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Conservation Biology of Elasmobranchs

Steven Branstetter (editor)

U.S. Department of Commerce

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U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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National Marine Fisheries Service

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Introduction

Elasmobranchs are vital and valuable components of the marine biota. From an ecological perspective they occupy the role of top predators within marine food webs, providing a regulatory control that helps balance the ecosystem. From an evolutionary perspective, this group represents an early divergence along the vertebrate line that produced many unusual, but highly successful, adaptations in function and form.

From man's perspective, elasmobranchs have been considered both an unavoidable nuisance, and an exploitable fishery resource. A few of the large shark species have earned a dubious notoriety because of sporadic attacks on humans that occur in coastal areas each year worldwide; the hysteria surrounding an encounter with a shark can be costly to the tourist industry. More importantly, elasmobranchs are often considered a detriment to commercial fishing operations; they cause significant economic damage to catches and fishing gear. On the other hand, consumer attitudes have changed concerning many previously unpopular food fishes, including elasmobranchs, and this group of fishes has been increasingly used by both recreational and commercial fishing interests. Many elasmobranchs have become a popular target of recreational fishermen for food and sport because of their abundance, size, and availability in coastal waters. Similarly, commercial fisheries for elasmobranchs have developed or expanded from an increased demand for elasmobranch food products.

Unfortunately, elasmobranch stock-recruitment relationships are generally density-dependent, and their innate biological characteristics of slow growth, late maturation, and low fecundity do not support extensive exploitation. Today, many elasmobranch populations, and stocks, are jeopardized by overexploitation, and substantially reduced populations will have long-term negative impacts, not only for the elasmobranch stocks (and human user-groups), but to the marine community of which they are a part. There are numerous examples of imbalances that have occurred within communities after the primary apex predators were removed or reduced.

This was the third symposium convened in less than four years designed to elucidate the status of elasmobranch resources worldwide. Twenty-four authors contributed 16 formal and two informal presentations on a variety of topics concerning elasmobranch biology, use, management, and conservation. Nine of the 16 formal oral presentations translated into eight manuscripts for the proceedings of this symposium. Three presentations were slated for publication elsewhere, and four authors considered their results too preliminary to warrant publication at this time. In addition, this volume contains one paper by Sandra Zeiner that was a co-winner of the 1991 American Elasmobranch Society *Gruber Award* for the best student presentation.

The development of the symposium was possible only with the help of Sandra Zeiner and Jefferey Howe of the Symposium Committee. I would like to thank Michael Smith (Chair, Local Organizing Committee, the American Society of Ichthyologists and Herpetologists) and the host institution (The American Museum of Natural History, New York) for their support. I want to extend a special note of appreciation to Harold (Wes) Pratt Jr. (Chair, Local Organizing Committee, the American Elasmobranch Society) for his many hours of help in coordinating the symposium as part of the AES meeting. I congratulate the session chairs — John Morrissey, Robert Hueter, and Jefferey Howe — for keeping the ever-changing program on schedule. Each article was peer-reviewed by at least two anonymous referees consisting of symposium participants and 'outside' experts. Overall, 21 individuals contributed comments that improved the quality of these manuscripts; their expertise is greatly appreciated. Finally, I wish to thank the authors and symposium participants. These contributions will benefit man's efforts to understand and ultimately conserve this important marine resource.

Steven Branstetter, Editor
Gulf and South Atlantic Fisheries
Development Foundation
Tampa, Florida, 1993

Trends in Shark Abundance from 1974 to 1991 for the Chesapeake Bight Region of the U.S. Mid-Atlantic Coast*

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ABSTRACT

Recent stock assessments indicate that the shark stock of the western North Atlantic is exploited at a rate twice the maximum sustainable yield. This finding is supported by data generated by the Virginia Institute of Marine Science longline program for sharks of the Chesapeake Bay and adjacent coastal waters. Trends in catch per unit of effort since 1974 indicate 60–80% reductions in population size for the common species — sandbar (*Carcharhinus plumbeus*), dusky (*C. obscurus*), sand tiger (*Odontaspis taurus*), and tiger (*Galeocerdo cuvier*) sharks. Declines include numbers of individuals for all species, size classes within species, and in one case a strong decline in relative abundance. Given the limited ability of sharks to increase their population size, these results suggest that stock recovery will probably require decades.

Introduction

The sharks of the northwest Atlantic have been increasingly exploited by recreational and commercial fisheries over the last 20 years. Because many of the species are highly migratory (Casey and Kohler, 1990), they are available to numerous regional fisheries on the U.S. east coast, and in some instances, to fisheries in Cuba, Mexico, and other Latin American countries (Springer, 1979; Anderson, 1990a; Bonfil et al., 1990). Thus there is wide-scale fishing pressure on the populations.

U.S. interest in recreational shark fishing rose in the mid-1970's following the release of the movie "Jaws"; shark fishing clubs and tournaments expanded throughout the region (Casey and Hoey, 1985; Hueter[1]). Additionally, apparent declines in abundance of traditional teleost target species like tuna, marlin, and snapper led many charter and head boat captains to fish for sharks to satisfy clients (NMFS[2]). Recreational catches are estimated at 2.5 million sharks annually, or 35,000 metric tons; annual mortality associated with this catch may exceed 10,000 t (Hoff and Musick, 1990).

Commercial use of sharks has been sporadic and based on economic parameters of supply and demand. Based on the success of a 1940's Florida-based fishery for shark liver oils (Springer and French, 1944; Springer, 1949, 1951), shark fishing was later promoted as a control measure against the economic damages sharks caused to other fishing operations and to the tourist service industry (Springer and Gilbert, 1963; Beaumariage, 1968). However, although sharks were a major bycatch in various fisheries (Cody et al., 1981; Anderson, 1985, 1990a, 1990b; Berkeley and Campos, 1988), the catch was usually discarded because of its

*VIMS Contribution No. 1782

[1] Hueter. R. E. 1991.—Survey of the Florida recreational shark fishery utilizing shark tournament data and selected longline data. Final Report to Fla. Dept. Natl. Resources, Grant #6627, 74 p.

[2] National Marine Fisheries Service (NMFS). 1991. Draft (19 April 1991) Secretarial Shark fishery management plan for the Atlantic Ocean. U.S. Dep. Commer. NOAA, Nat. Mar. Fish. Serv., Southeast Regional Center, St. Petersburg, FL, 127 p.

exclude the capture of small fish. A standard 100 hook longline covered about 2 km (1.25 miles).

Complete records were kept for each set. Data included 1) location; 2) start and finish times for set and haul operations; 3) water depth; 4) water temperatures at the surface and bottom (to a maximum of 30 m); 5) number of hooks; and 6) bait type. Each shark caught was identified to species; measured for pre-caudal length (PCL), fork length (FL), and total length (TL) to the nearest cm; weighed (lbs.); and sexed. Pertinent biological data and samples were collected. Healthy sharks not needed for biological sampling were tagged with M-type dart tags supplied by the National Marine Fisheries Service and released after species, length, and sex were determined; lengths were estimated for those large sharks that could not be safely boarded. Sharks that broke the gangion or dislodged the hook after being brought alongside were counted as a catch, and noted as a "lost" shark. Broken gangions, or 'bite-offs,' retrieved during haul-back, were not recorded as a lost shark.

Yearly fishing efforts varied with programmatic support and immediate research goals (Table 1). During 1980 and 1981, stations were surveyed on a monthly basis from May through October; 1990 and 1991 efforts replicated the 1980–81 effort, in addition to sampling ancillary localities. However, some years were represented by as little as 200–500 hooks of effort. Sampling within a depth stratum was sometimes confined to a single month which provided limited information on the spatial and temporal distributions of species over an entire year (Table 2). Sampling months varied among years, and some depth strata were sampled disproportionately. Additionally, shifting prioritites during the 1980's led to efforts over a wider geographic range, from Washington Canyon in the north to Cape Hatteras in the south. Ancillary localities of similar habitat were sometimes fished in lieu of established stations, and offshore (>100 m) sampling was greater than 1/3 of the total effort during this period (Fig. 1).

Sampling was directed at biological and ecological objectives; fishery analysis was not an a priori objective of the sampling program. Even when effort is evenly distributed, longlining as a sampling method is notorious for its variable catch rates (Branstetter, 1981a; Berkeley and Campos, 1988). Combined with changing programmatic goals and sampling effort, these variations precluded the use of standard statistical procedures. Large sample sizes that would reduce such variability were not always available in this data base (Table 1; Table 2); thus, graphically-apparent trends between consecutive years were not always significantly different. Yoccoz (1991) emphasized that statistical significance, or lack thereof, does not equate with biological significance, and that biological significance levels should be set before sampling begins. For this reason, this presentation is restricted to analysis of trends over the 18-yr period. For illustrative purposes, low-effort years were combined into multi-year categories by grouping 1974–79 and 1982–89. Although combining data from consecutive years reduced the information available for a given year, it provided a more equitable basis of effort to illustrate the long-term continuum in catch and effort trends around the comprehensive high-effort survey periods 1980–1981 and 1990–1991.

Catch per unit of effort (CPUE) was defined as the total number of sharks caught for the total number of hooks fished, multiplied by 100 within each sampling category, although the number of hooks per set increased over time (Table 1). CPUE was analyzed for total catch and by individual species in designated year categories. Because sharks segregate by sex and size, disjunctly distributed by depth on a seasonal basis, CPUE was analyzed for each time-series by depth strata and by month. The majority of species considered were coastal sharks; thus, because of the relatively higher percentage of hooks fished in offshore (>100 m) waters during the 1980's and in 1990 (Fig. 1, D–E), species-specific CPUE analyses were restricted to efforts from the Bay to the 100-m depth contour to avoid negatively biasing results for these species. Efforts in the >100-m depth category were included only for total CPUE and CPUE for the more widely distributed dusky and scalloped hammerhead sharks. Additionally, after 1981, new sampling areas — offshore (>100 m) areas away from the standard station at Norfolk Canyon, and a lagoon within the Virginia eastern shore peninsula — were fished for very specific purposes. These efforts (Fig. 1, D–F) were not directly comparable with previous data, and were excluded from analyses.

Results

A total of 383 sets, comprising of 33,115 hooks, caught 2,736 sharks of 20 species. Based on categorization of data and exclusion of extraneous efforts, this report (Table 1) includes 329 sets, totalling 28,329 hooks, that caught 2346 sharks of 20 species (Table 3). Analyses are provided for six species taken consistantly throughout the survey period. Other species, some of which were taken in good numbers, occurred only sporadically over time; thus they were excluded from further analyses.

Relative Abundance

Species composition remained relatively stable throughout the survey (Fig. 2); however, the numbers of individuals collected declined strongly over the survey period even though effort generally increased. The sandbar shark (*Carcharhinus plumbeus*) was the dominant

Table 2
Monthly (May through October) distribution of effort by depth strata over the time period 1974— 1991. A plus (+) indicates a month surveyed, a dash (—) indicates no survey.

Region	1974 MJJASO	1975 MJJASO	1976 MJJASO	1977 MJJASO	1978 MJJASO	1979 MJJASO	1980 MJJASO	1981 MJJASO	1982 MJJASO
Bay	–+–++–	––+–+–	–+––––	+++–––	––––––	++––––	++++++	–+++++	+–––––
<10 m	+–+++–	++++++	–++–+–	––++++	–+––––	––+–––	++++++	++++++	–––+––
10–20 m	–++––+	+–––++	––––––	+–––––	–+––––	––––––	++++++	++++++	––––––
20–100 m	–––++–	++++––	–++–––	++–+––	––––––	––––+–	+++++–	–+++++	+–––––
>100 m	––––––	–––––	––+–––	––––––	––––––	––––+–	+–++––	–++–++	–––+––

Region	1983 MJJASO	1984 MJJASO	1985 MJJASO	1986 MJJASO	1987 MJJASO	1988 MJJASO	1989 MJJASO	1990 MJJASO	1991 MJJASO
Bay	––––––	––––––	––––––	––––––	––––––	––––––	––––+–	++++++	–++++–
<10 m	––+++–	––+–+–	––––––	–––+––	–++–––	––+–––	––––+–	++++++	+++++–
10–20 m	––––+–	–+––––	––+–––	––++––	––––+–	––––+–	––––+–	–+++++	+++++–
20–100 m	–++–––	–––+––	––––––	––+–––	––+–+–	––––+–	––––+–	–+++++	+++++–
>100 m	––+–––	––+++–	––+–––	––+–––	––––+–	––––+–	––––+–	–++++–	––+++–

species collected in the lower Chesapeake Bay and adjacent coastal regions, and constituted over 55% of the total catch. In contrast, relative abundance declined for the dusky shark (*Carcharhinus obscurus*). From 1974 through 1981 this species composed 10–20% of the total catch, and declined to approximately 5% of the total during 1982–1989. In 1990 only three individuals (1%) were collected; in 1991 only six (2%). This was in stark contrast to the 1980 catch of 117 dusky sharks.

Table 3
Numbers of individuals of 20 species of sharks collected on VIMS longlines from 1974 through 1991. Species are listed by order of abundance.

Species analyzed		
sandbar shark	*Carcharhinus plumbeus*	1293
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	352
dusky shark	*Carcharhinus obscurus*	243
sand tiger	*Odontaspis taurus*	113
tiger shark	*Galeocerdo cuvier*	53
scalloped hammerhead	*Sphyrna lewini*	38
Miscellaneous coastal species		
smooth dogfish	*Mustelus canis*	94
blacktip shark	*Carcharhinus limbatus*	56
spinner shark	*Carcharhinus brevipinna*	6
bull shark	*Carcharhinus leucas*	5
lemon shark	*Negaprion brevirostris*	5
spiny dogfish	*Squalus acanthias*	5
blacknose shark	*Carcharhinus acronotus*	1
Atlantic angel shark	*Squatina dumeril*	1
Miscellaneous oceanic species		
bignose shark	*Carcharhinus altimus*	37
silky shark	*Carcharhinus falciformis*	18
shortfin mako	*Isurus oxyrinchus*	15
blue shark	*Prionace glauca*	9
bigeye thresher	*Alopias superciliosus*	1
night shark	*Carcharhinus signatus*	1

Catch per Unit of Effort (CPUE)

CPUE for individual years (Fig. 3A) indicated an overall decline in shark abundance; however, fluctuations between consecutive years were often explainable as sampling biases associated with the months, location, and number of hooks fished during a given year. For example, the extremely low CPUE's for 1985 and 1986 were biased because of the large percentage of hooks fished in relatively unproductive offshore waters (Table 1). Reductions in variability were possible by combining three or four consecutive low-effort years into a single category (Fig. 3B); however, this eight-category method offered only slightly greater resolution of long-term trends than a six-category time-series (Fig. 3C). The six-category method is used here.

CPUE by Species

Total CPUE (Fig. 3C) was strongly affected by the dominance of the sandbar shark catch (Fig. 4A). Total CPUE and sandbar shark CPUE declined approximately two-thirds over the sampling period. For sandbar sharks, catches included neonates and large adults.

CPUE over time declined at varying rates for the other species. The strongest decline in CPUE was that of the dusky shark (Fig. 4B). This one-time common species in the Virginia region has only rarely been caught on longlines in recent years. The majority of individuals collected were juveniles. The sand tiger (*Odontaspis taurus*) and the tiger shark (*Galeocerdo cuvier*), were caught regularly, but in low numbers, on longlines. Catch rates for the sand tiger declined about 75% over

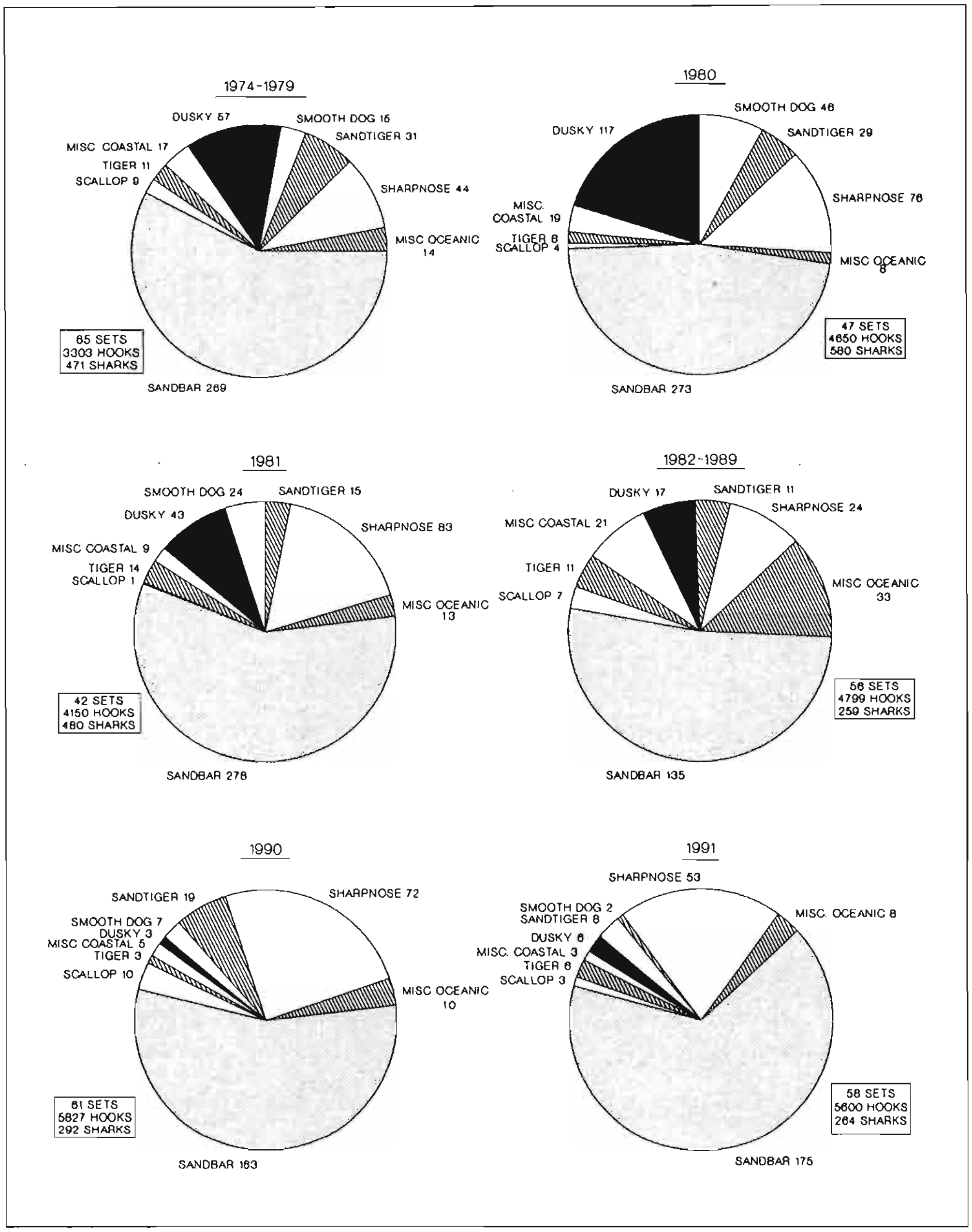

Figure 2

Relative abundance of shark species collected by VIMS longlines by year-group or year from 1974 through 1991.

the survey period (Fig. 4C). The tiger shark generally was caught at depths >10 m; catch rates in the mid-continental shelf region (10–100 m) declined almost 80% (Fig. 4E).

CPUE for two species, the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) and the scalloped hammerhead (*Sphyrna lewini*), did not show the same distinct trend in this analysis. Atlantic sharpnose sharks were taken in substantial numbers during mid-summer, but catches were sporadic and clustered, reflecting the schooling behavior of this species. Although a slight decline is suggested in Figure 4D, it is not of the magnitude shown by the other species, and normal variation in occurrence could explain this effect; however, more detailed CPUE analyses in the following sections suggested possible declines in abundance. The number of scalloped hammerheads collected was similar to that of tiger sharks, but there was not such a distinct downward trend in CPUE, although a decline is suggested by the data (Fig. 4F).

99 of the 106 juvenile (<150 cm) dusky sharks taken in that depth zone. Approximately equal numbers of dusky sharks were taken at each station, but one station was discontinued after 1983, thereby possibly biasing the apparent decline. However, CPUE for the other continuously fished coastal station also showed a similar strong decline; from 1974–81 CPUE was 43/1733 {2.48}, but from 1982–91 CPUE was 1/1486 {0.067}. The sand tiger was caught most frequently on sets made in the Bay and coastal (<10 m) waters, and CPUE declined about 75% over the survey period. (Fig. 4C) In the case of the Atlantic sharpnose shark, a distinct decline was not apparent when looking at total CPUE over time; however, in the <10 m depth range, there was a marked decline in CPUE. In the 10–20 m depth range, where the species appeared to be most common, catch rates appeared rather stable.

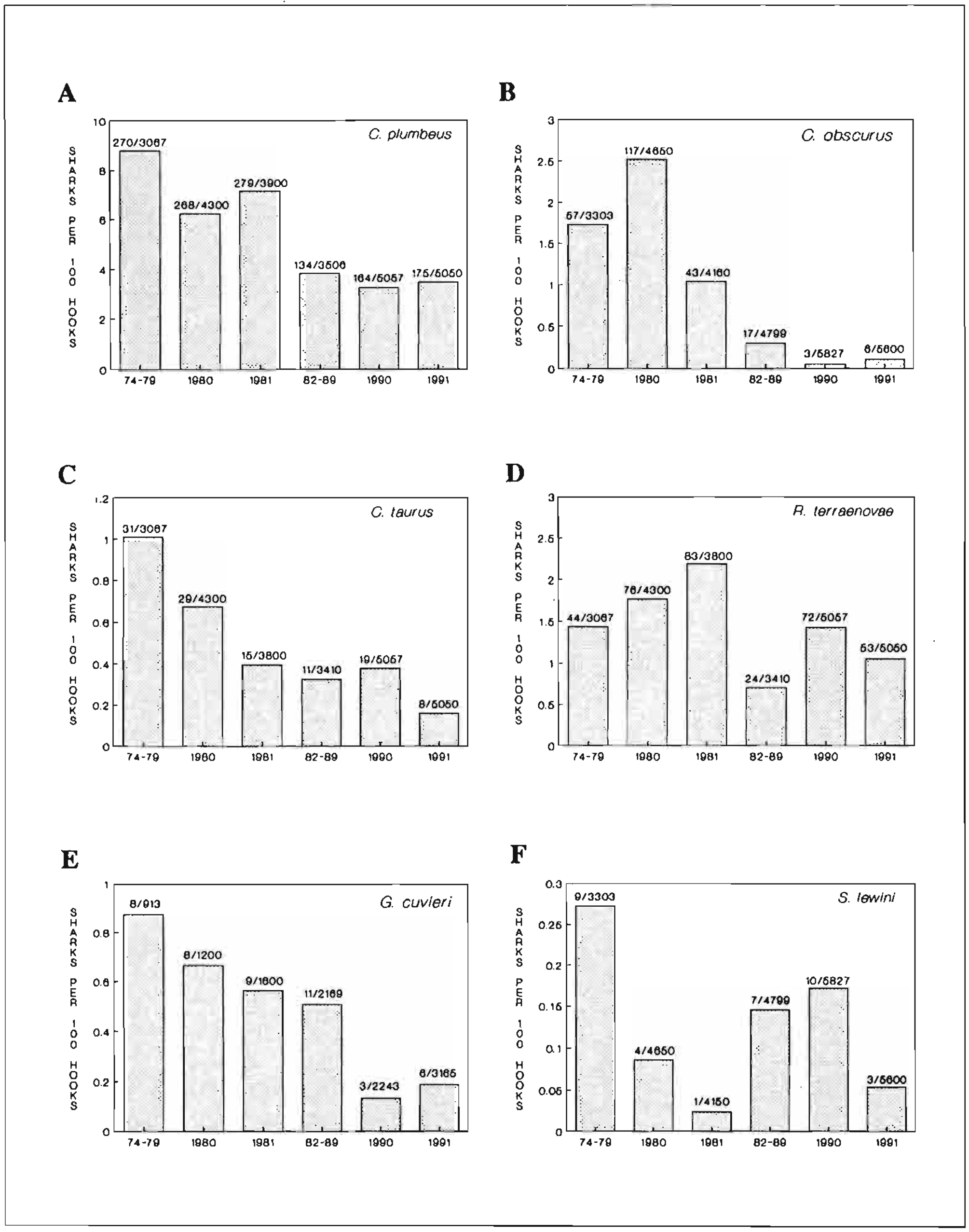

Figure 4

Catch per unit of effort for six species taken commonly on VIMS longlines, 1974–1991. (**A**) sandbar (Bay to 100 m), (**B**) dusky (Bay to >100 m), (**C**) sand tiger (Bay to 100 m), (**D**) Atlantic sharpnose (Bay to 100 m), (**E**) tiger (10-100 m), and (**F**) scalloped hammerhead sharks (Bay to >100 m). Numbers above the bars represent sharks/hooks.

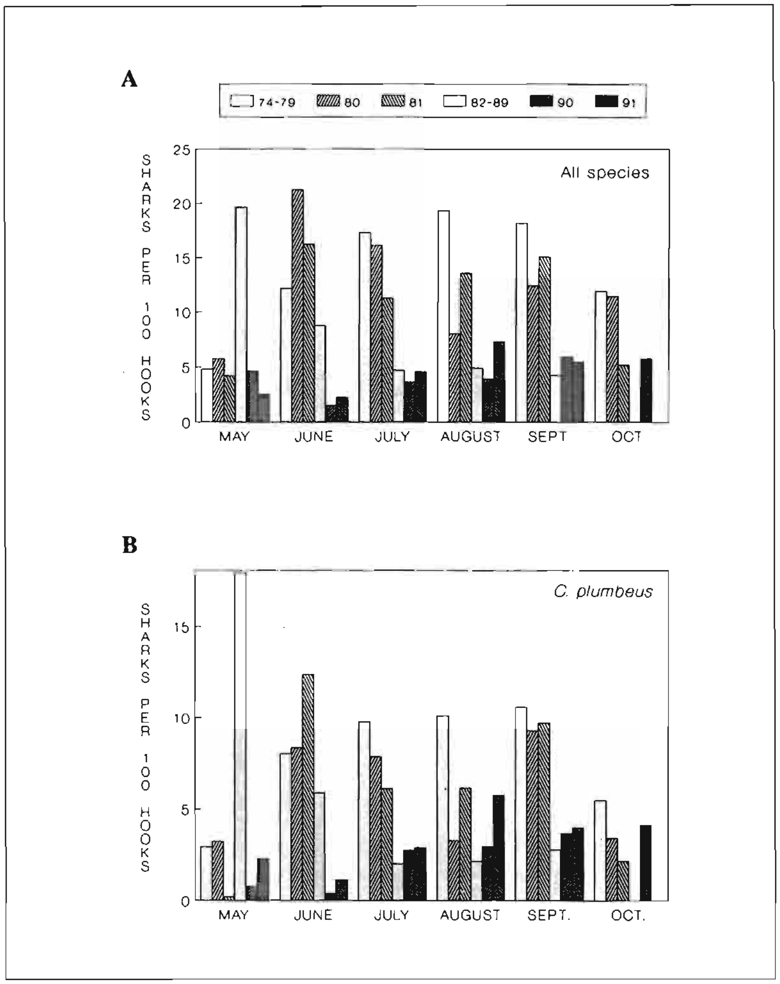

Figure 6
Shark catch per unit of effort on longlines by month by year category for (**A**) all species, and (**B**) sandbar sharks.

Catch per Unit of Effort for Size Categories of Common Species

Two species, sandbar and dusky sharks, were collected in sufficient quantities to examine CPUE by size groups. Juvenile sandbar sharks were more abundant in the lower Chesapeake Bay, whereas juvenile dusky sharks were more abundant in shallow coastal habitats outside the Bay (Musick and Colvocoresses, 1988).

The majority of sandbar sharks collected were juveniles and adolescents, 50–150 cm TL, taken in bay and coastal (<10 m) waters, whereas sub-adults and adults were more common in waters >10 m (Fig. 7A). The sandbar shark catch was categorized into four 50 cm size groups, and analyzed for CPUE by depth.

- Group 1 —juveniles (50–100 cm TL)
- Group 2 — adolescents (100–150 cm TL)
- Group 3 — sub-adults and young adults (150–200 cm TL)
- Group 4 — large adults (>200 cm TL)

These categories had some general biological significance; the majority of small sandbar sharks collected in the nursery are <100 cm TL, but adolescents use nursery grounds until they are approximately 130–150 cm TL (Casey et al., 1985; Branstetter, 1990), and the majority of sub-adults and adults taken are less than 200 cm TL (Dodrill, 1977; Branstetter, 1981b; Casey et al., 1985) (Table 4).

Catch rates differed for juvenile and adolescent fish taken in their primary habitat - Bay and coastal (<10 m) waters (Figure 7B). For juveniles 50-100 cm, CPUE declined continually until 1990. During 1990 and 1991, catch rates showed a marked increase; and reasons for this apparent increase are discussed later. In contrast, catch rates continually declined for the 100–150 cm adolescents.

Because of the overall lower number of sub-adult and adult sharks collected, data from all depths (Bay to 100 m) were used for CPUE analysis of larger fish. Again, both size groups exhibited marked declines over the survey period (Fig. 7C). This was especially true for fish

Table 4
Percent distributions of sandbar shark size classes (cm TL) collected in each depth stratum from Chesapeake Bay to the 100-m depth contour for each time-series. Some time series may not total 100% because of rounding.

	Size class (%)					Size class (%)			
Years	<100	100–150	150-200	>200		<100	100–150	150–200	>200
Bay					**<10m**				
74–79	55	38	4	3		34	50	11	5
1980	4	83	4	9		34	59	3	3
1981	17	64	10	9		17	76	7	1
82–89	33	33	22	11		11	86	4	0
1990	69	30	1	0		63	32	5	0
1991	85	15	0	0		20	60	20	0
Mean %	44	44	7	5		30	61	7	2
10–20 m					**20–100 m**				
74–79	47	47	7	0		0	33	63	4
1980	12	24	32	32		3	30	60	8
1981	0	16	67	18		0	17	81	2
82–89	4	8	84	4		0	28	70	2
1990	13	38	50	0		0	36	64	0
1991	0	44	56	0		0	50	50	0
Mean %	13	30	49	9		1	32	65	3

Discussion

The VIMS longline catch was dominated by the sandbar shark. Large sandbar sharks use the mid- Atlantic region seasonally as a feeding ground; more importantly, the bays, inlets, and barrier island areas from Chesapeake Bay to New Jersey are a major nursery ground for this species (Milstein, 1978; Medved and Marshall, 1981, 1983; Casey et al., 1985; Musick and Colvocoresses, 1988). Juveniles occupy these areas during the summer for the first several years of life until they are 130–150 cm TL, moving offshore and south in winter, and returning in the spring (Casey et al., 1985; Musick and Colvocoresses, 1988). Use of nursery grounds may reduce juvenile mortality associated with predation by larger sharks (Branstetter, 1990).

CPUE increased markedly within the Bay for 1990 and 1991 (Fig. 5A), primarily from catches of juvenile (50–100 cm TL) sandbar sharks in their nursery ground (Table 4; Fig. 7B). Although this phenomenon is similar to a documented proliferation of juvenile dusky sharks off South Africa (van der Elst, 1979) which was associated with a drastic decline in large predatory sharks. The apparent increase in relative abundance of small sandbar sharks that we observed in Chesapeake Bay may also be due to increased survivorship of young of the year, because of a large decline (60–80%) in large coastal sharks that are their principal predators. Regardless, this compensatory mechanism can be only temporary at best as the remaining mature females are captured by the fishery.

This abundance of small, juvenile sandbar sharks within Chesapeake Bay artifically inflated the overall catch rates during this time period; overall catch rates appeared to be relatively stable since the early 1980's (Fig. 3). Exclusion of all Bay efforts removed this bias and indicated a continued decline in CPUE, even between 1990 and 1991 (Fig. 9). By excluding efforts in the sandbar shark nursery ground, where individuals are concentrated in specific areas, this analysis provides a more realistic trend in shark population abundance for the region over time.

Table 5
Catch by year category of dusky shark individuals in three size classes taken on VIMS longines, 1974-1991, from Chesapeake Bay to the 100 m depth contour.

		Size class (cm TL)		
Group	Hooks	<150	150–275	>275
74–79	3067	37	4	6
1980	4300	105	12	0
1981	3800	28	12	1
82–89	3410	5	8	2
1990	5057	3	0	0
1991	5050	5	1	0
Total	24684	183	37	9

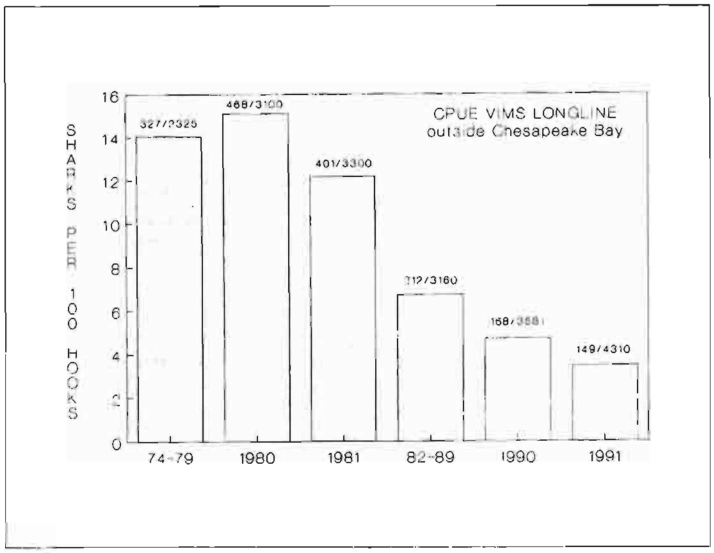

Figure 9
Catch per unit of effort on longlines fished in the Chesapeake Bight, excluding efforts in the sandbar shark nursery ground within Chesapeake Bay.

tinct reproductive groups of females: one that pupped in late June–early July, and the other in December–January. However, their data, in combination with additional literature records (Dodrill, 1977; Branstetter, 1981b), can also be used to illustrate a single-phased gestation period of about 22 months. With a one-year resting stage for post- partum females, the entire reproductive cycle would require at least three years. Dodrill (1977) noted that only about 20% of the mature females he examined were gravid. The number of young is 6–12, and most litters comprise about 10 pups (Natanson, 1990)that are correspondingly large (90–100 cm TL) in relation to the extended gestation period. The oldest specimens aged (Natanson, 1990) were 30–35 years old; thus, with a three-year reproductive cycle, the species may reproduce only about seven times.

Given the direct relationship between stock and recruitment for sharks (Holden, 1974, 1977), the declines in juvenile abundance strongly suggests a reduced parental stock size (Musick and Colvocoresses, 1988). Large dusky sharks have become a rarity in recreational fishing tournaments and commercial landings (Hueter;[1] Burgess[3]). A longer reproductive cycle, and corresponding lowered annual production, coupled with increased fishing mortality, may be important in the apparent reductions in the population size of this species over the last 10 years.

Based on their biology, estimates of the intrinsic rate of increase (r) for slow-growing species such as the sandbar and dusky sharks are between 0.015 and 0.020 (Hoenig and Gruber, 1990; Hoff, 1990). In other words, with a stable age structure, the population can increase only about 2% per year; thus there is little flexibility in the population's ability to withstand additional mortality associated with fishing (Hoff, 1990). It is probable that some of the declines of sandbar and dusky sharks are associated with the recent exponential rise in commercial efforts; both species are preferred targets of this fishery. However, the decline in the CPUE for both species in the VIMS survey began in the early 1980's, prior to the escalation of the U.S.-directed commercial fishery about 1985 (NMFS[2]). These early declines may have been associated with the combined heavy fishing pressure from 1) the recreational shark fishery that expanded rapidly along the U.S. Atlantic coast in the 1970's (Casey and Hoey, 1985), 2) the bycatch associated with an expanding swordfish and tuna longline fishery in the late 1970's and early 1980's (Berkeley and Campos, 1988), and 3) increasing foreign efforts such as the expanding Mexican shark fishery in Yucatan (Bonfil et al. 1990) that probably harvests the same stock (Hoff and Musick, 1990). Thus, the directed U.S. commercial fishery may simply have been the "straw that broke the camel's back."

In contrast to these slow-growing species, the Atlantic sharpnose shark grows rapidly, matures quickly, and reproduces often. Females mature in 3–4 years (85 cm TL), and give birth to 4–6 relatively large young (30 cm TL) after an 11–12 month gestation period (Branstetter, 1981b, 1987; Parsons, 1983 a and b, 1985). The repro-

[3]G. Burgess. Univ. Fla., Gainesville, FL, pers. commun. 1991)

Bonfil, R., D. de Anda, and R. Mena.
1990. Shark fisheries in Mexico: the case of Yucatan as an example. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, T. Taniuchi, eds.), p. 427–441. NOAA Tech. Rep. NMFS 90.

Branstetter, S.
1981a. Shark fishery potential for the north-central Gulf of Mexico. Dauphin Island Sea Lab (Ala.) Tech. Rep. 81-001, 21 p.
1981b. Biological notes on the sharks of the north-central Gulf of Mexico. Contrib. Mar. Sci. 24:13–34.
1987. Age and growth validation of newborn sharks held in laboratory aquaria, with comments on the life history of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae.* Copeia 1987:291–300.
1990. Early life-history implications of selected carcharhinoid and lamnoid sharks of the Northwest Atlantic. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 17–28. NOAA Tech. Rep. NMFS 90.

Branstetter, S., and J.A. Musick.
In press. A comparison of shark catch rates on longlines using rope/steel (Yankee) and monofilament gangions. Mar. Fish. Rev.

Byers, R.D.
1940. The California shark fishery. Calif. Fish and Game 26(1):23–28.

Cailliet, G.M., and D.W. Bedford.
1983. The biology of three pelagic sharks from California waters, and their emerging fisheries. Calif. Coop. Fish. Invest. Rep. 24:57-69.

Casey, J.G., and J.J. Hoey.
1985. Estimated catches of large sharks by U.S. recreational fishermen in the Atlantic and Gulf of Mexico. *In* Shark catches from selected fisheries off the U.S. East Coast, p. 5–19. NOAA Tech. Rep. NMFS 31.

Casey, J.G., and N.E. Kohler.
1990. Long distance movements of Atlantic sharks from the NMFS cooperative shark tagging program. *In* Discovering sharks (S.H. Gruber, ed.), p. 87–91. American Littoral Society, New Jersey.

Casey, J.G. H.L. Pratt Jr., N. Kohler, and C.E. Stillwell.
1990. The shark tagger: 1990 summary. Newsletter, coop. shark tagging program. U.S. Dep. Commer., NOAA, NMFS, Narragansett, RI, 12 p.
1991. The shark tagger: spring 1991. Newsletter, coop. shark tagging program. U.S. Dep. Commer., NOAA, NMFS, Narragansett, RI, 2 p.

Casey, J.G., H.L. Pratt, Jr., and C.E. Stillwell.
1985. Age and growth of the sandbar shark (*Carcharhinus plumbeus*) from the western North Alantic. Can. J. Fish. Aquat. Sci. 42(5):963–975.

Clark, E., and K. von Schmidt.
1965. Sharks of the central Gulf coast of Florida. Bull. Mar. Sci. 15:13–83.

Cliff, G., S.F.J. Dudley, and B. Davis.
1989. Sharks caught in the protective gill nets off Natal, South Africa. 1. The sandbar shark, *Carcharhinus plumbeus* (Nardo). South Afr. J. Mar. Sci. 7:255–265.

Cody, T.J., B.E. Fuls, G.C. Matlock, and C.E. Bryan.
1981. Assessment of bottom longline fishing off the Central Texas coast; a completion report. Texas Parks and Wildl. Dep., Coastal Fish. Branch, Mgmt. Data Ser. 22, 51 p.

Colvocoresses, J.A., and J.A. Musick.
1980. A preliminary evaluation of the potential for a shark fishery in Virginia. Va. Inst. Mar. Sci., Special Sci. Rep., No. 234, 39 p.

Cook, D.
1982. Virginia's winter shark fishery a promising alternative. Mar. Res. Bull., Va. Sea Grant 12(4), 12 p.

Cook, S. (editor)
1987. Sharks; an inquiry into biology, behavior, fisheries, and use. proceedings of a conference; Portland, OR, 13-15 October 1985. Oregon State Univ. Ext. Service, 237 p.

Dodrill, J.W.
1977. A hook and line survey of the sharks found within five hundred meters of shore along Melbourne Beach, Brevard County, Florida. M.S. thesis, Florida Inst. Technol., Melbourne, FL, 304 p.

Florida Sea Grant.
1985. Manual on shark fishing. Florida Sea Grant College, Sea Grant Rep. No. 73, 44 p.

Graham, G.
1987. The development of Gulf coast shark fisheries; synopsis. *In* Sharks: an inquiry into biology, behavior, fisheries, and use (S. Cook, ed.), p. 179–181. Oregon State Univ. Ext. Service.

Grant, C.J., R.L. Sandland, and A.M. Olsen.
1979. Estimation of growth, mortality and yield per recruit of the Australian school shark, *Galeorhinus australis* (Macleay), from tag recoveries. Austr. J. Mar. Freshwater Res. 30:625–637.

Gordievskaya, V.S.
1971. (1973). Shark flesh in the food industry. Israel program for scientific translation for NOAA/NMFS. IPST catalog No. 60080 2, Springfield, VA, 26 p.

Hoenig, J.M., and S.H. Gruber.
1990. Life-history patterns in the elasmobranchs: implications for fisheries management. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr, S.H. Gruber, and T. Taniuchi, eds.), p. 1–16. NOAA Tech. Rep. NMFS 90.

Hoff, T.B.
1990. Conservation and management of the Western North Atlantic shark resource based on the life history strategy limitations of sandbar sharks. Ph.D. diss., Univ. Delaware, 282 p.

Hoff, T.B., and J.A. Musick.
1990. Western North Atlantic shark fishery management problems and informational requirements. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 455-472. NOAA Tech. Rep. NMFS 90.

Holden, M.J.
1974. Problems in the rational exploitation of elasmobranch populations and some suggested solutions. *In* Sea fisheries research (F.R. Hardin-Jones, ed.), p. 117–137. John Wiley and Sons, N.Y.
1977. Elasmobranchs. *In* Fish population dynamics (J.A. Gulland, ed.), p. 187–214. John Wiley and Sons, New York.

Holts, D.B.
1988. Review of U.S. west coast commercial shark fisheries. Mar. Fish. Rev. 50(1):1–8.

Kleign, L.J.K.
1974. Results of experimental and exploratory shark fishing off northeastern South America. Mar. Fish. Rev. 36(9):67–78.

Shark Bycatch in the Northern Gulf of Mexico Tuna Longline Fishery, 1988-91, with Observations on the Nearshore Directed Shark Fishery

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ABSTRACT

Observers aboard domestic tuna and shark longline vessels in the Gulf of Mexico from January 1988 to December 1991 recorded detailed catch and effort information from each set. A total of 87 tuna trips (302 sets) and 8 shark trips (53 sets) were surveyed, and 1,965 sharks of 18 species were recorded. The mean catch rate for the offshore tuna sets was 0.3 sharks/100 hooks, and the mean catch rate for the nearshore shark sets was 8.3 sharks/100 hooks. Shark mortality on tuna sets was 46.5% and 92.2% on shark sets. Silky sharks dominated the tuna bycatch, and substantial numbers of coastal species were caught over deep water in the vicinity of the Mississippi River Delta on tuna longlines. Dusky, thresher, and silky sharks tended to occur in deep water much farther from land (>150 km). In the combined tuna and shark set data, females predominated in the coastal species whereas males were more numerous in the pelagic species. The mean lengths of 11 species, were smaller than their reported sizes at maturity. Shark landings have declined in the Gulf since 1989 and fleet size has been reduced. A continuing observer program could be very useful to biologists conducting yearly stock assessments under the pending federal shark fishery management plan.

Introduction

Prior to the 1980's, there was little directed fishing effort for sharks in the Gulf of Mexico (hereafter referred to as the "Gulf"). Mexico's small artisanal shark fisheries in the western Gulf produced <1,000 metric tons (t) a year until 1970 when landings began to increase steadily. By 1981, Mexico's shark landings had risen to >9,000 t (Anderson, 1990) and exceeded 10,000 t/yr for the remainder of that decade. Cuba fished for sharks on the west Florida continental shelf until the late 1970's, but catches were usually less than 100 t/yr (Anderson, 1985). In 1976, Cuba's Gulf shark landings reached 1000 t, but no catches from U.S. waters have been reported since that time. A U.S. domestic shark fishery became firmly established in the northern Gulf in 1986 (NMFS[1]), although a few vessels had fished exclusively for sharks since 1981 (Miget, 1983). By 1989, there were about 55 full-time shark vessels (NMFS[1]) and 30–50 part-time shark boats in the Gulf. Shark landings peaked at over 5,600 t (Table 1), then declined sharply in 1990.

Sharks have been a substantial bycatch in other fisheries in the Gulf as well. In 1957, Japan began longlining for tuna in the Gulf (Iwamoto, 1965), and by the mid-1970's, this fishery was discarding >100 t of sharks annually (Anderson, 1985). This foreign longlining operation ceased voluntarily under an international agreement in 1982 (Honma et al., 1985). In the early 1970's, a domestic swordfish fishery became established in the Gulf (Anderson, 1990). This seasonal fishery, occurring during the fall and winter, had an estimated shark bycatch that increased from <600 t/yr in the 1970's to >1,000 t/yr in 1980 (Anderson, 1990).

Sharks were usually an unwelcome bycatch in the swordfish fishery, but this attitude changed during the mid-1980's. A domestic demand for yellowfin tuna (Adams[2]), coupled with a domestic and foreign market

[1] National Marine Fisheries Service. 1989. Draft secretarial shark fishery management plan for the Atlantic Ocean. U.S. Dep. Commer., NOAA, SE Regional Office. St. Petersburg, FL, 116 p.

[2] Adams, C. 1987. Yellowfin tuna: trends in production and value. Staff paper 308, Food and Resource Econ. Dep., Univ. Florida, Gainesville, 20 p.

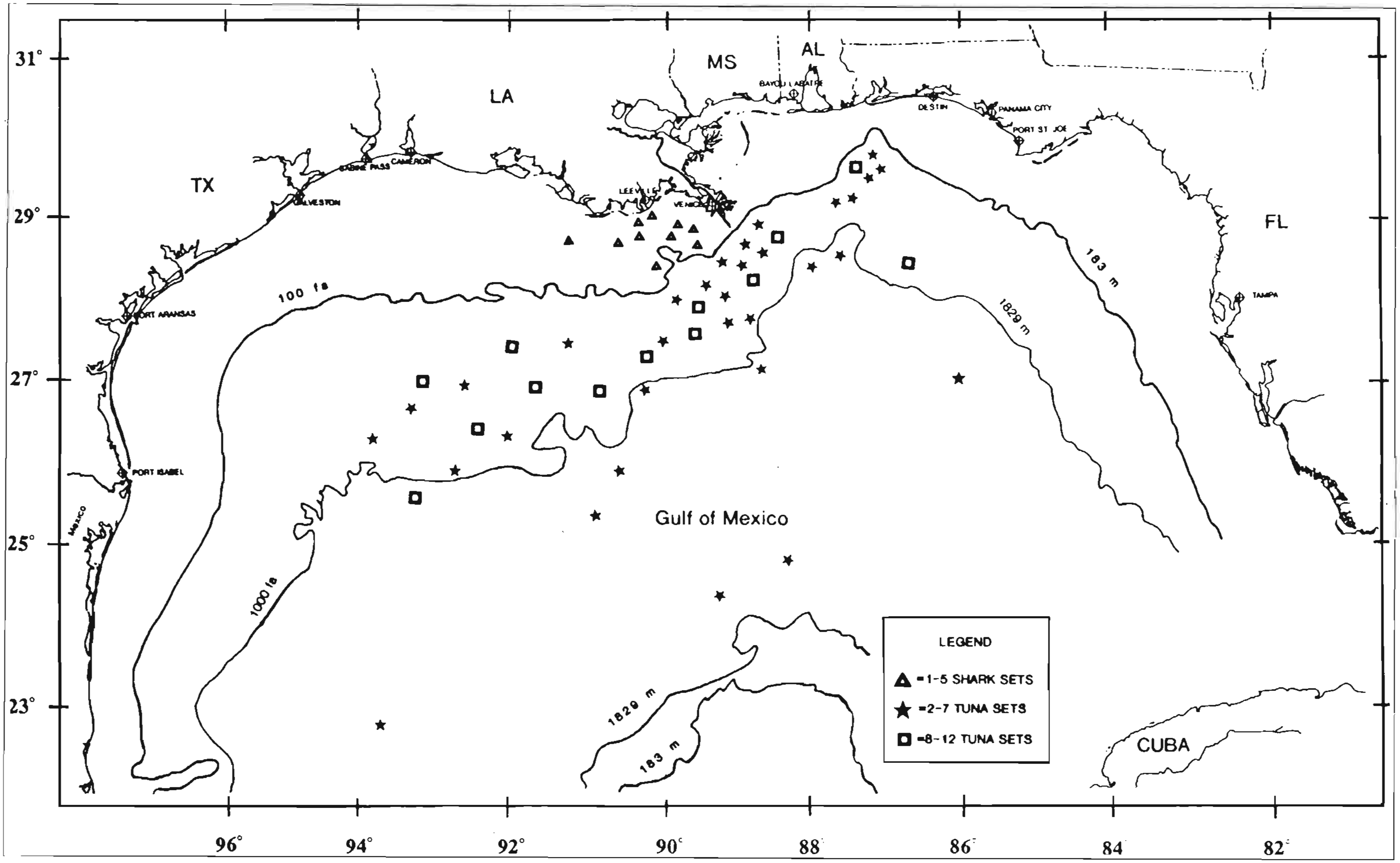

Figure 1
Locations of groups of shark sets (triangles) and tuna sets (stars and squares) surveyed by Louisiana State University observers, 1988–91.

was restricted while fishing in the Gulf in 1978–81 from retaining any shark bycatch (Witzell, 1985). Finning appears to have decreased slightly in 1991 because of negative publicity which influenced many buyers to insist that carcasses be landed along with the fins. Because many tuna fishermen did not like handling shark carcasses, they discarded all sharks.

Although silky sharks were the most abundant species caught by tuna longlines in the Gulf (Table 2), only 48.3% of the 120 retained sharks were pelagic species. The next four species in order of overall abundance (spinner, blacktip, dusky, and sandbar sharks) were "coastal species" as categorized by Parrack[5]. Other tuna and swordfish gear surveys in the Gulf had also listed silky sharks as the primary species collected, but they had recorded oceanic whitetip, scalloped hammerhead, and dusky sharks as secondarily dominant (Bullis, 1976; Branstetter, 1987a; NMFS[4]).

The coastal species most often retained for sale were blacktip, spinner, and dusky sharks, and these represented 51.7% of the retained shark catch. The data from this study do not support Parrack's[5] statement that pelagic species represented 90% of the landed shark bycatch by weight in the Gulf tuna longline fishery. Parrack based his conclusion on logbook and trip ticket data, but the LSU observers noted that this data was probably suspect. They found that few tuna fishermen could accurately identify shark species, or they called everything a "mako" because mako sharks commanded the highest dockside price. Buyers seldom disputed the identification of headless, finless, and eviscerated carcasses.

Shortfin mako, thresher, bigeye thresher, large blacktip, large silky, and large spinner sharks were usually retained for sale (Table 2) if undamaged. The bigeye thresher, first recorded from the Gulf in 1980 (Branstetter and McEachran, 1983), and the thresher shark were very desirable species, contrary to Parrack's[5] finding that these species were considered unmarketable or worth so little as to be discarded at sea. Most of the bull, dusky, and sand tiger sharks were too large to be brought aboard easily and were cut loose; scalloped hammerhead, oceanic whitetip, and sandbar sharks were considered unmarketable except for their fins; all tiger and lemon sharks were cut loose immediately. Small silky and spinner sharks were generally caught in large quantities at one time; the fishermen usually finned them and discarded the carcasses.

Species composition of the shark bycatch varied by month (Table 2), and was strongly seasonal. August and October produced the most species, and January and March the least. Blacktip and dusky sharks were recorded in nine months out of the year and were most common from August through November. Sandbar sharks were recorded in six months out of the year and were most common from May through August. Scalloped hammerheads were recorded in eight months out of the year, shortfin mako and silky sharks in seven months of the year, and sand tiger, spinner, thresher, and tiger sharks in six months of the year. These variations in abundances were probably biased towards the warmer summer and fall months when longlining effort and observer coverage were apparently greatest, but they still were indicative of nearshore-offshore (or vice versa) movement patterns for some of the coastal species. For example, the shark bottom longline data showed that pregnant female blacktip sharks were abundant in nearshore waters in April and May where they probably gathered in large schools to give birth. Blacktip sharks were not caught offshore in the tuna bycatch at that time (Table 2) but appeared offshore in August after the pupping and breeding season was over.

Besides seasonal variations in species abundances, there were notable variations in species abundances by year (Table 3). Blacktip sharks were the most numerous of the shark species in the tuna bycatch in 1988, spinner sharks, followed by dusky and sandbar sharks predominated in 1989, dusky sharks predominated in 1990, and silky sharks predominated in 1991. Bull, lemon, tiger, and Atlantic sharpnose sharks were en-

Table 3
Shark catch from tuna sets by year.

Shark species	1988	1989	1990	1991
Blacktip	37	17	4	3
Spinner		76		2
Bull		6		2
Dusky		35	16	3
Sandbar		41	1	9
Sand tiger		15	2	1
Lemon	3			
Tiger	1	3	1	3
Scalloped hammerhead	2	26	3	6
Unknown hammerhead		1		
Atlantic sharpnose		1		
Shortfin mako	5	8	3	4
Longfin mako		1	1	2
Big-eye thresher		2	2	
Thresher	6	5		4
Silky		2	8	99
Oceanic whitetip		1		5
Unidentified		10	3	25
Total	54	250	44	168
No. of sets	49	85	59	109
No. of hooks	25,211	39,997	33,935	81,589
Catch rate (# fish/100 hooks)	0.2	0.6	0.1	0.2

[5] Parrack, M.L. 1990. A study of shark exploitation in U.S. Atlantic coastal waters during 1986–1989. U.S. Dep. Commer., NOAA, NMFS, SE Fisheries Science Center, Miami, FL, 14 p.

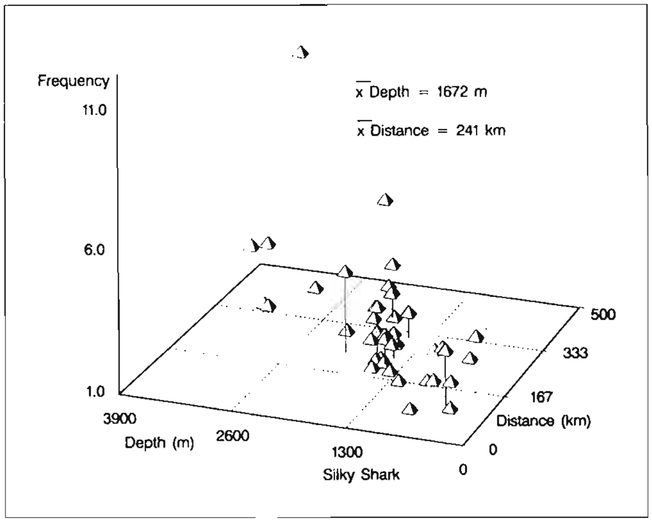

Figure 2
Numbers of silky sharks by sea floor depth and distance from nearest shoreline recorded by observers aboard tuna vessels in the Gulf of Mexico, 1988–91.

sets (17,404 hooks) produced 1,449 sharks for a mean catch rate of 8.3 sharks/100 hooks (Table 5). Overall mortality rate of the discarded sharks was 92.2%. The short gangion lines (3.1 m) restricted mobility needed for ventilation, so few sharks were landed alive.

As was expected, coastal species dominated the catches. The most abundant species overall was the blacktip shark (Table 5). Bull sharks were second in abundance of those species retained for sale. Most of the blacktip and bull sharks caught during the April and May trips were pregnant females with near full-term pups. Smooth dogfish were second in overall abundance, but these were retained for shark bait rather than for sale, as were Atlantic sharpnose sharks. Scalloped hammerheads were unmarketable and were usually finned and discarded. The only pelagic species captured (one each) were shortfin mako and silky sharks (Table 5). Dusky sharks were surprisingly rare in this nearshore fishery.

Biological Data

Owing to the nature of the commercial fisheries under observation, little biological data beyond species, total length, sex, and, occasionally, dock weight, could be gathered from each shark. The shark set data complements the tuna set data by extending areal coverage, and all biological data were combined from both fisheries. Mean lengths for females were greater than those for males except for lemon, sandbar, and oceanic whitetip sharks (Table 6). No female bigeye thresher, sand tiger, thresher, or tiger sharks were measured.

Mean lengths for male and female longfin mako, blacktip, oceanic whitetip, silky, sandbar, and spinner sharks, male shortfin mako, dusky, and thresher sharks, and female scalloped hammerhead and lemon sharks were smaller than their reported sizes at maturity (Branstetter, 1981, 1987a, 1987b; Compagno, 1984; Branstetter and McEachran, 1986; Branstetter and Stiles 1987; Berkeley and Campos, 1988; Pratt and Casey 1990). This indicates that, at least in several species, a preponderance of immature sharks were captured both in nearshore waters by the directed shark fishery, and in offshore waters by the tuna fishery. Females were more numerous than males in most of the coastal species, including blacktip, Atlantic sharpnose, bull, dusky, and spinner sharks (Table 7), but males predominated in the more pelagic species, including bigeye thresher, longfin mako, oceanic whitetip, scalloped hammerhead, shortfin mako, and silky sharks. In contrast, Berkeley and Campos (1988), who surveyed the shark bycatch in Florida's east coast commercial swordfish fishery, found that there was a preponderance of immature females in the pelagic species, and expressed concern that these sharks might be vulnerable to overfishing. However, because males and females may segregate by habitat, and because sampling was not ecologically uniform in either the aforementioned study or in this current study, these sex ratios may or may not be biologically significant in terms of stock health.

Status of the Fisheries

Since 1989, shark landings in the U.S. Gulf have steadily declined (Table 1). Tuna landings also dropped from

Table 5
Shark catch and bycatch from shark-directed sets, February 1989 to January 1991.

Shark species	No. retained	No. discarded	No. discarded alive	Total
Blacktip	666	8	0	674
Smooth dogfish	226	163	0	389
Atlantic sharpnose	167	37	0	204
Bull	43	2	2	45
Spinner	31	8	8	39
Sandbar	31	10	10	41
Lemon	8	0	—	8
Scalloped hammerhead	5	26	1	31
Dusky	2	0	—	2
Silky	1	0	—	1
Shortfin mako	1	0	—	1
Unknown	0	14	0	14
Total	1,181	268	21	1,449

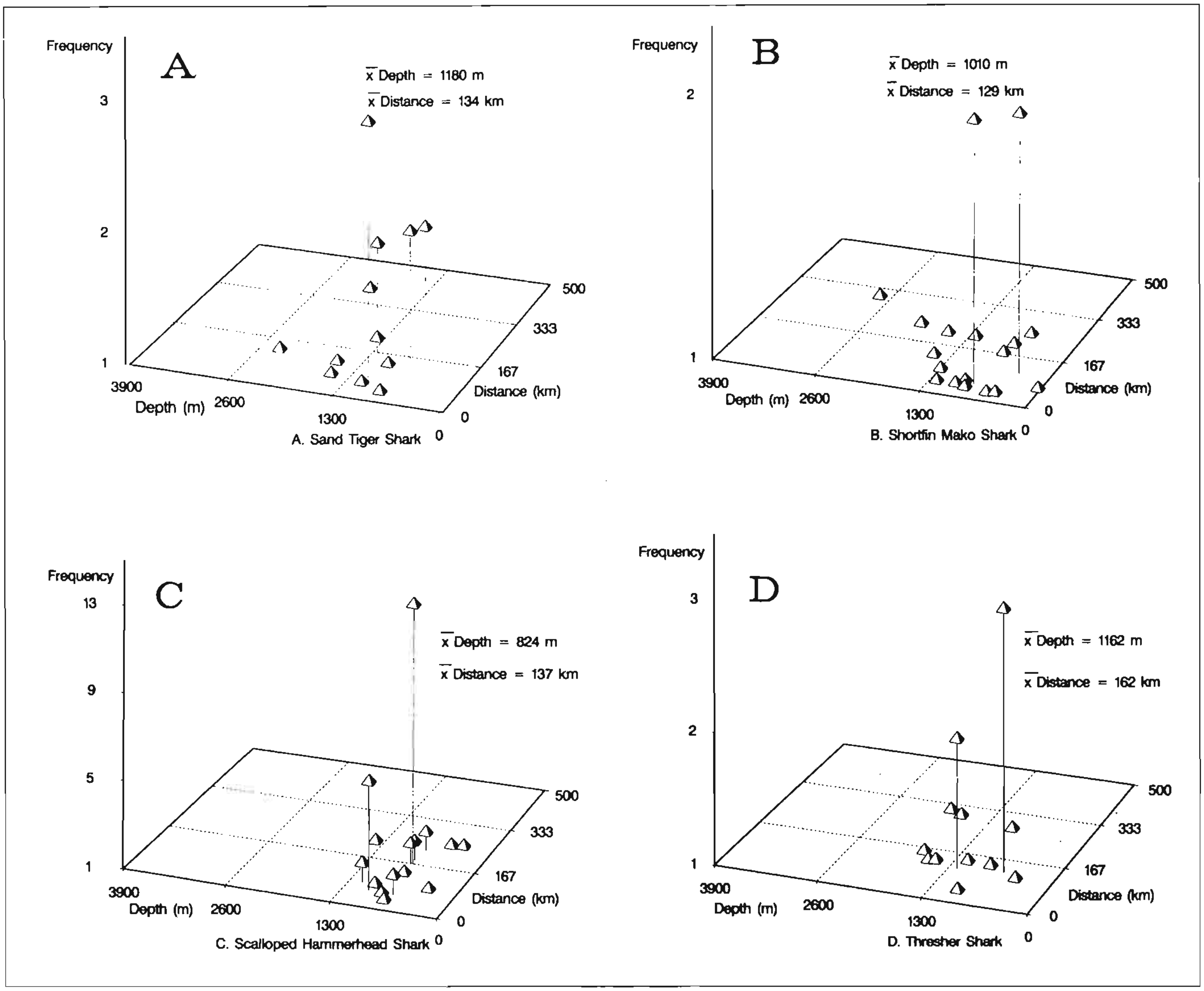

Figure 4

Numbers of sand tiger sharks (**A**), shortfin mako sharks (**B**), scalloped hammerhead sharks (**C**), and thresher sharks (**D**) by sea floor depth and distance from nearest shoreline recorded by observers aboard tuna vessels in the Gulf of Mexico, 1988–91.

quotas will effectively regulate the nearshore directed shark fishery, which catches a limited number of coastal species, quotas will do little to decrease the shark bycatch and associated mortality of the tuna and swordfish fishery. Additionally, sharks cause such damage to hooked tunas and swordfish that fishermen may continue to kill many of them unless faced with a stiff federal fine for such an offense; this measure would be nearly impossible to enforce unless observer coverage was made mandatory, greatly expanded, and tied in to the NMFS or Coast Guard enforcement network.

Under this pending shark fishery management plan, yearly stock assessments would be enhanced by the results generated from this study that showed shark landings from tuna trips were represented by more than pelagic species. Commercial shark bottom longline gear probably effectively samples many of the most common coastal shark species. These populations could be monitored via observers as this would be the only way to obtain species composition of the catches. On the other hand, tuna longline gear coverage is apparently so spotty that it would not be a reliable way of monitoring most coastal or pelagic shark populations on a yearly basis. However, placing observers aboard these vessels would complement the nearshore shark vessel effort because many highly migratory coastal species are also caught by tuna vessels. Onboard observers would be the only means of recording yearly fluctuations in species composition of the shark bycatch. Relative abundances of some of the pelagic shark species in the tuna bycatch over a period of several years might be useful indicators of the status of these populations.

the blue shark, *Prionace glauca*, and the pelagic stingray, *Dasyatis violacea*, from the Gulf of Mexico. NE Gulf Sci. 6(1):59–61.

1986. Age and growth of four Carcharhinid sharks common in the Gulf of Mexico: a summary paper. *In* Indo-Pacific fish biology: proc. of the second international conference on Indo- Pacific fishes (T. Uyeno, R. Arai, T. Taniuchi, and K. Matsuura, eds.), p. 361–371. Ichthyol. Soc. Japan, Tokyo.

Branstettler, S., and R. Stiles.

1987. Age and growth estimates of the bull shark, *Carcharhinus leucas*, from the northern Gulf of Mexico. Environ. Biol. Fishes 20(3):169–181.

Bullis, H. R.

1976. Observations on the pelagic sharks off the southeastern United States. *In* Sharks and man: a perspective (W. Seaman, ed.), p. 14. Florida Sea Grant Program Rep. 10.

Compagno, L.J.V.

1984. FAO species catalogue. Vol. 4: Sharks of the world: an annotated and illustrated catalogue of shark species known to date, Parts I and II. FAO Fish Synop. 125, 655 p.

Honma, M., T. Matsumoto, and H. Kono.

1985. Comparison of two abundance indices based on Japanese catch and effort data by one-degree and five-degree squares for the Atlantic bluefin in the Gulf of Mexico. Collect. Vol. Sci. Papers ICCAT 22:254–264.

Iwamoto, T.

1965. Summary of tuna observations in the Gulf of Mexico on cruises of the exploratory fishing vessel *Oregon*, 1950–63. Comm. Fish. Rev. 27(1):7–14.

Miget, R.

1983. Beleaguered Texas shrimpers go to school on Gulf sharks. Nat. Fisherman, Feb. 1983, p. 62–63.

Pratt, H.L. Jr., and J.G. Casey.

1990. Shark reproductive strategies as a limiting factor in directed fisheries, with a review of Holden's method of estimating growth parameters. *In* Elasmobranchs as living resources: advances in the biology, ecology, and systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.). p. 97–109. NOAA Tech. Rep. NMFS 90.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott.

1991. Common and scientific names of fishes from the United States and Canada, 5th ed. AFS Special Publ. 20, Am. Fish. Soc., Bethesda, Maryland, 183 p.

Robins, C.R., and G.C. Ray.

1986. A field guide to Atlantic Coast fishes (North America). Houghton Mifflin Co., Boston, Massachusetts, p.31.

Schaudt, K.J., G.Z. Forristall, D.C. Biggs, O.K. Huh, and J.B. Bole.

1991. The evolution of Nelson Eddy, 1989. Proc. 23rd Ann. Offshore Technol. Conf.; Houston, Texas, 6–9 May, 1991, p. 335–343.

Witzell, W.N.

1985. The incidental capture of sharks in the Atlantic United States Fishery Conservation Zone by the Japanese tuna longline fleet. *In* Shark catches from selected fisheries off the U.S. East Coast, p. 21–22. NOAA Tech. Rep. NMFS 31.

An Overview of Mexican Shark Fisheries, with Suggestions for Shark Conservation in Mexico

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ABSTRACT

With a known shark fauna approaching 100 species, 40 of which have direct commercial importance, Mexico has the potential for a sustained shark industry if strict conservation measures can be instituted. Shark fisheries have long been important to the Mexican economy; the oldest fishery is in Mazatlan, Sinaloa, and another is near Alvarado, Veracruz. Adequate biological and fisheries data are lacking for the two large oceanic shark faunas of Mexico. Landing data are divided into two categories: tiburones, sharks over 1.5-m total length; and cazones, less than 1.5-m total length. Thus, juveniles and adults of the same species are categorized differently which complicates fishery analyses. Management of shark resources is the responsibility of the government, and there is a vital need to sensitize the fishing secretariat concerning shark conservation.

Introduction

Sharks serve an important ecological role as apex predators, and in Mexico, they are also a strong component in marine fisheries. Shark fishing is often pursued by fishermen who lack funds for other more expensive fishing ventures. In the current fisheries that we have observed, only the meat or fins are used. When the meat cannot be refrigerated, it must be dried which requires a large amount of time and labor before it can be sold. Markets for shark meat are widespread; in the large La Viga fish market in Mexico City, sharks form an important part of the fish that are sold. Many impoverished Mexicans eat shark regularly (Applegate et. al., 1979), and several typical Mexican dishes are based on shark meat. Although present fisheries do not use skins, shark skin has long been used in Mexico and elsewhere for high quality shoes and other leather products. Additionally, there is a potential for the development of markets for other shark products.

With extensive coasts bordering both the Atlantic and Pacific Oceans, Mexico could play an important role in shark conservation. Almost half of the shark species have commercial value, and in recent year shark landings have risen dramatically (Fig. 1). Although there is an increasing interest from the Mexican government on the future of these fish, little is known about the biology or fishery aspects of this resource. The objectives of this paper are to summarize information concerning Mexican shark fisheries and comment on future needs for effective shark management.

Institutions Involved in the Shark Fishery

In Mexico there are several governmental institutions associated with the management of marine resources such as sharks. The most important of these institutions are the following:

Secretaria de Pesca (SEPESCA)

This governmental office is in charge of all legal and administrative aspects concerned with fishing in Mexico, as well as with the general management of all marine resources. Fishing permits and licenses are issued for commercial ventures and scientific research. This agency

Secretaria de Educacion Publica(SEP)

SEP is in charge of all federal schools and museums, and regulates private education and technological institutes. One of its dependencies directly concerned with fishing is Unidad en Ciencia y Tecologia del Mar. Here students are trained in the field of fishing technology, engineering, and biology. This Unidad has worked in conjunction with UNAM on shark taxonomy, fishing arts, and industrial use of shark products, and has supported research leading to several scientific publications (e.g. Applegate et al., 1979).

Secretaria de Marina

This is the Mexican Navy, which is responsible for guarding Mexican waters within the 200 mile exclusive economic zone. Permits to enter and leave Mexican ports must be obtained from the Navy. The Navy has a center for biological investigation and, in the past, has shown a keen interest in shark studies. The Navy would be very important in any national plan for shark conservation.

Consejo Nacional de Ciencia y Tecnologia(CONACyT)

This is the federal funding agency for scientific research in Mexico. In the past, CONACyT supported a project carried out by the group Cipactli, from the Geological Institute, which resulted in one of the first studies to be done on Mexican Caribbean sharks (Applegate[1]).

Historical Aspects of the Fishery and Scientific Research

We believe that shark fishing is a very old Mexican endeavor; fisheries undoubtedly existed the last century. Until the Second World War, little was published concerning the Mexican shark fishery. Much of what we have discovered concerning the history of the fishery has come from personal interviews with elderly and respected fishermen, and has been incorporated in a series of unpublished technical reports available from the authors.

Pacific Coast

It is believed that shark fishing began in Mazatlan, Sinaloa. In 1870, Steindachner (*in* Beebe and Tee-Van, 1941) listed a specimen of *Triakis* taken in Mazatlan. This specimen was probably obtained from the fish market, thus an active fishery may have existed at the time. Shark fisheries were probably small, sporadic, and nomadic until the Second World War.

The lack of cod liver oil during the Second World War promoted a fishery that obtained Vitamin A and Vitamin D from the livers of sharks. This fishery was particularly strong on the Pacific coast, reaching its peak in 1944, when 9,000 metric tons were reported for the commercial catch (Castillo, 1990). Even though the synthesis of Vitamin A caused the collapse of the shark liver industry (Moss, 1989; and Castillo, 1990), this effort represents the start of the present day shark fisheries in Mexico.

According to unpublished data from SEPESCA there was a continuous increase in the captures of sharks from the early 1950's until the early 1970's. Later in this decade, the landings increased dramatically, and since the early 1980's, landings have leveled off at about 100,000 t (Fig. 1). These data apply to the country as whole, but some ports, such as Mazatlan, have shown a steady decline in catch since 1960's (Kato, 1965).

From the 1950's until present, a number of localities have been highly important to the Mexican shark fishery. Perhaps the most relevant of these fishing areas is Isla Isabela off the State of Nayarit. This island has never been continuously inhabited, but fishermen come from Teacapan and the Boca de Camichin, Nayarit, to spend one or two months a year in order to fish for sharks. This fishery appears to be healthy.

In Baja California there has been a long history of small scale shark fisheries that lasted only a short time before disappearing. In the late 1960's, a shark processing plant was developed near San Jose del Cabo, but the plant lasted less than three years. A current fishery developed in 1991, north of Santa Rosalia in Baja California Sur, targets the big-eye thresher *Alopias superciliosus.*

On the mainland, a 1970's fishery south of Isla Isabela, in Zihuatanejo, Guerrero, utilized the whole shark; perhaps for the first time in Mexico. Jaws were sold to tourists, fins were dried, the skin was taken for leather, and the oil from the livers was rendered. The remaining viscera and vertebral column were cooked, dried, and ground for use as chicken food and fertilizer. Unfortunately, the local supply of sharks was soon exhausted and boats had to go hundreds of miles to fish, thus leading to the demise of this fishery.

In the southern-most part of the Pacific region of Mexico in the late 1970's large tiger sharks, *Galeocerdo cuvier*, were fished in the states of Chiapas and Oaxaca (Avila et al., 1981). Only the meat was taken, although tiger shark skin is marketable. These fisheries do not exist today, although at the time, they appeared to show great promise.

[1] Applegate, S.P., L. Espinosa-Arrubarrena, K. Johnson-Diaz, and J.L. Cabral. 1992. Tiburones Mexicanos: area Caribena. Sec. de Pesca. Mem. del taller de trabajo y ciclo de conferencias de tiburones de Mexico y Australia (17-19 Marzo de 1992). In house publ., Instituto Nacional de la Pesca.

Table 1

A list of shark species currently known from Mexican waters. A = Species confined to the Atlantic; P = Species confined to the Pacific; A + P = Species occurring in both the Atlantic and the Pacific; commercial species marked with an asterisk (*). Species are arranged in phylogenetic sequence, and includes some species not considered valid by Compagno (1984).

	Heptranchias perlo	A		*Cetorhinus maximus*	P	*	*Carcharhinus brachyurus*	A + P
	Hexanchus griseus	A + P	*	*Carcharodon carcharias*	A + P	*	*Carcharhinus brevipinna*	A
	Hexanchus vitulus	A	*	*Isurus oxyrinchus*	A + P	*	*Carcharhinus falciformis*	A + P
	Notorhynchus cepedianus	P		*Isurus paucus*	A		*Carcharhinus galapagensis*	P
	Echinorhinus cookei	P		*Lamna ditropis*	P		*Carcharhinus isodon*	A
	Centrophorus acus	A		*Apristurus brunneus*	P	*	*Carcharhinus leucus*	A + P
	Centrophorus granulosus	A		*Apristurus kampae*	P	*	*Carcharhinus limbatus*	A + P
	Centrophorus uyato	A		*Apristurus laurussoni*	A		*Carcharhinus longimanus*	A + P
	Dalatias licha	A		*Apristurus parvipinnis*	A	*	*Carcharhinus obscurus*	A + P
	Etmopterus pusillus	A		*Apristurus riveri*	A	*	*Carcharhinus perezi*	A
	Etmoptrus schultzi	A		*Cephaloscyllium ventrosum*	P	*	*Carcharhinus plumbeus*	A
	Scymnodon obscurus	A		*Cephalurus cephalus*	P	*	*Carcharhinus porosus*	A + P
	Somniosus pacificus	P		*Galeus arae*	A	*	*Carcharhinus signatus*	A
	Squalus acanthias	P		*Galeus piperatus*	P	*	*Galeocerdo cuvier*	A + P
	Squalus asper	A		*Parmaturus campechiensis*	A	*	*Nasolamna velox*	P
	Squalus blainvillei	A		*Parmaturus xaniurus*	P	*	*Negaprion brevirostris*	A
*	*Squalus cubensis*	A		*Scyliorhinus hesperius*	A	*	*Negaprion fronto*	P
	Squalus mitsukurii	A		*Scyliorhinus retifer*	A	*	*Rhizoprionodon longurio*	P
*	*Squatina californica*	P	*	*Mustelus californicus*	P	*	*Rhizoprionodon porosus*	A
*	*Squatina dumeril*	A	*	*Mustelus canis*	A	*	*Rhizoprionodon terraenovae*	A
*	*Heterodontus francisci*	P	*	*Mustelus dorsalis*	P	*	*Prionace glauca*	A + P
*	*Heterodontus mexicanus*	P	*	*Mustelus henlei*	P		*Sphyrna corona*	P
*	*Ginglymostoma cirratum*	A + P	*	*Mustelus lunulatus*	P	*	*Sphyrna lewini*	A + P
	Rhincodon typus	A + P	*	*Mustelus norrisi*	A		*Sphyrna media*	A + P
	Carcharias taurus	A		*Galeorhinus galeus*	P	*	*Sphyrna mokarran*	A + P
	Odontaspis ferox	P	*	*Triakis semifasciata*	P	*	*Sphyrna tiburo*	A + P
	Alopias superciliosus	A + P		*Carcharhinus albimarginatus*	P	*	*Sphyrna zygaena*	A + P
	Alopias pelagicus	P	*	*Carcharhinus acronotus*	A			
*	*Alopias vulpinus*	A + P	*	*Carcharhinus altimus*	A + P			

been identified for the bull shark, *Carcharhinus leucas*, in Caribbean Mexican waters (Applegate[1]). From a commercial perspective this is probably the most important species. It is used extensively in Mexico for its meat, skin, and fins, and it has a potential market for its oil. The bull shark pups in shallow bays and estuaries favoring low salinities (Compagno, 1984). Two known nursery areas in Mexico are 1) near Teacapan in an estuary of the Rio Canas and the Rio Acaponeta, south of Mazatlan, Sinaloa (reported in this paper for the first time) and 2) in Chetumal Bay in Quintana Roo. A number of small bull sharks have been collected at the first locality and raised in the aquarium at Mazatlan, where we examined them. The second locality (Chetumal Bay), so far as we know, has been fished by only our research group. Once we have studied these nurseries and located others, it might be feasible to create nearby artificial areas for young bull sharks and raise them for future release. Fishing in these areas would be easily controlled by appropriate legislation.

Another avenue of research centers on the possibility of a sport fishing tagging program. Except for the work done by Kato and Carvallo (1967), little tagging of Mexican sharks has been undertaken. Sport fishing for sharks (as an alternative catch to billfish) occurs off Mazatlan, Sinaloa. In this instance, the most common shark that we have observed is the silky shark (*Carcharhinus falciformis*). Even though these sharks occur in great numbers, there is insufficient data to know what effect this catch has on the local population. Billfish are often tagged and released, but not sharks. A tagging program could provide important data concerning the movements of this pelagic species in the Pacific. On the east coast, short fin makos (*Isurus oxyrinchus*), are common in the springtime off Cozumel Island in the Caribbean and are often taken by American and Mexican sports fishermen. These catches also represent an excellent opportunity for starting a tagging program to collect data on the distribution and seasonality of this species.

A third goal is the recognition of special areas where sharks congregate. Klimley (1981) and Klimley and Nelson (1981) have reported on the schooling scalloped hammerheads (*Sphyrna lewini*) from the southern Gulf of California. Such large concentrations of sharks are certainly subject to fishing and these areas

Klimley, A.P., and D.R. Nelson
1981. Schooling of the scalloped hammerhead *Sphyrna lewini* in the Gulf of California. Fish. Bull. 79:256–360.

Moss, S.A.
1989. Sharks, an introduction for the amateur naturalist. Prentice Hall Inc., New Jersey, 246 p

Springer, S., and M.H. Wagner.
1966. *Galeus piperatus*, a new shark of the family Scyliorhinidae from the Gulf of California. Los Angel. Cty. Mus. Contrib. Sci. 110:1–9.

Taylor, L.R.
1972. *Apristurus kampae* a new species of scyliorhinid shark from the eastern Pacific Ocean. Copeia (1):71–78.

Taylor, L.R., and J.L. Castro-Aguirre.
1972. *Heterodontus mexicanus*, a new horn shark from the Gulf of California. An. Esc. Nac. Ciencias Biol., Mexico 19:1–25.

Status and Review of the California Skate Fishery

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ABSTRACT

California commercial skate landings for 1916-90 have ranged from 22.865 metric tons (t) to 286.349 t annually. Landings from central California account for 72% of the total skate catch; the north and south regions contribute 20% and 8%, respectively. Since 1916, skate landings have represented an annual mean of 11.8% of the total California commercial elasmobranch landings. Skate landing fluctuations are correlated with changes in California trawl fisheries. There is no evidence of seasonal landing patterns (by month) but there appears to be a 20–26 year landing cycle. The biological knowledge of California's three most commercially important batoid species big skate (*Raja binoculata*), California skate (*Raja inornata*) and longnose skate (*Raja rhina*) is summarized.

Introduction

Skates are the largest and most widely distributed group of batoid fishes, with approximately 230 described species in two families (McEachran, 1990). They are benthic fishes and occur in all seas but are most common in cold temperate and polar waters. The various species range from inshore shallow waters to 3,000 m deep; however, they are limited to mid-depths along the continental shelf at tropical latitudes.

Two genera and nine species of skates in the family Rajidae occur in California waters (Eschmeyer et al., 1983; Zorzi and Anderson, 1988). Four Bathyraja species occurring in California waters are the deep sea skate (*B. abyssicola*), sandpaper skate (*B. interrupta* = *B. kincaidii*, [Ishihara and Ishiyama, 1985]), black skate (*B. trachura*) and white skate (*B. spinosissima*). Five Raja species occurring in California waters are the big skate (*R. binoculata*), California skate (*R. inornata*), longnose skate (*R. rhina*), broad skate (*R. badia*) and starry skate (*R. stellulata*). *R. badia* is a rare species with only two records from California (Zorzi and Anderson, 1988); the other four Raja species are commonly found inshore and also occur in deeper water (Eschmeyer et al., 1983). *Bathyraja* are not landed in the fishery, but three species of *Raja* are commercially used.

Natural History

Raja inornata, the California skate (Fig. 1A) ranges from the Strait of Juan De Fuca, Canada, to off central Baja California, Mexico. It is common inshore in shallow bays at depths of 18 m or less to a depth of 671 m (Eschmeyer et al., 1983). It attains a maximum total length (TL) of about 76 cm (Eschmeyer et al., 1983). Both females and males reach sexual maturity at lengths of about 52 cm (L. Martin, unpubl. data). It feeds on shrimps and probably other invertebrates. *R. inornata* is taken incidentally by trawlers and is perhaps California's most commercially important species, (Roedel and Ripley, 1950).

Templeman (1984) found that the thorny skate, *R. radiata*, moved 100–240 miles from tagging sites in 2–11 years. Although relatively little is known about the movements of *R. rhina*, *R. binoculata*, and *R. ornata*, it is possible that they migrate outside of California waters.

Use of Skate

Skates are exploited for food worldwide and represent as much as 42% (Taniuchi, 1990) to 55% (Compagno, 1990) of the total global elasmobranch catch annually. Landing records indicate that skates have been fished commercially in California since at least 1916. Little is known about the catch composition of the California skate fishery of the past several decades. According to Roedel and Ripley (1950), the three most commercially important skate species are *R. inornata*, *R. rhina*, and *R. binoculata*; the former two species are landed and marketed more frequently than the latter. Zeiner's (1991) work and work by the senior author (L. Martin, unpubl. data), both based on collections from the commercial fishery, support Roedel and Ripley's (1950) contention that *R. inornata* and *R. rhina* dominate the commercial fishery. Review of the landing data (Holts and Bedford[1]; Oliphant et al., 1990; Holtz[2]) shows that the three commercially landed skate species, collectively, have been among the ten most harvested elasmobranchs, in terms of biomass, in California since at least 1976.

Only the skinned pectoral fins, or "wings," of skates are marketed; the remainder is discarded. Before marketing, the wholesaler skins the wings, using a skinning machine (Fig. 2). Handling, processing, and storage characteristics have been described for Atlantic species by Wilhelm and Jobe (1988). Because skinning machines cannot accommodate skates weighing more than one kilogram (kg), only a small proportion of the skates caught are retained; larger skates are discarded at sea (Roedel and Ripley, 1950).

Currently skate wings are sold, fresh and fresh-frozen, predominantly in the oriental fish markets in southern California (Zorzi and Martin, 1992). Wings are also dried or salted and dehydrated for the oriental trade. Esteemed by the Japanese (Taniuchi, 1990), the dried skate wing is eaten with wine or processed into skate wing products, such as "kamaboko" (fish meat jelly [Ishihara, 1990]. In 1991, the demand for skate wings in the U.S. oriental market increased to such a level that they were imported from the orient into the southern California market. Skates have been processed for fish meal, but such enterprises have failed, usually for economic reasons (Roedel and Ripley, 1950). Skates have been used as substitutes for scallops (Griffith et al., 1984; Lamb and Edgel, 1986). The purpose of this paper is 1) to review and summarize California's annual skate landing data by region (north, central, and southern California), season, and value, 2) to compare skate landings to landings in associated fisheries, and 3) to discuss the concerns associated with an expansion of the California skate fishery.

Methods

To assess trends, published annual skate landing data (weights) for the years 1916–86 were taken from the California Department of Fish and Game's Fish Bulletin (Appendix 1), and other unpublished data for the years 1987–90 were made available by the California Department of Fish and Game and the University of California's Sea Grant Program. All weights were originally reported in pounds and were converted to metric tons (t) (2,205 pounds = 1 t).

Skate landing data from 1926 through 1990 were reviewed and summarized by statistical area, region (combined areas), and season. California's coastal waters are divided into six areas, as designated by the California Department of Fish and Game, for the purpose of reporting marine fisheries statistics (Oliphant et al., 1990). The areas were combined into three regions designated as "north," "central," and "south" (Fig. 3). Trends in landings were compared with the California landing data for rockfish and flatfish trawl and setnet fisheries and shark fisheries. General trends, or periodicity, in annual landings since 1916 were evaluated by identifying high catch years as "peak" years and low catch years as "minimum" years. The mean annual landing was calculated for peak and minimum years. The mean number of years between peak years and between minimum years, and from peak to minimum years was also calculated. General trends in landing cycles were noted (outliers within the trend were ignored).

The average number of skates landed annually from 1976 to 1990 was estimated based on 1) the relationships between the wing weight, total body weight, and total annual landings (dressed weight) and 2) the assumption that the average weight of a marketable skate equals approximately 1 kg (Roedel and Ripley, 1950; L. Martin, unpubl. data). Annual landing weights are wing weights (WW), which represent approximately 32% of total body weight (BW) (L. Martin, unpubl. data); thus, the landing data for year "y" when increased by 68% of its value and multiplied by 1000 kg per 1 t yields the

[1] Holts, D., and D. Bedford. 1989. Report of the assessment methods workshop for sharks. U.S. Dep. Commerce, NOAA, NMFS, Southwest Fish. Sci. Cent. (Pelagic Fisheries Resources, P.O. Box 271, La Jolla, CA 92038) Admin. Rep. LJ-89-11, 20 p.

[2] Holts, D., marine biologist, NMFS, Southwest Fisheries Science Center, Pelagic Fisheries Resources, P.O. 271, La Jolla, CA 92038, unpubl. data 1991.

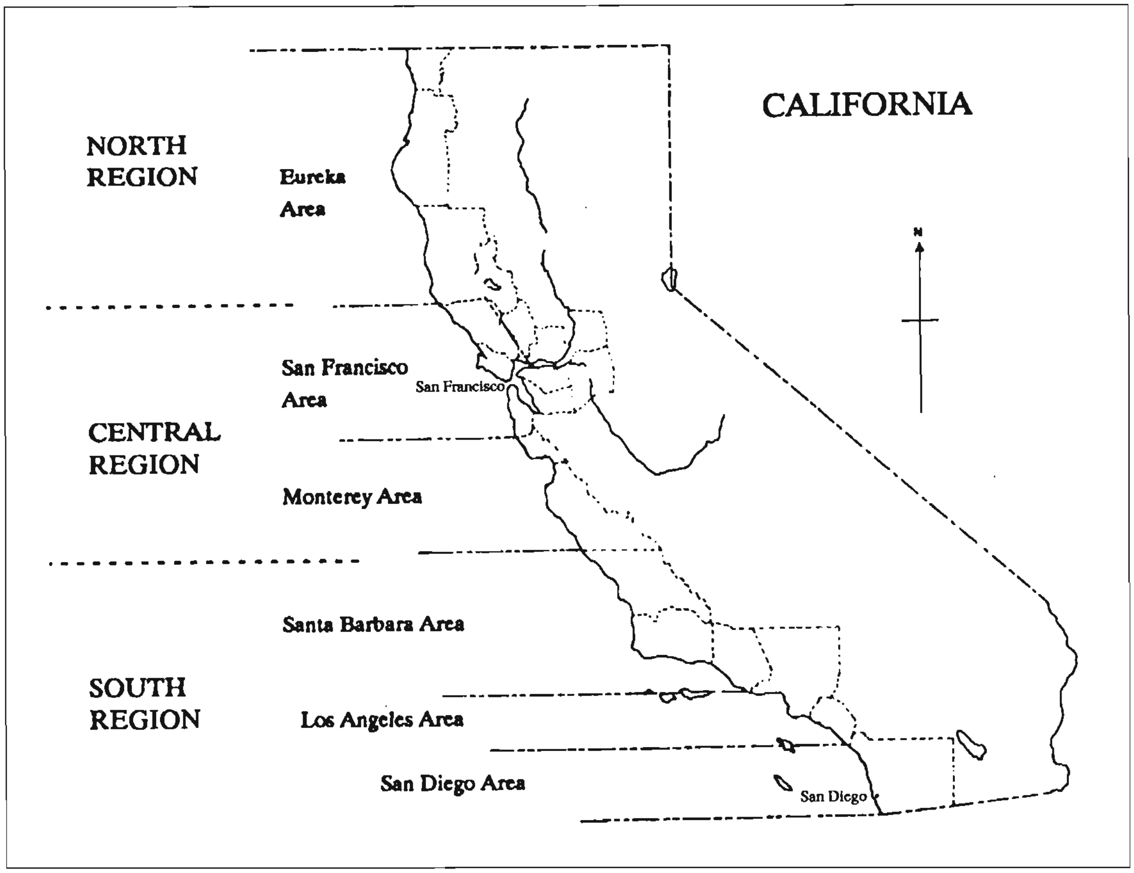

Figure 3
Map of California showing statistical areas and regions by which skate landing data were sorted.

total number of skates, with a BW of 1kg, landed that year (TSy), such that

$$[(WW_y + (WW_y \times 0.68)]t \times 1000 \text{ kg/t} = TS_y.$$

Results and Discussion

Review of the Skate Fishery

Since 1916, the annual commercial skate landings in California have ranged from 22.865 t to 286.349 t and have fluctuated widely from year to year (Fig. 4). Peak landings in 1920, 1928, 1938, 1953, 1961, and 1981 had a mean of 212.872 t (SD = 50.39 t) and ranged from 135.740 t in 1961 to 286.349 in 1981 (Table 1). Time between peaks ranged from 8 to 20 years, with a mean of 12.2 years (SD = 5.2 years). There were 14 years in which landings exceeded the lowest peak year landings (135.740 t). Minimum landings in the years 1921, 1931, 1944, 1954, 1971, and 1984 occurred from 1 to 10 years (mean = 4.5 years, SD = 3.2 yr) following each peak. The mean minimum annual landing was 46.003 t (SD = 22.234 t), ranging from 22.865 t to 79.265 t annually (Table 1). Time between minimum years ranged from 7 to 20 years, with a mean of 12.6 years (SD = 4.8 yr). There were 38 years in which landings fell below the landings in the highest minimum landing year (79.265 t).

Skate landings are probably affected by the effort and success of the target fisheries in which they occur as a bycatch. The success and effort of the target fisheries may interact such that there is little apparent correlation between landings of the target species and skate landings. For example, a high catch of the target species could result in limited storage space for skates and a subsequent drop in skate landings. According to Frey (1971) fluctuations in landings have roughly followed the trends of general economic conditions, the peaks of production occurring at about the same time as periods of economic plenty. In regard to Frey's (1971) premise, it appears that the skate landings do partially reflect changes in landings in the other California trawl fisheries, particularly in the rockfish and flatfish fisheries, but direct correlations are inconsistent and there is often a lag of several years. For example, during World War I the increased demand for protein resulted in peak rockfish landings of about 3,718.821 t in 1918, and flatfish landings peaked at about 7,709.751 t (exclusive of Pacific halibut, *Hippoglossus stenolepis*) in 1917

(Fish Bulletin no. 74; Appendix 1); this preceded the 1920 skate landings peak catch of 217.595 t (Fig. 4). The next peak in flatfish landings occurred in 1929 with over 6,349.206 t landed; between 1922 and 1926 there was also a slight increase in rockfish landings (Fish Bulletin no. 74; Appendix 1). Similarly, skate landings declined in 1921, then increased to peak in 1928 at 208.123 t. Between 1929 and 1932, during the Great Depression, flatfish landings fell to an average of 4,761.905 t annually (Fish Bulletin no 74; Appendix 1) and from 1929 through 1931 skate landings also declined. The next peak in skate landings, in 1938, may have corresponded with 1) the peak catch of flatfishes *Eopsetta jordani*, *Errex zachirus*, and *Platichthys stellatus* in 1939 (Frey 1971) and 2) the abrupt increase in shark landings, primarily soupfin, *Galeorhinus galeus*, caught in the bottom-fishing "set" gill net fishery in 1938. From 1939 through 1942, when many fishermen shifted to the soupfin fishery, there was a decrease in the flatfish fishery (except starry flounder, *Platichthys stellatus*) (Fish Bulletin no. 74; Appendix 1). In 1944, despite increased fishing effort, shark landings fell to about one-quarter of the record 1939 landings (Frey, 1971) and the skate fishery also reached an all time low (Fig. 4). After World War II, an expanded trawler fleet, using stronger and larger gear, fished at greater depths and in new areas, resulting in increased flatfish landings from 1945 through 1948 (Fish Bulletin nos. 74, 80; Appendix 1). The introduction of the balloon trawl net in 1943 led to a rapid expansion of the rockfish fishery, and rockfish landings increased reaching an all time high in 1958 (Fish Bulletin nos. 80, 86, 89, 95, 102, 105, 108; Appendix 1). Co-incidental with the increased effort in associated fisheries there was a steady annual increase in skate landings from 1945 to 1961, interrupted by peak landings in 1953 and concluding with the 1961 peak. This was followed by a 10-year decline to a minimum of 27.769 t in 1971. Similarly, between 1959 and 1970 rockfish landings also declined (Fish Bulletin nos. 111, 117, 121, 125, 129, 132, 135, 138, 144, 149, 153, 154; Appendix 1). The 1981 peak in skates landings was followed by a decline through 1984. Between 1984 and 1986 there was an inconsistent, but general decrease and leveling off of both rockfish and flatfish landings (Fish Bulletin no. 174; Appendix 1).

Skate Landings by Area and Region: 1948–89

Review of the skate landing data supports Frey's (1971) earlier statement that San Francisco and Monterey are the leading areas for skate landings. The central California region has dominated the state's skate catch from 1926 through 1989, accounting for 72% of cumulative total, ranging from 21–98% annually (Fig. 5,

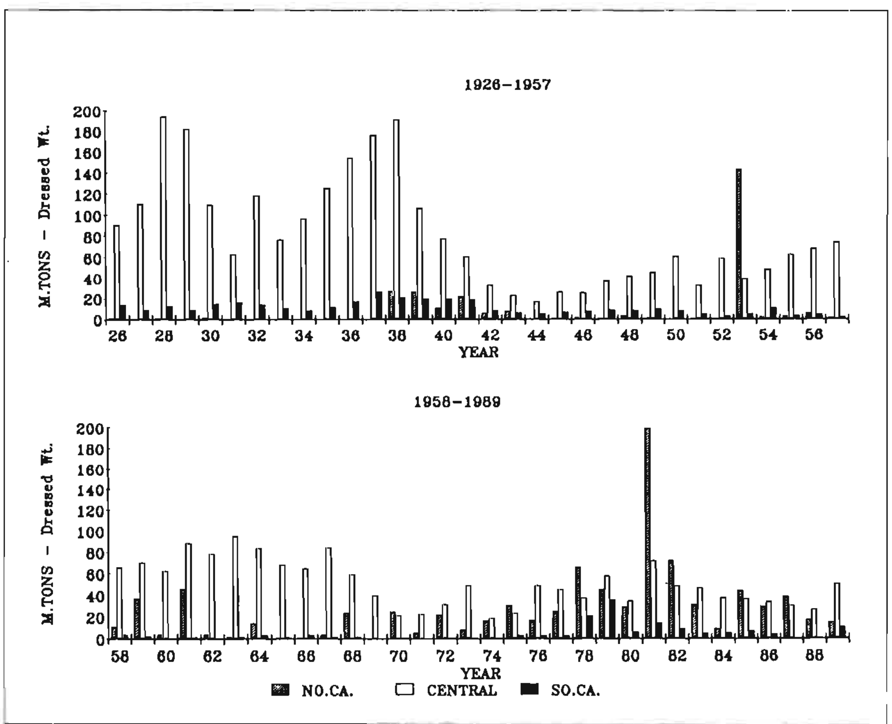

Figure 5

California commercial skate landings, by region, 1926-89. Landing data from the California Department of Fish and Game's Fish Bulletin (Appendix) and from the University of California Sea Grant Program.

Table 2 (Continued)

Year	Total state (t)	North (t)	North (%)	Central (t)	Central (%)	Southstate (t)	Southstate (%)
1978	124.738	65.966	52.88	37.881	30.37	20.891	16.75
1879	140.368	45.892	32.69	58.267	41.51	36.208	25.80
1980	70.390	29.550	41.98	34.852	49.51	5.988	8.51
1981	286.349	199.825	69.78	72.113	25.18	14.410	5.03
1982	130.521	72.365	55.44	48.913	37.47	9.243	7.08
1983	84.210	31.728	37.68	47.122	55.96	5.360	6.36
1984	52.739	37.971	17.47	37.971	72.00	5.554	10.53
1985	88.812	37.036	50.52	37.036	51.70	6.909	7.78
1986	68.082	34.209	43.72	34.209	50.25	4.104	6/03
1987	69.590	30.646	55.96	30.646	44.04	0.000	0.00
1988	44.041	26.847	39.04	26.847	60.96	0.000	0.00
1987	76.420	50.743	19.77	50.743	66.40	10.570	13.83
Total	5936.213	4274.400	19.57	4274.400	72.01	500.083	8.42

Table 2). Landings in the San Francisco area represent 71% of the central region landings and 51% of the total state landings. Landings in the Monterey area account for 29% of the central region landings and 21% of the total state landings.

Contrary to Frey's (1971) statement that few skates are landed outside of the San Francisco and Monterey areas, 28% of the skates landed since 1926 have been landed in the north and south regions combined. Twenty-percent of the total cumulative state landings were taken in the north region which had the highest landings in the years 1953, 1970, 1975, 1978, 1981, 1982, 1985, and 1987 (Fig. 5) and generally have played an increasing role since about 1970. High catches in the north region in the years 1953, 1978, and 1981 occurred in the same peak total annual catch years. Although only 8% of the total cumulative state landings were taken in the south region, this region contributed 10–24% to the total annual catch in 19 of the years between 1926 and 1954, and landings in the south region in 1926–37, 1940, 1942, 1944–52, 1954, 1955, and 1966 were greater than landings in the north (Fig. 5).

Although the skate landings in Oregon and Washington are a small percentage of their total landings, they are higher than California's annual average skate landings of 82.256 t (since 1970). In Washington alone, the average annual skate catch is 126.527 t (90.700 t from Puget Sound and 35.827 t from coastal waters) (Pattie[3]).

[3] Brad Pattie, Washington State Dep. Fisheries, 7600 Sand Point Way NE, Seattle, WA 98115. Pers. Commun. 1991.

Skate Landings by Season: 1969–89

There are no obvious trends in the skate catch related to season; however, since 1969 the greatest number of skates landed in California have tended to be taken in late winter and early spring. During this 20-year period, February and March were months of highest catch for four years. May, April, and July were highest for three, two, and two years respectively.

Skate Landing Cycles

Skate distributions and therefore landings may have been affected by fluctuations in oceanographic conditions, such as those occurring during El Niño. The effects of El Niño on the distribution of some fishes and consequent fluctuations in sport or commercial landings have been noted by several authors (Bailey and Incze, 1985; Fiedler, 1986; Mysak, 1986; Squire, 1987). Schoener and Fluharty (1985) reported three types of distributional changes in marine organisms during the El Niño years of 1940–41, 1957–58 and 1982–83 including 1) range extensions, 2) range anomalies, and 3) habitat anomalies where organisms were found shallower (deeper) or closer inshore (offshore) than normal. Karinen et al. (1985) noted the occurrence of 5 elasmobranch species outside their normal or known range during the 1981–82 El Niño. Ignoring the high catch years of 1928, 1929, and 1953, there was a periodicity to the skate landings, such that, since 1916, there have been three cycles in landings (Fig. 4). The first complete cycle began in 1921 and ended in 1944; the second cycle extended from 1944 to 1971, and the skates remained at about \$0.12 per pound. By 1986 the ex-vessel skate price had risen to \$0.25 per pound, but was relatively low compared with the ex-vessel price of \$0.56 per pound for miscellaneous shark and \$1.43 to \$1.60 per pound for thresher shark, *Alopias vulpinus* (Holts, 1988). The 1991 ex-vessel price for skate wings was \$0.28 per pound, whereas shark meat reached as high as \$2.40 per pound. In early 1992 skates appeared in the fresh fish market in Monterey, California, at a retail price of \$4.99 per pound, compared with \$5.50 per pound for the fairly popular shortfin mako shark (*Isurus oxyrinchus*).

The Skate Population

Based on the existing data it is not possible to determine if skate populations in California have been impacted by historic or current levels of fishing. However, there is preliminary evidence that the fishery removes high numbers of immature individuals from the skate population. The formula $[(WW^y + (WW^y \times 0.68)]t \times 1000\ kg/t = TS^y$, used to determine numbers of individual skates landed in a designated year applied to the peak year 1981 (286.349 t), yields approximately 481,000 immature skates taken from California waters and 335,700 taken from the north region alone. Approximately 154,900 skates were landed annually during the years 1976–1990 when the annual mean landing was 92.224 t. This latter figure (154,900) is a more representative estimate of the annual number of skates taken from California waters than the figure for 1981. A BW of 1 kg corresponds to a total length for *R. binoculata* and *R. rhina* of about 50 cm (Zeiner, 1991; L. Martin, unpubl. data) and ages of about 3–4 years (Zeiner, 1991) for both species. Thus, most animals landed in the fishery are well under size and age at maturity for both sexes of *R. binoculata* and *R. rhina.*

Skate Fishery Management

Like data for other elasmobranch fisheries (Hoff and Musick, 1990), landing data for skates does not accurately reflect the total biomass removed from the population, because only a small proportion of the skates caught are retained and reported in the landings (Roedel and Ripley, 1950). Although some skate species are more fecund and have higher growth rates than many shark species, compared with the bony fishes, they have relatively slow growth rates, late age at maturity, and they bear relatively few young (Holden, 1973, 1974, 1977; Ryland and Ajayi, 1984; Waring, 1984; Martin and Cailliet, 1988; Zeiner, 1991). These characteristics make all elasmobranchs vulnerable to overfishing (Holden, 1977; Compagno, 1990; Hoff and Musick, 1990; Pratt and Casey, 1990). Skates appear to have been overfished in several other areas, as indicated by the decrease in annual batoid landings over the last five years in the Japanese fishery (Taniuchi, 1990) and the diminished landings of *R. batis* in the Irish Sea fishery (Brander, 1981).

The appearance of skate wings in the fresh fish market, selling for nearly \$5.00/lb. indicates an increase in the popularity of this food fish and a possible consequential expansion of the California skate fishery. The suggestion by Roedel and Ripley (1950) that skates represented an "under-utilized" resource may be true. Certainly skates, caught as a bycatch of another fishery and discarded because they are not economically marketable, are a wasted resource and therefore are "under-utilized." Whether or not skates are also under- or over-exploited is another question and one that this paper does not attempt to answer. However, regardless of the level of utilization and given the typical elasmobranch reproductive profile (as discussed above), if large numbers of immature individuals continue to be removed from the population, then a significant expansion of the fishery (increased exploitation) without appropriate management would be ill advised.

The information needed to produce an effective skate fishery management plan includes 1) landing data on size and sex for each species landed, 2) survival rates of skates released from the catch, 3) validation of Zeiner's (1991) age and growth work on *R. binoculata* and *R. rhina,* 4) determination of life-history parameters (growth rates, ages at maturity, age-specific fecundities, etc.) for each of the three commercial skate species and 5) determination of population characteristics, including population movements, for each species.

Finally, with skate fisheries operating in California, Oregon, and Washington, and given the absence of information on "stock" structure, it would be advisable to develop a management plan that encompasses the entire eastern Pacific region. When better data on "management units," as defined by Hoff and Musick (1990) become available, the management approach could, and should, be modified.

Acknowledgments

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Literature Cited

Allen, J. M., and G.B. Smith.
1988. Atlas and Zoography of Common Fishes in the Bering Sea and Northeastern Pacific. NOAA Tech. Rep. NMFS 66.

State Univ., Stanislaus and Moss Landing Marine Laboratories, 53 p.
Zorzi, G.D., and M.E. Anderson.
1988. Records of the deep-sea skates, *Raja (Amblyraja) badia* Garmen, 1899 and *Bathyraja abyssicola* (Gilbert, 1896) in the Eastern north Pacific, with a new key to California skates. Calif. Fish and Game 74 (2):87–105.
Zorzi, G.D., and L.K. Martin.
1992. Skate and Rays. *In* California's living marine resources and their utilization (W.S. Leet, C.M. Dewees, and C.W. Haugen, eds.), p. 56–58. California Sea Grant Extension Publication UCSGEP-92-12.

APPENDIX

1929. The commercial fish catch of California for the years 1926 and 1927. State of California, Bureau of Commercial Fisheries, Fish Bulletin 15, 93 p.
1930. The commercial fish catch of California for the year 1928. State of California, Bureau of Commercial Fisheries, Fish Bulletin 20, 61 p.
1931. The commercial fish catch of California for the year 1929. State of California, Bureau of Commercial Fisheries, Fish Bulletin 20, 133 p.
1935. The commercial fish catch of California for the years 1930–1934. State of California, Bureau of Commercial Fisheries. Fish Bulletin 44, 124 p.
1937. The commercial fish catch of California for the year 1935. State of California, Bureau of Commercial Fisheries. Fish Bulletin 49, 170 p.
1940. The commercial fish catch of California for the years 1936–1939. State of California, Bureau of Marine Fisheries, Fish Bulletin 57, 50 p.
1941. The commercial fish catch of California for the year 1940. State of California, Bureau of Marine Fisheries, Fish Bulletin 58, 47 p.
1944. The commercial fish catch of California for the years 1941 and 1942. State of California, Bureau of Marine Fisheries, Fish Bulletin 59, 68 p.
1946. The commercial fish catch of California for the years 1943 and 1944. State of California, Bureau of Marine Fisheries, Fish Bulletin 63, 81 p.
1947. The commercial fish catch of California for the years 1945 and 1946. State of California, Bureau of Marine Fisheries, Fish Bulletin 67, 80 p.
1949. The commercial fish catch of California for the years 1947 with an historical review 1919–1947. State of California, Bureau of Marine Fisheries, Fish Bulletin 74, 80 p.
1951. The marine fish catch of California for the years 1948–1949. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 80, 87 p.
1952. The commercial fish catch of California for the year 1950. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 86, 120 p.
1953. The commercial fish catch of California for the year 1951. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 89, 68 p.
1954. The marine fish catch of California for the year 1952. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 95, 64 p..
1956. The marine fish catch of California for the year 1953–1954. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 102, 99 p.
1958. The marine fish catch of California for the year 1955–1956. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 105, 104 p.
1960. The marine fish catch of California for the years 1957 and 1958. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 108, 74 p.
1960. The marine fish catch of California for the year 1959. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 111, 44 p.
1961. The marine fish catch of California for the year 1960. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 117, 45 p.
1963. The California marine fish catch for 1961. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 121, 56 p.
1964. The California marine fish catch for 1962. State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 125, 45 p.

Application of Mitochondrial DNA Sequence Analysis to the Problem of Species Identification of Sharks

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ABSTRACT

Efforts are currently being implemented to protect and manage specific species of sharks. This requires that species designations are accurately assigned. Unfortunately, species identification can be difficult because many species are morphologically similar and commercial fishermen often remove the fins, entrails,and heads at sea, a practice that eliminates most or all diagnostic characters used for species identification. There are a number of genetic methods that can be employed as forensic tools for identifying species from carcasses. This paper briefly reviews methods of mitochondrial DNA (mtDNA) analysis and presents some preliminary data that illustrates the potential utility of mtDNA analysis to identify species of sharks from tissue samples.

Introduction

Fisheries catch statistics reveal two important features related to sharks. First, fishing pressure on sharks is increasing (see papers in Pratt et al., 1990). Second, catch statistics are rarely compiled for individual species or even genera of sharks (FAO, 1990). Although catch statistics are kept for species of teleosts, the catch of all requiem sharks, for instance, is listed under the family designation Carcharhinidae (FAO, 1990). The Carcharhinidae encompasses a diverse assemblage of sharks with marked differences in morphology, ecology, and life history among genera and species (Compagno, 1988). The genus *Carcharhinus* itself is represented by 32 recognized species (Garrick, 1982, 1985). The breadth of biological diversity encompassed by this genus is exemplified by species such as the large and widely-distributed bull shark (*C. leucas*) that can invade freshwater habitats, the oceanic whitetip shark (*C. longimanus*) that patrols the warm epipelagic surface waters of the world's oceans, and the smalltail shark (*C. porosus*) that rarely exceeds a meter in length and is found nearshore only in the tropical eastern Pacific and western Atlantic.

Many carcharhinid sharks are phenotypically similar and are often confused taxonomically,which may explain why the species are lumped together in fisheries statistics. For example, *Carcharhinus brevipinna* and *C. limbatus* both have black-tipped fins, are morphologically similar, and the scarcity of *C. brevipinna* records may be an artifact of misidentification of this species as *C. limbatus* (Branstetter, 1982).

The problem of species identification is further compounded by the fact that once caught, sharks are frequently gutted to keep the flesh from spoiling, and the heads and fins are removed. Thus, sharks on the docks resemble torpedoes, lacking teeth and fins that serve as the best and sometimes the only diagnostic characters for identifying species (Compagno, 1984). If species of sharks are to be managed as separate gene pools, we need a method for identifying species from tissue samples that can be taken from the carcasses.

Several methods are available to identify species based on analysis of proteins and DNA. For proteins, isoelectric focusing (IEF), sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE), and allozyme electrophoresis are efficient and rapid methods that allow identification of species from muscle tissue samples, even when tissues have been cooked (i.e. IEF [Nu el al. 1989]) or stored for long periods of time at –20°C[1]. IEF is being used by the Texas Parks and Wildlife Department and the National Marine Fisheries Ser-

[1] D. Buth, Professor, UCLA, pers. commun. 1991.

years ago. Because substitution rates for nuclear DNA are approximately 10 times slower than for mtDNA (Wilson et al.,1985), similar levels of resolution can be achieved by surveying 40 loci by electrophoresis (Nei, 1985, p. 253).

RFLP analysis of mtDNA has been extremely useful for describing population structure for a wide variety of organisms (Avise et al., 1987) as well as for distinguishing among stocks for fisheries purposes (Ferris and Berg, 1987; Martin et al., 1992b). RFLP analysis of purified whole mtDNA's can reveal diagnostic patterns (Fig. 3) and mtDNA sequence analysis of 16 species of *Carcharhinus* and allied genera shows that morphologically similar species are genetically distinct (Martin, 1992) such that most species can be distinguished using standard RFLP analysis with one or two enzymes.

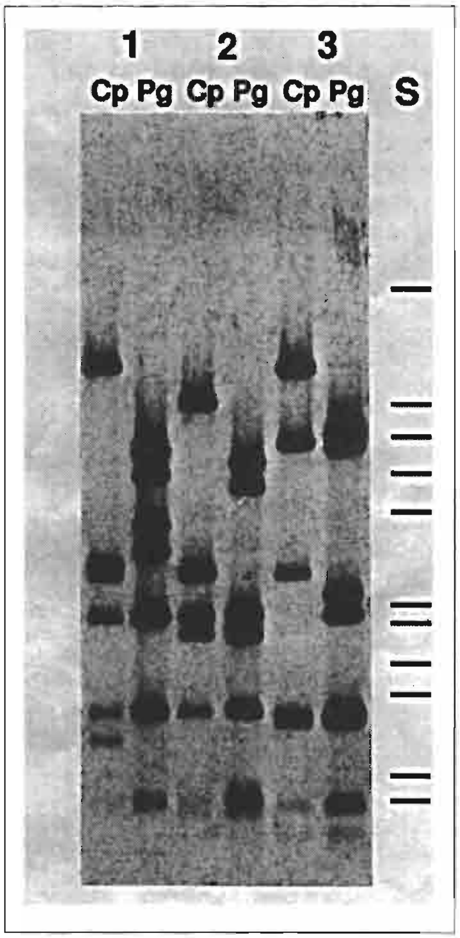

Figure 3
RFLP profiles for *Carcharhinus plumbeus* (CP) and *Prionace glauca* (Pg). For each lane double-digestions were done with *Bcl* I and *Sal* I (1), *Xho* I (2) and *Bgl* II (3). S is a lambda cut with *Hind* III-*Eco* RI for use as a size standard. Fragment sizes (in kilobases) for the lambda size standard are, in order of increasing size (from top to bottom): 21.2, 5.2, 4.9, 4.3, 3.5, 2.0, 1.9, 1.6,, 1.3, 1.0, 0.8. Methods: Purified mtDNA was obtained following the methods of Lansman et al. (1981), i.e., digested with a pair of enzymes following the manufactures guidelines, end-labeled with radioactive nucleotides by using Klenow enzyme, the fragments separated in a 1% TBE agarose gel, the gel dried, and the fragments visualized by exposure to X-ray film overnight.

Enzymatic Amplification and RFLP Analysis

The polymerase chain reaction (PCR) is a technique that enables the amplification of small segments of DNA (Saiki et al., 1988). By using PCR it is possible to retrieve DNA sequences from ancient tissue (Paabo, 1989; Hagelberg and Clegg, 1991) and a range of tissue types preserved by various means (e.g., teeth, jaws, cartilage, fins, dried or salted flesh, blood, preserved museum specimens, as well as from fresh, frozen, or ethanol-preserved samples of liver, heart, kidney, gills, muscle). Protocols have been developed for the isolation and characterization of mtDNA from sharks (Martin, 1992). With sets of conserved primers, different regions of elasmobranch mitochondrial genomes that evolve at remarkably different rates (Cann et al., 1987) (see Fig. 4) can be amplified and subjected to sequence analysis. Specific regions can be chosen to address questions of differing temporal resolution. For example,

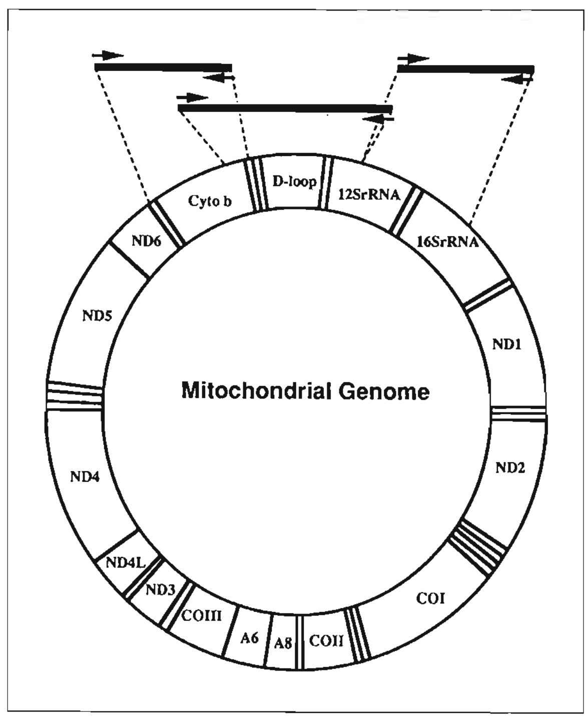

Figure 4
Map of the vertebrate mitochondrial genome (based on mammals and frogs) showing the location of the primers that have been developed to amplify and characterize specific gene regions of elasmobranch mtDNA. For the primer sequences, consult Martin (1992).

Before RFLP analysis of PCR-amplified DNA can be adopted as a versatile and efficient forensic tool, it is necessary to determine to what extent, if any, within-species variation in mtDNA sequence decreases the probability that species are accurately identified from small pieces of their mitochondrial genomes. Preliminary analysis indicates that levels of within-species mtDNA sequence diversity are remarkably low (A. Martin, unpubl. data), suggesting that within-species mtDNA diversity will probably not pose a significant problem. Nevertheless, it will be necessary to compile a library of RFLP fragment patterns for each species before the method can be used in forensics.

This technique can also be used to delineate populations (stock structure). The most versatile region to characterize for this fisheries purpose is the non-coding D-loop (see Fig. 4) because this region evolves about 10-20 times faster than the remainder of the genome. As an example, amplification and RFLP analysis of the D-loop and the flanking sequences allows differentiation among hammerhead sharks from different oceans (Fig. 7) and has also been successfully used to describe the population genetics of a North Pacific pelagic marine fish from small muscle samples preserved in ethanol, pieces of frozen liver, and in some cases, from a few eggs less than 1 mm in diameter (Martin et al., 1992). An important advantage of this method is that DNA can be extracted, amplified, digested with endonucleases, and fragment patterns determined for as many as 48 samples in a day; efficiency that permits processing of large numbers of individuals. Furthermore, the same unambiguous data can be obtained regardless of the available tissue type, and the method is relatively insensitive to tissue quality.

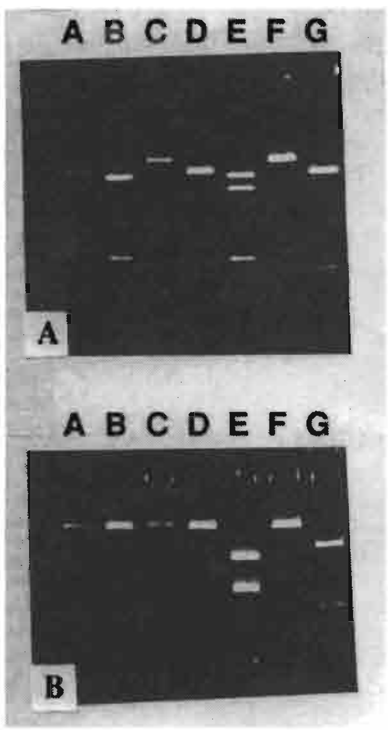

Figure 6
An example of fragment patterns resulting from digestion of PCR-amplified DNA with the 4-base pair endonucleases (**A**) *Hae* III and (**B**) *Hha* I. The DNA was amplified in 100 µL, 15 µL were removed and the enzymes added directly to the amplification cocktail. The sample was allowed to digest for 1–3 hours, 10 µL subject to electrophoresis through a 1.5% agarose gel, and the fragments were visualized with ethidium bromide stain which makes the bands fluorescent when exposed to UV light (see Martin et al., 1992). Fragment sizes are given in Table 1. Lanes: A = *Carcharhinus perezi*; B = *Rhizoprionodon terrenovai*; C = *C. limbatus*; D = *C. falciformis*; E = *C. porosus*; F= *C. amblyrhynchos*; G = *C. plumbeus*.

DNA Sequence Data

DNA sequence provides the greatest resolution of an individual's genotype (see Fig. 2). For studying the genetic relationships among individuals and establishing the genetic difference between individual genomes, there is no substitute (for example, see Vigilant et al., 1991). As part of a larger study on the pattern of diversification in carcharhinid sharks, morphologically similar species of *Carcharhinus* are distinguishable on the

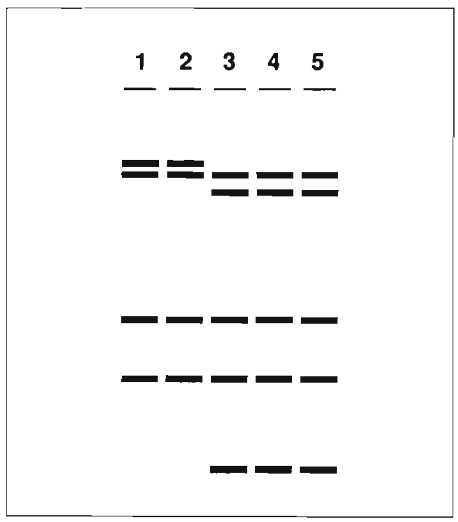

Figure 7
RFLP patterns for hammerheads (*Sphyrna lewini*) collected from five localities. The entire D-loop and flanking gene regions were amplified and digested with *Hae* III directly in the PCR buffer as described in figure 6 legend and in Martin et al. (1992). 1 = Florida keys; 2 = Atlantic coast of Panama; 3 = Hawaii; 4 = Gulf of California; 5 = Pacific coast of Panama.

Garrick, J.A.F.
1982. Sharks of the genus *Carcharhinus*. NOAA Tech. Rep., NMFS Circ. 445.
1985. Additions to a revision of the shark genus *Carcharhinus*: synonymy of *Aprionodon* and *Hypoprion*, and a description of a new species of *Carcharhinus*. NOAA Tech. Rep., NMFS. 34:1–26.

Hagelberg, E., and J.B. Clegg.
1991. Isolation and characterization of DNA from archeological bone. Proc. R. Soc. Lond. *(B.)* 244:45–50.

Hillis, D. M., and C. Moritz.
1990. Molecular systematics. Sinauer Press, 588 p.

Lansman, R.A., R.O. Shade, J.F. Shapira, and J.C. Avise.
1981. The use of restriction endonucleases to measure mitochondrial DNA sequence relatedness in natural populations. III. Techniques and potential applications. J. Mol. Evol. 17:214–226.

Lavery, S., and J.B. Shaklee.
1991. Genetic evidence for separation to two sharks, *Carcharhinus limbatus* and *C. tilstoni*, from Northern Australia. Mar. Biol. 108:1–8.

Lavery, S.
1992. Electrophoretic analysis of phylogenetic relationships among Australian carcharhinid sharks. Aust. J. Mar. Freshwater. Res. 43:97–108.

Martin, A.P.
1992. Mitochondrial DNA in sharks: molecular evolution and evolutionary inferences. Ph.D. diss., Univ. of Hawaii, Honolulu, HI, 216 p.

Martin, A.P., G.J. P. Naylor, and S.R. Palumbi.
1992a. The rate of nucleotide substitution in sharks is slow compared to mammals. Nature 3–57:153-155.

Martin, A.P., R. Humphreys, and S.R. Palumbi.
1992b. Panmixis in the North Pacific Armorhead (*Pseudopentaceros wheeleri*): application of PCR to fisheries problems. Can. J. Fish. Aquat. Sci. 49:2386–2391.

Moritz, C., T. Dowling, and W. Brown.
1987a. Evolution of animal mitochondrial DNA: relevance for population biology and systematics. Ann. Rev. Ecol. Syst. 18:269–292.

Naylor, G.J.P.
1989. The phylogenetic relationships of Carcharhiniform sharks inferred from electrophoretic data. Ph.D. diss., Univ. Maryland, 131 p.

Nei, M.
1985. Molecular evolutionary genetics. Columbia Univ. Press, NY, 512 p.

Paabo, S.
1989. Ancient DNA: extraction, characterization, molecular cloning and enzymatic amplification. Proc. Natl. Acad. Sci. USA 86:1939–1943.

Pratt, H. L. Jr., S. H. Gruber, and T.Taniuchi, eds.
1990. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries. NOAA Technical Report NMFS 90, 519 p.

Saiki, R.K., D.H. Gelfand, S. Stoffe, S.J. Scharf, R. Higuchi, G.T. Horn, K.B. Mullis, and H.A. Erlich.
1988. Primer-directed enzymatic amplification of DNA with a thermostable DNA polymerase. Science 239:487–491.

Sole-Cava, A.M., C. M. Vooren, and J. A.Levy.
1983. Isozymic differentiation of sibling species of Squatina (Chondrichthyes) in south Brazil. Comp. Biochem. Physiol. 75B:355–358.

Vigilant, L., M. Stoneking, H. Harpending, K. Hawkes, and A. C. Wilson.
1991. African populations and the evolution of human mitochondrial DNA. Science 253:1503-1507.

Wilson, A.C., R.L. Cann, S.M. Carr, M.L. George, U.B. Gyllenstein, K. M. Helm-Bychowski, R. G. Higuchi, S. R. Palumbi, E. M. Pragar, R.D. Sage, and M. Stoneking.
1985. Mitochondrial DNA and two perspectives on evolutionary genetics. Biol. J. Linn. Soc. 26:375–400.

Shark Conservation — Educating the Public

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ABSTRACT

Current fishing pressure on elasmobranchs has reached levels that are seriously impacting shark populations, and public education regarding the importance of shark resources is essential to timely implementation of appropriate regulatory policy. The primary educational goal of the Monterey Bay Aquarium's temporary (one-year) "Sharks" exhibition and supporting programs was to debunk the popular "Jaws" image while increasing public interest in elasmobranch conservation. About 1.7 million people visited the exhibition and 8,000 participated in associated education programs. Pre- and post- visit interviews revealed changes in visitor attitudes and decreases in misconceptions or mistaken information about sharks as a result of viewing this exhibit. Based on the success of this program, suggestions are made for increasing the interaction between scientists and the public.

Introduction

While insufficient information on elasmobranch life history and fishery characteristics is often cited as reason for the inadequacy of elasmobranch fishing regulations (Anderson and Teshima, 1990; Bonfil et al., 1990; Hoff and Musick, 1990; Pratt and Casey, 1990; Cailliet, 1992), progress is slowly being made toward regulation of elasmobranch fisheries as indicated by the development of the Western North Atlantic Fishery Management Plan (Hoff and Music, 1990; Manire and Gruber, 1990) and recent actions by the California Fish and Game Commission and by other western states (Bedford, 1987; Holts, 1988). It is debatable, however, whether or not adequate management policies can be implemented before some species are significantly impacted (Compagno, 1990; Manire and Gruber, 1990). Timely implementation of elasmobranch fishery regulations may depend as much on changing the public's perception of sharks and on cultivating a conservation ethic, as on attaining much needed life-history information. While conducting research necessary to support management implementation, scientists should also take an active and visible role in public education. Orr (1991) states that the large gap between strong public support for the environment and the environment as a national political issue is partly explained by the failure of scientists to communicate adequately with society. As Kinsman (1991) points out, there is a growing concern about the environment by many outside the environmental and academic circles, however "conservation efforts 'legitimized' by scientists seem distant, and the scientists themselves unapproachable. Part of our responsibility must be to diminish that distance." Interactions between the scientific community and public aquariums and the public education activities undertaken by each group may play an important role in ensuring a timely implementation of much needed management policies.

The Shark Exhibition

In an attempt to increase public interest in elasmobranch conservation, the Monterey Bay Aquarium presented a special "Sharks" exhibition, January through December, 1991, featuring live sharks and a series of interactive exhibits that was augmented by a lecture series, family workshops, a students' art festival, high school and public auditorium programs, and publication of a natural history book. The main theme of the exhibit was that "sharks are not what you think." Subthemes included 1) sharks are not all big and dangerous; 2) sharks are threatened by overfishing and are in about these themes, 96% of the visitors recalled seeing the former theme expressed in the exhibit and 86% recalled seeing the latter theme expressed.

- Over 90% of visitors said they learned something about sharks that they did not know before. This included facts about their reproductive process, their sensory abilities, that there are many varieties of sharks in nature, and that some shark populations are decreasing.
- There were strong decreases in misconceptions and misinformation about sharks as well as the addition of new images that were less threatening and more respectful of sharks. For example, the proportion of visitors who responded affirmatively to the question "Do most sharks have big sharp teeth?" was 71% in the pre-visit survey, compared to 23% in the post-visit survey. Similarly, 52% of the pre-visit respondents said most sharks were dangerous and 42% said most sharks were large; in comparison only 14% of the post-visit respondents replied in the affirmative to the same questions.
- Visitor responses in the exit interview indicated that their enhanced understanding and appreciation of sharks resulted from a variety of exhibit elements. When asked what was the most impressive exhibit element, 31% of the visitors answered live sharks, 15% said the reproduction and egg case exhibit and 13% said interaction. Fifty-five percent of the visitors reported that the written signs and labels were a principal source of information about shark characteristics. Forty-seven percent of the visitors said the videos were the most effective element to communicate the message about conservation and preservation, while 39% said that the written signs and labels were most effective.

The Scientist's Role in Elasmobranch Conservation Education

Although the lack of public interest in elasmobranch research, conservation, and management has been attributed to limited awareness and understanding of these topics (Anderson and Teshima, 1990; Compagno, 1990; Manire and Gruber, 1990), the results of this survey indicate that the public is receptive to new information concerning sharks and to the need for shark conservation. Compagno (1990), Manire and Gruber (1990) and others suggested that a concerted effort should be undertaken to increase public awareness of the importance of shark resources and the need for an adequate fishery management policy. Although institutions such as zoos and aquariums usually take the lead role in such activities, cultivating support for elasmobranch conservation is certainly as much the responsibility of the individual scientist.

Because people and the media are fascinated by sharks, the opportunities to educate the public about elasmobranchs are much greater than for many other conservation issues. Scientists should take advantage of this fascination and participate in conservation education by 1) producing lectures and publications for the general public, 2) being available to the media and educational organizations (for interviews, resources, information, etc.), and 3) notifying the media about events involving elasmobranch biology and conservation.

Essential to effectively impacting the management process via public education is that the public be offered a means of taking action. The public can support elasmobranch conservation efforts by 1) writing letters to regulatory agencies and political representatives, 2) changing behaviors which directly impact shark populations (i.e., participation in shark tournaments), 3) providing financial support to appropriate organizations, and 4) furthering their own education and that of others. Scientists interacting with the public and media should include in their repertoire specific details to allow motivated members of the public to pursue action along a number of the avenues listed above.

Acknowledgments

Numerous staff members of the Monterey Bay Aquarium's Education, Exhibitions, and Curatorial Divisions have contributed to this paper through their instrumental roles in the development and implementation of the shark exhibition, exhibit evaluation, and supporting programs. Their inspiration and support is greatly appreciated.

Literature Cited

Anderson, E.D., and K. Teshima,
1990. Workshop on fisheries management. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H. L. Pratt Jr., S. H. Gruber, and T. Taniuchi, eds.), p. 499–503. NOAA Tech. Rep. NMFS 90.

Bedford, D.
1987. Shark management: a case history — the California pelagic shark and swordfish fishery. *In* Sharks: an inquiry into biology, behavior, fisheries, and use (S. Cook, ed.), p. 161–171. Oregon State Univ. Sea Grant Publication, Corvallis, OR.

Bonfil, R., D. de Anda, and R. Mena
1990. Shark Fisheries in Mexico: The Case of Yucatan as an Example. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H. L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 391–414. NOAA Tech. Rep. NMFS 90.

A Preliminary Estimate of Natural Mortality of Age-0 Lemon Sharks, *Negaprion brevirostris*

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ABSTRACT

Determination of natural mortality rate is an important step in understanding and quantifying the population dynamics of a species. This is the first study using elasmobranchs which directly measured the rate of natural mortality. An unexploited population of lemon sharks, *Negaprion brevirostris*, in Bimini, Bahamas, was and continues to be censused to determine natural mortality. Preliminary results indicate an instantaneous natural mortality rate (*M*) ranging from 0.60–1.01 for lemon sharks in their first year of life (equivalent to an annual mortality of as much as 64%). The natural mortality rate must be highest in this age class and must be very low and possibly zero in subsequent age classes for the population to remain viable.

Introduction

There have been few attempts to estimate natural mortality in elasmobranchs. Yokota (1951) estimated the natural mortality of the ray *Dasyatis akajei* to be 0.28 using age composition of an exploited population. Aasen (1963) used length distribution and growth of the porbeagle, *Lamna nasus*, to derive an estimate of *M* of 0.18 and Grant et al. (1979) used a regression from tag recovery data to estimate a natural mortality rate of 0.10 for exploited stocks of the school shark, *Galeorhinus australis* (= *G. galeus*). For the spiny dogfish, *Squalus acanthias*, Holden (1977) estimated *M* to be 0.10 based on a length-fecundity relationship, Wood et al. (1979) used simulation data and estimated *M* to be 0.094 for an equilibrium population, and Jensen (1984) used commercial catch-effort data to derive an *M* of 0.5. For the little skate, *Raja erinacea*, Waring (1984) used the relationship between the growth parameter *K* and instantaneous natural mortality as described by Beverton and Holt (1959) to estimate M between 0.4 and 0.5. Finally, for an estimate of natural mortality for the leopard shark, *Triakis semifasciata*, Smith and Abramson (1990) used Hoenig's (1983) regression based on the maximum attained age of a species to estimate *M* to be 0.14 overall and assumed it was double that in the first year.

Beverton and Holt (1957) believed natural mortality to be the most important parameter affecting the yield curve of a commercial species. Because elasmobranchs are, or are becoming, over-exploited around the world, (Hoff and Musick, 1990; Taniuchi, 1990; and other papers in this report), it becomes increasingly important that estimates of natural mortality of elasmobranchs be made in order to understand their overall rates of production and thus possible potential yields.

Survival data from elasmobranch commercial and sport fisheries are generally unavailable (Hoenig and Gruber, 1990). In a situation where fishing mortality (*F*) is non-existent, total instantaneous mortality (*Z*) is equal to the instantaneous rate of natural mortality (*M*). Therefore, as part of our ongoing study of the population dynamics of the lemon shark (Gruber and Stout, 1983; Brown and Gruber, 1988; Gruber et al., 1988; Cortes and Gruber, 1990), we have undertaken a multi-year field experiment to determine both the natu-

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measured to the nearest 5 mm (precaudal and total length), sexed, scanned for the presence of a Passive Integrated Transponder tag (PIT tag, Destron/IDI Corp.), and externally marked by punching a 4-mm hole in a fin (dorsal, anal, etc.) that represented the site from which the shark was captured. If no PIT tag was found, one was inserted intramuscularly below the first dorsal fin (Manire and Gruber, 1991). Sharks were placed in a holding pen within 15–30 minutes of capture and held there until the census was completed. On one occasion (Census 2–August 1990), we released the sharks from the pen after the second night to determine rate and success of sharks homing back to their site of capture and on the third night censused only the sharks which had not been captured on the two previous nights.

In this paper, we present only data for 1990 young-of-the-year (YOY) lemon sharks. These sharks were easily separable from the other age classes by length-frequency generated during the first two censuses and by tag information thereafter. Analysis of the data for Age 1 and older sharks awaits further sampling experiments.

Population Estimates

Closure was assumed during each removal (census) because 1) each removal experiment was outside the birth period 2) each removal was completed in about 62 hours, during which natural deaths would be negligible and 3) the study population was limited to Age–0 and Age–1 sharks which are highly site attached (Morrissey and Gruber, In press) and thus should not have been moving into or out of the study site.

Several methods are available for estimating population size with removal data. The method of Seber and LeCren (1967) requires only two sampling periods and produces reliable results with a relatively small population if the capture probability during each period exceeds 80% (Seber, 1982). The formula is as follows:

$$N = (u_1^2) / (u_1 - u_2), \tag{1}$$

where N = population size,
u_1 = number of captures on first sampling,
u_2 = number of captures on second sampling.

Variance of this estimate can be calculated as

$$\mathrm{Var}(N) = Nq^2(1+q)/p^3 + 2q(1-p^2-q^3)/(p^5-b^2) \tag{2}$$

where $p = (u_1 - u_2) / u_1$,
$q = 1 - p$,
and $b = q(1 + q) / p^3$,

or more simply as

$$\mathrm{Var}(N) = u_1^2 u_2^2 (u_1+u_2) / (u_1-u_2)^4.$$

We also used a Maximum Likelihood Estimator (computer program CAPTURE [White et al., 1982; Rexstad and Burnham, 1991]) which provides a more precise estimate of population size, sampling variance and a Profile Likelihood Interval (a confidence interval based on the asymptotic χ^2 distribution of the generalized likelihood ratio test [Otis et al., 1978; Rexstad and Burnham, 1991]).

Mortality Estimate

Once a temporal series of population estimates has been made, the total mortality rate can then be calculated. Assuming no births, immigration, emigration, and fishing mortality, any change in abundance must be attributable to natural mortality. It is also assumed that the probability of capture of each individual is the same throughout the population on each capture occasion (Zippin, 1958).

The total instantaneous mortality rate (Z) (Ricker, 1975), is equal to the number of fish, including new recruits, which would die during the year if recruitments exactly balance mortality from day to day. Expressed as a fraction or multiple of the steady density of the stock, this can be calculated as follows:

$$N_t/N_0 = e^{-Zt} \tag{3}$$

where N_0 = population size at the beginning,
N_t = population size at the end,
t = time (fraction of a year),
and Z = total instantaneous mortality rate.

Actual mortality rate (or annual expectation of death), designated A, which is perhaps a more heuristic measure of mortality, is defined by Ricker (1975) as the fraction of the fish present at the start of a year which actually die during that year. It can be calculated as follows:

$$A = 1 - e^{-Z}. \tag{4}$$

Further, the survival rate, designated S, can be calculated as follows:

$$S = e^{-Z}. \tag{5}$$

Survival rate is defined by Ricker (1975) as that fraction of the fish present at the start of a year which will survive for that year.

Results

During five censuses we captured 147 juvenile lemon sharks and tagged 141 of which 36 were 1990 YOY.

- May 1991 — at least 13 of 1990 YOY present.

We calculated several estimates of natural mortality. Based on the July 1990 estimate of 30 sharks (as modified to account for the one untagged capture of Aug 1990) coupled to the May and June 1991 data of 13 sharks, we calculated a mortality rate for the first year of life of lemon sharks:

Total instantaneous mortality rate (Z) = 0.94
Actual mortality rate (A) = 0.61
Survival rate (S) = 0.39.

Using the maximum estimate for census 1 (32 sharks) and the minimum of 13 sharks for the May 1991 census, we yielded estimates of

$$Z_{max} = 1.01,\ A_{max} = 0.64,\ S_{min} = 0.36.$$

Likewise, the minimum mortality rate was calculated by using the minimum population estimate of census 1 (29 sharks) and the maximum population estimate of census 4 (17 sharks). This yielded minimum estimates of

$$Z_{min} = 0.60,\ A_{min} = 0.44,\ S_{max} = 0.56.$$

Discussion

Several factors make this population of sharks suitable for the determination of natural mortality. First, the juvenile lemon sharks are virtually unexploited. Second, a high degree of site attachment by individuals (Gruber et al., 1988; Morrissey and Gruber, 1993) and the relative isolation of the juvenile population provide a situation similar to that of freshwater lakes. Because of this, we assumed a closed population, ideal for the determination of natural mortality.

One disadvantage of the census was the small population size, numbering less than 100. This small size and slow individual growth prohibited the use of length-frequency analysis to estimate mortality of age classes.

Removal methods reliably and accurately estimate abundance as long as a large portion of that population is removed on each sampling occasion (Seber and LeCren, 1967; Seber, 1982). The removal model assumes closure during the censusing period, i.e., no births or deaths and no immigration or emigration. While the assumption of complete closure cannot be completely verified in an open marine ecosystem, a close approximation to the complete closure assumption must be made (Seber, 1982) and is made here.

Hoenig and Gruber (1990) estimated first-year survivability of sharks under a variety of scenarios to range from 16 to 97%. Our calculated survivability of 39% falls below the 50% estimate used for most of Hoenig and Gruber's (1990) calculations, but equals the minimum rate Hoenig and Gruber (1990) estimated for an unexploited population to maintain equilibrium. These estimates suggest that the Bimini population is near equilibrium and is therefore highly vulnerable to exploitation.

Equal mortality for all age classes is believed to be the case for some long-lived teleosts (Seber, 1982) and has been assumed in elasmobranch studies (Wood et al., 1979), but our findings indicate that this is not the case with this population. According to our study, juvenile lemon sharks experience a very high mortality rate during their first year, probably due to predation from large sharks (Branstetter, 1990; Cortes and Gruber, 1990) in the first few months of life.

One important fact has emerged during this preliminary portion of this study: some of the 1990 YOY population had avoided capture during Censuses 2 or 4, or during both, and were later captured, thereby calling into question our assumption of equal probability of capture. Possible reasons for the invalidity of the equal probability of capture assumption include immigration and emigration from the study site or subsequent avoidance of the net by learning processes. We believe the latter explanation to be more likely for two reasons. First, the high degree of site attachment noted in Table 1 and the fact that none of this cohort were ever captured beyond site 8 makes migration highly unlikely. Second, the capture probability of our study population on their first exposure to a gill net was 84% per set in July, 1990, whereas by May, 1991, it had decreased to about 38% (5 of 13) of the documentable population. However, the capture probability in May, 1991, for the new age class not previously exposed to gill nets was 80%. During this study, we observed that juvenile lemon sharks from this and other populations became progressively more difficult to capture in nets with repeated capture attempts and this could artificially inflate mortality estimates.

Abundance estimates must account for learning processes and other behavioral biases. Although White et al. (1982) recommended the use of a behavioral bias estimator ($M(b)$) of Zippin (1958), this method uses only first captures to estimate the total population size at each census. However, because we captured nearly 100% of the population each census, there were insufficient new captures after the first census, which precluded the use of this estimator. We hope to minimize the behavioral bias in the future by sampling the population only once annually (so as to preclude repetitive learning processes) and by baiting sharks to the nets (to increase our capture rate).

Because of these potential biases in our data we must emphasize that these are preliminary results. All noted

Rexstad, E. and K. Burnham.
1991. User's guide for interactive program CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit Publication, 29 p.
Ricker, W.E.
1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Canada No. 191, 382 p.
Seber, G.A.F.
1982. The estimation of animal abundance and related parameters, Second ed. Charles Griffin and Co., London and High Wycombe, 654 p.
Seber, G.A.F., and E.D. LeCren.
1967. Estimating population parameters from catches large relative to the population. J. Anim. Ecol. 36:631–643.
Smith, S.E., and N.J. Abramson.
1990. Leopard shark *Triakis semifasciata* distribution, mortality rate, yield, and stock replenishment estimates based on a tagging study in San Francisco Bay. Fish. Bull. 88(2):371–381.
Taniuchi, T.
1990. The role of elasmobranchs in Japanese fisheries. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 415–426. NOAA Tech. Rep. NMFS 90.
Waring, G.T.
1984. Age, growth, and mortality of the little skate off the northeast coast of the United States. Trans. Am. Fish. Soc. 113:314–321.
White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis.
1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, Pub. #LA8787-NERP, Los Alamos, New Mexico, 235 p.
Wood, C.C., K.S. Ketchen, and R.J. Beamish.
1979. Population dynamics of spiny dogfish (*Squalus acanthias*) in British Columbia waters. J. Fish. Res. Board Can. 36:647–656.
Yokota, T.
1951. Studies on the stocks of sharks and rays. II. Age composition of the ray *Dasyatis akajei* (Muller and Henle), as observed in the catch by trawlers landed at Totoro, Miyazaki prefecture during a period between September, 1949 to May, 1950. Bull. Japan. Soc. Sci. Fish. 16(12):188–189.
Zippin, C.
1958. The removal method of population estimation. J. Wildl. Manage. 22(1):82–90.

Biological Parameters of Commercially Exploited Silky Sharks, *Carcharhinus falciformis*, from the Campeche Bank, Mexico.

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ABSTRACT

Age, growth, and reproductive parameters were estimated for silky sharks (*Carcharhinus falciformis*) off the Yucatan peninsula, Mexico, as a first and essential step towards the assessment and management of the species. Commercial catches were sampled from March 1985 to August 1989. Silky sharks off Yucatan are born in early summer after a 12 month gestation period at c. 76 cm TL. Males mature at 225 cm TL ($\approx$10 y) and females at 232–245 cm TL (>12+ y). Maximum ages determined by analysis of alizarin-red-S-stained thin vertebral sections, were 22+ yr for females and 20+ yr for males. No differences in growth between the sexes were detected. Individual growth is quite variable in this species, but the von Bertalanffy model adequately described population growth. Parameters estimates of this model for combined sexes were: $k = 0.101$, $L_{inf} = 311$ cm TL and $t_0 = -2.718$. Age and growth determinations are supported by back-calculation and length frequency analysis. Present results are compared with those of previous studies for this species, and future work for Gulf of Mexico populations is proposed.

Introduction

The silky shark, *Carcharhinus falciformis* (Bibron), is a large, pantropical species attaining 330 cm TL (Garrick et al., 1964) that inhabits both coastal and oceanic waters. Fisheries for this species probably exist worldwide (Compagno, 1984). In southeast Mexico, the silky shark represents one of the more important species in the Yucatan shark fishery (Bonfil, 1987), and it is also exploited commercially along the rest of the Gulf of Mexico and on the Pacific coast of Mexico.

Worldwide there have been very few studies concerning silky shark biology. This has hindered studies of its potential for exploitation. Various discrete accounts of its biology are known thanks to its regular presence as bycatch on tuna, billfish, and other fisheries (Strasburg, 1958; Springer, 1960; Guitart-Manday, 1975). Apart from the studies of the uterus and placentation made by Gilbert and Schlernitzauer (1965, 1966), specific records of reproduction in this species are limited to the scattered field observations of, among others, Strasburg (1958), Springer (1960), Bane (1966), Bass et al. (1973), Stevens (1984, a and b), and Branstetter (1987), with the latter providing the most updated and comprehensive account. Schwartz (1983) reported limited data on its age and growth, and Branstetter and McEachran (1986) and Branstetter (1987) estimated the age and growth of populations in the Northwest Gulf of Mexico.

In Mexico, no specific studies on the biology of this species have been published. Only species accounts (Castro-Aguirre, 1967; Applegate et al., 1979) and its importance and structure in the commercial fisheries (Bonfil, 1987; Bonfil et al., 1988, 1990) have been reported. The present study analyzes the information gathered in almost five years of sampling commercial catches, and aims to estimate reproductive parameters and the age and growth of the silky shark, *Carcharhinus falciformis*, from the Campeche Bank, Mexico.

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measured from the insertion of the inner corner of the pelvic fin to the distal tip of the clasper to the shortest millimetre. Given the distinct process of clasper development common to many shark species (Gilbert and Heath, 1972; Parsons, 1983; Natanson and Cailliet, 1986; Peres and Vooren, 1991), clasper length as a percentage of total length was plotted against total length in order to estimate the minimum size at which all males were mature. Pratt (1979) noted that external features can be misleading regarding sexual maturity for female sharks. Therefore, female maturity estimates were restricted to those fish examined at the processing plants. Females were considered mature if ripe ovarian eggs or embryos were present, or if distention of the uterus showed evidence of prior pregnancy. Whenever pregnant females were examined, all embryos in the litter were measured and sexed.

For age and growth studies, a sample of 4 or 5 vertebrae were removed from the region directly below the first dorsal fin for a total of 83 *Carcharhinus falciformis* of both sexes (43♂, 40♀), from newborn to adult sharks, found in the Campeche Bank. Each sample was fixed in 10% formalin for 24 hours, and stored in 70% isopropanol for up to 4 years. For the preparation of the thin sections, one vertebra from the sample was selected, and excessive connective tissue and vertebral processes were removed. Cleaned centra were placed in 50% bleach for periods varying from 5 minutes to several hours, depending on the size of the vertebrae; the larger ones required up to 6 hours and one or two changes of bleach solution. This treatment cleaned most of the unwanted connective tissue remaining on the face and around the centra (Cailliet et al., 1983). Care was taken not to leave samples in the bleach solution too long as this can soften and deform the whole centra. Afterwards, all centra were thoroughly rinsed in running tap water. Cleaned centra were cut in half across a frontal plane using an Isomet low speed saw. A thin (ca. 0.21 mm) slice was obtained from one of these halves by using the same cutting tool, thus a bow-tie shaped section was obtained for each centra.

Two staining techniques were tested on twin sets of 6 vertebrae of different sizes. First, an adaptation of the technique shown by Stevens (1975) was used. This consisted of immersion in a solution of silver nitrate (1%) coupled with exposure to UV light (direct sunlight) for 1–5 min, followed by removal of excess silver and by fixation with soaking in sodium thiosulphate (5%) for a couple of minutes. The second group of vertebrae were stained in an aqueous solution of alizarin red S and 0.1% NaOH in a ratio of 1:9 (Gruber and Stout, 1983) for periods varying between 20 minutes and 4 hours according to the centra sizes, larger ones taking more time. The samples were then rinsed for 15 minutes in running tap water and fixed in a solution of 3% hydrogen peroxide. All stained vertebrae were finally rinsed in tap water and stored back in isopropyl alcohol.

Throughout this paper, we follow the definitions of Wilson et al. (1983), according to which "an annulus is a concentric zone, band or mark, that is either a ridge or valley, or translucent or opaque. A unit passage time (i.e. 1 year) is not inherently implied." The terms band, ring, mark, or zone are regarded by the above mentioned authors as auxiliary descriptive terms. Following Cailliet et al. (1983), rings are treated here as the narrowest kind of concentric mark observed, and bands as wider concentric marks composed of groups of rings. Counts and measures of growth bands were performed on the thin sections viewed at 5× magnification under a binocular microscope equipped with an eyepiece micrometer. The centra faces were used only as an aid for identifying and counting poorly defined bands in the corpus calcareum and intermedialia. Both transmitted and reflected light were used to examine the samples depending on the quality of the definition of the growth marks. To increase contrast of the growth marks, transmitted light surrounding the sections was sometimes partially blocked by inserting suitable pieces of common writing paper between the container and the microscope platform.

Two separate counts were made by a single reader (senior author) for each sample, without knowledge of the total length or sex of the shark. When the two counts differed, a third reading produced a count that matched one of the first two. Agreeing counts were used in the calculation of the mean length at age for each age class.

The centrum radius was measured as a perpendicular line from the focus to the most distal edge of the vertebrae, which usually lay in the corpus calcareum. Distances to each growth mark were also measured as perpendicular lines from the focus to the most distal point of each growth mark along the corpus calcareum (Fig. 2). Marginal increments were measured perpendicularly from the last growth mark to the edge of the centrum. Birth marks were identified as a change in the angle of the inner margin of the corpus calcareum; this was sometimes coupled with a faint narrow annulus traversing the intermedialia. In most cases this annulus was proximal to the angle change.

Back-calculated lengths were derived from the vertebral radius-total length regression equation. The Dahl-Lea method (Casey et al., 1985; Branstetter, 1987) was also used, but discarded as it did not adequately describe early growth compared with the regression method. Care was taken to assign correct ages to the mean lengths-at-age as these can be different for direct vertebrae readings (length at time of capture) and back-calculated data (length at annuli formation).

With a maximum likelihood computer program (Genstat5), von Bertalanffy growth curves were fitted

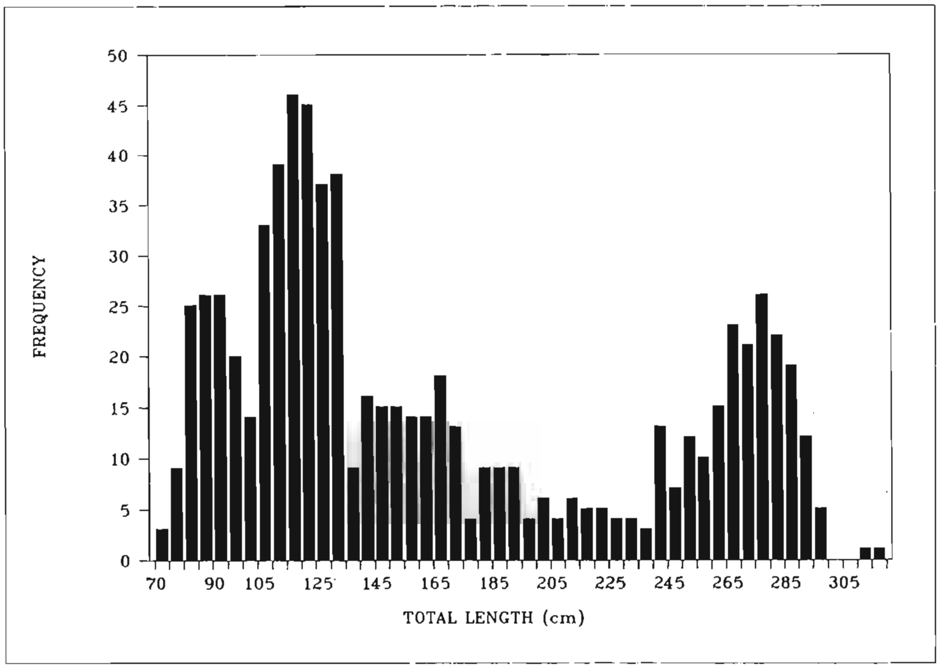

Figure 3
Length-frequency data set of the 738 freeliving sharks analyzed in the study, and used as one of the summarized data sets in the LFD analysis.

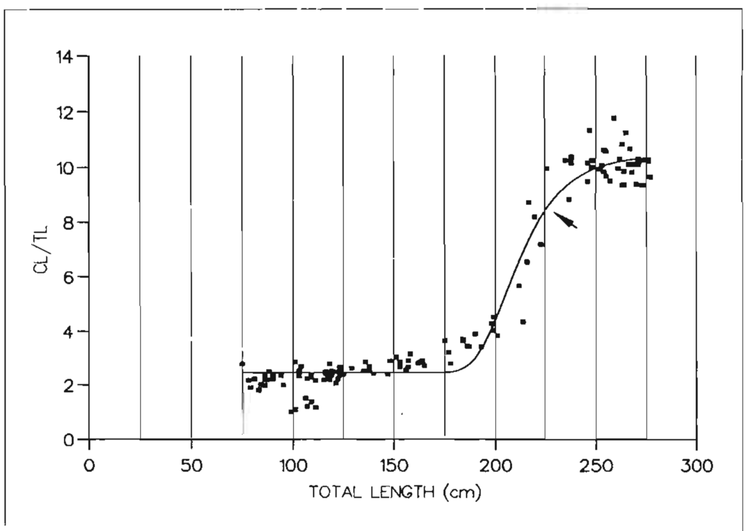

Figure 4
Estimation of size at first sexual maturity for male silky shark, based on the relative development of clasper length with total length. Squares are observations, arrow shows approximate size at which all sharks are mature.

ish and blackish bands on centra faces, poor differentiation was obtained on the exposed frontral-cut surfaces of the centra halves and the thin sections. In contrast, alizarin-red-S stained vertebrae provided a more consistent differentiation of the banding pattern throughout the centrum faces, frontal-cut surfaces, and thin sections. For this reason, and because of the ease of the alizarin-red-S method, this method was adopted for all samples.

In the corpus calcareum of a typical centrum section there was a clear pattern of annuli pairs composed of a broad dark purple band followed by a narrower light

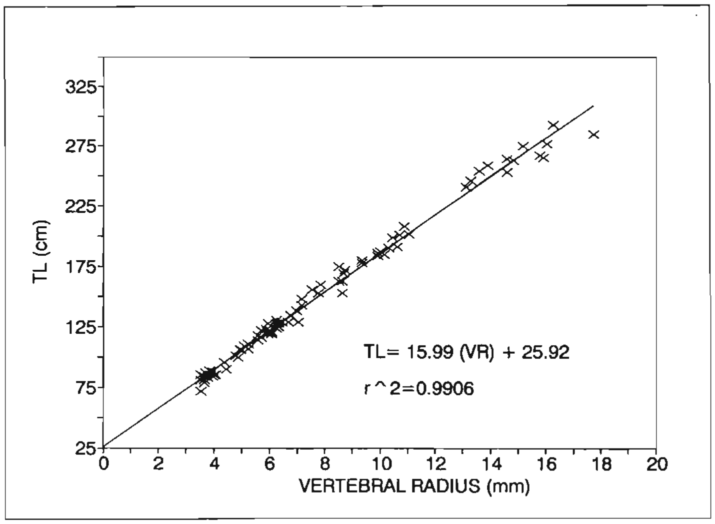

Figure 7
Linear relationship between vertebral radius and total length for silky sharks of the Campeche Bank.

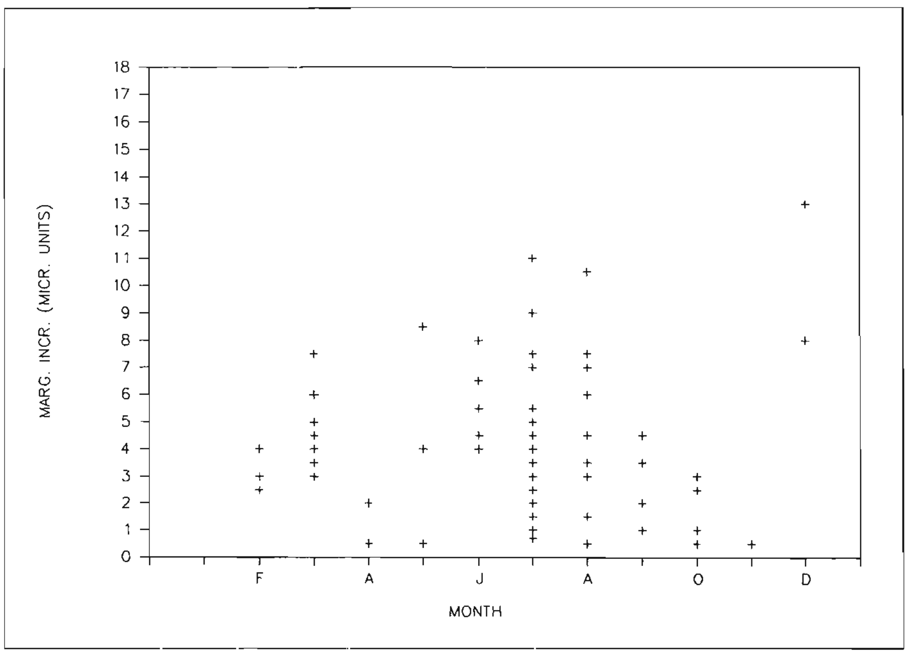

Figure 8
Estimation of time of annulus formation in centra of silky sharks based on the analysis of marginal increments for each month (neonates without winter mark excluded).

minimum in February (Fig. 8). Accordingly annulus formation occurred sometime between August and December. For growth calculations, December 30 was taken as the date of annulus formation.

With a July birth for silky sharks on the Campeche Bank and a December annulus formation, the first winter annulus represents only 6 months of growth; subsequent annuli formed annually. This was supported by the fact that mean growth represented by this first band was 13 cm, about half the average growth observed from the first to the second winter annulus (20 cm).

Fits of the von Bertalanffy Growth Model (VBGM) to the observed data for each sex provided values of k = 0.091, L_{inf} = 314.9 cm TL, and t_0 = −3.18 yr for females,

Table 2
Back calculated mean total lengths-at-age for silky sharks from the Campeche Bank (cm).

		Growth marks																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Age class	*n*	0	0+	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+	16+	17+	18+	19+	20+	21+	22+
Birth	15	76																							
1	6	74	88																						
2	16	74	87	109																					
3	11	74	85	100	118																				
4	5	75	92	108	128	149																			
5	4	77	94	114	135	149	162																		
6	4	75	85	107	124	141	156	172																	
7	5	76	87	107	119	134	146	159	174																
8	3	74	90	106	117	130	141	155	167	181															
10	1	67	80	108	133	143	156	164	172	181	189	195													
13	1	78	88	116	144	154	170	176	182	188	200	209	214	225	234										
14	1	80	96	118	142	168	191	202	212	220	229	234	241	244	253	258									
15	1	73	80	94	117	144	170	193	212	220	227	233	238	241	244	246	247								
16	1	75	84	99	111	130	144	151	161	170	187	205	216	220	226	230	236	241							
17	2	77	92	106	129	146	164	176	191	204	215	221	226	231	237	241	245	252	256						
19	2	76	87	108	124	145	168	191	210	225	233	242	247	251	255	258	261	264	266	268	270				
20	2	76	89	102	121	145	164	179	202	217	226	236	242	246	249	252	255	257	259	261	263	265			
21	2	76	86	109	128	144	167	192	208	223	230	238	246	252	259	266	271	276	281	284	287	291	293		
23	1	73	96	131	140	153	162	172	178	184	197	211	222	236	244	251	265	268	273	277	279	281	282	284	285
Mean TL		75	88	108	127	145	161	176	189	201	213	222	233	239	245	250	254	260	267	272	275	279	288	284	285
SD		3	4	8	10	10	13	16	19	21	18	17	13	12	11	11	12	13	10	10	11	13	8		
Observed (direct readings)																									
Mean TL		84	96	119	129	160	176	183	188	187		202			241	264	259	254	257		265	269	275		293
SD		5	9	10	8	6	16	15	11	2									11		12	6	10		
n		15	6	16	11	5	4	4	5	3		1			11	1	1	1	2		2	2	2		1

Pratt (1979) found that the growth of claspers, testes, and epididymis of blue sharks is gradual and does not provide any clue to the approach of sexual maturity. Further, he determined that many male blue sharks, apparently fully mature when externally examined, lacked spermatophores and had small ductus defferentia and were thus not completely mature. Contrary to these findings, male silky sharks do have a well defined adolescence that extends approximately from 200 to 225 cm TL. The lack of internal examination of sharks in our study prevents verification of maturity derived from external features only. Further work will be needed to fully understand the onset of sexual maturity in male silky sharks.

The gestation time and birth season found here support Branstetter's (1987) suggestion of a 12-month late-spring-based cycle for development of *Carcharhinus falciformis* embryos in the Gulf of Mexico. Our findings are in contrast with Strasburg (1958), Fourmanoir (1961), Stevens (1984b),and Stevens and McLoughlin (1991), who noted an absence of a defined seasonality for reproduction in the Indian and Pacific Ocean populations. Although Strasburg (1958) does not present raw data, his analysis of 12 litters points towards a true difference in seasonality of reproduction between Gulf of Mexico and central Pacific populations. Based on these observations, Branstetter (1990) suggested silky shark populations might lack seasonal gestation periods in tropical areas; however, the Campeche Bank population has a seasonal gestation period and occupies in a tropical area. Furthermore, the populations studied by Bass et al. (1973) and Stevens (1984, a and b), and Stevens and McLoughlin (1991) all share roughly the same temperature ranges of the Gulf of Mexico but do not show a seasonal gestation period. Although available data are limited, there may be true differences among geographic populations. Estimation of the span of the total reproductive cycle in the females (i.e., if they give birth every year, or every other year) is also poorly known and should also be considered for future work. Branstetter (1987) gives the only available observations suggesting the entire cycle may take two years.

Age and Growth

Annuli, and growth bands, were readily discernible in silky shark vertebral centra. The poor resolution of bands on thin sections of vertebrae stained with silver nitrate was explained by Brown and Gruber (1988), who found that silver nitrate crystals formed in the sections and obscured the resolution needed for detailed studies.

The choice of December 30 for the date of annulus formation is only a preliminary estimate, as marginal increments appeared to decrease from August to November, and small sample sizes during this period prevented conclusive evidence. Branstetter (1987) reached the same conclusion for an early winter annulus formation for silkies in a nearby area but also suffered from few autumn data. More samples from the months of September to January are needed to document more accurately the date of annulus formation for Gulf of Mexico silky sharks.

Back calculations of size at birth (75 cm TL) matched the reproductive data on size at birth (76 cm TL). The present value of L_{inf} = 311 cm TL is in agreement with the maximum lengths of silky sharks collected in the Campeche Bank, which are 308 cm and 314 cm TL for females and males respectively. Longevity of the species is expected to be more than the 22+ years found for the largest specimen aged in this study (a 293 cm TL female). Several vertebral samples of sharks >300 cm TL in our possession are still waiting to be processed.

Our results differ somewhat with those found by Branstetter (1987) in the Northwest Gulf of Mexico. His fit of the von Bertalanffy model produced parameter estimates with a larger k (0.153), and a lower asymptotic length (290.5 cm TL) than those of the Campeche Bank (k = 0.101; L_{inf} = 311 cm TL). Furthermore, mean lengths-at-age between studies do not match for most of the sample range; Branstetter's values are consistently larger than the ones reported here.

Various explanations could be given for the disagreements found in growth parameters (sample bias, method of fitting the VBGM, combination of both); still, the differences in lengths-at-age remain unexplained. The sample size of both studies were rather similar, but the size ranges differed. Most vertebrae used in Branstetter's study came from sharks between 100 and 210 cm TL, but in our case two major groups at 80–205 cm and 240–295 cm TL constituted most of the samples. This difference may have a considerable effect on the shape of the VBGC and thus on the parameters. One of the reasons for Branstetter's low L_{inf} value is the absence of really large sharks in his samples. His largest specimen (267 cm TL) at age 13 was younger than the four sharks 275–293 cm TL aged in our study. The inclusion of larger, older specimens in our vertebrae samples is translated into a higher value of L_{inf} and a corresponding lower k value. In fact Branstetter (p.170) noted that the substitution of a L_{inf} value of 325 cm TL (which is closer to that presented here) produced a k value of 0.11 for his data, more in agreement with our findings. Accordingly, this could be the reason behind our different VBGM parameters.

Several hypotheses can be drawn to explain the different lengths-at-age of silky sharks from the Campeche Bank and the Northwestern Gulf of Mexico. Either true variations exist, or more likely, something is producing

for allowing us to take vertebrae and measure the catches at their plants. Also fishery officers Juan Marfil, Jesus de la Rosa, and Israel Priego helped with logistics in their own ports. The Government of the State of Yucatan provided a grant for part of this project, through its Ministry of Economic Development. Juan C. Seijo gave considerable support toward making this project happen, and Julio Sanchez allowed the use of laboratory equipment essential for some of the studies. Ratana Chuenpagdee analyzed some of the data for reproduction. The British Council gave a grant to the senior author, who was allowed to complete the analytical part of this work in the U.K. Finally, Steve Branstetter and an anonymous reviewer provided very helpful comments to the original manuscript.

Literature Cited

Applegate, S.P., L. Espinosa, L. Menchaca and F. Sotelo.
1979. Tiburones Mexicanos. Subsecretaria de Educacion e Investigacion Tecnologica, Direccion General de Ciencias y Tecnologia del Mar, 146 p. (In Spanish.)

Bane, G.W. Jr.
1966. Observations on the silky shark, *Carcharhinus falciformis*, in the Gulf of Guinea. Copeia 1966:354–356.

Bass, A.J., J.D. D'Aubrey, and N. Kistnasamy.
1973. Sharks of the east coast of southern Africa. I. The genus *Carcharhinus* (Carcharhinidae). Oceanogr. Res. Inst. (Durban), Invest. Rep. 33, 168 p.

Bonfil, R.
1987. Composicion por especies de la pesqueria de tiburon y cazon de Yucatan y relaciones morfometricas para las principales especies. Instituto Nacional de la Pesca, Centro Regional de Investigacion Pesquera de Yucalpeten, Contribuciones de Investigacion Pesquera, Doc. Tec. 1:1–10. (In Spanish.)

Bonfil, R., R. Mena, y D. de Anda.
1988. El Recurso Tiburon-cazon en El sureste de Mexico. *In* Los Recursos Pesqueros del Pais. Secretaria de Pesca, Mexico, 421–439 p. (In Spanish.)

Bonfil, R., D. De Anda, and R. Mena.
1990. Shark fisheries in Mexico: the case of Yucatan as an example. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds), p. 427–441. NOAA Tech. Rep. NMFS 90.

Branstetter, S.
1987. Age, growth and reproductive biology of the silky shark, *Carcharhinus falciformis*, and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. Environ. Biol. Fish. 19 (3):161–173.
1990. Early life history implications of selected Carcharhinoid and Lamnoid sharks of the northwest Atlantic. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 17–28. NOAA Tech. Rep. NMFS. 90.

Branstetter, S., and J.D. McEachran.
1986. Age and growth of four carcharhinid sharks common to the Gulf of Mexico: a summary paper, p. 361–371. *In* Indo Pacific fish biology: proceedings of the second international conference on Indo Pacific fishes (T. Uyeno, R.T. Taniuchi, and K. Matsuura, eds.), p. 361–371. Ichthyol. Soc. Japan, Tokyo.

Brown, C.G., and S.H. Gruber.
1988. Age assessment of the lemon shark, *Negaprion brevirostris*, using tetracycline validated vertebral centra. Copeia 1988:747–753

Cadenat, J., and J. Blache.
1981. Requins de Mediterranee et d'Atlantique. Faune tropicale XXI, ORSTOM, Paris, 330 p. (In French.)

Cailliet, G.M., L.K. Martin, D. Kusher, P. Wolf, and B.A. Welden.
1983. Techniques for enhancing vertebral bands in age estimation of California elasmobranchs. NOAA Tech. Rep. NMFS 8:157–165.

Cailliet, G.M., K.G. Yudin, S. Tanaka, and T. Taniuchi.
1990. Growth characteristics of two populations of *Mustelus manazo* from Japan based upon cross-readings of vertebral bands. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 167–177. NOAA Tech. Rep. NMFS 90.

Casey, J.G., H.L. Pratt Jr., and C.E. Stillwell.
1985. Age and growth of the sandbar shark, *Carcharhinus plumbeus*, from the northwestern Atlantic. Can. J. Fish. Aquat. Sci. 42: 963–975.

Castro-Aguirre, J.L.
1967. Contribucion al estudio de los tiburones de Mexico. B.Sc. thesis, Instituto Politecnico Nacional, Mexico D.F., Mexico, 257 p.

Clark, E., and K. von Schmidt.
1965. Sharks of the central coast of Florida. Bull. Mar. Sci. 15(1):13–83.

Compagno, L.J.V.
1984. FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Parts 1 and 2. FAO Fish. Synop. 125, 655 p.

Fourmanoir, P.
1961. Requins de la cote ouest de Madagascar. Mem. Inst. Sci. Madagascar (Ser. F), 4:1–81. (In French.)

Garrick, J.A.F., R.H. Backus, and R.H. Gibbs Jr.
1964. *Carcharhinus floridanus*, the silky shark, a synonym of *C. falciformis*. Copeia 1964:369–375.

Gilbert, P.W., and G.W. Heath.
1972. The clasper-siphon sac mechanism in *Squalus acanthias* and *Mustelus canis*. Comp. Biochem. Physiol. 42A:97–119.

Gilbert, P.W., and D.A. Schlernitzauer.
1965. Placentation in the silky shark, *Carcharhinus falciformis* and bonnetshark, *Shpyrna tiburo*. Anat. Rec. 151 (3):452.
1966. The placenta and gravid uterus of *Carcharhinus falciformis*. Copeia 1966(3):451–457.

Gruber, S.H., and R.G. Stout.
1983. Biological materials for the study of age and growth in a tropical marine elasmobranch, the lemon shark, *Negaprion brevirostris* (Poey). NOAA Tech. Rep. NMFS 8:193–205.

Guitart-Manday, D.
1975. Las pesquerias pelagico-oceanicas de corto radio de accion en la region noroccidental de Cuba. Acad. de Cien. de Cuba. Ser. Oceanologica. 31, 26 p. (In Spanish.)

Hoff, T.B.
1990. Conservation and management of the western north Atlantic shark resource based on the life history strategy limitations of sandbar sharks. Ph.D. diss., Univ. Delaware, 282 p.

Natanson, L. J., and G. M. Cailliet.
1986. Reproduction and development of the Pacific angel shark, *Squatina californica*, off Santa Barbara, California. Copeia 1986:987–994.

Growth Characteristics and Estimates of Age at Maturity of Two Species of Skates (*Raja binoculata* and *Raja rhina*) from Monterey Bay, California

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ABSTRACT

Estimates of growth and age at first maturity were determined for 171 *Raja binoculata* (big skate) and 132 *R. rhina* (longnose skate) collected between 1980 and 1981 along the central California coast. Analyses of vertebral centrum edges by month of capture suggested that a translucent growth zone forms in winter and an opaque growth zone forms in summer for both species. Age estimates for *R. binoculata* (175 to 1607 mm TL) ranged between 0 and 12; those for *R. rhina* (303 to 1322 mm TL) ranged between ages 3 and 13. The logistic growth function (LGF) fit the length-at-age data for *R. binoculata* better than a von Bertalanffy growth function (VBGF). Theoretical asymptotic length (L_∞ =1678 mm TL) was slightly greater for females than that for males (L_∞ =1388 mm TL), although growth coefficients were similar (k=0.37 and 0.43, respectively). The VBGF provided the best fit for *R. rhina*; females had slightly higher theoretical asymptotic length (L_∞ =1069 mm TL) and lower coefficient (k=0.16) than males (L_∞ =952 mm TL, k=0.26). Age at reproductive maturity was estimated at age 8–11 for *R. binoculata* and age 6–9 for *R. rhina*.

Introduction

The order Rajiformes comprises over 350 species of demersal skates (Compagno et al., 1989). The relatively large size and abundance of some species make them suitable for commercial harvest (Steven, 1932; Frey, 1971; Brander, 1981; Talley, 1983). Skates off the California coast have been exploited for food since the early 1900's (Steven, 1932). Five species of skates inhabit the waters off California, and two are important to the commercial fishery: the big skate (*Raja binoculata*) and the longnose skate (*Raja rhina*) (Holts, 1988). *R. binoculata* is the largest species, growing to a length of 240 cm total length. *R. rhina* has a long snout and is considerably smaller than *R. binoculata*, with a total length of 137 cm. Both species range from Alaska to Baja California, Mexico. Most of the skates landed in California are bycatch from trawlers, trammel nets, and longlines. The pectoral fins (wings) are used in domestic ethnic markets, especially Oriental, Italian, and Yugoslavian (Talley, 1983). The skate fishery is restricted generally to the San Francisco and Monterey areas (Oliphant, 1979; Talley, 1983), and in recent years skate landings in California have fluctuated between 26 and 348 metric tons (t); the average landing for 1980–90 was 125 t.

Life-history information for most species of California skates is unavailable. Available information suggests that skates have relatively slow growth rates and low reproductive potentials. Thus, as with other elasmo-

t_0 = theoretical age at zero length.

Additionally, data were fit to the logistic growth equation:

$$Y(t) = K/\{1+[(K - Y^0)/Y^0]\ [\exp(-rt)]\}$$

where Y_t = Length at time (age) t
K = Asymptotic length
r = logistic growth coefficient
Y_0 = size at birth.

Both equations were fit using a software program, FISHPARM (Prager et al., 1987).

Results

Maturity

Raja binoculata—Between January 1980 and September 1981, 171 *Raja binoculata* were captured from Monterey Bay: 103 males (175 to 1321 mm) and 68 females (227 to 1607 mm). *R. binoculata* were captured in all months except November and December. The relationship between TL (mm) and weight (kg) was significant and curvilinear (Fig. 2).

Males appear to mature at 1000–1100 mm (Fig. 3). Males (n=38) less than 782 mm had straight vas deferens, and were staged as immature. Twenty-nine specimens (782–1086 mm) showed moderate coiling of the vas deferens, and were staged as maturing. All males larger than 1086 mm were staged as fully mature.

The analysis of maturity stages indicates that female *R. binoculata* mature at sizes greater than 1300 mm (Fig. 4). Immature females ranged from 200 to 1300 mm, and maturing specimens between 500 and 1200 mm. Specimens larger than 1300 mm were staged as mature.

Raja rhina—Between January 1980 and August 1981, 132 *Raja rhina* were captured from Monterey Bay: 64 males (359 to 1322 mm) and 68 females (303 to 1068 mm). *R. rhina* were captured during seven months, excluding May, June, September, November, and December. The relationship between TL (mm) and weight (kg) was significant and curvilinear (Fig. 5).

Males become sexually mature at 615–740 mm (Fig. 6). Males smaller than 615 mm (n=17) had straight vas deferens and were immature. Twenty-two specimens (615–740 mm), showed moderate coiling of the vas deferens and were staged as maturing. All *Raja rhina* larger than 740 mm were sexually mature.

Our analysis of the maturity stages indicates that female *R. rhina* may become sexually mature at 700 mm (Fig. 7). Although females ranging between 300 and 900 mm were immature, those between 600 and 1000 mm were maturing. All females >1000 mm were staged as sexually mature.

Age Analysis

Centrum Relationship—The centrum diameter of *R. binoculata* increased in a significant and linear fashion with TL (mm) (CD=0.29+0.008 TL, R^2=0.93: Fig 8). The translucent rings were much broader than the opaque rings (Fig. 1A). The relationship between TL (mm) and CD (mm) for both sexes combined was

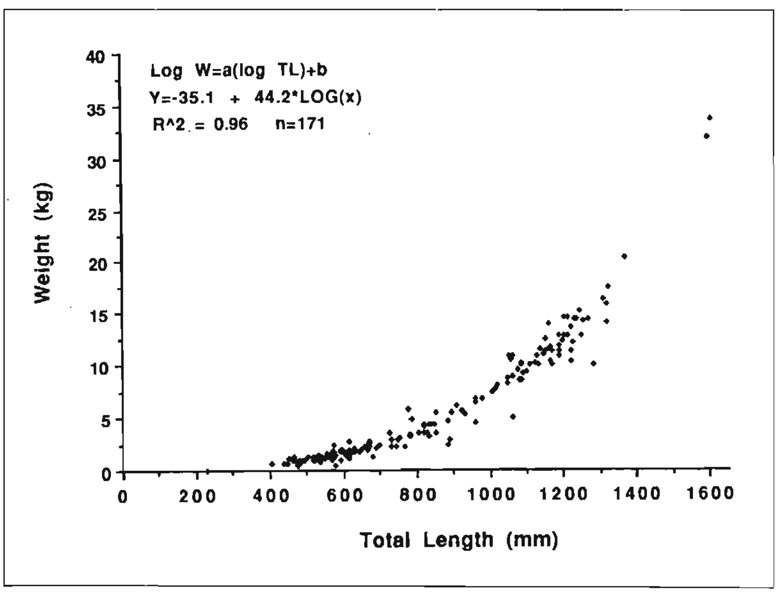


Figure 2
Relationship of weight and total length for both male and female *Raja binoculata* used in this study.

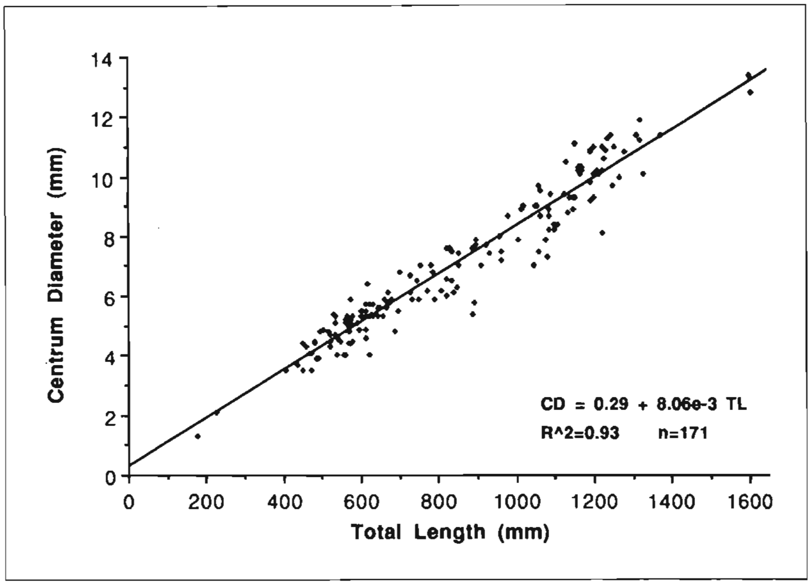


Figure 5
Relationship of weight and total length for both male and female *Raja rhina* used in this study.

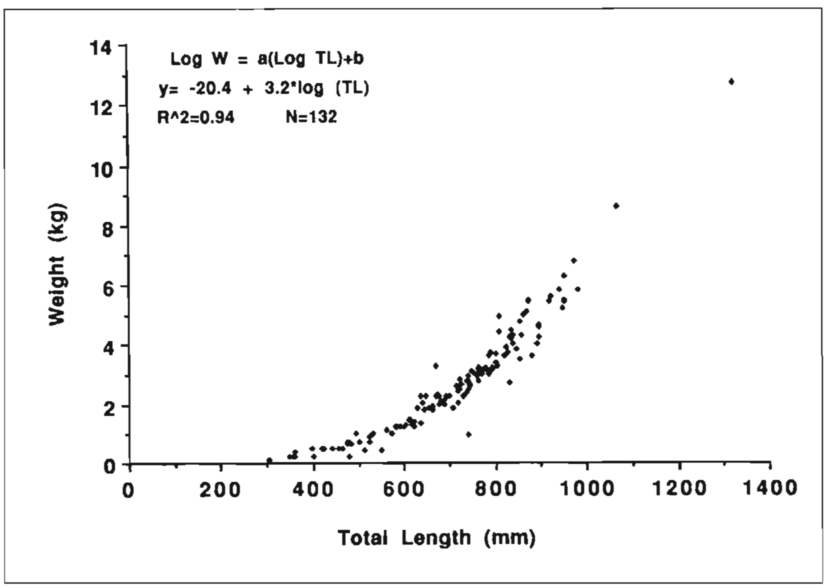


Figure 6
The relationship between total length and inner clasper length of 64 male *Raja rhina*.

significant and linear in *Raja rhina*: (CD=0.31+0.0084 TL, R^2 =0.83: Fig. 9).

Precision Analysis—Results of the precision analyses are summarized in Figures 10 and 11 for *Raja binoculata* and *R. rhina*, respectively. Average percent error (APE) and percent error (D) associated with the senior author's readings were 5% and 4%, respectively, for the former, and 4% and 3% for the latter species. Precision of age estimates between readers was relatively good and high percentages of agreement were calculated in all size classes of each species. For *R. binoculata*, 95% of the small, 100% of the medium, and 90% of the large fish had age estimates that agreed within 2 years. For *R. rhina*, 100% of the samples had counts that agreed within 2 years.

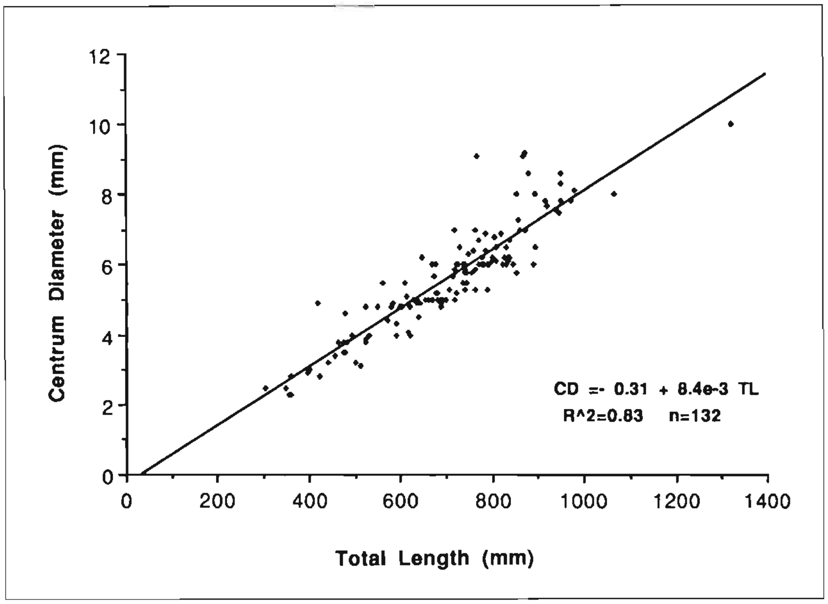


Figure 9
Relationship between total length and centrum diameter for both male and female *Raja rhina* used in this study.

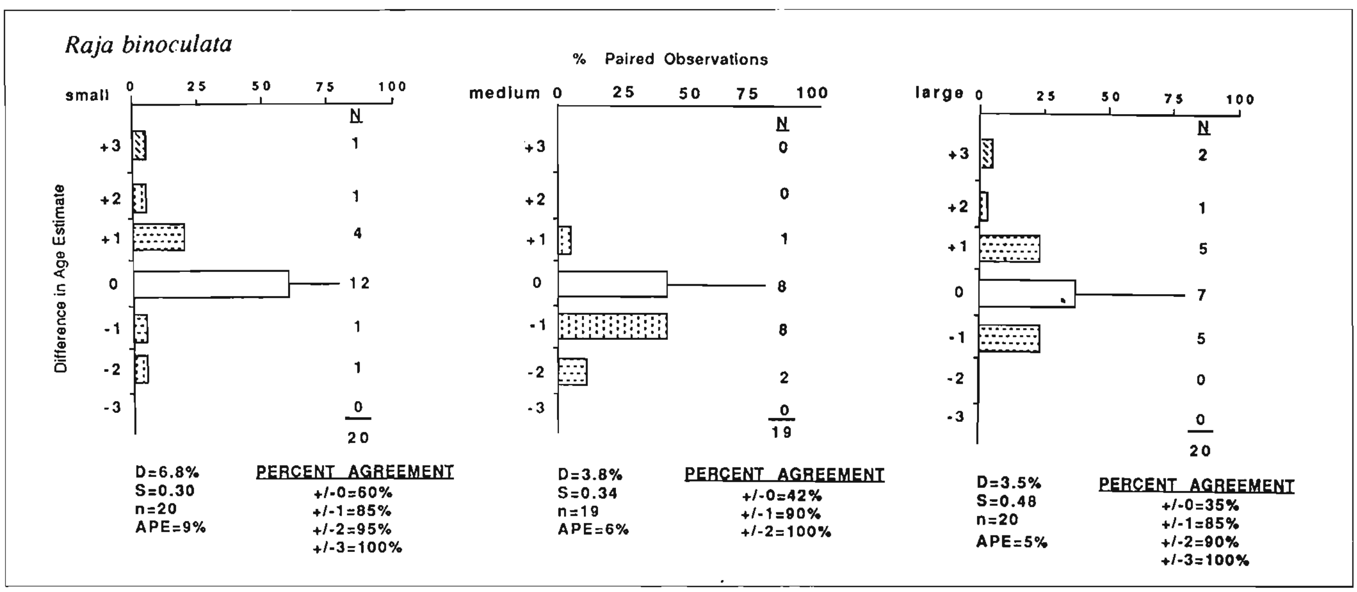


Figure 10
Precision of age determination of *Raja binoculata.* Histograms represent the difference (as the percentage of paired band counts by 0, 1, 2, and 3 years) between the two readers. The proportions of counts which agreed within a certain number of band counts are listed under "percent agreement," the symbols D, S, *n*, and APE represent Beamish and Fournier's (1981) and Chang's (1982) percent error, standard deviation, number of centra (sample size) and average percent error, respectively. *N* is the number of centra for that age estimate.

translucent rings form in the winter and opaque ones in summer. Opaque edges were found in specimens from January through August, while translucent edges were found during all months.

Age Determination

Male *Raja binoculata* that were staged as immature were estimated to be age 5 or younger. Fully mature males

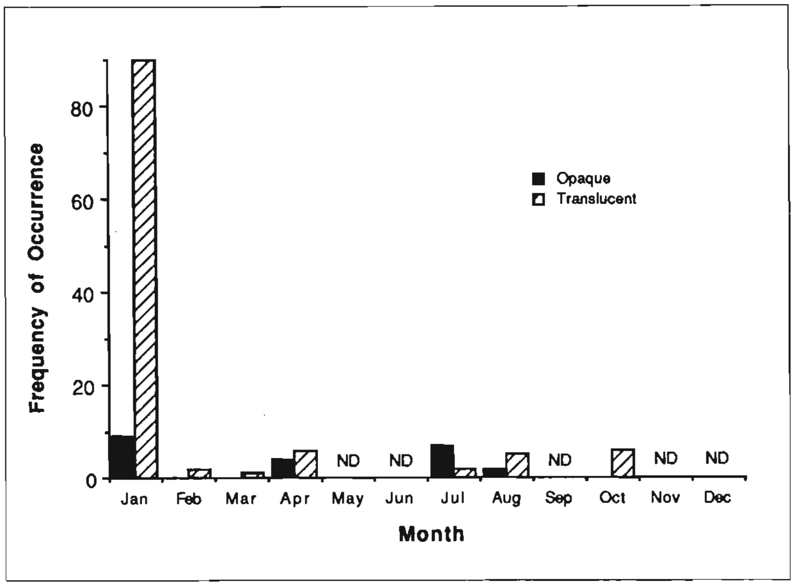
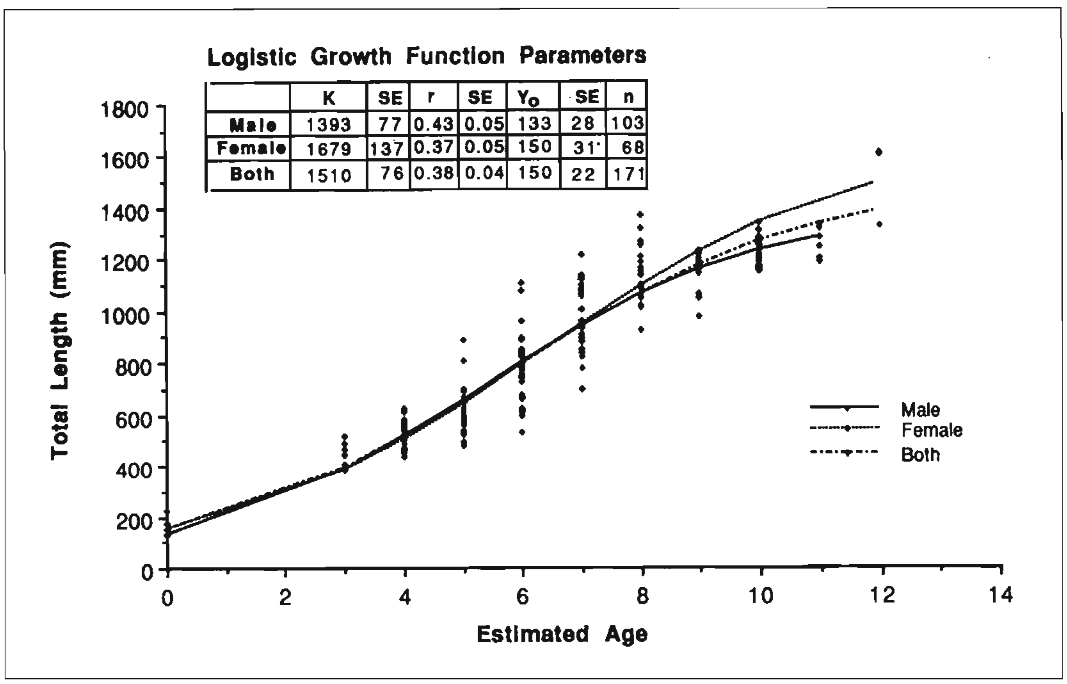


Figure 13
Seasonal changes in centrum edge characteristics of *Raja rhina*. ND=no data.



	K	SE	r	SE	Y_0	SE	n
Male	1393	77	0.43	0.05	133	28	103
Female	1679	137	0.37	0.05	150	31	68
Both	1510	76	0.38	0.04	150	22	171

Figure 14
The logistic growth curve for male, female and both sexes combined of *Raja binoculata*.

age data for *R. rhina* for males, females and both sexes combined (Fig. 15). Males ranged between age 3 (359 mm) and age 13 (1322 mm). Age 0–2 males were absent from our collections. Females ranged between age 2 (303 mm) and age 12 (1086 mm), and age 0 and 1 females were unavailable to us. There appeared to be no substantial difference in the growth parameters between males and females.

Discussion

Determination of sexual maturity in male elasmobranchs is most frequently observed by changes in relative size, and hardness and development of claspers (Pratt, 1988). Skates exhibit an abrupt transition in clasper total-length relationship upon sexual maturity, similar to other batiods (Smith and Merriner, 1987). Based on from each calendar month would probably better define the season of zonal deposition.

Factors that mediate the temporal periodicity of calcium deposition in elasmobranch centra are not known. Changes in temperature, salinity, light, and diet (Stevens, 1975), and stress-related activities such as migration (Pratt and Casey, 1983) have been suggested. For *Raja binoculata* and *R. rhina*, changes in the diet from low calcium when young to an increased calcium-rich diet when older[1], and an unloading of calcium from the plasma to the vertebrae associated with inshore migrations, or both, may be responsible for the opaque bands being deposited. Opaque edges were found in specimens captured inshore in the summer. Similarly, movement in and out of shallow water at all times of the year, and associated temperature and salinity differences may be responsible for the translucent edge found in all sample months.

The von Bertalanffy growth equation for *Raja binoculata* overestimated L_∞ for the females and underestimated the L_∞ for both sexes combined. Growth in length as shown in the logistic growth curve *R. binoculata* (Fig. 14) is fastest during the third to eighth year for males and third to tenth year for females and decreases thereafter. Females grow slower (r=0.37) yet reach a larger size (L_∞ =1679 mm) than the males (r=0.43; L_∞ =1393 mm). The growth parameters for males and females are not substantially different. The estimated asymptotic length (1510 mm) for combined sexes approximates the maximum length observed during the study (1607 mm), but underestimates the maximum reported in the literature, 2400 mm (8 feet) (Eschmeyer et al., 1983). This may be due to the limited data points for older individuals.

The growth parameters generated from the von Bertalanffy growth equation for *Raja rhina* indicate that growth is similar for both sexes (Fig. 15). However in both cases, the calculated asymptotic lengths for *Raja rhina* were smaller than the reported size for this species. The largest specimen in our study was 1322 mm, whereas the reported maximum size in the literature is 1370 mm (Miller and Lea, 1972). Calculations of L_∞ for both sexes (1047 mm) combined underestimates the maximum length (1322 mm) observed during this study and in the literature.

The growth coefficient values for *Raja binoculata* and *Raja rhina* are comparable to those reported in the literature for other skates (Holden and Vince, 1973; Waring, 1984). A comparison of the growth coefficient values from both species shows that *Raja binoculata* has a faster growth rate than *Raja rhina* and attains its asymptotic length sooner.

One must consider sample size and biases when obtaining specimens. In this study, even though the sample sizes were relatively small, the biases were real but unavoidable because specimens for these two species were obtained from commercial fishing vessels. Owing to gear selection and marketable size, a narrow size range was taken. Thus the smaller and larger size classes were underrepresented which led to underestimated L_∞ in the growth equations for both species of skates.

The age of the oldest *Raja rhina* (13, TL=1322 mm; Fig. 14) may be overestimated. False rings (rings which do not completely encircle the centra) may have been counted on this specimen, thus increasing the age estimates. Richards et al., (1963) occasionally saw false rings in the centra of *Raja eglanteria*. Waring (1984) observed checks (false rings) in *Raja erinacea* and speculated that these checks formed in response to physiological stress.

Some difficulty was encountered in estimating the age of *Raja binoculata* and *Raja rhina* because of the appearance of the first and last ring formation. Daiber (1960) and Richards et al. (1963) experienced difficulty interpreting the first ring, which varied in width depending on whether the skate was born in the spring or autumn. Brander and Palmer (1985) reported difficulties interpreting the "nucleus," the first ring, and therefore a consistent birth date for their study. In this study, centra with four to eight annuli were the easiest to read, but we found it difficult to distinguish the rings of the younger (0–3) and older (9–12) skates. Brander and Palmer (1985) stated that when growth is reduced because of food limitations, environmental conditions, or other causes, the appearance of an annulus may change; they suggested that the method of age determination may require modification.

Only by validating the growth zones can age estimates for either of these species of skates be established confidently (Beamish and McFarlane, 1983; Cailliet, 1990). Validation techniques suggested by Cailliet et al. (1986) such as laboratory grow outs, tag-recapture, and perhaps oxytetracycline labeling alone could be used in future studies to validate the age estimates for these species.

Holden (1977) questioned the idea of sustainable fisheries for elasmobranchs, basing his conclusion on the linear relationship between stock and recruitment for most elasmobranchs. According to Holts (1988), elasmobranchs are so vulnerable to over-exploitation that certain populations may continue to decline for some time even if fishing pressures were removed immediately.

Skate landings as reported in the U.S. at present are incomplete and various species are seldom distinguished

[1] Badkin, R. 1990. Food habits of two size groups of the big skate (*Raja binoculata*) occurring off the Central California Coast. Student paper. Moss Landing Marine Lab., P.O. Box 450, Moss Landing, CA 95390.

Pratt, H.L. Jr.
1988. Elasmobranch gonad structure: a description and survey. Copeia 1988:719–729.
Pratt, H.L. Jr., and J.G. Casey.
1983. Age and growth of the short fin mako, *Isurus oxyrinchus*, using four methods. Can. J. Fish. Aquat. Sci. 40:1944–1957.
Richards, S.W., D. Merriman, and L.H. Calhoun.
1963. Studies on the marine resources of southern New England. IX. The biology of the little skate *Raja erinacea* Mitchell. Bull. Bingham. Oceanogr. Coll. 18(3):4–67.
Ryland, J.S., and T.O. Ajayi.
1984. Growth and population dynamics of three *Raja* species (Batoidei) in Carmarthen Bay, British Isles. J. Cons. Cons. Int. Explor. Mer. 41:111–120.
Smith, J.W., and J.V. Merriner.
1987. Age and growth, movements and distribution of the cownose ray, *Rhinoptera bonasus* in Chesapeake Bay. Estuaries 10(2):153–164.
Steven, G.A.
1932. Rays and skates of Devon and Cornwall. II. A study of the fishery; with notes on the occurrence, migrations and habits of the species. New Series 18(1):1–33.
Stevens, J.P.
1975. Vertebral rings as a means of age determination in the blue shark *Prionace glauca* L. J. Mar. Biol. Assoc. U.K. 55:657–665.
Talley K.
1983. Skate. *In* "Pacific fishing," June 1983, p. 62–67.
Waring, G.T.
1984. Age, growth and mortality of the little skate off the Northeast Coast of the United States. Trans. Am. Fish. Soc. 113:314–321.

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