A REVIEW OF THE SOUTHERN CALIFORNIA EXPERIMENTAL DRIFT LONGLINE FISHERY FOR SHARKS, 1988–1991

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ABSTRACT

In 1988 the California Fish and Game Commission authorized an experimental drift longline fishery with a number of restrictions to a select group of commercial longline fishermen. Target species were shortfin mako shark (*Isurus oxyrinchus*) and blue shark (*Prionace glauca*).

During the first two years of this fishery, Department of Fish and Game personnel observed 19% of all fishing operations. Blue sharks and shortfin mako sharks accounted for approximately 91% of the catch, with blue sharks approximately twice as common as shortfin mako sharks. Shortfin mako shark catch per unit of effort (CPUE) changed little during the first two seasons, declined in the third season, then increased sharply in the fourth season. CPUE generally peaked in July and August. No striped marlin (*Tetrapturus audax*) were observed in the catch, and bycatch of other species was minimal. Length-frequency distributions of shortfin mako sharks exhibited two primary modes believed to represent ages two and three, indicating that the fishery harvested mostly juveniles.

RESUMEN

En 1988 la Comisión de Pesca y Caza de California autorizó una pesquería experimental de palangre a la deriva a un grupo selecto de pescadores; se impusieron varias restricciones. El objetivo de la pesquería fueron los tiburones marrajo (*Isurus oxyrinchus*) y azul (*Prionace glauca*).

Durante los primeros dos años de la pesquería, personal del Departamento de Caza y Pesca pudo observar el 19% de todas las maniobras de pesca. Los tiburones azul y marrajo contribuyeron el 91% de la captura y la razón de tiburones azul a marrajo fué de aproximadamente dos a uno. La captura por unidad de esfuerzo (CPUE) del tiburón marrajo cambió poco durante las primeras dos estaciones, declinó en la tercera, e incrementó marcadamente en la cuarta. La CPUE generalmente alcanzó los máximos valores en Julio y Agosto. No se observaron marlin (*Tetrapturus audax*) en la captura, y la captura de otras especies fué mínima. Hubo dos modas en las distribuciones de frecuencia de la longitud de los tiburones marrajo, y se piensa que éstas representan las edades dos y tres; ésto indicaría que la pesquería atrapó principalmente juveniles.

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INTRODUCTION

Commercial shark fishing operations have increased in recent years. During the late 1970s, a drift gill net fishery targeting swordfish (*Xiphias gladius*) and common thresher shark (*Alopias vulpinus*) developed off the southern California coast (Hanan et al. 1993). In the Santa Barbara Channel, a set gill net fishery for Pacific angel shark (*Squatina californica*) also began in the late 1970s (Herrick and Hanan 1988). Beginning in the mid 1980s, a shark fishery using drift longline gear developed in southern California, and by 1987, as interest continued to increase, the California Department of Fish and Game (the Department) determined that this gear was illegal, and prohibited its use within state waters. Participating fishermen applied to the California Fish and Game Commission (the Commission) for an experimental gear permit to continue fishing with drift longline gear. They stated that their methods were based on techniques developed by the National Marine Fisheries Service and would target shortfin mako sharks (*Isurus oxyrinchus*) and blue sharks (*Prionace glauca*).

Because of concern over potential incidental catch of striped marlin (*Tetrapturus audax*), an at-sea observer program was required to monitor the catch. The Commission issued ten permits in 1988 and 1989, and observers were assigned to vessels to document the species composition taken by longline gear. The Commission allowed the experimental fishery to continue during 1990 and 1991, but in 1992, on the Department's recommendation, denied the renewal of these permits.

Dockside and at-sea sampling results, as well as analysis of logbook information documenting species composition, size distribution, and CPUE data were compiled for the four years this fishery was authorized and are presented in this paper. This information is vital for proper management of fishery-sensitive species such as sharks, which are increasingly targeted by commercial and recreational fisheries.

THE FISHERY

Conditions and Regulations

The Commission authorized a limited experimental drift longline fishery in 1988 with a number of conditions regulating gear, seasons, areas, and harvest quotas (table 1). The Commission limited the number of ves-

TABLE 1
Summary of Main Conditions and Regulations Imposed on the Experimental Longline Fishery

	1988	1989	1990	1991
Permittees	10	10	6	8
Quota (lbs)	None	240,000	175,000	175,000
Maximum length of longline (miles)	5	4	4	4
Observers	Present	Present	Not present	Not present
Blue shark minimum catch	0	0	40,000	0
Season	April 1–Nov. 10	May 1–Sept. 15	May 1–Sept. 15	May 1–Dec. 31

sel permits issued, ranging from ten the first year to six in 1990. The initial ten permits were issued to longline fishermen who had (1) landed a minimum of 10,000 pounds of shortfin mako shark during 1987 and (2) been selected through a random lottery draw. Although there was no catch quota in 1988, quotas were imposed for the remaining three years of the fishery. The use of the longline gear was seasonally restricted in the area from Point Vicente and Santa Catalina Island in Los Angeles County to Point Loma in San Diego County (figure 1). The purpose of the closure was to minimize conflicts between other commercial shark and sport shark fisheries. Permittees were also required to notify the Department when and where they would land their catch so that Department personnel could sample the catch for information about length, weight, and sex.

Fleet and Gear Description

Longline vessels varied in length from 9 to 15 meters and typically carried a crew of two. The standard gear was restricted to a single drift longline not longer than 6.4 kilometers and constructed of stainless steel cable. Hooks were suspended from stainless steel leaders (gangions) not longer than 4 m, and spaced at approximately 16 m intervals (figure 2). The main line was suspended by buoys set at every fifth or sixth hook. Buoy lines were rarely longer than 10 m, resulting in fishing depths of 10–20 meters. Unlike set longline vessels, which disengage from the gear, drift longline gear remains attached to the vessel during fishing operations. Gear was normally deployed during daylight. Soak times ranged from 30 minutes to 10 hours, and averaged approximately 5 hours.

METHODS

Landing Data

The dressed weight (head, fins, and viscera removed) of shortfin mako and blue sharks was compiled by the Department's Marine Fisheries Statistics Unit from landing receipts, and is reported in pounds. Landing receipts must be completed by commercial fish buyers for each landing purchased. Estimates from the hook and line sport fishery for shortfin mako sharks for 1980 through 1989 were obtained from the Marine Recreational Fisheries Statistics Survey (MRFSS), and included creel census of private boats and commercial passenger fish-

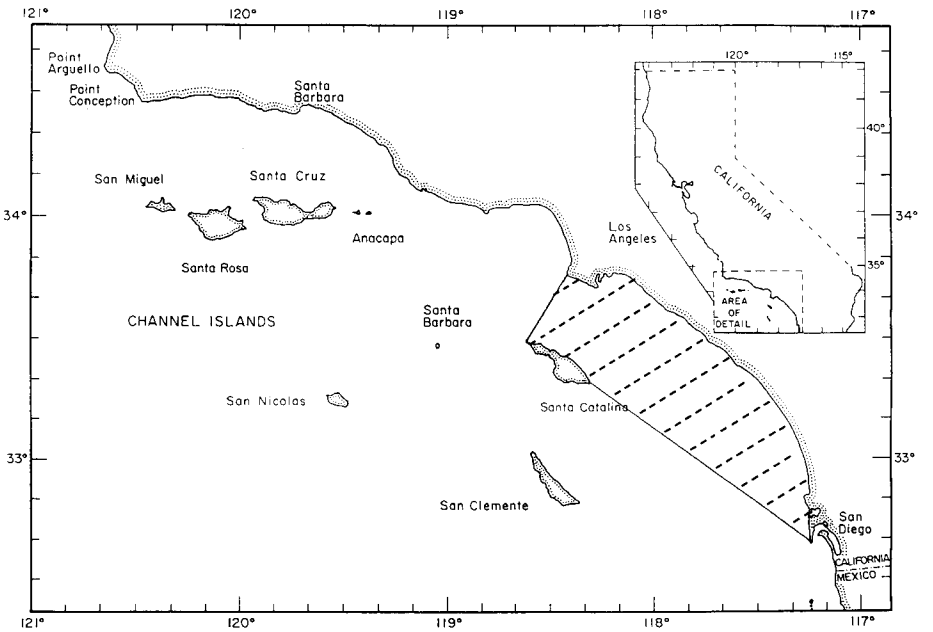

Figure 1. Area closed to experimental drift longline fishery from August 1 to September 15 (*dashed lines*).

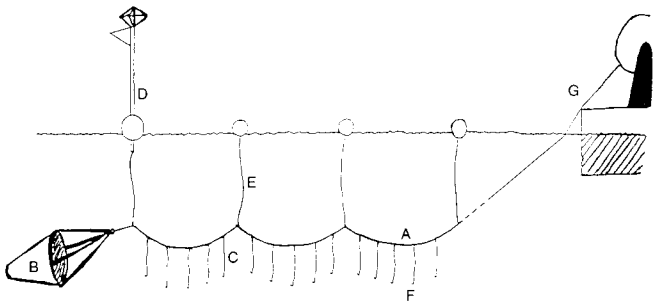

Figure 2. Diagram of typical drift longline gear in operation. *A*, mainline (stainless steel cable); *B*, sea anchor; *C*, gangion (wire, 6–12 ft); *D*, buoy with radar reflector; *E*, buoy line (10 ft); *F*, stainless steel hooks; *G*, fishing vessel.

ing vessel (CPFV) anglers. Sport-caught estimates for 1990, 1991, and 1992 are from the CPFV logbooks only, because the MRFSS was discontinued after 1989.

Observer Data

During the first two years of the fishery, vessels were required to carry Department personnel as observers, whose function was to determine species composition of the catch. Trips to be sampled were selected at random. Observers boarded boats before they left the dock and remained on board for the duration of the trip. Observers identified and enumerated all species captured by the longline gear. The observer program was discontinued by the Commission after 1989 because of the low bycatch of state and federally prohibited species and because of funding restrictions.

Concerns over possible high incidental catch and mortality of released blue sharks led the Department to establish qualitative criteria for assessing the condition of these sharks upon release (table 2).

TABLE 2
Qualitative Criteria Used to Assess Condition of Released Blue Sharks

1. Good: only slight signs of stress
   a. Minor wounds
   b. Cuts to lip or jaw
   c. Little to no bleeding
   d. Jaw not severed
   e. Physically active
2. Poor: alive but showing signs of severe stress
   a. Moderate wounds, cuts close to gill slits
   b. Jaw severed completely
   c. Injuries in pharynx, but vital organs, branchial arteries, or veins not injured
   d. Moderate bleeding
   e. Little physical activity
3. Moribund: dead or severely wounded
   a. Severe injuries from hook removal extend beyond pharynx into gill slits
   b. Pectoral or other fins removed
   c. Bleeding from severed branchial arteries and veins
   d. No physical activity

Dockside Sampling Data

Permittees were required to notify the Department at least 24 hours before landing their catch. Department personnel then attempted to sample each landing for length, weight, and sex during each year of the fishery. Because sharks were dressed at sea, alternate lengths and dressed weights were recorded.

Logbook Data

Each permittee was required to maintain a daily record of fishing activities on a logbook form issued by the Department. The four-year average rate of compliance was estimated at approximately 75%. For each set, the numbers and estimated weight of all sharks caught, the start and finish time, the start and finish location, depth and length of the main line, the number of hooks used, and water temperature were required to be recorded.

Calculation of CPUE and total effort. Total CPUE values were calculated from logbook data, for shortfin mako sharks only. CPUE was defined as the number of shortfin mako sharks caught per hook-hour.

CPUE = (N/H)

where:

N = total number of sharks reported in logbooks

H = total number of hooks multiplied by the total hours fished as reported in logbooks

CPUE was calculated by month, year, and Fish and Game block area (10-minute latitude-longitude blocks).

Total effort (H) was measured in hook-hours and summed by year and Fish and Game block.

CPUE analysis. Since the variances were heterogenous and the data were not distributed normally (even after transformation), a nonparametric one-way procedure was run on SAS to test for differences in total CPUE among years (SAS Institute Inc. 1987). The Kruskal-Wallis test was used with CPUE as the independent factor.

RESULTS

Landing Data

Shortfin mako shark landings decreased steadily from 270,000 pounds in 1988 to 110,000 pounds in 1991. Blue shark landings increased to 42,800 pounds in 1990, then dropped to 0 pounds in 1991 (table 3).

TABLE 3
Shortfin Mako Shark and Blue Shark Drift Longline Landings (lbs), 1988–1991

	1988	1989	1990	1991
Shortfin mako shark	269,604	177,928	174,215	110,513
Blue shark	2,462	10,818	42,818	0
Total	272,066	188,746	217,033	110,513

Source: California Department of Fish and Game landing receipts (landings from experimental fishery exclusively).

TABLE 4
Number and Percentage of Species Captured on Drift Longline Gear, 1988 and 1989

	1988		1989	
Species	No.	%	No.	%
Blue shark	1,900	62.1	1,320	62.0
Shortfin mako shark	883	28.9	610	28.7
Pelagic stingray	265	8.7	194	9.1
Ocean sunfish	1	—	2	0.1
California sea lion[a]	3	0.1	2	0.1
Hammerhead shark	2	0.1	0	0
Finescale triggerfish	1	—	0	0
Giant sea bass	1	—	0	0
Pacific mackerel	2	0.1	0	0

Source: observer data (no observer program in 1990 and 1991).
[a]Released alive

Observer Data

Department observers sampled approximately 19% of the total longline fishing effort during 1988 and 1989, and documented over 5,100 animals in the catch. Species composition was similar in both years. Blue sharks made up 62% of the total catch, shortfin mako sharks 29%, and pelagic stingrays (*Dasyatis violacea*) nearly 9% (table 4). The rest of the catch (less than 1%) consisted of California sea lions (*Zalophus californianus*), green sea turtles (*Chelonia mydas*), giant seabass (*Stereolepis gigas*), common thresher shark (*Alopius vulpinus*), ocean sunfish (*Mola mola*), pacific mackerel (*Scomber japonicus*), and finescale triggerfish (*Balistes polylepis*).

During 1988, Department observers recorded that 52% of the blue sharks released were judged in "good" condition, and likely to survive. Observers estimated that 88% of the blue sharks returned to the water were in "good" condition during 1989.

Dockside Sampling Data

A total of 3,719 shortfin mako sharks were measured over the four-year period. Alternate length (AL) ranged from 19 to 102 cm. Mean length of males ranged from 47.0 cm AL in 1988 to 50.0 cm in 1991, while mean lengths of females ranged from 47.0 cm in 1988 to 49.7 cm in 1991. Two distinct modes (42 and 53 cm AL) were present during each year of the fishery (figure 3).

The sex ratio for shortfin mako sharks was fairly consistent by year (1.3 males per female in 1988 and 1990, and 1.2 males per female in 1989 and 1991).

Logbook Data

The highest CPUE values were concentrated in a band of water located from 10 to 30 miles from the mainland between the southeast end of Santa Cruz Island and the southeast end of San Clemente Island (figure 4). Higher CPUE values were generally located farther offshore from 1988 through 1990, whereas during 1991 high CPUE values were located both offshore and inshore. Although no clear trend in CPUE values was observed from year to year, several areas exhibited high CPUE throughout the fishery, particularly an area approximately 10 miles north of Santa Catalina Island and another area 10–20 miles southeast of San Clemente Island.

Over the four years, monthly patterns of CPUE were similar; CPUE was low in April and May, steadily increased to a peak in July and August, then generally decreased in September (figure 5).

The highest effort values were also associated with the area of highest CPUE values (figure 4). Moderate-to-high effort values were concentrated in areas adjacent to the southeast ends of Santa Catalina and San Clemente islands, throughout the four years of the fishery.

Total effort decreased sharply from 609,026 hook-hours in 1988 to 377,382 hook-hours in 1989. Total effort increased moderately to 461,524 hook-hours in 1990, then fell dramatically to 157,720 hook- hours during 1991. Among years, differences in total CPUE were significant ($p = 0.035$). CPUE was 0.0157 fish/hook-hour in 1988 and 0.0156 fish/hook-hour in 1989. CPUE declined in 1990 to 0.0114 fish/hook-hour, then increased to 0.0163 fish/hook-hour in 1991.

DISCUSSION

Landing Data

Decreasing landings of shortfin mako sharks resulted from several factors: (1) quotas of 240,000 pounds for the 1989 season and 175,000 pounds for the 1990 and 1991 seasons were established as additional controls on the fishery; (2) unfavorable market conditions due to increased imports and decreased demand from East Coast buyers negatively influenced fishery effort in 1991, when the price for shortfin mako sharks dropped from $1.65 per pound to $0.80 per pound in July (Department landing data). For the remainder of that season, permittees had difficulty finding markets for their catch.

The longline fishery was not the sole source of shortfin mako shark landings from southern California waters: a commercial drift gill net and hook and line sport fishery also landed substantial numbers of these sharks (table 5). From 1988 to 1991, the experimental drift longline fishery accounted for 41% of the total commercial landings (Department landing data). The remaining 59% was landed by the drift gill net fishery. The sport fishery, which appears to be increasing in southern California, holds several annual tournaments targeting shortfin mako sharks (Bedford 1992). Estimates from the Marine Recreational Fisheries Statistics Survey (MRFSS) indicate that sport landings accounted for 25% of the total combined sport and commercial shortfin mako shark

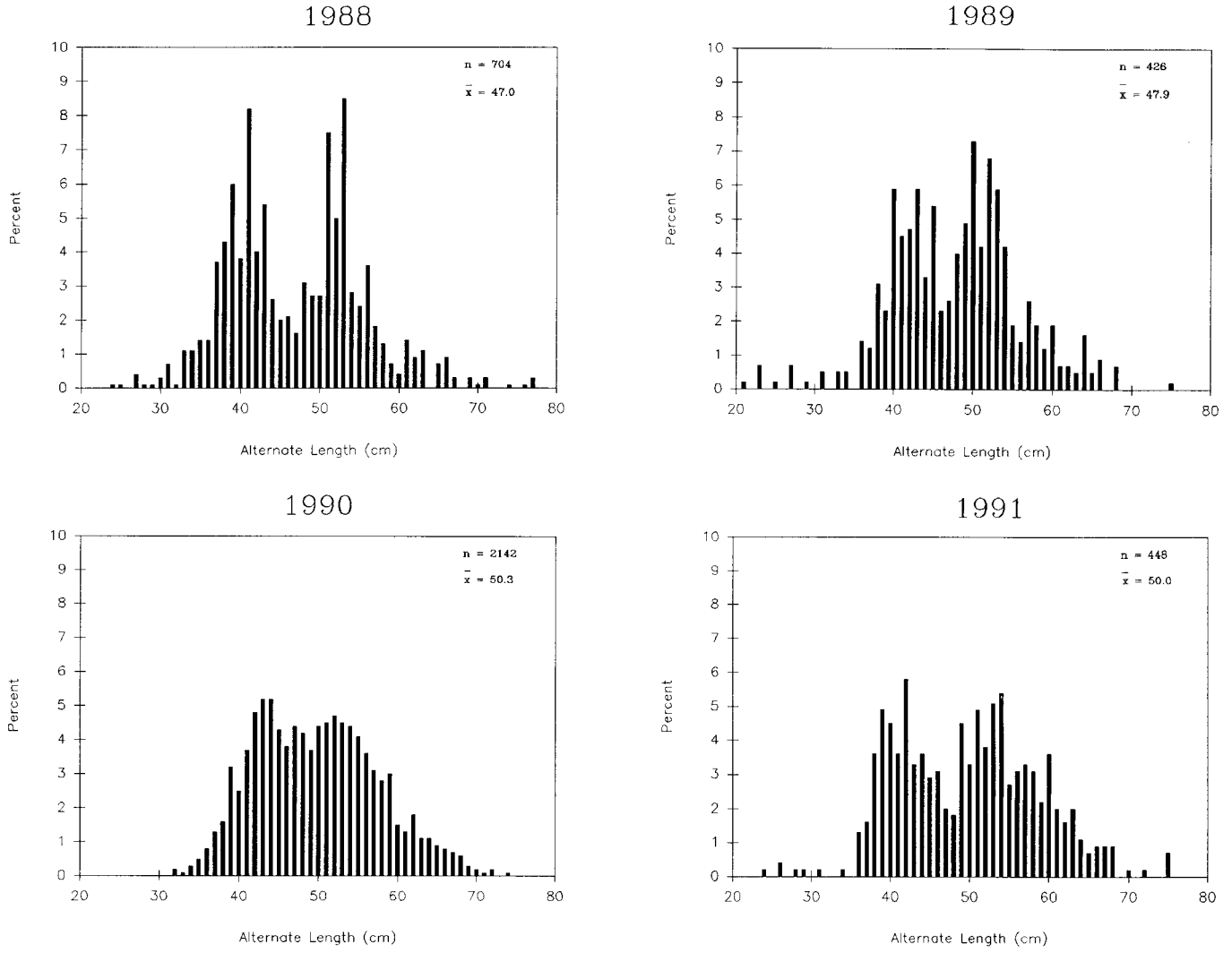

Figure 3. Length-frequency distribution of shortfin mako sharks taken by drift longlines, 1988–91.

landings during 1988 and 1989 (U.S. Dept. Commerce 1984–92).

Because of the high incidental catch of blue sharks and the successful experimental fishery for blue sharks in southern California during 1979 and 1980 (West Coast Fishery Development Foundation 1981), the Commission required permittees to develop a market for blue sharks during the 1989 and 1990 fishing seasons. In 1989, several wholesalers attempted to market blue shark for human consumption, for leather, and for crab bait, but there were no return buyers for those markets. Despite these difficulties, the Commission required that a minimum quota of 40,000 pounds of blue shark be marketed for human consumption for the 1990 season, but few wholesalers were willing to buy the 43,000 pounds landed (table 3) because no retail demand existed. Permittees resisted further attempts to develop a market for blue sharks because of low value relative to shortfin mako sharks and costly processing to prevent spoilage (high content of blood urea quickly converts to ammonia when a fish dies, making the meat unpalatable). Responding to this situation, the Commission did not set a minimum quota for blue sharks in 1991, and no landings were recorded.

Observer Data

The high percentage of blue sharks in the catch was not surprising. Department shark-tagging studies with hook and line gear in the late 1980s indicated that blue sharks were much more abundant than shortfin mako sharks in the Southern California Bight (Dennis Bedford, California Department of Fish and Game, pers. comm.). Strasburg (1958) found a 35 to 1 ratio of blue sharks to shortfin mako sharks in the central Pacific Ocean during the 1950s.

The large increase (52% vs 80%) from 1988 to 1989

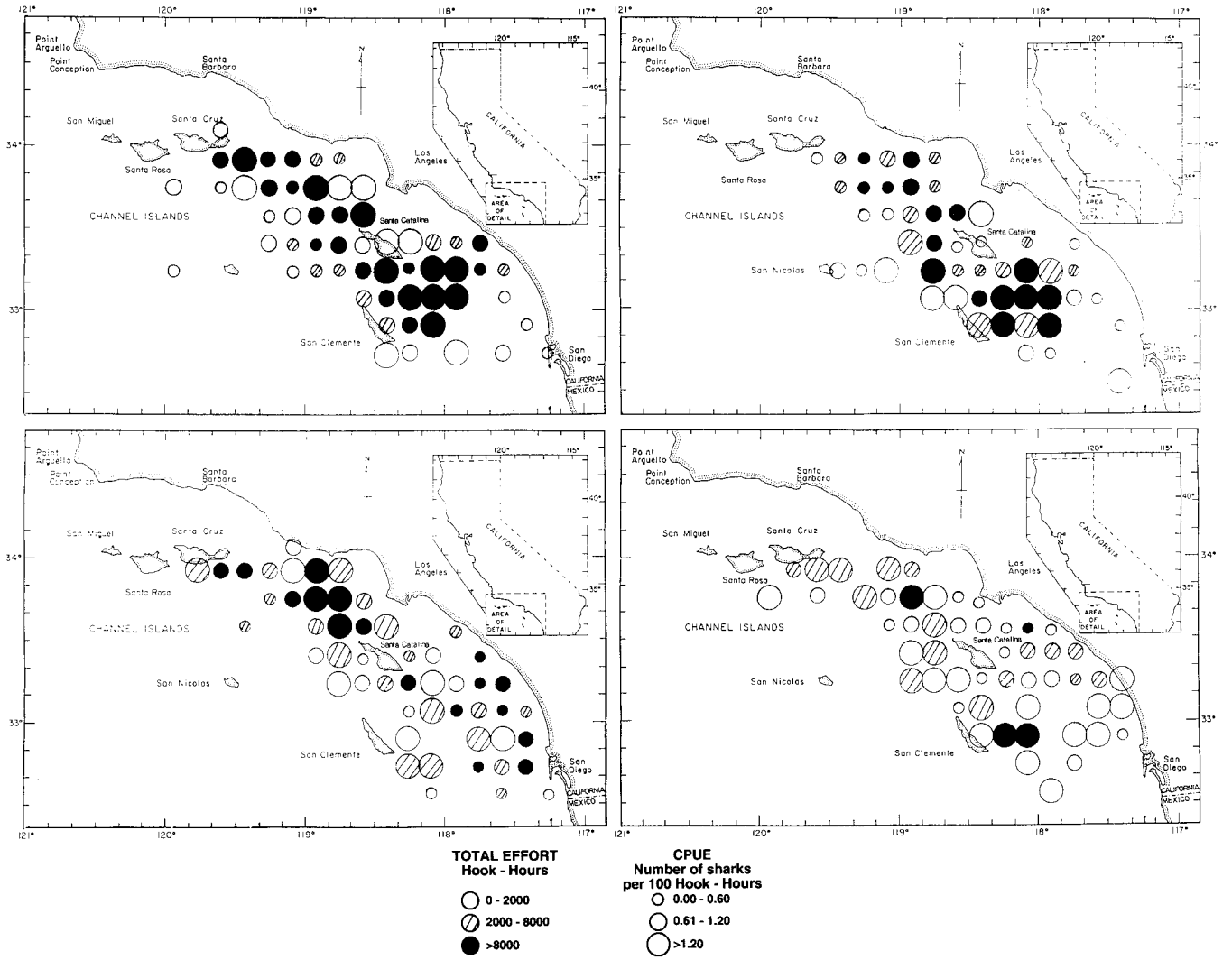

Figure 4. Total effort and catch per unit of effort for shortfin mako sharks by Fish and Game blocks for 1988 (*upper left*), 1989 (*upper right*), 1990 (*lower left*), and 1991 (*lower right*).

in released blue sharks judged to be in "good" condition was due to the development and wide use in the fishery of long-handled hook-removal pliers. Use of these pliers reduced injury and improved release condition because hooks could usually be removed without cutting the sharks' tissues. Interviews with longline permittees indicated that the pliers were also widely used in 1990 and 1991.

Additional concerns expressed by the Department about this fishery included incidental catches of commercially prohibited species such as striped marlin (*Tetrapturus audax*), as well as state and federally protected species such as sea turtles and marine mammals. Although sport anglers commonly use monofilament line to take striped marlin with bait and lures, no marlin were observed in the catch, and less than 1% of the total catch consisted of other prohibited species during 1988 and 1989. Perhaps this gear's steel cable construction deterred marlin from taking the bait despite their common occurrence in the Southern California Bight.

Pelagic stingrays, the third most abundant species captured, are found throughout tropical seas, as far north as Point Dume in southern California. Until recently, stingrays were considered rare off southern California (Miller and Lea 1972), but they appear to be vulnerable to both drift longline and drift gill net gear (Hanan et al. 1993).

This drift longline gear appeared to bring in less bycatch than the California drift gill net fishery. Observers recorded a total of 9 species captured on drift longline gear, whereas 71 species were documented from the drift gill net fishery (Hanan et al. 1993). Unlike fish caught in drift gill nets, most of the longline bycatch can be released alive.

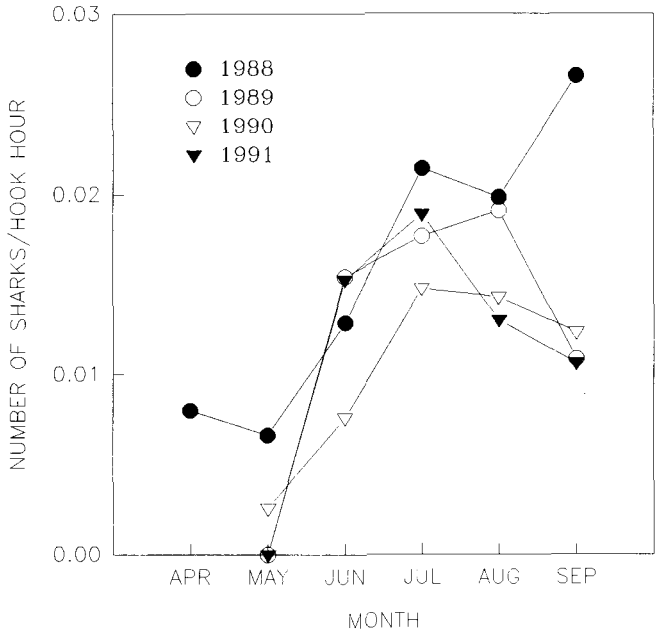

Figure 5. Monthly longline catch per unit of effort for shortfin mako sharks, 1988–91.

Dockside Sampling Data

Length distributions of shortfin mako sharks varied little throughout the four years of the fishery, and available information indicates that this fishery harvested primarily juvenile shortfin mako sharks. Length-at-age calculations by Cailliet et al. (1983) indicate that the two primary modes (42 and 53 cm AL) correspond to two- and three-year-old sharks, although it has also been suggested that these modes represent one- and two-year-old sharks (Dennis Bedford, pers. comm.). Cailliet et al. (1983), using vertebral analysis, state that shortfin mako sharks do not reach maturity until age seven, whereas Pratt and Casey (1983)—using vertebral analysis, tag return data, and modal analysis—found that Atlantic shortfin mako sharks matured at age three for males and age seven for females. Length-at-age estimates from Cailliet et al. (1983), and size-frequency data from this fishery indicate that approximately 81% of the shortfin mako shark catch was three years old or younger and likely to be immature. If shortfin mako sharks do not begin to mature until age seven, then it would take at least five years for the effects of harvesting large numbers of juvenile sharks to manifest themselves in the reproductive capacity of the stock and in future stock productivity.

Length-frequency data for shortfin mako sharks captured in the drift gill net fishery were very similar to data from the drift longline fishery (Hanan et al. 1993). The predominance of juvenile shortfin mako sharks in the catch from these two fisheries suggests that the Southern California Bight serves as a nursery area for shortfin mako sharks.

TABLE 5
Annual California Landings (lbs) of Shortfin Mako Shark, 1980–1992

Year	Commercial longline gear[a]	Commercial gillnet gear[b]	Total commercial landings	Sport landings	Total landings
1980		155,336	155,336	9,886	165,222
1981		277,345	277,345	236,259	513,604
1982		533,839	533,839	17,703	551,542
1983		330,260	330,260	23,885	354,145
1984		242,837	242,837	73,410	316,247
1985		226,695	226,695	196,192	422,887
1986	1,875	471,809	473,684	73,444	250,128
1987	64,077	547,943	612,020	452,148	1,064,168
1988	269,604	219,613	489,217	207,418	696,635
1989	177,928	210,394	388,322	92,314	480,636
1990	174,215	385,970	560,185	9,360[c]	569,545
1991	110,513	204,588	315,101	5,560[c]	320,661
1992	587	213,255	213,842	5,360[c]	219,202

[a]Includes all reported landings.
[b]Includes drift gill net, set gill net, and purse seine landings.
[c]1990–92 CPFV sport landings only.

Logbook Data

From 1988 through 1991, CPUE increased overall, with a sharp drop in 1990. However, because of a number of unknown variables that could affect CPUE (e.g., nonrandom distribution of fishing effort, emigration and immigration of animals, increased fishing skill of permittees), it is not clear whether CPUE represents an accurate index of shortfin mako shark abundance. CPUE data from a greater span of years and number of permittees may be required to identify the relationship between CPUE and abundance.

As in the drift longline fishery, catches of shortfin mako sharks from the drift gill net fishery peaked in August (Hanan et al. 1993). Because shortfin mako sharks are distributed within the warmer ocean waters of the Pacific (Cailliet and Bedford 1983), it seems probable that peak CPUEs would occur during July and August, when surface water temperatures are highest in coastal waters of the Southern California Bight. Shortfin mako sharks may be moving into the Southern California Bight during the summer to feed on Pacific mackerel, which are more available in the summer (Konno and Wolf 1992).

CONCLUSION

In summary, caution should be taken before allowing any fishery to develop which harvests predominately juveniles, especially slow-growing, late-maturing, low-fecund species such as elasmobranchs. Species possessing these characteristics are most vulnerable to overfishing (Holden 1973, 1974). Basic biological information such as age and growth, age and length at first maturity, fecundity, and gestation period must be validated. Information on juvenile and adult migratory patterns also

must be acquired. Until this information is obtained for shortfin mako sharks, it would seem unwise to encourage further exploitation of this species in the Southern California Bight.

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