Central Pacific Swordfish, *Xiphias gladius*, Fishery Development, Biology, and Research

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ABSTRACT

The development of the Hawaii longline fishery for swordfish, *Xiphias gladius*, in the central North Pacific, which began in 1988, is described. Swordfish landings in the Hawaii fishery reached 6,000 metric tons in 1993. To put the Hawaii fishery in perspective, swordfish fisheries and their production in the Pacific and the world are reviewed, along with swordfish biology and stock dynamics information from the Pacific and Atlantic Oceans. The fishery monitoring and research strategies of the Honolulu Laboratory are described, and potential avenues for collaboration are suggested.

Introduction

Prior to 1988, swordfish, *Xiphias gladius*, was an incidental component of the Hawaii longline fishery targeted on tuna. The fishery for swordfish expanded rapidly in 1990 and 1991 until swordfish contributed 51% of longline landings by weight and 50% by revenue (Ito[1]). The Hawaii longline fishery thus became the single largest swordfish fishery in the central-eastern Pacific (Skillman et al., 1993). A few boats based in California and Alaska have also participated in the central Pacific swordfish longline fishery. The rapid increase in the Hawaii fishery and the perception based on events in the western Atlantic fishery (Beardsley, 1978; Miyake and Rey, 1989) that the species is more sensitive to exploitation than other large pelagic fishes (e.g., most tunas) has led to concerns for the long-term stability of the Hawaii fishery and the status of the resource in the central Pacific (WPRFMC[2]).

This paper provides an overview of swordfish fisheries with emphasis on the development of the Hawaii fishery, a review of swordfish biology and stock dynamics, and a description of monitoring activities and stock assessment and research strategies at the National Marine Fisheries Service (NMFS) Honolulu Laboratory.

Swordfish Fisheries

Global

Evidence of the harvesting of swordfish dates to 3,000–4,000 B.C. in Japan (Ueyanagi, 1974) and to Aristotle's time (384–322 B.C.) in the Mediterranean (Berkeley, 1989). Commercial harpoon fishing for swordfish began off the northeast coast of North America by the 1870's (Berkeley, 1989); the harpoon fishery in California began in the early 1900's (Beardsley, 1978). Drift gill nets have today largely displaced the use of harpoons in coastal fisheries, including off California (Hanan et al., 1993). High-seas fishing for swordfish began in the early 1950's when the Japanese longline fleet began seasonal targeting in the northwest Pacific (Yamanaka, 1958). Today, subsurface longline gear remains the dominant gear for harvesting swordfish on the high seas, though much of the take is a bycatch of tuna fishing. In addition, minor catches occurred in

[1] Ito, R. Y. 1992. Western Pacific pelagic fisheries in 1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-92-15, 38 p. Honolulu Lab., Southwest Fish. Sci. Cent., NMFS, Honolulu, HI 96822-2396.

[2] Western Pacific Regional Fishery Management Council (WPRFMC). 1993. Amendment 7 to the Fishery Management Plan for the Pacific Fisheries of the Western Pacific. Western Pac. Reg. Fish. Manage. Counc., 1164 Bishop St., Rm. 1405, Honolulu, HI 96813.

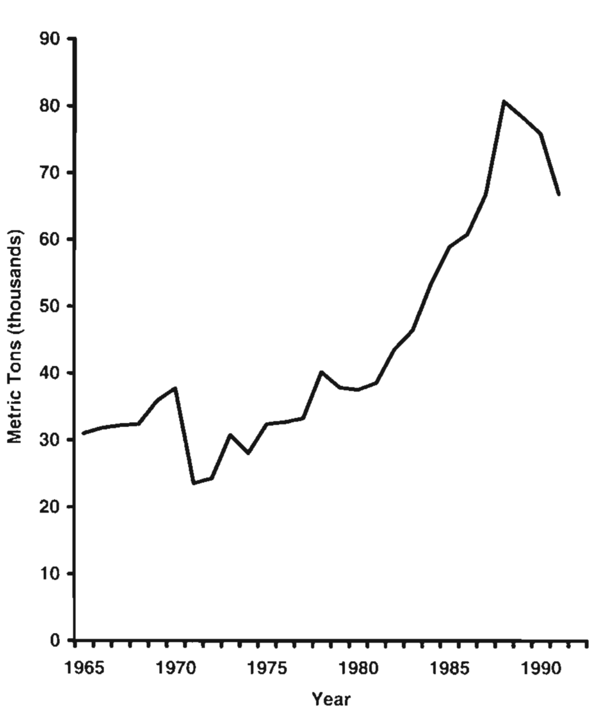

Figure 1
World swordfish landings (FAO, 1993).

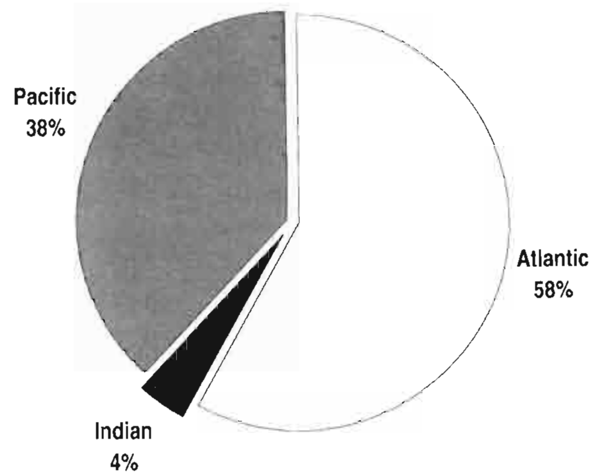

Figure 2
Swordfish landings by ocean in 1990 (FAO electronic database).

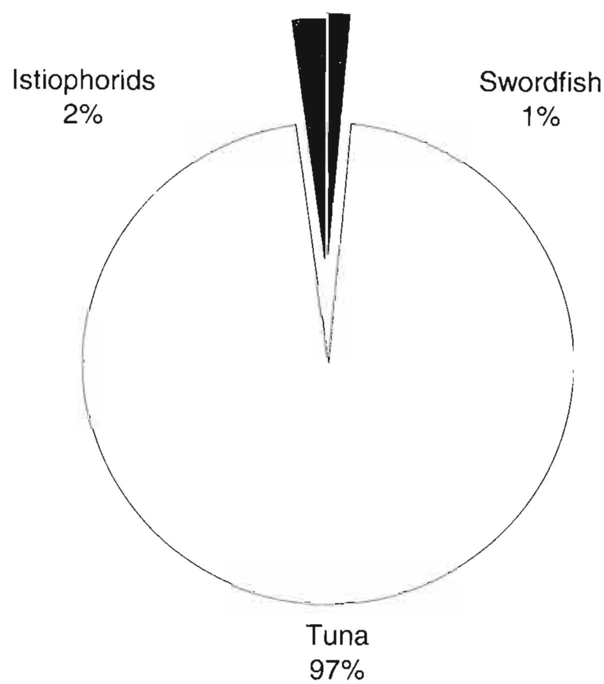

Figure 3
Catch composition of large pelagic species in the Pacific in 1990 (FAO electronic database).

the high-seas driftnet fisheries in the central North Pacific, which ceased at the end of 1992. World catches of swordfish remained fairly steady during 1965-80 at around 30,000 metric tons (t) and then increased through 1988 to a high of 81,000 t (Fig. 1). Reported landings declined during 1990–91 for the first time since 1979.

Pacific

Although the Pacific Ocean is approximately twice the size of the Atlantic Ocean, Pacific landings of swordfish in 1990 made up only 38% of the reported world catch (Fig. 2) or approximately 29,000 t (FAO, 1993). The 1990 reported catch in the Atlantic, including the Mediterranean Sea, was about 45,000 t and in the Indian Ocean only 3,000 t.

In the Pacific, 1990 swordfish landings accounted for only 1.3% of the harvest of large pelagic finfish (Fig. 3). The fishery for tuna was by far the largest at 2,155,000 t, while landings of Istiophorid billfishes at nearly 53,000 t were almost double the swordfish landings. However, there were more landings of swordfish in 1990 than of Indo-Pacific blue marlin, *Makaira mazara*, the Istiophorid with the most landings (22,000 t). The Japanese fishery (conprised of pelagic longline, driftnet, set net, and, in the early years, harpoon) accounted for 90% or more of landings in the Pacific during 1952–60 (Fig. 4). While Japanese landings, primarily from tuna longline operations, remained relatively stable after 1960, their pro-

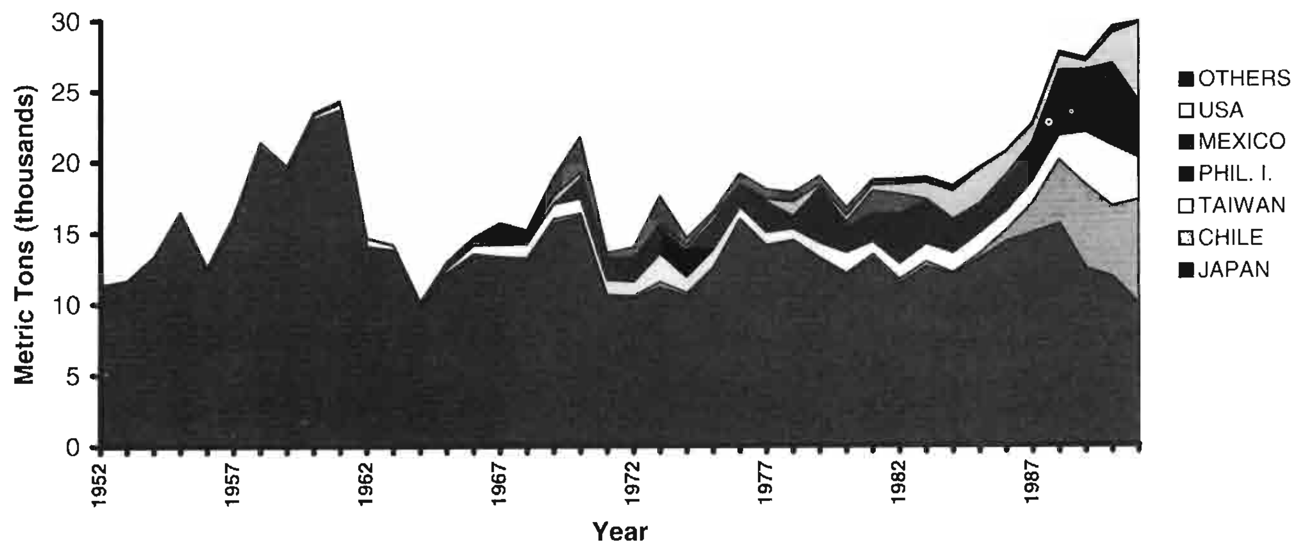

Figure 4
Area plot of Pacific Ocean swordfish catches by country, 1952–91 (FAO electronic database).

portion of the total catch declined to 40% by 1990 with the addition of other, primarily coastal, fisheries targeting swordfish. With the growth of these other fisheries, total Pacific landings since 1988 have surpassed the previous high established by the Japanese fishery in 1961. While the United States (U.S.) fishery has grown, particularly after 1982, it accounted for more than 10% of the total Pacific catch only three times through 1991 (Table 1), the most current year of summary statistics.[3]

In the central-eastern Pacific FAO statistical areas 67 and 77 (Fig. 5), Japan also dominated the fishery in the early years, accounting for >85% of the reported landings through 1979 (Table 2). The Japanese longline fishery probably was responsible for the majority of these landings, given that the large-mesh driftnet fishery targeting billfishes and tunas operated primarily in the western Pacific and generally accounted for <10% of the Pacific swordfish landings reported by Japan (Ueyanagi et al., 1989). While landings by Taiwan ranked third highest in the entire Pacific, their longline landings in the central-eastern Pacific have been less significant; those by Korea were even smaller. After 1979, landings from the driftnet fisheries based in Mexico and California increased substantially, while landings by Japan, Korea, and Taiwan remained fairly steady. Large landings in the California and Mexico fisheries have tended to occur in alternate years, possibly in response to the effects of El Niño episodes (Fig. 6). For example, while California and Mexico accounted for about 35% of the central-eastern Pacific swordfish harvests from 1981 to 1990, California's landings were half the size of Mexico's landings in 1982, 4 times larger in 1986, and one-tenth as large in 1990.

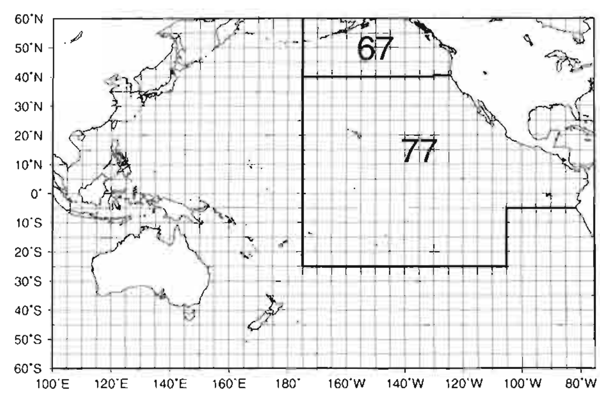

Figure 5
FAO fishery statistical areas 67 and 77 in the central-eastern Pacific.

The high-seas longline fisheries have operated throughout much of the Pacific; this has been particularly true of the Japanese fishery (Fig. 7). Species targeting in this fishery has changed over the years, which accounts for some of the change in the distribution of

[3] Hawaii landings accounted for >10% of total Pacific landings in 1992–95.

effort. Of course, species targeting varies seasonally as well. Korean longline fishing effort was initially concentrated in the central South Pacific in association with the albacore fishery and later spread progressively into the equatorial zone, extending to the coast of Central America and into the central North Pacific (Fig. 8) because of targeting on other tuna species. Taiwanese longline fishing effort was also initially concentrated in the South Pacific in association with the albacore fishery (Fig. 9) and later spread west to Australia, along the equator, and into the central and western North Pacific.

Hawaii

The Hawaii swordfish fishery developed along with the introduction of longline fishing technology from the Atlantic Ocean in 1989. Monofilament main line replaced the fiber rope used in tuna longline gear, and hydraulic reels replaced specialized line haulers. Squid replaced finfishes as bait, consistent with the known diet of adult swordfish, although finfishes are a significant portion of the diet (Palko et al., 1981). In addition, light sticks were added to the hook droppers to improve the swordfish catch.

Table 1

Pacific Ocean landings of swordfish in metric tons, 1952–91. "Others" includes Ecuador, French Polynesia, Korea, Peru, and Tonga. From Bartoo and Coan (1989), updated using FAO's electronic database and FAO (1993). See Table 2 for updates of U.S. data.

Year	Japan	Chile	Taiwan	Philippines	Mexico	USA	Others	Total
1952	11,182					157	0	11,339
1953	11,604					85	0	11,689
1954	13,301		77			14	0	13,392
1955	16,220		185			80	0	16,485
1956	12,167		254			163	0	12,584
1957	15,771		250			222	0	16,243
1958	20,815		247			279	0	21,341
1959	19,136		262			265	0	19,663
1960	22,944		273			192	0	23,409
1961	23,636		432			218	0	24,286
1962	14,037		544			23	0	14,604
1963	13,775		300			58	0	14,133
1964	9,703		300			109	0	10,112
1965	11,955	200	300			194	300	12,949
1966	13,283	200	600			277	241	14,601
1967	13,083	200	838			181	1,347	15,649
1968	12,983	200	974			118	855	15,230
1969	15,612	300	1,023			610	1,289	18,934
1970	16,100	200	1,053	1,400	0	400	2,515	21,768
1971	10,400	200	1,033	1,500	0	100	315	13,548
1972	10,400	100	1,005	1,600	2	100	715	13,922
1973	11,100	400	1,987	1,700	4	300	2,015	17,506
1974	10,498	218	1,116	1,848	6	295	585	14,566
1975	12,361	137	1,239	1,976	0	393	273	16,379
1976	15,843	13	856	1,558	0	39	739	19,048
1977	13,997	32	902	2,103	0	220	685	17,939
1978	14,333	56	779	890	0	1,009	634	17,701
1979	13,091	40	1,060	3,845	7	249	553	18,845
1980	11,953	104	1,459	1,716	380	489	545	16,646
1981	13,078	294	909	1,940	1,575	443	348	18,587
1982	11,350	285	1,107	3,468	1,365	726	348	18,649
1983	12,511	342	1,268	2,974	120	1,195	360	18,770
1984	11,986	103	1,387	2,274	47	2,009	352	18,158
1985	13,083	342	1,429	2,036	18	2,370	148	19,426
1986	14,271	764	1,357	2,089	422	1,585	70	20,558
1987	14,867	2,059	1,540	2,137	550	1,221	194	22,568
1988	15,496	4,455	1,690	4,034	613	1,086	245	27,619
1989	12,367	5,824	3,692	3,756	690	588	263	27,180
1990	11,767	4,955	4,217	3,187	2,650	2,150	474	29,400
1991	9,889	7,255	2,933	3,139	861	5,526	151	29,754

Table 2

Central-eastern Pacific swordfish catches in metric tons, 1950–93. "Others" includes Korea, French Polynesia, and Tonga. Non-U.S. data from Bartoo and Coan (1989), updated using FAO statistics for areas 67 and 77 (FAO, 1993). Data for Hawaii from SWFSC,[1] Hamm and Kassman,[2] Hamm and Quach,[3] Ito,[4] and WPRFMC[5,6] and for the U.S. west coast from NMFS Southwest Region summaries of Pacific Fishery Information Network data.

Year	Japan	Taiwan	Mexico	U.S. west coast	Hawaii	Others	Total
1950					13		
1951					17		
1952				157	12		157
1953				85	5		85
1954				14	5		14
1955				80	17		80
1956				163	13		163
1957				222	13		222
1958				279	12		279
1959				265	9		265
1960				192	13		192
1961				218	10		218
1962				23	12		23
1963				58	10		58
1964	5,500		0	109	11		5,609
1965	2,700	0	0	194	8		2,894
1966	2,800		0	277	7		3,077
1967	1,900	0	0	181	6		2,081
1968	2,600	0	0	118	5		2,718
1969	4,400	0	0	610	6		5,010
1970	5,600	100	0	400	5		6,100
1971	2,700	0	0	100	1		2,800
1972	3,400	100	2	100			3,602
1973	4,100	100	4	300	0		4,504
1974	2,330	183	6	295	0		2,814
1975	2,139	165	0	393			2,697
1976	3,591	36	0	39	2	242	3,910
1977	2,743	113	0	220	19	140	3,235
1978	2,615	108	0	1,009	14	29	3,775
1979	2,735	181	7	249	12	43	3,227
1980	3,299	117	380	489	15	23	4,323
1981	3,381	105	1,575	443	9	38	5,551
1982	2,666	85	1,365	726	18	98	4,958
1983	2,654	131	120	1,195	16	94	4,210
1984	2,589	133	47	2,009	10	51	4,839
1985	2,578	137	18	2,370	5	54	5,162
1986	2,792	130	422	1,585	7	23	4,959
1987	3,917	150	550	1,176	45	92	5,930
1988	4,123	160	613	1,041	45	68	6,050
1989	3,566	400	690	316	272	58	5,302
1990	3,556	460	2,650	245	1,905	70	8,886
1991				1,029	4,497		
1992				1,548	5,735		
1993				1,743	6,124		

1 Southwest Fisheries Science Center (SWFSC). 1993. Annual and average monthly trends in catch of large pelagic species in Hawaii, 1949–78. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., SWFSC Honolulu Lab. Admin. Rep. H-83-24, 74 p. SWFSC, 2570 Dole St., Honolulu, HI 96822-2396.

2 Hamm, D. C., and T. T. Kassman. 1986. Fishery statistics of the western Pacific, vol. 1. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-86-04, p. var. Available from SWFSC, 2570 Dole St., Honolulu, HI 96822-2396.

3 Hamm, D. C., and M. M. Quach. 1988. Fishery statistics of the western Pacific, vol. 3. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. H-88-04, p. var. Available from SWFSC, 2570 Dole St., Honolulu, HI 96822-2396.

4 Ito, R. Y. 1992. Western Pacific pelagic fisheries in 1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-92-15, 38 p. Honolulu Lab., SWFSC, NMFS, 2570 Dole St., Honolulu, HI 96822-2296.

5 Western Pacific Regional Fishery Management Council (WPRFMC). 1993. Pelagic fisheries of the Western Pacific Region 1992 annual report. Western Pac. Reg. Fish. Manage. Counc., 1164 Bishop St., Rm. 1405, Honolulu, HI 96813.

6 Western Pacific Regional Fishery Management Council (WPRFMC). 1994. Pelagic fisheries of the Western Pacific Region 1993 annual report. Western Pac. Reg. Fish. Manage. Counc., 1164 Bishop St., Rm. 1405, Honolulu, HI 96813.

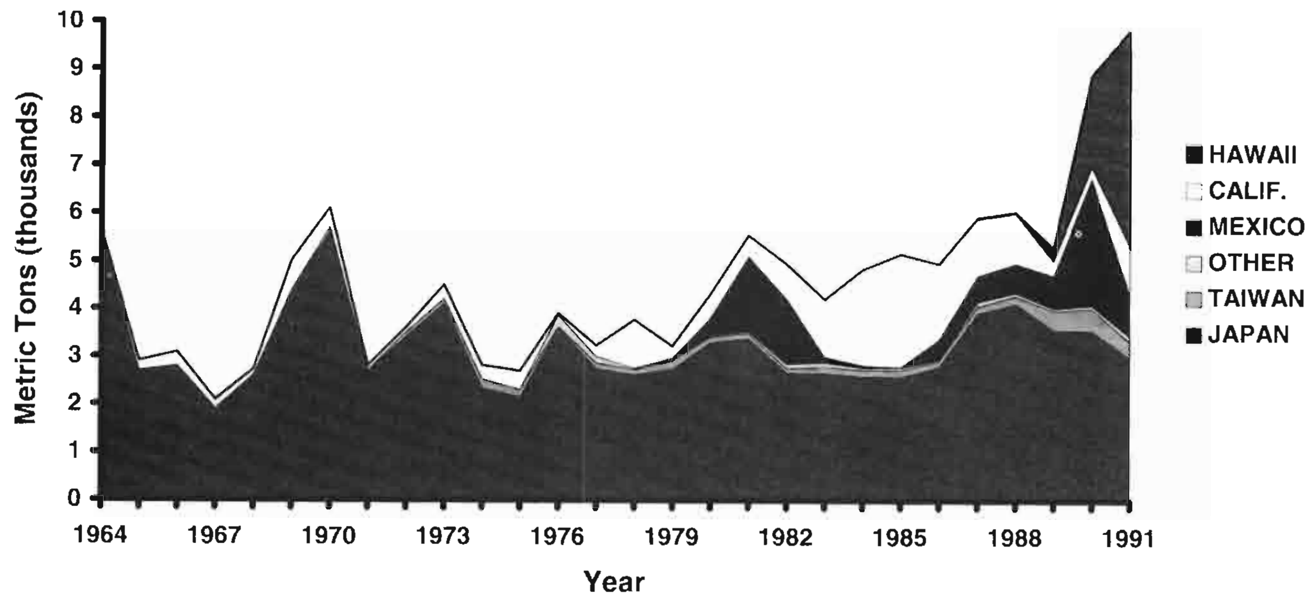

Figure 6

Area plot of swordfish landings in FAO statistical areas 67 and 77 in the northeast and east-central Pacific (FAO electronic database).

Swordfish gear is set at dusk and hauled at dawn or earlier, rather than being set at dawn and hauled at midday as is typical with tuna gear. This is consistent with the observation that swordfish in offshore waters swim near the surface at night and at depth during the day (Carey, 1990). Swordfish longline gear is configured to fish at depths of 15–25 m, with 2–3 hooks between floats, whereas tuna gear is rigged to fish at depths of 150–300 m with 5–15 hooks between floats, depending on the species being targeted.

If a concentration of swordfish is found as the gear is being hauled, some boats will cut the main line, terminate it with a float or radio beacon, set additional gear in the area, and then continue to haul the remainder of the gear. Some vessels fish for both swordfish and tuna on different portions of a trip or even by having some segments of the gear along the main line configured for swordfish, and others for tuna.

The longline fishery in Hawaii underwent a gradual decline in number of boats from the early 1950's to 1975–76, during which time the fleet was reduced by about 80% (Fig. 10). During 1977–87, the trend reversed and the number of boats roughly doubled. Then, from 1987 to 1991, the number of boats nearly quadrupled. In April 1991, a moratorium was put into effect under the authority of a new U.S. federal law, the Magnuson Fishery Management and Conservation Act. The moratorium prevented the entry of new boats into the Hawaii longline fishery and restricted the transfer of vessel permits. Consequently, in 1992 the number of boats active in the fishery declined from 140 to 123.

From a single boat in 1988, the estimated number of boats targeting swordfish on at least one trip per year increased to 114 in 1991 (Ito, 1998). The swordfish fleet increased in size when some Hawaii tuna longline and lobster boats switched to targeting swordfish, and other boats relocated from U.S. longline fisheries in the northeast coastal states and the Gulf of Mexico (Ito[1]).

Prior to 1989, swordfish were an incidental take in the tuna fishery in Hawaii, with landings averaging 10 t during 1952–86 (Table 2). Reported swordfish landings increased in 1987 and 1988 to 45 t because of the large increase in the number of longline boats. The swordfish fishery began in earnest in 1989, when 11 boats participated in the fishery and landings increased to nearly 300 t, 500% over the previous high (Fig. 11). Landings rapidly increased again in 1990 (by 600%) and then by more modest amounts in 1991, 1992, and 1993 (136%, 28%, and 7%, respectively). By 1990, the Hawaii fishery accounted for 21% of reported swordfish landings in the central-eastern Pacific. Since California landings were down in 1990, total U.S. landings accounted for only 24% of total reported landings, but Mexico and U.S. landings together accounted for 54%. With 1991 Hawaii landings increasing to 4,500 t, and assuming other catches equal to those in 1990 (more recent data were not available), Hawaii may have accounted for 40% of the landings in the region.[4] Similarly, projected total U.S. landings and combined U.S. and Mexican landings for 1991 may have accounted for 50% and 60%, respectively, of regional landings (Fig. 6).[5]

The proportion of swordfish in total pelagic landings in Hawaii has changed dramatically with the development of the swordfish fishery (Fig. 12). In 1977, the species composition in the Hawaii pelagic fishery was comparable to that in the Pacific in 1990 (Fig. 3), except that there was more marlin (9.5% versus 2.4%) and less tuna (88.2% versus 96.3%). The proportion of swordfish had not changed much by 1987, the year prior to the rapid expansion of the fleet (Fig. 12), but the proportion of marlin had increased to 22.2% and tuna had decreased to 74.9%. Subsequently, the proportion of swordfish increased substantially while the proportions of tuna and, to a lesser extent, of marlin declined.

Almost all the swordfish landed in Hawaii are transshipped fresh to the U.S. mainland. Some dealers buy only directly from fishing boats, others do so on occasion, and the remainder bid for the fish at the Honolulu fresh fish auction. Some vessel operators transship their landings under consignment to dealers on the mainland. The transshipped product has been headed, gilled, gutted, and finned (all fins). Fish below 23 kg are marketed locally only, and processing is limited to removing the lobes of the caudal fin and the bill. Shark- or bird-damaged swordfish are also generally marketed locally. The estimated dockside revenue generated from swordfish landings in Hawaii has risen in proportion to catches, reaching nearly $27 million in 1993 (Table 3).

Examination of the distribution of Hawaii longline fishing effort became possible in November 1990 when sub-

[4] In fact, Hawaii catches made up approximately 37% of regional catches in 1991–93 and then declined to 23% in 1995.

[5] In fact, U.S. and combined U.S.–Mexican landings accounted for 38% and 45%, respectively, in 1991; they stayed at about this level through 1994, then declined to 28% and 32%, respectively, in 1995.

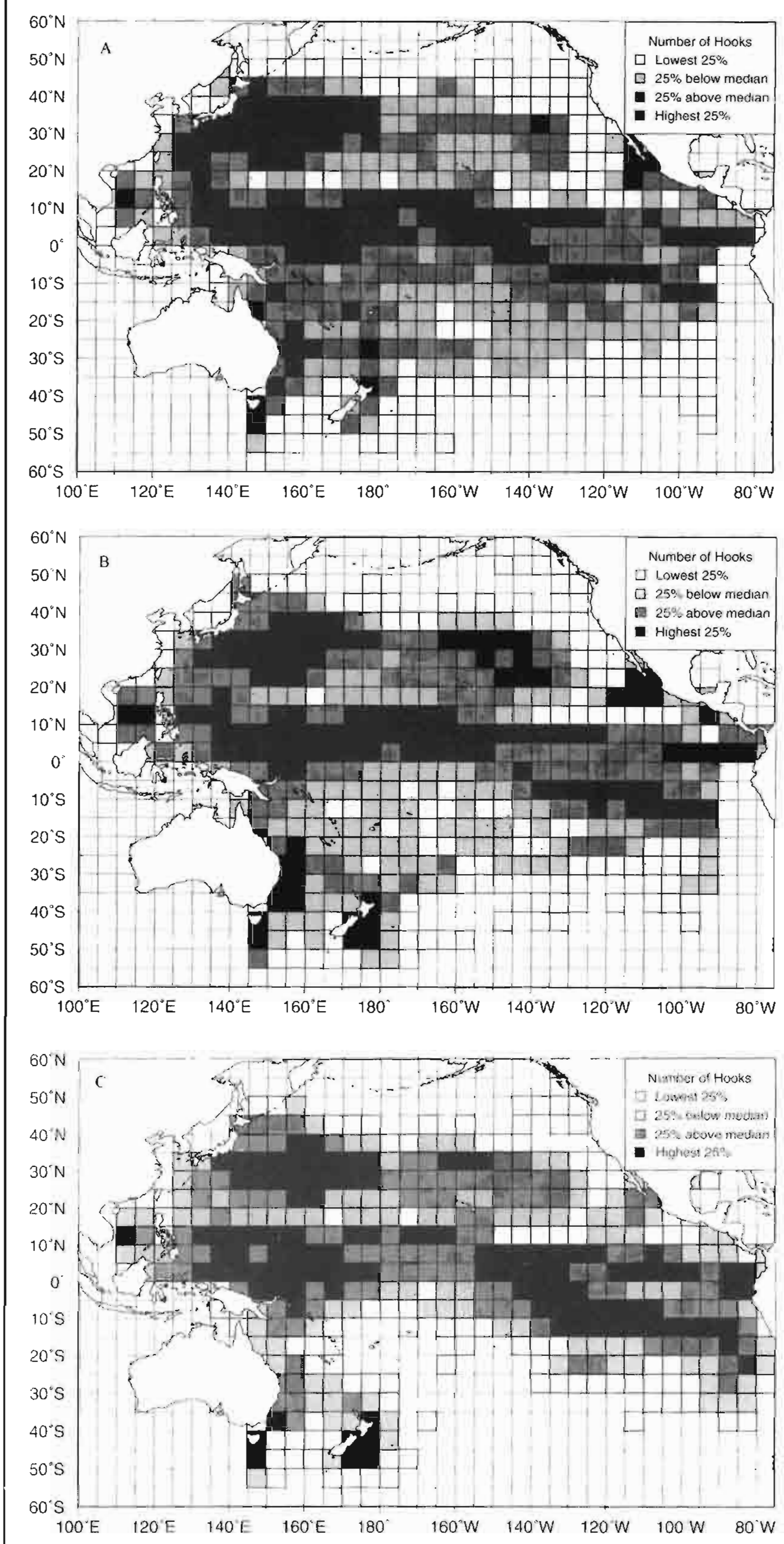

Figure 7

Distribution of Japanese longline fishing effort in (A) 1962–69, (B) 1970–75, and (C) 1976–80.

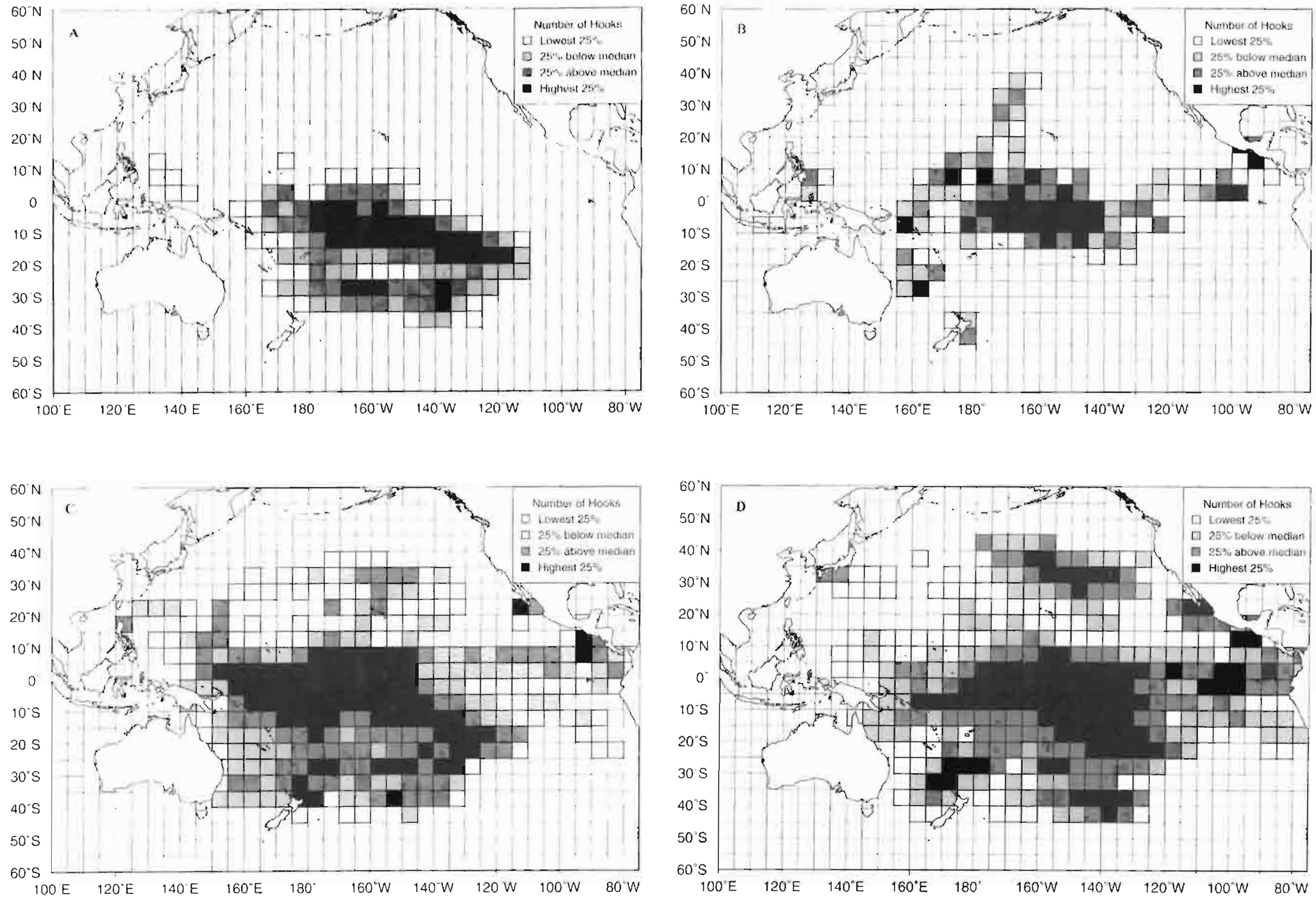

Figure 8
Distribution of Korean longline fishing effort in (A) 1966–69, (B) 1975, (C) 1977–80, and (D) 1981–87.

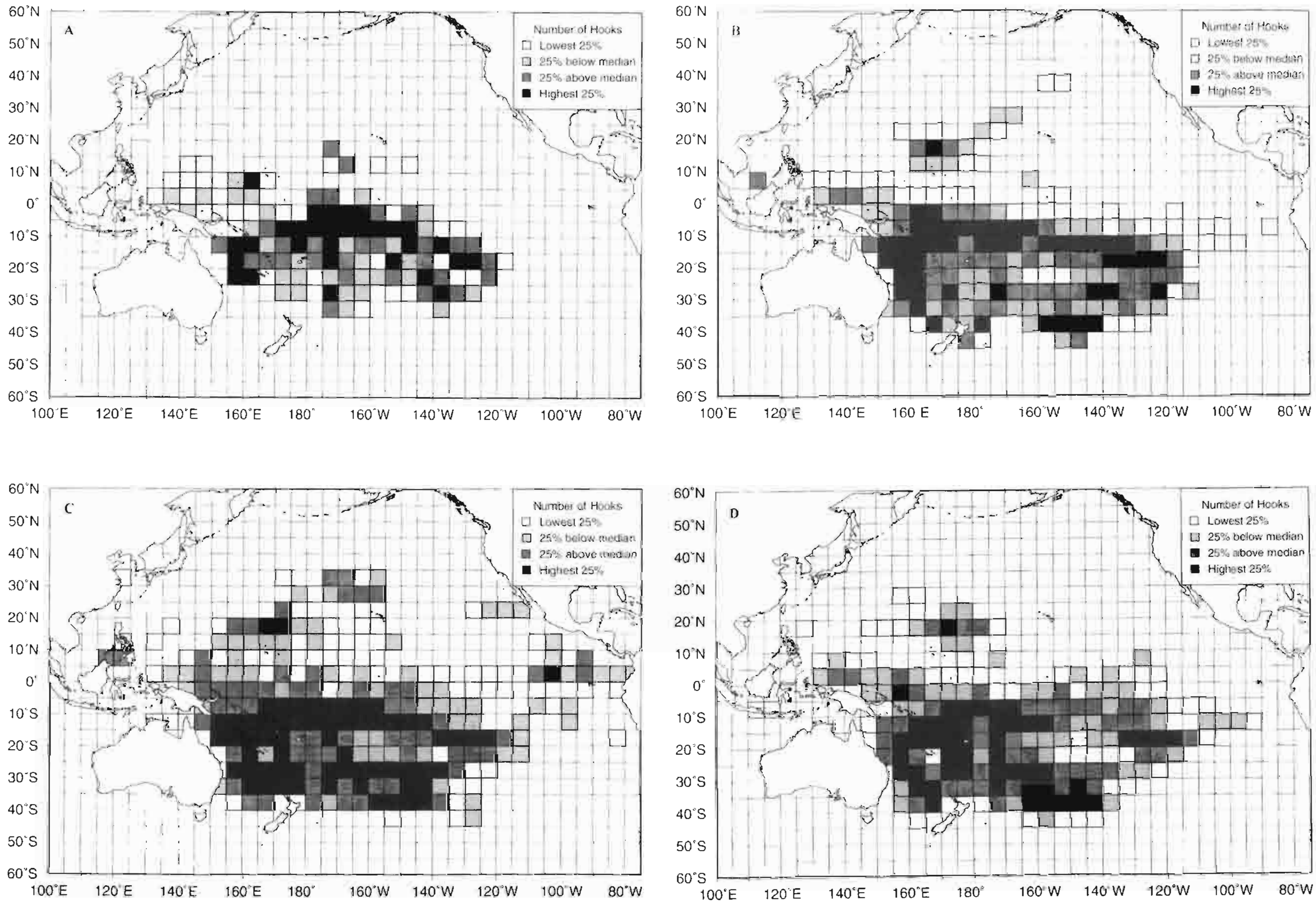

Figure 9
Distribution of Taiwanese longline fishing effort in (A) 1967–69, (B) 1970–75, (C) 1976–80, and (D) 1981–86.

mission of logbooks became mandatory. During November and December 1990, the fleet was limited to waters around the main Hawaiian Islands and the southernmost of the northwestern Hawaiian Islands (Fig. 13). In 1991, effort occurred from latitude 0° to 50°N and from longitude 140°W to 180°. While the highest level of effort was again in waters around the main islands and the northwestern islands, considerable effort was expended south and especially north of the archipelago. During 1992 and 1993, higher concentrations of effort extended into the northwestern Hawaiian Islands and waters to the northwest. Also, the limits of the Hawaii longline fishery expanded to the north, west, and east. Effort by the Hawaii fishery reached as far east as Japanese effort through 1980 (Fig. 7), but fell 5° in longitude short of the eastward extent of Korean effort (Fig. 8).

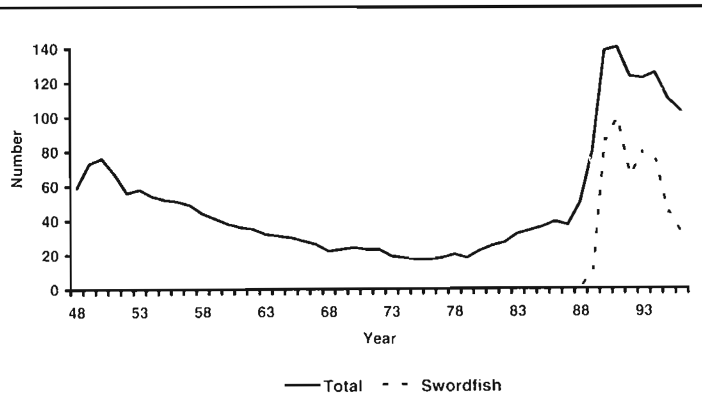

Figure 10
Estimated number of Hawaii longline boats, including those exclusively targeting swordfish. Data from Hawaii Division of Aquatic Resources, 1948–53, and NMFS logbook data, 1991–93.

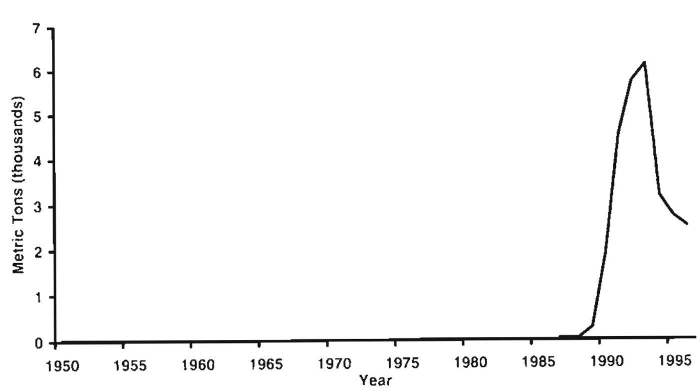

Figure 11
Annual Hawaii swordfish catches, 1950–96. Data from Hawaii Division of Aquatic Resources and NMFS shoreside monitoring.

The highest catch rates of swordfish in the Hawaii longline fishery (Fig. 14) occurred in the farthest northwestern and northern areas into which the fishery expanded (Fig. 13). As will be shown in the section on resource distribution, the areas of high catch rate by the Hawaii fleet coincide with the central Pacific portion of a region of high catch rate extending from the western to the central Pacific (Fig. 15). Thus, it appears that the Hawaii swordfish fishery developed in a region of resource abundance and that the expansion of the fishery to the northwest and north was due to the portion of the Hawaii longline fleet targeted on swordfish. It is also apparent that a considerable portion of the fishing effort of the Hawaii fleet is still being expended near the main Hawaiian Islands in the pursuit of tuna. An examination of indicators of species targeting and possibly Gulland's (1955) concentration index could demarcate specific locations of segments of the fleet targeting swordfish or tuna.

Population Biology and Dynamics

Effective management requires knowledge of various basic aspects of swordfish biology so that the dynamics of the resource and the impacts of the fishery and management actions can be assessed.

Range and Distribution

Swordfish distribution was inferred from the distribution of Japanese longline catch rates because the fishing effort for this fishery is distributed more widely than any other (Fig. 7, 8, 9). These catch rates are for the most part a measure of the availability and vulnerability of swordfish adults to gear not used to target swordfish. As always, the real abundance and thus distribution of the resource may differ from what the fishery statistics indicate. Information about fisheries targeting swordfish is also used here.

Swordfish has a wide distribution in the Pacific, from latitude 50°N to 45°S and from the western margin of the Pacific to the west coasts of the American continents, based on swordfish catch rates for the Japanese longline fishery during 1962–80 (Fig. 15). In the South Pacific, catch rates declined toward the southern limit of the effort distribution (Fig. 7), but in the North Pacific, high catch rates generally continued up to the northern limit of the effort distribution. The reasons for this differ-

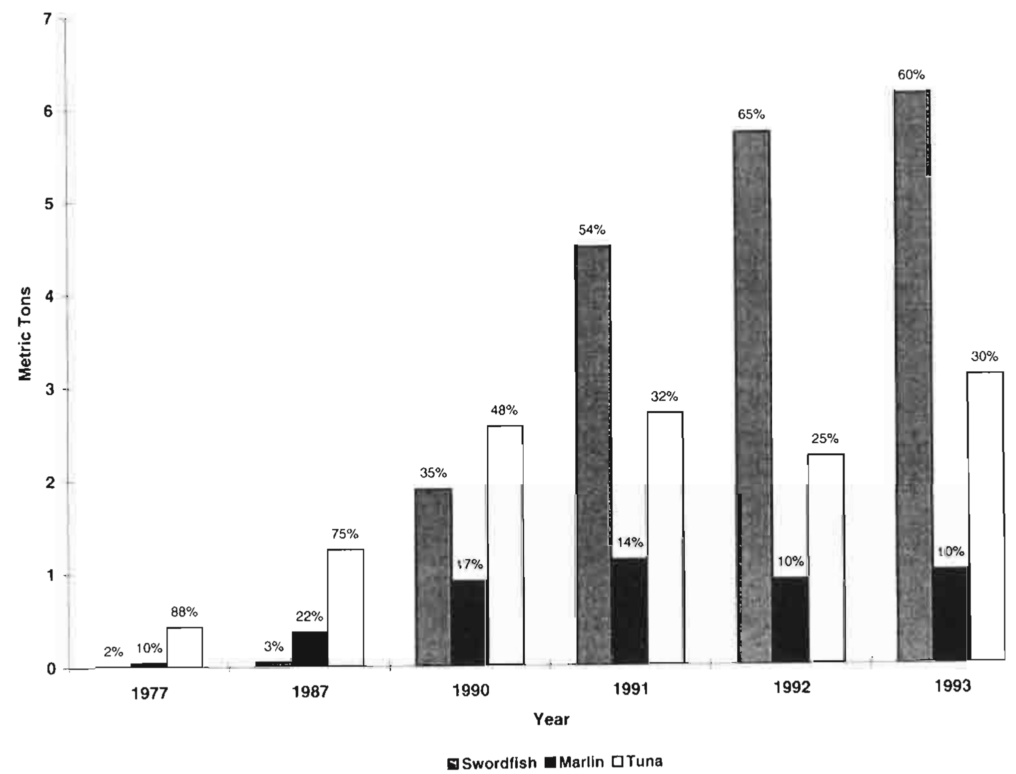

Figure 12
Species composition by weight and by percentage weight of catches by the Hawaii longline fishery, 1977–93.

ence are not clear; it may be due to the occurrence of the resource north of the fishery limits, to data aggregation by 5° latitudinal sections, to strong ecological boundaries, to fleet licensing restrictions, or to some combination of these.

There were high catch rates in several areas, with considerable variation in their extent. The largest, most consistent region of high catch rates was a broad band across the North Pacific from Japan eastward to about 140°W. High catch rates also occurred along the western margin of the Pacific from the equator to the coast of China; this region extended northeast to Japan and connected with the North Pacific region in the earlier periods summarized. Coastal fisheries using harpoon and other gears also operated in this area. The second largest region of high catch rates was off Australia, extending variable distances into the central South Pacific at different times. There appeared to be several regions of high catch rates off the west coast of the Americas; one off the coast of California and Mexico did not extend far enough to the northwest to connect with the west-central North Pacific region or far enough south along the coast to connect with another small region off central America. Drift net fisheries are also conducted in these coastal waters off California and Mexico. A region appeared off South America with

Table 3
Revenue from longline-caught swordfish in Hawaii, 1987–93 (Ito[1]; WPRFMC[2]).

Year	U.S. Dollars (thousands)
1987	200
1988	200
1989	1,100
1990	9,700
1991	22,000
1992	24,270
1993	26,830

[1] Ito, R. Y. 1992. Western Pacific pelagic fisheries in 1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep. H-92-15, 38 p. Honolulu Lab., SWFSC, NMFS, Honolulu, HI 96822-2396.

[2] Western Pacific Regional Fishery Management Council (WPRFMC). 1994. Pelagic fisheries of the Western Pacific Region 1993 annual report. Western Pac. Reg. Fish. Manage. Counc., 1164 Bishop St., Rm. 1405, Honolulu, HI 96813.

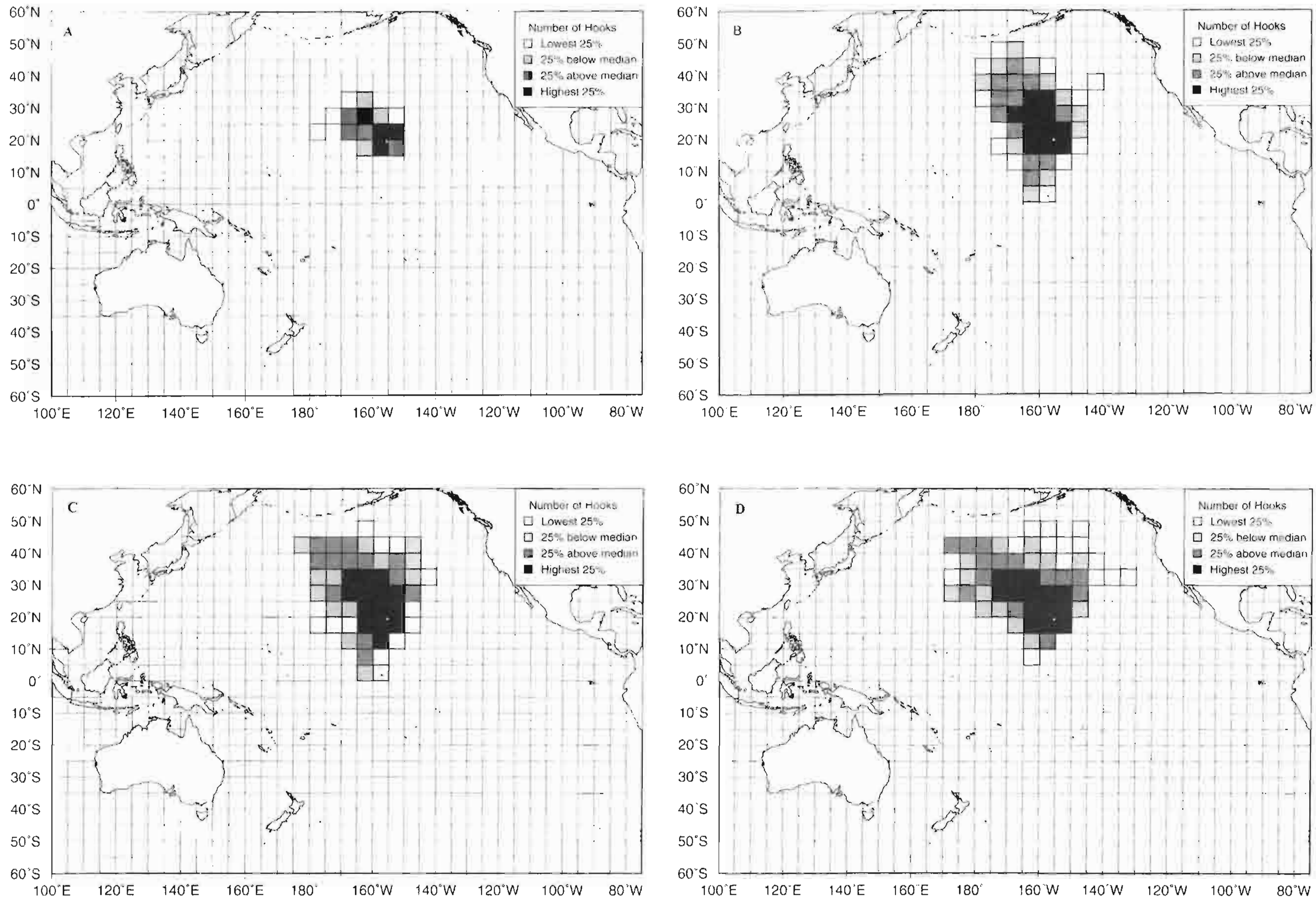

Figure 13
Distribution of Hawaii longline fishing effort in (A) November–December 1990, (B) 1991, (C) 1992, and (D) 1993.

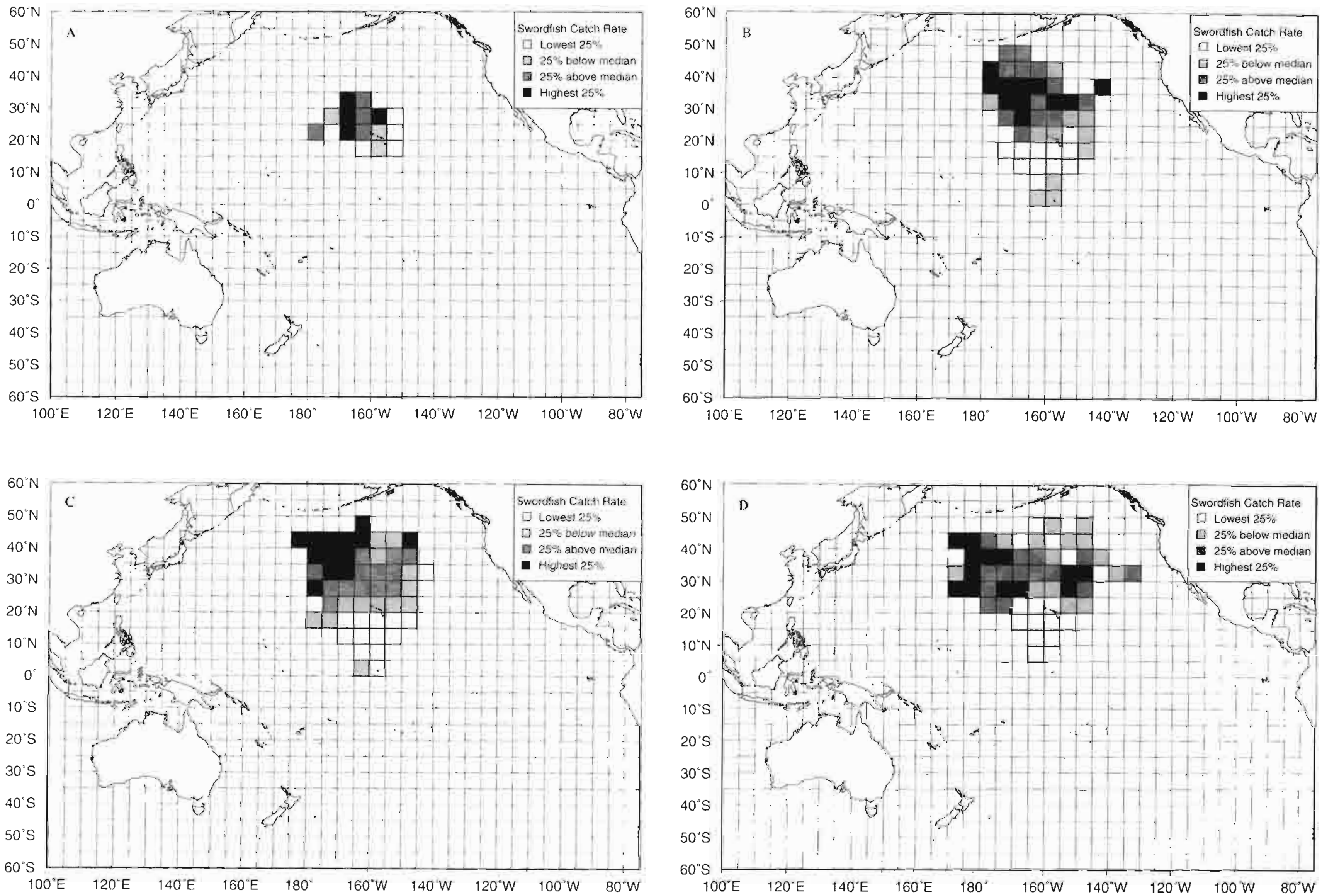

Figure 14

Distribution of catch rates (swordfish per 1,000 hooks) for the Hawaii longline fishery during (A) November–December 1990, (B) 1991, (C) 1992, and (D) 1993.

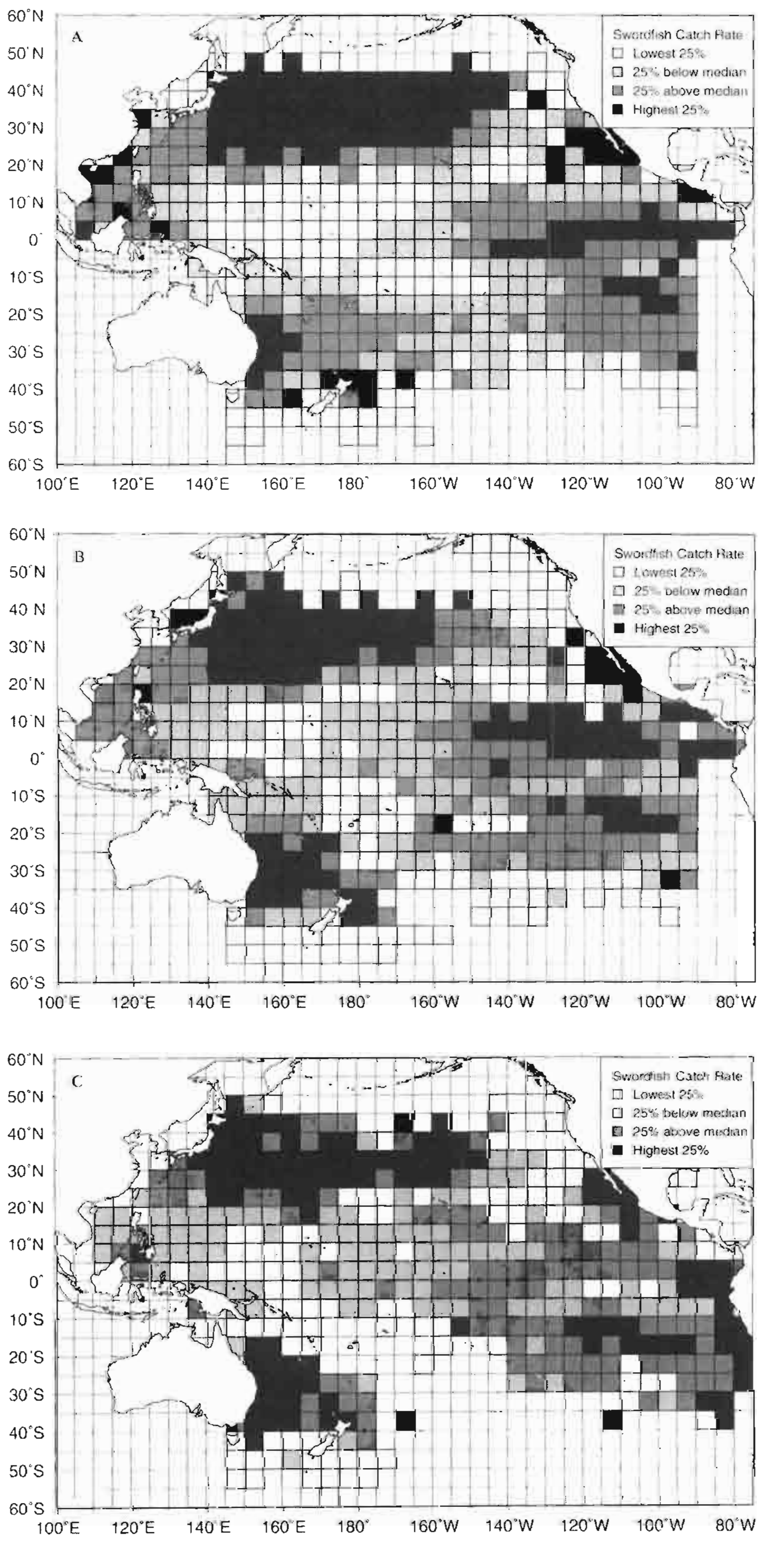

Figure 15
Distribution of catch rates (swordfish per 1,000 hooks) for the Japanese longline fishery during (A) 1962–69, (B) 1970–75, and (C) 1976–80.

extensions into the central Pacific along the equator and at middle southern latitudes, but it never quite joined with the region extending eastward from Australia. The Chilean fishery also takes place in these coastal waters off South America.

Stock Structure and Movement

The stock structure of swordfish is poorly understood. For stock assessment purposes, a single, Pacific-wide stock generally has been assumed, with the possibility that there are separate stocks associated with known fishing grounds in the western-central North Pacific, eastern Pacific, and western South Pacific (Sakagawa and Bell, 1980; Bartoo and Coan, 1989; Skillman, 1989). Only a single swordfish tag recapture has been recorded in the Pacific. This fish, which weighed approximately 11 kg when it was tagged and released from a commercial fishing boat at 29°N, 154°W on 24 April 1992, was recaptured in the same general area 11 months later at a weight of 32 kg. Tagging results in the Atlantic have indicated that swordfish movement is primarily latitudinal (Berkeley, 1989) and that fish tagged in the summer tend to return to the same locale in subsequent summers (Beckett, 1974).

Progress on the use of genetics to determine swordfish stock structure is reported by Grijalva-Chon et al. (1996) and in the present publication (Alvarado Bremer, Leclerc, and Ely, 1998; Chow, 1998).

Size at Maturity and Spawning

U.S. federal law (the Magnuson Fishery Management and Conservation Act) requires the prevention of recruitment overfishing. Thus, an estimate of size at maturity is necessary to assess trends and the dynamics of the mature, spawning component of the stock. All of the published estimates (Table 4) are based on small

Table 4

Estimates of swordfish size at maturity. Values are in the units published by the authors: EFL = eye–fork length, LJFL = lower jaw–fork length, and RWT = round weight.

Ocean	Sex	Smallest mature	All mature	Size at maturity	Units	N[1]	Source[2]
Pacific	Female	140		170	cm EFL	362	1
		83.0		156.5[3]	kg RWT	15	2
		150		170	cm EFL	~58	3
Atlantic	Female	70			cm LJFL	NG	4
		74			kg RWT	NG	5
		160	235	171	cm LJFL	NG	6
	Male	100			cm LJFL	NG	4
		21			kg RWT	NG	5
		90	165	113	cm LJFL	NG	6

[1] NG = not given.
[2] 1 = Kume and Joseph (1969), 2 = Uchiyama and Shomura (1974), 3 = Yabe et al. (1959), 4 = Ovchinnikov (1970), 5 = Palko et al. (1981) referencing personal communication from E. Houde, 6 = Hoey et al. (1989) referencing personal communication from R. Taylor.
[3] Median between the smallest and largest mature fish in the sample.

sample sizes, and none are based on modern histological techniques necessary to determine maturity in indeterminate spawners, which swordfish may be, and to estimate fecundity.

For the eastern tropical Pacific, Kume and Joseph (1969) classified ovary samples collected from the Japanese longline fleet using values of the gonado-somatic index (GSI), the ratio of gonad weight to the cube of eye orbit–fork length (EFL). While they stated that there was no established relationship between GSI and state of maturation for swordfish, they observed that there was a cluster of samples with low ovary weights and GSI values <3.0, which they classified as immature or undeveloped. Mature fish were defined as having GSI values ≥3.0.

For the central Pacific, Uchiyama and Shomura (1974) classified, according to the most mature ovum stage present, a small sample of ovaries collected from commercial longline boats operating in the vicinity of Hawaii. The ovum stages identified were primordial, early developmental, developing, early ripe, ripe, and residual. Taking the occurrence of early ripe or later stages as indicating maturity, I determined that the mature fish in their samples ranged from 83.0 to 246.3 kg round (unprocessed or whole) weight (RWT), with the median at 156.5 kg RWT.

For the western Pacific, Yabe et al. (1959) plotted ovary weight versus EFL of samples collected from the swordfish fishing grounds (30–45°N, 140°E–180°). They observed a cluster of points with small ovary weights, which they interpreted as immature fish, and a length range in which ovary weight increased rapidly with body size. They interpreted this range (150–170 cm EFL) as the size at maturity, and also gave age at maturity as 5–6 years. Sosa-Nishizaki (1990) indicated a similar range (150–160 cm EFL) using samples collected from across the Pacific in all seasons.

For the Atlantic Ocean (Table 4), Palko et al. (1981) provided estimates of size at maturity for female and male swordfish, referencing Ovchinnikov (1970), without any details of origin of the samples or methods used. They also provided estimates for swordfish taken off the southeast coast of the U.S., referencing a personal communication from E. Houde. Also, Hoey et al. (1989) provided estimates from gonads collected off the coast of Florida, referencing a personal communication from R. Taylor. These estimates for female and male swordfish were for the size at which mature fish were first found, the size at maturity (size at which 50% of the specimens were classified as mature), and the size when all specimens in the spawning season were mature. Miyake and Rey (1989) stated that swordfish age 4 and above were mature.

Since these estimates were reported in different units of measure (EFL, lower jaw–fork length, and RWT; Table 4), I converted them to EFL using research data collected in the central Pacific to facilitate comparison. For females, all the estimates except that by Ovchinnikov (1970) clustered around 150 cm EFL. For males, a smaller size at maturity was indicated, around 100 cm EFL, but fewer estimates were available and only for the Atlantic.

Uchiyama and Shomura (1974) found that sexually mature swordfish with developed gonads occurred in Hawaiian waters from April through July. Swordfish were rarely present at other times and were generally small, immature fish. Kume and Joseph (1969) found that sexually immature female swordfish were present in the eastern Pacific in all months, whereas females in spawning condition were most abundant during March–

July north of the equator and around January south of the equator.

To evaluate the occurrence of mature swordfish captured with longline gear, Sosa-Nishizaki (1990) divided the Pacific into five areas, one spanning the equator from 10°N to 10°S, and two areas each in the North and South Pacific, divided at longitude 150°W. In the northwest area, spawning appeared to be concentrated in waters from the Hawaiian Archipelago southward and occurred during April–July. Spawning was not apparent in the northeast area. In the southeast area, spawning occurred in noncoastal pelagic waters during October–January. In the southwest area, spawning was concentrated in the Coral Sea during November–February and in waters around Fiji during May–July. Mature fish were found in all months in the equatorial area and exhibited no seasonal trend. Sosa-Nishizaki (1990) believed the equatorial area to be an area of mixing of stocks from north and south.

Growth

The ability to establish the age of fish allows us to classify landings by age-class and to model fish growth. Estimates of growth model parameters can be used in various age-based and age-structured stock assessment models (Table 5). Current efforts to age central Pacific swordfish are described in Uchiyama et al. (1998).

All the studies cited in a recent summary of growth model parameters (Sakagawa and Bell, 1980; updated by Boggs, 1989) are based on very few samples, and the estimates should be regarded as provisional. The only reference for the Pacific was Yabe et al. (1959; Table 5); from the data they present, the fifth and largest modal size used to fit the growth model was 148 cm EFL. Thus, their model is not representative of growth of larger, older fish. The Japanese swordfish longline fishery in the 1950's was conducted at night, north of 30°N from 140° to 160°E (Kume and Morita, 1966), and caught mostly small swordfish.

Similar problems due to lack of data for large fish exist with several models presented for the Atlantic (Caddy, 1976, 1977; Berkeley and Houde, 1983; Wilson and Dean, 1983; Tsimenides and Tserpes, 1989). Models by Radtke and Hurley (1983) and the International Commission for Conservation of Atlantic Tunas (ICCAT, 1989) were fit with data from large fish, but data from small fish were not available for the tag recapture model (ICCAT, 1989). The models from these two sources provided quite different estimates of length at age. If the tag recapture model were accepted as the most reliable, it would suggest that the otolith ridges used by Radtke and Hurley (1983) to age fish were formed less often than once a year.

Table 5

Estimates of von Bertalanffy growth parameters and mortality rate for swordfish. Natural mortality rates (*M*) calculated from *K* using the equation of Murphy and Sakagawa (1977). Table derived from Sakagawa and Bell (1980) as updated by Boggs (1989) and again here using sources 4 and 7.[1]

Ocean	Method	*N*	Sex[2]	Size range[3] (cm)	Source[1]	*K*	t_0 (yr)	L_∞	*M*
Pacific	Length modes		U	61–245	1	0.124	–1.169	309	0.22
Atlantic	Length modes and vertebrae		U	50–260	2	0.230[4]		365[4]	0.21–0.43[5]
	Anal ray	275	M	70–270	3	0.19	–2.04	217	0.35
	internal zones	164	F			0.09	–2.59	340	0.15
	Anal ray	427	M	54–215	4	0.34	–1.22	194	0.64
	internal zones	455	F			0.25	–1.52	220	0.47
	Otolith	39	M	79–209	5	age estimates, no model			
	internal zones	39	F	102–290					
	Otolith	73	M	88–208	6	0.07	–3.94	277	0.12
	ridges	195	F	80–270		0.12	–1.68	267	0.21
	Tag recapture	84	U	90–260	7	Gompertz growth model[6]			

[1] 1 = Yabe et al. (1959), 2 = Caddy (1976, 1977), 3 = Berkeley and Houde (1983), 4 = Tsimenides and Tserpes (1989), 5. = Wilson and Dean (1983), 6 = Radtke and Hurley (1983), 7 = ICCAT (1989).
[2] M = male, F = female, U = unknown or unreported.
[3] Pacific and Atlantic size ranges are for eye–fork length and lower jaw–fork length, respectively.
[4] These estimates of *K* and L_∞ from Caddy (1977) do not match the size-at-age groups given in Caddy (1976).
[5] Total mortality, Z = 0.12–0.65 and 0.16–0.59 using data from the harpoon and longline fisheries, respectively.
[6] Dressed weight (lbs) = 305.56 exp (–4.6235 exp (–0.305815 · Age)), with Age in yr.

In more recent reports, Prince et al. (1988) described the reading of presumed annual increments on anal fin rays. However, they could not verify their interpretation of the annual increments using mean monthly marginal increment widths or mean marginal increment ratios. Ehrhardt (1992), in a reanalysis of the same data, provided statistical evidence that verified the use of annual increments by Prince et al. (1988). Miyake and Rey (1989) indicated that the model derived from tagging returns (SEFC, 1987) is the most accurate available and has been used by ICCAT for stock assessment. Two problems occur in gathering tag and recapture data for swordfish: it is difficult and dangerous to determine fish size prior to release, and sex of the recaptured fish must be determined when the fish are dressed at sea. ICCAT (1989) presented an updated model based on tag recaptures, a Gompertz growth model (Table 5).

Mortality

Few estimates of the instantaneous rates of swordfish total mortality, *Z*, natural mortality, *M*, and fishing mortality, *F*, have been published, especially for the Pacific. All available estimates are based on small sample sizes and many use approximate methods; thus, the estimates are very preliminary. Using the model of Beverton and Holt (1956), which requires estimates of the von Bertalanffy growth coefficients *K* and L_∞, the size of swordfish when recruited to the fishery, and the mean size of swordfish in the catch, Caddy (1977) estimated *Z* using data from the Canadian harpoon (0.12–0.65) and longline (0.16–0.59) fisheries. Tagging studies, according to Caddy, could also be used to estimate *Z*, but these estimates would be subject to considerable variation caused by immigration and emigration.

All available estimates of the instantaneous rate of natural mortality, *M*, were obtained by indirect means. One estimate of *M* (0.2–0.4) was inferred from estimates for tunas and considerations of life expectancy (Caddy, 1977). All other estimates of *M* were based on estimates of the von Bertalanffy growth parameter, *K*, and an empirical relationship between *M* and *K* from Murphy and Sakagawa (1977). This regression was computed using three data points for bluefin tuna, *Thunnus thynnus*, albacore, *T. alalunga*, and yellowfin tuna, *T. albacares*. Given the concerns about bias in the estimation of growth discussed in the previous section, similar concerns should be held for estimates of *M* based on *K* from these growth models. Estimates of M using this procedure were first provided by Caddy (1977); were recomputed utilizing several published estimates of *K* by Sakagawa and Bell (1980); were updated by Boggs (1989); and are updated again here using estimates of *K* in Tsimenides and Tserpes (1989) and ICCAT (1989) (Table 5). Separate estimates of *M* for males and females are given by Berkeley and Houde (1983), Radtke and Hurley (1983), and Tsimenides and Tserpes (1989). An estimate of *M* could not be computed for the growth model from tagged fish in the Atlantic because the Gompertz model does not include the parameter *K*. The single estimate for the Pacific ($M = 0.22$) was computed by Boggs (1989) using *K* estimated from data in Yabe et al. (1959). Most of the estimates in Table 5 fall within the range inferred from tunas, in spite of the use of different tissues and size ranges of specimen in determining the growth models.

Caddy (1977) mentions two methods to estimate *M* directly, but no estimates using these techniques have been published. First, he discussed using the catch-curve method, which requires data collected before heavy exploitation has occurred, but he pointed out that the method would be difficult to apply because swordfish stocks are spatially structured by sex and age. Second, he discussed Suda's method utilizing estimates of *Z* and fishing effort at two or more levels of fishing (Morita, 1977), but no estimates using this procedure were provided.

No estimates of the instantaneous rate of fishing mortality, *F*, have been published for the Pacific. For the Atlantic, estimates of *F* by age/size classes have resulted from stock assessments conducted using virtual population analysis (VPA; Swordfish Assessment Group, SCRS, 1992). Caddy (1977) suggested using length-based analysis to estimate fishing mortality, which requires estimates of L_∞, M/K, and exploitation rate, *E*, and the existence of a stable size frequency (Jones[6]). He also discussed the use of tagging data but provided no estimates using either of these methods.

In summary, no reliable estimates of *Z*, *F*, or *M* exist for Pacific swordfish fisheries. While rates can be inferred from studies conducted in other areas, those estimates also suffer from some of the same problems described above.

Stock Assessment

In both the Pacific and Atlantic Oceans, the first attempts to assess the status of swordfish stocks used Schaefer's (1954) equilibrium stock-production model or similar models (Pella and Tomlinson, 1969; Fox, 1970). Production models were used because they inte-

[6] Jones, R. 1974. Assessing the long-term effects of changes in fishing effort and mesh size from length composition data. ICES Meeting Doc. C.M. 1974/F:33, 12 p. Demersal Fish (Northern) Comm., Int. Counc. Explor. Sea, Palaegade 2-4, DK-1261, Copenhagen, K., Denmark.

grate the effects of growth, natural mortality, and recruitment into a rate of stock increase that is dependent only on mean stock size. Therefore, production models have modest data requirements, requiring only two of the three commonly available fishery statistics, namely catch, effort, and an index of stock abundance (e.g., catch rate). Also, the results from such a model are simple to understand and to convey to resource managers. Production models do estimate maximum sustainable yield (MSY) accurately until MSY is exceeded.

Those attempting to assess the resource in the Pacific have noted that the predominant fishery, the Japanese longline fishery, underwent a number of changes in species targeting, bait, and gear configuration (Bartoo and Coan, 1989; Skillman, 1989). Prior to 1962 most swordfish catches resulted from a night-set longline fishery in the western Pacific targeting swordfish and using squid as bait. Over the next two years, the Japanese fishery changed to a predominately day-set fishery targeting tunas and using mixed bait. The tuna fishery has since undergone considerable expansion, and deep longlining was introduced in the 1970's to target bigeye tuna (Suzuki and Warashina, 1977). In 1976, nylon branch lines began to be used on small longline boats and by 1989 had become the dominant type of main line on these boats (Warashina, 1991). Problems have been experienced with the durability of monofilament-nylon main lines on Japanese distant-water longline boats (Katsuo-Maguro Tsushin, 1993), but their use appears to be expanding (Katsuo-Maguro Tsushin, 1994a, b). Data on these changes in gear efficiency and targeting were not readily available to standardize statistics on the Japanese longline fishing effort, and the stocks were probably not in equilibrium given the expanded level of fishing. Thus, little confidence has been placed in the results of equilibrium production models even when such modeling was attempted, e.g. an MSY of 18,000–20,000 t (Sakagawa and Bell, 1980; Skillman, 1989). The conclusion in the latter two papers and in Bartoo and Coan (1989) was that the fishery had not overexploited the stock, catch rates had remained relatively stable over time, and the resource was in good condition. It should be noted that Pacific landings (Table 1) have increased considerably and by 1991 had exceeded previous estimates of MSY by some 8,000–10,000 t.[7]

Similar problems with time series of nonstandardized fishing effort were encountered in attempting to assess Atlantic stocks using equilibrium stock-production models (Kikawa and Honma, 1981; Farber and Conser, 1983). Therefore, Atlantic researchers turned in 1985 to the use of age-structured assessment models, because these depend only on age-composition data and estimates of growth, natural mortality, and fishing mortality in the terminal year of the fishery (Conser et al., 1986). A VPA model was used to estimate stock size and fishing mortality at age, with the best estimates in the earlier years of the time series, because VPA is a backward-sequencing procedure. With the addition of average weight-at-age data, estimates of stock biomass, surplus production, and female spawning-stock biomass also became available. Such information helped in the evaluation of whether the Atlantic fishery in the course of its development had a significant impact on the stock.

Estimates from VPA were often analyzed with age-based models, e.g. estimated yield per recruit was used to estimate spawning-stock biomass per recruit. Over the next several years, different formulations of the VPA model and different means of tuning the model were used to deal with uncertainties in estimates of growth (particularly for older fish and also by sex) and natural mortality (Restrepo, 1991; Restrepo and Powers, 1991; Hiramatsu, 1992; Restrepo et al., 1992). These assessments were also used to deal with differences in size composition estimation among different fisheries and the lack of data on sex composition of landings. Since so much ancillary information was being incorporated to tune the VPA to handle these problems and obtain better estimates, an integrated approach called ADAPT was employed with the VPA (Conser and Powers, 1990; Restrepo et al., 1991; Mohn, 1992; Powers and Restrepo, 1992; Hiramatsu, 1993; Gavaris[8]).

However, Conser et al. (1992) noted that the abandonment of stock-production models for the ADAPT-VPA approach may not have been wise for several reasons. First, growth models that adequately modeled the growth of older age groups had not been developed. Second, logistical sampling problems had precluded the development of age–length keys, thus requiring the use of cohort slicing to estimate catch-at-age using size-frequency data, landings data, and growth models. Third, since the causal mechanism for the observed preponderance of females at larger sizes had not been determined, it was unclear whether to incorporate sexually dimorphic growth, differences in natural mortality by sex, differences in availability by sex, or some combination of these or other possible causes in the assessments.

Because of these problems, interest in the use of stock-production models was renewed, but this time in nonequilibrium (or dynamic) versions. In contrast to VPA, time-series estimates (e.g. biomass) from a stock-production model are estimated more accurately at the

[7] By 1995, Pacific catches exceeded these MSY estimates by 10,000–12,000 t.

[8] Gavaris, S. 1988. An adaptive framework for the estimation of population size. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/29, 12 p. Marine Fish Div., Dep. Fisheries and Oceans, St. Andrews, N.B., E0G 2X1 Canada.

end of the time series because a forward-sequencing computational procedure is used. Vaughan and Scott (1991) compared the performance of three models: the equilibrium logistic production model (Schaefer, 1954); the Pella and Tomlinson (1969) generalized model, with an adjustment for nonequilibrium (Fox, 1975); and Schnute's (1977) dynamic logistic model. While catch in a given year is a function of effort in the same year in the equilibrium stock production model, catch in the current year is a function of effort in the same year plus catch and effort in the previous year in Schnute's model. Vaughan and Scott (1991) found that an MSY estimate was highest for the equilibrium model and lowest for the dynamic model, as expected. Estimates based on the model with nonequilibrium adjustment were close to the dynamic model, but generally higher. Conser et al. (1992) proposed using Shepherd's[9] nonequilibrium stock-production model and provided a statistical basis for estimating the parameters. The dynamic nature of this model is based on biomass in a given year as a function of biomass at the start of the previous year, plus net production and catch. Another nonequilibrium model (ASPIC, a surplus-production model incorporating covariates) has been developed that is similar to the Pella and Tomlinson (1969) model but uses an analytical solution to the yield equation rather than a numerical solution (Prager, 1992, 1993b; Prager[10]). Prager (1992) noted that since the model is a forward solution, it can be modified to handle different patterns of fishing or data collection as easily as with simulation models, which is a benefit also noted by Methot (1989, 1990) in discussing his stock-synthesis model. Thus, ASPIC can use several data series, e.g. catch-and-effort data from different gears or different periods in a fishery. Auxiliary population-biomass estimates or other information can be used to tune the model. Also, bootstrapping can be used to construct approximate nonparametric confidence intervals (Prager, 1993a).

Issues and Problems

With the recent development of swordfish fisheries in the Pacific, a number of issues and problems have arisen pertaining to fishery management, biological research, and data collection.

Fishery Management

Under U.S. federal law, fishery management actions for U.S. waters are initiated by regional councils and implemented by the NMFS. Deliberations and resultant management actions taken by the Western Pacific Regional Fishery Management Council (WPRFMC) and the NMFS indicate three primary fishery management concerns associated with the swordfish fishery in the central Pacific:

Stock Dynamics and Overfishing—The size of the harvest of the expanding central-eastern North Pacific longline fishery directed at swordfish could possibly cause overutilization (harvesting beyond MSY) or even recruitment overfishing. The expansion of this fishery and coastal fisheries also targeting swordfish has changed the nature of the Pacific swordfish fishery; previously, the vast majority of swordfish were taken incidental to tuna fishing operations. A species targeted by a number of fisheries is more likely to become overfished than one taken incidentally, although bycatch can result in overfishing. Harvesting of subadults by some segments of the Hawaii fishery, and probably other fisheries as well, could lead to yield-per-recruit concerns, but this issue has not been raised, at least formally, in the Hawaii fishery. Relevant U.S. domestic management actions are the Fishery Management Plan for Pelagic Species in the Western Pacific Region and the first amendment to the plan, which specified an objective definition of recruitment overfishing.

Incidental Take of Protected Species—In U.S. fisheries, this is regulated by domestic law (Endangered Species Act). The take of marine turtles reported by the Hawaii-based longline fishery exceeded the allowable limits set for the fishery before the expansion in fleet size or targeting on swordfish had occurred. Because of this, consultations under the Endangered Species Act were conducted in 1994. The impact of such bycatches on protected species and their prevention is increasingly becoming a fisheries management issue.

Bycatch—Sharks (primarily blue shark, *Prionace glauca*) comprise the largest catch of the Hawaii-based swordfish longline fishery, although landing numbers have been low. Some finning of blue shark occurs, but estimates of landings in round weight are not currently available. Reported landings of whole sharks have consisted primarily of mako, *Isurus* spp., and thresher, *Alopias* spp., but have been a very small proportion of total longline landings. The incidental hooking of sharks may become a management issue if the take becomes large and if fishery or ecological impacts become significant.

The Pacific Regional Fishery Management Council (PRFMC) and the North Pacific Regional Fishery Management Council have not developed a fishery manage-

[9] Shepherd, J. G. 1987. Towards improved stock-production models. Int. Counc. Explor. Sea (ICES) Working Group on Methods of Fish Stock Assessment, Working Pap. 6, 16 p. ICES, Palaegade 2-4, DK-1261, Copenhagen, K., Denmark.

[10] Prager, M. H. 1993. User's manual for ASPIC: a stock-production model incorporating covariates, program version 3.30. U.S. Dep. Commer., NOAA, Natl. Mar. Fish Serv., Southeast Fish. Sci. Cent., Miami Lab. Doc. MIA-92/93, no. 55, 31 p. SEFSC, NMFS, Miami, FL.

ment plan for swordfish or similar pelagic species. The states of Washington and Oregon do not allow driftnet- or longline-caught fish to be landed, while California allows driftnet fishing but not longline fishing in waters off its coast. However, Oregon is in the process of permitting driftnet fishing (Hanan[11]).[12] At present, there is no administrative mechanism for coordination of U.S. swordfish management in the central and eastern Pacific, although the PRFMC could serve that role on the U.S. west coast. In the North Pacific there is no regional fishery management body with the authority to manage swordfish.

Biological Knowledge

As discussed above, swordfish biology in the Pacific is poorly known, and estimates of population parameters necessary for stock assessment are generally lacking. Although some of these shortcomings are addressed in this symposium, no formal or informal arrangement exists for assessing priorities and facilitating the coordination of research among nations and scientists to improve our knowledge of this species.

Fishery Monitoring

Data collection activities are driven by local interests and historical practices. Landings data on the U.S. west coast are maintained in a database by the Pacific Marine Fisheries Commission, but data formats are not standardized between states supplying the data. Alaska does not routinely collect landings data from the longline boats fishing in the central North Pacific. The Honolulu Laboratory, in collaboration with American Samoa, Hawaii, Guam, and the Northern Mariana Islands, maintains a landings database, but it contains little data on swordfish other than for Hawaii. No regional or more broadly based arrangement between nations exists to coordinate data-collection activities for swordfish or provide a forum for exchanging or accessing data. Thus, in general, statistics necessary to assess the status of swordfish in the Pacific are either unavailable or inaccessible on a timely basis.

Honolulu Laboratory Research

Fishery Monitoring

The Honolulu Laboratory's swordfish fishery monitoring program aims to estimate production from the Hawaii fishery and collect data on the associated fishing and marketing sectors. This program is briefly described here.

Production—The weight of individual swordfish landed, ex-vessel revenue, and price are collected as part of a shoreside monitoring program conducted in conjunction with the State of Hawaii's Division of Aquatic Resources (Ito et al., 1998).

Interaction with Endangered Species—A mandatory observer program for the Hawaii longline fishery was established in 1994 by the NMFS Southwest Region to collect data on interactions of marine turtles with longline gear.

Biological Sampling—Observers from the mandatory program also collect swordfish otolith, fin, gonad, and stomach samples; determine the sex of swordfish retained; collect detailed data on catches and discards; and record length measurements for all fishes brought on board. Biological sampling also takes place on Honolulu Laboratory research cruises.

Cooperative Efforts—The following possible cooperative efforts have been discussed:

- Establish an ad hoc working group to facilitate and coordinate the collection and exchange of fishery data (weight of landings, effort and catch data, and fish sizes) for the swordfish fisheries based in Hawaii, California, Oregon, and Alaska.
- Establish a regional ad hoc working group with members from Japan and other distant-water fishing nations, Mexico, and the U.S. to facilitate sharing of data for stock assessment purposes.

Vessel Specifics—For Hawaii longline boats, data on vessel specifications, crew size, and the type and amount of gear carried are obtained from federal fishing permit applications. Personal interviews provide additional information (Ito et al., 1998).

Effort and Catch—Submission of logbooks became mandatory for Hawaii longline boats in November 1990, according to the second amendment to the Fishery Management Plan for Pelagic Species of the Western Pacific Region. These logbooks provide data on fishing effort expended daily by latitude and longitude, resulting catches by species, discards, fishing gear, and vessel operations. In addition, for longline boats fishing out of California ports, an industry association has developed a voluntary logbook which is being considered for adoption by California and the PRFMC (Hanan[4]).[13] The La Jolla

[11] Hanan, D. A. 1996. Marine Resources Division, California Department of Fish and Game. SWFSC, P.O. Box 271, La Jolla, CA 92038-0271. Personal commun.

[12] In 1996, regulatins were passed in Oregon allowing both the use of drift nets and the landing of longline-caught fish.

[13] As of 1996, California requires the submission of logbooks by longline boats landing in the state.

Laboratory obtains summary logbook data for the high-seas Japanese, Korean, and Taiwanese longline fisheries, although data after 1990 are not available from Japan.

Oceanography Research

The goal of the Honolulu Laboratory's biological research on swordfish is to provide estimates of parameters needed for stock assessment modeling and to model the effect of gear characteristics on swordfish catch rates. Fishery oceanographic research will examine the effect of major oceanographic phenomena, e.g. El Niño, on swordfish distribution and catch rates.

Age and Growth—Efforts to refine estimates of age will continue by evaluating alternative light and electron microscope procedures and by attempting to validate ageing procedures. Sampling protocols will be revised to improve coverage of the size range of swordfish harvested by the Hawaii fleet and of the spatial range of the fishing fleet.

Size at Maturity—Sampling protocols will be developed to improve the collection of samples from the commercial longline fishery so that the precision of size-at-maturity estimates may be improved.

Fishery Oceanography—One approach will examine the effect of temperature gradients, as deduced from satellite data, on swordfish distribution and catch rates. Another will involve the use of satellite altimetry data on a mesoscale. Timely access to high-quality fisheries data and satellite oceanographic data will facilitate such research.

Stock Structure—The Honolulu Laboratory will continue to facilitate genetic research on swordfish by providing opportunities to scientists from across the Pacific to use the Laboratory's research vessel and to obtain samples.

Possible Cooperative Research—The following cooperative research has been proposed:

- Comparison of ageing techniques used by different scientists by exchanging swordfish hard parts collected from different segments of the Pacific fishery. This would also facilitate the identification of differences in regional growth, if they exist, better than independent research efforts.
- Archival tagging in fisheries across the range of the species would provide an opportunity for experiments to compare the effects of different oceanographic environments on movement.
- Joint acoustical tracking of swordfish in geographically-separated fisheries with differing oceanographic regimes would provide for more extensive testing of swordfish habitat preferences than tracking in any single fishery location.

Stock Assessment

The Honolulu Laboratory's stock assessment strategy involves a series of assessment techniques designed to progressively improve our understanding of resource dynamics. Almost all studies would benefit from, and in many cases require, cooperation and collaboration with researchers from across the Pacific to improve the quality of biological and fishery information and improve access to information.

Production Modeling—Once current, comprehensive statistics are available, initial efforts to assess the status of swordfish will employ dynamic stock-production modeling.

Yield per Recruit—Yield-per-recruit models will be employed to provide preliminary estimates of the effect of harvesting young fish, particularly by some segments of the Hawaii fleet.

Simulators—Stock and harvest simulators should be developed early on to guide stock-assessment and data-collection activities by predicting potential impacts of continued fishery development on stock dynamics.

Age-structured Modeling—Age- (or length-) structured stock-assessment models will be used to determine in more detail the impact of the fishery on the stock, e.g. the spawning component.

Spatial–Temporal Dynamics—The spatial and temporal variation of swordfish size in the catches of the Hawaii fleet will be compared to the results from the landings-based report in this symposium (DiNardo and Kwok, 1998). This and possibly other types of research will make it possible to standardize fishing effort statistics for the Hawaii longline fleet.

Possible Cooperative Research

- Cooperation between nations will be required to standardize effort statistics, due to changes in the high-seas longline fisheries of Japan, Korea, and Taiwan, the expansion of coastal fisheries, and the development of new fisheries using longline and other gear. A standardized time series of fishing effort statistics is needed to conduct unbiased production-model assessments.

- The use of nonequilibrium production models capable of including geographically-separated fisheries in a single model should provide better understanding of stock dynamics and more useful parameter estimates than fits using composite data.
- Because age- and length-structured models are dependent on age- or size-composition data from all geographically-separated segments of the fishery, at least cooperative development of the data sets is needed. Collaborative utilization of these data in fitting the models would be the best way of resolving data problems and would facilitate a common understanding of the resource status.
- Examination of the spatial and temporal dynamics of swordfish size distribution (DiNardo and Kwok, 1998) could best be extended by collaboration among investigators with access to comparable size data from other geographically-separated or overlapping fisheries.

Acknowledgments

I am grateful to Norman Bartoo, Gerard T. DiNardo, Doyle A. Hanan, Russell Y. Ito, and Jerry A. Wetherall for their review of earlier versions of this paper. Geographical charts were generated using the computer program Generic Mapping Tools, version 2.1.4 (Wessel and Smith, 1991).

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NOAA Technical Report NMFS 142

A Technical Report of the *Fishery Bulletin*

Biology and Fisheries of Swordfish, *Xiphias gladius*

Papers from the International Symposium on Pacific Swordfish, Ensenada, Mexico, 11–14 December 1994

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Cover illustration by Katherine Zecca

December 1998

U.S. Department of Commerce
Seattle, Washington