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STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

FISH BULLETIN 175

THE CALIFORNIA DRIFT GILL NET FISHERY FOR SHARKS AND SWORDFISH, 1981-82 THROUGH 1990-91

by

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1993

ABSTRACT

California's drift gill net fishery developed rapidly in the late 1970s off southern California. The fishery originally targeted the common thresher *Alopias vulpinus*. Almost immediately swordfish *Xiphias gladius* and shortfin mako *Isurus oxyrinchus* became important components of the catch.

We examined and summarized data obtained from the California logbook system, landing receipts, and market samples taken from this fishery over the 10 fishing seasons from 1981-82 through 1990-91. During this period the fishery evolved from a small nearshore experiment to a major California fishery. Significant changes in nearly every aspect of the fishery occurred including boats and gear, techniques and regulations, fishing areas and seasons, and targeted species. These data form a base line from which changes in the fishery and harvested stocks can be compared in the future.

The drift gill net fishery operates primarily in the area between San Diego and Cape Mendocino and concentrates much of its effort on swordfish in the Southern California Bight during the months of May to December. During the period studied, fishing effort decreased 50% to 60%, from highs of approximately 11,000 sets to a low of about 4000 sets in the 1990-91 season. This decrease in effort corresponds to a decrease in total landings of approximately the same proportions. Decreases in landings of common thresher were over 80%, while swordfish and shortfin mako landings decreased 60% and 40% respectively. Average sizes of swordfish showed no change during the 1981-82 to 1990-91 fishing seasons. Average sizes of shortfin makos showed a decrease of approximately 40% from the 1982-83 through the 1985-86 fishing season, but rebounded during the 1989-90 season to within 15% of the 1982-83 season. Average sizes of common thresher, however, decreased 30% from the 1982-83 season and remained low. This may indicate a decline in the common thresher stock or reflect changes in the season and area of fishing operations.

A number of problems and conflicts occurred during the first 10 years of the fishery (e.g. bycatch of marine mammals and striped marlin *Tetrapturus audax*) which were resolved for the most part through the cooperative efforts of the commercial industry, the sport industry, environmental groups, and State and Federal governments. The incidental catch of marine mammals is apparently low and not compromising any stocks, although the potential for damage remains and therefore monitoring is prudent. Bycatch of other fishes does not appear to be a problem except for the catch of blue sharks *Prionace glauca*, which has an unknown affect on local stocks.

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INTRODUCTION

California's drift gill net fishery for pelagic sharks and swordfish *Xiphias gladius* developed in the late 1970s off southern California. The initial concept of catching large pelagic sharks was inspired by the occasional catch of sharks in gill nets used to drift near shore for California barracuda *Sphyraena argentea* and white seabass *Atractoscion nobilis*. The fishery evolved rapidly as fishermen modified coastal gill nets and techniques for catching white seabass, sharks, California halibut *Paralichthys californicus*, and California flyingfish *Cypselurus californicus*.

The successful development of the drift gill net fishery might be attributed to greater fuel efficiency than in some other fisheries, pelagic shark resource abundance, consumer acceptance of shark as a food fish, and the perseverance of fishermen pursuing a new source of livelihood. As fishing techniques and gear improved, market demand for sharks increased, and in less than 5 years the number of drift gill net permits grew to over 200. These shark fishermen soon discovered that the nets were also efficient at catching swordfish, worth nearly four times the dockside value of sharks (Bedford 1987; Holts 1988). The value of swordfish and market demand for the high quality, relatively inexpensive sharks encouraged further development; fishermen started exploring new areas farther offshore and northward off Oregon and Washington.

As the fishery expanded, conflicts emerged with the commercial harpoon fishery for swordfish and with the recreational hook-and-line fishery for striped marlin *Tetrapturus audax* and swordfish, though few swordfish were caught by hook and line. Commercial harpoon fishermen and recreational fishermen feared reduced availability of swordfish and striped marlin. Additionally, striped marlin were specifically reserved for the recreational fishery and could not be sold even if caught incidentally. Another bycatch problem that developed was the incidental catch of marine mammals (Hanan and Scholl 1985; Diamond et al. 1986, 1987), especially California sea lions *Zalophus californianus*, which were caught in large numbers in drift gill nets near the Channel Islands. Because of these conflicts, concern for the targeted fish resources (Hanan 1984), and the fact that very little was known about the population status or biology of thresher sharks *Alopias* spp. (Berkson 1985), the Legislature enacted a series of laws regulating the new fishery (Bedford 1987).

In this bulletin, we review the first 10 years of the California drift gill net fishery, including a fishery description, catch and fishing-effort summaries, regulations, and biological summaries.

THE FISHERY

The drift gill net fishery originally targeted common thresher *Alopias vulpinus* and shortfin mako *Isurus oxyrinchus* (locally known as bonito shark). Almost immediately swordfish became an important component of the catch. Additionally, some other unexpected or previously considered rare species were caught. These included two other thresher shark species, bigeye thresher *A. superciliosus* and pelagic thresher *A. pelagicus*[1]. Fishermen and fish buyers learned what was marketable and in some cases developed markets for fishes not previously available in commercial quantities (e.g. opah *Lampris guttatus* and louvar *Luvarus imperialis*). The bycatch of nontarget fishes varied by year, but some of the more predictable and saleable bycatches were albacore *Thunnus alalunga* and other tunas, Pacific bonito *Sarda chiliensis*, and white seabass (Table 1).

During the period reviewed, primary ports for the drift gill net vessels were San Diego, San Pedro, and Santa Barbara; additionally, some boats utilized Dana Point, Port Hueneme, Ventura, Port San Luis, Morro Bay, Monterey, Moss Landing, and San Francisco Bay area ports. Depending on where they were fishing, drift gill net boats landed fish at all of these ports as well as several others.

Fish availability, market price, weather conditions, vessel fishing range, and fish-cooling capabilities dictated the length of fishing trips. Drift gill net trips ranged from one night to one month and total trips per year varied widely by skipper. Some skippers made only short trips while others remained at sea 2 to 3 weeks or more (Diamond et al. 1986). After extended trips or when catch rates were low, fishermen often docked at ports other than their home port to allow for shore leave or to wait for improved fishing conditions. Often they were gone from home port several months, returning only to change fishing gear for the opening of a different fishery.

Areas of operation for the drift gill net fishery were the nearshore banks, canyons, and escarpments near the offshore islands (water depths ranged from 400 to 1000 fathoms [fm]; Figures 1 and 2). Gradually, as the fishery matured and larger vessels entered the fishery, operations moved offshore and northward to the more distant seamounts and to the edge of the continental shelf. During and among fishing seasons, fishing areas shifted depending on availability of targeted fish and legislated time and area closures. Fishing effort varied from season to season and peaked in the mid-1980s (Figure 3).

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[1]*Although this species has not been previously reported in California waters, three California Department of Fish and Game observers including one of the authors (Hanan) identified this species in the observed catch. Pelagic threshers were also reported and measured by CDFG samplers at the docks as the sharks were offloaded. Unfortunately, no specimens were photographed or retained.*

Using radios, some fishermen communicated in coded messages with other members of loosely formed organizations called "code groups." They shared location information and presence or absence of desired fish. When catch rates were low, code-group members spread throughout the fishing range in search of fish and kept each other informed of fishing conditions, catch rates, and other pertinent information. Often, fishing vessels moved rapidly from one area to another based on information from their code group.

Because of competition for available fish and code-group loyalty, airplanes were hired to observe catches of other code groups. To counter this spy tactic, fishermen sometimes covered their catch with tarps or created fake fish by leaving a fish head protruding from under a tarp. Sometimes pilots would throttle back their engines and glide over a fishing boat in hopes of covertly gaining information.

In the first few years of the fishery, most of the fishing vessels were wooden or fiberglass; gradually there was a transition to steel or aluminum as the fishery developed. Vessel size ranged from 30 to 75 ft. Average vessel size increased with time, especially for those fishing farther offshore and northward. Fish holds were generally below decks and capacity varied depending on boat size and configuration. Fish-cooling capabilities varied widely from none to ice, brine spray, or refrigeration.

Crew size ranged from one to six. Crew members were compensated usually with a share of the catch proceeds or sometimes with cash wages. When shares were used as compensation, often they were split in some combination of the following: a share to the owner, a share to the skipper, a share or shares to the boat (for food, fuel, and other overhead), a share for each crew member, and sometimes one for the permit holder, who may or may not have been one of the aforementioned.

Drift gill net permits were issued to individual fishermen rather than to boats; thus the value of boats did not become artificially inflated, and permit holders could buy new boats as needed. Because of a requirement that a permit holder be onboard during fishing operations, some permit holders would "hire out" (ride for cash or a share) on other fishing vessels for skippers who did not have a permit. The practice of hiring out was eliminated in 1980 by requiring permit applicants to declare on which fishing vessel they would be using the permit. Also in 1980, the legislature made the drift gill net fishery a limited entry fishery, setting a maximum number of permits and allowing those already involved to continue fishing. The number of drift gill net vessels may have been as high as 300 in 1985, but there were rarely more than 100 active vessels during any of the fishing seasons described here.

TABLE 1. Landings (lb) by California drift gill net vessels during the 1981-82 through 1990-91 fishing seasons, compiled from landing receipts. Data for 1990-91 are preliminary. Some landings reported here are of species (i.e. angel sharks) not usually caught by drift gill net vessels, but have been included because they were reported on landing receipts.

Species	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
Sharks[a]										
Angel shark, Pacific	2,551	-	10,172	1,210	1,049	358	-	107	-	-
Blacktip shark	-	-	-	440	-	-	-	-	-	-
Blue shark	27,642	7,253	4,943	278	-	1,056	1,086	226	-	65
Cow shark	-	-	36	523	-	-	-	-	-	-
Dogfish, spiny	-	1,663	-	-	71	-	44	-	9	2
Dusky shark	-	-	174	-	-	-	-	-	-	-
Hammerhead shark	2,038	904	31,515	4,493	2,373	4,170	1,244	129	-	1,481
Leopard shark	540	348	608	290	189	78	60	400	211	72
Mako, shortfin	245,725	507,420	283,810	169,978	175,918	333,696	284,134	135,388	165,298	317,722
Salmon shark	-	996	66	-	1,169	960	135	265	179	-
Sevengill shark	104	-	-	104	-	-	-	-	-	-
Smoothhound, brown	6,084	3,779	2,927	164	13	2,600	2,170	6,205	1,675	1,447
Smoothhound, gray	-	422	57	16	-	343	-	-	-	-
Soupfin shark	28,251	11,855	6,878	10,788	8,708	2,346	4,937	2,725	2,224	2,238
Thresher, bigeye	-	34,197	85,965	59,320	102,648	39,773	23,022	8,563	20,116	38,192
Thresher, common	2,172,649	2,020,642	1,367,220	1,180,683	1,167,282	452,685	465,638	503,309	426,358	456,845
Thresher, pelagic	-	-	11,070	11,391	640	127	2,184	772	249	1,632
White shark	-	-	28	45	266	433	245	150	52	-
Shark, unspecified	232,736	14,482	19,130	6,350	8,362	1,351	448	333	1,180	1,139

TABLE 1. (Continued.)

Species	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
Other fishes										
Albacore	1,135	16,068	104,803	175,223	228,838	202,792	136,161	80,478	28,110	22,528
Barracuda, California	17,502	14,477	1,173	382	1,077	4,176	126	1,596	515	679
Bonita, Pacific	26,004	20,937	32,026	5,944	1,845	7,115	10,307	812	2,705	1,503
Butterfish, Pacific	66	329	-	15	-	-	18	7	-	-
Dolphinfish	-	49	70	-	164	714	66	105	12	98
Louvar	-	-	-	10,808	20,811	8,186	7,779	4,292	5,992	9,470
Mackerel, jack	4,489	6	-	-	-	-	-	-	-	-
Mackerel, Pacific	10,698	2,246	438	11	220	2,025	432	438	158	602
Mackerel, unspecified	-	1,512	291	3,228	1,099	1,909	107	137	396	42
Opah	1,735	57,896	163,840	260,934	242,174	139,678	60,506	47,675	100,461	80,079
Sardine, Pacific	-	-	-	-	-	84	122	-	25	83
Seabass, white	97,547	2,812	2,196	1,156	3,356	4,837	485	2,337	527	4,524
Sheephead, California	182	212	369	30	-	-	-	-	-	-
Swordfish	707,729	1,533,971	2,517,352	3,387,829	3,054,303	2,708,092	1,804,611	1,631,182	1,685,734	1,504,894
Tuna, bigeye	1,868	3,524	17,026	5,804	3,646	8,378	9,549	10,603	849	1,394
Tuna, bluefin	937	1,375	2,827	7,681	4,556	4,959	2,031	3,798	5,509	17,479
Tuna, skipjack	-	22	25,354	12,465	-	-	571	-	9,953	1,907
Tuna, yellowfin	7,933	9,372	33,059	21,917	15,694	16,496	5,808	3,049	2,151	2,724
Tuna, unspecified	12,753	33,757	43,665	1,923	782	6,937	8,358	3,949	8,129	3,364
Wahoo	-	41	-	-	-	10	90	-	-	-
Yellowtail	28,474	838	1,418	1,188	2,136	3,592	1,092	2,728	159	1,419
Totals	3,637,372	4,303,405	4,770,506	5,342,611	5,049,389	3,959,956	2,833,566	2,451,758	2,468,936	2,473,624

[a] *The occurence of some of these species within the range of the California drift gill net fishery is unconfirmed. Published landing figures (Oliphant et al. 1990) have included several of these species under "Sharks, miscellaneous" or, in the case of pelagic thresher, under "Shark, common thresher."*

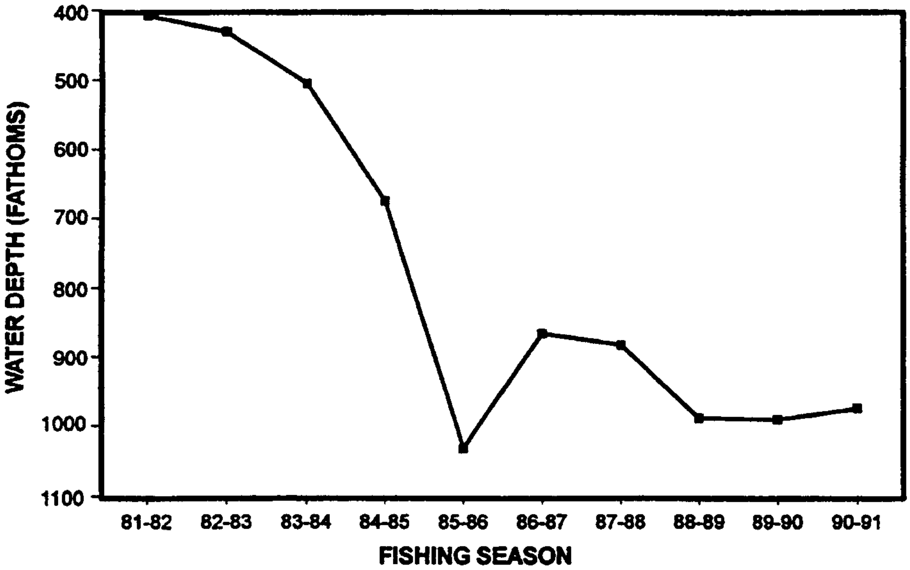


FIGURE 1. Average water depths (fathoms) fished by California drift gill net vessels for the 1981-82 through 1990-91 fishing seasons.

There was some illegal fishing (e.g. fishing without permits, use of excessively long nets, and other violations), but the value of the vessels and gear, combined with an active state enforcement program and costly penalties (e.g. the boat, net, and/or catch were subject to seizure and sale by court order upon conviction), discouraged the more blatant illegal activities.

Gear and Fishing Operations

The visual characteristics of this fleet were distinctive. Often, 50 or more vessels fished within several miles of each other and at night could be identified by their bobbing, weaving mast lights. During the day they were more difficult to locate, but once sighted they were striking with the large net reel behind the cabin, the metal net or propeller guards raised above the stern, and the colorful bumper-ball floats stored along the wheelhouse (Figure 4). The net guards had the look of a large baseball catcher's mask or the face guard on a football helmet. Most drift gill net vessels employed a hydraulic or electric winch and boom for lifting the catch into or out of the hold and occasionally to assist in bringing aboard large fish.

Some skippers had previously harpooned swordfish and when issued a drift gill net permit were called dual permittees. In addition to net gear, their vessels

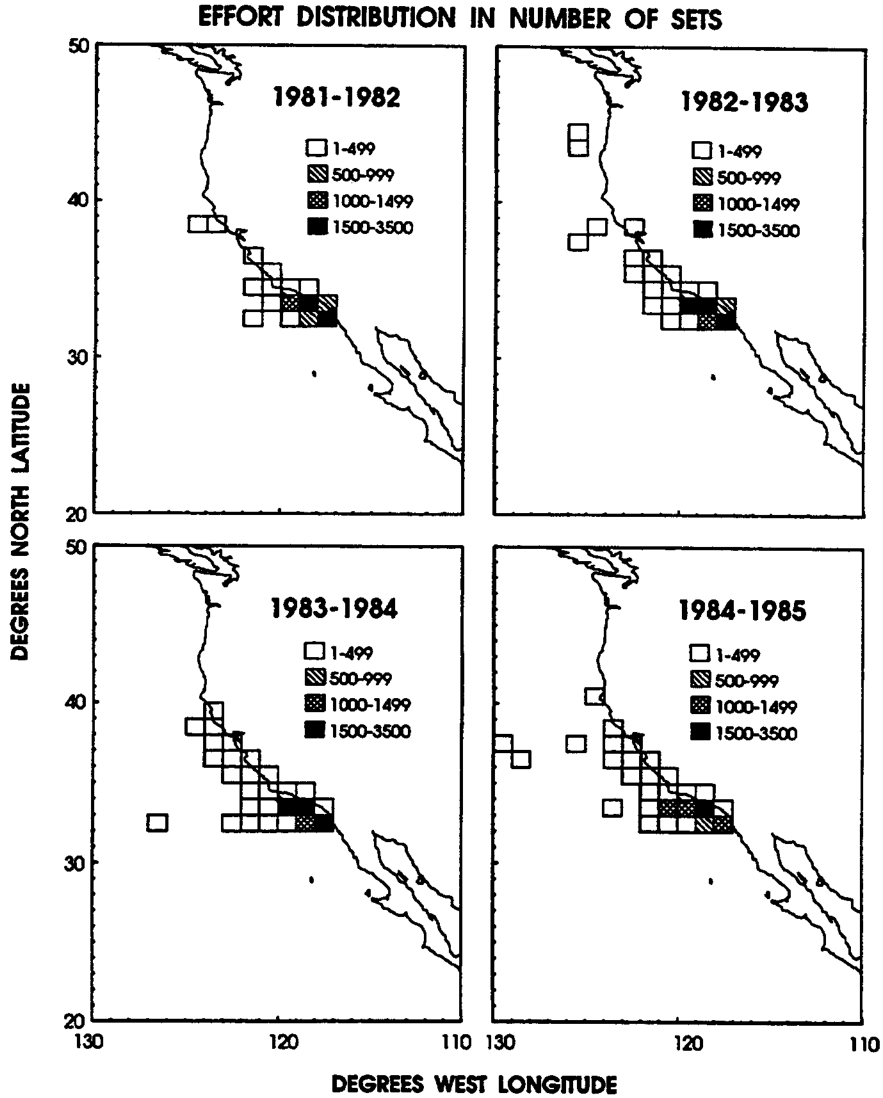


FIGURE 2a. Distribution of fishing effort by 1° quadrangles in number of sets, from California drift gill net logbook data for the 1981-82 through 1984-85 fishing seasons.

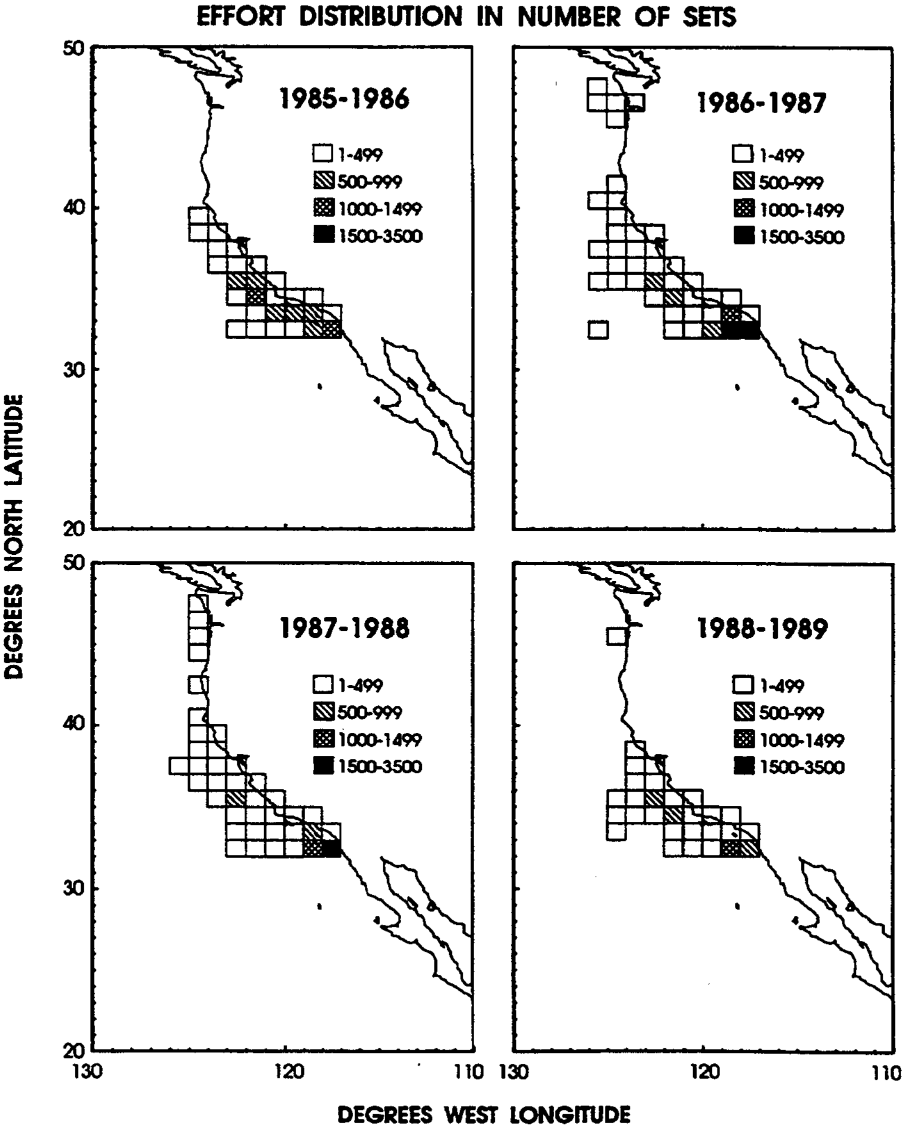


FIGURE 2b. Distribution of fishing effort by 1 ° quadrangles in number of sets, from California drift gill net logbook data for the 1985-86 through 1988-89 fishing seasons.

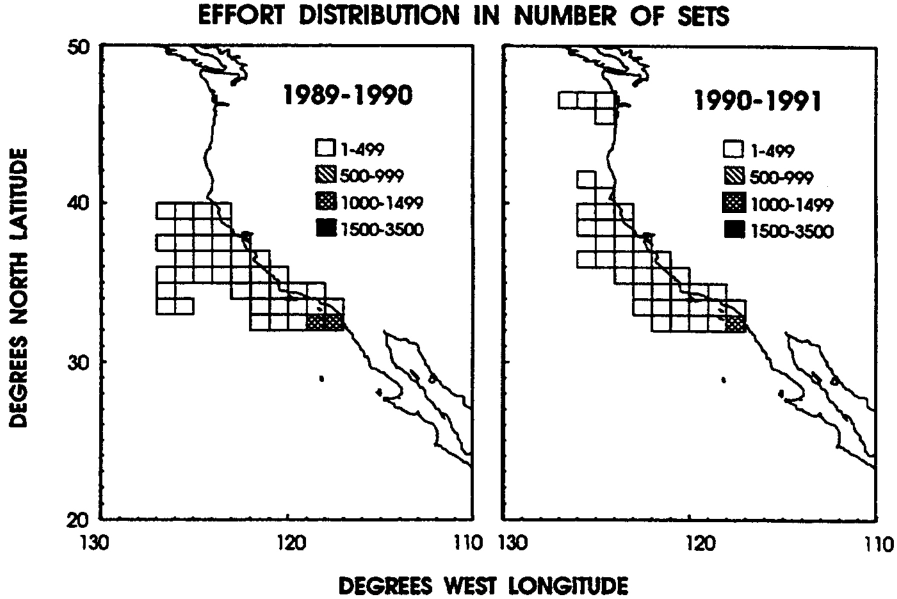


FIGURE 2c. Distribution of fishing effort by 1 ° quadrangles in number of sets, from California drift gill net logbook data for the 1989-90 and 1990-91 fishing seasons.

had wooden or metal planks extending 10 to 15 ft beyond the bow ending in a bow pulpit. Fishermen harpooned swordfish from the pulpit using harpoons tipped with a metal dart ("lily iron") designed to detach from the harpoon after striking the fish. The dart was attached by a line to large floats, and after striking a fish, the floats were released to tire the fish and keep it at the surface for later retrieval. Some vessels had a crow's nest high above the deck from which a fisherman could spot fish, direct the harpooner, and often steer the boat (Bedford and Hagerman 1983).

Nets used in the drift gill net fishery (Figure 5) ranged from 800 to 1000 fm in length. They were constructed of 3-strand, #24 to #30 twisted nylon tied to form meshes. The net was attached to the float line by means of a hanging line laced through two to four meshes of the top of the net and tied at intervals of 8 to 24 inches along the float line (Figure 5 detail). The number of meshes per hanging determined the amount of slack or tautness of the net and varied widely among skippers. The number of meshes between the cork and lead lines (depth of net) varied from 50 to 100 meshes depending on the skipper's preference. Average mesh size varied from about 13 to 19 inches stretched (Figure 6a).

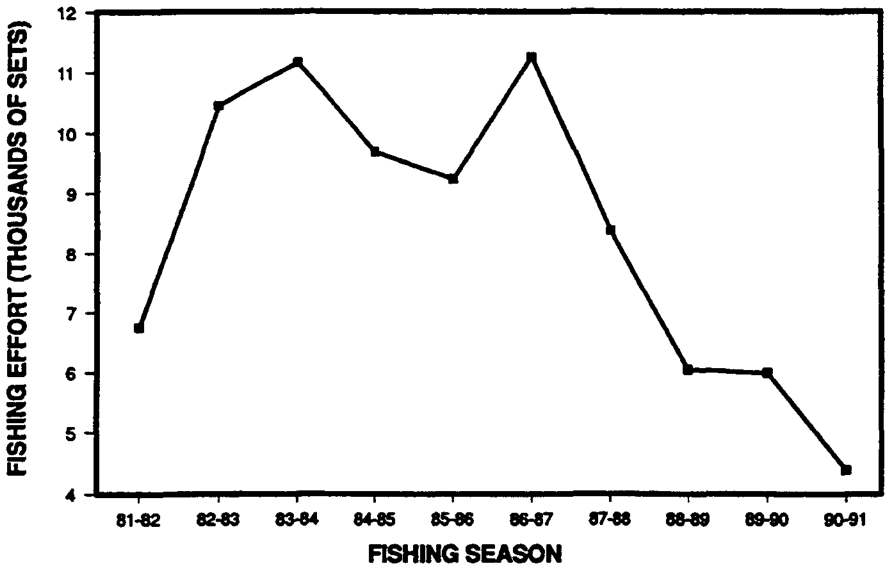


FIGURE 3. Estimated fishing effort in number of sets for California drift gill net vessels by fishing seasons 1981-82 through 1990-91.

Drift gill nets were usually fished with the float line 18 to 26 ft below the surface (Figure 6b) to allow small boats to pass over them. Fishing depth was maintained by tying buoy lines from the float line to bumper-balls at regular intervals of about 60 ft. The bumper-balls floated at the surface to buoy and maintain the net at a desired depth below the surface (Figure 5). The buoy lines were occasionally lengthened to as much as 90 ft when the skipper anticipated targeted fish to be at greater depths. A radar reflector and strobe light on a 6-ft pole was required at the end of the net. The reflectors allowed other boats to detect and avoid the nets and facilitated enforcement of maximum net lengths by patrol boats or airplanes. The bumper-ball floats, also visible on radar, showed the effect of currents and wind on net layout.

The nets were usually deployed or set each evening and usually only one or two people were needed. Deployment started by tossing the radar-reflector buoy overboard. The buoy was attached to the net via several fathoms of line followed by a length of netting sufficient to cause drag. The vessel was driven forward slowly as the net was payed out using the forward momentum of the boat and hydraulic-reel braking to control the speed of deployment. The buoy lines to the bumper-ball floats were snapped to the float line as the net was payed out. To

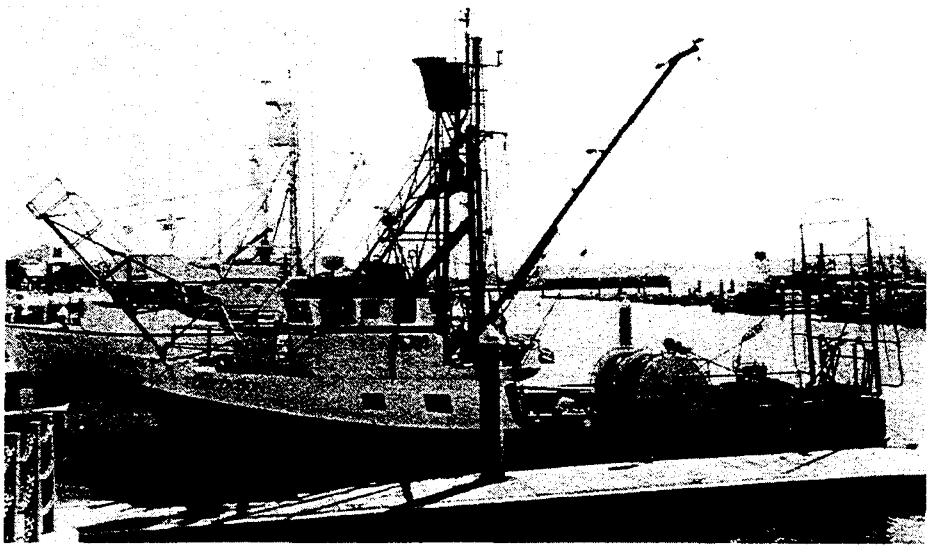


FIGURE 4. California drift gill net vessel with swordfish plank and pulpit at the bow, crow's nest atop the mast, net reel amidships, and net guard raised above the stern.

attract swordfish and increase the catch, many fishermen also attached chemical light-sticks to the net as it was payed out.

The nets were often set perpendicular to currents or across temperature, salinity, or turbidity fronts, because the fish tended to swim along those fronts. Each skipper seemed to choose the area to be fished based on a different set of criteria (e.g. some would not fish during a full moon, others tried to set in water of a particular color, and some tried to set on or near surfacing bait). In general, they tended to fish banks and escarpments which were also productive areas for bait and other fish.

The vessel remained attached to one end of the net while fishing, although sometimes it was detached and moved to the opposite end to change the drift pattern or fishing characteristics. Occasionally, if a net got too close to shore or the vessel drifted back over its net (putting a twist in the net and reducing its fishing capability), the skipper would pull and reset the net.

Nets were fished an average of 9 h. The net was pulled each morning with net pull taking 2 to 4 h. Because the whole net was required to be out of the water by 2 h after sunrise, the time at which a skipper would start the net pull differed depending on expected catch, length of net, duration of net pull, and time of year.

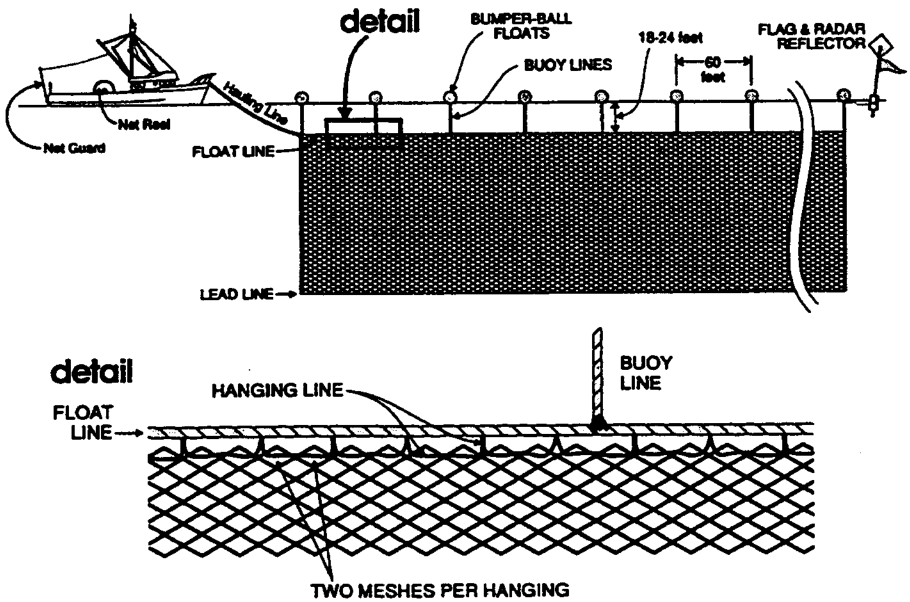


FIGURE 5. Design of typical net in California drift gill net fishery.

The start of a net pull was often between 0100 and 0300 h, ending around sunrise. Net retrieval usually required all hands, each working on a particular task. The net guard was lowered over the stern to keep the net out of the propeller while it was pulled over the stern by the hydraulic net reel. In effect, this caused the boat to be pulled backward until late in the net pull, when the drag of the boat exceeded the drag of the net. Some vessels had rollers on the stern over which the net passed, thus facilitating retrieval and reducing net wear. Most vessels also used vertical guides to direct the net evenly from side to side on the net reel in much the same way as fishing line is wound on a fishing reel. Between sets, the net was stored on the reel, often covered with a tarp.

Most vessels had a secondary control panel (flying bridge), with engine throttle and net reel hydraulic controls, near the stern. As the net was pulled, anything caught in the net was usually seen coming to the surface; the reel was slowed and stopped if the catch was large. The catch was either pulled aboard in the net or, if too large, tied with a line so as not to be lost, and winched aboard.

Once onboard, entangled fish were removed from the net using routine procedures. Shark fins were cut off before removal. With thresher sharks, the tail, which was nearly as long as the body, also was cut off. Swordfish were removed by first

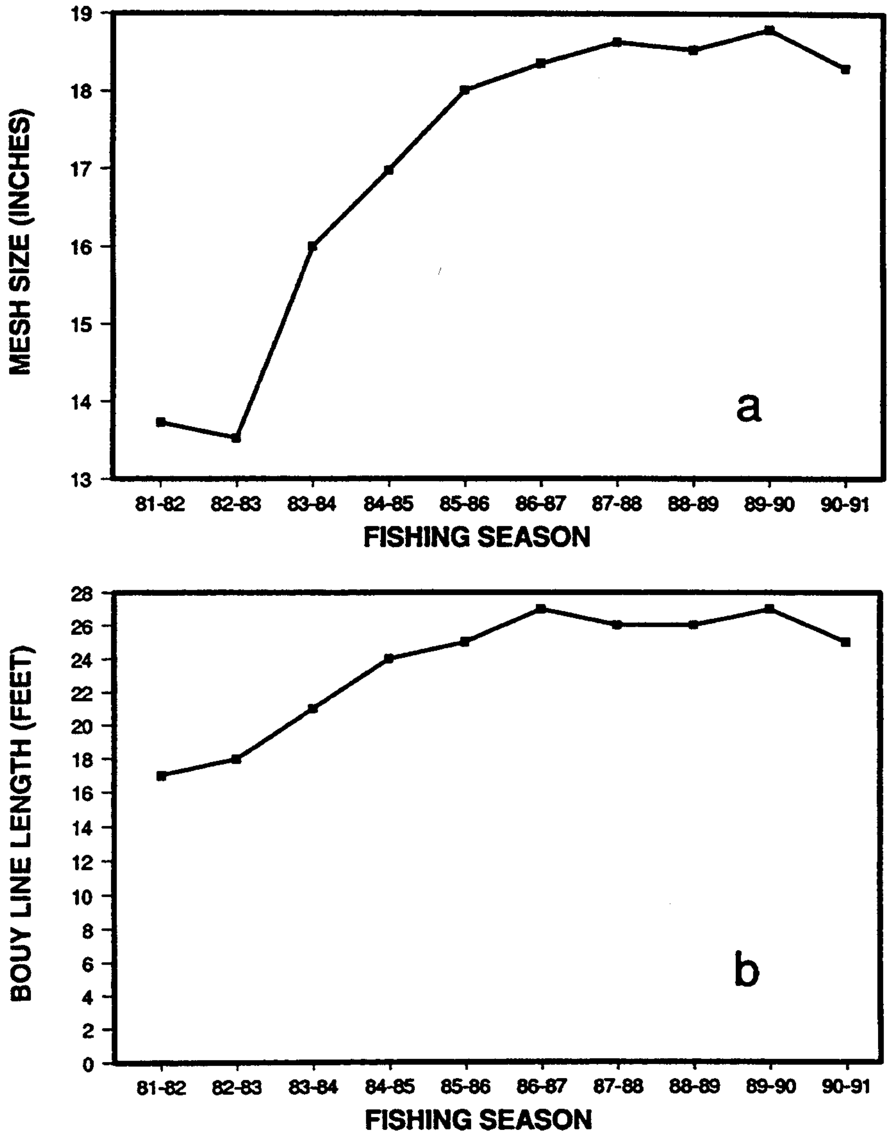


FIGURE 6. Average mesh size in inches (a) and buoy-line length in feet (b) used by California drift gill net vessels during the 1981-82 through 1990-91 fishing seasons.

sawing off the bill or "beak" and then removing the fins. One or more strands of the netting were sometimes cut to remove the entangled catch, but usually only as a last resort and often only with the skipper's permission, since holes in the net reduced fishing capacity and required repair at a later time. Depending on the number of fish caught or the rate at which they were coming aboard, the catch was either cleaned immediately or stacked on deck to be cleaned later. Cleaning of sharks and swordfish included head removal and evisceration. The unwanted parts were discarded at sea and the carcasses washed with sea water. Usually the thin belly meat (belly flaps) was discarded, although the crew would sometimes cook and consume this part. Some skippers kept the shark fins for drying and sale, but most discarded them. If the hold was large enough, shark carcasses were stored separately from swordfish to maintain swordfish quality.

Some fish became entangled early during a set, while others were entangled later or during the net pull. There were no trends in catch locations in the net relative to distance from the fishing vessel or to depth between the cork and lead lines. Except for blue sharks *Prionace glauca*, molas *Mola mola*, and pelagic sting rays *Dasyatis violacea*, most fish were dead when pulled aboard. Blue sharks often swam near or even through the netting as it was retrieved, accounting for many of them being alive when pulled aboard. Since blue sharks are unpredictable and likely to bite, they were usually clubbed immediately, removed from the net, and discarded on the down-current side of the net. The molas were thrown back alive, although sometimes they were kept until completion of the net pull to avoid reentanglement, a frequent occurrence with molas. Pelagic sting rays were removed and immediately tossed overboard. It was common for their tail barb to be hooked in the net, and often just barbs were found indicating they had freed themselves prior to net retrieval.

Marine mammals tended to roll up in the net when caught. Usually a few strands of the net had to be cut to remove them. Most sea lions and seals were dead when retrieved. Those still alive were released at the water line when possible or killed, removed from the net, and discard. If a marine mammal was too large for the hydraulic equipment to pull aboard, it was cut free at the water line.

Catch

Catches varied by fish species, by season, and among years. Depending on the season and year, one set could yield as many as 15 swordfish, 20 shortfin makos, 20 thresher sharks, and 20 opahs, although many sets caught no marketable fish. Fish buyers often paid a prearranged price for the fish and often had agreements to buy all or a prearranged portion of the catch from a particular vessel. Most of the catch was sold in local markets (Herrick and Hanan 1988). Ex-vessel prices ranged from about $2.00 to $4.00/lb for swordfish, $1.00 to $2.00/lb for shark, and $0.25 to $0.50/lb (round weight) for opah. During the 10-year period covered in this study, mean annual landings were 2 million lb of swordfish, 1 million lb of common thresher, 40,000 lb of bigeye thresher, 3000 lb of pelagic thresher, and 262,000 lb of shortfin mako shark. Average landings over the last 5 years were quite close to the 10-year average, although there were declining trends in the total catch landed for most species (Table 1).

Effort

Fishing effort used in this study was obtained from skippers' logbooks. Compliance with logbook reporting regulations was estimated to have been greater than 90% (Miller et al. 1983; Beeson and Hanan 1991), therefore total effort estimates based on logs was assumed to be accurate. Other studies have combined logbook information with landing receipt information to improve estimates of effort (Beeson and Hanan 1991); however, to evaluate effort trends we used only the logbook data.

During the 10-year period covered in this study, the annual distribution of effort in the drift gill net fishery shifted geographically from concentration in the nearshore Southern California Bight to more even distribution northward and offshore (Figure 2). Our observations suggest that fishing effort concentrated in the Southern California Bight during spring and shifted northward and offshore as the season progressed. In fall, fishing effort shifted southward to target swordfish. In spite of these general trends, there were also skippers who always fished the Southern California Bight and did not change their area of fishing operations. They preferred not to fish during periods when target species moved to other areas.

In the first 5 years of the study period, total annual effort nearly doubled to a high of 11,000 sets in the 1986-87 fishing season and subsequently declined to a low of 4000 sets in the 1990-91 season (Figure 3). This decline in effort coincides with increasing regulations and laws governing this fishery.

REGULATIONS AND LAWS PERTINENT TO THE DRIFT GILL NET FISHERY

During a 4-month period (December 1979 through March 1980), swordfish incidentally caught by drift gill net were allowed by the California Fish and Game Commission to be landed and sold. When the Commission denied a request to authorize drift gill net use for catching swordfish, legislation was passed allowing special permits for drift gill net fishing (Hanan 1984; Bedford 1987). The permits were issued to those proving previous experience, significant investment, or competency in the fishery. Permit fees ($150 for shark, $150 for swordfish) were established to fund required research, and the permittee was compelled to be onboard the vessel during fishing operations. Fish buyers were required to pay $0.01/lb privilege tax on thresher sharks and shortfin makos and to report aggregate weight and total number of swordfish received. Recreational fishermen were required to report their catch of striped marlin. The allowable incidental catch of swordfish in the drift gill net fishery was set at 25% of the number of swordfish taken by the commercial harpoon and hook-and-line fisheries in any month. A similar quota of 10% of the recreational catch was set for striped marlin caught incidentally in the drift gill net fishery.

The California Department of Fish and Game (CDFG) was directed by the Legislature to study the drift gill net shark fishery, determine the effects of the fishery on swordfish and striped marlin, set up an observer program to observe the fishing operations on vessels fishing under drift gill net and harpoon permits, and report its findings. A mandatory daily logbook system was established. Drift gill net mesh sizes were set at 8 inches or larger, twine size at #18 or larger, and net length at 6000 ft or less. Additionally, the nets could be fished only between 2 h before sunset and 2 h after sunrise.

Because regulations for the drift gill net fishery were to expire in 1982 and there was legislative interest in continuing to regulate the fishery, new legislation was enacted which allowed direct targeting of commercial fishing on swordfish during a portion of the year. Commercial landings of swordfish were not tied to the sport or commercial catch of marlin or shark as had previously been required. This legislation also established the drift gill net fishery as a limited entry fishery with a maximum of 150 permits. Because the actual number of permits exceeded 150 at that time, new entrants were not allowed into the fishery until the actual number of permits issued dropped below 150. The bill increased the minimum stretched mesh size requirement to 14 inches, required the permittee to specify the fishing vessel on which the permit would be used, and specified that each net would have a radar reflector at least 10 inches in diameter on a 6-ft pole at the net end opposite the fishing vessel.

To control the incidental catch of seals and sea lions, the same legislation established time and area closures for the early summer (1 May through 31 July) around the Channel Islands. The bill also established time and area closures between the Channel Islands and the mainland during periods of expected high use by recreational or harpoon fishermen and closed the drift gill net fishery for sharks during 1 February through 30 April. It specified that during 1 May through 15 September, incidental landings of swordfish must not exceed landings of thresher shark and shortfin mako for any permittee during any calendar month, but it allowed swordfish to be landed from 16 September through 31 January without any shark poundage landing requirement. It gave the CDFG power to evaluate and close the shark and swordfish fisheries if landings of either exceeded 1.5 million lb during any 12-month period.

In 1984, an additional 35 permits were established for taking swordfish north of Point Arguello. This legislation was passed to allow entry into the drift gill net fishery to fishermen who may have missed the earlier opportunity as the fishery developed off southern California and moved northward to central and northern California.

Legislation passed in 1985 eliminated the equal shark-swordfish landing requirement and established new time and area closures intended to reduce the bycatch of marine mammals. The closures prohibited drift gill nets within 25 nautical miles of the mainland coast from 15 December through 31 January and within 75 miles of the mainland coast from 1 June through 14 August. It set the drift gill net season to 15 August through 31 January. It established a fee of $100 to transfer the permit to a boat other than the one specified on the application. A "shark drift gill net" was defined as "a drift gill net of 14 inches or greater mesh size." The legislation allowed for a maximum of 250 fm of spare or replacement netting to be aboard the fishing vessels at any time.

In 1986, the drift gill net fishery was eliminated within 12 miles of the coast north of Point Arguello and in certain areas in the Gulf of the Farallones near the mouth of San Francisco Bay. The thresher shark fishing season was reduced to 30 days in May.

More time and area closures were added in 1987 within the Southern California Bight and net length restrictions were clarified.

In 1988, legislation required that pelvic fins be left intact on thresher sharks until after landing to enable sex determination during market sampling by the CDFG. Also swordfish could be sold only to licensed fish buyers or dealers.

The U.S. Congress passed legislation in 1988 amending the Marine Mammal Protection Act of 1972 (MMPA). The amendments required vessels owners in the drift gill net fishery, which was considered likely to have marine mammal interactions, to obtain and display Federal MMPA exemption permits, report marine mammal kills, and allow Federal observers to board and observe fishing operations.

Legislation enacted in 1989 prohibited drift gill net fishing within 75 nautical miles of the mainland from 1 May through 14 July and continued the previously enacted prohibition from 1 February through 30 April; thus, it virtually eliminated the directed thresher shark fishery in California. It also directed the CDFG to revoke permits for specified findings and allowed permit transfers between fishermen for a fee of $1000. It eliminated the requirement for drift gill net permits for taking sharks north of Point Arguello.

Also in 1989, the states of California, Oregon, and Washington enacted a tristate interjurisdictional fishery monitoring plan for thresher sharks (PSMFC 1990).

During 1990, the drift gill net permit fee was temporarily increased to $330 ($250 for a partial year), a one-time between-boat permit transfer fee of $130 was continued, and a $1500 fee to transfer permits between fishermen was established.

BYCATCH

Observer programs were mandated for the developing drift gill net fishery in 1980 and observation begun in October of that year; thus, detailed data were gathered on incidental catches during the early years of this fishery. There were no systematic observations during the 1986-87 through 1989-90 fishing seasons, after which the National Marine Fisheries Service (NMFS) established an observer program as mandated by the MMPA. Data were recorded by observers onboard or nearby the drift gill net vessels during observed net pulls. Observers recorded detailed fishing information including number of each species in the catch.

During the first 6 years of the fishery, the CDFG had two observer programs. The first observed 262 net pulls during the 1980-81, 1981-82, and 1982-83 fishing seasons. These observations were made by observers who boarded drift gill net vessels prior to leaving the fishing port and stayed aboard until the vessel returned to port. The second program observed 181 net pulls during the 1983-84, 1984-85, and 1985-86 fishing seasons. These observations were made by observers transferred to the drift gill net vessels from a CDFG vessel at the fishing grounds just prior to the net pull and transferred back to the CDFG vessel after completion of the net pull. This method of obtaining observations allowed more random selection of drift gill net vessels than the previous program, since any vessel on the fishing grounds could be boarded and observed during a net pull without regard for living space—a major consideration in selecting vessels to observe during the first observation program.

The NMFS established a mandatory drift gill net observer program during the 1990-91 fishing season and observed 195 net pulls using a sampling scheme similar to the first CDFG program. The program differed by requiring vessels to take observers on a preset proportion of the fishing trips (Lennert et al. 1991).

Observers recorded bycatch by taxon for fish, mammals, and turtles (Table 2). The potential catch of striped marlin was of particular concern to all involved in this fishery, since striped marlin were designated a sport fish in California and were not to be sold even if caught incidentally in commercial fisheries. Drift gill net fishermen were required to notify the CDFG when marlin were caught and to surrender them to the CDFG upon docking. The bycatch of striped marlin was closely monitored while the CDFG observer program was in existence. During that period, the striped marlin bycatch (Table 3) was not considered large enough to warrant additional closures or further restrictions of the fishery (Bedford 1985).

Pinnipeds and turtles, as well as small and large cetaceans, were observed caught in the drift gill net fishery (Table 3), although large cetaceans tended to break through the nets or to break free after entangling. Observations of marine mammals caught incidentally to the fishing operations (Diamond et al. 1986, 1987) were used with estimates of fishing effort to calculate total marine mammal mortalities by time and area in the fishery (Hanan et al. 1988; Herrick and Hanan 1988; Hanan and Diamond 1989; Lennert et al. 1991; Perkins et al. 1991, 1992). There were no major changes in the rates of entanglement during the period examined except for a decrease in the catch rate of pinnipeds near the Channel Islands after the implementation of time and area closures. Part of the rationale for a fishing closure within 25 miles of shore was to protect gray whales *Eschrichtius robustus*, although there were no observations of gray whales killed in the drift gill net fishery and apparently no significant effect on the population (Heyning and Lewis 1990). Heyning and Lewis (1990) also state that the entanglement of balaenopterid whales may be substantial in this fishery. Miller et al. (1983) estimated, based on dock-side interviews of fishermen, that three gray whales and one large baleen whale were killed in this fishery in 1980.

Two species of sea turtles, Ridley's *Lepidochelys olivacea* and loggerhead *Caretta*, were observed caught in the drift gill net fishery (Diamond et al. 1986, 1987). All turtles caught appeared to be dead when removed from the nets.

As mentioned above, some of the incidental catch (e.g. swordfish and opahs) became important and were even targeted as the fishery evolved. Basically, the fishermen kept what could be sold and released or discarded that which could not be sold (e.g. blue sharks, molas, and marine mammals).

TABLE 2. Target and bycatch species taken in the Calfornia drift gill net fisheries during the 1981-82 through 1990-91 fishing seasons, compiled from landing receipts and observer logs.

Common name	Scientific name
Sharks and rays	
Angel shark, Pacific	*Squatina californica*
Basking shark	*Cetorhinus maximus*
Bat ray	*Myliobatis californica*
Blacktip shark	*Carcharhinus limbatus*
Blue shark	*Prionace glauca*
Bull shark	*Carcharhinus leucas*
Cow shark (unspecified)	Hexanchidae
Dogfish, spiny	*Squalus acanthias*
Dusky shark	*Carcharhinus obscurus*
Electric ray, Pacific	*Torpedo californica*
Hammerhead shark (unspecified)	*Sphyrna* spp.
Leopard shark	*Triakis semifasciata*
Mako, shortfin	*Isurus oxyrinchus*
Manta	*Manta birostris*
Megamouth shark	*Megachasma pelagios*
Salmon shark	*Lamna ditropis*
Sevengill shark	*Notorynchus cepedianus*
Smoothhound, brown	*Mustelus henlei*
Smoothhound, gray	*Mustelus californicus*
Soupfin shark	*Galeorhinus zyopterus*
Stingray, pelagic	*Dasyatis violacea*
Thresher, bigeye	*Alopias superciliosus*
Thresher, common	*Alopias vulpinus*
Thresher, pelagic	*Alopius pelagicus*
White shark	*Carcharodon carcharias*
Shark (unspecified)	
Other fishes	
Albacore	*Thunnus alalunga*
Anchovy, northern	*Engraulis mordax*
Barracuda, California	*Sphyraena argentea*
Bass, kelp	*Paralabrax clathratus*
Bonito, Pacific	*Sarda chiliensis*
Butterfish, Pacific	*Peprilus simillimus*
Dolphinfish (Mahi mahi)	*Coryphaena hippurus*
Hake, Pacific	*Merluccius productus*
Louvar	*Luvarus imperialis*
Mackerel, bullet	*Auxis rochei*
Mackerel, jack	*Trachurus symetricus*
Mackerel, Pacific	*Scomber japonicus*

TABLE 2. (continued)

Common name	Scientific name
Other fishes (continued)	
Marlin, black	*Makaira indica*
Marlin, striped	*Tetrapturus audax*
Mola (Ocean sunfish)	*Mola mola*
Needlefish, California	*Strongylura exilis*
Opah	*Lampris guttatus*
Pipefish (unspecified)	Syngnathidae
Remora (unspecified)	Echeneidae
Salmon (unspecified)	*Oncorhynchus* spp.
Sardine, Pacific	*Sardinops sagax*
Seabass, white	*Atractoscion nobilis*
Sheephead, California	*Semicossyphus pulcher*
Skipjack, black	*Euthynnus lineatus*
Swordfish	*Xiphias gladius*
Tuna, bigeye	*Thunnus obesus*
Tuna, bluefin	*Thunnus thynnus*
Tuna, skipjack	*Katsuwonus pelamis*
Tuna, yellowfin	*Thunnus albacares*
Whitefish, ocean	*Caulolatilus princeps*
Wahoo	*Acanthocybium solandri*
Yellowtail	*Seriola lalandi*
Marine mammals	
Beaked whale (mesoplodont)	*Mesoplodon* spp.
Common dolphin	*Delphinus delphis*
Dall's porpoise	*Phocoenoides dalli*
Elephant seal, northern	*Mirounga angustirostris*
Finback whale	*Balaenoptera physalus*
Gray whale, California	*Eschrichtius robustus*
Harbor seal, Pacific	*Phoca vitulina*
Minke whale	*Balaenoptera acutorostrata*
Pilot whale, short-finned	*Globicephala macrorhynchus*
Right whale dolphin, northern	*Lissodelphis borealis*
Risso's dolphin	*Grampus griseus*
Sea lion, California	*Zalophus californianus*
White-sided dolphin, Pacific	*Lagenorhynchus obliquidens*
Turtles	
Loggerhead	*Caretta caretta*
Ridley's	*Lepidochelys olivacea*

TABLE 3. Observed bycatch rates (individuals per net) of striped marlin, marine mammals, and turtles in the California drift gill net fishery during the 1980-81 through 1984-85 and 1990-91 seasons. Observations for the 1980-81 through 1982-83 seasons are combined as they represent the first sampling method used by the CDFG. The 1990-91 data were collected by the NMFS.

	1980-83[a]	1983-84	1984-85	1985-86	1990-91
Number of observations	226	71	44	66	195
Striped marlin	0.048	0.085	0.068	0.061	0.067
Marine mammals					
California sea lion	0.364	0.085	0.023	0.015	0.026
Northern elephant seal	-	0.028	-	0.030	0.021
Pacific harbor seal	-	-	-	0.015	0.005
Common dolphin	-	-	0.068	0.106	0.077
Dall's porpoise	-	-	-	-	0.010
Northern right whale dolphin	-	-	-	0.015	0.005
Pacific white-sided dolphin	0.004	-	-	-	0.015
Risso's dolphin	-	-	-	-	0.010
Baleen whale (unspecified)	0.009	-	-	-	-
Finback whale	0.004	-	-	-	-
Gray whale	0.004[b]	-	-	-	-
Mesoplodont beaked whale	-	-	-	0.030	0.005
Minke whale	-	-	0.023	0.015	-
Short-finned pilot whale	0.009	-	-	-	0.005
Turtles					
Loggerhead	-	0.014	-	-	-
Ridley's	-	0.014	-	-	-

[a] *There were 262 net pulls observed during the period October 1980 to April 1983 when the fishery was allowed year-round. Bycatch-rate data are presented for only the May through January period to allow comparison to subsequent years when the fishery was closed February through April. There was an additional closure within 75 miles of shore 1 May through 14 July 1990, but all data for the 1990-91 season are presented.*

[b] *This represents one animal, which was released alive.*

From a political viewpoint, the important species in the bycatch were gray whale, striped marlin, minke whale *Balaenoptera acutorostrata*, California sea lion, common dolphin *Delphinus delphinus*, and blue shark; from an economic viewpoint, swordfish, albacore, and opah. Species of special interest or novelty included megamouth shark *Megachasma pelagios*, basking shark *Cetorhinus maximus*, and white shark *Carcharodon carcharias*.

STATUS OF BIOLOGICAL KNOWLEDGE

Swordfish

Swordfish have a cosmopolitan distribution in tropical, subtropical, and temperate waters of the Pacific Ocean between lat. 50°N and 45°S and usually in water temperatures greater than 13°C (Nakamura 1985). Areas of highest apparent abundance (based on hook rates from worldwide longline fisheries) occur in waters off Australia, Mexico, Peru, Japan, and in the North Pacific Transition Zone (Sakagawa and Bell 1980). Swordfish larvae are found throughout the tropical central and western Pacific and are often associated with the 24°C surface isotherm (Nishikawa and Ueyanagi 1974).

Swordfish are both epipelagic and mesopelagic and have been reported to depths of at least 550 m. Sonic tracking experiments off southern Baja California, Mexico indicate that swordfish move from inshore areas during the day seaward to deeper areas at dusk and return to inshore areas at sunrise. Larger swordfish tend to spend more time farther offshore (Carey and Robison 1981; Carey 1990). The number of swordfish tagged in the Pacific is very low and returns have yet to confirm trans-Pacific movements. Catch records from Japanese longliners suggest a movement from the tip of Baja California in the spring northward in the summer and fall to at least the waters off California (Kume and Joseph 1969). Catch records from the California drift gill net fishery show swordfish passing through the fishery from August through January (Sakagawa 1989).

Data on length-weight relations for swordfish in the Pacific are very limited. Skillman and Yong (1974) described the relation as

$$W = 2.3296 \times 10^{-7} L^{3.5305}$$

where W = round weight (kg) and L = length from tip of upper bill to fork (cm). However, the relation is based on a sample of only seven fish between 150 and 325 cm. More length-weight data from larger samples and greater length ranges are available for swordfish in the Atlantic Ocean (Palko et al. 1981).

Most swordfish are landed dressed; a conversion factor from dressed weight to round weight was established by California Fish and Game Commission for landing-tax purposes. The regulation specifies that, for taxing, round weight be 145% of the landed weight (Calif. Code of Reg., Title 14, section 187).

There is good evidence that male and female swordfish grow at different rates with females attaining the larger sizes (Kume and Joseph 1969). While male swordfish seldom exceed 140 kg, females may grow to 500 kg in the South Pacific. Swordfish in the western Pacific grow approximately 25 to 30 cm/year, whereas swordfish in the eastern Pacific grow approximately 38 cm/year. Approximate ages at length are as follows (Yabe et al. 1959):

Fork length (FL) range (cm)	Age: Months	Age: Years
38- 68	6-17	1
68- 98	18-29	2
98-128	30-41	3
128-158	42-53	4
158-189	54-65	5

Swordfish spawn throughout the year in warm equatorial waters, usually in close proximity to the 24°C surface isotherm (Nishikawa and Ueyanagi 1974). However, fish in spawning condition are caught more frequently during March through July in the northern latitudes and during January in the southern latitudes (Kume and Joseph 1969). There is some evidence of seasonal spawning 1 to 2 months earlier in the southwestern Pacific than around Hawaii (Matsumoto and Kazama 1974). First spawning occurs at 5 or 6 years. Fecundity is estimated at 2 to 5 million eggs per spawning in the western Pacific (Nakamura 1985).

Larval swordfish, 9.0 to 14.0 mm total length (TL), feed on organisms such as mysids and amphipods, and start feeding on fish at about 21 cm (Yabe et al. 1959). Juveniles and larger swordfish are opportunistic feeders concentrating on areas of high food abundance. They feed on local species of squid, fish, and pelagic crustaceans during the night (Scott and Tibbo 1968), and various bottom species while inhabiting deeper waters during the day (Nakamura 1985). The Southern California Bight provides swordfish ample prey during the summer and fall months around offshore banks and submarine escarpments.

There are no estimates of natural (*M*) or fishing (*F*) mortality rates for swordfish in the Pacific Ocean. Because of their longevity, *M* is thought to be low compared to other billfishes. Estimates of *M* for northwestern Atlantic swordfish range from 0.21 to 0.43 and estimates of total mortality rates range from 0.12 to 0.65 for the harpoon fishery and 0.16 to 0.59 for the longline fishery (Beardsley 1978).

Currently, there are two stock-structure hypotheses for Pacific swordfish (Sakagawa and Bell 1980). The first hypothesis suggests a single Pacific-wide stock in a contiguous distribution with zones of high catches, high abundance, and the assumption that the population is sufficiently mobile within its range to prevent local depletion. The second hypothesis emphasizes three stocks in areas of high abundance made contiguous over a broad area of low abundance. In both cases, stock assessments conclude that Pacific swordfish populations are not overfished and that the resource is healthy (Bartoo and Coan 1989) and being fished at levels much lower than in the mid-1960s.

Thresher Sharks

Three species of thresher sharks are taken in California's drift gill net fishery: common thresher, bigeye thresher, and pelagic thresher. Although all three are closely related and share many common traits, they are caught at vastly different rates in this fishery.

Common Thresher

Common threshers are distributed throughout all tropical and temperate oceans. They are both coastal and oceanic but have a greater apparent abundance within 40 miles of shore (Strasburg 1958). They are strong swimmers, although transoceanic migrations are undocumented in the Pacific. In the eastern North Pacific they are abundant over the continental and insular shelves (Compagno 1984a), distributed seasonally from Baja California to Vancouver Island, British Columbia.

Common threshers move northward from Baja California into southern California following the warmwater isotherms in early spring. Large mature common threshers continue northward to at least Vancouver Island in late summer and fall, where the sex ratio can be five males per female (Stick and Hreha 1988, 1989). Presumably there is a southward movement in winter. Juveniles tend to remain in shallow, nearshore areas especially within the Southern California Bight, which may be an important nursery area (Bedford 1992). Immature fish are seldom found north of Cape Mendocino, California (Holts and Bedford 1989).

The caudal fin or tail of thresher sharks represents about 50% of total body length. Minimum size at birth was estimated at 139 cm TL, while maximum total length, based on a sample of 143 common threshers taken off California, was estimated at 636 cm for females and 493 cm for males (Cailliet and Bedford 1983). Maximum age was also estimated to be as high as 45 to 50 years (Cailliet et al. 1983).

The relation between alternate length (AL, distance from origin of first dorsal fin to origin of second dorsal fin) and dressed weight was determined for 110 common threshers (combined sexes) sampled at Washington and Oregon ports (Stick and Hreha 1988). That relation was

$$W = 0.001305(AL)^{2.750031}$$

were W = dressed weight (lb) and AL = alternate length (cm). There are no data relating dressed to round weight for common threshers. The California Fish and Game Commission established regulations for determining landing taxes which specify a 170% factor of the landed weight to be the round weight for taxing purposes.

Reproduction in common threshers is ovoviviparous. After absorption of the yolk sac, developing fetuses obtain nourishment by eating eggs still developing in the uterus (Bigelow and Schroeder 1948; Otake and Mizue 1981). Females mature at 315 cm TL in the Pacific (Strasburg 1958) and males reach maturity at about 333 cm TL (Cailliet and Bedford 1983). Mating occurs in summer. Gestation lasts 9 months and female common threshers give birth each spring (March to June) to an average of four fully developed pups (Bedford 1985).

Thresher sharks use their tail to thrash and stun their prey. In the eastern North Pacific, their diet consists of small pelagic species including anchovies, herring, mackerel, sardines, and squid (Hart 1973; Stick and Hreha 1989).

Due to their long life and the advanced stage and condition of newborn pups, natural mortality is presumed low. There has been one attempt at estimating fishing mortality for the eastern Pacific common thresher. Hanan (1984) suggested sustainable mortality rates for a closed fishery, although preliminary, were very low ($F = 0.007$ to 0.049), implying that only a small portion of the stock could be removed annually without compromising the stock.

Separate oceanic stocks may exist; differences have been observed in numbers of offspring and size at maturity in the Indian Ocean (Gubanov 1972) and in the North Pacific (Strasburg 1958; Cailliet and Bedford 1983). Fishery data suggest that the common thresher resource off California consists of a single, coast-wide stock. This stock appears to have a seasonal north-south movement pattern. Numerous thresher sharks taken off the California coast have carried hooks from the Japanese billfish and tuna longline fishery indicating long-distance movement from southern or offshore areas (Bedford 1985). However, the declining catch and smaller size of individuals in the catch indicate immigration has not kept pace with the harvest rates predicted by Hanan (1984). A preliminary population assessment for the 1980-84 period, using catch per unit effort and cohort analysis, indicated that the local stock could not sustain the level of catch evaluated in that 4-year period of study (Berkson 1985). More complete or rigorous stock assessments have not been conducted. During the period and area of this study, fishery data showed that catches of common thresher decreased and the average size remained small in spite of the numerous regulations restricting fishing effort (Cailliet et al. in press).

Pelagic Thresher

Pelagic threshers are found in tropical Pacific and Indian Ocean waters. They are oceanic and epipelagic and occasionally found near inshore areas. Little is known concerning their movements off the coasts of California and Mexico.

They are smaller than other thresher sharks and grow from 96 cm at birth to 330 cm maximum length (Compagno 1984a). Reproduction is ovoviviparous with two pups per litter. Size at maturity is not well documented but is between 264 and 282 cm TL (Otake and Mizue 1981; Compagno 1984a).

There is no information on mortality rates or stock status in the Pacific. Evidence from the longline fishery suggests a population center off central Baja California which shifts northward during strong El Niño events.

Bigeye Thresher

Bigeye threshers, like common threshers, are oceanic and coastal in tropical, sub-tropical, and warmer temperate seas. They are epipelagic and have been reported to depths of at least 500 m (Compagno 1984a). In the eastern North Pacific they are found on the high seas, over continental and insular shelves, and occasionally in shallow inshore areas. The first report of this species from southern California waters was of a 1963 occurrence of a bigeye thresher caught in a set gill net (Fitch and Craig 1964).

Maximum reported size is 461 cm TL for females and 378 cm TL for males. Size at birth is between 64 and 106 cm TL (Gruber and Compagno 1981). The length-weight relation reported for 16 Atlantic bigeye threshers by Stillwell and Casey (1976) is

$$\text{Log } Y \text{ (WT)} = 11.1204 + 2.99269 \text{ Log } X \text{ (FL)}$$

where WT = weight (kg) and FL = fork length (cm).

Reproduction is ovoviviparous as in other thresher sharks. Males mature at about 300 cm TL (3 to 4 years) while females become sexually mature at about 350 cm TL (5 to 6 years old; Gruber and Compagno 1981).

Bigeye threshers have specialized eyes adapted to low light levels. Their eyes can roll up into upward-directed sockets allowing them to feed on prey species silhouetted above. Their prey consists of small pelagic fish, squid, and crustaceans (Stillwell and Casey 1976; Gruber and Compagno 1981).

Although fished throughout its range, very little is known about mortality rates, stock structure, or stock status. The species is widely, though sparsely, distributed and may commonly inhabit deep water (Gruber and Compagno 1981).

Shortfin Mako

Shortfin makos are found in all tropical and warmer temperate oceans and in both coastal and open-ocean habitats. In the extreme northern and southern portions of their range, they follow warm water masses poleward in summers. They are highly migratory and considered one of the fastest and most active ocean predators (Compagno 1984a). General movement patterns or centers of abundance in the eastern North Pacific are not well known (Strasburg 1958). Juveniles are generally caught more frequently in the waters off southern California in the summer months and seldom caught north of the Mendocino Escarpment. Juveniles are near-surface swimmers and rarely descend below the thermocline (Holts and Bedford in press). Adults are occasionally caught around the Channel Islands and outer banks of the Southern California Bight in late summer.

Maximum total length reported is 390 cm for females and 280 cm for males. The largest shortfin mako reported off California was 351 cm and weighed 468 kg (Applegate 1976). Cailliet et al. (1983) estimated von Bertalanffy asymptotic growth from 44 southern California shortfin makos (combined sexes) at L_∞ = 321 cm TL, with an estimated life span of 45 years. Pratt and Casey (1983), assuming two vertebral growth bands per year, determined asymptotic growth from 109 Atlantic shortfin makos at L_∞ = 345 cm FL for females and 302 cm FL for males. Strasburg (1958) described the length-weight relation as

$$\log WT\ (lb) = -4.608 + 2.925 \times TL\ (cm)$$

for central Pacific shortfin makos, and Stevens (1983) reported

$$WT\ (kg) = 4.582 \times 10^{-6}\ TL^{3.10}\ (cm)$$

from 80 shortfin makos taken off New South Wales.

Reproduction is ovoviviparous with 4 to 16 pups per litter. Gestation is about 1 year with parturition occurring in late spring followed by mating in the summer months. Females mature at 280 cm TL (7 to 8 years) and males mature at 195 cm TL. Mean size at birth is 70 cm TL (Stevens 1983).

Shortfin makos are active feeders on a variety of epipelagic species (Stillwell and Kohler 1982). Off California these include mackerel, bonito, anchovy, tuna, other sharks, and squid. They are even known to kill and eat swordfish (Bigelow and Schroeder 1948).

There are no estimates of natural or fishing mortality rates for the shortfin mako. Stock structure and abundance of shortfin makos in the eastern Pacific are poorly understood. Length-frequency and catch data from the drift gill net fishery suggest that southern California waters are part of an important nursery area for shortfin makos in the eastern Pacific.

Blue Shark

Blue sharks are circumglobal in all tropical and temperate waters. In the North Pacific, seasonal migrations occur between lat. 20° and 50°N. They are epipelagic and generally considered abundant in the offshore and coastal waters of the western United States and Mexico (Compagno 1984b). The northward movement extends into the Gulf of Alaska as waters warm during summer months. Movement southward occurs during winter months (Strasburg 1958). In coastal areas, mature females tend to start their northward journey in early spring as warm water moves northward, while juveniles of both sexes follow closely. Large males start later and tend to stay farther offshore (Bedford 1985). Juveniles and subadults are abundant within the Southern California Bight and in Monterey Bay from May to October (Sciarrotta and Nelson 1977; Tricas 1979).

Cailliet and Bedford (1983) determined asymptotic growth (L_∞) from 130 southern California blue sharks at 242 cm TL for females and 295 cm TL for males. Length-weight relations for Pacific blue shark were described by Nakano et al. (1985) as

$$WT = 3.838 \times 10^{-6}\ L^{3.174} \text{ for males}$$

$$WT = 2.328 \times 10^{-6}\ L^{3.294} \text{ for females}$$

where WT = weight (kg) and L = precaudal length (cm). Strasburg (1958) reported

$$\log WT = -5.396 + 3.13439(\log TL) \text{ for combined sexes}$$

where WT = weight (lb) and TL = total length (cm).

Blue sharks are viviparous, thus developing embryos are initially nourished from a yolk sac. Once the yolk sac is exhausted, developing young obtain nourishment and oxygen from the maternal blood stream through a placenta. Females mature at 140 to 160 cm FL (5 to 6 years) and males mature a year earlier between 130 and 160 cm FL (Nakano 1991). Maximum age is estimated to be at least 20 years (Cailliet and Bedford 1983; Nakano 1991). Gestation is 9 to 12 months. Brood size varies considerably depending on the female's size and condition, with over 100 young in a single brood reported, although 20 to 40 young are more typical (Strasburg 1958). Nakano (1991) examined 669 pregnant females from the North Pacific and found a mean litter size of 25.6 pups with an overall sex ratio of 1:1. Off California, parturition occurs in early spring and mating occurs during late spring to early winter. The Southern California Bight is a major pupping area and generally considered a nursery area for immature blue sharks. They are often seen on calm days moving slowly with dorsal fin and tail lobe protruding from the water.

In the coastal waters off California, blue sharks feed on anchovy, mackerel, hake, dogfish, squid, and pelagic crustaceans (Tricas 1979; Harvey 1989). Juveniles may make shoreward movements at night to feed in shallow water especially in the Southern California Bight, where numerous islands and submerged banks attract ample prey (Sciarrotta and Nelson 1977).

The size of the blue shark stock subject to the drift gill net fishery is unknown. There are no local or Pacific-wide estimates of stocks or abundance. Local availability undergoes major seasonal fluctuations with more juveniles (1 to 3 years old) caught in the coastal waters from early spring to early winter. Mature adults are uncommon in coastal waters. Local abundance probably depends on recruitment from coastal Mexican and offshore areas. A blue shark tagged off southern California was recovered near Midway Island in the central Pacific (J.S. Sunada, CDFG, pers. comm.), suggesting that it is a cosmopolitan species and that the local stock is not a closed population.

Fishery-dependent and -independent data needed for determining abundance, mortality, and distribution are inadequate. Blue sharks caught incidentally are usually discarded because the meat is considered unsuitable for human consumption; thus this catch often goes undocumented and little biological data are gathered.

Opah

Opahs are found in all tropical and temperate oceans. In the eastern North Pacific they are caught in the drift gill net fishery for swordfish, by trollers from the Gulf of California to the Gulf of Alaska (Hart 1973), and as incidental catches in other fisheries operating off southern California. They are rarely caught in large numbers and are thought to be widely but sparsely distributed (Allen 1992). General movement patterns are unknown, although opahs occur in the waters off California at all times of the year to depths of 365 m (Harald 1939). These fish may reach 180 cm and exceed 225 to 275 kg in the Atlantic. The largest reported off California was 73 kg (Harald 1939).

Opah feed on crustaceans, cephalopods, and small boney fishes (Allen 1992). There is little information on growth, reproduction, stock size, or status of the opah stock. They are apparently more abundant off California following El Niño years. Because opah is not a target species in any fishery, current landings probably have little impact on the population as a whole (Allen 1992).

Tuna

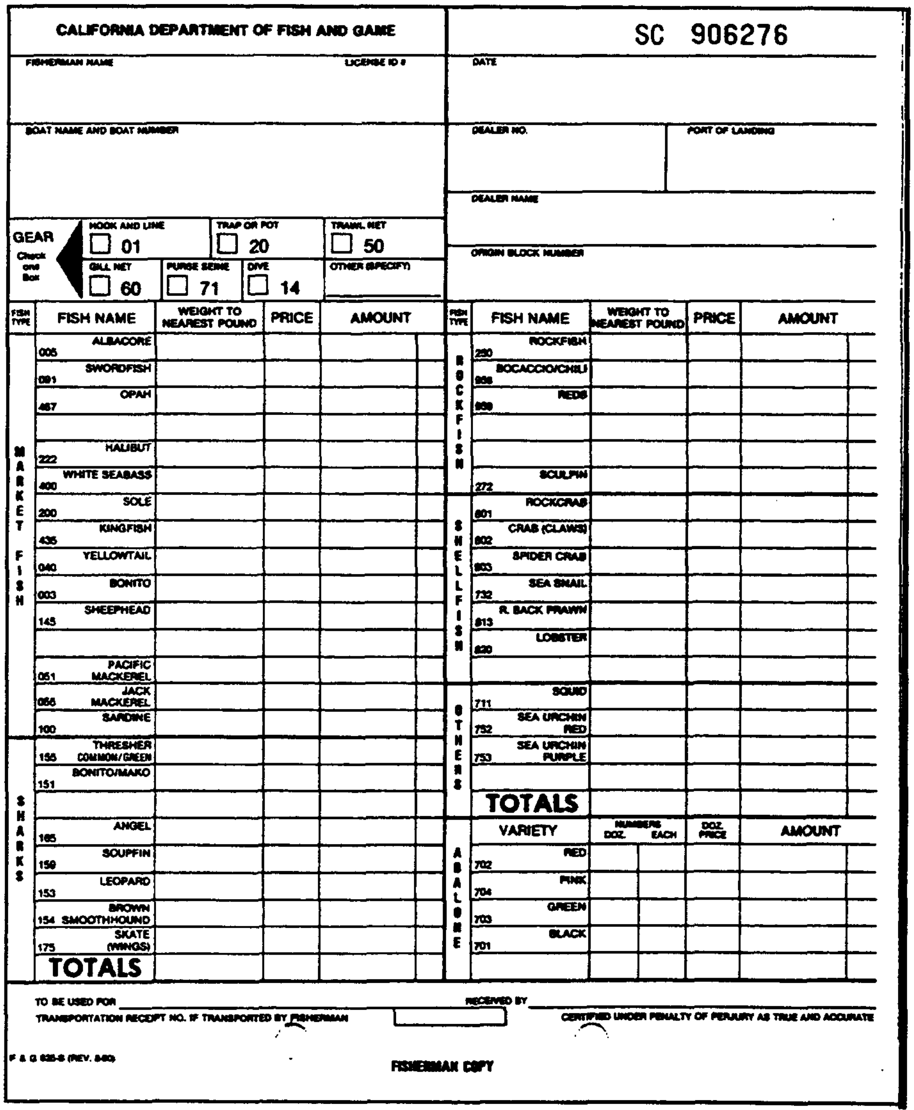
The California drift gill net fishery occasionally catches albacore, skipjack, bigeye, and yellowfin tunas. The status of biological knowledge, stock status, and summaries of directed fisheries for those species can be found in Bartoo (1987), Bayliff (1992), Laurs and Dotson (1992), and Wild (1992).

CATCH ANALYSIS

Landings

Commercial fish buyers have been required to complete a landing receipt (Figure 7) for each landing purchased in California since the early 1900s. The buyer recorded species landed, quantity landed (pounds), price, and fishing gear used (Bureau of Marine Fisheries 1952). Other data such as area fished could have been reported on the landing receipts but often these sections were left blank.

While the instructions for the landing receipts asked buyers to report gill net landings by type of gill net (drift or set), the receipts have an entry only for generic gill net (coded as entangling net in the data base). Because of this ambiguity on the receipt, fish buyers at times neglected to identify the type of gill net used. Also, swordfish, thresher sharks, and shortfin makos, species typically caught by drift gill net, were sometimes reported taken by gear such as trawls, trammel nets, and encircling net—gear that does not ordinarily catch these species. Be-


CALIFORNIA DEPARTMENT OF FISH AND GAME

SC 906276

FISHERMAN NAME | LICENSE ID # | DATE

BOAT NAME AND BOAT NUMBER | DEALER NO. | PORT OF LANDING

DEALER NAME

GEAR Check one Box: HOOK AND LINE 01 | TRAP OR POT 20 | TRAWL NET 50 | GILL NET 60 | PURSE SEINE 71 | DIVE 14 | OTHER (SPECIFY)

ORIGIN BLOCK NUMBER

FISH TYPE	FISH NAME	WEIGHT TO NEAREST POUND	PRICE	AMOUNT
MARKET FISH	005 ALBACORE			
	091 SWORDFISH			
	467 OPAH			
	222 HALIBUT			
	400 WHITE SEABASS			
	200 SOLE			
	435 KINGFISH			
	040 YELLOWTAIL			
	003 BONITO			
	145 SHEEPHEAD			
	051 PACIFIC MACKEREL			
	056 JACK MACKEREL			
	100 SARDINE			
SHARKS	155 THRESHER COMMON/GREEN			
	151 BONITO/MAKO			
	165 ANGEL			
	159 SOUPFIN			
	153 LEOPARD			
	154 BROWN SMOOTHHOUND			
	175 SKATE (WINGS)			
	TOTALS			

FISH TYPE	FISH NAME	WEIGHT TO NEAREST POUND	PRICE	AMOUNT
ROCKFISH	250 ROCKFISH			
	956 BOCACCIO/CHILI			
	959 REDS			
	272 SCULPIN			
SHELLFISH	801 ROCKCRAB			
	802 CRAB (CLAWS)			
	803 SPIDER CRAB			
	732 SEA SNAIL			
	813 R. BACK PRAWN			
	820 LOBSTER			
OTHERS	711 SQUID			
	752 SEA URCHIN RED			
	753 SEA URCHIN PURPLE			
	TOTALS			

FISH TYPE	VARIETY	NUMBERS DOZ.	NUMBERS EACH	DOZ. PRICE	AMOUNT
ABALONE	702 RED				
	704 PINK				
	703 GREEN				
	701 BLACK				

TO BE USED FOR TRANSPORTATION RECEIPT NO. IF TRANSPORTED BY FISHERMAN

RECEIVED BY

CERTIFIED UNDER PENALTY OF PERJURY AS TRUE AND ACCURATE

F & G 635-8 (REV. 8-80)

FISHERMAN COPY

FIGURE 7. Current landing receipt used by commercial buyers of fish landed by the California drift gill net fishery.

cause of these problems associated with reported gear types, criteria were developed to estimate actual landings of the drift gill net fishery.

Landing receipts were separated into three categories: 1) landings with gear reported as drift gill net, 2) landings by vessels with drift gill net-permitted skippers but with gear reported as other than drift gill net, and 3) landings with gear reported as entangling net, trawl, trammel net, encircling net, or set gill net. All landings in category 1 were assumed correct and summed directly as drift gill net landings. (This included the landings for a relatively small number of vessels using drift gill nets and targeting species such as California barracuda, white seabass, and yellowtail *Seriola lalandi*. These vessels fish nearshore waters and use nets with 6-inch or smaller mesh. Their landings are included in Tables 1 and 2.)

Criteria for identifying and separating drift gill net landings from categories 2 and 3 were based on category 1 landings for the 1981-82 and 1982-83 seasons, the period with the fewest reports of catch by unspecified net type (no net type reported in the landing receipt gear code section). Landings for this period were summarized to determine the relative proportions of fish species for both drift and set gill nets. Typically, drift gill net landings had catch proportions of swordfish greater than 20%, thresher shark greater than 30%, and shortfin mako greater than 18%; whereas landings from set gill nets had catch proportions of swordfish less than 6%, thresher shark less than 8%, and shortfin mako less than 2%. Relatively large percentages of Pacific herring *Clupea pallasi* (greater than 70%) were identified as set gill nets. Also noted in set net landings were angel shark, rays, and skates; these nearshore species were rarely reported in drift gill net landings.

Based on the above findings, category 2 and 3 landings were considered drift gill net landings if no Pacific herring was landed and if landings receipts reported gear as entangling nets, trammel nets, trawls, encircling nets, or set gill nets and the landing contained more than 20% swordfish, 30% thresher shark, or 18% shortfin mako. Landings were not included in the drift gill net summaries if angel sharks, rays, skates, or California sheephead *Semicossyphus pulcher* were reported.

Landings in category 2 were screened with additional criteria if the reported gear was "unknown." These landings were considered drift gill net landings if 1) swordfish was greater than 20% and thresher shark greater than 30% of the fish landed, or 2) swordfish landed was greater than 20% and shortfin mako was greater than 18%, or 3) thresher shark was greater than 30% and shortfin mako was greater than 18%. These criteria were developed to insure that "gear unknown" landings reported as 100% swordfish would not be included as gill net landings, but more appropriately as harpoon landings.

Data summarized with the above criteria show that the number of drift gill net vessel landings increased to a high of 3500 in the 1983-84 season and decreased steadily to a low of 1500 in the 1990-91 season (Figure 8a). The number of drift gill net vessels peaked in 1985-86 at 309 and decreased to less than 200 in the 1990-91 season (Figure 8b). The number of vessels shown in Figure 8b are at times higher than the annual 250-vessel permit limit. This was caused by the criteria used to estimate drift gill net fishery landings, where some landings with

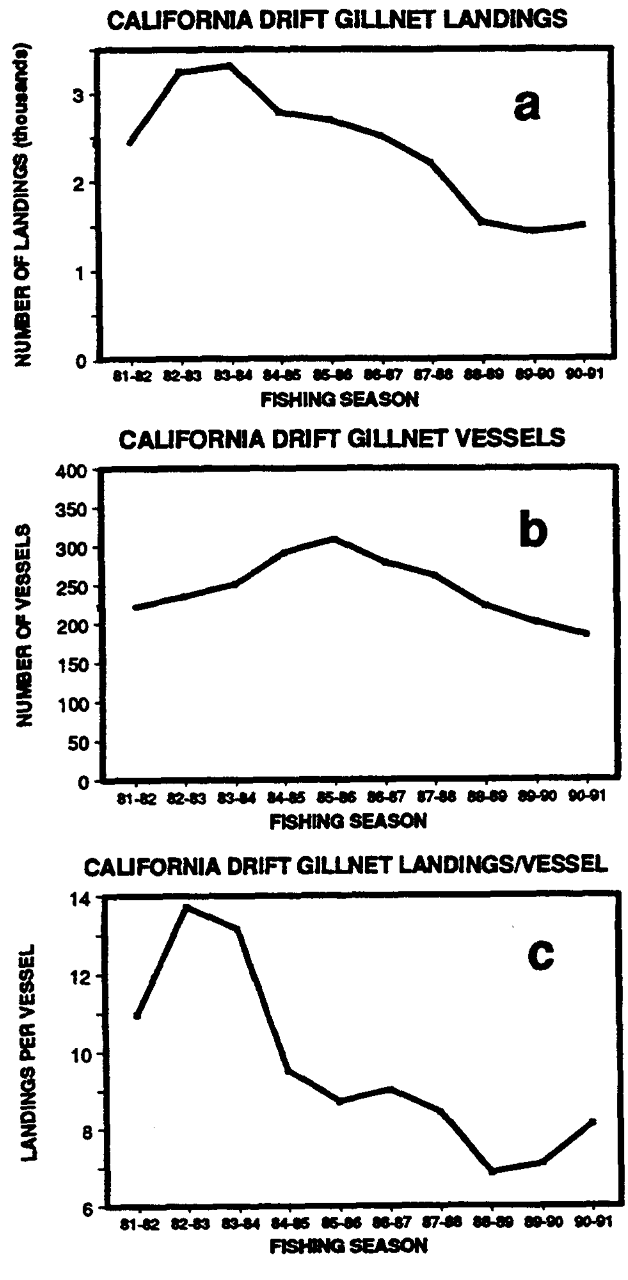


FIGURE 8. Number of landings (a), vessels (b), and landings per vessel (c) for the California drift gill net fishery, 1981-82 through 1990-91.

gear identified as drift gill net were made by a nonpermitted vessel. Landings per vessel decreased sharply from a high of 13 in the 1982-83 season to lows of seven and eight in the 1988-89 to 1990-91 seasons (Figure 8c).

The principle species landed by the drift gill net fishery were swordfish, common thresher, and shortfin mako (Table 1). Common thresher dominated the catch in the 1981-82 (60%) and 1982-83 (48%) fishing seasons, but swordfish dominated during the 1983-84 to 1990-91 (53% to 68%) fishing seasons (Figure 9). Swordfish landings increased from a low of 700,000 lb in the 1981-82 season to a high of 3.4 million lb in the 1984-85 season and then declined to 1.5 million lb in the 1990-91 season. Common thresher landings decreased steadily from a high of 2.2 million lb in the 1981-82 season to a relatively constant level of 400,000 to 500,000 lb during the 1986-87 to 1990-91 seasons. Landings of shortfin mako peaked in the 1982-83 season at 500,000 lb, but have remained relatively stable between 200,000 and 300,000 lb since then.

Other species were also landed in the drift gill net fishery, although in lesser quantities (Table 1). The largest quantity in this group was tuna, dominated by albacore which peaked at over 200,000 lb in the 1985-86 season and dwindled to 23,000 lb in the 1990-91 season. Shark landings other than thresher and shortfin mako were dominated by the "unspecified shark" category during the early seasons and by soupfin shark during the later seasons. The recorded high landings of over 200,000 lb of "unspecified shark" in the 1981-82 season may include a high rate of accidental or intentional misidentification of illegally caught and landed swordfish. Opah dominated catches of other fish species and reached a high of 260,000 lb in the 1984-85 season.

Logbooks

Logbooks have been collected from skippers of California drift gill net vessels under a mandatory logbook system implemented in 1980 (Huppert and Odemar 1986). Data collected from the logbooks include catches (number of fish) by species, date, mesh size, length of net, hours soaked, set number, geographical position of set, and other information such as the drift gill net permit number and vessel registration number (Figure 10).

Geographical positions entered on logbooks were CDFG block numbers (usually a 10-min square). We converted these block numbers to latitude and longitude for plotting. Some catch locations were either a series of block numbers or blocks larger than a 10-min square. For those cases, a latitude and longitude for a quadrangle encompassing all of the catch locations was chosen (e.g. 1°, 5°, 5° x 10°, or larger quadrangle).

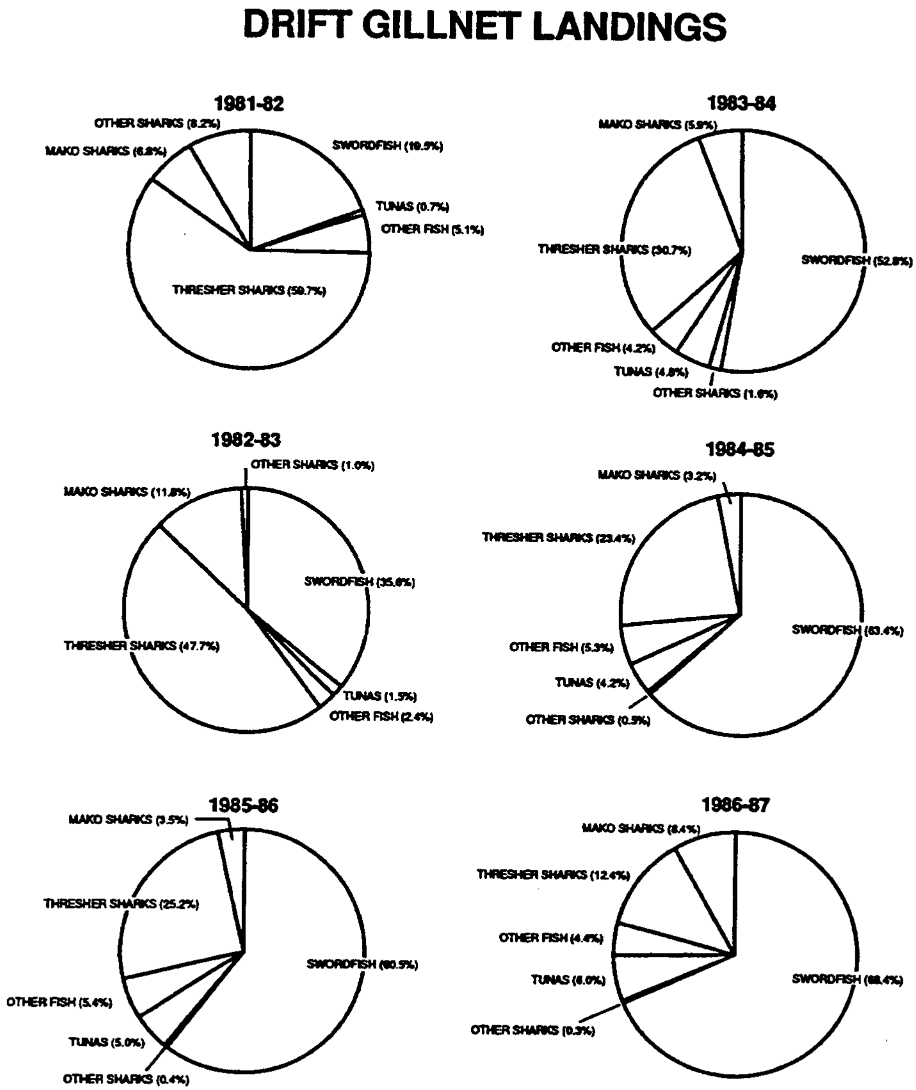


FIGURE 9a. Species composition of California drift gill net landings for the 1981-82 through 1986-87 fishing seasons.

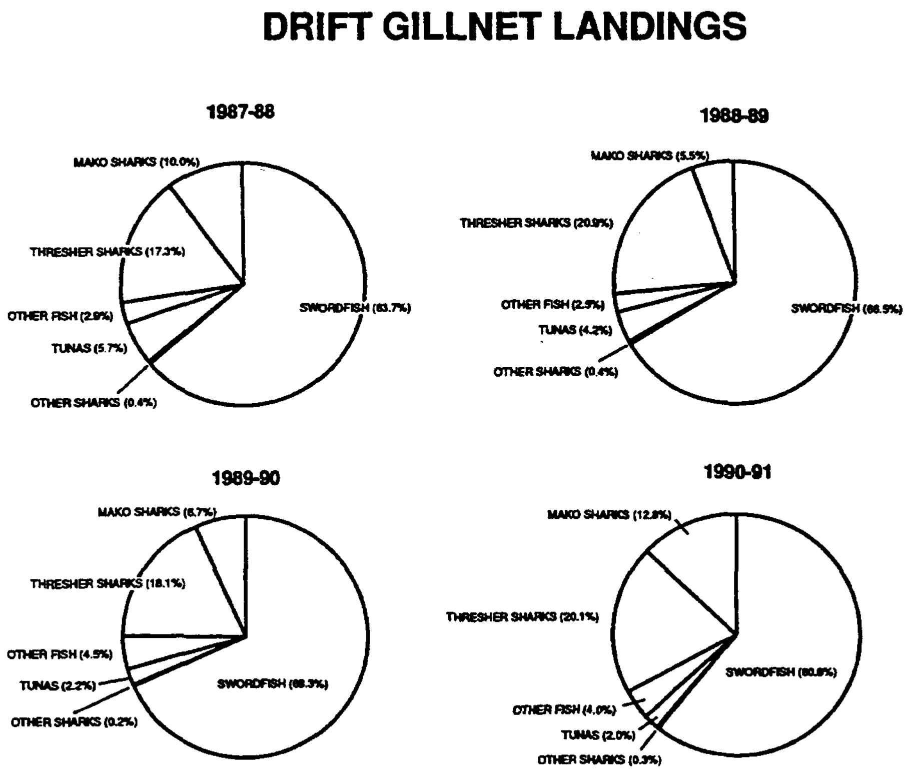
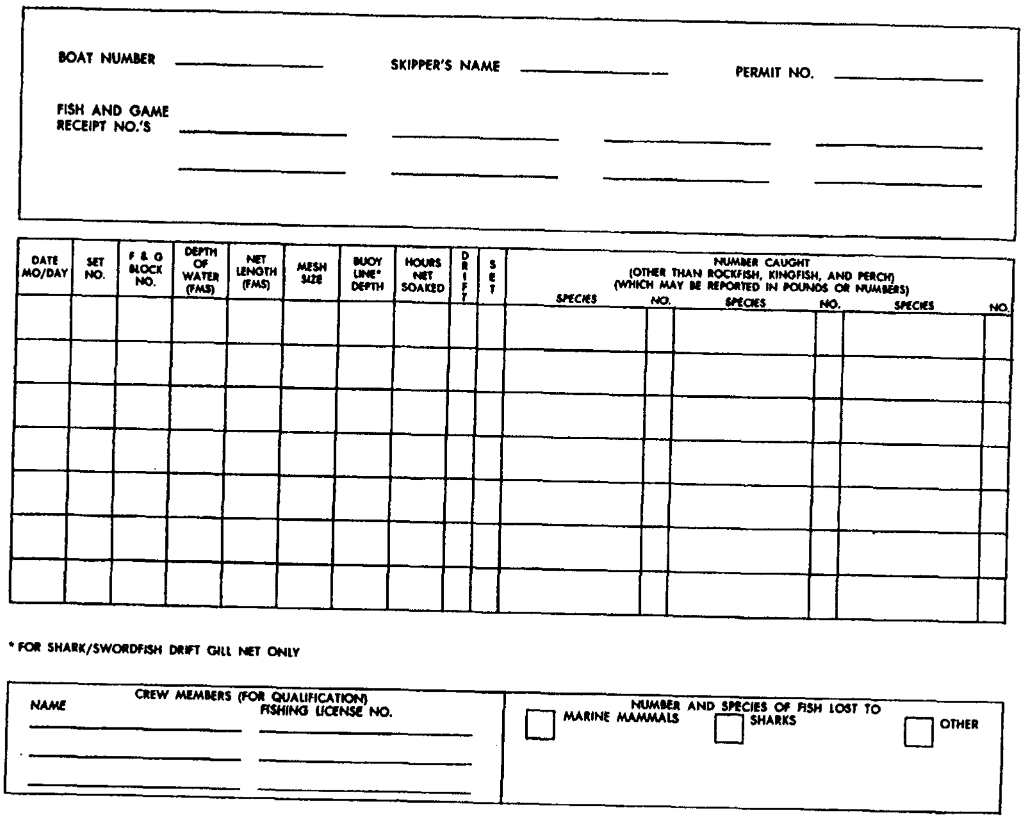


FIGURE 9b. Species composition of California drift gill net landings for the 1987-88 through 1990-91 fishing seasons.

Logbooks were collected from a majority of the drift gill net fleet and included data on most species caught, especially those that could be sold. Due to the volume of the data collected, this report will show seasonal and geographical distributions of only the four major species groups: swordfish, thresher sharks (common, pelagic, and bigeye), shortfin mako, and opah.

Coverage rates (proportion of landed fish weight reported in the logbooks) were determined by converting logbook catch to weight (number of fish times mean weight) and dividing by the corresponding weight reported on the landing receipt. Coverage rates in the 1981-82 season were very low, 6% for swordfish, 1% for thresher sharks, and 1% for shortfin makos. This was probably due to the newness of the logbook program that contributed to a low logbook return rate and possibly some deliberate misreporting of landings. Coverage rates for other



BOAT NUMBER ________ SKIPPER'S NAME ________ PERMIT NO. ________

FISH AND GAME RECEIPT NO.'S ________ ________ ________ ________

________ ________ ________ ________

DATE MO/DAY	SET NO.	F & G BLOCK NO.	DEPTH OF WATER (FMS)	NET LENGTH (FMS)	MESH SIZE	BUOY LINE* DEPTH	HOURS NET SOAKED	DRIFT	SET	NUMBER CAUGHT (OTHER THAN ROCKFISH, KINGFISH, AND PERCH) (WHICH MAY BE REPORTED IN POUNDS OR NUMBERS)					
										SPECIES	NO.	SPECIES	NO.	SPECIES	NO.

* FOR SHARK/SWORDFISH DRIFT GILL NET ONLY

CREW MEMBERS (FOR QUALIFICATION)

NAME	FISHING LICENSE NO.

NUMBER AND SPECIES OF FISH LOST TO

☐ MARINE MAMMALS ☐ SHARKS ☐ OTHER

FIGURE 10. Current California Department of Fish and Game logbook used to record catches and fishing effort of drift gill net vessels.

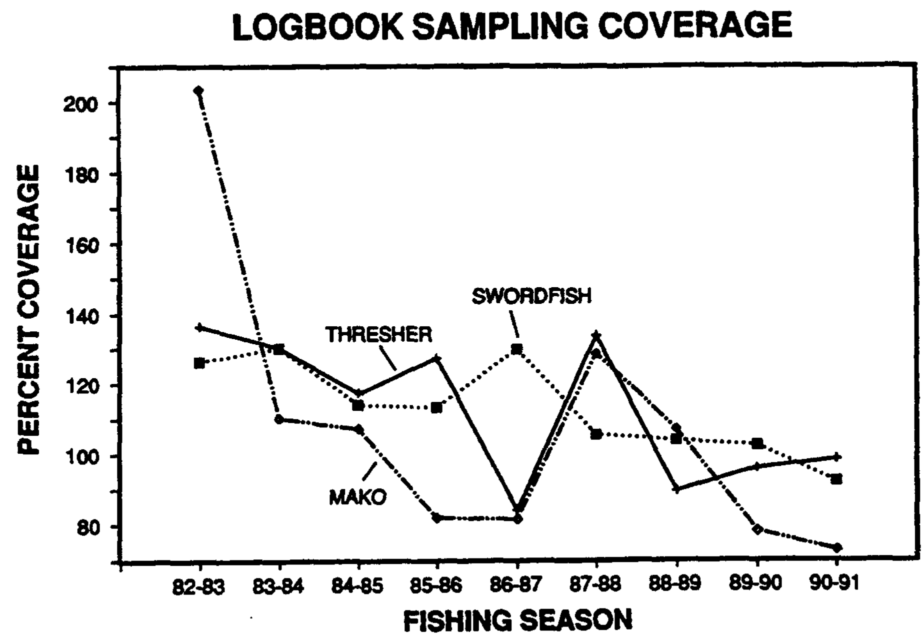


FIGURE 11. Coverage rates for drift gill net logbooks, 1982-83 through 1990-91. Rates are calculated as logged catch/landed weight. Coverage rates for the 1981-82 season were unusually low (6% for swordfish, 1% for common thresher and shortfin mako) and have not been included.

years for each of these species were almost always greater than 100% (Figure 11). Coverage rates over 100% may have been caused by overestimates in the reported logbook catches, or our calculated mean weights may have been biased high and overestimated actual landings. Also, landing receipts with an incorrectly recorded gear code (whether an inadvertent mistake or a conscious effort to subvert catch-ratio regulations) may not have been included in the summaries of drift gill net-caught fish.

Swordfish

Logbook data closely followed landings data showing a peak in the catch during the 1984-85 season of 26,000 swordfish and a decreasing trend to 9000 swordfish in the 1990-91 season (Figure 12a). Catches of swordfish usually began in May to July in each fishing season, peaked in October and November and tapered off in December and January of the following year (Figure 12b).

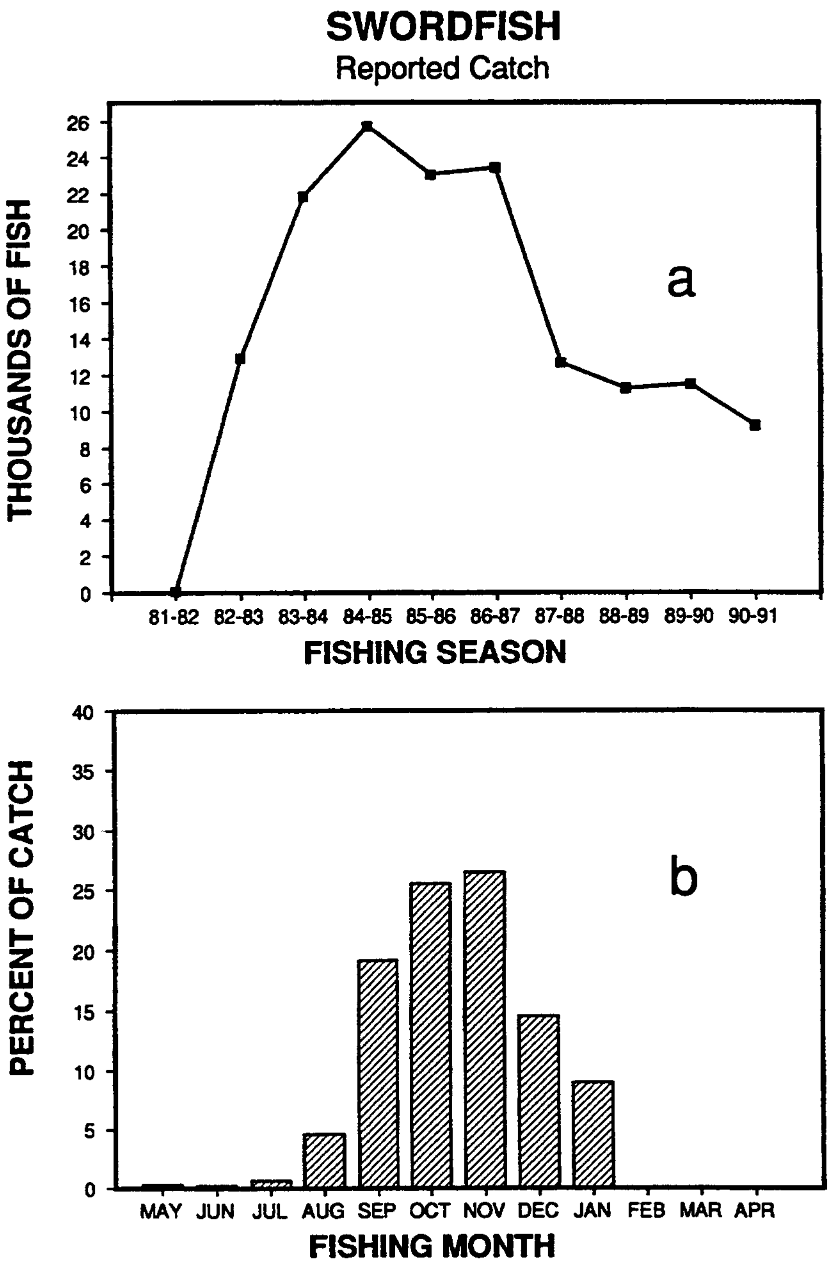


FIGURE 12. Logged catch of swordfish in number of fish by fishing season, 1981-82 through 1990-91 (a) and logged catch by month, all fishing seasons combined (b).

Swordfish were caught mainly in waters between San Diego and San Francisco and within 300 miles of shore (Figure 13). During the 1981-82 and 1982-83 seasons, areas of highest catches were off San Diego and expanded to include some areas around the Channel Islands during the following seasons. Small numbers of swordfish were also caught in areas between San Francisco and the California-Oregon border and within 120 miles of the shoreline. Some catches occurred farther north off Oregon and Washington, but because in some seasons the exact positions were not reported (designated only as off Oregon), they are depicted here in a 1° square at lat. 40° to 41° N (Figure 13).

Common Thresher

The catch of common thresher reported on logbooks in 1981-82 was only 1000 fish, while landings exceeded 2 million lb. In 1982-83, logbook-reported catches climbed to over 20,000 fish and remained relatively high through the 1985-86 season (Figure 14a). Beginning with the 1986-87 season, the Legislature reduced the drift gill net thresher shark fishery to 30 days in May. As a result, mean catches of common thresher dropped to 6000 fish per season. In 1990-91, the Legislature closed the spring drift gill net fishery within 75 miles of shore, thus eliminating the directed thresher shark fishery in California.

When not restricted by closures, the highest proportion of catch was reported during May and June with 50% of the annual catch taken during these 2 months. The remainder of the catch was taken as incidental catch as the drift gill net fishery targeted swordfish during the summer and fall months. During the 10-year period, total catch varied somewhat between seasons, although the rate fluctuated little after the initial months of May and June (Figure 14b).

During the first years, most of the catch of common threshers was concentrated within the Southern California Bight. As the fishery expanded northward in 1982, catches off San Francisco (and north to about the Mendocino Ridge) became an important component of the total catch (Figure 15). A few drift gill net vessels fished Oregon and Washington waters near the Columbia River in 1986 and 1987 and landed 58,000 lb of common thresher in California. An additional 890,000 lb, landed in Oregon and Washington during these 2 years (Stick and Hreha 1988), are not included in our analyses.

Pelagic and Bigeye Threshers

During the 10 fishing seasons 1981-82 to 1990-91, only 624 pelagic and 1891 bigeye threshers were reported on logbooks, although more may have been misreported as common threshers. A high proportion of the pelagic thresher catch was reported for May (Figure 16). They were also frequently caught in October

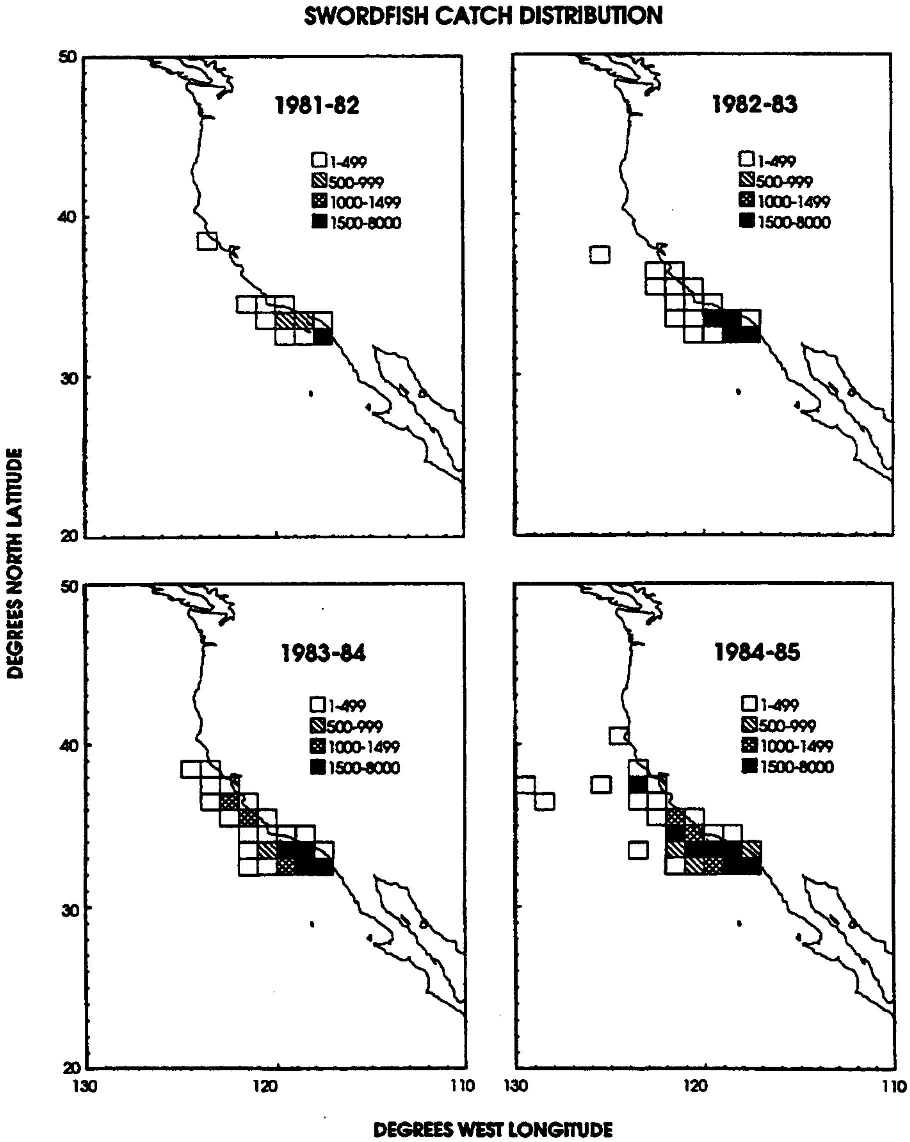


FIGURE 13a. Distribution of swordfish catches by 1° quadrangle from California drift gill net logbook data for the 1981-82 through 1984-85 fishing seasons.

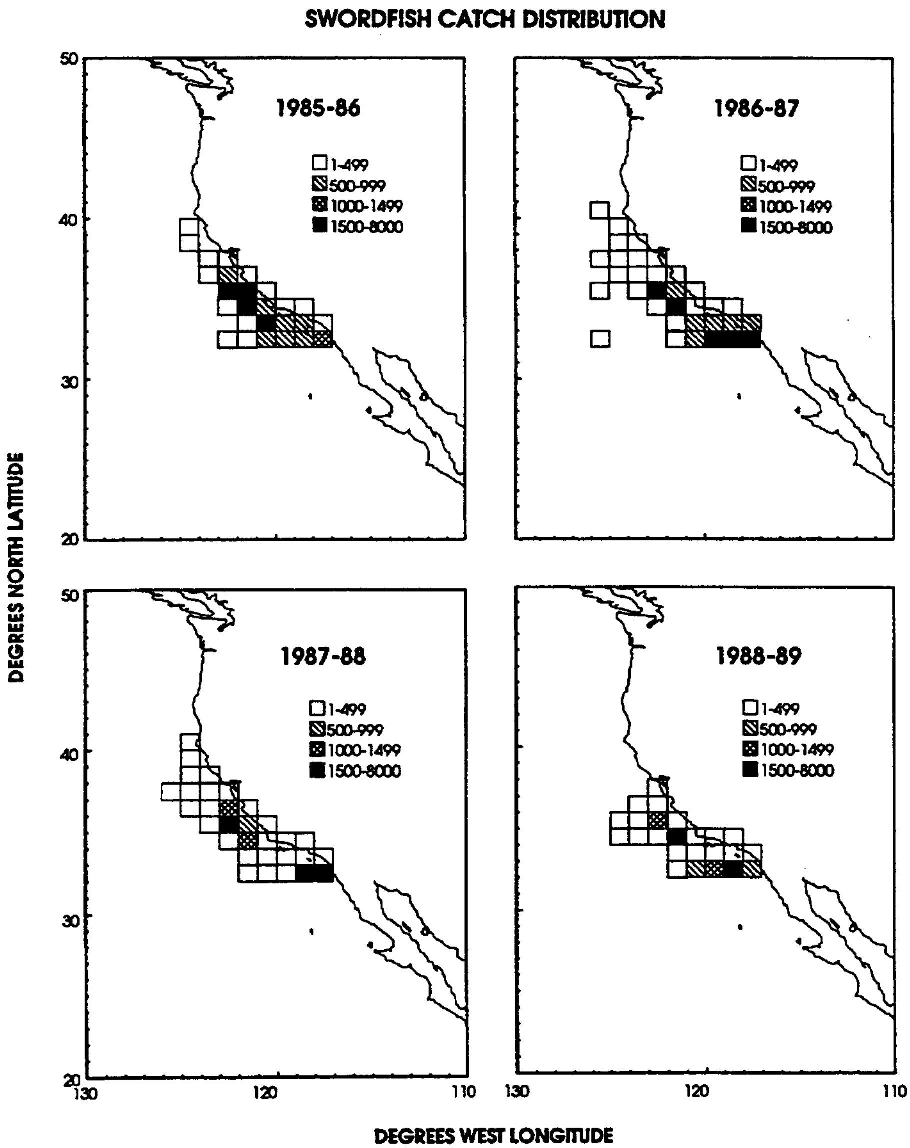


FIGURE 13b. Distribution of swordfish catches by 1° quadrangle from California drift gill net logbook data for the 1985-86 through 1988-89 fishing seasons.

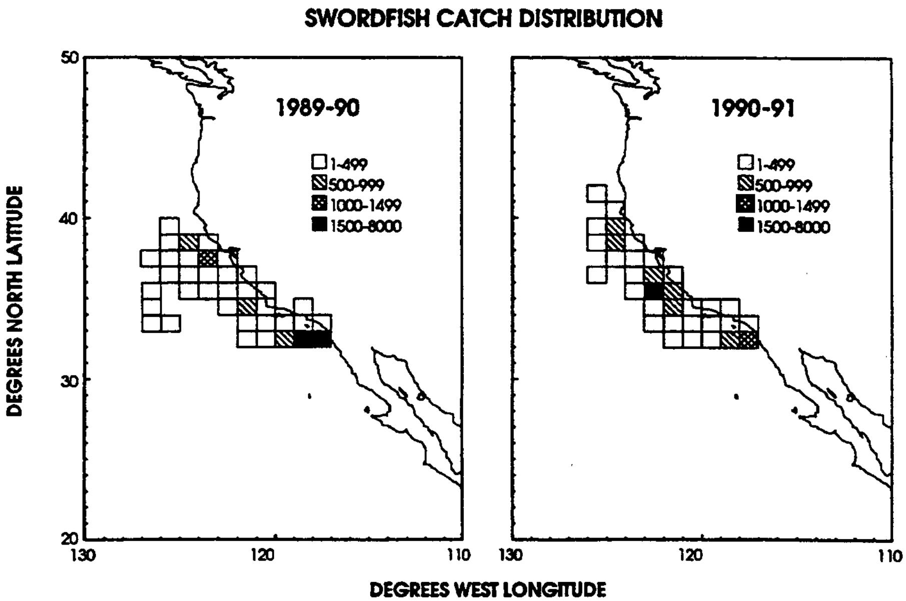


FIGURE 13c. Distribution of swordfish catches by 1° quadrangle from California drift gill net logbook data for the 1989-90 and 1990-91 fishing seasons.

through January. Bigeye threshers were caught in August to November with a peak in September (Figure 17). Catches of both species were concentrated in the southern areas of the Southern California Bight (Figures 18 and 19).

Shortfin Mako

Reported catches of shortfin mako peaked in the 1982-83 season at 19,500 fish and again in the 1986-87 season at 13,500 fish (Figure 20a). The 1981-82 reported catch (299 shortfin makos) was apparently low, because landings of 250,000 lb were reported on landing receipts. Average catch in the remaining years was just over 9300 fish or about 318,000 lb. Between the 1981-82 and 1988-89 seasons, shortfin makos were caught incidentally to thresher shark and swordfish from May to January, although the greatest portion was taken during July through September (Figure 20b). The proportion of catch in May declined substantially after the 1989 drift gill net fishing closure within 75 miles of shore during the spring. Overall, catches for the 10 years of data peaked in August and declined through winter months (Figure 20b).

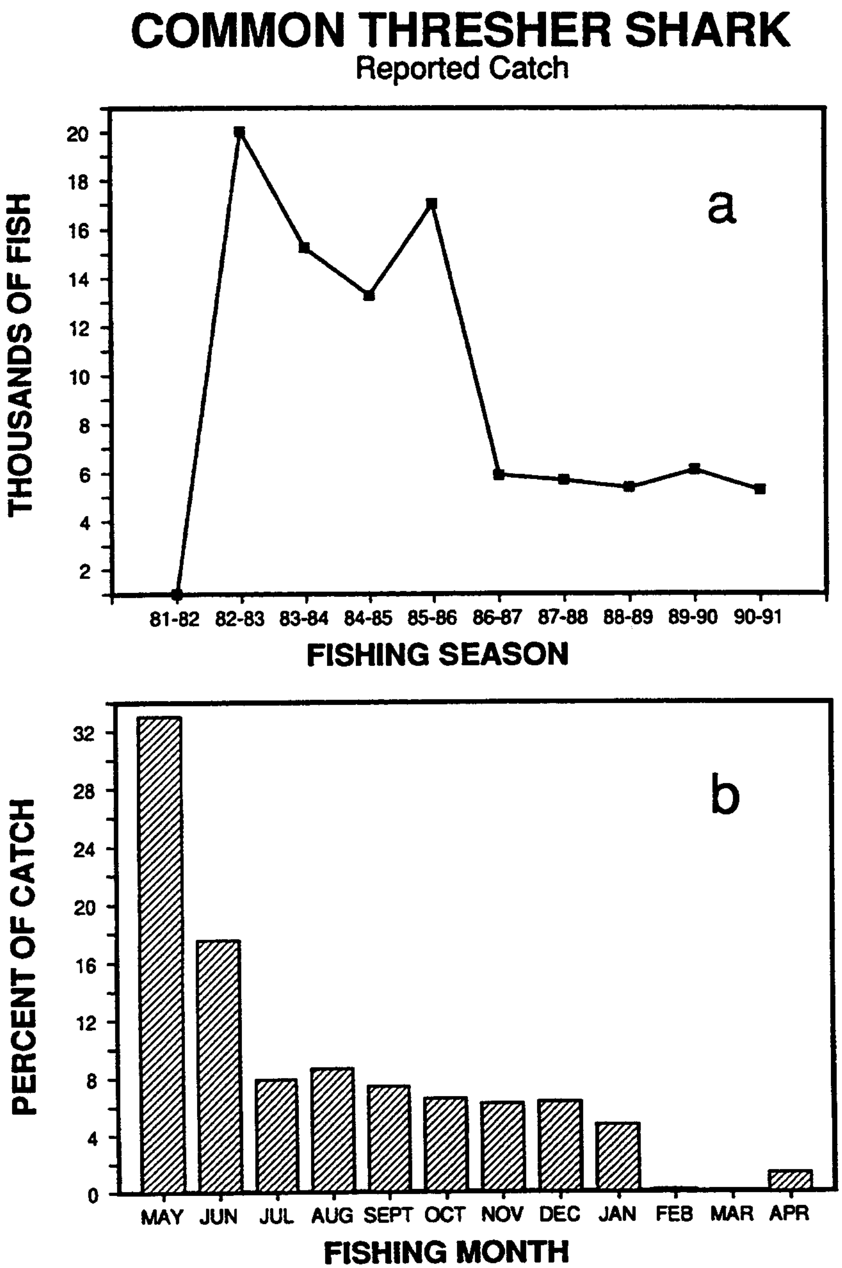


FIGURE 14. Logged catch of common thresher in number of fish by fishing season, 1981-82 through 1990-91 (a) and logged catch by month, all fishing seasons combined (b).

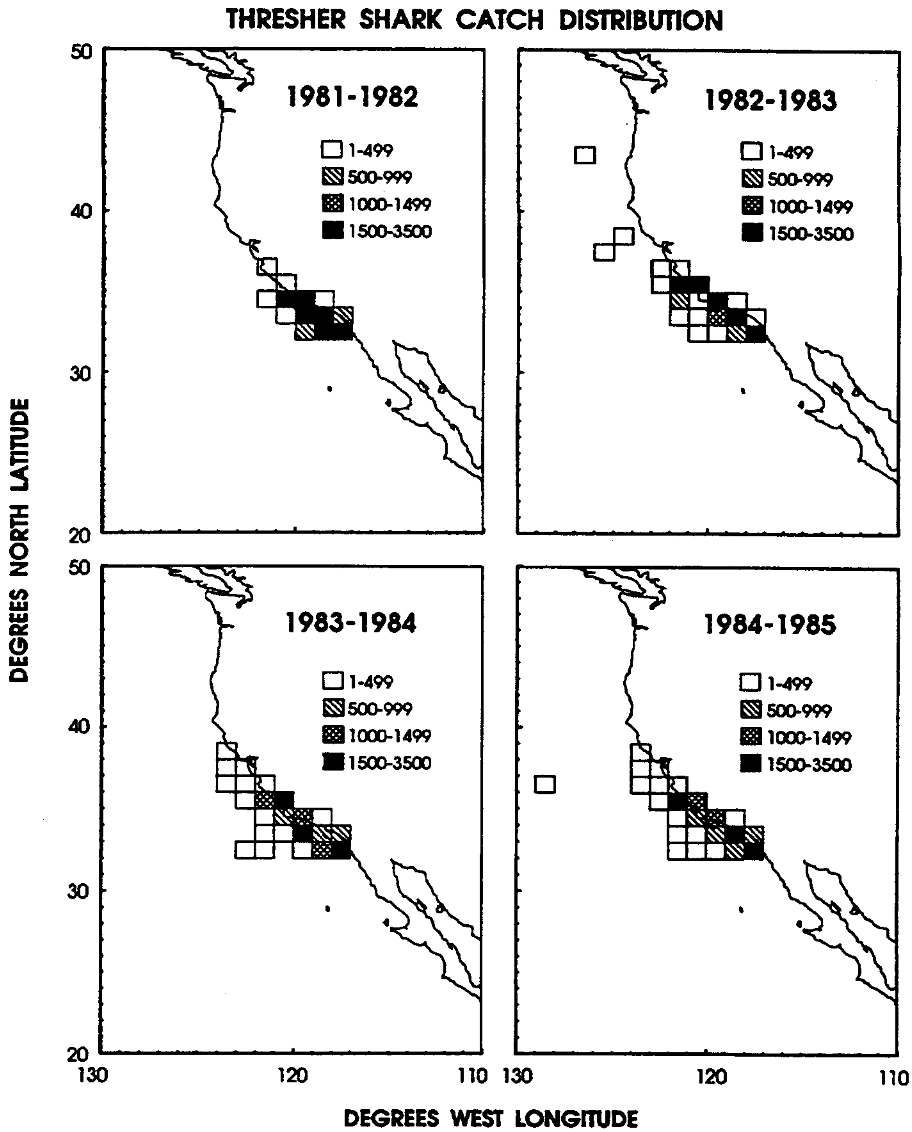


FIGURE 15a. Distribution of common thresher catches by 1° quadrangle from California drift gill net logbook data for the 1981-82 through 1984-85 fishing seasons.

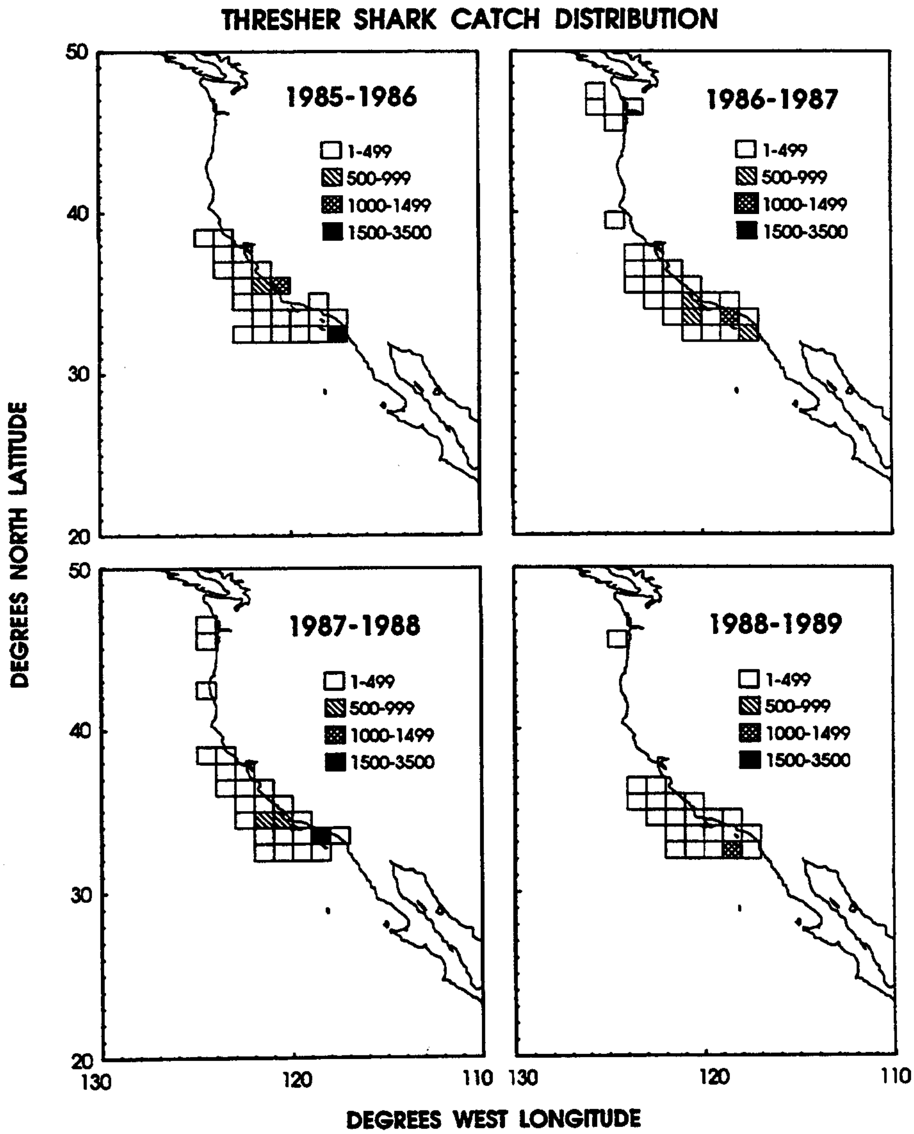


FIGURE 15b. Distribution of common thresher catches by 1° quadrangle from California drift gill net logbook data for the 1985-86 through 1988-89 fishing seasons.

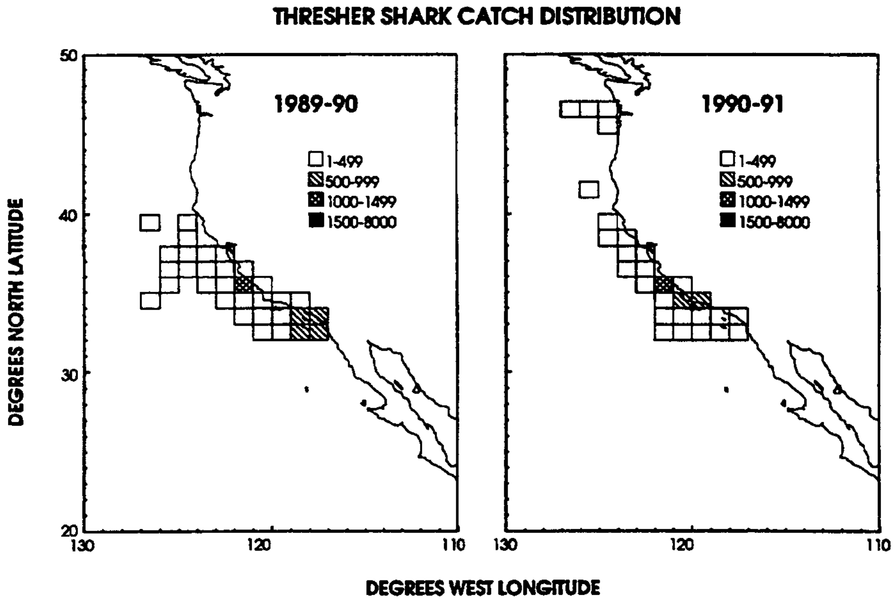


FIGURE 15c. Distribution of common thresher catches by 1° quadrangle from California drift gill net logbook data for the 1989-90 and 1990-91 fishing seasons.

Greatest shortfin mako catches were reported within the Southern California Bight. Sparse catches were recorded northward to about San Francisco in the early years following the 1982-83 season. Shortfin mako catches were rarely reported north of Cape Mendocino or beyond 200 miles from shore (Figure 21).

Opah

Logbook catch data for opah closely followed landings data and showed peaks of 4300 fish in the 1984-85 season and 4100 fish in the 1985-86 season. After 1986, opah catches declined to a low of 600 fish in the 1988-89 season, then increased to 1300 fish in the 1989-90 season and 1100 fish in the 1990-91 season. Monthly catch summaries peaked in May (Figure 22), especially during the 1986-87 and 1988-89 seasons when 46% to 49% of the catch was reported in May. For the balance of the year, catches were rather evenly distributed during June to January with a peak in August. Opah catches occur throughout the range of the fishery, but are highest in the south (Figure 23).

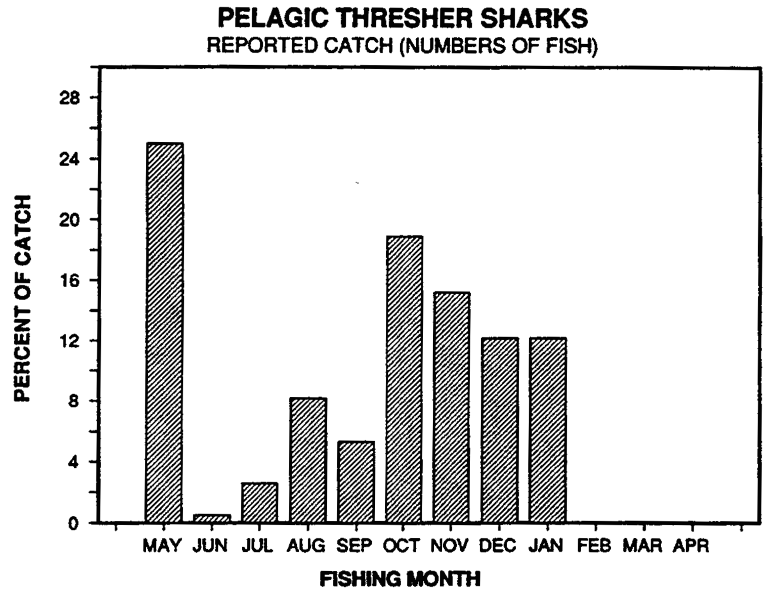


FIGURE 16. Logged catch of pelagic thresher in number of fish by month, all fishing seasons, 1981-82 through 1990-91 combined.

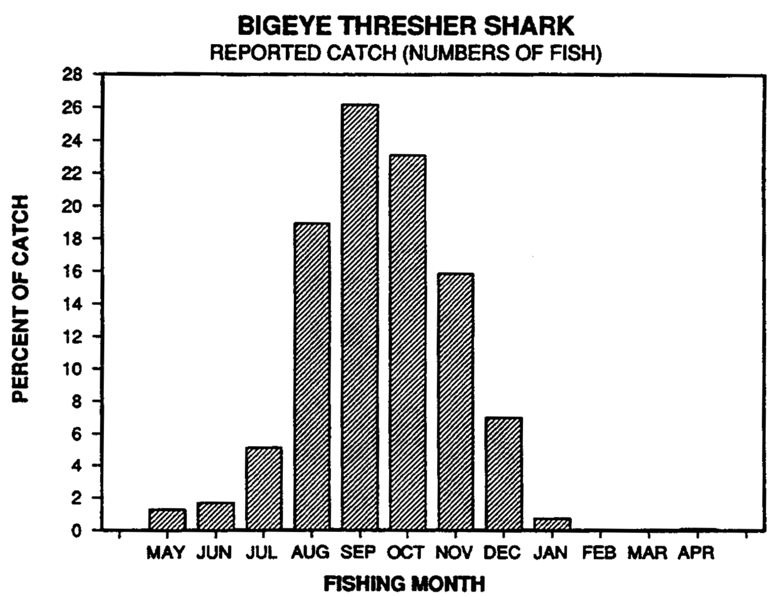


FIGURE 17. Logged catch of bigeye thresher in number of fish by month, all fishing seasons, 1981-82 through 1990-91 combined.

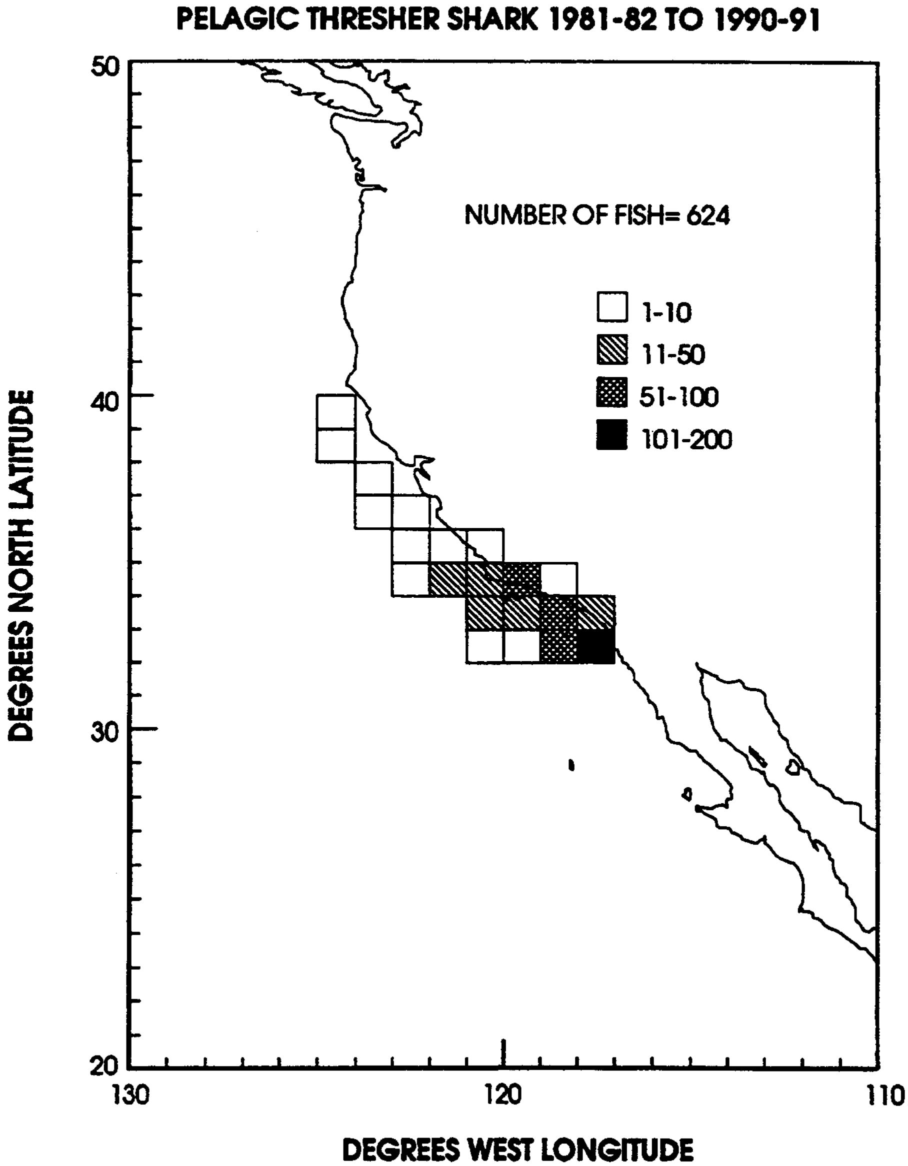


FIGURE 18. Distribution of pelagic thresher catches by 1° quadrangle from California drift gill net logbook data for the 1981-82 through 1990-91 fishing seasons.

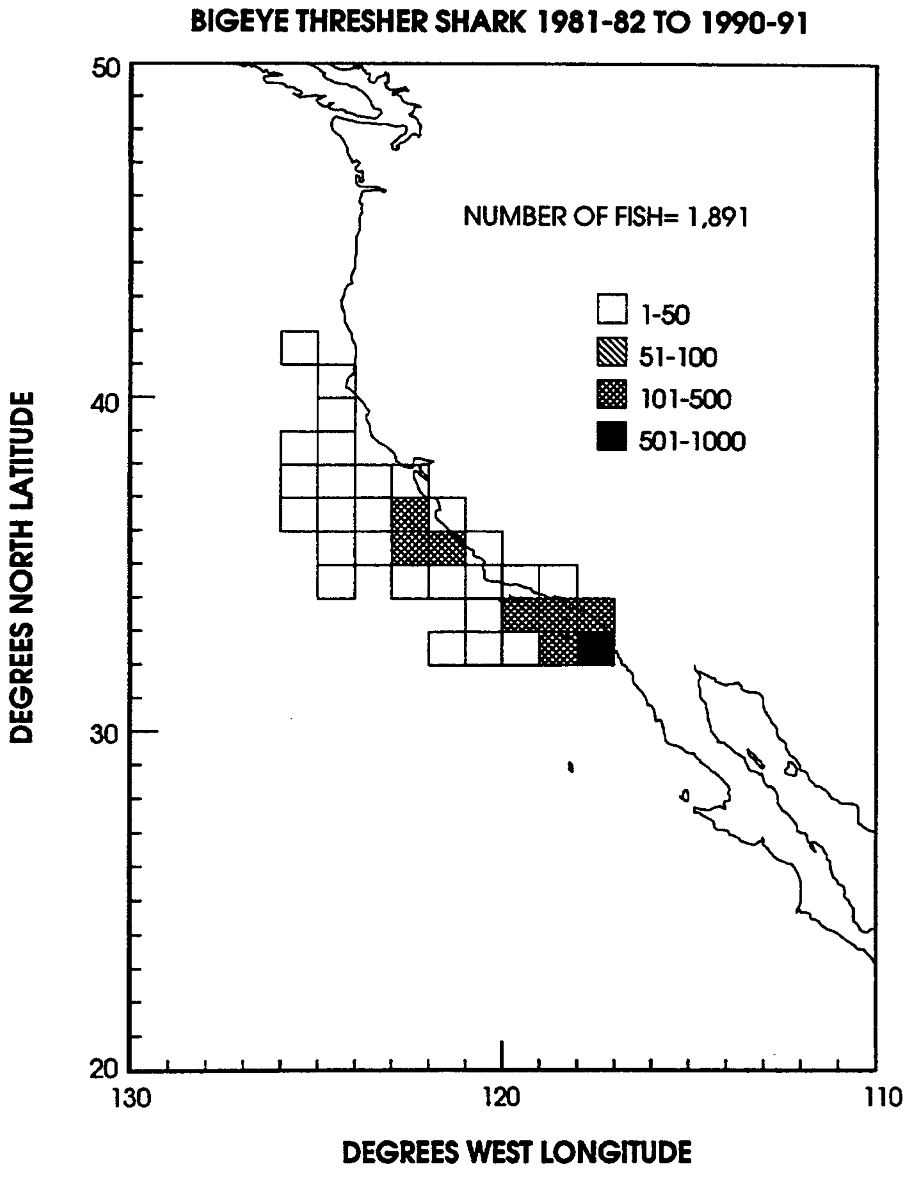


FIGURE 19. Distribution of bigeye thresher catches by 1° quadrangle from California drift gill net logbook data for the 1981-82 through 1990-91 fishing seasons.

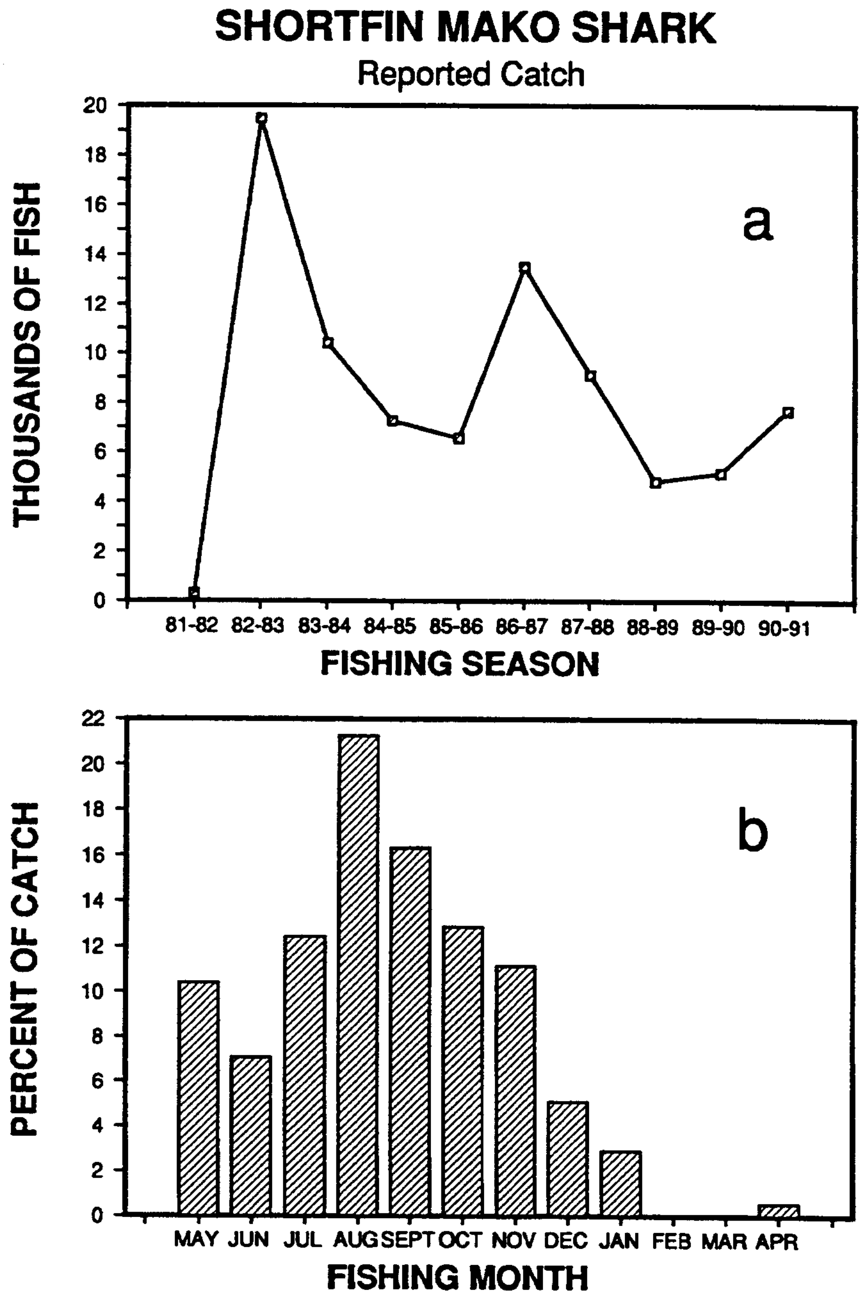


FIGURE 20. Logged catch of shortfin mako in number of fish by fishing season, 1981-82 through 1990-91 (a) and logged catch by month, all fishing seasons combined (b).

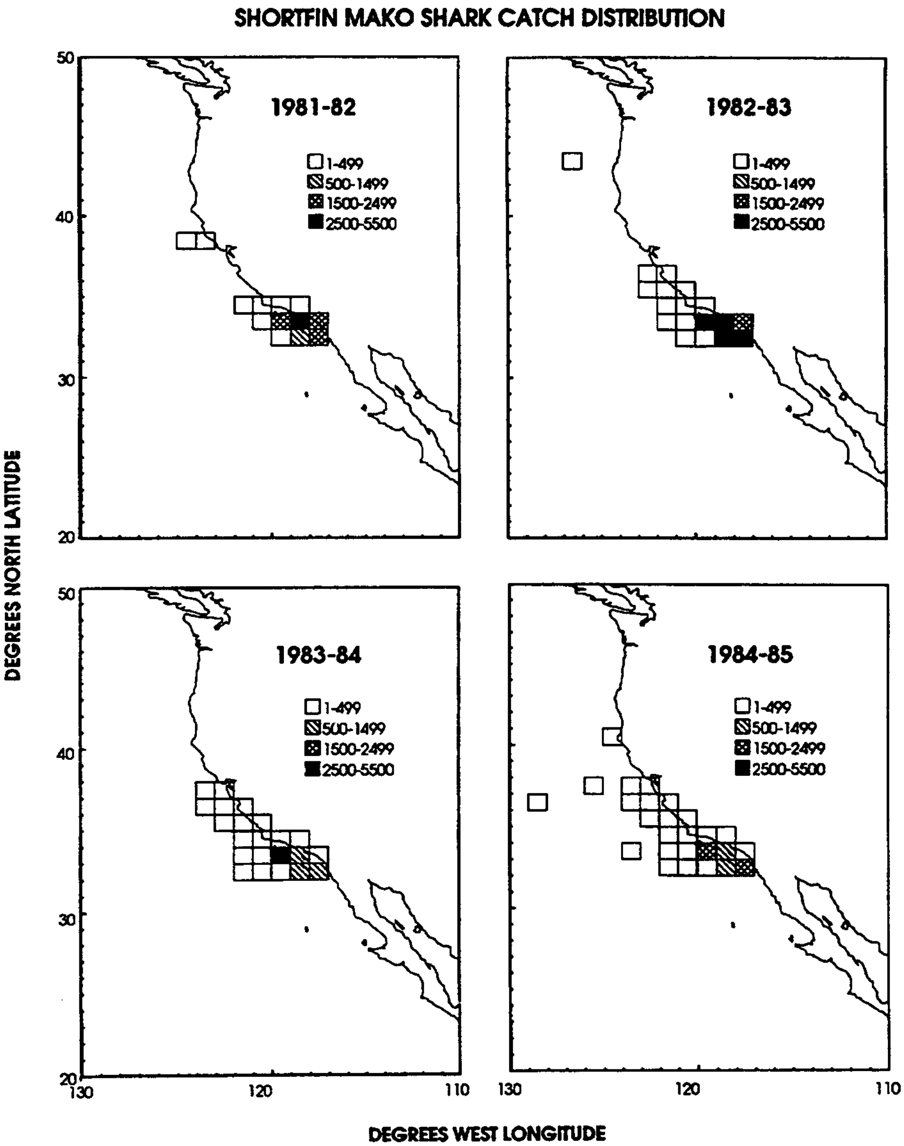


FIGURE 21a. Distibution of shortfin mako catches by 1° quadrangle from California drift gill net logbook data for the 1981-82 through 1984-84 fishing seasons.

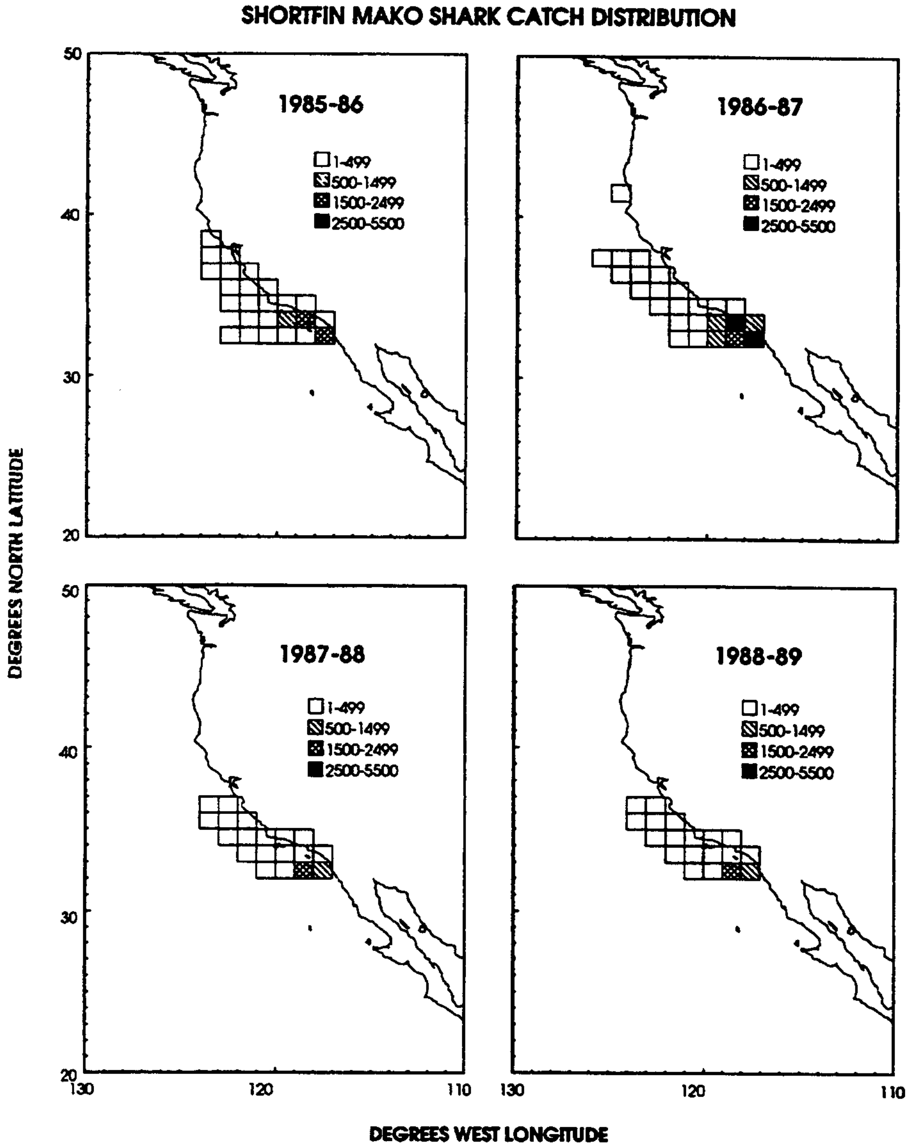


FIGURE 21b. Distribution of shortfin mako catches by 1° quadrangle from California drift gill net logbook data for the 1985-86 through 1988-89 fishing seasons.

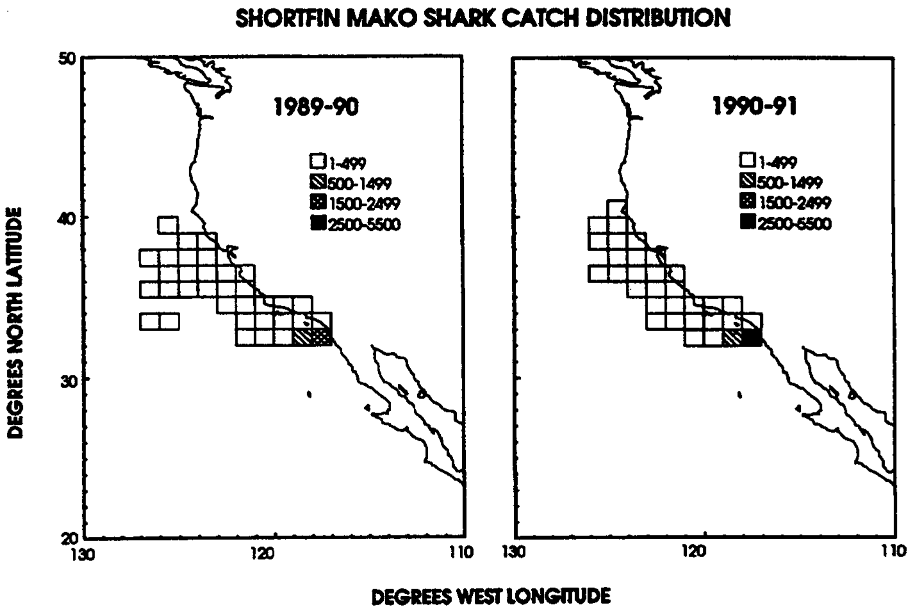


FIGURE 21c. Distribution of shortfin mako catches by 1°quadrangle from California drift gill net logbook data for the 1989-90 and 1990-91 fishing seasons.

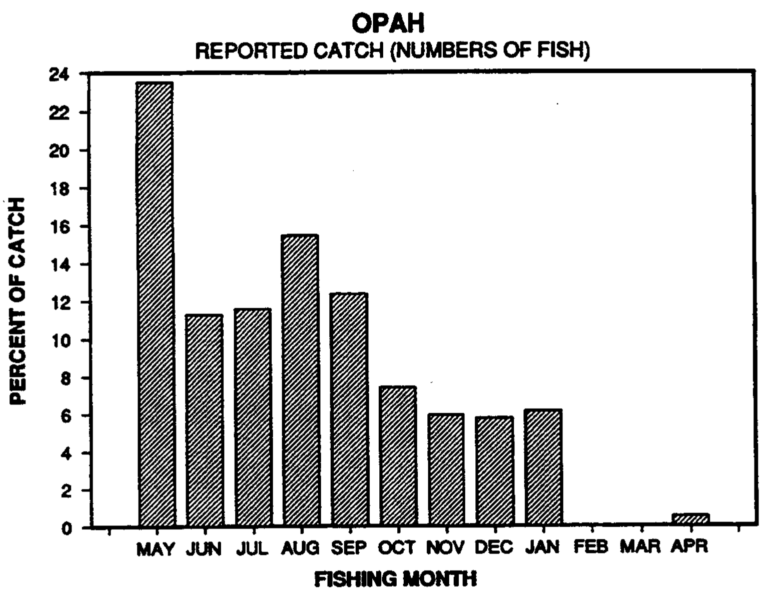


FIGURE 22. Logged catch of opah in number of fish by month, all fishing seasons, 1981-82 through 1990-91 combined.

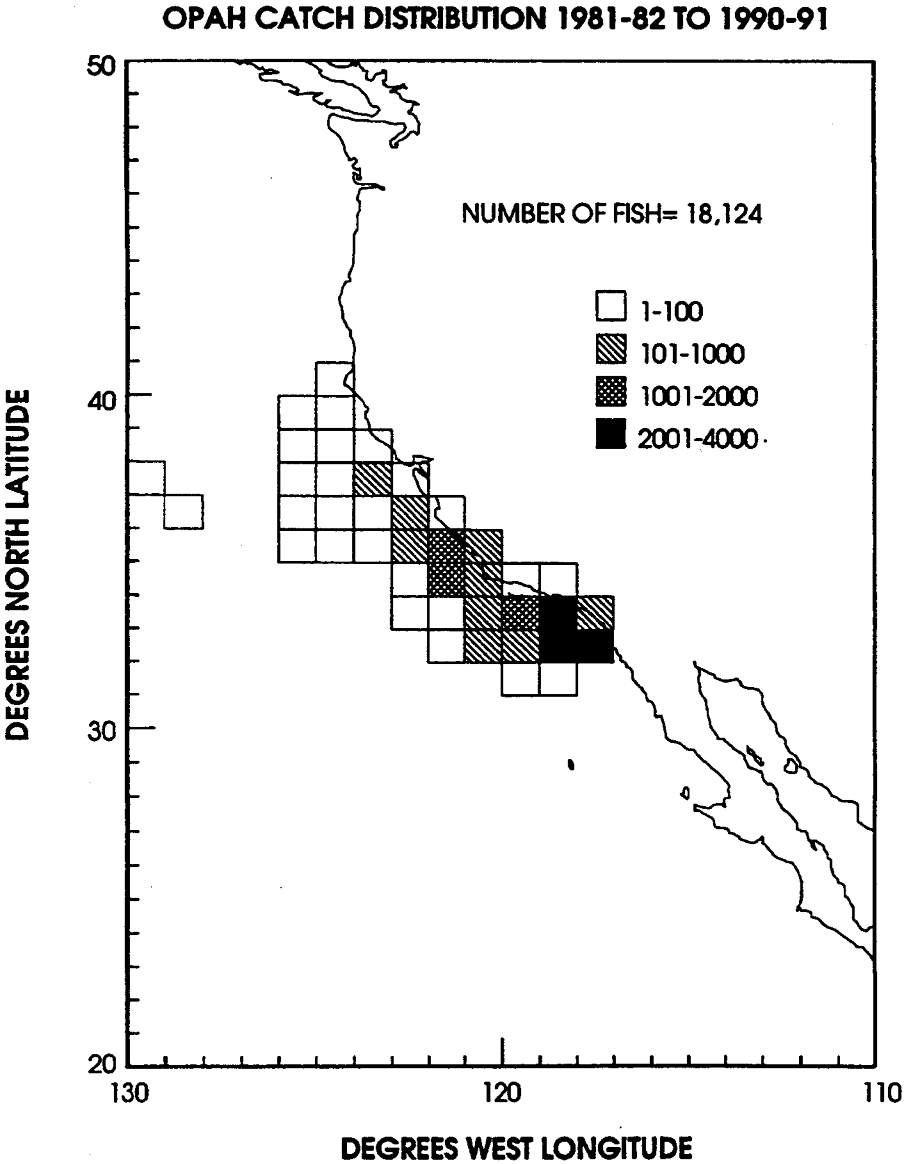


FIGURE 23. Distribution of opah catches by 1°quadrangle from California drift gill net logbook data for the 1981-82 through 1990-91 fishing seasons.

SIZE COMPOSITION

The CDFG began a program in 1981 to sample the landings of drift gill net vessels as catches were unloaded at commercial markets (Odemar 1982). Samples were taken at ports as far north as San Francisco and as far south as San Diego. While the majority of the samples were from catches made in the Southern California Bight, some samples were from catches made as far north as Oregon and Washington, as far south as the California-Mexico border, or as far as 250 miles offshore. Port samplers recorded lengths and weights of swordfish, thresher sharks, and shortfin makos (Figure 24). Sharks and swordfish were dressed at sea (headed and eviscerated), therefore lengths of these species measured at the wholesalers were alternate lengths (AL). Alternate length for swordfish was measured from the anterior margin of the cleithrum to the fork of the tail; for sharks, AL was measured from the origin of the first dorsal fin to the origin of the second dorsal fin (Figure 25). Measurements were taken with calipers to the nearest millimeter.

Lengths and weights, as well as other biological parameters (sex, pup counts, etc.), were recorded occasionally for other species (tunas, opah, louvar, etc.). Although size-composition samples were taken of many species of fish from landings at commercial fish markets, the vast majority of the samples were of swordfish, thresher sharks (common, pelagic, and bigeye) and shortfin mako (Table 4).

Size-composition coverage rates were estimated as the number of fish measured divided by the number of fish reported in logbooks. Coverage rates were highest for swordfish in all seasons except 1982-83 and 1989-90 when thresher sharks or shortfin mako were targeted by samplers (Figure 26). Swordfish samples rose from a low of 207 in the 1981-82 season to a high of 4972 in the 1986-87 season and dropped to 1029 in the 1990-91 season. The highest swordfish size-composition coverage rates (28%) were obtained during the 1988-89 season. Common thresher samples decreased from a high of 1568 in the 1983-84 season to a low of 665 in the 1987-88 season. Common thresher size-composition coverage rates were highest during the 1989-90 season. Shortfin mako samples rose from a low of three in the 1981-82 season to a high of 1097 in the 1989-90 season; size-composition coverage rates were highest during the 1989-90 season. Size-composition coverage rates estimated for the 1981-82 season were unrealistically high for swordfish (356%) and thresher sharks (106%) due to low logbook coverage rates. Coverage rates for shortfin mako were 1% for the 1981-82 and 1982-83 seasons.

COMMERCIAL GROUNDFISH & DRIFT GILLNET
MARKET SAMPLES

BOAT NAME ______________ LANDING DATE MM-DD-YY

BOAT # ______ SPS CODE ___ PORT CODE ___ F&G BLOCK # ___

DEPTH fa. ___ GEAR __ MARKET ___ SAMPLE WT. _____ LANDING WT. _____

SAMPLER ___ AGE SAMPLE Y or N SAMPLE CONDITION: W or D SAMPLE # ____

#	LENGTH	SEX	WEIGHT LBS.	AGE	YC	R/L	#	LENGTH	SEX	WEIGHT LBS.	AGE	YC	R/L
1							21						
2							22						
3							23						
4							24						
5							25						
6							26						
7							27						
8							28						
9							29						
10							30						
11							31						
12							32						
13							33						
14							34						
15							35						
16							36						
17							37						
18							38						
19							39						
20							40						

COMMENTS ______________________________

003 - PACIFIC BONITO (BO) - FORK LENGTH
040 - YELLOWTAIL (YT) - FORK LENGTH
091 - SWORDFISH - CLEITHRUM TO FORK
097 - BIGEYE THRESHER - ALTERNATE LENGTH
098 - PELAGIC THRESHER - ALTERNATE LENGTH
130 - BARRACUDA (B) - TOTAL LENGTH
151 - BONITO SHARK - ALTERNATE LENGTH
155 - COMMON THRESHER - ALTERNATE LENGTH
165 - ANGEL SHARK (AS) - ALTERNATE LENGTH
222 - CALIF.HALIBUT (CH) - TOTAL LENGTH
400 - WHITE SEA BASS (WSB) - TOTAL LENGTH
467 - OPAH - FORK LENGTH

GEAR 01 = HOOK & LINE
27 = TRAP
56 = TRAWL
66 = SET GILLNET
65 = DRIFT GILLNET

CONDITION W = WHOLE (Not Gutted)
D = DRESSED

SEX CODES 0 = UNKNOWN
1 = MALE
2 = FEMALE

11/89

FIGURE 24. Current California Department of Fish and Game sampling form used to record fish measurements from California drift gill net landings.

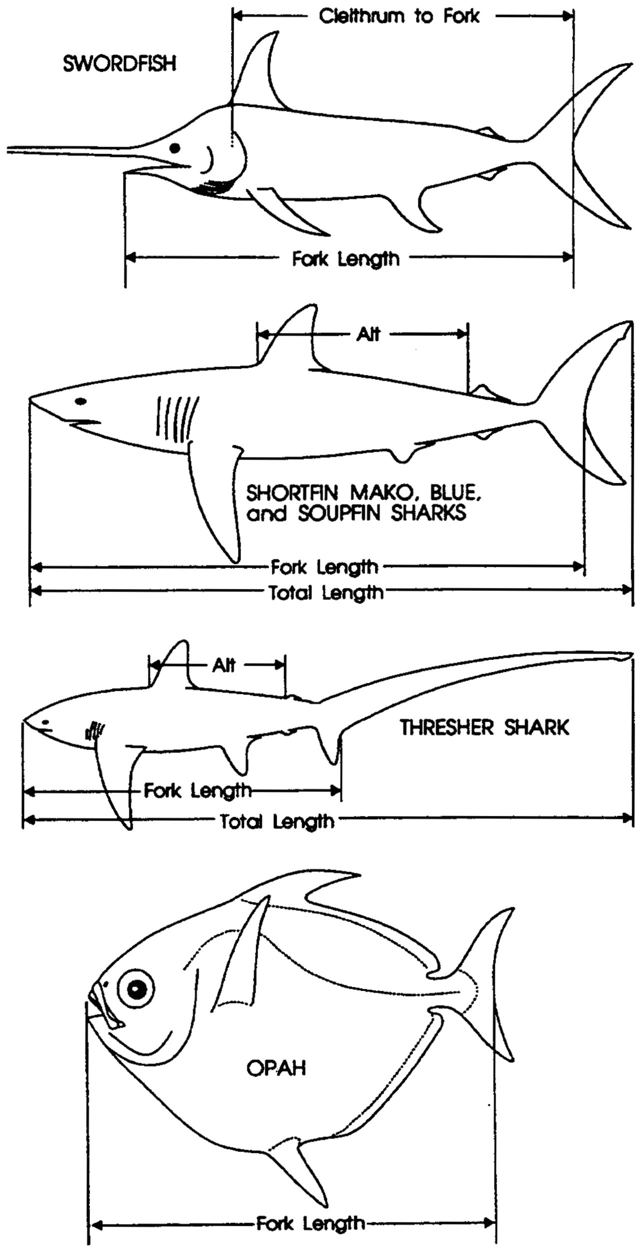


FIGURE 25. Alternate length measurements of swordfish, thresher sharks, other sharks, and opah recorded by samplers of California drift gill net landings.

TABLE 4. Numbers and lengths of fishes by species taken in the California drift gill net fishery and sampled at California fish markets during the 1981-82 through 1990-91 fishing seasons. AL = alternate length, FL = fork length.

Species	Number measured	Length (cm)	
		Mean	Range
Sharks			
Angel shark, Pacific	48	11.6 (AL)	9-13 (AL)
Blacktip shark	1	118.0 (AL)	118 (AL)
Blue shark	7	77.3 (AL)	68-105 (AL)
Hammerhead shark	16	91.2 (AL)	78-102 (AL)
Mako, shortfin	5,659	46.8 (AL)	6-134 (AL)
Salmon shark	9	93.2 (AL)	83-98 (AL)
Soupfin shark	32	56.8 (AL)	38-81 (AL)
Thresher, bigeye	468	53.0 (AL)	22-104 (AL)
Thresher, common	9,646	60.4 (AL)	12-136 (AL)
Thresher, pelagic	116	64.1 (AL)	28-100 (AL)
White shark	2	88.5 (AL)	87-90 (AL)
Other fishes			
Albacore	214	102.9 (FL)	50-133 (FL)
Bonito, Pacific	2	69.5 (FL)	69-70 (FL)
Louvar	142	101.5 (FL)	48-163 (FL)
Opah	1,967	99.3 (FL)	10-242 (FL)
Swordfish	22,870	143.8 (AL)	37-250 (AL)
Tuna, bigeye	58	128.7 (FL)	92-161 (FL)
Tuna, yellowfin	27	138.3 (FL)	96-191 (FL)

Swordfish

The sizes of swordfish sampled during the 1981-82 through 1990-91 fishing seasons (22,870 fish measured) ranged from 37 to 250 cm AL with a mean of 144 cm AL (Table 4; Figure 27). Fish reported as less than 47 cm were considered errors in measurement or measurements of shark-damaged fish and were not included in our summaries. The bulk of the measurements were between 100 and 195 cm. By year, the means varied between 128 and 152 cm, with peaks in

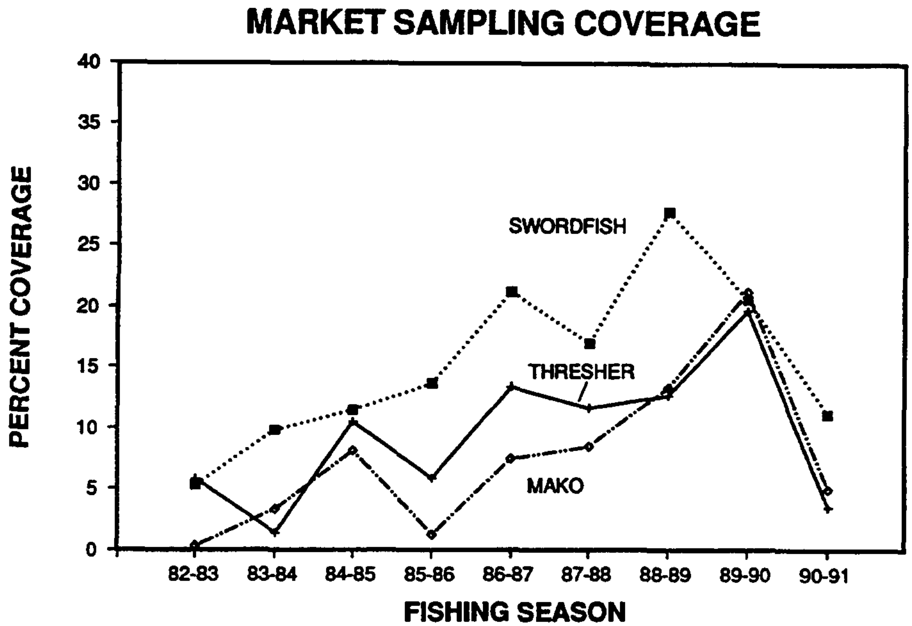


FIGURE 26. Coverage rates for market sampling of swordfish, common thresher, and shortfin mako. Coverage rates for the 1981-82 season were unrealistically high for swordfish (356%) and common thresher (106%) due to low logbook coverage rates, while shortfin mako rates were at 1% and are not presented.

1982-83, 1985-86, and 1988-89 (Figure 28). Larger swordfish (150 to 160 cm AL) tended to be caught off the northern California and Oregon coasts, with smaller fish (130 to 145 cm AL) taken farther south (Figure 29). The primary mode of fish caught north of lat. 35°N tended to be 2 to 5 cm larger than that of fish caught south of that line. Also, the average weights of fish caught north of lat. 35°N were as much as 17 kg (dressed weight) more than fish caught farther south. Swordfish caught during June to December tended to be larger (140 to 155 cm AL) with the largest caught in August (Figure 30). Smaller swordfish (100 to 135 cm AL) were caught during January to May, although sample sizes in these months were relatively low. Length-to-age conversion tables revealed that the majority of the sampled catch was immature swordfish 3 to 5 years old.

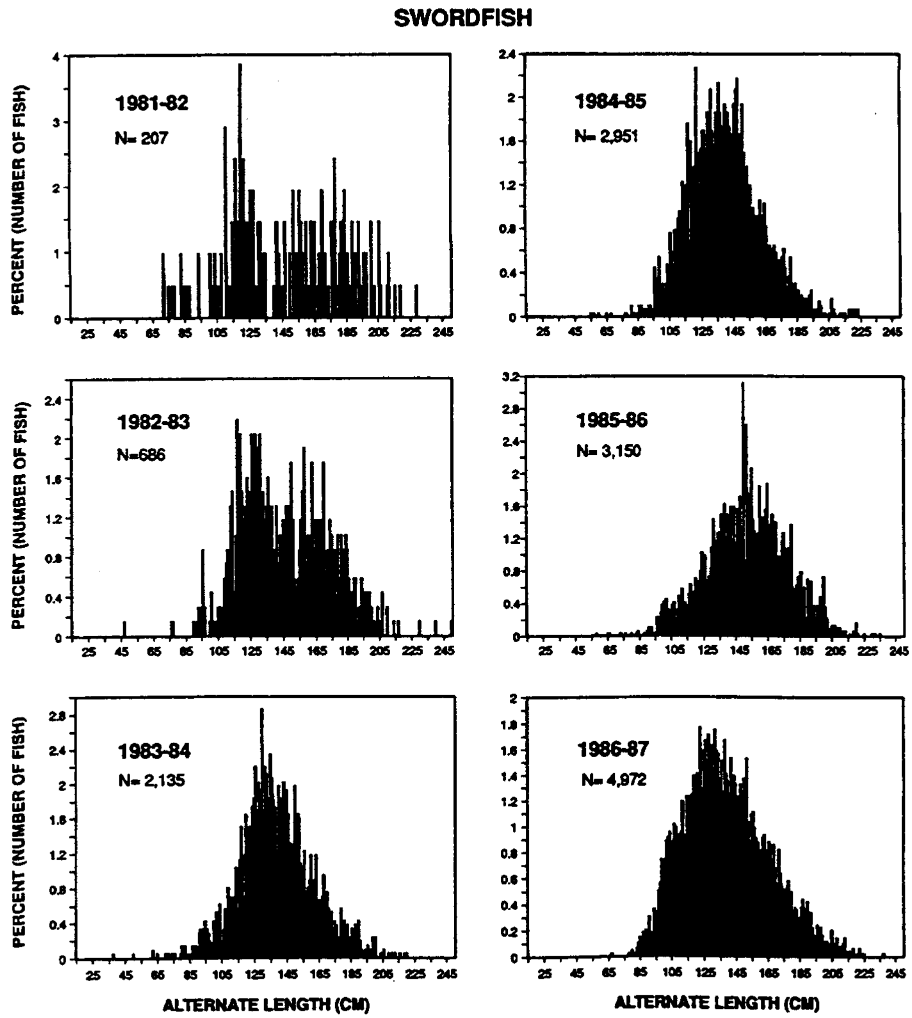


FIGURE 27a. Length-frequency distribution of swordfish sampled at California markets during the 1981-82 through 1986-87 fishing seasons.

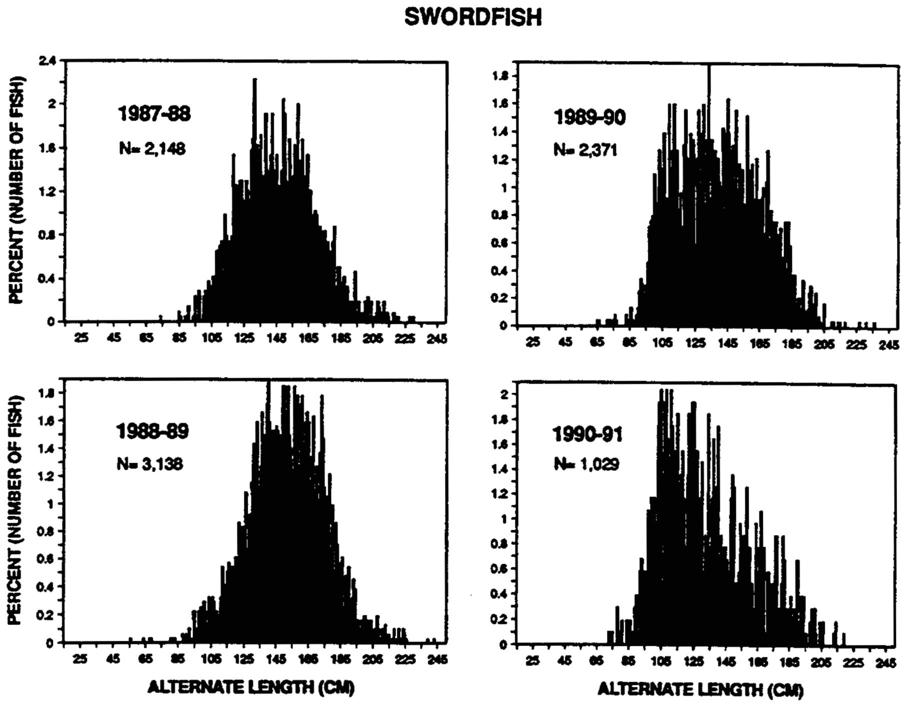


FIGURE 27b. Length-frequency distribution of swordfish sampled at California markets during the 1987-88 through 1990-91 fishing seasons.

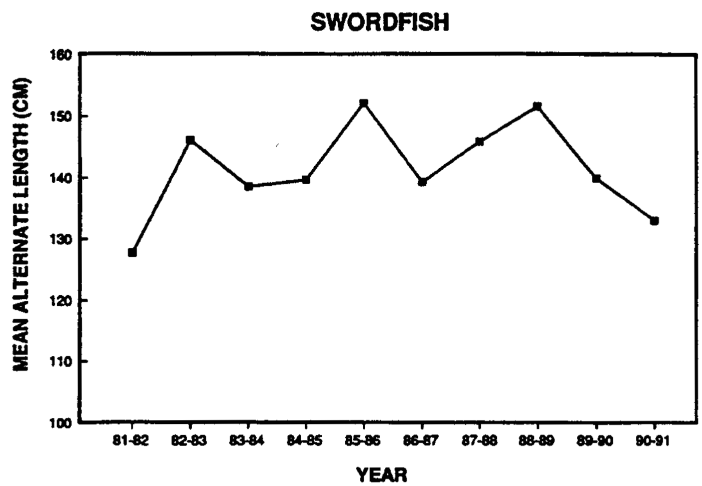


FIGURE 28. Mean alternate length of swordfish sampled at California markets, 1981-82 through 1990-91 fishing seasons.

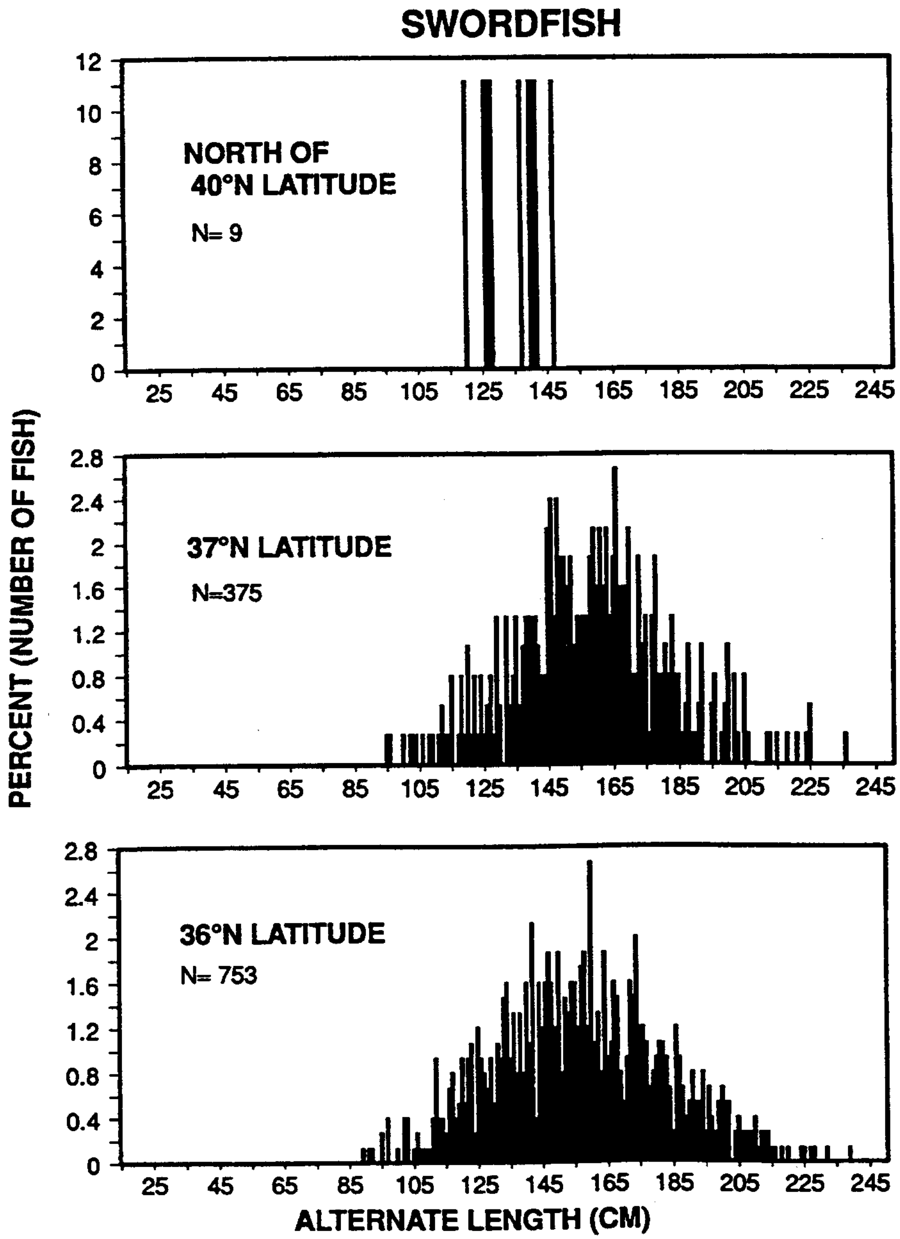


FIGURE 29. Length-frequency distribution of swordfish by latitudinal bands of catch location, from California market samples, 1981-82 through 1990-91 fishing seasons.

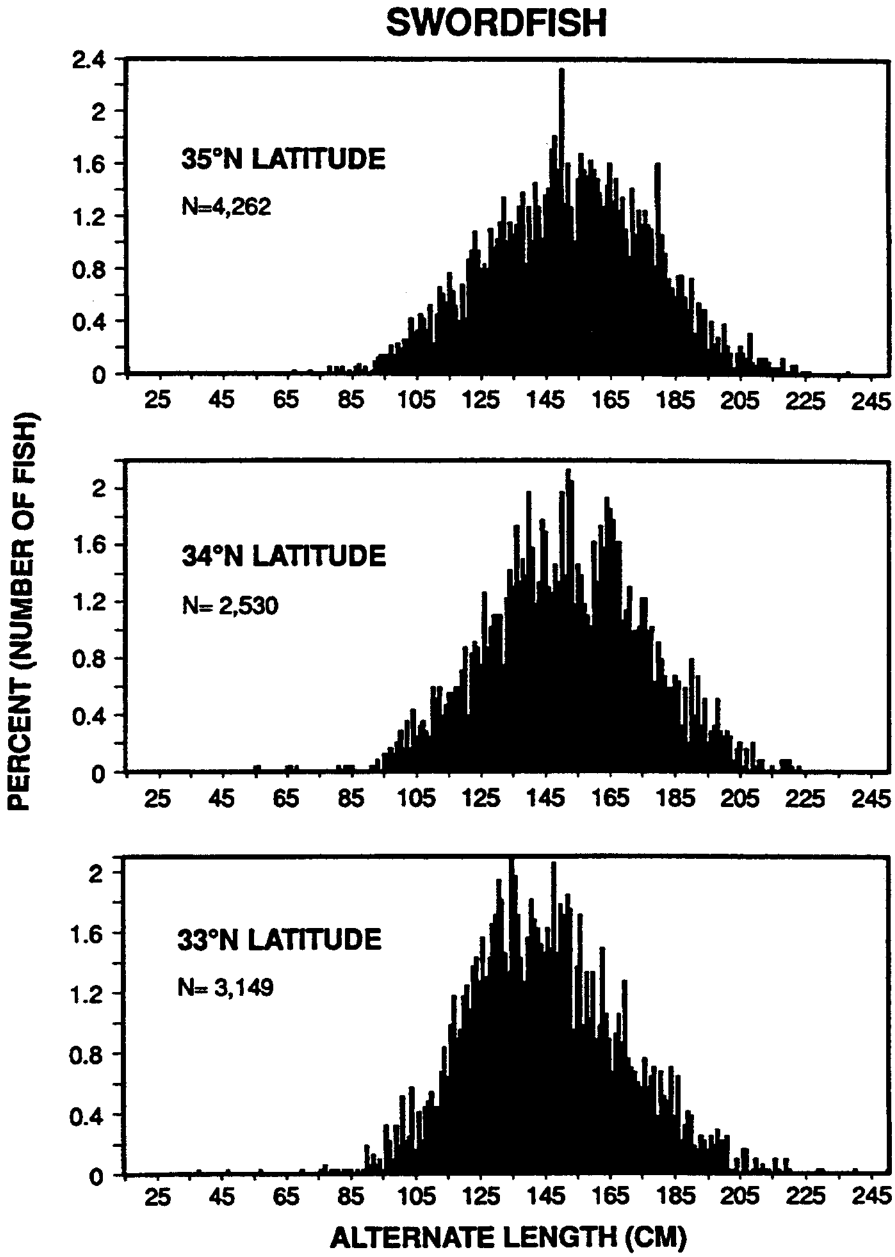


FIGURE 29. (continued)

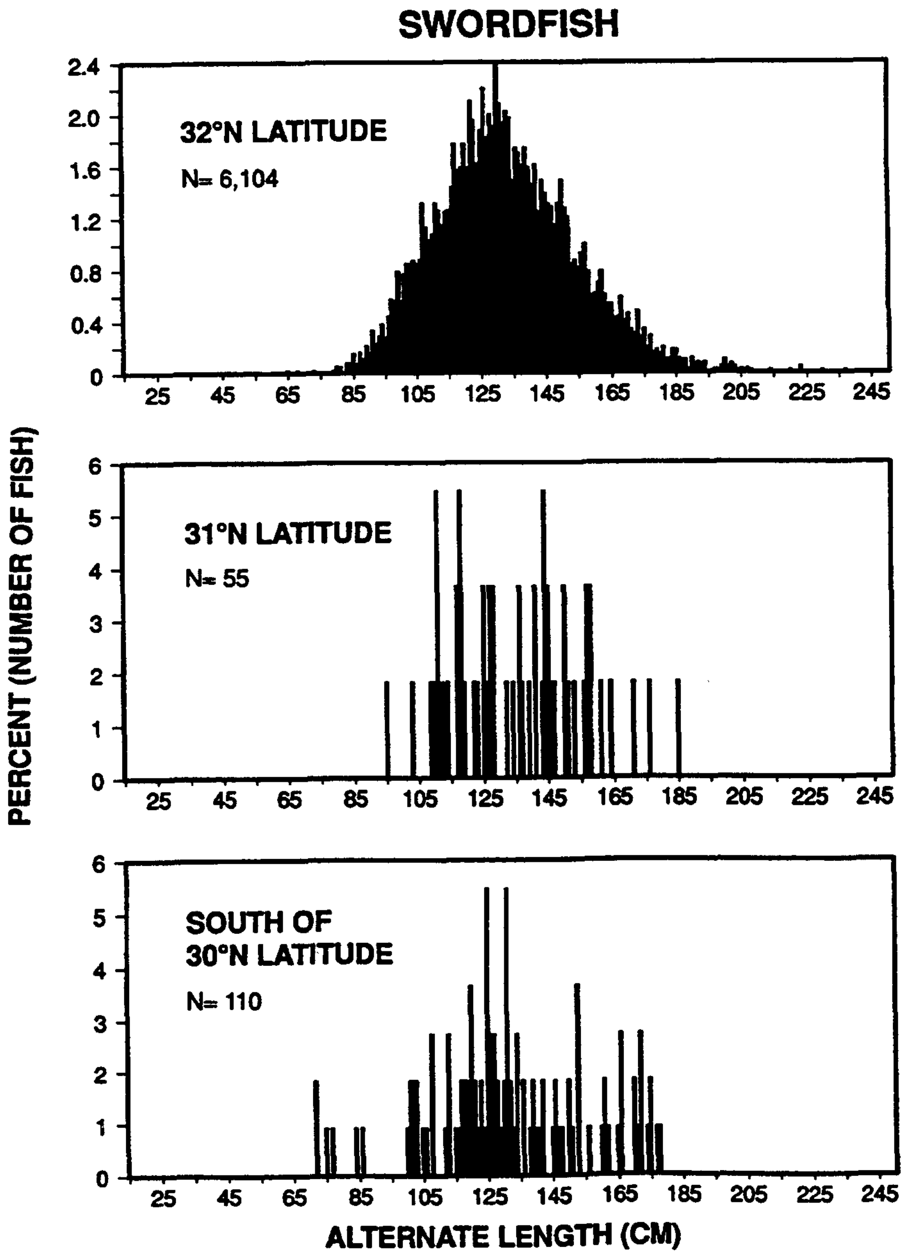


FIGURE 29. (continued)

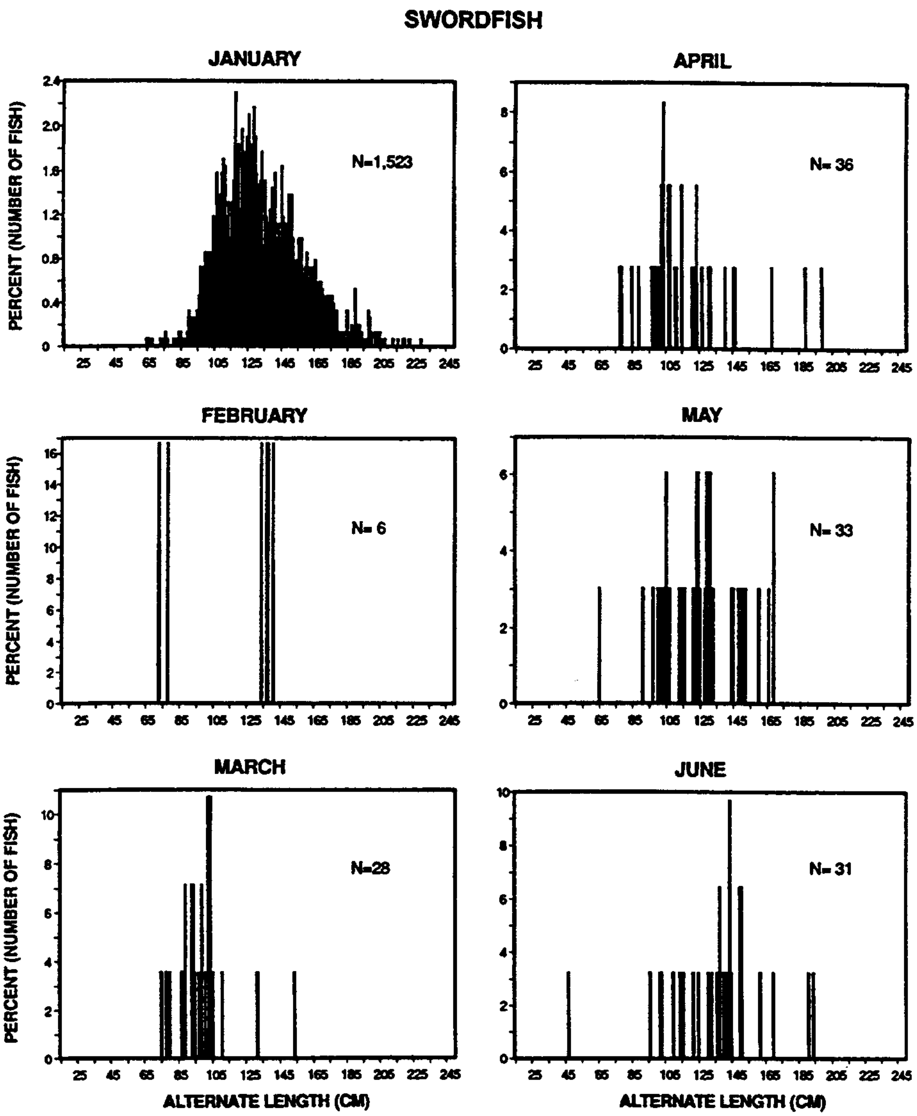


FIGURE 30a. Length-frequency distribution of swordfish by month, January to June, sampled at California markets during the 1981-82 through 1990-91 fishing seasons.

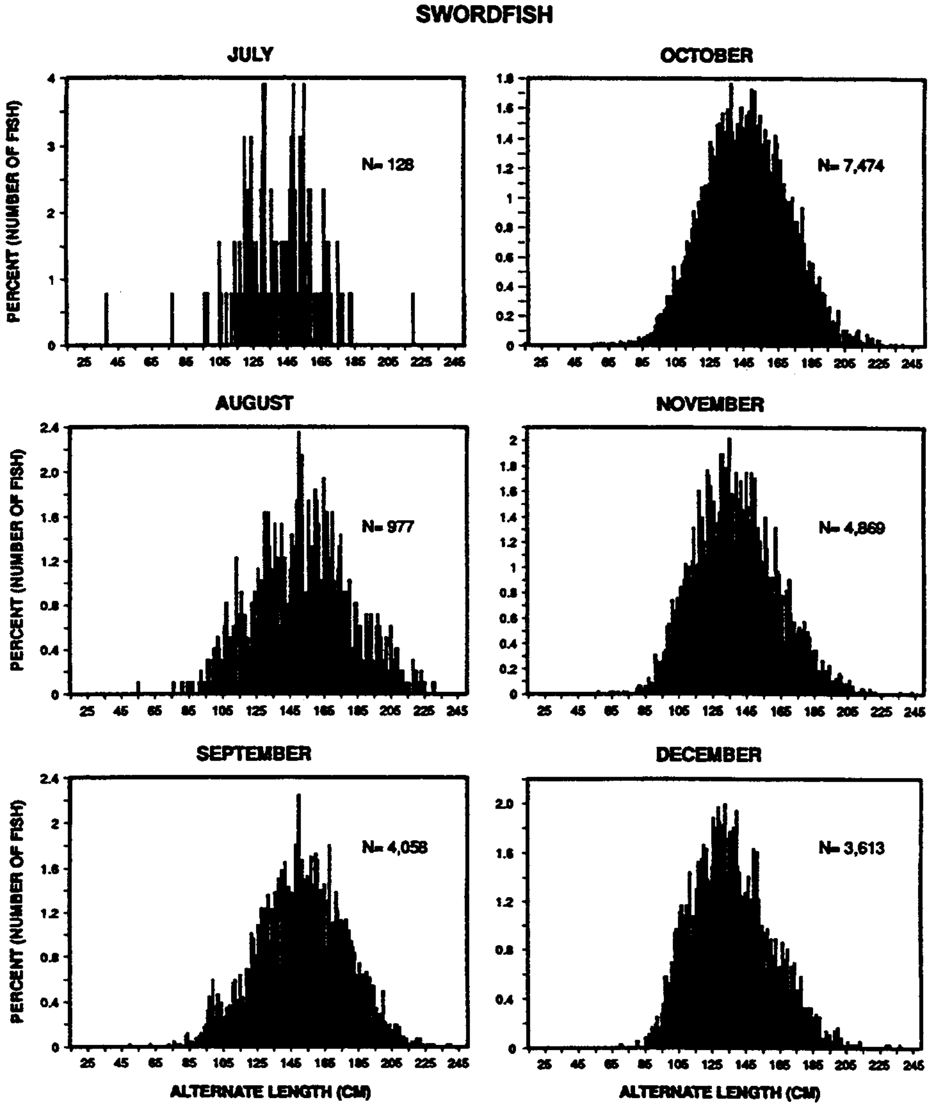


FIGURE 30b. Length-frequency distribution of swordfish by month, July to December, sampled at California markets during the 1981-82 through 1990-91 fishing seasons.

Common Thresher

During the 10-year period covered, port samplers measured a total of 9646 common threshers ranging from 12 to 136 cm AL with a mean of 60 cm AL (Table 4); most ranged between 40 and 80 cm AL (Figure 31). The alternate length for common thresher represented approximately 17.5 percent of the total length. The means were 65 and 68 cm AL, respectively, for the 1981-82 and 1982-83 seasons, which were fished primarily in the Southern California Bight. The mean length of common threshers peaked in the 1982-83 season at 68 cm AL and steadily declined to a low of 51 cm AL in 1989-90 (Figure 32) even though the drift gill net fishery expanded into previously unfished areas. The size of maturity was estimated at 333 cm TL (56 cm AL) for males and 390 cm TL (75 cm AL) for females (Cailliet and Bedford 1983). Length frequencies indicate that a majority of the catch were immature sharks; mature adults, especially females, represented only a small percentage of the landings during any of the fishing seasons.

As the fishery expanded northward, larger sharks were caught. Common threshers from north of lat. 36°N ranged from 50 to 98 cm AL (Figure 33). In the 1986-87 and 1987-88 seasons off Oregon and Washington, most common threshers caught were adult. A large number of those were males and averaged 76 to 79 cm AL (Stick and Hreha 1988). A small portion (16 individuals) of the Oregon and Washington catch was measured in California and had a mean AL of 75 cm with a range of 63 to 99 cm AL. The range of sizes for common threshers sampled from the lat. 32° to 35°N bands was similar, although those from off San Diego may tend to be somewhat larger (Figure 33). Common threshers caught during July, August, and September tended to be larger (mean AL = 60 cm to 65 cm.; Figure 34). A higher percentage of smaller fish are taken in October, November, and December.

Pelagic and Bigeye Threshers

Only 116 pelagic and 468 bigeye threshers were measured during the 1981-82 through 1990-91 fishing seasons (Table 4; Figure 35). The small sample sizes are possibly due to misidentifying and recording these species as common threshers. Both species are similar in size to the common thresher and can be difficult to distinguish when cleaned and dressed for market. No trends by season or catch location were apparent for either species.

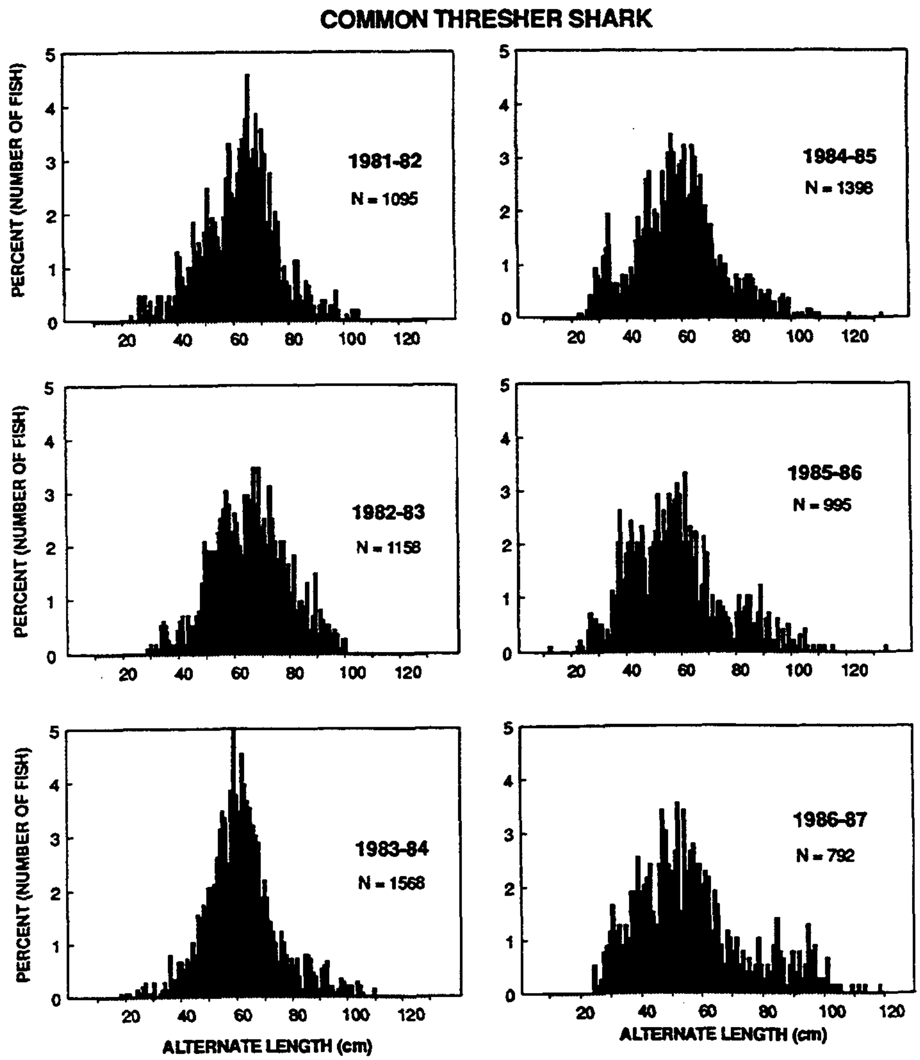


FIGURE 31a. Length-frequency distribution of common thresher sampled at California markets during the 1981-82 through 1986-87 fishing seasons.

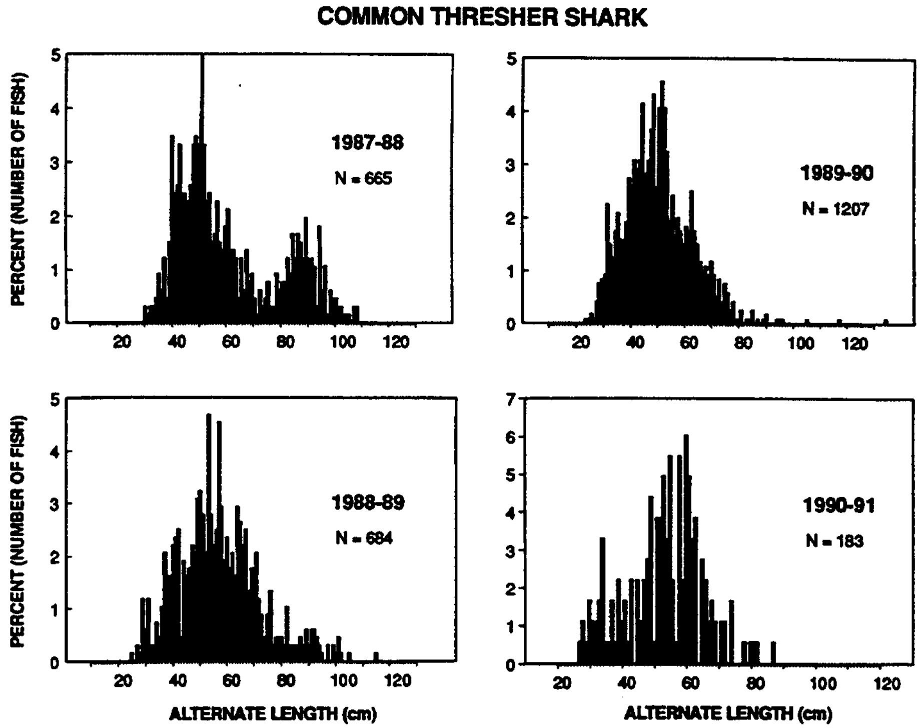


FIGURE 31b. Length-frequency distrbution of common thresher sampled at California markets during the 1987-88 through 1990-91 fishing seasons.

Shortfin Mako

A total of 5659 shortfin makos were sampled by the CDFG during 1981-82 through 1990-91. Length measurements ranged from 6 to 134 cm AL (Table 4; Figure 36) with a mean of 47 cm AL. Reported lengths of fish less than 20 cm are suspect and are probably erroneous measurements. The mean length declined from 58 cm AL in 1982-83 to less than 35 cm AL in 1985-86, then averaged about 47 cm AL over the next 5 years (Figure 37). Length distributions for the 1982-83 and 1985-86 seasons may unrepresentative due to the small sample sizes and limited area (south of Point Conception) and season (late October and early November) of coverage.

There was a trend towards larger shortfin makos in the northern areas (Figure 38). Shortfin makos caught south of San Diego (the lat. 32°N band and south) had a mean AL length of 43 cm, while those off San Diego and Los Angeles had

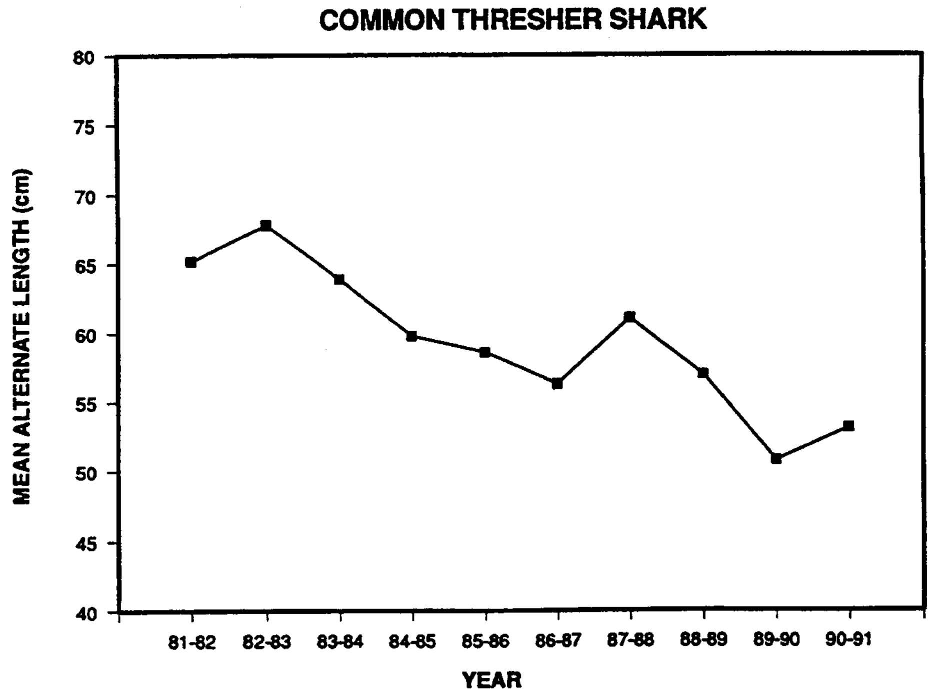


FIGURE 32. Mean alternate length of common thresher sampled at California markets, 1981-82 through 1990-91 fishing seasons.

a mean AL length of 49 cm. Shortfin makos sampled from the lat. 35° and 36°N bands (San Luis Obispo to Santa Cruz) had annual AL means ranging from 52 to 55 cm. Shortfin makos caught during May through August tended to be larger than those caught during October through December (Figure 39).

Alternate length of the shortfin mako shark represents about 34% of total body length. Because males mature at 195 cm TL (66 cm AL) and females mature at 280 cm TL (95 cm AL; Stevens 1983), it is clear that the catch was composed almost entirely of juveniles.

Opah

During the period covered, 1967 opahs were measured and sizes ranged from 10 to 242 cm FL (Table 4; Figure 40). The majority of the lengths were centered in three modes at 80, 100, and 112 cm FL. Due to the small number of opahs measured, any difference between sizes of fish caught in the north and south were not evident.

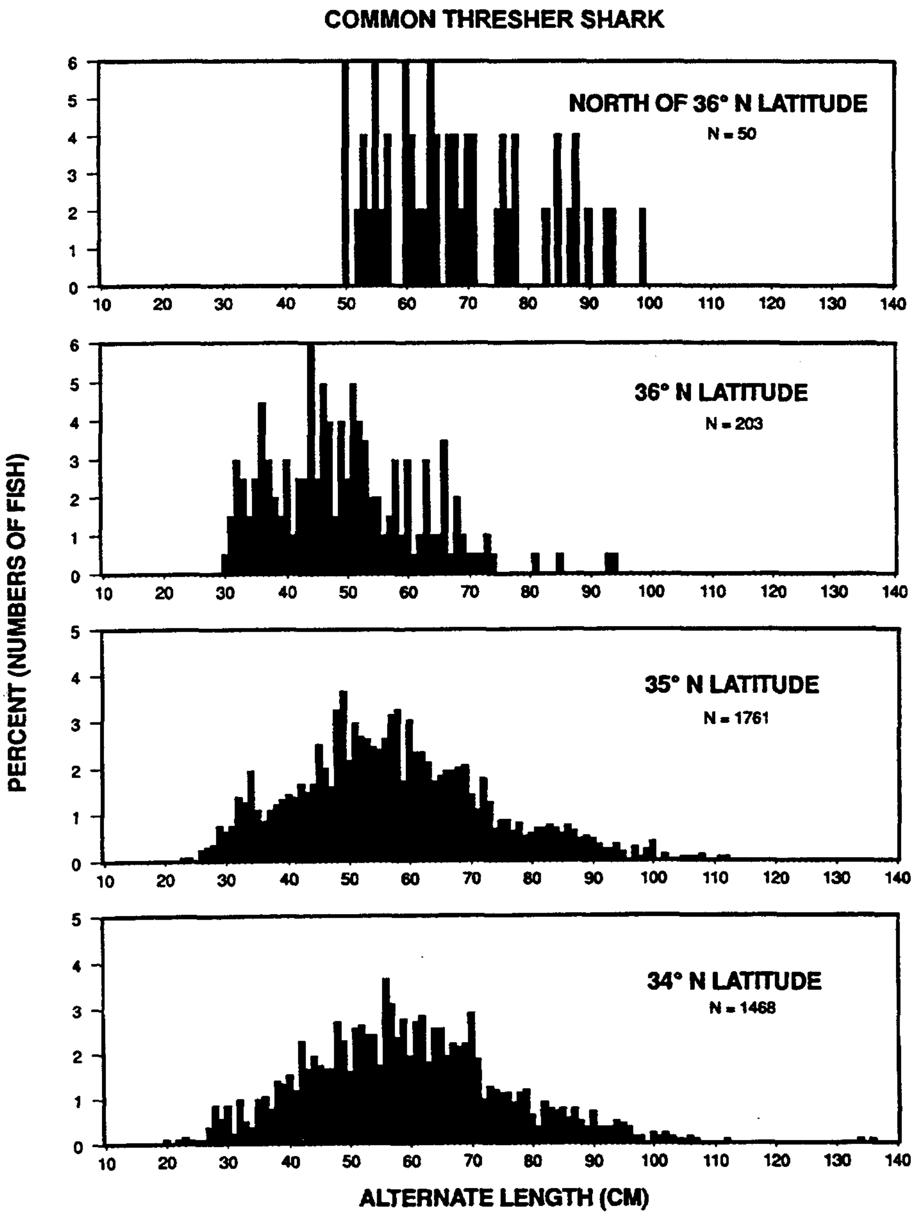


FIGURE 33. Length-frequency distribution of common thresher by latitudial bands of catch location, from California market samples, 1981-82 through 1990-91 fishing seasons.

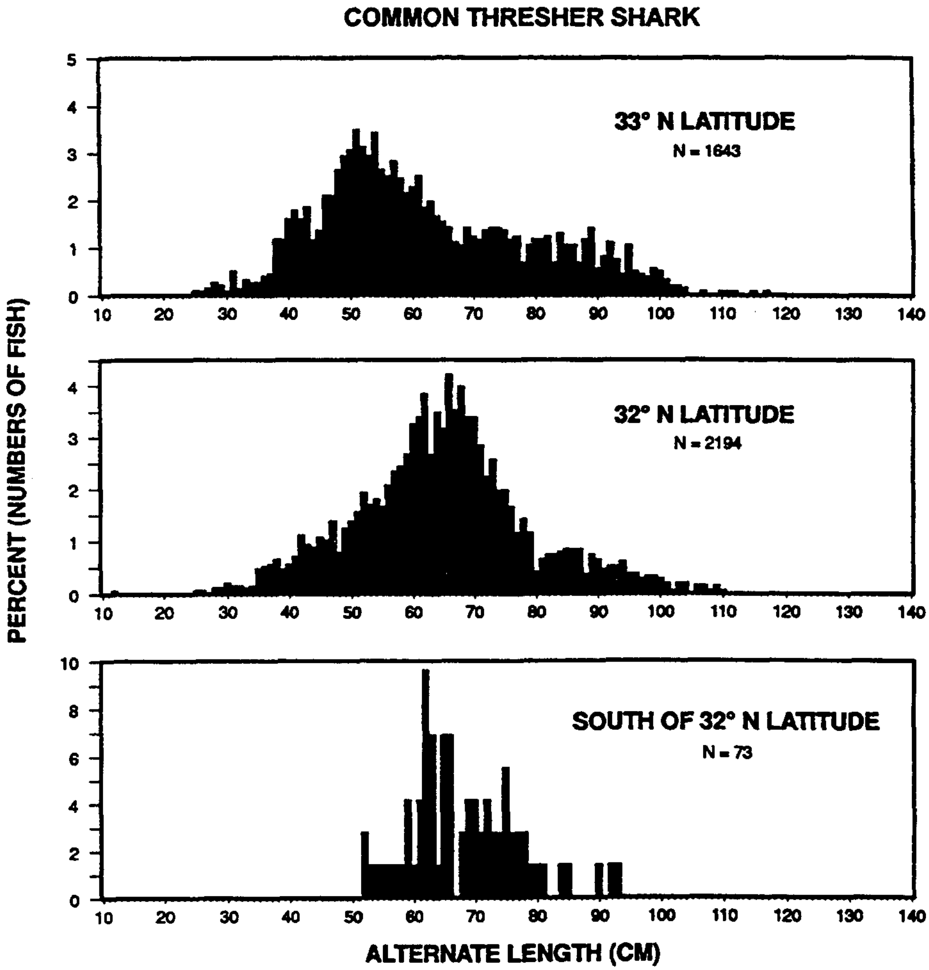


FIGURE 33. (continued)

DISCUSSION

We have presented a description of the California drift gill net fishery, which evolved from a small nearshore experiment to a major California fishery. There have been major changes in nearly every aspect of the fishery including boats, gear, fishing techniques, regulations, fishing areas, seasons, and targeted species. We are particularly pleased with the manner in which we were able to incorporate both landing receipt and logbook data along with market samples to

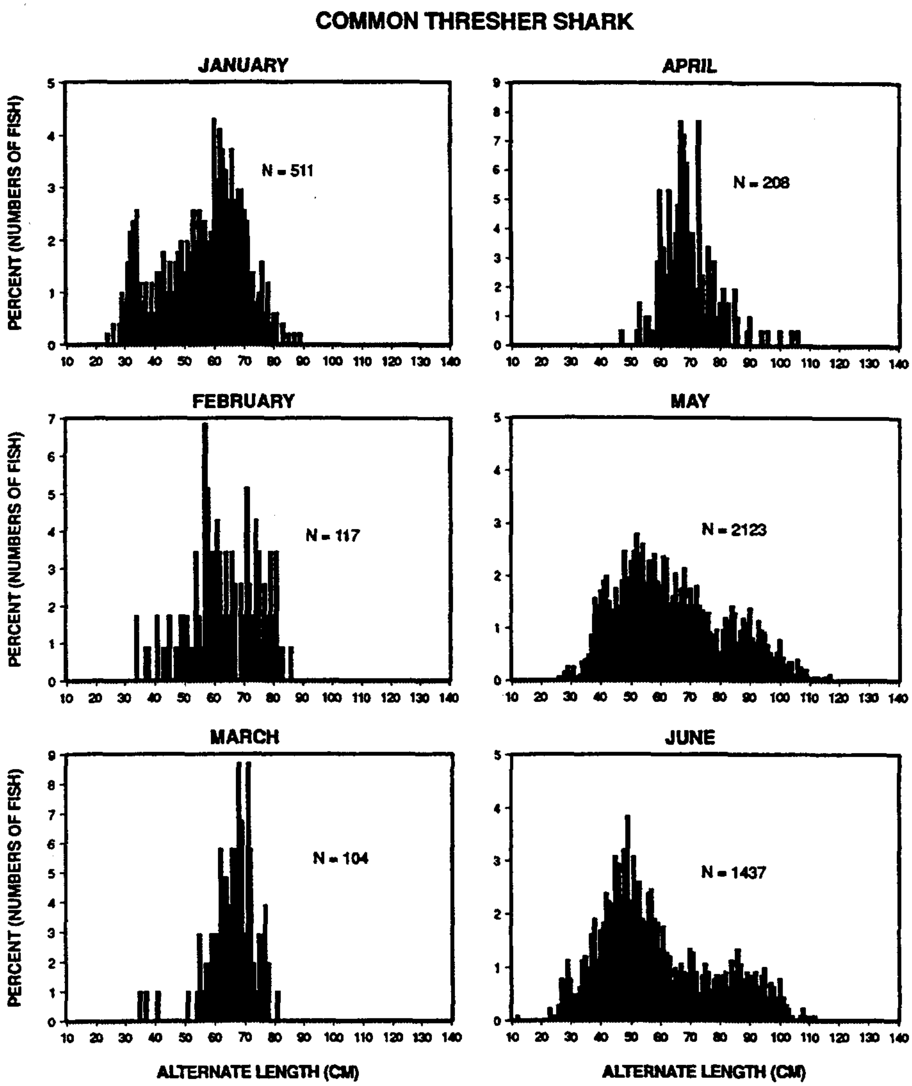


FIGURE 34a. Length-frequency distibution of common thresher by month, January to June, sampled at California markets during the 1981-82 through 1990-91 fishing seasons.

summarize important facets of the fishery. We encourage others to utilize these sources for further, more in-depth analyses of this fishery and related stocks.

We feel that the quality of all data collected for the drift gill net fishery, while relatively high in some areas, can be improved. We found some confusion in the way logbooks were completed, especially in the recording of catch. In some cases,

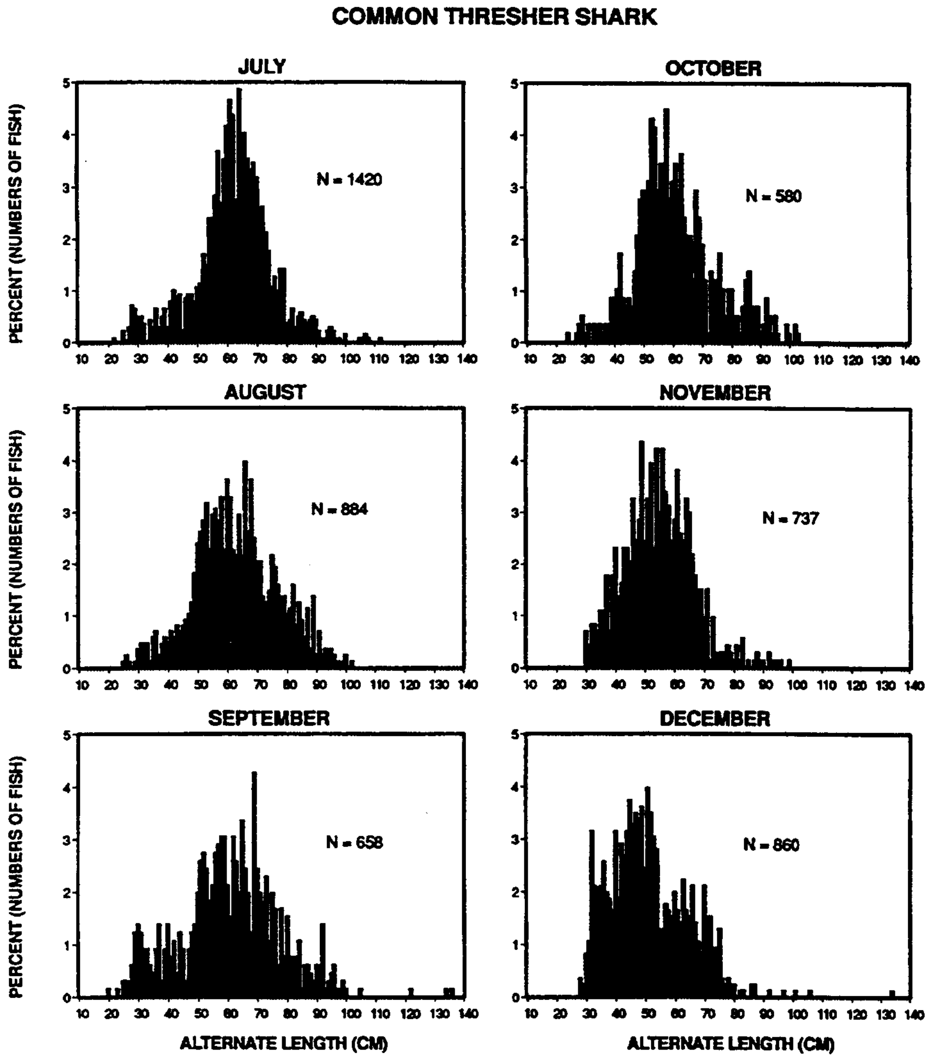


FIGURE 34b. Length-frequency distribution of common thresher by month, July to December, sampled at California markets during the 1981-82 through 1990-91 fishing seasons.

catch was reported by number, in other cases by weight, and many times without any indication of which units were used or if a combination of both was used. Much of this confusion could be eliminated if more complete instructions were provided with the logbooks. There was also some intentional misrepresentation such as miscoding of gear types on landing receipts and net-caught swordfish

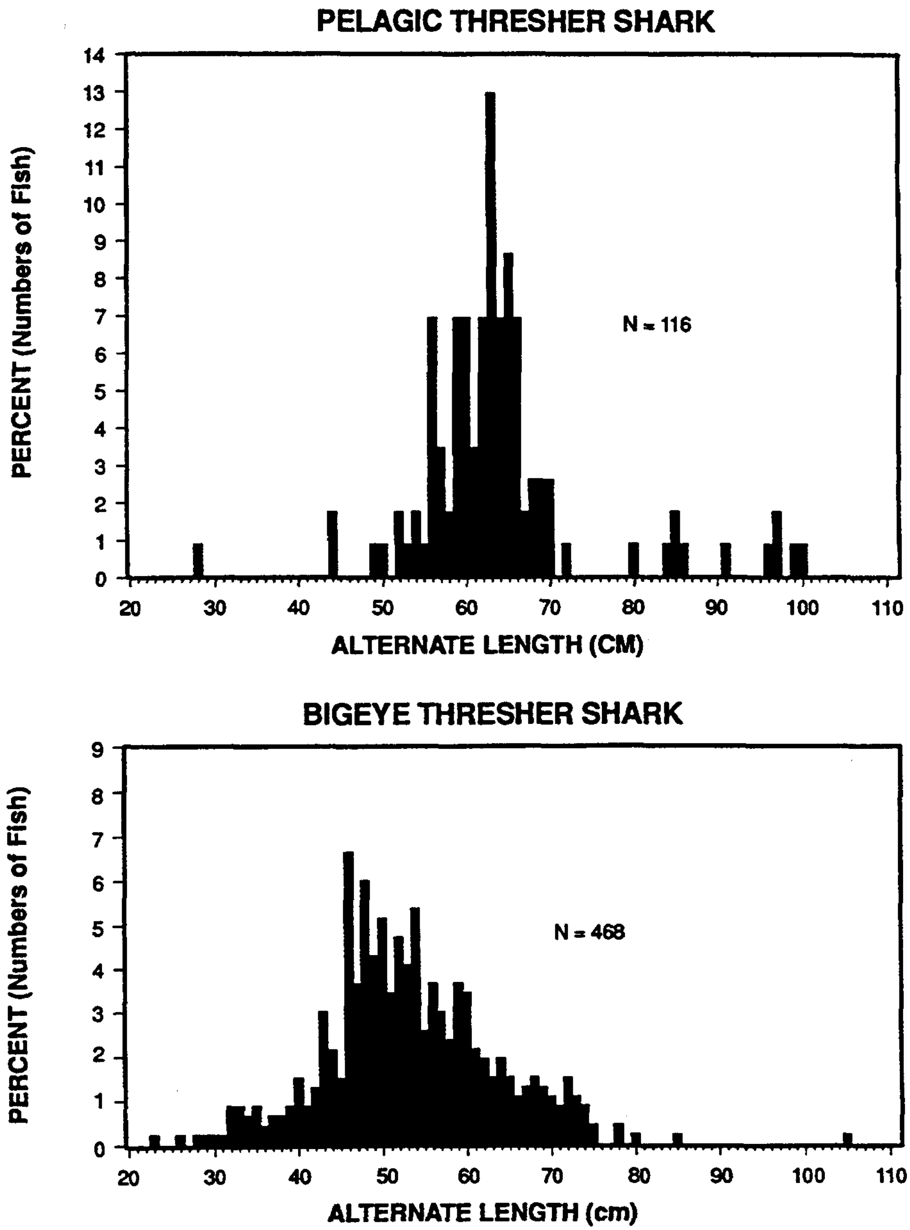


FIGURE 35. Length-frequency distribution of pelagic thresher and bigeye thresher sampled at California markets during the 1981-82 through 1990-91 fishing seasons.

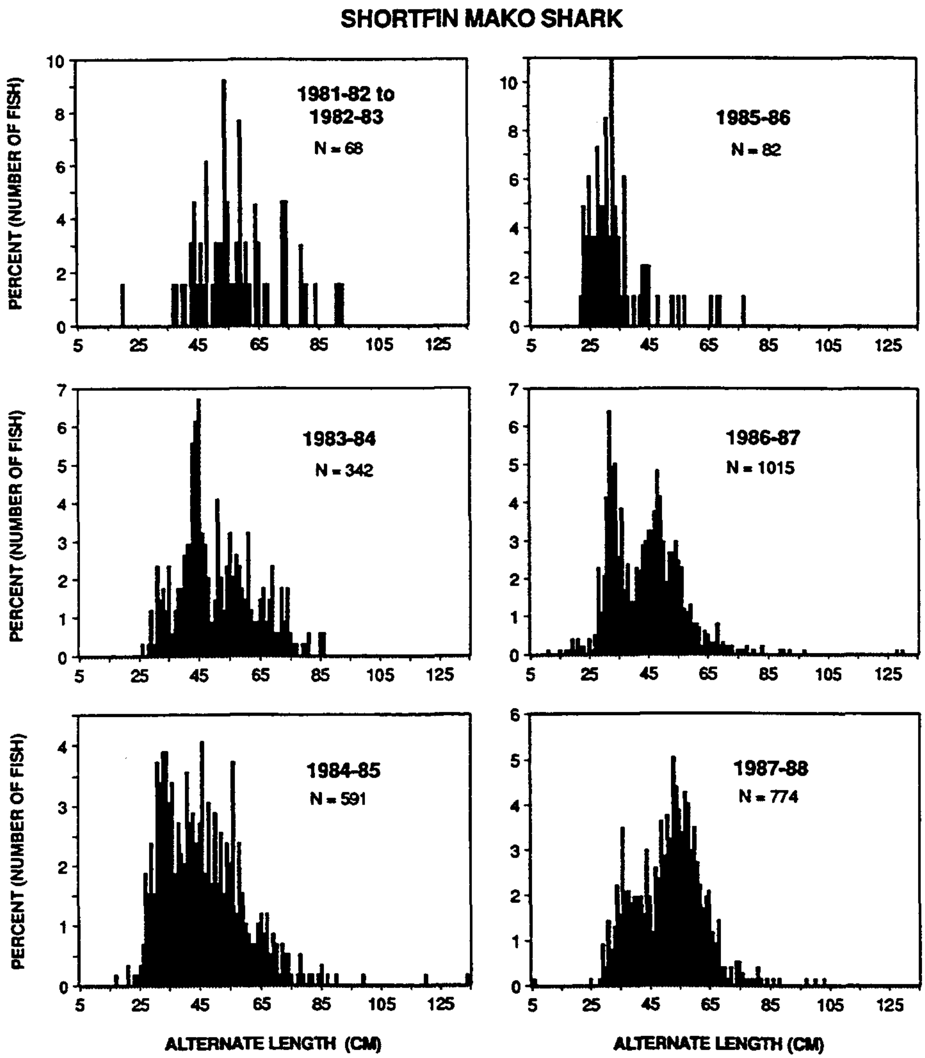


FIGURE 36a. Length-frequency distribution of shortfin mako sampled at California markets during the 1981-82 through 1987-88 fishing seasons.

stuck with a harpoon after capture (especially during the period when swordfish landings from drift gill net gear were not allowed to exceed shark landings).

Coverage rates of the market sampling system for sizes of fish are comparable to other fishery sampling programs. However, the adequacy of this level of sampling is difficult to assess since no formal sampling plan exists. The quality of

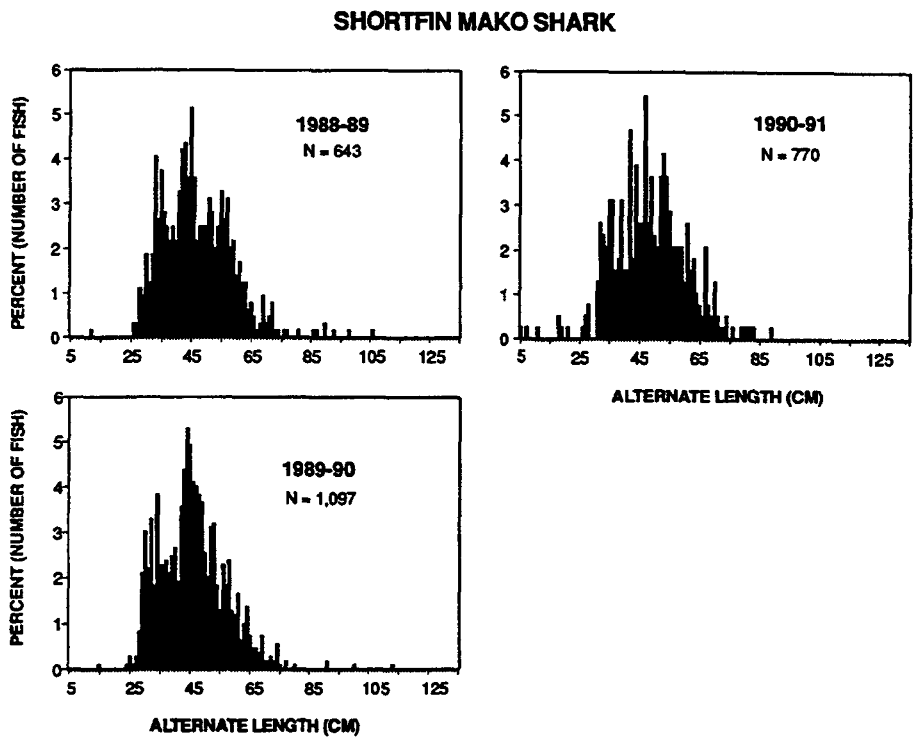


FIGURE 36b. Length-frequency distribution of shortfin mako sampled at California markets during the 1988-89 through 1990-1991 fishing seasons.

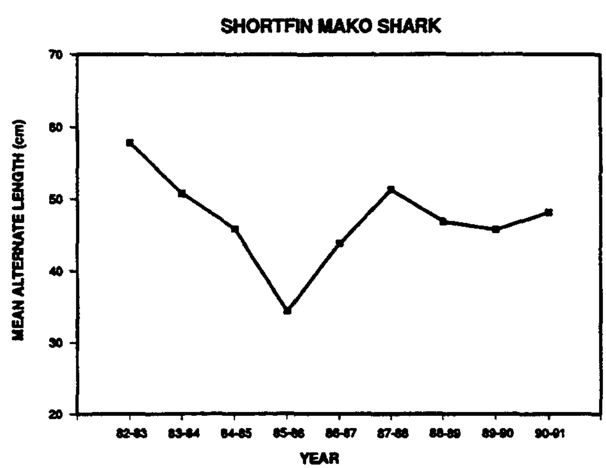


FIGURE 37. Mean alternate length of shortfin mako sampled at California markets, 1982-83 through 1990-91 fishing seasons.

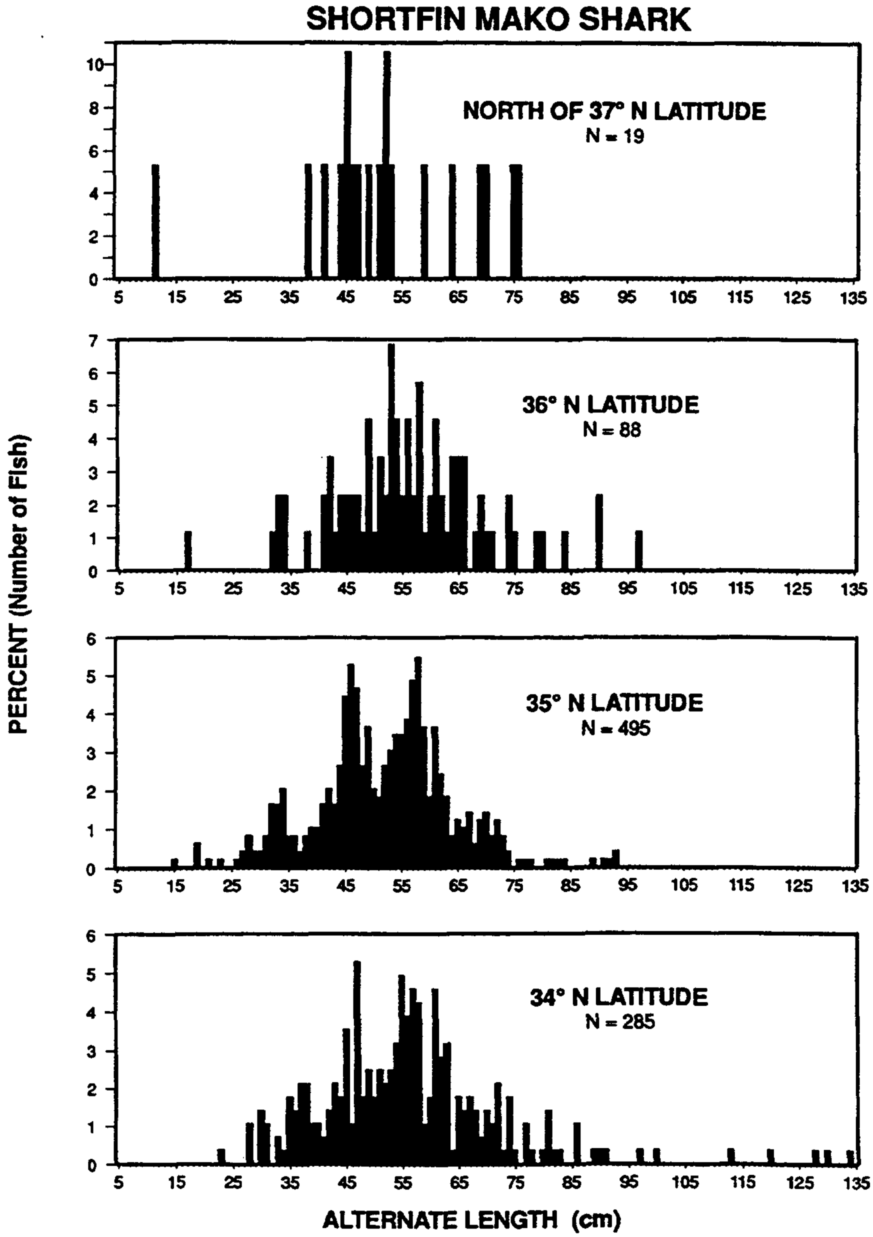


FIGURE 38. Length-frequency distribution of shortfin mako by latitudinal bands of catch location, from California market samples, 1981-82 through 1990-91 fishing seasons.

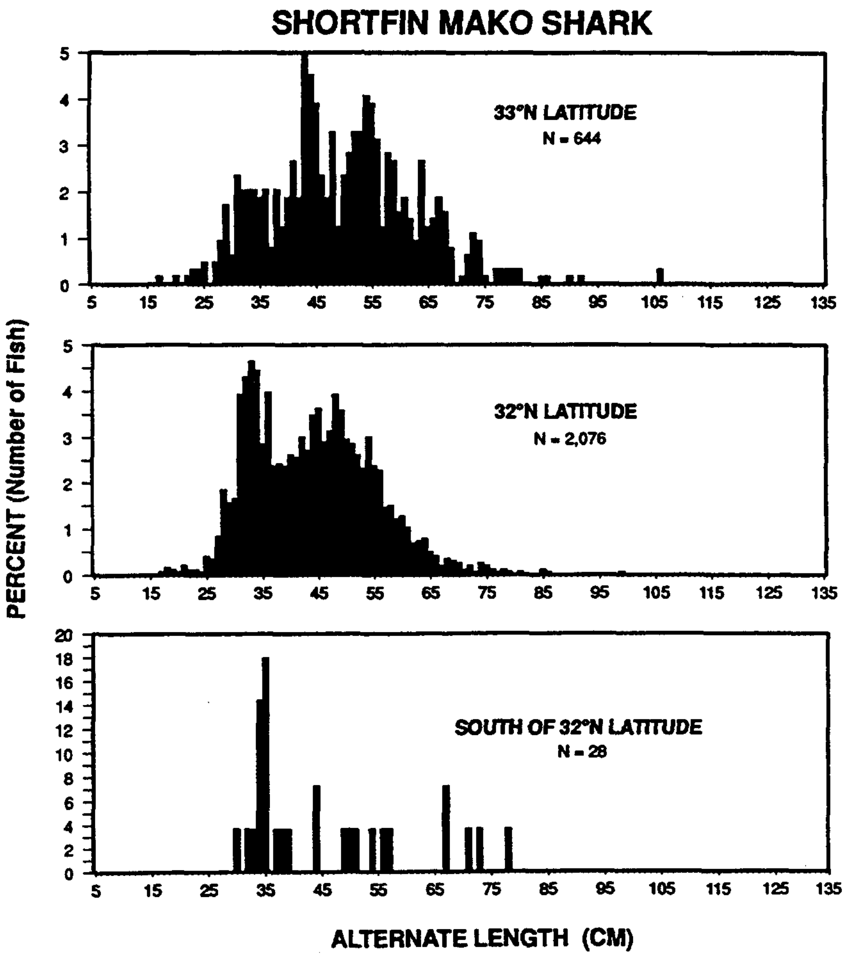


FIGURE 38. (continued)

length data may be improved by the establishment of a formal sampling plan which would evaluate sample sizes by species and month of landing.

We made major assumptions to separate landings between set gill net and drift gill net gear, because many landing receipts did not distinguish between the two nets and reported gear type only as gill net. These assumptions may have biased estimates of landings for some species and may have biased estimates for number of vessels using drift gill nets. While we feel that these biases are relatively low, a revision of landing receipts to allow for separate entries for drift and set gill nets as well as instructions explaining the problems in separating these catches

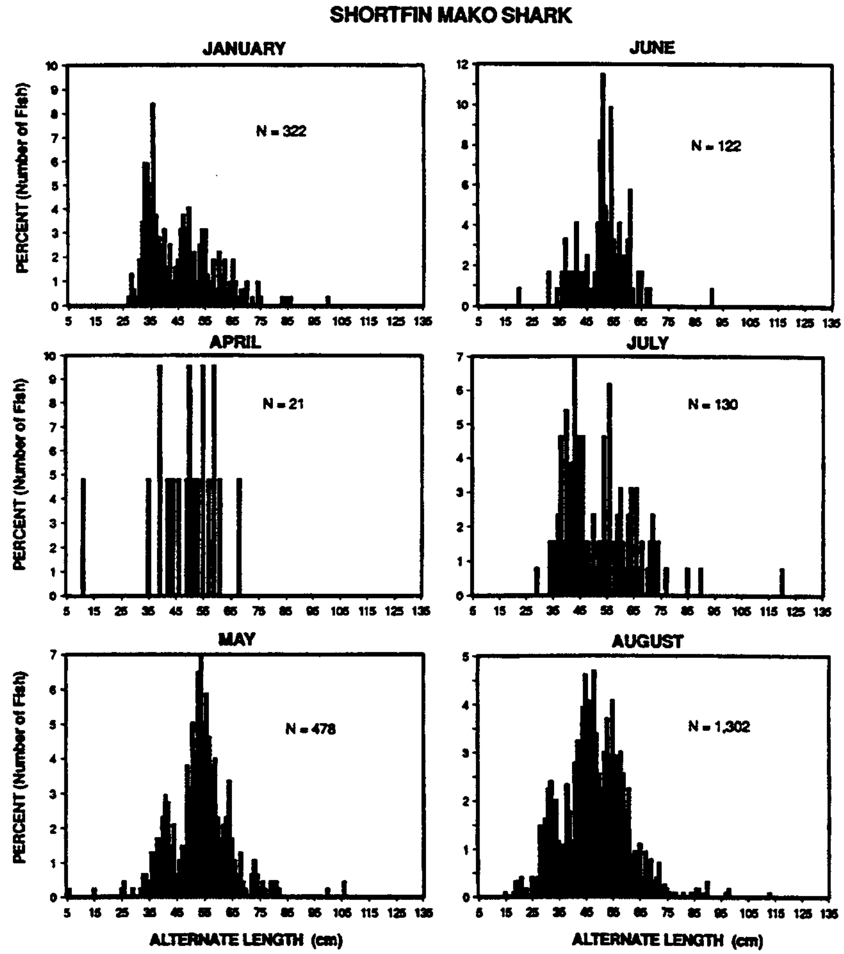


FIGURE 39a. Length-frequency distribution of shortfin mako by month, January to August, sampled at California markets, 1981-82 through 1990-91 fishing seasons.

and soliciting compliance in accurately entering the gear type would eliminate the need for many of these assumptions and increase the quality of the landings data.

This study summarizes the pertinent available data obtained from the California logbook system, landing receipts, and market sampling. These data form a base line from which changes in the fishery and harvested stocks can be com-

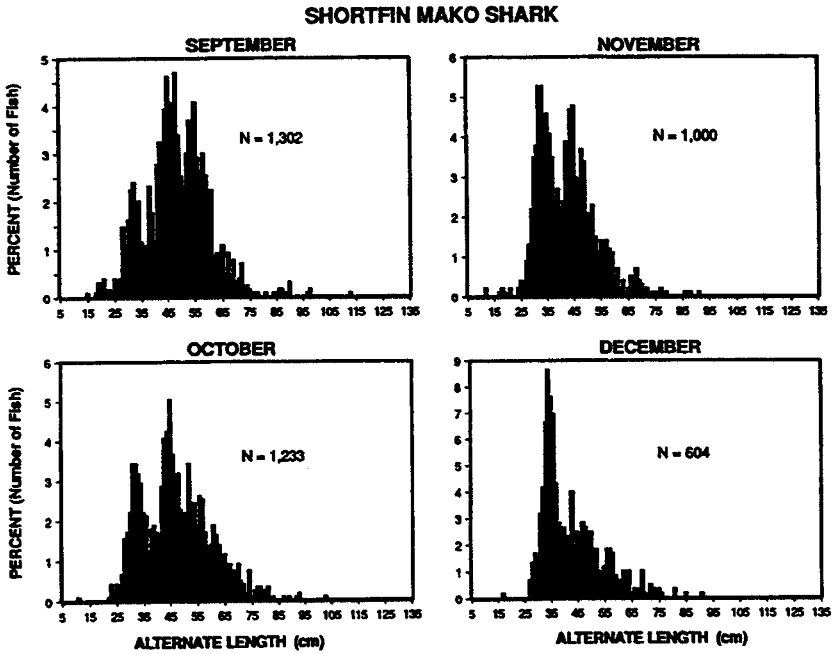


FIGURE 39b. Length-frequency distribution of shortfin mako by month, September to December, sampled at California markets, 1981-82 through 1990-91 fishing seasons.

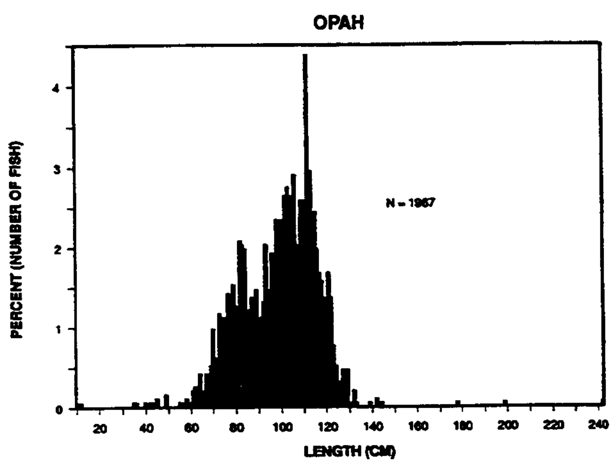


FIGURE 40. Length-frequency distribution of opah sampled at California markets, 1981-82 through 1990-91 fishing seasons.

pared in the future. More detailed analyses of trends in the fishery and the resources should follow.

We have shown that the California drift gill net fishery operated primarily in the area between San Diego and Cape Mendocino, concentrating on swordfish in the Southern California Bight during the months of May to December.

Since the 1985-86 fishing season, fishing effort has decreased 50% to 60% and the decreasing effort corresponds to decreasing total landings of the same proportions. Both decreases are due in part to the spring fishing closure for sharks. Decreases in landings of common thresher were over 80%, while swordfish and shortfin mako landings decreased 60% and 40%, respectively. Sizes of swordfish showed no increasing or decreasing trend. Mean sizes of common thresher decreased 21% from the 1982-83 season to less than 55 cm AL in the 1990-91 season. There was no significant change in the mean size of shortfin mako, although a small sample size in 1982-83 and nonrepresentative sample in 1985-86 were responsible for a seeming decrease during the period we examined (Figure 37).

The decreases in landings can be directly related to decreased fishing effort. However, the corresponding decreases in mean size of common thresher may indicate a problem within this population or that the fishery does not operate at the times or in the areas when big fish are present. We therefore recommend that further investigations including catch per unit effort be conducted for the major species caught by this fishery.

There have been a number of problems and conflicts that have occurred during the first 10 years of the fishery (e.g. sea lion, gray whale, and marlin bycatch). These have been addressed and resolved interactively through the cooperative efforts of the commercial industry, the recreational fishing industry, environmental groups, and State and Federal governments. These efforts, which included many specific, problem-oriented time and area restrictions, resulted in an overall reduction in fishing intensity and the bycatch of marine mammals.

Concerns regarding the drift gill net fishery are similar to those expressed when the fishery started. Specifically, shark fisheries throughout the world historically have not been sustained and in fact, tend to decline significantly or crash rather suddenly (Compagno 1990). Shortfin makos and common threshers taken by the California drift gill net fishery within the Southern California Bight are primarily juveniles. In response to declines in the quantity and size of common thresher caught, the State virtually eliminated the directed fishery with area and season closures. If the number and size of shortfin makos caught should also decline, similar management controls may be warranted.

In the early 1980s, the incidental catch of marine mammals was relatively high, but time and area closures around the Channel Islands and along the mainland apparently were successful in reducing that catch. Currently, the incidental catch of marine mammals in this fishery is apparently not compromising any stocks, but the potential for a significant bycatch remains and may involve some species listed under the Endangered Species Act. Thus, continued monitoring, as with the NMFS mandatory observer program, is prudent.

Bycatch of fish does not appear to be a problem except possibly for blue sharks which are caught but not utilized. As this catch is not reported or monitored, it might also be a significant problem in determining the status of local populations. Important changes in abundance may not be detected in time to make prudent management decisions. Because fishing mortality and stock status of blue shark are unknown, close monitoring of the commercial as well as recreational fisheries is warranted.

ACKNOWLEDGMENTS

The efforts of Marilyn Beeson (CDFG), Corrin Holder (CDFG), Doug Prescott (NMFS), Laura Halko (NMFS), Cheryl Brown (NMFS), and John Childers (NMFS) to organize and prepare the data used in this bulletin are gratefully appreciated. We thank Ken Raymond for producing the extensive graphics. John Sunada and the CDFG Market Fisheries Unit are thanked for making the market sampling data available.

Dennis Bedford (CDFG) is recognized for development of the CDFG observer program and initiating many of the drift gill net research activities. His helpful suggestions improved the manuscript. Tony West (California Gillnetters Association) was generous in sharing his knowledge of the fishery.

Richard Klingbeil (CDFG), Dr. Gary Sakagawa (NMFS), Dr. Norman Bartoo (NMFS), Dr. Jay Barlow (NMFS), John Sunada (CDFG), Gene Fleming (CDFG), and Dr. Christopher Dewees (California Sea Grant Extension Program) are thanked for critical manuscript review. Portions of the funding for this work were provided by cooperative agreements Nos. NA89AB-H-MM036, NA86-ABD-00201, and NMFS Data Rescue Funding.

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