A Review of the Commercial Fisheries for Sharks on the West Coast of the United States

G. M. Cailliet[A], D. B. Holts[B], and D. Bedford[C]

[A]Moss Landing Marine Laboratories, P.O. Box 450, Moss Landing, CA 95039.
[B]Southwest Fisheries Science Center, NMFS/NOAA, P.O. Box 271, La Jolla, CA 92116-0271.
[C]California Dept of Fish and Game, 330 Golden Shore, Suite 50, Long Beach, CA 90802.

Abstract

Six species presently dominate commercial fisheries for sharks off the western United States. The oldest of these fisheries (for soupfin shark, *Galeorhinus zyopterus* [=*galeus*]) was decimated in 1944 but has persisted for the past two decades on a small scale, averaging between 150,000 and 250,000 pounds (~68-114 MT) annually. The largest (for spiny dogfish, *Squalus acanthias*) has consistently produced landings in excess of 5 million lbs (~2273 MT) annually. The blue shark (*Prionace glauca*) fishery, in operation experimentally between 1979 and 1980, now is part of a long-line operation with markets still being explored. A drift gill net and experimental long-line fishery targets on common thresher shark (*Alopias vulpinus*) and shortfin mako shark (*Isurus oxyrinchus*). Declines in catches and size composition of the common thresher fishery have required serious management actions such as time/area closures, permit limitations, and low total allowable landings. The shortfin mako shark fishery has not seriously declined, but only takes one, two and sometimes three year old sharks. Landings of Pacific angel sharks (*Squatina californica*) in a localized bottom gill net fishery peaked in 1985 and 1986 at 1.2 million lbs (~546 MT) annually, but drastically declined due to decreased availability and alternative sources of low-cost, imported shark meat. The leopard shark (*Triakis semifasciata*), another common inshore species, is fished both recreationally and commercially, with its landings fluctuating between 18,000 and 100,000 lbs (~8-46 MT) per year, but no signicant decline. Thus, total west coast shark landings increased steadily through 1985, but have since declined. Declines have occurred mainly because slow growth, low fecundity and late age at maturity make elasmobranchs vulnerable to overfishing.

Introduction

Recent fisheries for elasmobranchs along the west coast of the United States began in the late 1970s and have continued to the present (Cailliet and Bedford 1983, Holts 1988). There were early warnings that these fisheries would most likely suffer from over- exploitation during early development (Holden 1974, 1977, Cailliet and Bedford 1983). The fisheries continued to expand until problems were very evident.

Elasmobranchs have low reproductive rates due to their low fecundity, slow growth rates, and late age of maturity (Holden 1974, 1977). These qualities, along with a natural inquisitiveness and lack of fear, make them vulnerable to overfishing (Anderson 1990, Compagno 1990). After the decline of the soupfin shark (*Galeorhinus zyopterus* [= *G. galeus*, Eschmeyer et al. 1983]) fishery for vitamin A-rich liver oil in the 1940s, sharks were viewed as a resource of little value. In the late 1970s, popular interest in shark meat created new market demands. Domestic landings and imports of numerous shark species increased several fold during the last decade and have since declined (Holts 1988). Although the reasons for these variations are many, the most identifiable are market fluctuations and susceptibility of these stocks to over-exploitation.

It is now obvious that the management options taken were insufficient to prevent the predicted declines (Bedford 1987, Richards 1987, Holts 1988). Because of this, there is an increasing need for careful monitoring of exploited shark populations on the west coast to prevent stock depletion in these fisheries similar to actions now proposed for the east and gulf coasts of the United States (Hoff and Musick 1990). Two west coast shark species (common thresher, *Alopias vulpinus* and Pacific angel, *Squatina californica*) show signs of depletion and others are being harvested at near-record levels.

The purpose of this paper is to: 1) update the status of these fisheries, based upon catch data collected by the fisheries agencies for the three west-coast states and the United States National Marine Fisheries Service (National Oceanic and Atmospheric Administration); 2) describe current management strategies and regulations; and 3) propose ideas that can be used to effectively regulate elasmobranch fisheries.

General Trends in West Coast Shark Fisheries

Shark landings along the west coast of the United States increased steadily through 1985, but have since declined (Table 1, Figure 1).

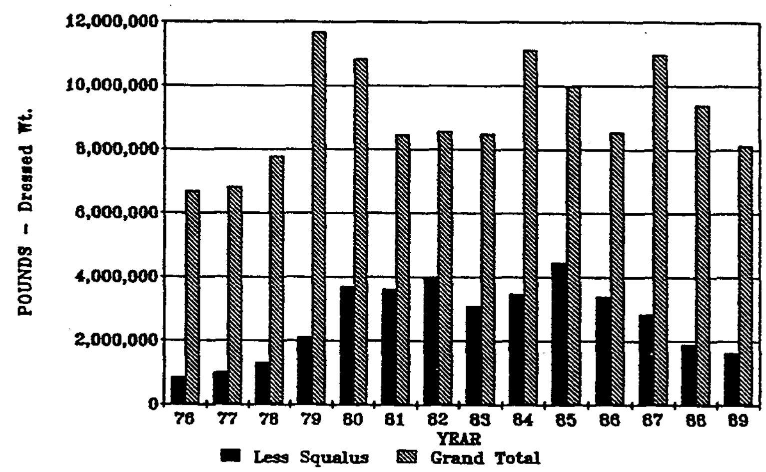

Fig. 1. Trends in annual west coast commercial shark landings (in pounds, dressed weight) from 1976 through 1989.

Early landings were almost 7 million pounds (~3,180 Metric Tons) in 1976 and 1977, followed by later peaks at approximately 11 million lbs (~5,000 MT) in four different years (1979, 1980, 1984, and 1987).

Currently, landings are about 8 million pounds (~3,636 MT). For the entire coast, these trends closely followed those of the spiny dogfish (*Squalus acanthias*), which has consistently represented the largest portion of the shark catch. The next most

Table 1. West coast commercial shark landings (in pounds) from 1976 through 1989.

Species	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976
Pacific Angel	268,252	491,348	940,187	1,241,130	1,237,810	633,250	351,344	317,953	260,031	110,022	123,652	82,383	366	690
Thresher, Bigeye	22,093	12,033	25,303	46,184	119,632	74,769	106,507	36,269	10,542	10,842				
Blue	13,621	7,270	3,907	2,850	2,356	3,940	13,983	57,838	202,898	192,130	83,966	35,904	98,365	9,928
Mako, Shortfin	388,322	489,217	612,020	456,063	215,126	244,021	322,953	527,677	275,830	155,336	35,334	27,436	19,911	2,293
Smoothhound, Brown	10,967	15,522	12,916	13,506	33,312	8,091	14,101	5,263	23,641	5,783	2,440	7,365	264	20
Thresher, Common	655,078	639,773	770,092	1,215,165	1,528,766	1,662,587	1,757,353	2,386,585	1,937,618	1,806,002	735,602	302,073	129,522	46,887
Cow	131	156	358	439	427	1,333	1,258	1,328	771	438	290	249		35
Dusky							120		196			103	202	50
Smoothhound, Grey	412	20		506	1,874	6,846	1,055	2,520		761	12,046	33,745		
Horn	32	137	53	197	363	613	485	7,541	2,286	8,465	21,055	273	1,156	6
Leopard	50,469	41,737	55,371	65,826	75,695	69,187	101,309	70,666	49,380	40,085	26,966	34,956	22,267	14,590
Thresher, Pelagic	249	772	2,294	237	640		10,923							
Salmon	351	268	255	2,252	2,016		230	996					77	
Sevengill	13	21	170	55	893	282	1,735	2,041	3,415	545		84		
Sixgill	135	20	55		4	96	128		317	12	20			
Hammerhead, Smooth	158	537	1,807	3,628	3,920	6,831	44,481	1,866	2,259		304	1,025	1,860	
Soupfin	170,834	146,595	227,690	197,164	243,661	558,280	176,155	249,070	257,348	192,119	221,840	176,070	162,166	182,390
Spiny Dogfish	6,502,244	7,498,128	8,140,022	5,153,659	5,534,759	7,653,279	5,398,472	4,593,164	4,832,581	7,141,589	9,562,516	6,476,814	5,813,829	5,831,992
Swell	4	2			20	222				163		2,795		
Great White	1,312	2,196	1,343	923	2,861	6,102	634	8,052	42	1,660	2,269			
Unspecified Shark	30,024	46,670	177,339	135,146	193,317	181,373	181,373	273,721	580,932	1,158,219	840,956	600,473	563,382	582,450
Total W.C. Sharks	8,114,701	9,392,422	10,971,182	8,534,930	9,197,452	11,111,102	8,484,599	8,542,550	8,440,087	10,824,171	11,669,256	7,781,748	6,813,367	6,671,385

abundant shark species overall in the commercial catch have been the common thresher, shortfin mako (*Isurus oxyrinchus*), Pacific angel, soupfin, blue (*Prionace glauca*) and leopard sharks (*Triakis semifasciata*).

Table 2. California commercial shark landings (in pounds)

Species	1989	1988	1987
Pacific angel	268,252	491,348	940,187
Thresher, bigeye	22,093	12,033	25,305
Blue	13,621	7,147	3,410
Mako, shortfin	388,322	489,217	612,020
Smoothound, brown	10,967	15,522	12,916
Thresher, common	649,174	536,711	525,104
Cow	131	156	358
Smoothound, grey	412	20	
Horn	32	137	53
Leopard	50,469	41,737	55,371
Thresher, Pelagic	249	772	2,294
Salmon	351	268	255
Sevengill	13	21	170
Sixgill		20	55
Hammerhead, smooth	158	537	1,807
Soupfin	166,305	140,566	201,489
Spiny Dogfish	3,430	3,789	53,935
Swell	4	2	
Great White	1,312	2,196	1,343
Unspecified shark	28,641	44,236	167,867
Total sharks	1,603,936	1,786,435	2,603,939
Skate, unspecified	168,511	127,861	169,712
Stingray		36	298

All weights are unloaded weights. Only the smoothhounds, horn and spiny dogfish are landed round weight. All others are market dressed in the field.

California shark catches, while most diverse, have shown a consistent decline in the last three years (Table 2). Landings in 1987 were 2.6 million lbs (~1,812 MT), dominated by Pacific angel, shortfin mako, and common thresher sharks. By 1989, the landings were down to 1.6 million lbs (~727 MT), and those of the common thresher dominated, with Pacific angel and shortfin mako shark catches showing significant declines. Due to the shortfin mako longline fishery, their landings subsequently increased. The soupfin shark catch has remained fairly consistent, but spiny dogfish, which were fairly common in 1987, had much lower catches during the next two years.

The commercial shark catches in Oregon were much less diverse and lower in abundance than those in California (Table 3). There has been a major decline from the 123,045 lbs (~56 MT) landed in 1987, dominated by the common thresher shark, to only 7,500 lbs (~3.4 MT) in 1989, dominated by soupfin sharks, mainly because Oregon cancelled their experimental fishery.

Table 3. Oregon commercial shark landings (in pounds)

Species	1989	1988	1987
Thresher, common	30	88,957	101,664
Sixgill	135		
Soupfin	3,265	3,029	17,511
Spiny Dogfish	698	1,110	225
Unspecified, shark	159	67	3,645
Total sharks	7,550	93,163	123,045

Off Washington there were only four species of sharks taken commercially, with the total annual catches remaining steady around 3.5 million lbs during the past three years (Table 4). Catches have always been dominated by spiny dogfish. The common thresher was commonly taken in 1987, but declined in the next two years.

Table 4. Washington commercial shark landings (in pounds).

Species	1989	1988	1987
Blue		123	497
Thresher, common	5,874	14,105	143,324
Soupfin	1,264	3,000	8,690
Spiny Dogfish	3,123,546	3,520,296	3,466,706
Unspecified, shark	1,224	2,367	5,827
Total sharks	3,131,908	3,539,891	3,624,044

The Spiny Dogfish Fishery

The spiny dogfish is one of the most abundant sharks in temperate waters around the world, and it has been an important commercial species in many areas of the world (Ketchen 1986, Hanchet 1988, Holts 1988). Over the past 13 years, catches have gone through radical changes, especially in Canadian waters (Table 5). In the middle 1970s, there was virtually no catch of spiny dogfish north of Washington, but catches have steadily increased from 1983 to the present. This has been paralleled by relatively consistent catches in Washington, which have varied from a peak year 9.4 million lbs (~4,273 MT) in 1979 to 3.1 million pounds (~1,409 MT) in 1989. Catches from Canadian waters but landed in the United States have paralled those from Washington. The catches from Oregon and California have never amounted to much (Table 5).

Table 5. Spiny dogfish landings (in pounds) in Washington, Oregon andCaliforniafrom 1976 through 1989.

	Washington			Oregon	California	Total U.S.
	WA. Waters	Can. Waters	Total WA.			West Coast
1989	3,123,546	3,374,570	6,498,116	698	3,430	6,502,244
1988	3,520,296	3,972,933	7,493,229	1,110	3,789	7,498,128
1987	3,466,706	4,619,156	8,085,862	225	53,935	8,140,022
1986	1,913,714	3,230,521	5,144,235	363	9,061	5,153,659
1985	2,837,927	2,839,863	5,677,790	290	1,002	5,679,082
1984	4,057,235	3,578,722	7,635,957		17,181	7,653,138
1983	3,915,984	1,427,956	5,343,940		54,532	5,398,472
1982	4,587,613		4,587,613		5,551	4,593,164
1981	4,542,064	275,671	4,817,735		14,846	4,832,581
1980	7,069,171	57,138	7,126,309		15,280	7,141,589
1979	9,435,004	10,000	9,445,004		117,512	9,562,516
1978	6,031,300	5,511	6,036,811		440,003	6,476,814
1977	5,428,652		5,428,652		384,177	5,812,829
1976	5,809,295		5,809,295		22,697	5,831,992

Historically, the spiny dogfish fishery has been subject to a "boom or bust" scenario (Anderson 1990). This may be due to its unique life history (Jones and Geen 1977; worldwide review in Hanchet 1988). It grows very slowly, lives a long time, has a very late age at first reproduction, low fecundity, and long gestation period, and is virtually absent from commercial fished areas for approximately the first 20 years of life. Without effort statistics, it is impossible to accurately depict what is happening to this population. However, it appears that it is commonly susceptible to overfishing, but that its longevity and absence from the fishery for much of its early life allows it to come back with vigor. Its present recovery is both a positive sign and a warning to carefully watch the north Pacific population.

The Common Thresher Shark Fishery

The drift gill net fishery for common thresher sharks began developing off the southern California coast in the late 1970s. Market demand grew rapidly and the fishery was further stimulated by the more valuable by-catch of swordfish (*Xiphias gladius*) (Cailliet and Bedford 1983, Holts 1988). Despite several attempts to limit the fishery, it grew and expanded for several years. Swordfish became the primary target species and the number of vessels grew to over 200 by 1982. Each year after 1982 brought more northern expansion, first to Morro Bay, then Monterey and San Francisco, and ultimately to Oregon and Washington.

Common thresher shark landings peaked in 1982 at 2.4 million lbs (~1,091 MT, dressed weight) and then declined (Table 1, Figure 2). The coastwide fishery for this once abundant shark is now a thing of the past. It may be many years before stocks can support the demands of commercial exploitation.

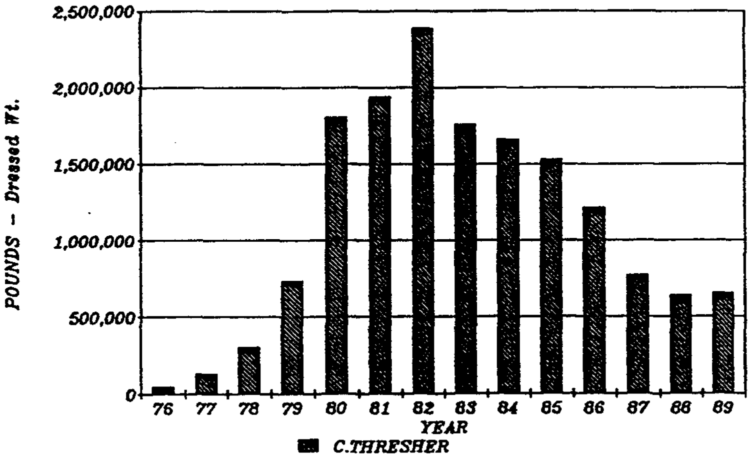

Fig. 2. Trends in annual west coast commercial common thresher (*Alopias vulpinus*) landings (in pounds, dressed weight) from 1976 through 1989.

Legislation passed in 1986 limited the directed common thresher shark fishery to 30 days during the month of May. Approximately 50 percent of the annual catch was taken during this period while the remainder was taken as a by-catch in the swordfish fishery during the fall and winter months. Small numbers of common thresher sharks were landed in Washington and Oregon during the mid-1980s, but declined drastically after 1988 (see Table 4). All directed fisheries for this species were terminated prior to the 1990 season and a tri-state management plan to limit the fishery was implemented in October, 1990. Common thresher sharks can still be taken and sold as a by-catch in the California drift gill net fishery for swordfish. While technically these sharks are not targetted during the swordfish season, nevertheless their landings are steady at about 0.6 million lbs (~273 MT) of one and two year old fish. However, only immature fish (averaging two years old) are taken (California Department of Fish and Game 1991).

The Shortfin Mako Shark Fishery

Shortfin mako (=bonito) sharks were taken primarily as an incidental but valuable by-catch in the California drift gill net fishery for swordfish and thresher shark. Only a few individuals have ever been taken off Oregon and Washington. There are a couple of good reasons why the shortfin mako shark is, only now, becoming the primary target of a commercial longline fishery. Although readily marketable, they average only 34 lbs (~15.5 kg) dressed weight off southern California, compared to the 150 lb (~68 kg) average for common threshers in the late 1970s (Cailliet and Bedford 1983). Thus, the catch from both drift gill nets and longlines has been almost entirely composed of juveniles (one, two, and three year olds: California Department of Fish and Game 1991), although some mature adults were taken. As long as the threshers were plentiful, fishermen paid little attention to the shortfin mako.

Shortfin mako drift gill net catch rates peaked at 537,000 lbs (~244 MT) in 1982, and, following the common thresher shark fishery, declined to 215,000 lbs (~98 MT) by 1985 (Table 1, Figure 3). A few longline vessels began working the southern California Bight in 1986 and 1987. Landings increased but have subsequently declined to a level below 400,000 lbs (~182 MT). It took this entirely new fishing gear to create commercial interest in the shortfin mako shark.

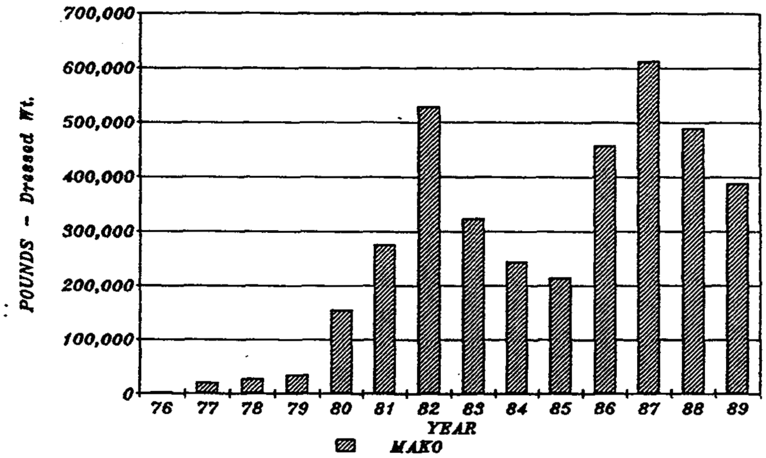

Fig. 3. Trends in annual west coast commercial bonito (= mako) shark (*Isurus oxyrinchus*) landings (in pounds, dressed weight) from 1976 through1989.

In 1988, the California Fish and Game Commission established an experimental, 10 vessel, longline shark fishery for shortfin mako and blue sharks. The gear is composed of a 3 to 4 mile (4.8 to 6.4 km) long stainless steel cable, to which leaders and baited hooks are attached. The entire cable is buoyed, at intervals of approximately 250-300 feet (75 to 90 m), so that the entire length of line remains in the near surface zone.

Continuation of this experimental fishery into 1990 required the most stringent regulations yet imposed on a shark fishery. These regulations stated that there will be: 1) only six (6) permits; 2) time/area closures away from sport fishing areas; 3) a total allowable landing quota set at 175,000 lbs (~80 MT); 4) a market developed to utilize the blue shark by-catch; and 5) a reduction of blue shark mortality. After three years, little progress has been made toward developing a market for blue shark. However, it has been demonstrated, beyond any doubt, that longlines are a potent gear for capturing mako sharks. During the first year of operation, the landings of approximately 240,000 pounds (~109 MT) were larger than the quota established later and equalled the entire "incidental catch," by the 250 vessel drift gill net fleet.

At some point during the mid-1980s, the shortfin mako shark captured the attention of the southern California sport fishing public as well. Surprisingly, prior to this time, little attention had been paid to it, even though these sharks have been long esteemed as game fish along the U.S. east coast. Between 1986 and 1989, estimates of the number of California angler trips for mako sharks grew ten fold, from 41,000 to over 410,000 trips annually. Commercial passenger fishing vessels ("party boats") now run shark fishing trips, on a regular basis, from nearly all southern California ports. The number of shortfin mako shark tournaments now takes second position, only to marlin tournaments, as southern California's most prestigious saltwater fishing event.

The experimental commercial long-line fishery was expected to continue on a year-to-year basis become California's first success at "resource stewardship" of an elasmobranch fishery. The 1990 season ended on September 30, 1990 with 175,000 lbs ((~80 MT) of shortfin mako shark landed. Blue shark mortality was reduced to near 22% and a small experimental market was established. In addition, the six permittees, in cooperation with the California Department of Fish and Game, reported tagging and releasing 600 shortfin mako sharks for distribution and abundance studies.

The shortfin mako shark population, like other oceanic sharks, is believed to be healthy, and relatively unexploited. Adults do not frequent California's coastal waters, and so are not subject to local fisheries. But a real threat to this shark population off California and elsewhere in the eastern Pacific lies in the potential for overexploitation by fisheries within the coastal "nursery" areas. This threat is particularly insidious, since the effect of over-fishing may not manifest itself for a number of years, until the missing juveniles would have themselves become the spawning stock. A sudden population collapse might follow. It appears that the lessons learned from the common thresher shark and others around the world inspired a far more conservative approach to this fishery's management, resulting in a denial by the California Fish and Game Commission for permits to continue the experimental drift longline fishery for shortfin mako sharks in 1992. In addition, in 1991 the Commission adopted specific bag limits (Section 27.60, Title 14, CCR) for the sport take of shortfin mako and five other species of sharks.

The Blue Shark Fishery

Prior to the California experimental longline fishery, the only fishery directing effort at blue sharks occurred in 1979-1980 when one longline vessel fished for blue and shortfin mako sharks off southern California (Cailliet and Bedford 1983). The greatest source of fishing mortality for blue sharks occurred from their incidental capture during the developmental years of the drift gill net fishery off southern California. Preliminary annual mortality estimates were 15,000 to 20,000 sharks during that period. Changes in gear design and time-area closures reduced this incidental take, but there are no current mortality estimates for this fishery.

Only a portion of those taken by commercial fisheries are reported (Tables 1, 2, and 4), because there is virtually no commercial use yet developed for them, and most are discarded or used for fish meal. A small percentage of blue sharks are also taken in the set net fisheries for the Pacific angel shark and California halibut (*Paralichthys californicus*).

The current experimental longline fishery off southern California averages about four blue sharks for each shortfin mako shark. The fishermen in this fishery have reduced the incidental mortality of blue sharks through the development and use of a de-hooking tool (modified fence pliers) to remove the hooks from live sharks. Permittees are required to develop a market for the blue sharks not released in the by-catch. In 1989, 9,130 pounds (~4 MT) of blue shark were sold and an additional 43,000 pounds (~20 MT) sold in the 1990 season for jerky and for "fish and chips."

The Angel Shark Set Net Fishery

A local fishery for angel sharks began developing in the Santa Barbara Channel during 1978 (Richards 1987). Initial marketing problems involved dressing the sharks at sea, which resulted in a 50% dressed landing weight of the live weight. There was an additional 50% loss at the fish market, with the net yield being 25-30%. The fishery expanded at an explosive rate as a result of more efficient processing procedures and new markets. These bottom dwelling sharks generally remain alive in the nets and small (< 42 inches or ~107 mm) individuals are returned to the sea in viable condition.

In 1985, the angel shark replaced the thresher shark as the principal food shark from southern California. Landings exceeded 1.2 million lbs (~546 MT) in both 1985 and 1986, but declined drastically by 1989 (Tables 1 and 2, Figure 4). This was a result of a combination of declining availability and alternative sources of low-cost imported shark meat.

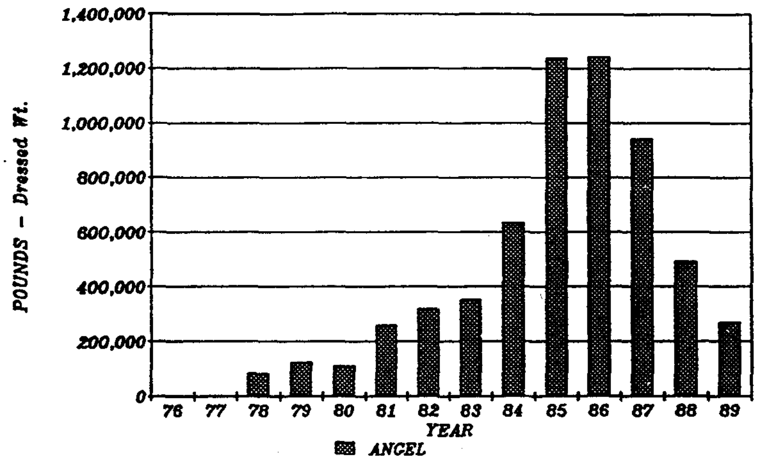

Fig. 4. Trends in annual west coast commercial angel shark (*Squatina californica*) landings (in pounds, dressed weight) from 1976 through 1989.

The most practical approach to take with this set net fishery was a minimum retention size limit, adopted in July 1988 (42 inches or 107 mm TL for females and 40 inches or 102 mm TL for males). Because the sharks caught are generally alive and hardy, release of undersized specimens would be a practical solution. Despite this management strategy, the continuation of a prosperous angel shark fishery did not occur. The major reasons for this include: 1) their lethargic and residental behavior; 2) their relatively low fecundity (Natanson and Cailliet 1986); 3) their apparently slow growth (Natanson and Cailliet 1990, Cailliet et al. 1992); 4) their demographic traits which make them susceptible to overfishing (Cailliet et al. 1992); and 5) the intensity of the set net fishery. However, as a result of Proposition 132, approved by California voters in 1990, set gill nets will not be allowed in nearshore waters, starting in 1994. Because fishermen must surrender their permits by 31 December 1993, this should effectively solve the problem of managing the Pacific angel shark fishery.

The Soupfin Shark Fishery

More than 24 million lbs (~10,909 MT) of soupfin shark were landed from California waters in the eight years ending in 1944. This fishery decimated the soupfin population. A very small but consistent set net fishery for soupfin sharks has persisted over the past couple of decades. Landings in this fishery have roughly averaged between 150,000 and 250,000 lbs (68 to 114 MT: Table 1, Figure 5). It can be and has been a target for commercial fishermen, but is most often taken incidental to other commercial species.

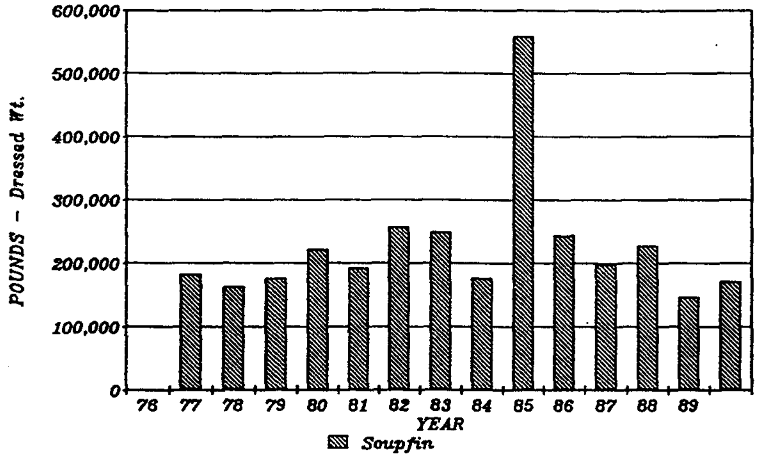

Fig. 5. Trends in annual west coast commercial soupfin shark (*Galeorhinus zyopterus [=galeus]*) landings (in pounds, dressed weight) from 1977 through 1989.

The Leopard Shark Fishery

The leopard shark (*Triakis semifasciata*), another common inshore species, is fished both recreationally, mainly by hook and line, and commercially, usually as a by-catch of other net fisheries (Smith and Abramson 1990). Its west coast landings have fluctuated from a low of 14,590 lbs (~7 MT) in 1976, to a high of over 100,000 lbs (~45 MT) in 1983 (Table 1, Figure 6).

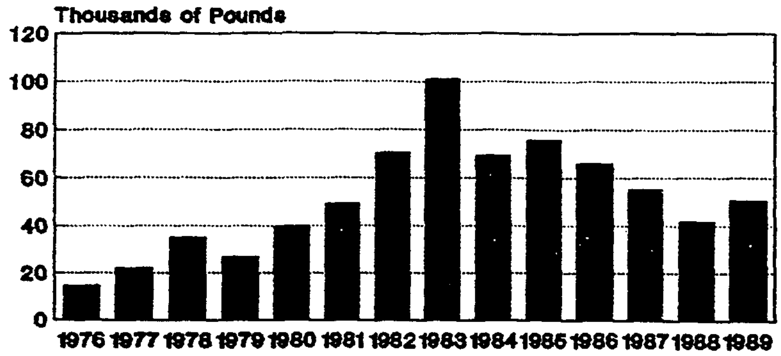

Fig. 6. Trends in annual west coast commercial leopard shark (*Triakis semifasciatus*) landings (in pounds, dressed weight) from 1977 through 1989.

Although there has been a general decline since then, there is no immediate reason for concern if growth, natural and fishing mortality, and demography estimates (Smith and Abramson 1990; Kusher et al. 1992; Cailliet 1992) are correct. Even so, the California Fish and Game Commission in 1991 adopted a minimum size (36 inches or 981 mm TL) and a bag limit (three per fisherman) for recreational anglers.

Management Strategies for Elasmobranch Fisheries

It is a tragedy of unsound resource management that it took an obvious decline in fishing success for both common thresher and angel sharks in California to finally prompt the state to adopt serious regulations. Unfortunately, throughout the history of shark fisheries, this is a common mistake, repeated again and again. Resource managers need to understand more basically the unique limitations imposed by the life histories of sharks and rays, so they can convince those who make and enforce the regulations that such fisheries need to be seriously limited.

Several recent actions in California and the other western U.S. states are promising. The initiation of the experimental longline fishery in 1990 for shortfin mako and blue sharks was accompanied by the strict regulations already described, including a limited number of permits, time/area closures away from sport fishing areas, a landings quota, development of a market for the blue shark by-catch, and a reduction of blue shark mortality. The California Fish and Game Commission's authority to authorize experimental fisheries was given to it by the legislature and intended to develop new fisheries, either by gear or species target changes. Experimental fisheries were never intended to perpetuate limited commercial fisheries. At some point, each experiment is declared a success or failure. If it is characterized as a success, the legislature can authorize a new commercial fishery. As mentioned, the experimental longline fishery for shortfin mako sharks was closed in 1992.

Also, approval of Proposition 132 in November, 1990 will limit the use of set gill nets inside three miles of the California coast and will consequently affect the fisheries for (and thus landings of) soupfin, Pacific angel and leopard sharks. Common thresher, blue, shortfin mako, and soupfin sharks, caught by drift gill nets, will not be affected by this law.

Management options in general for elasmobranch fisheries include:

1) no restrictions at all (ultimately an economic solution);

2) limited entry of fishermen and vessels into the fishery;

3) size limits; 3) bag limits;

4) closed areas and/or seasons;

5) quotas;

6) gear restrictions; and/or

7) closure or total shutdown of the fishery.

All of these measures have advantages and disadvantages relative to the particular fisheries in question.

Having no restrictions at all leads to the rapid decline of most elasmobranch populations, resulting in a wide-scale decimation of some major predator populations and possibly altering the ecosystems in which they operate. This option, although apparently the one most often used, is not a viable alternative.

Limited entry is a viable option if the fishery has not already developed a large fleet. Unfortunately, once the threat to a fishery is evident, it is usually too late to limit the number of fishermen or vessels allowed to use the resource. This approach is costly, both monetarily and legally, and should be considered only if all other possible approaches prove ineffective.

Size limits are valuable in that they can influence the age at entry into fishery, and thus have a major impact on the proportion of reproductively viable individuals subject to fishing mortality. This approach requires valid life history information such as age (Cailliet 1990, Cailliet et al. 1986), growth (Cailliet and Tanaka 1990), age composition, age-specific mortality, age-at-maturity, and age-specific natality (Pratt and Otake, 1990), which often provides demographic information (Cailliet 1992, Cailliet et al. 1992). These approaches are often costly and have not been used on many elasmobranch species, mainly because the life history information is unavailable (Cailliet 1990). Also, some gears (i.e. drift gill nets) do not allow for the live release of undersized fish.

However, with this information, fishery regulations can insure, either via logistic, dynamic pool, or demographic models (Hoenig and Gruber 1990), the continued stable existence of a fished stock. Unfortunately, this approach has only been used on a few elasmobranchs which support fisheries (Jones and Geen 1977, Grant et al. 1979, Ketchen 1986, Anderson 1990, Smith and Abramson 1990, Cailliet 1992, Cailliet et al. 1992).

Catch limits basically are strongly tied to the number of fishermen utilizing the resource. This approach also requires detailed life history information, especially good estimates of population size, and therefore can be expensive. It is very difficult to enforce and is used primarily in sport fisheries. In fact, as mentioned earlier, the California Fish and Game Commission in 1991 adopted specific bag limits for the sport take of shortfin mako, along with thresher, soupfin, sixgill (*Hexanchus griseus*), sevengill (*Notorhynchus cepedianus*) and leopard sharks.

Closed areas and seasons have been used with some success in California shark fisheries (Bedford 1987, Richards 1987, Holts 1988). This is usually the most successful when movement patterns or important life processes (reproduction, spawning, larval or juvenile growth, feeding, etc.) occur in a specific place at a specific time, and the fishery can be directed away from these. In most cases, however, these details are not well known for elasmobranch fishes subject to fishing pressure.

Quotas are another management approach and these have been used in only one shark fishery, the shortfin mako, in which a new gear was being used and evaluated. It is too early to determine whether this approach has been successful. To set quotas, a great deal of knowledge of the life history of the species involved is required. This approach has been used extensively for northeast Pacific fisheries to regulate groundfish catches. It often involves some equation, based upon maximum or optimum sustainable yield (MSY or OSY) estimates from extensive catch data collection and analysis, which leads to the total allowable catch (TAC) and can be revised from year to year, depending on future catch statistics. The use of fisheries models on elasmobranch populations is reviewed by Anderson (1990).

The final two approaches, gear restrictions and closure or shutdown of a fishery, may be the only viable one for some elasmobranch fisheries. It is hoped, however, that intelligent data gathering and decision making will occur prior to implementating these radical solutions.

Acknowledgements

This paper is the result of a long-standing relationship among the authors in which there is a continual exchange of information between those involved in doing basic research on elasmobranch fishes and those involved in monitoring the catches and suggesting solutions to problems. Linda K. Martin, Mary Nishimoto, Diana Watters, and Mary Yoklavich read the manuscript, provided comments, and helped with graphics. We wish to thank John West for his invitation to present this information at the Sharks Down Under conference, sponsored by the Taronga Zoo in Sydney, Australia. The work represented in this review was partially the result of research sponsored by the National Oceanic and Atmospheric Administration, National Sea Grant College Program, Department of Commerce, under grant numbers R/F-81 and R/5-84 through the California Sea Grant College Program, and in part by the California State Resources Agency, project numbers R/F-81 and R/F-84. The U. S. Government is authorized to produce and distribute reprints for governmental purposes.

References

Anderson, E. D. (1990). Fishery models as applied to elasmobranch fisheries. In 'Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries'. (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi.). pp. 473-484. (United States Department of Commerce, NOAA Technical Report 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' (Ed S. Cook.), pp. 161-171. (Oregon State University Sea Grant Publication, Corvallis, Oregon).

Cailliet, G. M. (1990). Elasmobranch age determination and verification: an updated review. In 'Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries' (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi.) pp. 157-65. (United States Department of Commerce, NOAA Technical Report NMFS 90).

Cailliet, G. M. (1992). Demography of the central California popoulation of leopard shark, (*Triakis semifasciata*). Australian Journal of Marine and Freshwater Research, 43,183-93.

Cailliet, G. M., and Bedford, D. W. (1983). The biological of three pelagic sharks from California waters, and their emerging fisheries: a review. California Cooperative Oceanic Fisheries Investigations, Report 24, 57-69.

Cailliet, G. M., H. F. Mollet, G. G. Pittenger, D. Bedford, and L. J. Natanson. (1992). Growth and demography of the Pacific angel shark (*Squatina californica*), based upon tag returns off California. Australian Journal of Marine and Freshwater Research 43, In Press.

Cailliet, G. M., Radtke, R. L., and Welden, B. A. (1986). Elasmobranch age determination and verification: a review. In 'Indo-Pacific Fish Biology: Proceedings of the Second International Conference on Indo-Pacific Fishes'. (Eds T. Uyeno, R. Arai, T. Taniuchi, and K. Matsuura). pp. 345-360. (Ichthyological Society of Japan, Tokyo).

Cailliet, G. M., and Tanaka, S. (1990). Recommendations for research needed to better understand the age and growth of elasmobranchs. In 'Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries' (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi) pp. 505-07. (United States Department of Commerce, NOAA Technical Report NMFS 90).

California Department of Fish and Game (1991). Review of some California fisheries for 1991. California Cooperative Oceanic Fisheries Investigations, Reports 30, 17.

Compagno, L. J. V. (1990). Shark exploitation and conservation. In 'Elasmobranchs as living resources: advances in the biology, ecology, systematis, and the status of the fisheries'. (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi.). pp. 391-414. (United States Department of Commerce, NOAA Technical Report NMFS 90).

Eschmeyer, W. N., Herald, E. S., and Hammann, H. (1983). 'Pacific coast fishes of North America'. (Houghton Mifflin Company, Boston, Massachusetts).

Grant, C. J., Sandland, R. L., and Olsen, A. M. (1979). Estimation of growth, mortality and yield per recruit of the Australian school shark, Galeorhinus australis (Macleay), from tag recoveries. Australian Journal of Marine and Freshwater Research 30, 625-37.

Hanchet, S. (1988). Reproductive biology of *Squalus acanthias* fromthe east coast, South Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 22, 537-549.

Hoenig, J. M., and Gruber, S. H. (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'. (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi). pp. 1-16. (United States Department of Commerce, NOAA Technical Report NMFS 90.

Hoff, T. B. and Musick, J. A. (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'. (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi). pp. 455-72. (United States Department of Commerce, NOAA Technical Report NMFS 90).

Holden, M. J. (1974). Problems in the rational exploitation of elasmobranch populations and some suggested solutions. In 'Sea Fisheries Research.' (Ed F. R. Harden-Jones) pp. 117-137. (John Wiley and Sons, New York).

Holden, M. J. (1977). Elasmobranchs. Chapter 9 In 'Fish Population Dynamics (Ed J.A. Gulland). pp. 187-215. (John Wiley and Sons, New York).

Holts, D. (1988). Review of U. S. west coast commercial shark fisheries. Marine Fisheries Review 50(1), 1-8.

Jones, B. C. and Geen, G. H. (1977). Reproduction and embryonic development of spiny dogfish (Squalus acanthias) in the Strait of Georgia, British Columbia. Journal of the Fisheries Research Board of Canada 34, 1286-92.

Ketchen, K. S. (1986). The spiny dogfish (*Squalus acanthias*) in the northeast Pacific and a history of its utilization. Canadian Special Publication in Fisheries and Aquatic Science, 88, 1-78.

Kusher, D. I., S. E. Smith, and G. M. Cailliet. (1992). Validated age and growth of the leopard shark, *Triakis semifasciata*, with comments on reproduction. Environmental Biology of Fishes, 35, 187-203.

Natanson, L. J., and Cailliet, G. M. (1986). Reproduction and development of the Pacific angel shark, *Squatina californica*, off Santa Barbara, California. Copeia 1986 (4), 987-994.

Natanson, L. J., and Cailliet, G. M. (1990). Vertebral growth zone deposition in Pacific angel sharks. Copeia 1990 (4), 1133-1145.

Pratt, H. L., Jr. and Otake, T. (1990). Recommendations for work needed to increase our knowledge of reproduction relative to fishery management. In 'Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries'. (Eds H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi). pp 509-10. (United States Department of Commerce, NOAA Technical Report NMFS 90).

Richards, J. B. (1987). Developing a localized fishery: the Pacific angel shark. In 'Sharks: an inquiry into biology, behavior, fisheries, and use' (Ed S. Cook). pp. 147-160. (Oregon State University Sea Grant Publication, Corvallis, Oregon).

Smith, S. E., and Abramson, N. J. (1990). Leopard shark *Triakis semifasciata* distribution, mortality rate, yield, and stock replenishment estimates based on a tagging study in San Francisco Bay. Fishery Bulletin, U. S. 88, 371-81.