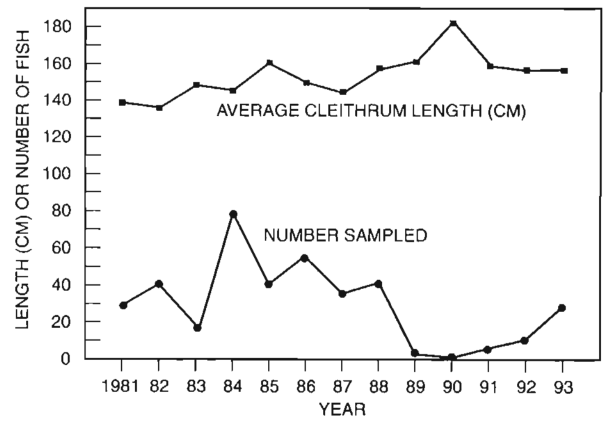

Figure 14
Number of swordfish sampled and annual estimates of average cleithrum length (cm) for swordfish caught by California harpoon fishery vessels during 1981–93.

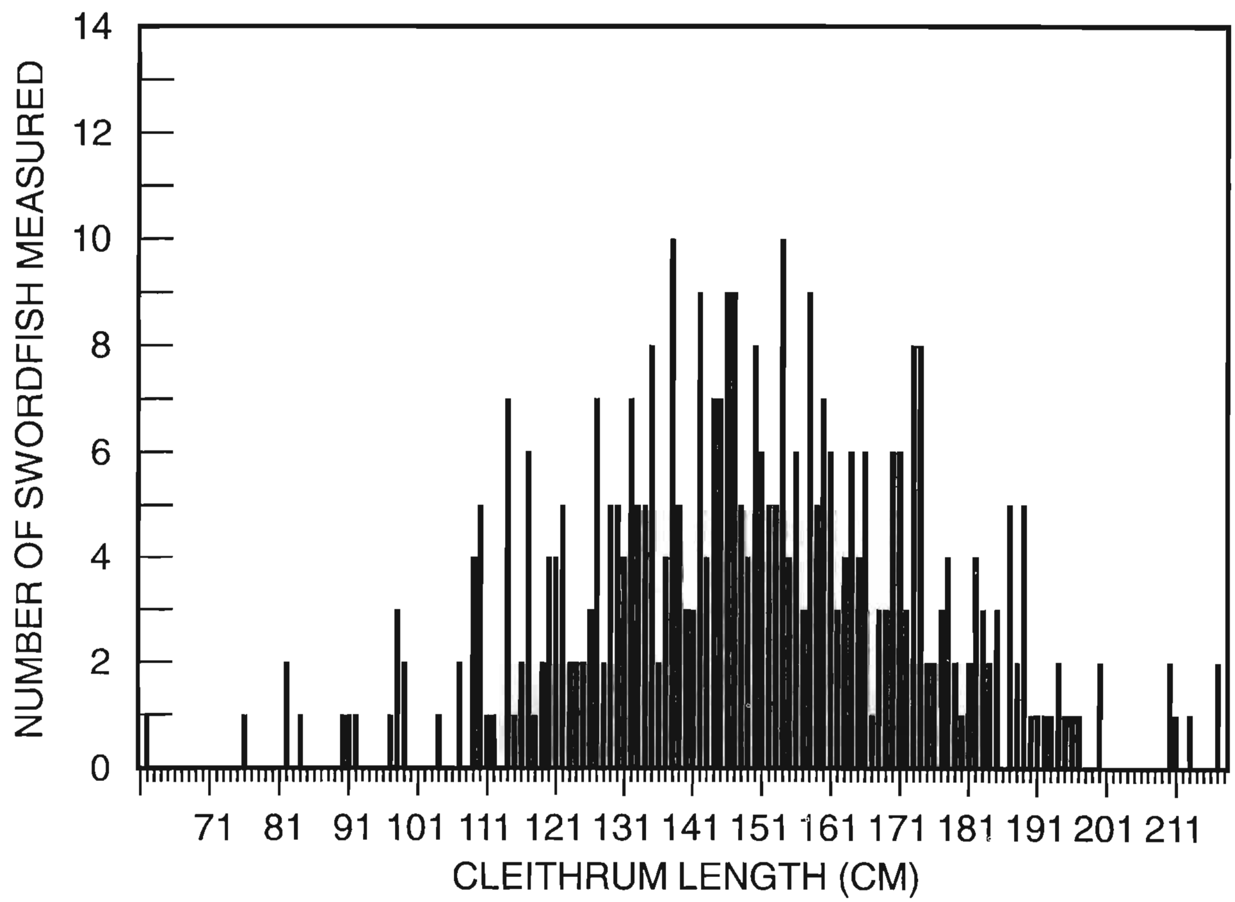

Figure 15
Size distribution (cleithrum length in cm) of swordfish sampled from California harpoon fishery vessels during 1981–93.

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