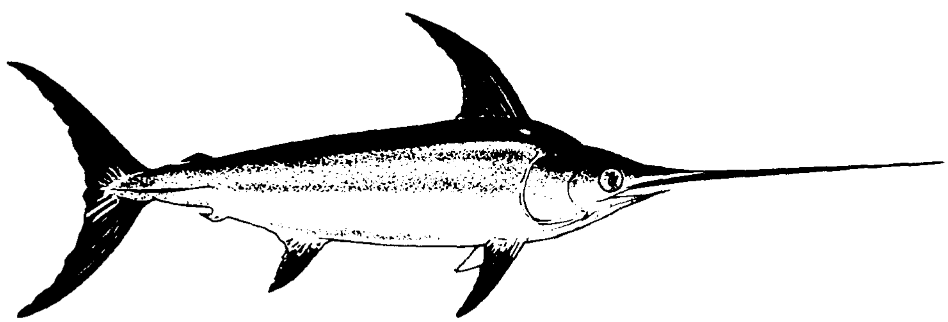
NOAA Technical Memorandum NMFS

JUNE 1999

PROCEEDINGS OF THE SECOND INTERNATIONAL PACIFIC SWORDFISH SYMPOSIUM



Edited by

Gerard T. DiNardo

NOAA-TM-NMFS-SWFSC-263

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

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CONTENTS

PREFACE

Swordfish (*Xiphias gladius*) are harvested commercially throughout their distribution in both coastal and high–seas fisheries. While most of the Pacific Ocean catch of swordfish is taken incidentally in fisheries targeting other fish species, particularly tunas, fishing operations targeting swordfish have increased substantially since the 1980s. Coastal fishing methods generally include harpooning, longlining, and drift gillnets. Fishing methods in the high seas include longlining and in the past drift gillnetting.

From 1952 to 1986 swordfish landings in the Pacific Ocean ranged between 12,000 and 20,000 metric tons (t). In the late 1980s and early 1990s, landings increased rapidly, peaking at 35,000 t in 1992. In recent years swordfish landings in the Pacific Ocean have averaged around 3,000 t.

The rapid increase in swordfish landings and directed fishing operations in the Pacific Ocean prompted the development of a symposium series on Pacific swordfish. The inaugural symposium was convened in Ensenada, Mexico in 1994 to address recent developments in swordfish fisheries, markets, and biological research in the Pacific Ocean.[1] In 1996, the symposium series was adopted by the newly formed Interim Scientific Committee for Tuna and Tuna—Like Species in the North Pacific Ocean (ISC). Furthermore, scientists from ISC member countries agreed that organizing future symposia would fall under the auspices of the ISC whose objective is to enhance scientific research and cooperation for conservation and rational utilization of tuna and tuna–like species which inhabit the North Pacific Ocean during part or all of their life cycle.

The Second International Swordfish Symposium was convened in Kahuku, Hawaii, March 3–6, 1997. The symposium provided a forum for the review and synthesis of recent developments in biological, fisheries oceanography, and resource assessment research on swordfish in the Pacific Ocean and relevant research in other oceans and a mechanism to promote international scientific collaboration in assessments of Pacific Ocean swordfish. Approximately 200 people, representing seven countries, participated in the symposium. Thorough descriptions of swordfish fisheries were presented by representatives from the United States, Japan, Philippines, Mexico, Chile, Australia, and the delegation from Réunion. A report on the Atlantic "experience" was presented by an ICCAT representative, and an Expert Panel was convened to discuss stock assessment approaches and data needs. Three concurrent working group sessions were held, focusing on specific themes—Biological Input to Stock Assessment, Fisheries Oceanography and Habitat, and Resource Assessment and Monitoring.

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[1]Barrett, I., O. Nishizaki, and N. Bartoo. 1998. Biology and fisheries of swordfish, *Xiphias gladius*. U.S. Dept. of Commerce, NOAA Tech. Report 142.

The conclusions and recommendations drawn from this symposium will benefit research conducted on Pacific Swordfish through the identification and advancement of methodologies in each of the research areas. The results should also be of considerable interest and applicable to swordfish research in other oceans, as many of the biological and migratory features as well as the research methodologies used may be similar.

I would like to thank Norman Bartoo, Oscar Sosa-Nishizaki, and Yuji Uozumi who put great effort into the organization of the Symposium as members of the Steering Committee; the working group chairs and rapporteurs Judith Kendig and Francine Fiust for editing and compiling the proceedings; and Martha Higa and Thomas Kazama for logistical support. The manuscript describing the swordfish fishery in Mexico was submitted in Spanish and subsequently translated into English. While the translated manuscript was approved by the authors, the Spanish version is included in the Appendix.

COUNTRY REPORTS

JAPANESE SWORDFISH FISHERIES IN THE PACIFIC OCEAN

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During the 1950s and 1960s, swordfish catch by Japanese fisheries was more than 80% of the total swordfish catch in the Pacific. The Japanese catch has been stable, but other countries such as the USA, Philippines, and Chile increased their catch in recent years and the percentage of the total catch by the Japanese has continued to decline. In the 1990s, the Japanese catch was only 36-45% of the total, although it is still the largest in the Pacific. In this paper, the current status of the Japanese swordfish fisheries is described using annual statistics of Japanese fisheries published by the Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries, as well as logbook data compiled by the National Research Institute of Far Seas Fisheries (NRIFSF). Recent research activities and data collection systems are also reviewed.

PRICE OF SWORDFISH IN THE JAPANESE MARKET

Table 1 shows the average price of frozen swordfish in Japan. The average price in the 1990s is about 680 yen per kg which is lower than the average (770 yen) in the 1980s (Anon., 1996). The price has gradually decreased in the last four years.

Table 1. Average price (yen per kg) of frozen swordfish in Japan (Anon., 1996).

Year	Swordfish
1980	773
1981	718
1982	862
1983	747
1984	902
1985	820
1986	791
1987	796
1988	697
1989	596
1990	646
1991	786
1992	691
1993	682
1994	587

JAPANESE SWORDFISH FISHERIES

The three swordfish fisheries in the Pacific are longline, large-mesh driftnet, and harpoon. These fisheries provide more than 95% of the total Japanese swordfish catch in the Pacific.

Longline

Longline fisheries are classified into three categories; i.e., coastal, offshore, and distant water. The ranges in boat size for the three categories are 10-20 gross registered tonnage (GRT), 20-120 GRT, and 120-500 GRT for coastal, offshore, and distant water longline fisheries, respectively. Table 2 shows the catch of swordfish by gear type. During the 1980s, the catch of swordfish by offshore and distant water longlines has been fairly stable at around 11,000 metric tons (t) (Uozumi and Uosaki, 1999). The catch decreased to approximately 8,500 t in 1991 but has increased again since 1993. The catch by coastal longlines (LL) fluctuated between 600 and 1,100 in the 1980s, but has increased to about 1,400 since 1993. The swordfish catch is the largest of the billfish catches, but it is only about 6% of the total Japanese longline catch in the Pacific.

Table 2. Swordfish catch (metric tons) by gear type in the Pacific Ocean.

Year	Offshore and distant water longline	Coastal LL	Driftnet	Harpoon	Others	Total
1980	8,913	824	1,746	398	72	11,953
1981	10,301	675	1,848	129	125	13,078
1982	8,957	839	1,257	195	102	11,350
1983	10,272	955	1,033	166	85	12,511
1984	9,529	1,141	1,053	117	147	11,987
1985	11,607	980	1,133	191	98	14,009
1986	11,721	960	1,264	123	133	14,201
1987	12,814	819	1,051	87	97	14,868
1988	13,394	665	1,234	173	40	15,506
1989	9,633	752	1,596	362	41	12,384
1990	9,432	690	1,027	128	15	11,292
1991	8,453	799	498	153	33	9,936
1992	8,654	1,181	887	381	22	11,125
1993	12,125	1,394	292	309	48	14,168
1994	11,053	1,357	421	308	40	13,179
1995	10,120	NA	NA	NA	NA	NA

Figure 1 shows the geographical distribution of swordfish catch by the Japanese longline in the 1990s. The swordfish catch is widely distributed in the Pacific. The catch in the North Pacific provides about 60% of the total Japanese catch in the Pacific. There are directed longline fisheries for swordfish in the coastal and offshore waters around Japan (see Uosaki and Takeuchi in this symposium). Most of the catch obtained around Japan are from these directed fisheries, while the catch of swordfish in the other areas is obtained by the distant water longline fishery targeting other species, such as bigeye. Nearly 40% of the swordfish catch in the Pacific and about 60% in the North Pacific is obtained by the swordfish-directed fisheries. Generally the longline gear of the swordfish-directed fishery has three or four branch lines and uses squid as bait. Buoy and branch lines used for the swordfish-directed fishery are much shorter than other tuna longlines. The operation is carried out at night. Nylon longline has recently been introduced in the Japanese longline fishery, but this type of gear is not used in the swordfish-directed fishery around Japan.

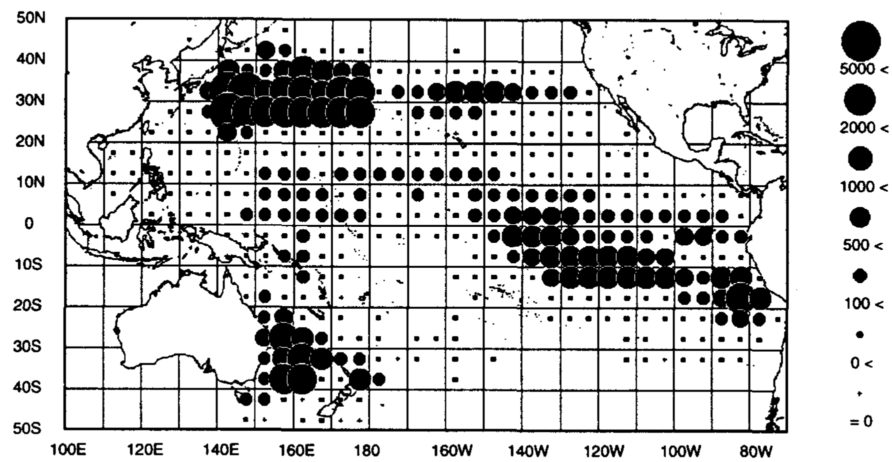

Figure 1. Geographic distribution of mean swordfish catch (thousand fish per year) of the Japanese longline fishery in the 1990s.

Large-Mesh Driftnet

The Japanese high-seas large-mesh driftnet fishery ceased in December 1992 as a result of a UN resolution banning large-scale high seas driftnet fishing. Currently driftnet fishing is conducted within the 200-mile EEZ of Japan off the Tohoku and Hokkaido region (Fig. 2). In recent years fishing effort has decreased significantly and the number of vessels in 1994 was about 40% of that in 1990. The swordfish catch was about 400 t after 1992, which was about 40% of the catch in the 1980s.

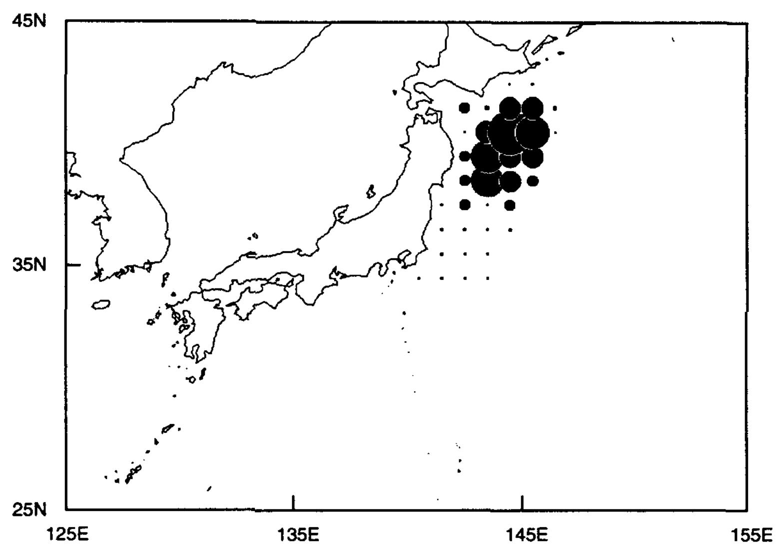

Figure 2. Geographic distribution of swordfish catch (number) of the Japanese large-mesh driftnet fishery in 1994.

Harpoon

Only catch statistics are available for this fishery. Catch fluctuated around 150 t in the 1980s, but increased to about 300 tons after 1991. Fishing grounds are located in the waters around Izu, in the middle section of Honsyu Island, and off Sanriku in the northern part of Honsyu Island.

FISHERY STATISTICS

Catalogues on available catch effort, and size data for each fishery are shown in Tables 3 and 4.

Table 3. Japanese Pacific Ocean swordfish catch and effort catalog.

Gear	Years	Species	Catch metric	Unit of effort	Time strata	Spatial resolution of data
Longline	1952-94	tunas & billfishes	number	hooks	month	5°X5°
Driftnet	1977-94	tunas & billfishes	number	tans	month	1°X1°

Table 4. Japanese Pacific Ocean size frequency catalog for swordfish.

Gear	Years	Kind of measurement	Interval	Time strata	Spatial resolution of data
Longline	1970-94	eye-fork length	5 cm	month	10°X20°
Driftnet	1977-94	processed weight	1 kg	month	port sampling

Catch and effort statistics

Longline

Logbooks of offshore and distant water longline fisheries have been collected since 1952. The systematic collection of logbooks for the coastal longline fishery began only recently. The NRIFSF is in charge of data processing and compilation. Significant changes in the longline logbook form were made in 1993 and included the addition of new information such as weight of fish (processed weight) and the kind of material(s) used for main and branch lines. The coverage rate of the logbook for the coastal fishery is unknown but is probably more than 50%. For the offshore and distant water longline fishery coverage rate is about 80% and 95%, respectively.

Large-Mesh Driftnet

Logbooks have been collected since 1977. Statistics for this fishery have been compiled by the NRIFSF. Coverage rate of the logbook is unknown, but it is assumed to be approximately 50%.

Harpoon

Only the landing statistics as shown in Table 2 are available.

Size Sampling

Longline

There are three sources of information on size data for longliner caught swordfish—measurements taken at the unloading sites, sales slips (weight only) obtained from wholesalers at major unloading ports, and on-board measurements undertaken by commercial, training, and research vessels. Prior to 1986 the sex of measured swordfish was not recorded. Since 1986 approximately 70% of the measured fish have been sexed.

Large-Mesh Driftnet

Size measurements of this fishery (processed weight) were taken at major unloading ports beginning in 1977, but sampling was terminated in 1995.

Harpoon

There is no size sampling for this fishery.

RESEARCH ACTIVITIES

Genetic Studies

Population analysis studies using mtDNA have been completed. Despite a high level of mtDNA variation within samples, no evidence of population structuring was observed in the Pacific.

Behavioral Studies by Experimental Longline Fishing

Hooking information of tunas in longline operations such as depth, temperature, and time of hooking have been collected by the R/V *Shoyo-maru* and several training boats of the fisheries high schools (Nakano, 1994; Okazaki and Nakano, 1995; Nakano and Seki, 1995). In conducting these experimental longlining studies, a small bathythermograph was developed by the Oceanographic Division of the NRIFSF and proved to be practical and effective.

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THE SWORDFISH FISHERY IN MEXICO: A DEVELOPMENT ALTERNATIVE

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Swordfish (*Xiphias gladius*) are found throughout the year in Mexican waters, and the fishery takes place mainly on the west coast of Baja California, with the port of Ensenada as the principal landing point for the catches. The fishing season for the Mexican fleet is from October through February, with the highest catches in November-January. After this season the resource moves south and is inaccessible to the fleet. In the south-central portion of the 200-mile Mexican Pacific Exclusive Economic Zone (MEEZ) swordfish are caught incidentally in the longline fishery for tunas.

The composition of the logged gillnet catches in the south of the Baja California peninsula shows a greater proportion of adult females, around 70-80%, and a length range of 90 to 245 cm, with an average of 164 cm (Castro et al., 1995). The age composition of the commercial catch of the Mexican fleet is estimated to cover a range of 1-9 years (Castro and Sosa, 1994), of which about 80% are mature females which, judging from the condition of the gonads observed, do not spawn in the catch area but seek warmer waters for reproduction. Length samples of swordfish analyzed by researchers from the National Fisheries Institutes Regional Fisheries Research Center in Manzanillo, Colima, aboard longline vessels targeting sharks in the south-central portion of the MEEZ in the 1980s show an average fork length of 267 cm, with a range of 128-334 cm.

In 1983 the government of Mexico restricted the use of longlines in the Pacific Ocean by limiting the catch of billfish within 50 miles of the coastline exclusively to the sport fishery, a regulation which remains in force to this day. This is one cause of the reduction in catch; another contributing factor is the great sensitivity of this species to environmental changes such as the presence of an El Nio event, which causes the resource to move northward and render it inaccessible to the Mexican fleet. Another important factor is the fishing effort of foreign fleets outside the MEEZ, which could affect the abundance of the resource in the Mexican fleets fishing area. Unlike the biological management of resources, which has a positive impact on the biological condition of the exploited populations, the majority of the measures applied to swordfish and striped marlin (*Tetrapturus audax*) in the northeastern Pacific have come about as a result of the actions of political groups, driven by the sport fishery in an attempt to limit the operations of the commercial fisheries. These types of regulations, more accurately defined as management with social and economic objectives, have affected the productive sectors with little effect on the status of the stocks of billfish of the Pacific.

Swordfish are a national resource whose exploitation should be promoted on the basis of estimates of abundance and sustainable yield, and should use those fishing gears, methods, and systems which national and international experience has shown allow high production from this resource and which are ecologically sound.

Since May 1995, the National Fisheries Institute has received requests from 10 companies, representing 15 multi-fishery vessels, seeking 20-year concessions for the commercial exploitation of swordfish. Some request permission to continue using drift gillnets, while others prefer changing to drift longlines, seeking better commercial opportunities in the foreign market.

This latter alternative has a greater chance of success in view of worldwide pressure to ban or restrict the use of driftnets. Steps are also being taken towards modifying the sport fishing regulations in order to separate swordfish from the other billfishes. The catch of swordfish in the sport fishery is insignificant and should not be included with other billfishes.

THE SWORDFISH FISHERY IN THE PACIFIC OCEAN

The fishery for swordfish in Mexican waters has developed mainly in two stages, the longline fishery, begun in 1964, and the driftnet fishery, begun in 1987. The catch of swordfish in the sport fishery is barely significant, about 30 fish annually.

Longlines

The Japanese longline fishery for billfish has been by far the most important in the eastern Pacific Ocean (EPO) in terms of duration, geographical coverage, and catch volume (Nakano and Bayliff, 1990). Exploratory trips by Japanese vessels in search of these resources of the EPO began about 1956, and by 1968 their fishing activities extended to most tropical and subtropical areas, including the present MEEZ.

In 1963 a great portion of the effort moved to the northeastern EPO, where exploration had revealed large concentrations of striped marlin, sailfish (*Istiophorus platypterus*), and swordfish, together with small proportions of blue marlin (*Makaira nigricans*) and black marlin (*M. indica*) (Joseph, 1972). The greatest catch rates for swordfish were obtained between the Revillagigedo Islands and the southern end of the Gulf of California and off the west coast of Baja California up to Baha Magdalena.

The most important area for the longline fishery for swordfish in Mexican waters is northwest of the southern tip of the Baja California peninsula and the mouth of the Gulf of California, in winter and spring (Fig. 1). In fact, the highest catch rates of swordfish in the northeastern Pacific have been recorded in this area and also the highest abundances of striped marlin in the Pacific and Indian Oceans; therefore, some authors call it the core area (Squire and Au, 1990). During summer and fall the catch of swordfish is generally low and the area of operations extended southward, in search of striped marlin, from Baha Magdalena and Cabo San Lucas to the Revillagigedo Islands.

Substantial fishing effort began in the core area in 1964 and remained at the same level until 1976. Throughout that period the catch per unit of effort (CPUE; fish per thousand hooks) of swordfish remained relatively stable, recording variable catches, with maxima in 1964 and 1972, of 13,519 and 13,677 fish, respectively (Fig. 2a).

Permits were issued for longlining by Mexican-Japanese joint-venture companies in 1980 and swordfish catches and CPUEs are depicted in Figure 2b. The restrictions imposed on the fishery in 1983, and the eventual cancellation of this type of permit in 1990, led to the development of the current Mexican fishery with drift gillnets.

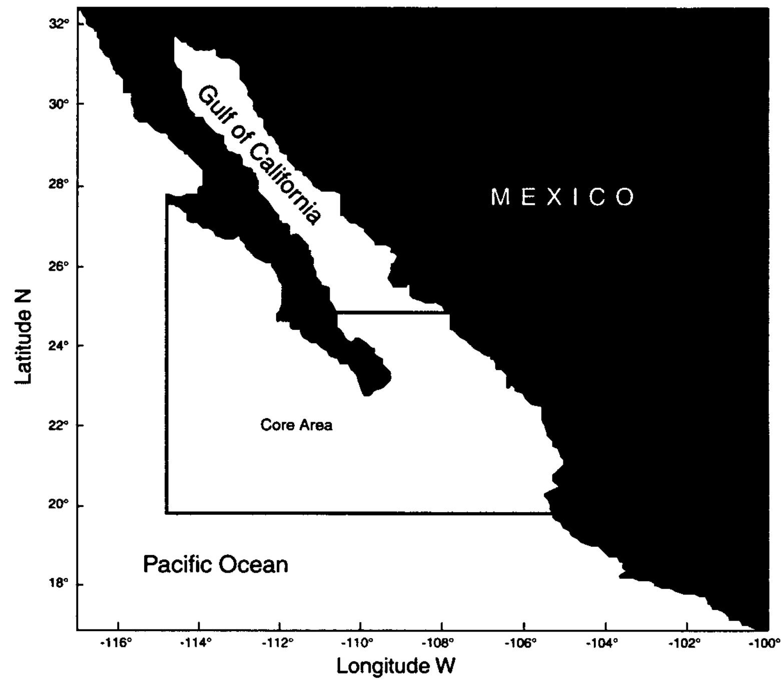

Figure 1. Core area of greatest abundance of swordfish in the northeastern Pacific (modified from Squire and Au, 1990).

Between 1980, when the joint-venture companies began, and 1989 the longline fishing effort in the MEEZ fluctuated greatly with a peak of 3,757,060 hooks set in 1988, which caught 48,022 striped marlin, 17,750 sailfish, and 5,313 swordfish. Those were record catches of marlin and sailfish for the 1980-1989 period, whereas the greatest catch of swordfish was in 1981, with 10,677 fish caught (Fig. 2).

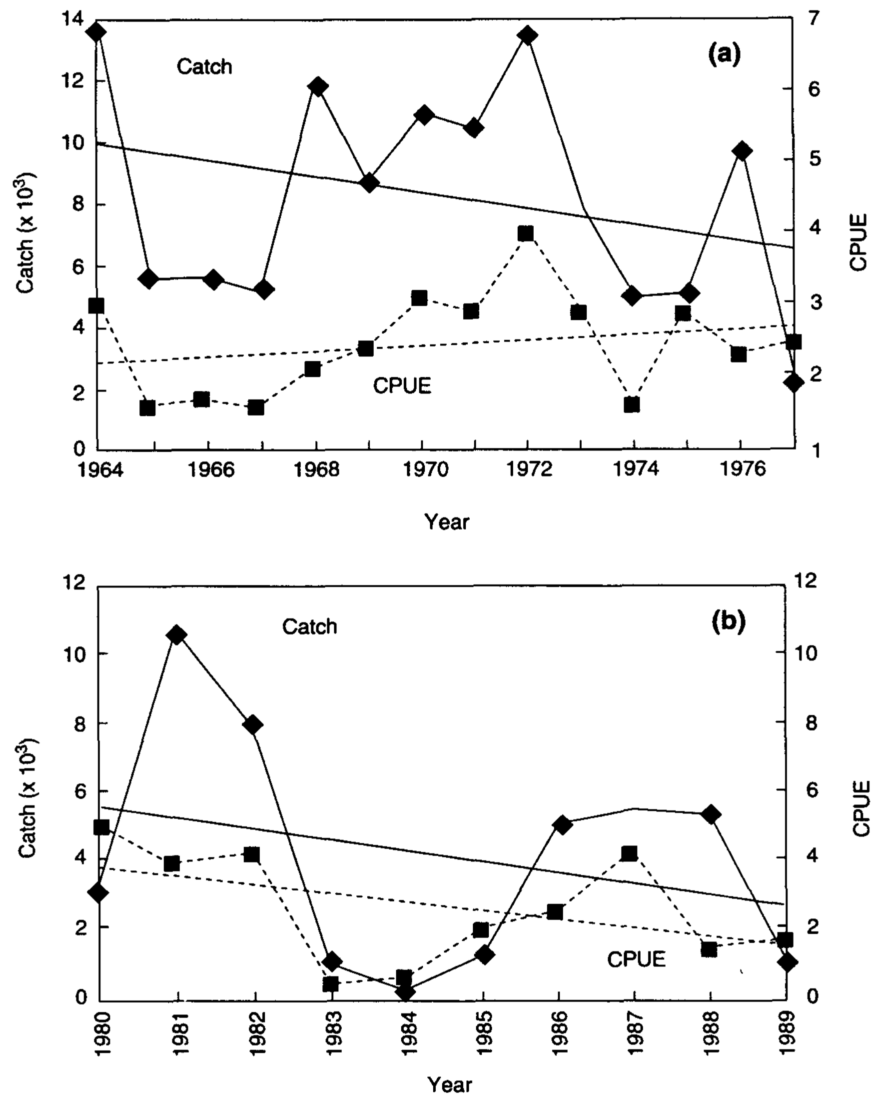

Figure 2. Catches and CPUE of swordfish and their trends: (a) Japanese longline fleet, core area south of Baja California, 1964-1977; (b) Joint-venture longline fleet, Mexican EEZ, 1980-1989.

Drift Gillnets

The gillnet fishery in California, which catches mostly sharks and swordfish, catches an annual average of 550 striped marlins and unknown quantities of black marlin (Hanan et al., 1993).

The use of drift gillnets is a relatively recent innovation in the Mexican billfish fishery, having begun in 1987. In 1992 the Mexican gillnet fleet consisted of 27 vessels with permits, 24 of which fished; in 1995 this number fell to 22 vessels. One factor in this reduction is the downward trend in the prices paid in foreign markets for swordfish caught with drift gillnets, compared to swordfish caught with longlines (Sakagawa, 1994). The gillnet vessels are shrimp and tuna boats with the adaptations necessary for this fishery.

The fleet operates along the west coast of Baja California in the same areas previously frequented by the longliners. Apparently, the main fishing activity takes place from September to January in two areas, one south of Punta Eugenia to latitude 23°N and the other from latitude 30°N to the northern limit of the MEEZ (Castro et al., 1995).

Published estimates of the production of swordfish from this fishery differ widely. Castro et al. (1995) report a minimum catch of 100 metric tons (t) in 1988 and a maximum of 700 t in 1993. However, Squire and Muhlia (1992) present data which range from 900 to 1,080 t of filleted product, equivalent to between 1,170 and 1,404 t in weight of whole fish.

Sport and Recreational Fisheries

The sport and recreational fishery takes place from southern California to Peru and catches an unknown quantity of billfishes. In the EPO billfish are also caught incidentally in the purse-seine fishery for tunas. According to the logbooks of observers on board the EPO purse-seine fleet, approximately 9% of sets made off central America have recorded catches of billfish (Squire and Muhlia, 1992).

Swordfish are one of the most sought-after trophy fish, but the number caught each year in the MEEZ is very small (~29 per year) and similar to that reported for the southern region of California (Anonymous, 1981).

MONITORING OF THE FISHERY

Catch and effort data is collected by means of arrival reports of fishing vessels at the end of each fishing trip, which includes days of fishing and the catch of swordfish in both weight and number.

A program to place scientific observers aboard fishing vessels to collect additional information has been initiated.

A potential source of information is the fishing captains logbooks, in which daily records of the fishing activities during each trip are maintained. The utility of this information still needs to be assessed.

Some academic institutions also conduct research on billfish species aboard commercial vessels, producing information pertinent to the understanding of the biology of these species.

CATCH, EFFORT, AND CPUE

Longlines

The CPUE of swordfish in the eastern Pacific has been stable since 1965, and it is estimated that the resource is capable of sustaining annual yields of 35,000 fish, equivalent to 2,800 t (Bartoo and Coan, 1989; Joseph, 1981). Various percentages of that yield have been caught in recent years by the gillnet fleets of Mexico and the U.S.A.

During 1964-80 the Japanese longline fishery caught an average of 7,273 swordfish annually in the core area of abundance, with an average CPUE of 2.48 fish per thousand hooks (Fig. 2).

Between 1980 and 1989 the joint-venture companies caught an annual average of 4,090 swordfish in the MEEZ, with an average CPUE of 2.51 fish per thousand hooks (Fig. 2), a value very similar to that obtained by the Japanese longliners during 1964-80.

It should be noted that between 1971 and 1976 the Japanese longline fleet caught an average of 35,000 swordfish annually in the entire eastern Pacific, a level equivalent to the estimated sustainable yield. Twenty-six percent of this catch (9,100 fish/year) was taken in the waters of the current MEEZ, with an average CPUE of 2.7, and a maximum of 3.9 swordfish per thousand hooks in 1972.

The fishing effort increased from 5 million hooks in 1961 to 91 million hooks in 1973, when the effort within 200 nautical miles of the Mexican coast was approximately 4 million hooks, 5.1% of the total for the EPO in that year. It is estimated that during the 1971-79 period the effort in the current MEEZ represented only 7% of the total effort applied in the entire EPO. However, the production of billfish was substantial, several times greater than would be expected with a level of effort of 7%. During 1971-76, the years prior to the establishment of the MEEZ, the Japanese fishery obtained 56% of its catches of striped marlin in the EPO from this area (Joseph, 1981).

Longline effort declined rapidly in 1976-77 after the MEEZ was established, and increased only after 1980, when permits were issued for the joint-venture companies. The effort off the coast of the United States was less than in Mexican waters and was mainly exploratory (Anonymous, 1980).

Drift Gillnets

The Mexican drift gillnet fishery for swordfish started in 1987, and catches reached a peak in 1991 with about 828 t; these catches have fallen to 131 and 154 t in 1994 and 1995, respectively (Fig. 3).

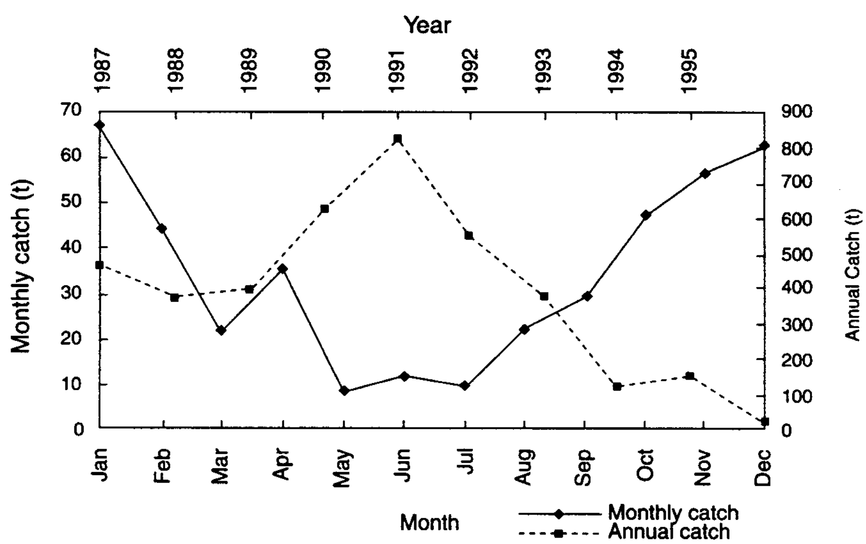

Figure 3. Average monthly catch (1987-1995) and annual catches of swordfish by the Mexican gillnet fleet (1996: preliminary data, January-June).

The Mexican gillnet fleet has an unknown bycatch of marlins (Squire and Muhlia, 1992). It is estimated that the total catch is made up of sharks (25%), various species of no commercial importance (25%), sunfish (*Mola* sp., 19%), tunas (*Thunnus* sp., 19%), and the remaining 12% swordfish, the species targeted by this fishery (Sosa et al., 1992).

The proportion of swordfish is low and reflects low efficiency in catching this resource.

It can be estimated in general terms from the data available that in the three years 1994-1996 the average CPUE per fishing trip and per day was 882.16 kg and 71.82 kg, respectively (Fig. 4). Number of trips, a very rough estimate of fishing effort, is used here because the number of effective fishing sets is unknown.

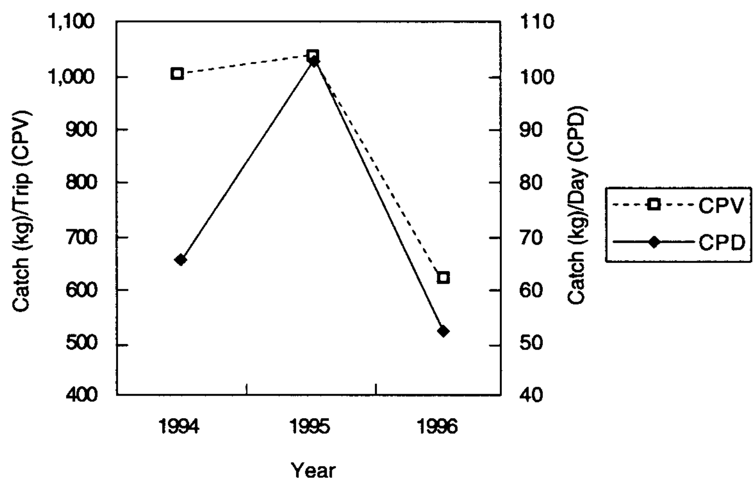

Figure 4. Catch of swordfish per unit of effort by trip and day in the Mexican gillnet fishery (1996: preliminary data, January-June).

Drift gillnets incidentally catch marine mammals and turtles. It is important to know the extent of these types of fortuitous catches in the Mexican fishery. The relative composition of the Mexican catches in recent years, grouped into three principal categories (sharks, swordfish, and scalefish), is shown in Figure 5.

Oceanic sharks predominate in the drift gillnet catches; little is known about the biological status of these populations. This is cause for concern because all over the world shark fisheries have proved fragile, tending to decline markedly or collapse suddenly (Compagno, 1990). There are examples of the ways in which drift gillnets can affect shark stocks. Most of the mako (*Isurus oxyrinchus*) and thresher (*Alopias pelagicus*, *A. superciliosus*, *A. vulpinus*) sharks caught off southern California were juveniles, and their average length declined 21% between 1982 and 1991. There are blue sharks (*Prionace glauca*) in the catches, but since they are discarded at sea without being recorded in the logbooks, their fishing mortality is unknown (Hanan et al., 1993).

Because drift gillnets are a passive gear which operates by intercepting the passage of the species it catches, there is the potential danger of causing what is known as ghost fishing, because lost nets (or parts of nets) can continue making catches for an indeterminate time period for as long as they remain in the water column.

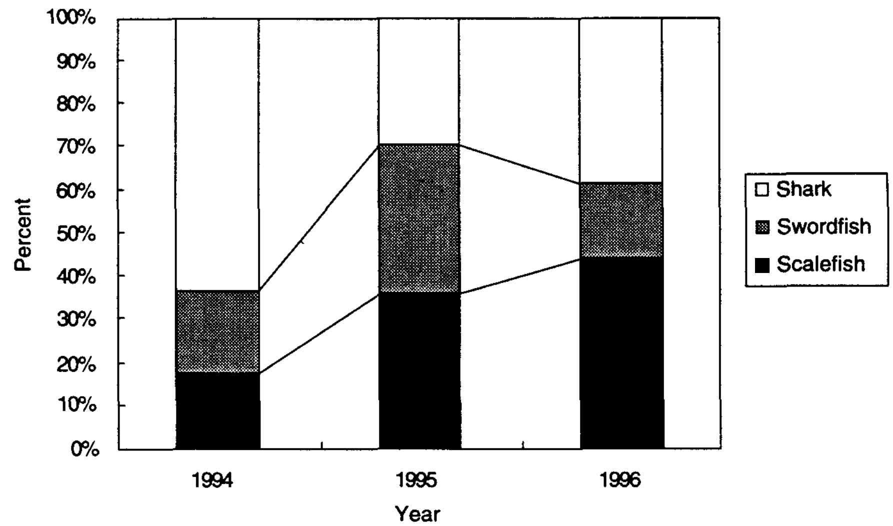

Figure 5. Relative composition of annual catches by the Mexican gillnet fleet grouped into 3 principal categories, shark, swordfish, and scalefish (1996: preliminary data, January-June).

RECOMMENDATIONS

A data collection system needs to be put into effect for fishing trips by the Mexican-flag gillnet fleet, with the aim of monitoring fishing operations and their catch. This would make it possible to carry out research into such essential aspects of the fishery as, for example, the geographical and temporal distribution of fishing effort, the volume and composition of the catches, the catch per unit of effort, and the population structure of the principal species. The system would also facilitate an understanding of the evolution of the biological status of the local populations and, if necessary, the timely adoption of decisions pertinent to the management of the resources.

The presence of scientific observers aboard the fleet, authorized by the Secretariat for the Environment, Natural Resources and Fisheries, is necessary in order to monitor the fishery and obtain the biological, fisheries, and technological information which will make possible the long-term exploitation of the resource and allow the maximum social benefit to be obtained from this activity with the least possible adverse environmental impact.

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U.S. SWORDFISH FISHERIES OF THE NORTH PACIFIC OCEAN

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INTRODUCTION

In 1960, U.S. North Pacific broadbill swordfish (*Xiphias gladius*) fisheries accounted for approximately 60% of the U.S. domestic production (Fisheries Statistics Division, 1997). Landings were an estimated 3,700 metric tons (t) worth $20 million. Three gear types (harpoon, drift gill net, and longline) make up the U.S. swordfish fisheries in the North Pacific. Harpooning for swordfish here dates back to the early 1900s (Coan et al., 1998) and primarily supplied the local market for swordfish up until the late 1970s. When the market expanded, harpoon landings peaked at 1,699 t in 1978 and have since declined (Fig. 1). The California drift gill net fishery, which began in 1980, replaced the harpoon fishery as the dominant swordfish fishery on the west coast, and drift gill net landings peaked at 2,400 t in 1985. Some swordfish caught in California could not be identified as to whether harpoon or gill net was used, and landings from such records is represented as unknown fishing gear landings.

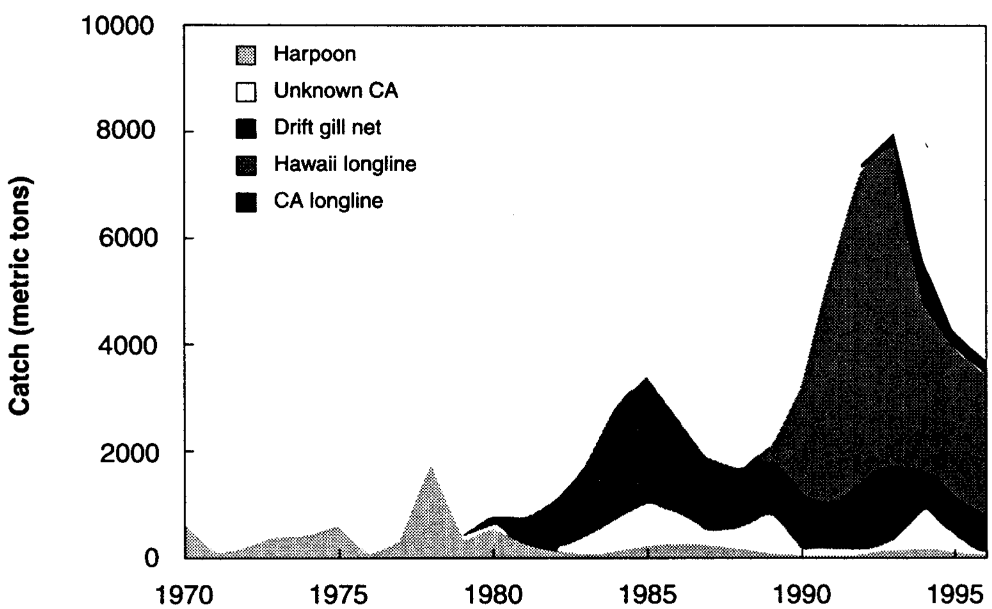

Figure 1. Catch by the U.S. swordfish fisheries of the North Pacific Ocean 1970-95.

Longlining for swordfish in Hawaii began in 1988 (Ito et al., 1998), grew rapidly with landings peaking at 6,040 t in 1993, and is currently the largest U.S. swordfish fishery in the North Pacific Ocean. California has a smaller fleet of longline vessels most of which originated from the Hawaii-based, Gulf of Mexico, or Atlantic longline fishery. The harpoon fishery is usually within a few miles of the California coast. The gill net fishery extends from coastal waters to well beyond the 200-mile U.S. Exclusive Economic Zone (EEZ), and longline fishing often extends beyond a thousand miles from U.S. ports, well into international waters (Coan et al., 1998; Hanan et al., 1993; Ito and Machado, 1996). This report describes each of the U.S. swordfish fisheries and sources of data for the North Pacific Ocean.

DESCRIPTION OF THE FISHERIES

Hawaii-Based Longline Fishery

Longlining for large tunas in Hawaii began in the early 1900s (June, 1950). A variety of marlin and other pelagic species were also caught, of which swordfish were only a small fraction of the landings (Yoshida, 1974; Kawamoto et al., 1989). The number of longline vessels increased rapidly in the late 1980s (Boggs and Ito, 1993). Concurrently, longline techniques used to target swordfish were introduced by U.S. longliners from the Gulf of Mexico and the Atlantic swordfish fisheries and helped to establish Hawaii as a major producer of swordfish. A federal moratorium capping the number of longline vessels at 167 was initiated in 1991 at which time the number of active longline vessels peaked at 141 with 114 of those vessels fishing for swordfish as their primary or secondary target (Ito et al., 1998) (Fig. 2). Some of the longline vessels during that time fished exclusively for swordfish throughout the entire year, but that activity has since declined. The number of active vessels decreased to 103 in 1996 of which 58 fished for swordfish as their primary or secondary target species.

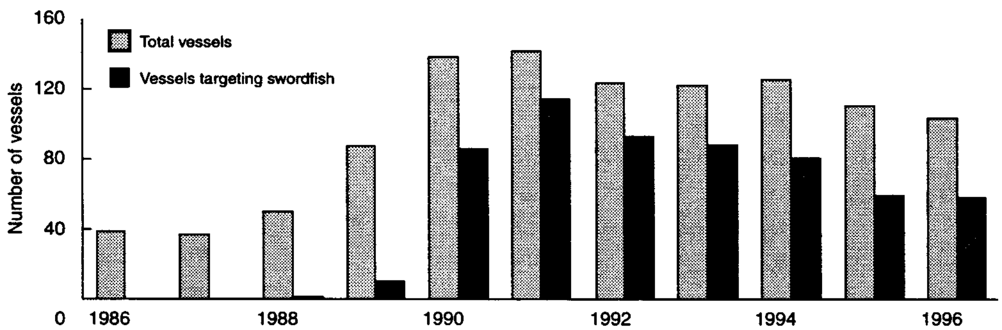

Figure 2. Total number of active Hawaii-based longline vessels and longlines targeting swordfish, 1986-96.

Longline gear consists of a monofilament main line which is stored on a large hydraulic reel. When deployed, 800 to 1,000 hooks baited with large squid are attached to 30-40 miles of main line. Chemical light sticks are also attached to branch lines. Swordfish longline gear is usually set in the evening, soaked overnight, and hauled the following morning. Fish landed are headed, gutted, finned, and packed in ice. Trips usually last about a month but occasionally exceed 2 months. Longlining for swordfish occurs year round, but effort is highest during the first and second quarters. The area fished by the Hawaii-based longline fleet ranged from latitude 5°N to 48°N and from longitude 170°E to 130°W, but the higher catches of swordfish are typically found north of the Hawaiian Islands (Curran et al., 1996).

The Hawaii-based longline fishery is the largest producer of swordfish of all U.S. North Pacific swordfish fisheries. Swordfish landings from this fishery began to increase in 1989 when a few vessels successfully targeted swordfish off Hawaii. Swordfish landings increased rapidly, peaking at 6,040 t in 1993, and declining to 2,644 t in 1996 (Table 1). Although there was a substantial decrease in landings after 1993, swordfish remains the largest component of Hawaii longline landings. Other species caught by the Hawaii-based longline fishery include sharks, bigeye tuna (*Thunnus obesus*), albacore (*T. alalunga*), yellowfin tuna (*T. albacares*), bluefin tuna (*T. thynnus*), marlins (*Istophoridae*), mahimahi (*Coryphaena hippurus*), moonfish (*Lampris guttatus*), wahoo (*Acanthocybium solandri*), and oilfish (*Gempylidae*). Interactions with turtles, seabirds, and marine mammals occur and are monitored by a Federal observer program.

Most of the swordfish landed in Hawaii are exported to the continental U.S. where demand is dependent upon the domestic swordfish market. Mean ex-vessel price (based on dollar per pound dressed weight) for swordfish ranged from $2.80 to $4.70, with a mean ex-vessel price of $3.25 (Table 2).

Swordfish CPUE (swordfish per 1,000 hooks) varies substantially depending on targeting practices (Fig. 3). Swordfish CPUE for trips specifically targeting swordfish peaked at 15.4 fish in 1991, dropped to 10.3 fish in 1994, and increased to 14.2 fish in 1996. Tuna-targeted trips had the lowest swordfish CPUE while mixed target trips had average swordfish CPUE throughout 1991-96. Swordfish-targeted trips usually have the highest swordfish CPUE during the first and second quarters of a year and lowest CPUE in the third quarter.

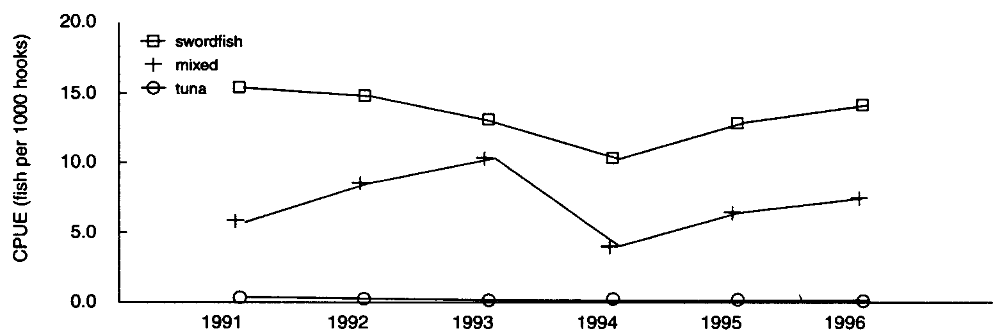

Figure 3. Hawaii-based longline catch-per-unit-effort (CPUE) by trip type, 1991-96.

The weights of individual swordfish were converted into estimates of cleithrum to fork length (CL) (James Uchiyama, pers. commun.). Swordfish mean CL increased from 152.4 cm in 1988 to 171.8 cm in 1992 and decreased slightly to 165.6 cm in 1996 (Table 3). The increase in mean CL from 1988 through 1992 may be related to increased targeting of swordfish and expansion of the area fished for swordfish (DiNardo and Kwok, 1998). Mean weight of swordfish landed by longliners targeting swordfish was generally larger than that of those caught by longliners targeting tunas (Ito and Machado, 1996).

California-Based Longline Fishery

The California-based longline fishery began in 1991 when 3 vessels based in San Pedro fished waters outside the U.S. EEZ (Vojkovich and Barsky, 1998). Since then, the fleet increased to 31 vessels in 1994 and declined to 14 vessels in 1996 (Fig. 4). The California-based longline fleet is composed of vessels that also participated in the Hawaii-based, Gulf of Mexico, or Atlantic ocean-based longline fleet.

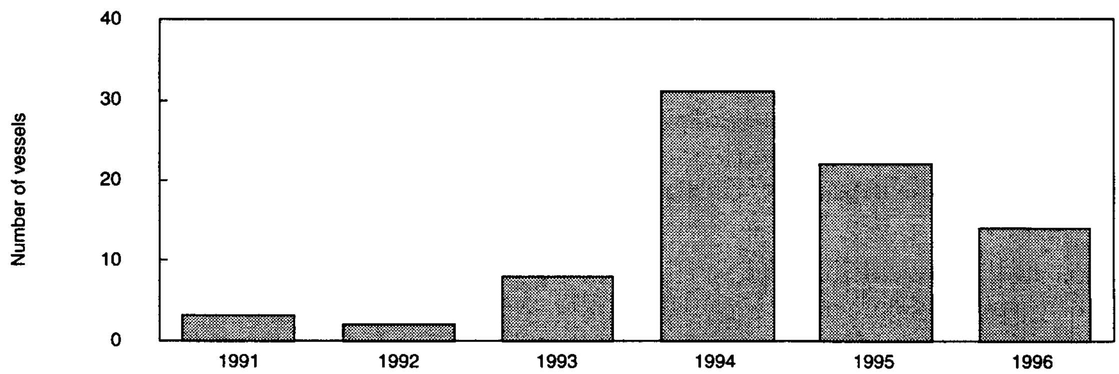

Figure 4. California-based longline vessels, 1991-96.

Incidental catches in the longline swordfish fishery include sharks, yellowfin tuna, bluefin tuna, bigeye tuna, albacore, mahimahi, moonfish, and oilfish. Marlins are also caught, but California Department of Fish and Game (CDFG) regulations prohibit landing these species caught on longlines. Although interactions with marine mammals, birds, and turtles are seldom reported, there is evidence that these species are also caught.

This fishery operates year round, with fishing trips lasting 21 days or less. Vessels normally set about 800 to 1,300 hooks at night. Light sticks are used, and bait is usually large squid. Longline vessels off-loading their catch in California must fish outside of the U.S. 200-mile EEZ. Logbook data indicate that fishing occurs between latitude 21°N to 40°N and longitude 130°W to 140°W.

The longline catch of swordfish was 41 t in 1991, increased to a high of 721 t in 1994, and decreased to an estimated 228 t in 1996 (Table 1). Ex-vessel prices for longline-caught swordfish are the lowest compared to prices for swordfish caught by other California swordfish fisheries (Table 2). During the period 1992-96, ex-vessel prices for longline-caught swordfish averaged $3.00-$3.50 dressed weight (CDFG, 1993-97).

California-based longline CPUE is measured as swordfish per 1,000 hooks. CPUE averaged seven fish per 1,000 hooks in 1994 and five fish per 1,000 hooks in 1995.

Longline caught swordfish CL is recorded as fish are unloaded at the markets. During 1994 and 1995, 1,500 CL measurements and 2,100 weights of longline-caught swordfish were recorded. Swordfish CL ranged from 73 cm to 226 cm CL with an average CL of 136 cm (Table 3).

California Drift Gill Net Fishery

The California drift gill net fishery for sharks (thresher shark, *Alopias vulpinus*, and shortfin mako shark, *Isurus oxyrinchus*) and swordfish developed in the late 1970s (Hanan et al., 1993). The fishery was originally directed toward sharks but changed in the early 1980s when regulations allowed for greater landings of swordfish. Incidental catches include tunas and other pelagic fish. Interactions with marine mammals and turtles also occur in this fishery. The number of drift gill net vessels peaked at 309 during 1985-86 and decreased to 112 vessels during 1995-96 (Fig. 5). CDFG currently limits the participants in the fishery to 150 permitted vessels.

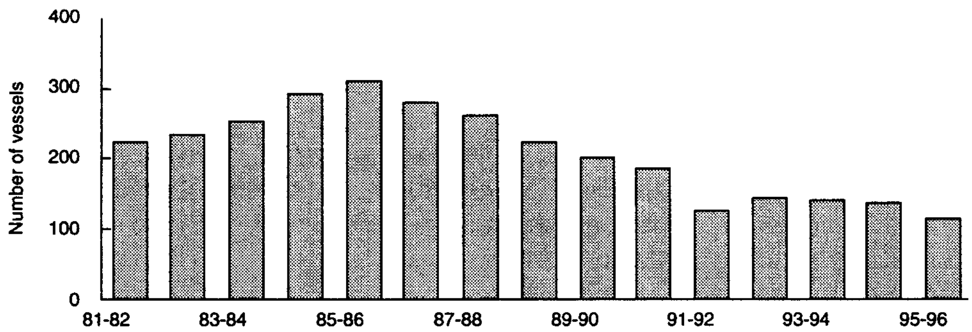

Figure 5. Number of California gill net vessels, 1981-82 through 1995-96.

Drift gill nets used in this fishery are made of 3-strand twisted nylon with mesh size varying from 33 cm to 48 cm (Hanan et al., 1993) and range in length from 1.5 to 1.8 km. The nets are set 46 to 61 cm below the surface in the evening and pulled before sunrise. The fishery begins in May of one year and continues until March or April of the next year. Fishing is concentrated in the Southern California Bight (waters off Point Conception down to the Mexican border) but occasionally extends up to San Francisco and the San Clemente Islands and as far north as Oregon. Swordfish are caught within 200 miles of shore and peak catches usually occur during October and November.

Drift gill net catches of swordfish ranged from a low of 160 t in 1980 to a high of 2,400 t in 1985. Since 1985, catches have decreased to 725 t in 1996 (Table 1). Average ex-vessel prices for these fish ranged from $4.00 to $4.25 for the period 1992-96 (Table 2) (CDFG, 1993-96).

CPUE has been generally stable ranging from 1.94 to 2.53 swordfish per set (Fig. 6).

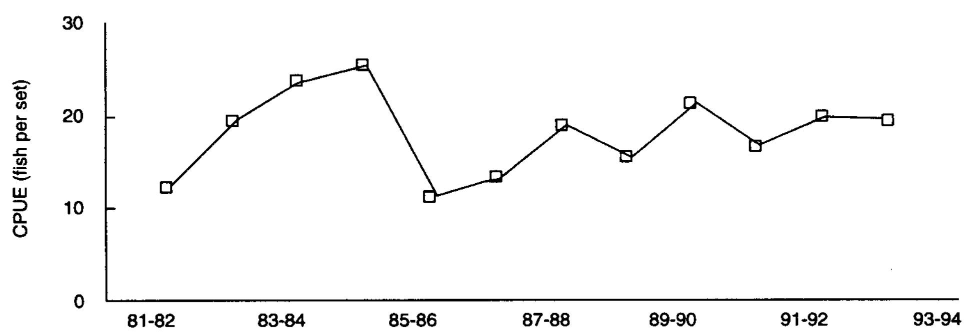

Figure 6. California drift net fishery catch-per-unit (CPUE), 1981-82 through 1993-94.

Swordfish CL ranged from 47 and 250 cm with a mean CL ranging from 132 cm to 152 cm (Table 3). Most of the fish were between 100 and 195 cm CL and were mostly immature individuals 3 to 5 years old. Larger swordfish (150-160 cm CL) tend to be caught off the northern California and Oregon coasts from June to December and smaller swordfish (130-145 cm CL) farther south off southern California from January to May.

California Harpoon Fishery

The California harpoon fishery began in the early 1900s. The number of harpoon vessels peaked in 1978 and 1980 at 309 and 305 vessels, respectively (Fig. 7), but participation dropped below 200 vessels in the early 1980s and leveled off between 87 to 116 vessels during the mid-1980s. The number of active vessels in the 1990s has been between 30 and 52. Harpoon gear consists of a handle about 3 to 5 m long, attached to a metal shank, approximately 0.6 m long and tipped with a removable bronze or iron dart (Coan et al., 1998). The dart is attached to a main line 15 to 46 m long, which terminates with floats and markers. Harpoon fishermen search for swordfish that bask on the sea surface. The prevalent method of sighting swordfish is looking for them while they are "finning" or basking on the surface in blue/green water of 54°F to 79°F. When a fish is spotted and harpooned, the handle is pulled free from the dart and the main line, marker flag, and floats are played out until these are free from the vessel. The fish is allowed to tire itself before being hauled aboard.

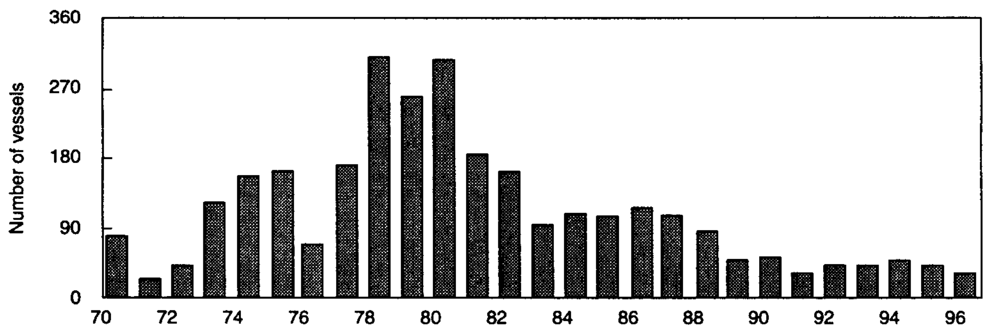

Figure 7. Number of California harpoon vessels, 1974-96.

The fishing area extends from San Diego to San Francisco (Coan et al., 1998). The fishery begins during April or May in waters off San Diego, peaks in July or August, and ends in December in waters off San Francisco. The fishery also catches a few sharks, mainly thresher shark.

Harpoon catches have been recorded as far back as 1918. Swordfish catches peaked in 1978 at 1,699 t, then decreased, averaging about 230 t during the period 1979-88, and about 80 t during 1989-95 (Table 1). Average ex-vessel prices for harpooned swordfish were the highest for all swordfish fisheries in California ranging from $5.00 to $5.25 per pound (Table 2) (CDFG, 1993-97).

Seventy-four percent of the swordfish pursued were actually harpooned and of these 91% were actually landed. Harpoon fishery CPUE (fish per day) was generally higher for vessels that used spotter aircraft than for vessels that did not (Coan et al., 1998). Combined CPUE (with and without aircraft) varied from a peak of 0.93 fish per day to a low of 0.14 fish per day (Fig. 8).

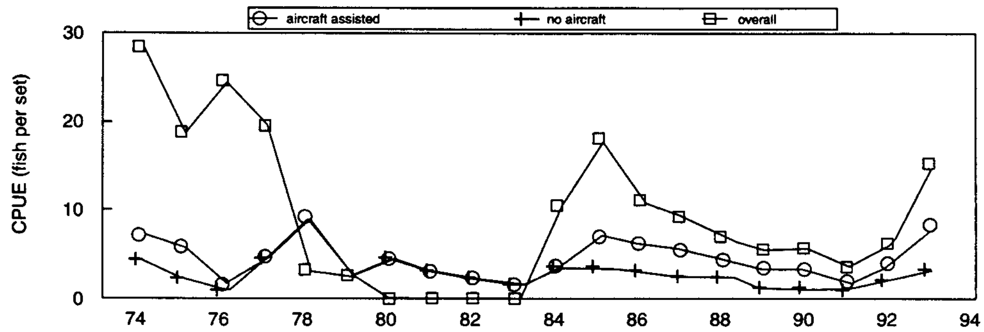

Figure 8. California harpoon fishery catch-per-unit-effort (CPUE) with aircraft assistance, without aircraft, and overall CPUE, 1974-93.

Harpoon-caught swordfish are measured by port samplers as fish are unloaded at markets. Since priority is given to measurement of drift gill net-caught fish, sample sizes of harpoon-caught fish are low (390 fish during 1981-93). CL for harpoon-caught swordfish ranged between 62 and 217 cm, with an average of 149 cm for all years combined. While mean CL is shown in Table 3 the small sample sizes, especially during 1989-91 (3, 1, and 6 fish, respectively), prevent comparisons among years.

DATA SOURCES

Hawaii

Data on the Hawaii-based longline fishery are available from six sources: federal longline logbooks; market sampling; State of Hawaii commercial fishermen catch reports; at-sea observer trips; NOAA ship *Townsend Cromwell* research cruises; and voluntary tag, release, and recovery information from fishermen. Tables 4 and 5 list availability and formats of data. Federal longline logbook data submission is mandatory and represents the most complete coverage of the Hawaii-based longline fishery. The market sample ranged from 25% to 90% of fish landed. Observers covered about 5% of the total longline trips. Each of the six data sets contains unique information that provides insight on the performance of the fishery and the biology and ecology of swordfish as well as other pelagic species caught. Linking the data sets also allows NMFS scientists to evaluate the accuracy of the data.

Since November 1990, all U.S.-based longline vessels in Hawaii have been required to maintain a daily federal longline logbook and submit it after each trip. Data recorded in the logbooks include fishing effort (number of hooks), number of fish caught by species, fishing location, gear configuration, oceanographic observations, and interactions with protected species.

Market data on longline catch were first collected by NMFS in 1987 and contain biological and economic information at the wholesale level. Fish are sampled at the market, and individual fish weights are recorded to the nearest half pound. Processed weights are raised to round weight based on process-specific conversion factors. Sex of fish is not available as most swordfish landed are headed, finned, and gutted.

State of Hawaii Division of Aquatic Resources (HDAR) commercial fisheries data are available from 1948 to the present. The HDAR requires longline fishermen to submit longline trip reports which list the pelagic species caught, number, pounds caught, pounds sold, and total value for each species.

A mandatory observer program began in February 1994 (Dollar, 1994) to quantify the incidental take of sea turtles in the Hawaii-based longline fishery. A suite of biological and oceanographic data are collected and these data provide detailed information on swordfish.

Since 1991, the NOAA ship *Townsend Cromwell* has dedicated one or two research cruises a year to collecting detailed data on swordfish biology and ecology. The cruises deploy standard monofilament longline gear to catch swordfish. Hook timers and time-depth recorders (TDRs) are used to collect information on fishing depth of the gear and on swordfish behavior. Observations on condition of the catch and biological measurements are recorded. Biological samples such as muscle tissue, gonads, stomach, otoliths, and anal fin rays are collected. Live swordfish specimens are tagged and released. Oceanographic conditions are monitored with expendable bathythermographs (XBTs), conductivity-temperature depth (CTD) casts, thermosalinograph (TSG), and acoustic Doppler current profile (ACDP) transects (C. Boggs, pers. commun.).

Swordfish tagging is conducted with the voluntary participation of longline fishermen and on research cruises. Tag, release, and recapture information such as names of fishermen, gear type, tagging and recovery location, and size estimates of fish are collected (Kazama, pers. commun.).

California

The California-based longline fishery is monitored through landing receipts, vessel logbooks, and landings sampling by the California Department of Fish and Game (CDFG). Landing receipts have been collected since the start of the fishery through a landings receipt system (Table 4). Vessel logbook data were collected on a voluntary basis from 1993 to 1994 before being replaced by a mandatory logbook system in 1995. Logbook information is recorded daily by fishermen. Positions are by degree and minute of the start and finish of the set. Hooks, catch, and bycatch are recorded for tunas, billfish, sharks, and other fish, as well as interactions with marine mammals, turtles, and seabirds. Other information on gear configuration, weather, and sea conditions is also collected. Landings sampling to measure the size of longline-caught swordfish began in 1991 in conjunction with sampling of the drift gill net landings (Table 5).

The California drift gill net fishery is monitored by landing receipts, vessel logbooks, landings sampling by the CDFG, and an observer program. Landing receipts and mandatory logbooks have been collected since the fishery's inception in 1980 (Table 4). Fishermen are required to record daily operations and catch. Location of operations and catch are recorded in 10-minute squares. Landings sampling to measure size of catch at local markets began in 1981 (Table 5). An observer program to monitor the drift gill net fishery was initiated and maintained by CDFG from 1980 to 1989 and has continued from 1990 under NMFS. The observer program is used to monitor bycatches, especially of marine mammals.

The California harpoon fishery is also monitored by landing receipts, vessel logbooks, and landings sampling by the CDFG. Landing receipts have been collected since the early 1900s through a landings receipt system (Table 4). A mandatory vessel logbook system for the harpoon fishery started in 1974. These logbooks are completed daily and allow recording of catches by location using CDFG 10-minute square codes. Information on aircraft assistance, water color, sea surface temperature and condition, harpooning success, and areas searched is also included. Landing sampling of swordfish began in 1981 in conjunction with the drift gill net sampling (Table 5).

SWORDFISH RESEARCH

The Honolulu Laboratory supports research on fishery management issues for the Western Pacific Regional Fishery Management Council as well as issues of special interest in American Samoa, Guam, Hawaii, and the Northern Marianas. The Laboratory is conducting several research projects specifically on swordfish (Table 6), with some projects in collaboration with the Joint Institute for Marine and Atmospheric Research (JIMAR) of the University of Hawaii which is funded by NOAA grants (Table 7).

ACKNOWLEDGMENTS

The comments of Gary T. Sakagawa and Steven A. Berkeley were especially helpful in producing this paper. We also thank Samuel G. Pooley, Kurt E. Kawamoto, Gerard DiNardo, and Daniel S. Curran for their reviews. We appreciate the assistance of Marija Vojkovich, Kristine Barsky, and Kevin Hill from the California Department of Fish and Game for providing the authors with summaries from their monitoring activities. Our gratitude is extended to Walter A. Machado of the Joint Institute for Marine and Atmospheric Research, and Jo-Anne Kushima of the Hawaii Division of Aquatic Resources for their monitoring efforts. Judy Kendig provided editorial support and her efforts are appreciated.

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Table 1. U.S. North Pacific swordfish catch (metric tons).*

Year	Hawaii Longline	California Longline	California Gill net	California Harpoon	California Unknown
1970	5	-	-	612	10
1971	1	-	-	99	3
1972	0	-	-	171	4
1973	0	-	-	399	4
1974	0	-	-	406	22
1975	<1	-	-	557	13
1976	<1	-	-	42	13
1977	17	-	-	318	19
1978	9	-	-	1,699	13
1979	7	-	-	329	57
1980	<1	-	160	566	62
1981	<1	-	464	260	28
1982	<1	-	919	158	35
1983	2	-	1,372	59	328
1984	1	-	2,137	104	648
1985	2	-	2,400	210	808
1986	3	-	1,695	236	605
1987	23	-	1,299	210	297
1988	23	-	1,101	180	357
1989	287	-	1,059	54	767
1990	1,939	-	1,040	51	144
1991	4,539	41	873	16	142
1992	5,819	42	1,393	78	77
1993	6,040	146	1,449	141	177
1994	3,121	721	760	152	777
1995	2,796	274	750	93	312
1996	2,644	228	725	83	-

Dashes indicate no fishery.

* Based on estimated whole weight.

Table 2. U.S. North Pacific average annual ex-vessel prices (dollars per pound dressed weight) for swordfish.

	Hawaii	California		
Year	Longline	Longline	Gill net	Harpoon
1987	4.70	-	na	na
1988	4.15	-	na	na
1989	3.30	-	na	na
1990	3.40	-	na	na
1991	3.10	na	na	na
1992	2.80	3.00	4.25	5.25
1993	2.95	3.30	4.25	5.00
1994	3.35	3.50	4.25	5.25
1995	3.25	3.00	4.00	5.00
1996	3.60	3.00	4.25	5.25

Dashes indicate no fishery and na indicates data not available.

Table 3. Average size of swordfish (cleithrum to fork length, cm) from U.S. North Pacific swordfish fisheries.

	Hawaii	California	California	
Year	Longline*	Longline	Gill net	Harpoon
1981	na	-	131.6	138.7
1982	na	-	146.1	135.7
1983	na	-	138.6	148.4
1984	na	-	139.7	145.2
1985	na	-	152.1	160.4
1986	na	-	139.3	149.6
1987	156.2 (58.6)	-	145.9	144.8
1988	152.4 (54.1)	-	151.6	157.4
1989	156.8 (59.5)	-	140.0	na
1990	162.5 (67.0)	-	133.1	na
1991	165.0 (70.4)	na	na	258.7
1992	171.8 (80.6)	na	na	156.6
1993	170.2 (78.1)	na	na	156.4
1994	167.3 (73.8)	136.0	na	na
1995	169.9 (77.6)	136.0	na	na
1996	165.6 (71.3)	na	na	na

Dashes indicate no fishery and na indicates data not available.

*Values in parentheses are average weight (kg).

Table 4. U.S. North Pacific swordfish catch-effort data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Unit of catch[4]	Type of effort	Time strata	Geographic resolution
1974	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1975	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1976	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1977	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1978	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1979	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1980	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1981	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1982	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1983	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1984	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN

Table 4 (continued). U.S. North Pacific swordfish catch-effort data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Unit of catch[4]	Type of effort	Time strata	Geographic resolution
1985	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1986	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1987	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1988	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1989	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
1990	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/HI	LL	OBS(V)	NO. FISH	NO. HOOKS	DAY	1°
1991	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/HI	LL	LB	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	OBS(V)	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	RC	NO. FISH	NO. HOOKS	DAY	1°

Table 4 (continued). U.S. North Pacific swordfish catch-effort data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Unit of catch[4]	Type of effort	Time strata	Geographic resolution
1992	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/HI	LL	LB	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	OBS(V)	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	RC	NO. FISH	NO. HOOKS	DAY	1°
1993	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/HI	LL	LB	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	OBS(V)	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	RC	NO. FISH	NO. HOOKS	DAY	1°
1994	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/CA	LL	LB	NO. FISH	SETS/ HOOKS	DAY	1°
	USA/HI	LL	LB	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	OBS(M)	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	RC	NO. FISH	NO. HOOKS	DAY	1°

Table 4 (continued). U.S. North Pacific swordfish catch-effort data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Unit of catch[4]	Type of effort	Time strata	Geographic resolution
1995	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/CA	LL	LB	NO. FISH	SETS/ HOOKS	DAY	1°
	USA/HI	LL	LB	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	OBS(M)	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	RC	NO. FISH	NO. HOOKS	DAY	1°
1996	USA/CA	GN	LB	NO. FISH	SETS/ DAYS	DAY	10 MIN
	USA/CA	GN	OBS(M)	NO. FISH	SETS/ DAYS	DAY	1°
	USA/CA	HP	LB	NO. FISH	PURSUITS/ DAYS	DAY	10 MIN
	USA/CA	LL	LB	NO. FISH	SETS/ HOOKS	DAY	1°
	USA/HI	LL	LB	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	OBS(M)	NO. FISH	NO. HOOKS	DAY	1°
	USA/HI	LL	RC	NO. FISH	NO. HOOKS	DAY	1°

[1]USA/CA=CALIFORNIA, USA/HI=HAWAII

[2]GN=GILL NET, HP=HARPOON, LL=LONGLINE

[3]LB=LOGBOOK DATA, OBS=OBSERVER DATA (V=VOLUNTARY, M=MANDATORY), RC=RESEARCH CRUISE DATA

[4]NO. FISH=NUMBER FISH

Table 5. U.S. North Pacific swordfish size frequency data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Time strata[4]	Geographic resolutions	Length	Interval	Wt[5]	Interval (LB)
1981	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
1982	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
1983	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
1984	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
1985	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
1986	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
1987	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
1988	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
1989	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5

Table 5 (continued). U.S. North Pacific swordfish size frequency data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Time strata[4]	Geographic resolutions	Length	Interval	Wt[5]	Interval (LB)
1990	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	OBS (V)	FISH DAY	1°	Y	CM(0.1)	Y	0.5
1991	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	LL	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	RC	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	TAG	FISH DAY	1°	Y	EST	Y	0.5
1992	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	LL	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	OBS (V)	FISH DAY	1°	Y	CM(0.1)	Y	0.5
1992	USA/HI	LL	RC	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	TAG	FISH DAY	1°	Y	EST	Y	0.5

Table 5 (continued). U.S. North Pacific swordfish size frequency data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Time strata[4]	Geographic resolutions	Length	Interval	Wt[5]	Interval (LB)
1993	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	LL	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	OBS (V)	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	RC	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	TAG	FISH DAY	1°	Y	EST	Y	0.5
1994	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	LL	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	OBS (M)	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	RC	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	TAG	FISH DAY	1°	Y	EST	Y	0.5
1995	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	LL	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	OBS (M)	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	RC	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	TAG	FISH DAY	1°	Y	EST	Y	0.5

Table 5 (continued). U.S. North Pacific swordfish size frequency data catalog.

Year	Country/ State[1]	Gear[2]	Data set[3]	Time strata[4]	Geographic resolutions	Length	Interval	Wt[5]	Interval (LB)
1996	USA/CA	GN	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	HP	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/CA	LL	MKT	LAND DATE	10 MIN	Y	1 MM	Y	1.0
	USA/HI	LL	MKT	LAND DATE	---	N	---	Y	0.5
	USA/HI	LL	OBS (M)	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	RC	FISH DAY	1°	Y	CM(0.1)	Y	0.5
	USA/HI	LL	TAG	FISH DAY	1°	Y	EST	Y	0.5

[1]USA/CA=CALIFORNIA, USA/HI=HAWAII
[2]GN=GILL NET, HP=HARPOON, LL=LONGLINE
[3]MKT=MARKET DATA, OBS=OBSERVER DATA (V=VOLUNTARY, M=MANDATORY), RC=RESEARCH CRUISE DATA, TAG=TAGGING STUDIES
[4]LAND DATE=DATE OF LANDINGS, FISH DAY=DATE OF FISHING
[5]Wt=WEIGHT

Table 6. Research projects on swordfish conducted by the NMFS Honolulu Laboratory.

RESEARCH PROJECT/LEAD INVESTIGATOR

1. Swordfish sex determination and size-at-maturity
2. Swordfish ageing using fin rays
3. Swordfish ageing using otoliths
4. Broadbill swordfish tagging project
5. Characteristics of the Subtropical Front ecosystem and defining preferential swordfish habitat.
6. Swordfish fisheries oceanography
7. Diet and trophic dynamics of swordfish
8. Spatial dynamics of swordfish in the North Pacific
9. Stock assessment of swordfish in the North Pacific

Table 7. Research projects on swordfish conducted by the Joint Institute of Marine and Atmospheric Research, University of Hawaii with funding from NOAA.

1. Remote sensing of oceanographic features and distribution of fishing effort around the Hawaiian Archipelago
2. Pop-up satellite transmitting archival tags (PSTATs) for studying swordfish movement and behavior
3. Swordfish stock structure
4. Generalized computer simulator for swordfish stock assessment and fishery management analysis

SWORDFISH FISHERIES IN THE PHILIPPINES

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INTRODUCTION

Swordfish are a bycatch of the Philippines tuna fishery. Within the tuna fishery swordfish are exploited by both the commercial and municipal fishing fleets and in the past several years the catch of swordfish has increased. Swordfish is also one of the main catches of sport fishing, which indicates some potential for development.

The majority of the swordfish catch is sold to the local hotels and restaurants to meet the high demand by foreign visitors. A portion of the catch is also exported to the United States, Europe, and other countries.

No biological study has been done on swordfish in the Philippines. This situation may change because of demand for and importance of swordfish in relation to the goal of sustainable fishery resources.

SWORDFISH FISHERIES

In the Philippines, the marine fisheries sector is categorized into municipal and commercial fisheries based on the size of the vessel. Municipal fisheries are those who use fishing vessels less than 3 gross tons (GT). Commercial fisheries are those with vessels greater than 3 GT. The predominant gear in municipal fishery are handlines. While in the commercial fishery several gears are used including: gill net, hook and line, and purse seine.

Total swordfish production from 1970 to 1995 has been variable, with a slight increase in production occurring in 1988. The reported increase is believed to result from an increase in export demand and improved efficiency in fishing for tunas (Table 1). The municipal fishery contributed more than 80% of the total swordfish production in most of the years, while the rest of the catch was contributed by the commercial fishery. Swordfish catch by gear type is outlined in Table 2.

Table 1. Total swordfish production in metric tons (1970-95).

Year	Commercial	Municipal	Total
1970	5		5
1971	27		27
1972	11		11
1973	3		3
1974			
1975			
1976		1558	1558
1977	1	2102	2103
1978	43	847	890
1979	25	3820	3845
1980	1	1715	1716
1981	4	1936	1940
1982	354	3114	3468
1983	15	2959	2974
1984	2	2272	2274
1985	1	2035	2036
1986	1	2083	2084
1987	91	2046	2137
1988	463	3571	4034
1989	531	3225	3756
1990	9	3257	3266
1991	157		157
1992	292	4014	4306
1993	313	4320	4633
1994	878	2763	3641
1995	771	3431	4202

For the commercial fisheries, the most important fishing grounds are the South Sulu Sea, the Visayan Sea, and West Palawan waters (Table 3). The most productive fishing grounds for the municipal fisheries are the East Sulu Sea, Cuyo Pass, South Sulu Sea, Lamon Bay, Bohol Sea, Moro Gulf, and West Sulu Sea (Table 4).

Information gathered from the sports fishing association indicate that they normally catch an average of three swordfish, with an average weight of around 60 kg, during sport fishing tournaments.

Table 2. Commercial fishery production (t) of swordfish by fishing gear.

Gear	1990	1991	1992	1993	1994	1995
Bagnet		42	10			
Danish Seine			3	26		19
Gillnet			13	3		127
Hook and line	3	82	266	250		511
Purse Seine	3	6		4		107
Ringnet						7
Troll Line				30		
Round Haul Seine		23				
Trawl	2	4				
Drift Gillnet	1					
TOTAL	9	157	292	311		771

Table 3. Commercial fishery production (t) of swordfish by statistical fishing area (1990-95).

Fishing Ground	1990	1991	1992	1993	1994	1995
Babuyan Channel						
Batangas Coast						
Bohol Sea				10	2	
Camotes Sea						
Cuyo Pass			1	20	8	
Davao Gulf						
East Sulu Sea	2		13	33		24
Guimaras Strait						
Lagonoy Gulf				2		
Lamon Bay	1			16		18
Leyte Gulf		2				29
Lingayen Gulf						
Manila Bay						
Moro Gulf	2	4	6	71	45	28
Ragay Gulf	1					
Samar Sea	1		10		1	
Sibuyan Sea			3	10	25	30
South Sulu Sea	1	40	98	69	653	314
Tayabas Bay		67	24		4	7
Visayan Sea		1		1	1	146
West Palawan Waters	1	26	70	65	76	98
West Sulu Sea		17	57	16	60	71
International Waters			10		3	6
TOTAL	9	157	292	313	878	771

Table 4. Municipal fishery production (t) of swordfish by statistical fishing area (1992-95).

Fishing area	1992	1993	1994	1995	Total
Babuyan Channel		7			7
Batangas Coast	102	96	37	52	287
Bohol Sea	193	91	230	206	720
Camotes Sea	37	11	2	8	58
Casiguran Sound	49	154	64	174	441
Cuyo Pass	294	505	350	274	1423
Davao Gulf	327	105	51	22	505
East Sulu Sea	2161	1829	568	809	5367
Guimaras Strait	1	16	174	116	307
Lagonoy Gulf	65	162	55	109	391
Lamon Bay	102	227	382	188	899
Leyte Gulf	100	35	39	185	359
Lingayen Gulf	2	102	19	7	130
Manila Bay		15	74	74	163
Moro Gulf	178	60	146	239	623
Ragay Gulf	16	60	111	86	273
Samar Sea	25	40	63	80	208
Sibuyan Sea	189	51	43	34	317
South Sulu Sea	32	588	153	129	902
Tayabas Bay	82	83	113	158	436
Visayan Sea	26	7	5	15	53
West Palawan Waters	11	12	8	51	82
West Sulu Sea	22	64	76	415	577
TOTAL	4014	4320	2763	3431	14528

FISHERY MONITORING AND REPORTING

The Bureau of Agricultural Statistics (BAS) is the government agency mandated to collect statistical data for all agricultural products, including fisheries statistics and the collection system adopted by the BAS is as follows.

Commercial Fish Landing Survey

Geographic Coverage

Catch data from the commercial fishery are collected from 72 of the 236 landing centers nationwide. These 72 landing centers, which are located in 34 provinces, are the top landing centers and contribute 90% of total fish catch based on 1987 production figures.

Method of Data Collection

Catch and effort data are collected via vessel captain interviews during peak unloading times or interviews with record keepers stationed at landing centers during non-peak unloading time.

The Sampling Design

A modified sampling design that captures the spatiotemporal aspects of the fishery is employed and the 72 landing centers comprise the survey's sampling domain.

Two-stage sampling is used to capture the temporal aspect. The primary sampling unit is one day and the secondary sampling unit is a 20-minute time interval within a day. Single-stage sampling is used to capture the spatial aspect and the sampling unit is the fishing vessel.

The data collector predetermines the peak landing time and establishes the 20-minute intervals for his assigned landing center by inquiry or familiarization with the activities at the landing center. For each vessel/gear-type combination only the first vessel to unload is sampled. If the number of vessel/gear-type combinations is too great the collector interviews as many vessel/gear-type combinations as possible.

This 20-minute interval process is repeated until all the fishing boats in the landing center have landed and unloaded.

In the case of mother/catcher boats, the number of carrier boats that land or unload are enumerated.

Municipal Fish Landing Survey

Geographic Coverage

The Municipal Fish Landing Survey is designed to provide data on municipal fish catch from boats of three gross tons or less by gear type, species, and fishing ground for each landing center.

The survey covers fish landing centers located in Manila and 23 provinces surrounding 12 bays in the Philippines. These landing centers are classified into major and minor centers based on the number of fishing vessels that use the center and the volume of fish landed. All major landing centers and 10 percent of the minor centers are surveyed.

The methods and frequency of data collection, as well as the sampling design, in the municipal fish landing survey are similar to those described for the commercial fish landing survey except that in minor municipal landing centers all unloading fishing vessels are enumerated.

Recently, the Bureau of Fisheries and Aquatic Resources (BFAR) collected swordfish and tuna catch statistics from major tuna landing centers in the Philippines in an effort to assess the fisheries. Under this design, catch and effort data are collected every two days. In addition, the total number of boats landing are also recorded for each sampling day.

Swordfish are normally dressed (e.g. gilled, gutted, headed, and finned) when landed so the data on swordfish landings do not record the round weight of fish caught. As such, no length measurement can be taken unless one goes on board the fishing boat or an arrangement with the boat's crew is undertaken. As previously stated, no swordfish research is being done except this initial activity. Further, no fishing boat is solely used for swordfish fishing. It is worthwhile to mention that one tuna fishing province in Mindanao (Sarangani) has about 4,000-5,000 handline boats which occasionally catch swordfish.

FUTURE RESEARCH PLANS

Relevant to the migratory habits of swordfish, it might be a good idea to conduct research on stock identification through analysis of as many gene markers as possible in order to determine whether the swordfish stock in the Philippines belongs to only one stock or to a bigger stock inhabiting the central Pacific. A program to collect biological samples would also be beneficial and would require adequate funding, which is presently non-existent, to hire sea-going biologists.

THE DEVELOPMENT OF THE LONGLINE FISHERY TARGETING SWORDFISH (*XIPHIAS GLADIUS*) IN RÉUNION ISLAND WATERS–PROCESSING AND MARKETING

François Poisson and François René
IFREMER, Ile de la Reunion, France

INTRODUCTION

During the last 5 years, Réunion has experienced rapid growth and development in all segments (artisanal fishery, Antarctic deep-sea fishery, longline fishery) in marked contrast to situations experienced by most other fishing communities in the European Union. The most rapid of these developments has taken place in the longline fishery which will this year not only equal but will overtake the artisanal fishery, at nearly 1,500 metric tons (t) per year (Figs. 1 and 2). This development is the result of modernization of traditional longlining techniques, such as the use of nylon monofilament main lines mechanically cast and hauled by a hydraulic wench, light sticks, squid bait, and an efficient land support system (satellite thermal charts integrating fishing and environmental data) (Petit et al., 1995). All of these advances have enabled net productivity gains, and the Réunion fleet, despite high labor costs, has become a notable contender in the market. Profitability of this fishery is due also to privileged access to both the European Union market (a solvent local market with high demand) and a profitable export market to Europe via mainland France.

This paper briefly describes the discipline and technical aspects of the Réunion fishery as well as the evolution of catch, catch-per-unit-effort, and CPUE. Processing the catch and marketing aspects will also be described and recommendations for better management options proffered.

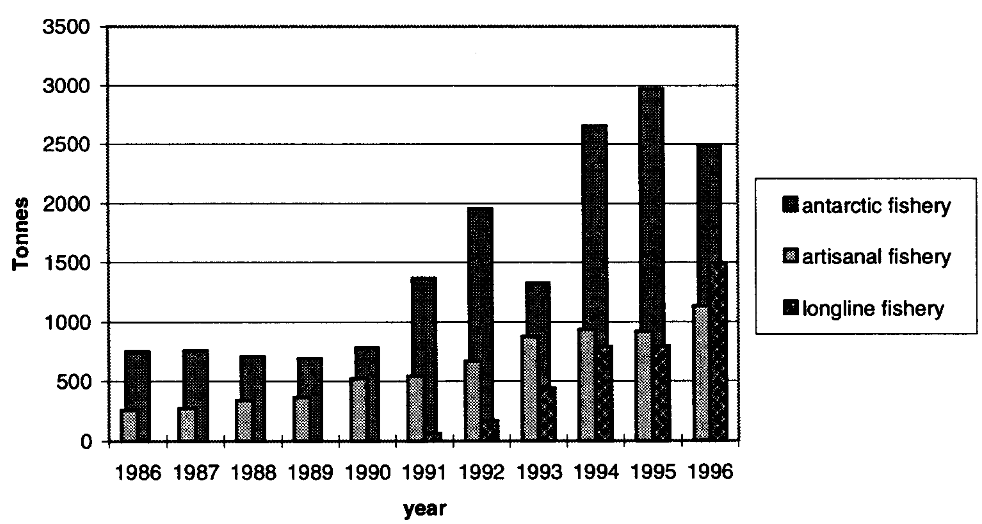

Figure 1. Evolution of Réunion fish production from 1986 to 1996.

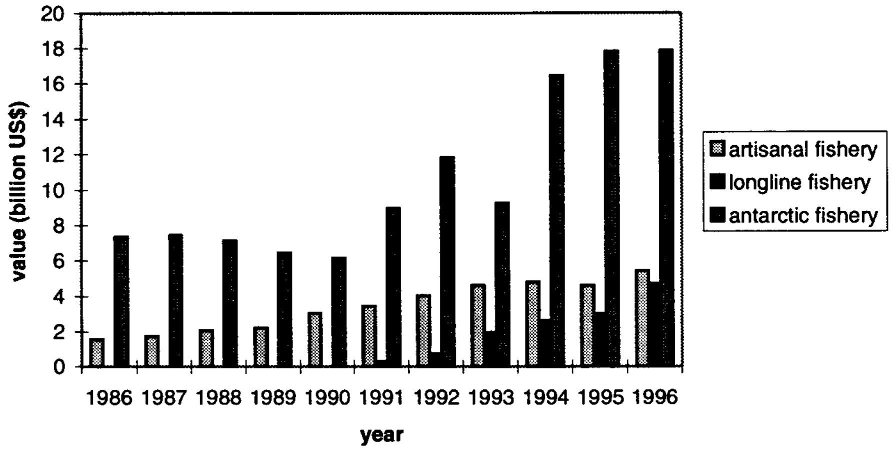

Figure 2. Evolution of Réunion fish value from 1986 to 1996.

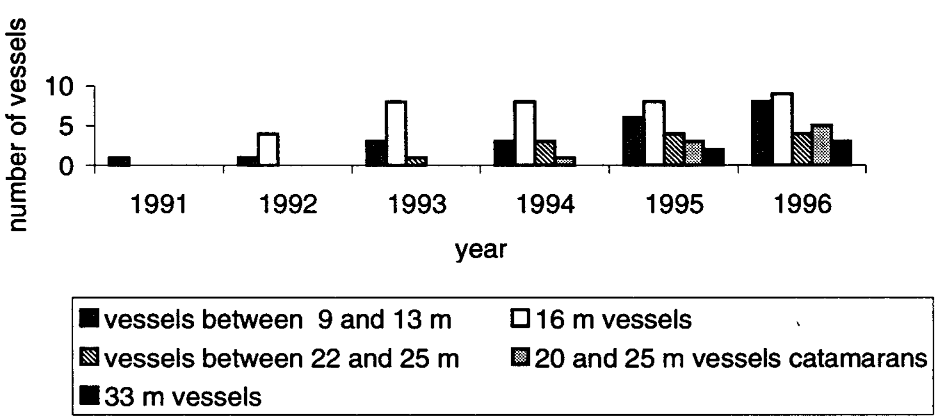

Figure 3. Evolution of the Réunion longline fleet between 1991 and 1996.

DESCRIPTION OF THE FISHERY, PROCESSING AND MARKET

The Vessels

Since 1994, the Réunion fleet has undergone various developments (Fig. 3), including the following:

- An increase in total number of vessels.
- Intensification of effort by vessels less than 16 m (9- to 13-m vessels remaining at sea 3-6 days per trip).
- Addition of 16-m longlining vessels (Benetau brand; size considered to be irregular by many shipping companies) to the deep-sea fishing fishing fleet.
- Increase the segment of 20- to 25-m-catamaran vessels, allowing for longer stays at sea

(18 to 25 days), onboard processing and storage (freezer holds) of vacuum-packed frozen loins.

- The appearance of 33-m longlining vessels capable of fishing for 35-45 days at sea and onboard processing of vacuum-packed frozen loins, as well as processing capabilities for bigeye tuna (*Thunnus obesus*) and Southern bluefin tuna (*Thunnus maccoyii*) destined for the Japanese sashimi market (René et al., 1997).

Fishing Gear and Methods

All Réunion vessels are equipped with a semiautomatic drifting longline system. The fishing techniques and methods used are described by Poisson et al. (1998) and have changed little since the installation of a beeper system (regular sound signals for manipulating the lines).

Processing the Catch

The type of processing is dictated by the market demand and length of sea stay. Figure 4 illustrates different swordfish processing methods and processing coefficients (proportion lost due to processing) at each handling stage. The three different types of onboard processing are distinguished as follows:

1. Swordfish, other billfish, and the few sharks retained are preserved headed, gutted, fins and the gills discarded (H&G) and stored under ice in insulated or refrigerated holds at 0°C.

2. Swordfish and other species weighing less than 20 kg are gutted and gilled (referred to as "dressed"). This is the common processing practice for vessels of 12 to 20 m.

3. Swordfish with a mean weight of 2-3 kg are frozen at -20° for the European market, while the same size tuna are frozen at -50°C for the Japanese sashimi market. The frozen swordfish are processed onboard at a cost of $1/kg for the processed product and leaves the factory at approximately $5/kg. Onboard loin processing requires refrigeration and is generally limited to vessels larger than 20 m since they are at sea longer than 20 days.

Only one type of onshore processing for fish caught by vessels smaller than 20 m exists.

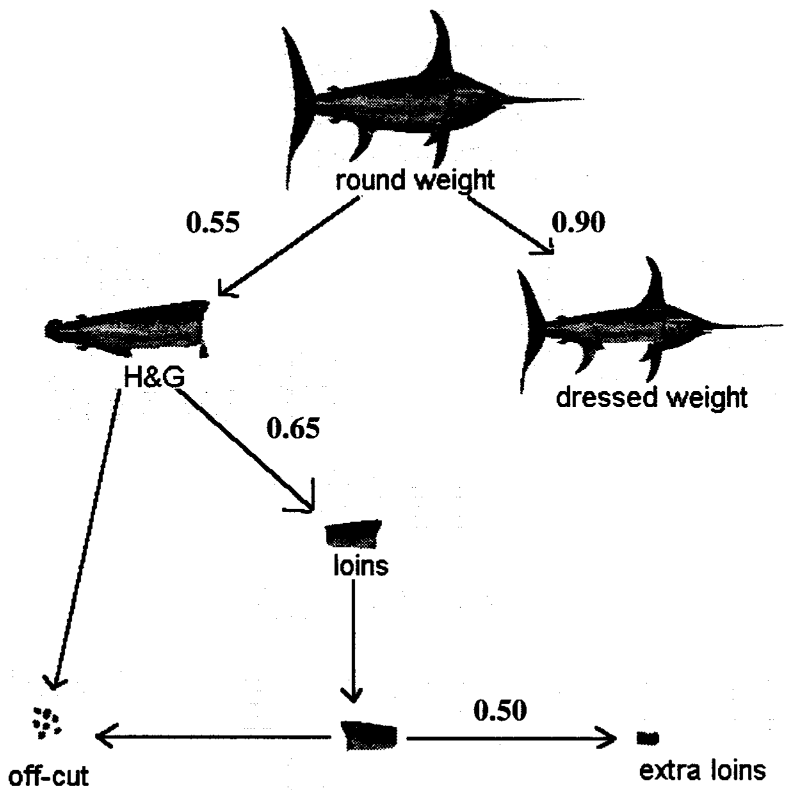

Figure 4. Principal processing techniques of the swordfish landed at Réunion-and associated processing coefficients (proportion lost due to processing).

Products

Processed fish from the longline fishery supply two complementary markets–local and export. These marketed products include the following:

- Tuna (yellowfin tuna, *Thunnus albacares;* albacore, *Thunnus alalunga*; and bigeye tuna (*Thunnus obesus*).

  Because of seasonal landing peaks, the processed tuna does not occupy a natural place on the local fresh fish market. This tuna is bought at \$2-\$3/kg (H&G), cut into loins, and vacuum packed in plastic. Approximately 70% of the landings associated with these species are processed this way. Production costs are around \$3/kg for the final packaged product. Sale prices for vacuum-packed tuna loins vary based on species but generally from \$5 to \$6/kg.

- Swordfish (*Xiphias gladius*).

  Approximately 70% of the landed swordfish are processed into loins. Production costs are around \$2/kg. The processed swordfish loins are exported at a price of approximately \$4/kg, resulting in a final product cost of \$8/kg.

Figure 5 (Cofrepeche, 1996) illustrates the flow of fishery products in Réunion. Among fresh fish, pelagics are first in quantity and value, especially those from the longline fishery. In 1966 this fishery represented Réunion's main capital contribution, aside from imports.

The local market is primarily supplied with fresh fish caught by vessels less than 20 m. Almost all pelagic catches (other than swordfish) by this class of vehicles are sold locally. Part of the local market, known as collective catering, is supplied with frozen tuna cubes produced by onshore processing units.

Exported fresh fish go mainly to Europe via Rungis, at an air freight cost of approximately $1.50/kg. To support a wider market, an export aid system, SLAE (Soutien Logistique pour l'Aide a l'Exportation) which is financed by the Réunion Regional Council, pays 50% of air freight costs and 80% of shipping freight costs. Price differentials exist between exported products, depending on the market. These differences are as follows:

- Fresh swordfish loin $9-$11/kg
- Frozen swordfish loin (-20°C) $5-$8/kg
- Fresh tuna loin $6-$8/kg
- Frozen tuna loin (-20°C) $4-$5/kg

Products are transported in freezer containers via the port of La Pointe des Galets in Réunion to Europe by way of France at a freight cost of less than $1/kg. Other products are exported, dressed and frozen, to the Star Kist Tuna factory in Puerto Rico.

The Japanese sashimi market is mainly supplied with products frozen at sea as stated above; however, the tuna loins are frozen at -50°C. Japanese freezer cargo ships specialize in the transport of sashimi quality tuna at a freight cost of less than $1/kg.

		great pelagics		other species		Total
officicial production		1500 t		3 343 t		4 843 t
Export	-	374 t	-	1 102 t	-	1 476 t
Import	+	423 t	+	3 640 t	+	4 063 t
Estimated production	+	700 à 900 t	+	300 à 1 100 t	+	1000 à 2 000 t
Consummation	=	2 200 à 2 400 t	=	6 200 à 7 000 t	=	8 400 à 9 400 t

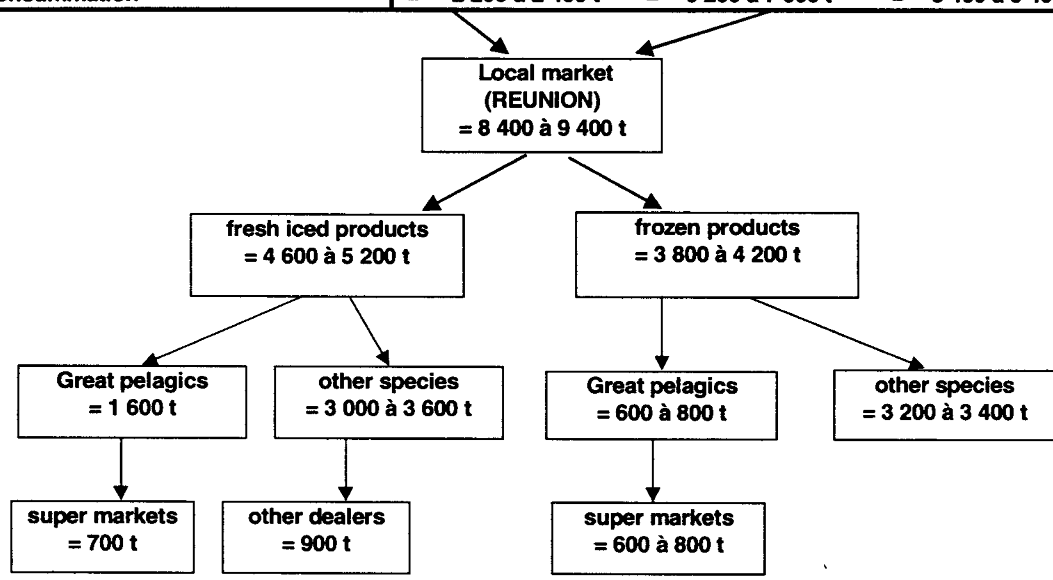

Figure 5. Réunion fish market, principal imports and exports, 1996 (COFREPECHE, SYNTHESE, CRPMEM.

FISHING STATISTICS AND OPERATION DATA

Methods and Materials

Data Collection

The collection of fishery statistics is the responsibility of the Fisheries Administration, who in turn send this information to national authorities such as FAO (IDTP) and IFREMER for ordering, processing, reproduction, and interpretation.

From an operational point of view, IFREMER has been able to build cooperation among fishermen, skippers, and company managers. IFREMER's imposition of strict confidentiality rules on the collected data has also contributed to cooperation with the fishing industry.

Fishing logbooks have been made available to all longline vessels and provide information on the geographical position of net settings, the number of hooks and light sticks used per set, the time lines are set and hauled, and the number of fish caught. Fish are classified by species, and their weight is estimated. The environmental and meteorological conditions are also recorded. These logbooks are regularly collected from skippers and company managers.

Available Data

The Réunion Fleet–Fishing statistics are submitted to the Fisheries Administration voluntarily by skippers and fishing companies. The available catch data represent comprehensive results of fishing operations for all registered companies in the *departement* (region). Companies must declare departure and return dates for each vessel, as well as the weight of all landed fish, divided by species (13 species currently coded) or by product type (loins, extra loins, etc.).

The Taiwanese Fleet–Authorization to operate in the French economic zone of Réunion and the surrounding islands for one year was granted to 28 Taiwanese longliners in November 1993 (Poisson et al., in press). This agreement stipulates that Star Kist, which controls the production of these vessels, submit logbooks completed by ship captains (ICCAT, print A model; Miyake and Hayasi, 1990) showing exact geographical locations of nets, number of hooks per set, number of fish caught by species or species group, and a declaration of tonnage landed at La Pointe des Galets for every fishing operation.

Results

Submitted logbooks represent only a portion of fishing activity. Logbook coverage rates (ratio of the number of trips listed in logbooks to the total number of estimated trips by the entire fleet) were 24% in 1992, 40% in 1993, 83% in 1994, 97% in 1995, and approximately 53% in 1996 (this paper was presented before all logbooks in 1996 had been collected).

Fishing Grounds and Seasons

Figures 6a-6d show the distribution and development of the Réunion fleet from 1993 to 1996, and Figures 7a-7c show the distribution of the Taiwanese fleet for the summers of 1993-95. These figures represent the density of fishing operations per 1° square for each year.

Species Caught

Table 1 provides a detailed list of the principal species caught by the local longline fleet. Onboard fish processing by the Taiwanese longliners made species determination uncertain at time of landins and no list of species can be provided. However, the occurrence of *Lampris guttatus* in the catch of Taiwanese longliners can be detected.

Table 1. List of the species caught by the local fleet

Target species	Bycatch species
Swordfish (*Xiphias gladius*)	Skate (unidentified)
Albacore (*Thunnus alalunga*)	Ocean sunfish (*Mola mola*)
Yellowfin tuna (*Thunnus albacares*)	Snoek (*Thyrsitoides sp*)
Bigeye tuna (*Thunnus obesus*)	Oilfish (*Ruvettus sp*)
Dolfin fish (*Coryphaena hippurus*)	Remora (*Remora sp*)
Sailfish (*Istiophorus platypterus*)	Crocodile shark (*Pseudocarcharias kamoharai*)
Blue marlin (*Makaira mazara*)	Silky shark (*Carcharinus falciformus*)
Spearfish (*Tetrapturus angustirostris*)	
Shortfin mako (*Isurus oxyrinchus*)	
Oceanic whitetip shark (*Carcharinus longimanus*)	
Scalloped hammerhead (*Sphyrna lewini*)	
Smooth hammerhead (*Sphyrna zygaena*)	
Blue shark (*Prionace glauca*)	

Quantities Caught

Swordfish catches in the Indian Ocean, traditionally a bycatch of the Asiatic longliners and Sri Lankan gillnetters, fluctuated between 2,000 and 4,000 t from 1985 to 1986. Following the development of specialized longline fishing and targeting of swordfish by the Taiwanese longliners, the catch greatly increased during 1993-94 (Poisson et al., 1998; Anon., 1995). Caution is advised when using these data, particularly the earlier years, as swordfish was not identified separately but rather grouped in with billfish.

Swordfish catches by the Réunion longline fleet are illustrated in Figure 8. In 1996, longline fishery landings exceeded those of the artisanal fishery.

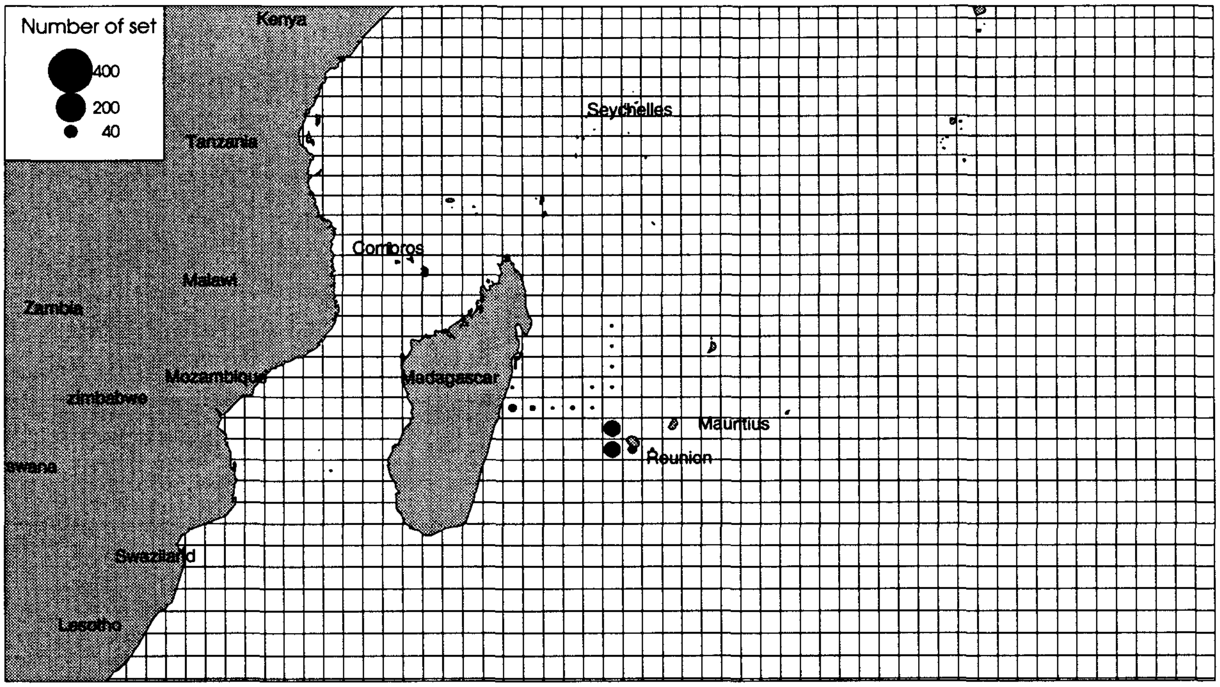

Figure 6a. Density and distribution of fishing operations of the Réunion longline fleet, 1993.

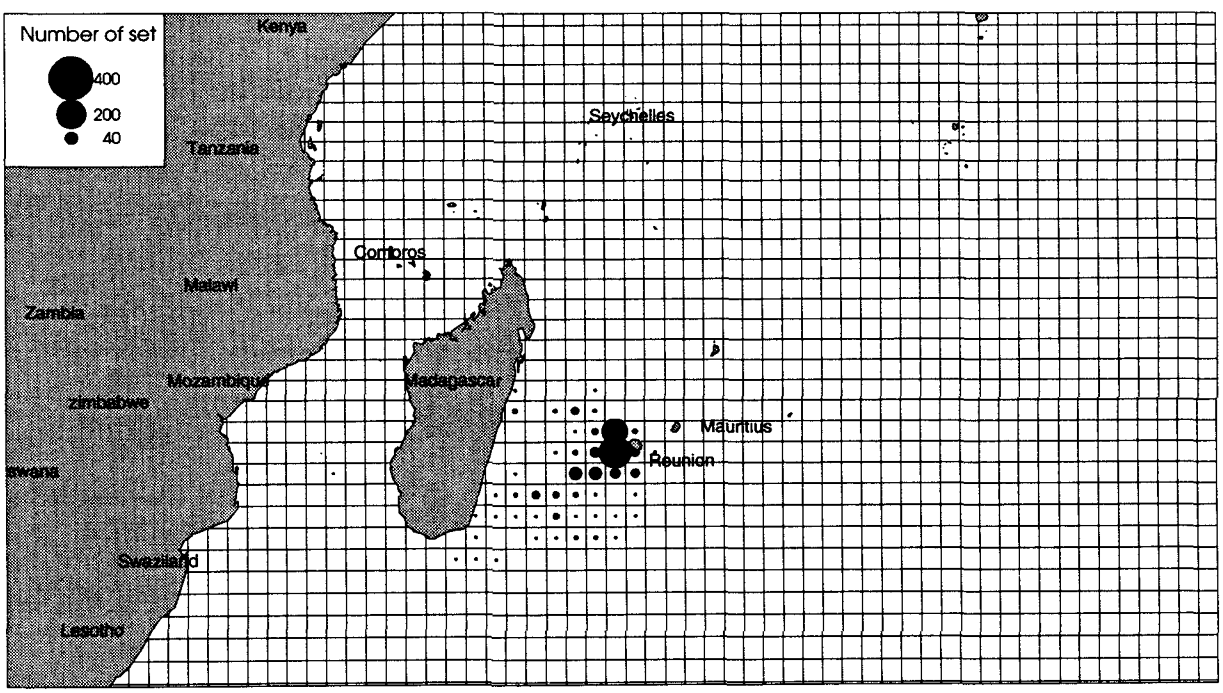

Figure 6b. Density and distribution of fishing operations of the Réunion longline fleet, 1994.

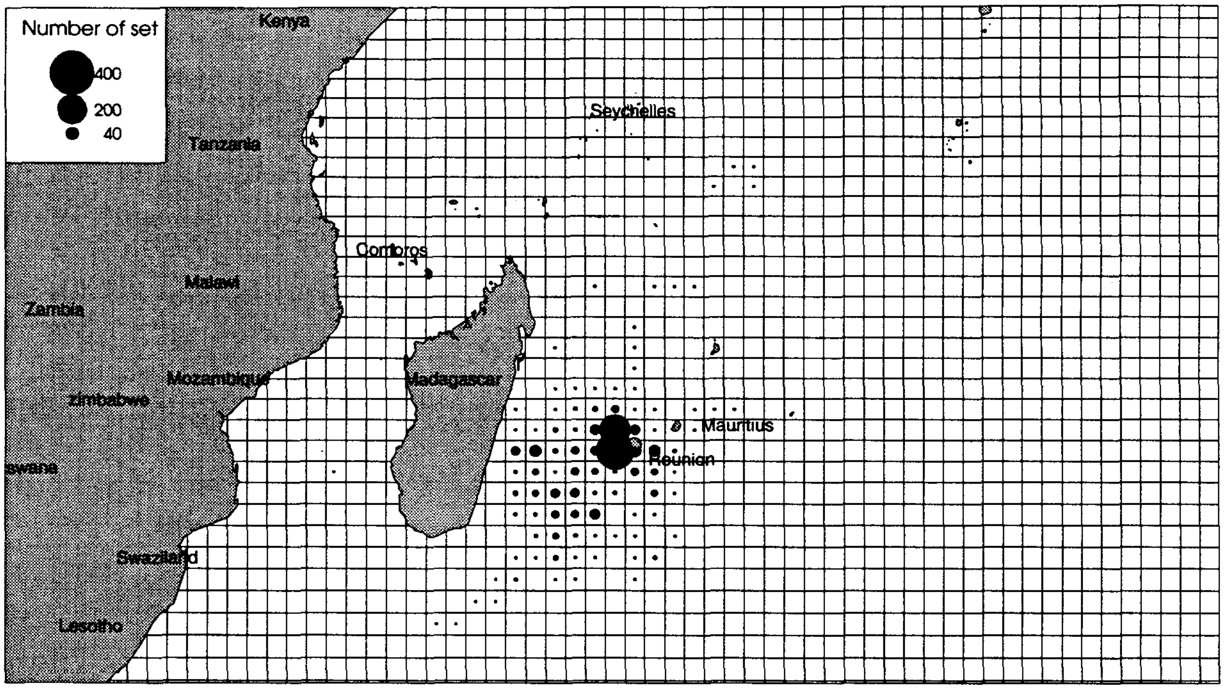

Figure 6c. Density and distribution of fishing operations of the Réunion longline fleet, 1995.

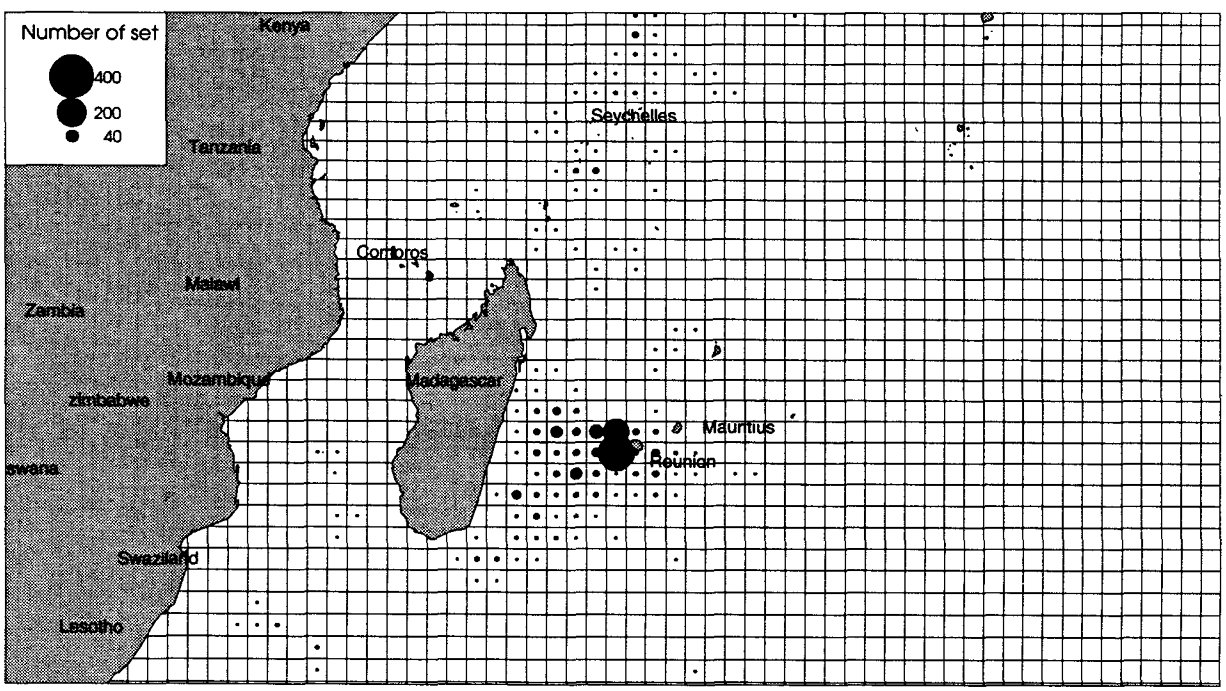

Figure 6d. Density and distribution of fishing operations of the Réunion longline fleet, 1996.

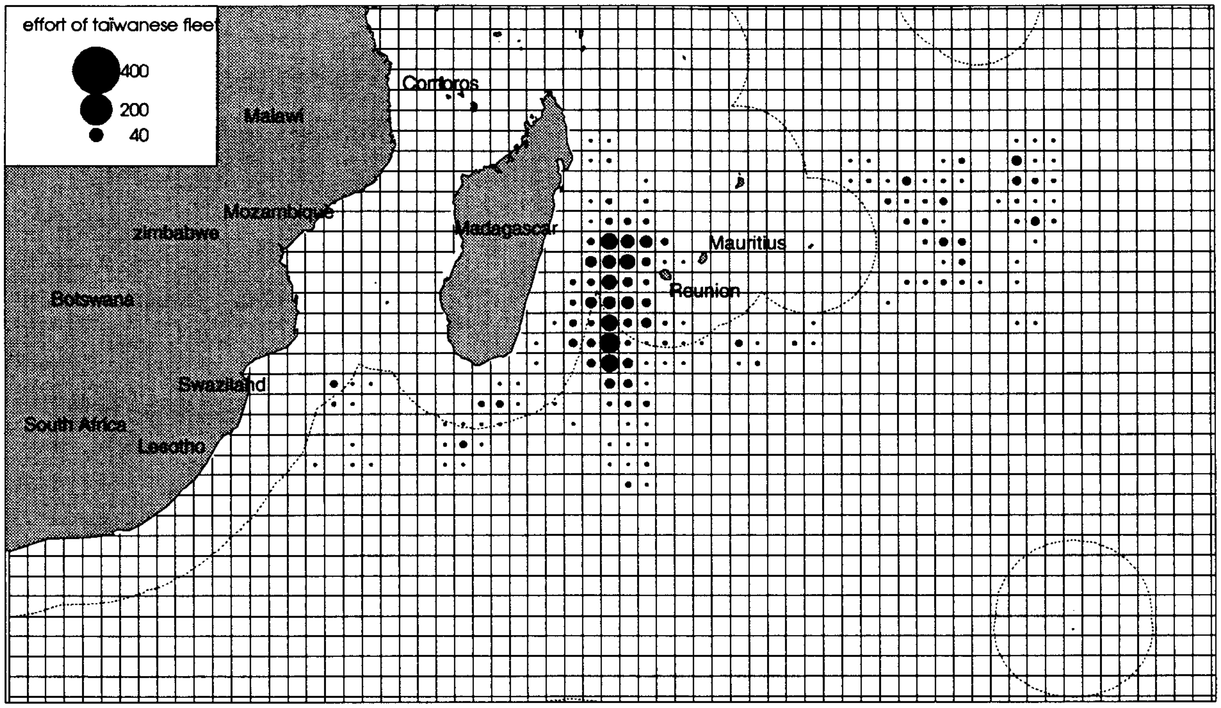

Figure 7a. Density and distribution of fishing operations of the Taiwanese longline fleet during the summer of 1993.

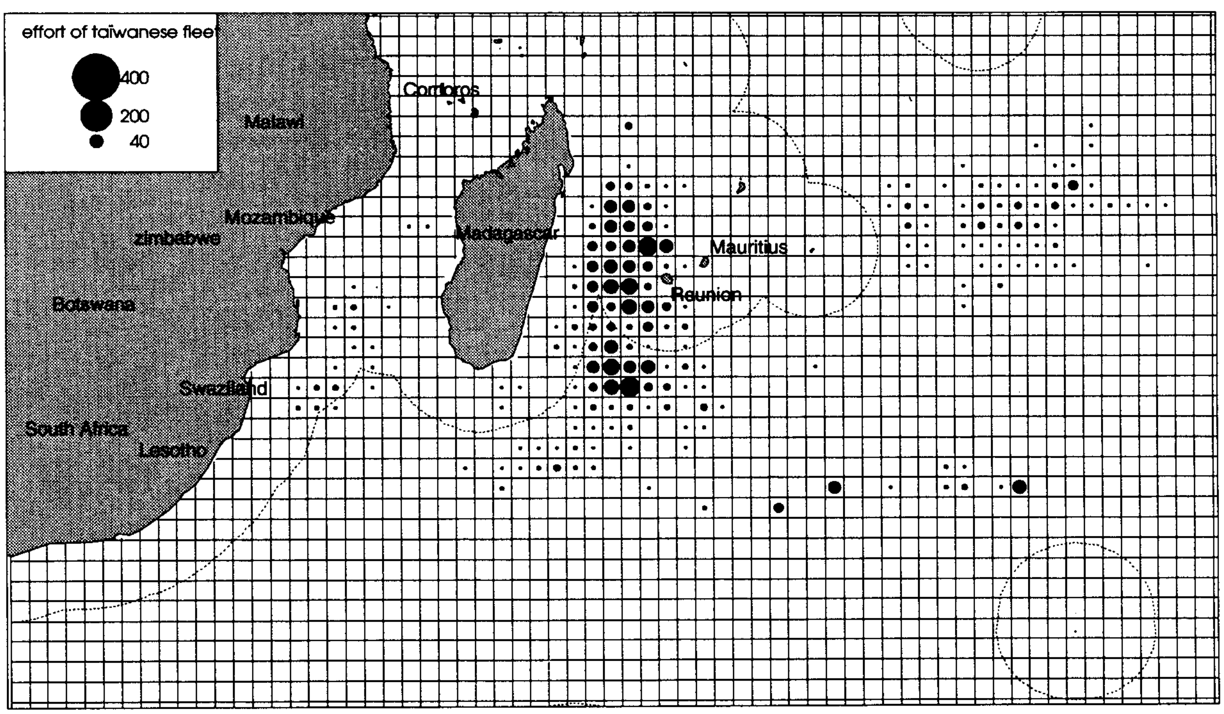

Figure 7b. Density and distribution of fishing operations of the Taiwanese longline fleet during the summer of 1994.

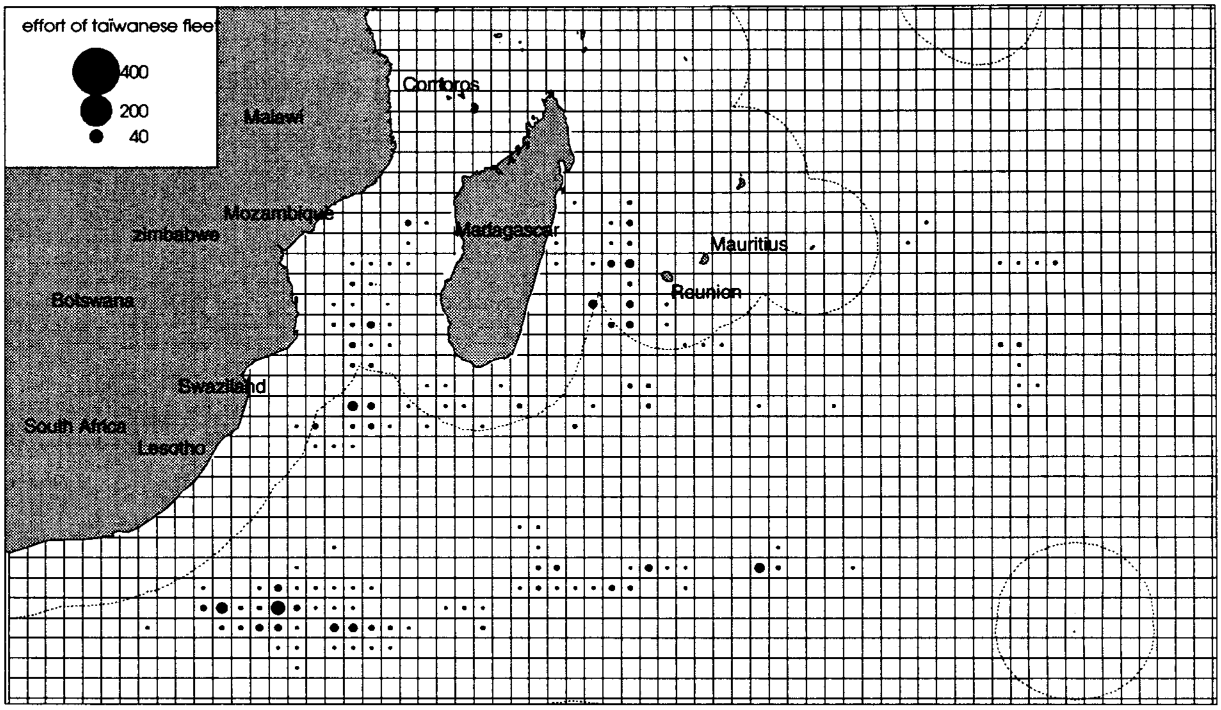

Figure 7c. Density and distribution of fishing operations of the Taiwanese longline fleet during the summer of 1995.

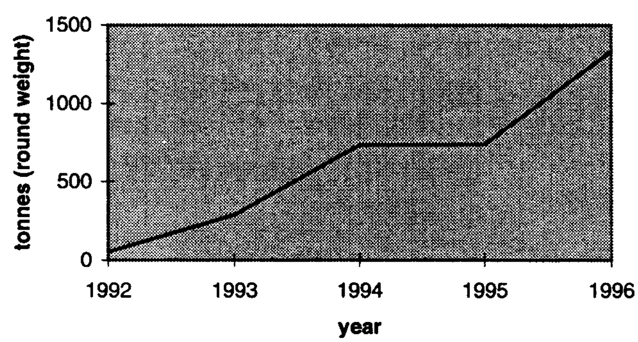

Figure 8. Time series of swordfish catch by the Réunion longline fleet.

Effort

Annual effort for both fleet segments, as well as overall, is shown in Table 2. These data include total number of hooks set by the local fleet, number of trips per year, and average total number of hooks per set. Because of the acquisition of more precise data, annual effort data have been revised since their first distribution (Tessier et al., 1995; Poisson et al., 1998).

Table 2. Annual estimates of total number of hooks set, number of trips per year and average number of hooks per set for two segments of the local longline fleet. Segment 1 corresponds to vessels between 9 and 16 m in length and segment 2 corresponds to vessels >16 m in length.

	1993		**1994**		**1995**		**1996**	
	segment 1	**segment 2**	**segment 1**	**segment 2**	**segment 1**	**segment 2**	**segment 1**	**segment 2**
Estimated total number of hooks (10^3)	382	6.5	487	220	480	551	550	1525
Number of trips per year	135	3	162	22	164	45	186	88
Average number of hooks used per set	687	717	694	763	762	939	778	1081

CPUE

Réunion longline fishery CPUEs were computed for two segments of the fleet based on vessel length and fishing location. The first segment groups vessels between 9 and 16 m in length that generally fish in the southwest quadrant of Réunion out to 200 nmi. The second segment groups vessels >16 m in length that normally fish beyond 200 nmi. The annual evolution of CPUE for the two groups is shown in Figures 9a and 9b.

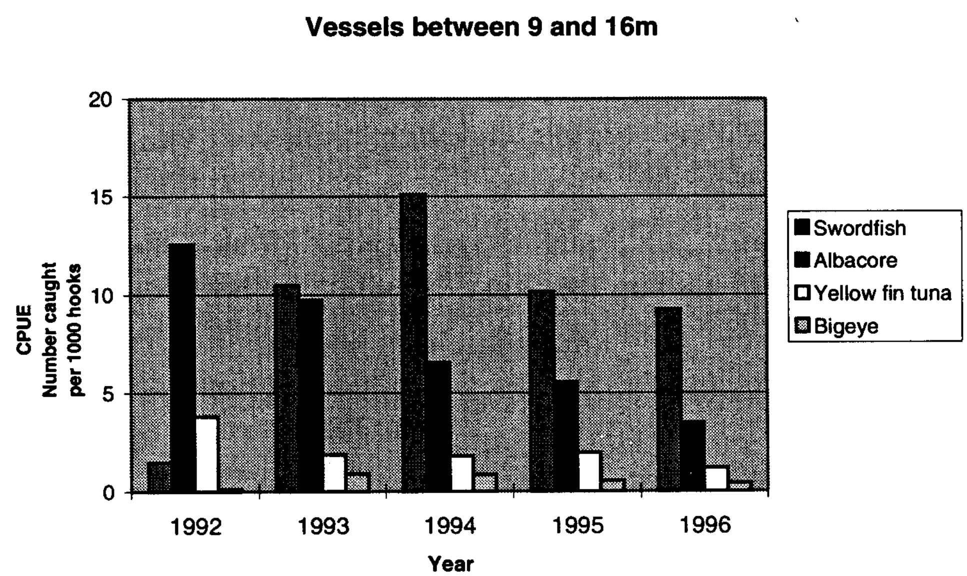

Figure 9a. Annual CPUEs of principal species caught by longline vessels ranging in length from 9 to 16 m.

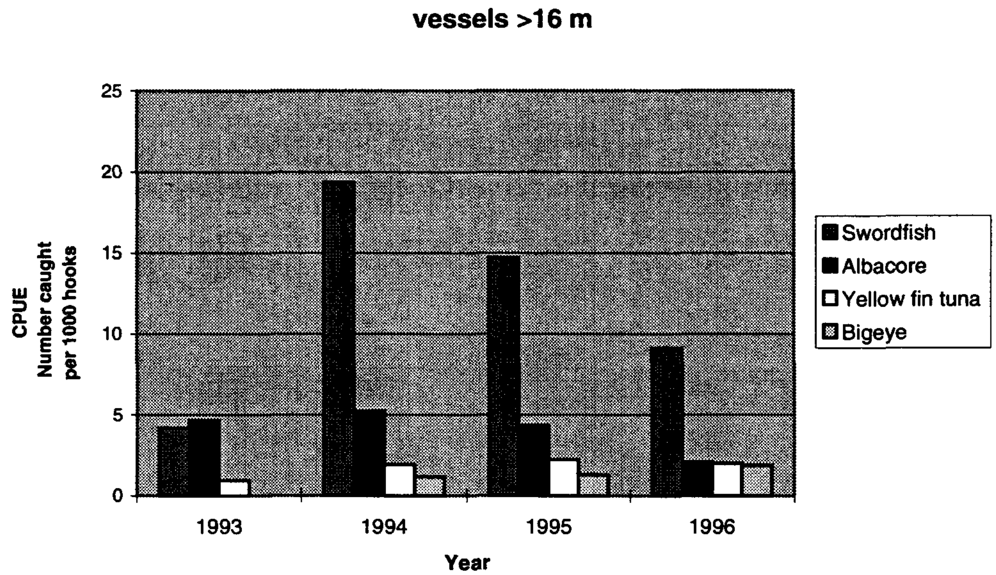

Figure 9b. Annual CPUEs for principal species caught by longline vessels whose length is >16 m.

DISCUSSION

Data Reliability

As shown in an earlier paper (Poisson et al., 1998), the logbook collection system set up in 1996 has been widely accepted by most fishing companies and skippers, who in return benefit from data and information that enables them to follow the evolution of the fishery. Data are kept entirely confidential. Eighty percent of all the logbooks are returned; the remaining 20% of fleet activity is estimated. In 1994, data was found to have reliability limits of ~10% between that estimated and that actually collected.

Growing difficulty exists in closely following nominal tonnage because of multiple fish processing operations at sea. Certain vessels modify their operations according to market demand (Fig. 5).

The following recommendations were proposed in 1995 to increase the reliability of data:

- Include a recapitulative table in the declaration forms covering, by species, number and weight of fish landed.
- Provide a theoretical size/weight conversion table to each skipper to improve estimates.
- Add other required information (number of sets per trip, number of fish caught, etc.) to the voluntary declaration forms.
-

All recommendations have yet to be complied with because of a lack of followup and support personnel (FREMER) and a lack of crew time on the vessels.

Fishing Grounds and Seasons

In 1995 the restriction on fishing within a limit of 30 nmi of Réunion was removed. From a practical point of view, the restriction removal has only slightly modified fleet movement, which now explores (for the 12-m and 16-m vessel segment) the 30-200 nmi zone. In fact, the removal of the restriction may actually result in an increase in longlines of less than 5 to 15 km in length which are deployed from 8- to 10-m vessels. In order to minimize occupational conflicts of nautical space, it seems necessary to exclude drifting longlines from territorial waters out to 12 nmi.

The spatiotemporal distribution of the longline fleet in 1995 and 1996 is related to persistent hydrodynamic conditions in the Indian Ocean (Lujhharms et al., 1981; Marsac et Piton, 1994; Piton, 1989; Donguy and Piton, 1991) as well as the development of the deep-sea fishing segment of the longline fleet (vessels greater than 19 m) that have onboard processing plants.

The transition to year-round fishing operations is now complete, but climatic hazards must be taken into consideration as they often prevent vessels from going to sea and modify catch possibilities. The very active cyclone season of 1995 (14 cyclones and associated storms) limited Réunion fleet activities and explains stagnation of the catches during 3-4 months of 1995.

Catch

The increase in catch seen during 1992, 1993, and 1994 resumed in 1996 after the stagnation of 1995. Along with the problems associated with heavy cyclone activity that year, the fleet lost most of its 16- and 25-m vessels, replacing them at the end of 1995 with new "factory" vessels: 20- to 25-m catamarans.

The observed growth in1996 can be explained by the following:

- Increased professionalism by some of the fishing companies.
- Growth of small but highly productive companies.
- Arrival of new companies, notably from the area of artisanal fishing.
- Progressive replacement of first generation vessels (25-m monocoques) with the better designed catamarans which are equipped with onboard processing facilities.

Effort

The reported increase in fishing effort from 1991 to 1994 (Poisson et al., 1998) has intensified despite the readjustment in 1995, principally due to the following:

- An increase in the fleet from 1 to 12 active vessels between 1991 and 1994, and to 22 vessels in 1996.
- An increase in the number of trips and sets caused by transition from a seasonal fishery to a year round operation (Table 2).
- An increase in the average number of hooks per set from 702 in 1993 to 930 in 1996 (Table 2).
- An expansion of the fishing grounds.

CPUE

The evolution of the Réunion fleet CPUE, calculated as the number caught per 1,000 hooks (Figs. 9a and 9b) is similar for both segments of the fleet.

For swordfish, the rapid increase in CPUE from 1992 to 1994 which was followed by the decline observed during 1994-96 was more pronounced for vessels in the larger segment of the fleet. For the other species CPUE has risen steadily since 1993.

The increase in swordfish CPUE is attributed to learning, the progressive mastery of longlining techniques (1992-94), and the targeting of more swordfish (Poisson et al., 1998). The decline in swordfish CPUE from 1994 to 1996 correlates with declines in CPUEs associated with other species caught in the longline fisheries, suggesting a change in availability due to environmental conditions and not a decline in stock size. Other factors that may contribute to the observed decline in swordfish CPUE include changes in fishing strategies and the introduction of new vessels with inexperienced crews. Since 1995 new vessels and crews have been entering the fishery.

Predation After Capture

The after-capture predation is principally caused by the following marine life:

- Sharks. The global percentage of loss to sharks is 2.2%. This percentage was calculated over 15 months (June 1994-September 1996) for 430 sets, set by five vessels (9-16 m) that caught 3,300 swordfish. Forty-two sets were affected, and 73 of 473 fish were attacked by sharks.
- Marine mammals: Losses due to pilot whales (*Globicephala macrorhynchus*) and false killer whales (*Pseudorca crassidens*) are approximately 1.5% and tesult from a single observation aboard a 12-m vessel from November 16, 1995 to September 26, 1996 (4 of 270 sets were attacked). For the 20-33-m vessels, three vessels were followed from October 20, 1995 to November 4, 1996. Percentage loss was established at 2.3% (14 out of 602 sets were attacked).

Total predation is low and estimated to be 4% to 5%. This observation is similar to the results of Gonzales Blazques (1994) for a 1993 Spanish fishing experimental expedition in the southwest zone of the Indian Ocean (Poisson and Mace, in press).

Processing and Marketing

Since 1994, the other major factor besides rapid production growth (Fig. 8) is a progressive mastering of new processing types and gain of new markets. The following processing and marketing developments have contributed to the increase in swordfish landing by the Réunion longline fishery:

- Setting up more longlining vessels with onboard processing plants which allows for fishing in wider areas, longer fishing expeditions, and at-sea processing.

- Establishment of onshore processing sites and enhancement of the infrastructure of existing onshore processing capabilities.

- Acceptance of re-exported Réunion fishery products within Europe.

The differential market value between fresh and frozen has led to the following changes in policies adopted by fishing companies:

- Promotion of fresh fish sales, essentially processed as loins, before and after being sent by air to France.

- Promotion of swordfish export sales to assure company profitability.

- Research into increasing the value of other catches (notably yellowfin tuna and albacore) sold on the local market as bycatch.

- Stabilizing the profitability of larger vessels through increasing the price of bigeye tuna and thon rouge du sud in whole dressed frozen tuna destined for the Japanese sashimi market.

CONCLUSION

The rapid development of the Réunion longline fishery is principally due to the following:

- Emergence of new fishing techniques and integration of updated technological and scientific knowledge of the fishery.

- Growth in demand of new fish products, notably swordfish and sashimi-quality tuna.

- Availability of cheap air freight from Réunion to Europe.

- Establishment of certain tax investment incentives.
- Availability of experienced French mainland fishermen pushed by the fishing crisis in Europe to seek work in Réunion.
- Movement of traditional non-longline artisanal fishermen toward this new activity (longlining).

In Réunion this rapid development has already led to profound, structural evolution in a sector confronted by accumulated changes of resource, market, and the production and processing units. This necessitates the introduction of an operational fisheries plan to management this development. Important considerations are an identified resource potential, a concern for stability in the local market, and the various social elements of the sector. It is imperative that this plan be supported by oceanic and socioeconomic research.

The exploitation of the fishery resource should be managed to guarantee sustainable levels of the stock. A research program is needed and should be structured around the following requirements:

- The collection of all catch and landing data in all major southern Indian Ocean ports.
- Implementation of a comprehensive biological program on swordfish.
- Data collection on bycatch.
- Improvement in selectivity of fishing gear.

In the long term, this program needs a commission to set up management of the pelagic fishery in the Indian Ocean. At the same time, control of the longline fishing fleet in the subregion must be established to assure that regulations defined for stock management are respected. The legal and technical means of this management must be developed at a subregional scale with the cooperation of all countries in the subregion. This cooperation is especially needed since the analysis of subregional data collected in recent studies shows rapid and uncontrolled increases in exploitation inside and outside the EEZ by foreign fleets.

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SWORDFISH FISHERIES IN THE EASTERN AUSTRALIAN FISHING ZONE: AN UPDATE OF DEVELOPMENTS DURING 1996

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SUMMARY

In the past, broadbill swordfish (*Xiphias gladius*) were a bycatch of Australian longliners fishing in the eastern waters of the 200–nautical mile Australian fishing zone (AFZ). The situation changed markedly in 1996 when several companies were licensed to export swordfish to markets in Hawaii and the U.S. mainland. By October 1996 more than 30 Australian longliners were targeting swordfish off southern Queensland (24–28°S, 153–156°E). To target swordfish they used shallow sets at night, light sticks, and squid for bait. The 1996 catch of swordfish reported in logbooks was 414 metric tons (t), compared with less than 50 t in previous years. Targeting of swordfish off southern Queensland continued into summer when sea surface temperatures exceeded 25°C.

Swordfish are rarely targeted by Japanese longliners fishing in the AFZ under bilateral agreements. Swordfish catches reported by Japanese longliners averaged 650 t a year in the eastern AFZ. However, their catches here have declined since 1988, mainly as a result of reduced activity in waters near southern Queensland. In 1996 Japanese longliners reported catching 205 t of swordfish in the eastern AFZ.

Despite being relatively abundant off Australia's east coast, swordfish remain a rare catch of recreational anglers. Anglers report tagging and releasing fewer than 10 swordfish a year.

Logbook programs are in place to monitor fishing activities of Australian and Japanese longliners. A program of observer cruises aboard Japanese longliners has operated since 1979, providing size composition data and biological observations. In 1995–96 observers were placed on Australian longliners off Cairns to collect data on bycatch levels and investigate catch composition in relation to the fishing depth of longlines.

DOMESTIC LONGLINE FISHERY

Prior to 1996, broadbill swordfish (*Xiphias gladius*) were a bycatch of Australian longliners fishing eastern waters[1] of the 200–nautical mile AFZ. The situation changed markedly in mid 1996 when Australian longliners commenced targeting swordfish off southern Queensland, and exporting it fresh to markets in Hawaii and the U.S. mainland. Caton et al. (1998) provide a comprehensive description of swordfish fisheries in the AFZ up to 1993. This paper provides an update of swordfish fisheries in the eastern AFZ, highlighting developments in the domestic longline fishery in 1996.

[1] We use the term 'eastern AFZ' to refer to Australian fishing zone waters that are east of 140°E.

Timing and Location

Traditionally, two separate regions of activity could be distinguished in the Australian longline fishery. For many years longliners targeted premium quality yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*T. obesus*) in cool waters south of 34°S during late summer (Fig. 1). Those activities sometimes extended to southern bluefin tuna (*T. maccoyii*) during winter. In early summer this longlining spreads northwards to Brisbane (27°S), where yellowfin and striped marlin (*Tetrapturus audax*) are targets. During the 1990s longline activity expanded in tropical waters near Cairns (16°S, 148°E), where catch rates of bigeye and yellowfin are higher.

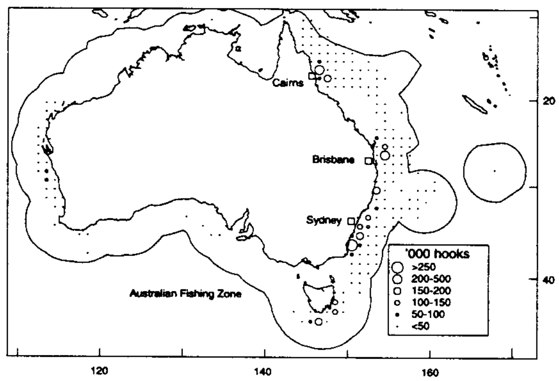

Figure 1. Distribution of fishing effort reported by Australia longliners in 1996.

Targeted longlining for swordfish commenced in June 1996. At that time longline fishermen reported that they were refining fishing gear and techniques for targeting swordfish. In August several of those longliners moved south to 40–120 nautical miles off southern Queensland (24–28°S, 153–156°E; Fig. 2). There, longliners concentrated on small 'hotspots,' often over deep sea canyons and seamounts where depths vary between 200 and 4,000 m. The southern Queensland grounds accounted for over 65% of swordfish reported by Australia longliners in the eastern AFZ in 1996.

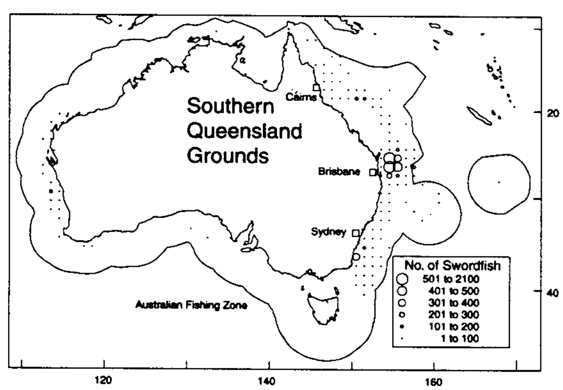

Figure 2. Distribution of swordfish catches reported by Australia longliners in 1996.

On the southern Queensland grounds activity peaked in October, with more than 30 longliners fishing. Caton et al. (in press) and Ward et al. (1996) noted swordfish were a winter (April–June) catch of Japanese longliners off southern Queensland. However, swordfish catches reported by Australia longliners do not seem to be related to sea surface temperature—off southern Queensland temperatures ranged between 20°C (September) and 27°C (February)—and several Australian fishermen believe that this is a year–round fishery.

Swordfish have been reported from waters where sea surface temperatures range from 5° to 27°C. While catch rates may not directly relate to sea surface temperature, the distribution of swordfish may be more closely related to the water temperature that they actually swim in. Swordfish also exhibit diurnal vertical migrations where they may be trying to thermoregulate their body temperature. A 1995–96 CSIRO study off Cairns indicates that during winter swordfish tend to be caught on the shallower hooks (approximately 40–80 m) of longline sets where water temperatures are 20-23°C (Campbell et. al., 1997). Surface temperatures were around 25°C. Water temperature at 200 m are 14°C and 8°C at 300 m. Conversely, during the summer season very few swordfish were caught (3) off Cairns. During this time the fishing depth was deeper at around 80-100 m with corresponding temperatures of 23°–24°. Surface temperatures were around 30°C.

Vessels and Fishing Gear

Most of the longliners fishing the southern Queensland grounds are 16–25 m long. They set between 600 to 1,000 hooks each day on monofilament lines, and most trips last 2–5 days. A few larger, 32-m longliners are also active. The larger longliners are at sea for 8–11 days and they set up to 1,200 hooks a day.

On the southern Queensland grounds, fishermen targeted swordfish by setting their longlines at sunset and hauling at dawn. They used cyalume light sticks (often on every branch line). Fishermen set their longlines very shallow, with hooks rarely deeper than 50 m. They use large (150–250 g) squid as bait. As well as being attractive to swordfish, compared with other baits, squid suffers less damage from small fish and other squids.

Catches

According to logbooks, longliners caught 8,656 swordfish amounting to 414 t dressed weight[2] in the eastern AFZ in 1996. Over 65% (275 t) of the 1996 swordfish catch was reported from southern Queensland. There, swordfish ranged from 10 to 300 kg with an average dressed weight of 50 kg.[3]

In 1996, catch rates on the southern Queensland grounds where longliners targeted swordfish were much higher than in other areas (563 kg/1000 hooks compared with 302 kg/1000 hooks for the entire eastern AFZ; Tables 1 and 2). Catch rates were quite variable, with several longliners reporting up to 3 t of swordfish in some sets. Highest catch rates were usually a few days after the full moon. Fishers also reported good catches of bigeye tuna during full moon periods. Longlining continued over other moon phases, but fewer large swordfish were caught at those times.

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[2] Swordfish weights reported in logbooks by Australian longliners are 'trunk' weights; i.e., the weight after the head, gills, viscera and tail have been removed. Note that Japanese longliners usually fillet swordfish that are larger than 20–30 kg, whereas they trunk smaller swordfish.

[3] This is not a true average weight, but the total dressed weight divided by the total number reported in logbooks; i.e., 414 t divided 8,656.

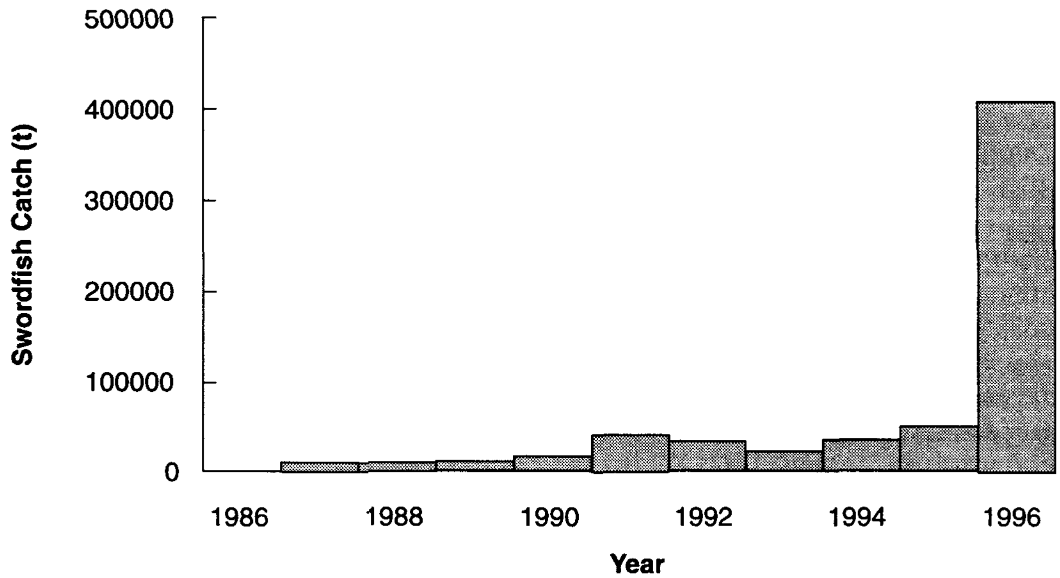

Figure 3. Annual catches (dressed weight) of swordfish reported by Australian longliners in the Australian fishing zone east of 140°E.

Table 1. Annual catches of swordfish and fishing effort reported by Australian longliners in the eastern AFZ, 1987-96. Note that the logbook coverage gradually improved over the period, from less than 80% before 1989 to 100% in 1996.

Year	No. of swordfish	Dressed weight (t)	Effort ('000 hooks)[a]	No. of vessels[a]	CPUE (kg/1000 hooks)[a]	Average weight (kg)[b]
1986	1	0	0	1	373	149
1987	214	11	107	40	100	50
1988	162	9	49	30	193	58
1989	234	10	66	49	152	43
1990	438	16	235	58	67	36
1991	1018	42	376	70	112	42
1992	866	34	511	60	67	40
1993	690	21	285	59	72	30
1994	1162	27	510	63	53	23
1995	1428	49	712	77	68	34
1996	8656	414	1370	98	302	48

[a] Where one or more swordfish were caught.

[b] This is not a true average weight, but the total weight divided by the total number.

Table 2. Annual catches of swordfish and fishing effort reported in logbooks by Australian longliners on the southern Queensland grounds (24-28°S, 153-156°E), 1987-96.

Year	No. of swordfish	Dressed weight (t)	Effort ('000 hooks)[a]	No. of vessels[a]	CPUE (kg/1000 hooks)[a]	Average weight (kg)[b]
1986	0	0	0	0	–	–
1987	39	2	107	3	15	40
1988	0	0	0	0	–	–
1989	2	0	1	2	112	64
1990	15	0	26	5	17	30
1991	24	1	69	3	19	53
1992	19	1	24	5	30	38
1993	2	0	1	1	63	38
1994	57	3	29	5	99	50
1995	356	16	140	9	118	46
1996	5478	275	488	35	563	50

[a] Where one or more swordfish were caught.

[b] This is not a true average weight, but the total weight divided by the total number.

Markets and Prospects

For many years fishermen have known that swordfish are abundant off Australia's east coast, as evidenced by catch rates reported by Japanese longliners. Access to U.S. markets was the main impetus for the development of a targeted fishery in Australia. The raising of mercury limits in Australia also helped, and over 40 t of the swordfish caught in 1996 were marketed locally. A few swordfish were also exported to specialist sashimi markets in Japan that seek fish with high fat levels. Targeting of swordfish is expected to expand geographically, with good availability known in southern areas (34–40°S) and northern areas (15–20°S) of the eastern AFZ (Fig. 2). Fishermen are also considering longlining for swordfish south of Norfolk Island (29°S, 168°E). The challenge for fisheries managers and scientists is to control fishing effort and establish a program to monitor and assess the fishery during this developmental period.

JAPANESE LONGLINE FISHERY

Japanese longlining commenced in eastern Australian waters in the 1950s and was well established by 1960. The longliners freeze their catch and land it in Japan for sale at sashimi markets. Since establishing a 200–nautical mile fishing zone in 1979, Australia has progressively restricted the access of Japanese longliners in the eastern AFZ. By 1991 the Japanese were not permitted to longline within 50 nautical miles of the coast, near the Great Barrier Reef off North Queensland nor in the cooler waters at 34–39°S off southeastern Australia (Caton and Ward, 1996). Substantial Japanese longline activity continues in eastern, southeastern, and western areas of the AFZ, and swordfish are regularly taken as an incidental catch. Japanese catches and catch rates of swordfish are highest off southern Queensland and northern New South Wales (24–34°S; Caton et al., in press).

There is a long time–series of swordfish catches by Japanese longliners off eastern Australia. Annual swordfish catches reported by Japanese longliners averaged about 650 t during 1984–96 (Table 3). From year–to–year, however, there is considerable variation in the distribution of longline effort, associated with access restrictions and changes in the distribution of target species, such as yellowfin, bigeye, and striped marlin. Swordfish catches and catch rates reported by Japanese longliners peaked in 1988. Swordfish catches then fell to 339 t[4] in 1995 and 205 t in 1996 when few longliners fished the eastern AFZ (Fig. 4).

Table 3. Annual catches of swordfish and fishing effort reported in logbooks by Japanese longliners in the eastern AFZ, 1980-96. These are mostly longliners fishing under bilateral agreements but include some longliners chartered by Australian companies and, occasionally, Japanese longliners fishing under joint venture agreements.

Eastern AFZ

Year	No. of swordfish ('000s)	Dressed Weight (t)	Effort ('000 hooks)[a]	CPUE (kg/1000 hooks)[a]	Average Weight (kg)[b]
1980	7	–	3528	–	–
1981	15	–	9392	–	–
1982	23	–	10,342	–	–
1983	12	8	7039	–	–
1984	13	564	7396	76	43
1985	17	726	8087	90	43
1986	14	663	6902	96	47
1987	16	812	8148	100	50
1988	26	1303	13,027	100	51
1989	22	1042	18,431	57	48
1990	14	657	12,303	53	46
1991	13	551	7961	69	43
1992	15	696	8575	81	47
1993	10	453	9083	50	46
1994	10	416	7194	58	43
1995	7	339	6387	53	48
1996	4	205	14,586	14	47
Average	14	648	9316	69	46

[a]Where one or more swordfish were caught.

[b]This is not a true average weight, but the total weight divided by the total number.

[4] Japanese longliners usually fillet swordfish that are larger than 20–30 kg, whereas they trunk smaller swordfish. Hence the weights of swordfish reported by the Japanese are likely to be a mixture of trunk and fillet weights. In contrast, Australian longliners do not fillet swordfish, and all weights of swordfish reported by Australia longliners are trunk weights.

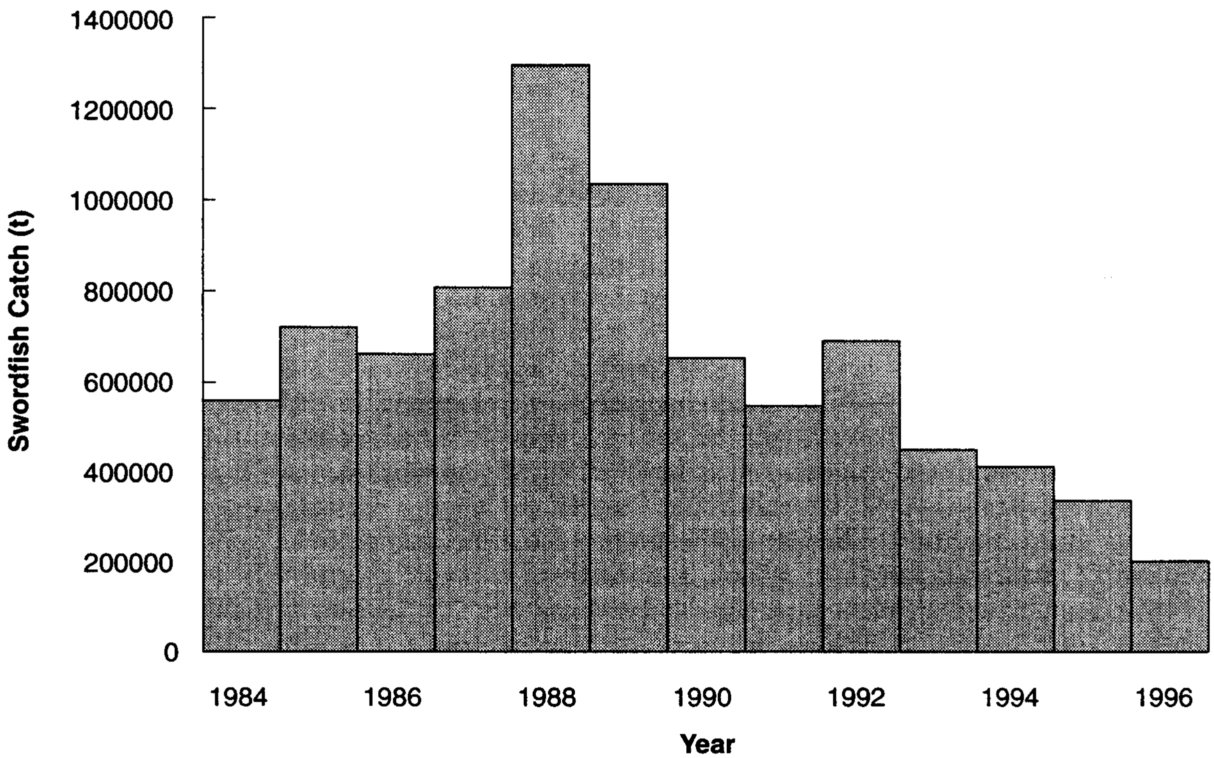

Figure 4. Annual catches (dressed weight) of swordfish reported by Japanese longliners in the Australian fishing zone east of 140°E, 1984-96.

In the previous section we described the expansion of longlining by Australian operators in the southern Queensland grounds (24–28°S, 153–156°E), which accounted for 65% of the Australian catch in 1996. Southern Queensland traditionally produced the highest catch rates of swordfish for the Japanese longline fleet in the southwestern Pacific. However, it usually accounted for only 15% of the swordfish catch reported by Japanese longliners in the eastern AFZ. In 1996 few Japanese longliners fished the southern Queensland grounds, reporting only 23 t from that area. The modest contribution of the grounds to the total swordfish catch reported by Japanese longliners tends to indicate that there is potential for further expansion of Australia longliners targeting swordfish in the eastern AFZ. Based on the Japanese logbook data, however, those areas might produce lower swordfish catch rates than southern Queensland.

RECREATIONAL ANGLING

Anglers have been taking tuna and billfish off eastern Australia since the early 1900s. During the 1970s, boats capable of operating offshore became available at reasonable prices, and angling for tuna and billfish grew in popularity. The popularity of angling for large pelagic species is also related to the ease of access to fishing grounds. The continental shelf is less than 8 nautical miles wide in some places along the southeastern coast, and anglers can catch tuna and billfish from the shore at several locations. Angling occurs over a wide geographical area and catches depend on season and targeting. However, anglers rarely catch swordfish. They attribute this to the style of fishing necessary to catch swordfish. This involves floating baits near the surface while drifting at night, which can be uncomfortable in exposed, southeastern waters. It may also be dangerous when returning through shallow harbor entrances in the dark.

Australian releases of tagged swordfish did not commence until 1985. The total number of releases is 37, with 8 of these swordfish released in 1996. Most of the tagged swordfish have been small juveniles (4-15 kg).

RESEARCH AND MONITORING

Diplock (1987, unpub.)[5] reported catches during the early development of the Australian longline fishery. A logbook was introduced for Australian longliners in 1986. Of the fishermen engaged in longlining off the east coast, however, less than 50% had logbooks before 1989. Field officers were employed in 1989 to visit fishermen and to distribute and collect logbooks. By 1990 approximately 85% of fishermen had been issued logbooks. Dendrinos and Skousen (1991)[6] estimated that 90% of the yellowfin landed by longliners were reported in logbooks. Field support of the logbook program lapsed in 1993. However, submission of logbooks by Australian longliners has improved as a result of the Australian Fisheries Management Authority (AFMA) making this a condition of license and instituting monthly auditing of logbook returns. The quality of Australian longline logbook data, however, remains uncertain. It is not regularly verified against independent data; e.g., landings, although the data collected by the CSIRO project indicate inconsistencies between the observer-collected data and the logbook data.

The Commonwealth introduced a logbook for Japanese longliners in 1979. Observers are placed on many Japanese longliners in the AFZ to verify catch reporting and to collect biological and fisheries data. Despite reasonable coverage of the Japanese fleet by Australian observers in the 1990s, there is uncertainty about the reliability of the logbook data because they are not routinely verified against observer data.

Large longliners chartered by Australian companies must complete the Australia longline logbook. Joint-venture longliners must record catches and activities each day in the foreign tuna longline logbook issued to bilateral longliners. Australia requires that bilateral and joint venture longliners must also report their position by radio each day. Before November 1990 they reported catches by radio for 6-day periods; they now report catches each day. In 1996 AFMA introduced a satellite–based vessel monitoring system (VMS) to replace the logbook and radio reporting systems for Japanese longliners. A vessel monitoring system using Inmarsat–A was introduced for position and catch reporting. Fishing craft and gear details are recorded in forms distributed to fishing companies by the Australian government. Information on fishing craft and gear is also available from licensing forms.

In 1995–96 CSIRO placed observers on Australian longliners off Cairns to collect data on bycatch levels and to investigate the performance of various longline configurations (Campbell et al., 1997). The project also provided information on catch composition in relation to the fishing depth of longlines. The project indicates that swordfish have a fairly high mortality rate when caught on a longline. Of the 37 swordfish caught during the study, 73% were dead upon retrieval of the line as compared with yellowfin (42%) and bigeye (25%) tunas. The average set time for the study was 1,200 minutes.

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[5]Diplock, J.H., and D. Watkins (unpublished). The NSW Tuna Longline Fishery. Draft of a New South Wales Department of Agriculture and Fisheries. Fisheries Research Institute Internal Report.

[6]Dendrinos, G., and T. Skousen. 1991. East Coast Tuna Longline Fishery. Data Summary for the Period 1989-1990. Australian Fisheries Service internal report.

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SPECIAL REPORTS

PERSPECTIVE ON ATLANTIC (AND MEDITERRANEAN) SWORDFISH FISHERIES AND ASSESSMENTS: THE ICCAT EXPERIENCE

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INTRODUCTION

This paper reviews the swordfish (*Xiphias gladius*) fisheries and assessments conducted by the International Commission for the Conservation of Atlantic Tunas (ICCAT). The first part of the presentation reviews the history of swordfish fisheries in the Atlantic, current status of the stocks, and current fishing regulations. The second part of the presentation reviews the input data and models used to assess the Atlantic swordfish stocks. Finally, the critical areas for improvement are identified in order to emphasize the focus of future work.

Given that this presentation was requested to assist in developing a stock assessment for Pacific swordfish, there are three goals: to inform the Pacific group of the status of the ICCAT fisheries, stocks, and stock assessments; to provide a guide to the unfamiliar 'gray' literature which may be of use to the Pacific group; and to inform the Pacific group of problems that have been encountered in the Atlantic and to identify the most critical areas for the focus and planning of future work.

BACKGROUND

Biology and Stock Structure

Swordfish are widely distributed in the Atlantic Ocean and Mediterranean Sea. They range from Canada to Argentina on the western side of the Atlantic Ocean and from Norway to South Africa on the eastern side. The management units for assessment purposes are a separate Mediterranean group, and north and south Atlantic groups separated at latitude 5°N. There is uncertainty as to whether the current management boundaries correspond to the biological stock boundaries (Anon., 1997a, Table 2). The General Fisheries Council of the Mediterranean (GFCM)/ICCAT Joint Consultations (Anon., 1990, 1996a) have considered the Mediterranean swordfish separate from the Atlantic stock(s) although information in de la Serna, Alot, and Godoy (1992) and de la Serna, Alot, and Mejuto (1992) indicate that there is some movement of swordfish between the Atlantic and Mediterranean. The precise location of the boundary between north and south at latitude 5°N is primarily a function of the ICCAT data base (Anon., 1995a, 1997a).

In the Atlantic, swordfish spawn in the tropical and subtropical waters throughout the year (Arocha and Lee, 1996; Mejuto and Garcia, 1997). They are found in the colder temperate waters during the summer months. In the Mediterranean, swordfish spawn in the summer months (de la Serna et al., 1996; De Metrio et al., 1995; Megalofonou et al., 1995) in the Strait of Messina and the Tyrrhenian Sea, and around the Balearic Islands (Megalofonou et al., 1987; Cavallero et al., 1991; Rey, 1988; de la Serna et al., 1996). Swordfish have extremely rapid early growth and by age 3 reach about 140 cm (LJFL) in the Atlantic (Anon., 1989) and 130 cm in the Mediterranean (de la Serna et al., 1996). Females grow faster than males and reach a larger maximum size (Berkeley and Houde, 1983 and Ehrhardt et al., 1996, Atlantic; Tserpes and Tsimenides, 1995, Mediterranean). In the Atlantic, swordfish are thought to mature by age 5 (Anon., 1989), while in the Mediterranean, females mature at age 3 and males at age 2 (de la Serna et al., 1996).

Fisheries in the Atlantic and Mediterranean

The most recent description of the fisheries in the Atlantic and the Mediterranean can be found in the ICCAT species group detailed reports (Anon., 1997a, 1996a, respectively) and summarized in the Standing Committee on Research and Statistics executive summaries (Anon., 1997b, 1996b, respectively). In 1995 catches in the north Atlantic and south Atlantic were 16,408 t and 19,900 t respectively. Catches in the north Atlantic have declined from peak levels in 1987 (20,224 t) as high-seas fleets redeployed to the south Atlantic, Pacific, and recently the Indian Ocean. Catches in the south Atlantic are now the highest on record. The catch levels in the Mediterranean (13,754 t in 1994) were similar to those of the north Atlantic, even though the Mediterranean is much smaller. There is concern that not all catches are reported and are thus underestimated (Anon., 1997a).

Swordfish fishing is carried out throughout the Atlantic and Mediterranean reflecting the cosmopolitan nature of the species. In the Atlantic, directed longline fisheries by Spain, the United States, and Canada have operated since the late 1950s or early 1960s, and harpoon fisheries have existed since the late 1800s. The Japanese tuna longline fishery started in 1956 and has operated throughout the Atlantic since then, with substantial catches of swordfish taken as bycatch by their tuna fisheries. Recent descriptions of these major fisheries can be found in Mejuto et al. (1997a), Uozumi (1997a), Stone and Porter (1997), and Cramer et al. (1993). Hoey et al. (1993) compares country operational codes over the history of the longline fishery in the Atlantic. There are also other directed swordfish fisheries (e.g., Portugal, Venezuela, Morocco, and Uruguay) and bycatch or opportunistic fisheries which take swordfish (e.g., Taiwan, Korea, France, Brazil). In the Mediterranean, swordfish are taken mainly by longline, though the largest producer of swordfish, Italy, takes about half of its catch by large-scale driftnet. After Italy, Greece and Spain are the largest producers of swordfish; other countries directing for swordfish include Algeria, Cyprus, Malta, Morocco, Tunisia, and Turkey (see detailed descriptions in Anon., 1990, 1996a).

Current Status of the ICCAT Swordfish Stocks

For the Atlantic, the most recent stock status advice is found in Anon., 1997a, b, and in Anon., 1996a, b for the Mediterranean.

North

The biomass and abundance in the north Atlantic stock are estimated to be the lowest on record, fishing mortality rates are well above common biological reference points, and the current catches (1995) are not sustainable. Recent assessment results indicate the new 1997 quota of 11,300 t (33% less than status quo) is not likely sufficiently low to arrest the decline of the stock.

South

Preliminary analyses indicate that current levels of harvest are not sustainable and that fishing at FMSY would maintain the stock at MSY levels. In order to achieve this level, substantial reductions in catch to around 13,000 t in 1997 and thereafter would likely be needed.

Mediterranean

Given the short time series of reliable data and the long history of exploitation of swordfish in the Mediterranean, it is uncertain where the stock is in relation to unexploited levels. Preliminary analyses and warning signs from the fishery suggest that the Mediterranean fishery cannot sustain continued heavy harvests of juveniles or further increases in fishing effort.

Current Regulations

ICCAT has no regulatory authority. The ICCAT Commission makes 'regulatory recommendations' (e.g., catch limits, minimum size restrictions) which are then adopted by member countries in their domestic management. In general, the ICCAT regulatory recommendations for swordfish have not been adhered to by all nations and their effectiveness in conserving Atlantic swordfish is less certain (Table 18 in Anon., 1997a). Because of a lack of compliance with regulatory recommendations, it is not possible to evaluate their effectiveness as if they had been perfectly implemented. In 1997, the Compliance Committee of the ICCAT Commission took measures to improve compliance by introducing penalties (quota penalties and trade restrictions) to member and non-member countries that do not comply to the ICCAT regulations.

In response to the 1996 report of the Standing Committee on Research and Statistics (SCRS; Anon., 1997b) the commission recommended that in 1997, 1998, and 1999 ICCAT member countries operating in the north Atlantic be restricted by reduced country-specific quotas totaling 11,300, 11,000, and 10,700 t, respectively. For the south Atlantic, it has been agreed that landings be capped to 1993/94 levels. The establishment of country-specific shares has been discussed, but no quotas have been implemented. A minimum size restriction for the entire Atlantic is continued (125 cm LJFL, 15% tolerance or 119 cm LJFL, no tolerance).

The ICCAT Commission has made no regulatory recommendations for the Mediterranean stock. However, in 1995 the European Union initiated minimum size and gear restrictions. The effectiveness of these measures has yet to be evaluated.

STOCK ASSESSMENTS

Of the swordfish stocks under ICCAT jurisdiction, the north Atlantic is by far the most rigorously assessed due to the quality of the data available and the emphasis placed on conservation there by member fishing nations. Although, there have been preliminary assessments conducted for the Mediterranean (Anon. 1996a) and for the south Atlantic (Anon., 1997a), only the north Atlantic will be discussed in detail here.

The ICCAT SCRS generally conducts biannual swordfish stock assessments prior to the SCRS Plenary, during intersessional meetings usually in September or October, when data are available. National scientists submit their catch and catch-at-size data to the ICCAT Secretariat in advance of the meeting so that the catch-at-size/age is available at the start of the meeting. Scientists from principal fishing nations generally submit the catch-at-size data raised to the entire catch (e.g., only a portion of the catch is sampled for size, and scientists extrapolate these samples to the entire catch, using as fine a scale as possible). National scientists present updated or new CPUE data in the form of SCRS documents (subsequently published in the ICCAT Collective Volumes of Scientific Papers, the 'Red Book series'). Other information is also presented in the form of SCRS documents. The ICCAT Swordfish Species Group generally meets for eight days to conduct a full stock assessment. The report of the species group then goes to the SCRS Plenary where it is peer reviewed and adopted. The quality of the peer review in ICCAT at this stage is not as rigorous as it could be, although there are recommendations to improve this in the future (Anon., 1997c). The executive summary (i.e., Anon., 1997b) forms the scientific advice to commissioners, and the detailed report (i.e., Anon., 1997a) is the record of the species group meeting. The chairman of the SCRS presents the scientific report to the ICCAT Commission which meets about one month after the SCRS Plenary.

Input Data

Catch

National scientists for major fishing nations submit the catch-at-size based on samples and raised to the entire catch. In Canada and the USA, size is determined primarily from dressed weights at landing. The coverage is excellent and approaching 100%. However, the measurement of fish dressed weight and subsequent conversion to LJFL may have a substantial effect on the total variance of lengths at age (Haist and Porter, 1993). The Spanish have a very extensive biological sampling program of fish landed whole (Mejuto and de la Serna, 1997b). The Japanese rely on onboard sampling by the industry (Uosaki and Uozumi, 1995). The catch and catch-at-size data for these nations are fairly good, although there is some suggestion that there may be unreported catches landed in Spanish ports by foreign vessels (Anon., 1997a). Other nations fishing in the Atlantic do not submit size data, and substitutions are made from existing size data for the same gear, time and area, on as fine a scale as possible. A shortcoming of the ICCAT database is that the catches are by large geographic area and need to be segregated using smaller geographic strata to examine such things as alternate stock boundaries and fine scale differences in sex ratios. In 1996, it was recommended that data be reported in 5x5 degree rectangles if possible (Anon. 1997a).

The mark-recapture growth curve developed by the SCRS in 1988 (Anon., 1989) was used to establish monthly boundaries for age slicing, which were then used to calculate the catch-at-age for the north Atlantic (see also Porter, 1994). In the 1992 swordfish stock assessment report (Anon., 1993), the SCRS emphasized that a source of error in developing the catch-at-age was the practice of ignoring individual variability in length at age. The practice was to assume a one-to-one age-length relationship, a Gompertz growth curve, and to apply 'cohort slicing' to the catches. It was recommended that an inter-sessional meeting be held to address appropriate size/age conversions for swordfish (and other tunas of interest to the SCRS). Two such meetings were held. During the first meeting (Anon., 1994), very basic simulated data were generated to evaluate the performance of various assessment methods in the presence of individual growth variability. Results from applying the various assessment methods to the simulated data were presented at the second meeting in 1994 (Anon., 1995b). The results indicate that while the practice of cohort-slicing introduces errors in the catch-at-age, the impact of such errors on assessment results is lessened by plusing the catches at a young age. This gives support to the use of a 5+ group for swordfish (see below). A real shortcoming of the Atlantic assessment is the lack of a validated growth curve. Although there are several growth curves available (Anon., 1989; Berkeley and Houde, 1983; Ehrhardt et al., 1996), without validation it is impossible to determine the 'true' growth rate. Further, the sampling has concentrated on the western side of the Atlantic, and has been based on a limited number of samples.

In 1996, a preliminary attempt was made to prepare a catch-at-size by sex for the north Atlantic. Concerns about some of the procedures used to develop the catch-at-size by sex and differences in those procedures among the various nations was addressed in 1997. Further details are provided in Anon. (1997a). The catch-at-age was created using the growth curve in Ehrhardt et al. (1996), although this sex-specific growth curve differs from other sex-specific growth curves examined previously by the SCRS. A working group was established to develop standardized approaches for the treatment of sex ratio at size, to develop catch-at-size by sex, and to review the merits of the available growth curves.

CPUE Data

Indices of CPUE from commercial longline fisheries (catch per 1000 hooks) in the Atlantic are used as a measure of relative abundance, both in VPA tuning and as estimates of percent change in population size in years when no stock assessment is conducted. General linear models are applied to standardize the catch rate series and can be thought of as a multiple regression that can use categorical independent variables (see Restrepo, 1997a). The dependent variables can be year, quarter or month, gear type or operational code, area, target species, etc., and the error term is assumed to be distributed log normally. The overall estimate of annual relative abundance in the current year is taken to be the coefficient associated with the year effect. A recent modification to this class of models has been to use an error family other than log normal distribution (McCullagh and Nelder, 1989) which may be more realistic. This was examined for swordfish data during the 1994 and 1996 assessments (Anon., 1995a, 1997a).

There are still problems in obtaining truly standardized CPUE. In some cases there is a significant interaction between year and other factors and if the magnitude is large, it is difficult to interpret; there are changes in catchability through time that may not be accounted for in models (i.e., technological changes and environment), and it is not clear that standardized CPUE series for localized fisheries are reflective of overall stock abundance. However for swordfish, which occur throughout the ocean and water column, commercial catch rates are thought to be a fairly good measure of relative abundance. The trends in relative catch rates are fairly similar among fleets, at least in the north Atlantic (see Fig. 9, Anon., 1997a). The methods and results for CPUE calculations are well documented for the north and south Atlantic as follows: north (age-specific)—Japan (Uozaki, 1997; by sex); Canada (Stone and Porter, 1997); Spain (Mejuto and de la Serna, 1997c; by sex); U.S.A. (Scott and Bertolino, 1997; by sex); north (biomass)—entire north Atlantic (Hoey et al., 1997); south—Spain (Mejuto and de la Serna, 1997c), Japan (Uozumi, 1997b), Taiwan (Uozumi, 1997c), Brazil (Arfelli et al., 1997).

Models

Swordfish was not assessed during the 1970s because U.S.A. mercury standards made the species undesirable for some fleets (see Table 1), and there was little concern over the status of the resource at that time. Since 1988 it has been assessed primarily through tuned VPAs (Powers and Restrepo, 1992) and recently non-equilibrium, lumped biomass (Prager, 1993a, b) or age-structured (Geromont, 1997; Restrepo, 1997b) production models. Other approaches such as length-structured sequential population analyses (Kimura and Scott, 1994), and VPA procedures that allow for modeling errors in the catch-at-age and abundance indices (e.g., Porch, 1996) have also been applied, but have not yet been adopted by the ICCAT Swordfish Species Group due to the heavier data and computational requirements and limited time at the species group sessions. Because of data limitations (quality and availability) and management constraints in the south Atlantic and Mediterranean, assessments have concentrated on the north Atlantic, although in 1996 a preliminary non-equilibrium production model was conducted for the south. The Mediterranean stock was assessed for the first time in 1994 using a preliminary sex-specific VPA. Although the results are considered preliminary, this is one of the few ICCAT assessments for a stock in that sea. These preliminary stock assessments have been useful exercises both to illustrate the shortcomings of the data and to provide incentive for improvement.

VPA

In the north Atlantic, the current base case VPA has the following specifications.

- Unsexed catch-at-age 1978-1995 (Table 3, Anon., 1997a); e.g., 1:1 sex ratio, growth rate based on mark-recapture data (Anon., 1989) was used to establish monthly boundaries for age slicing.

- Base case VPA was calibrated using 17 indices derived from standardized longline commercial catch rates using the ADAPT framework (Powers and Restrepo, 1992); Spanish and USA ages 1, 2, 3, 4, and 5+ (Mejuto and de la Serna, 1997c; Scott and Bertolino, 1997); Japanese ages 3, 4, 5+ (Uozaki, 1997); Canadian ages 2, 3, 4 and 5+ (Stone and Porter, 1997; Table 5, Anon., 1997a).

- Because indices vary in length, iterative re-weighting was not used. Alternate weighting schemes have been used in the past.

- Because higher catch rates were more variable, the model was fit using logarithmic transformation to stabilize the variances.

- The 5+ age grouping was used because of inability to reliably age fish older than 5.

- F-ratios were used to separate the 5+ stock size into cohorts for backcalculation into younger cohorts. F-ratios were used because of our inability to accurately determine catch-at-age for older fish. F-ratios for 1988-95 were fixed to 1.0 and F-ratios for 1978-82, 1983-87 were estimated. Extensive discussion in 1994 (Anon., 1995a) concluded that, although the F-ratio was very uncertain, an appropriate assumption on which to base analyses was that there was equal selectivity at age within the plus group for the period 1988-present. Hence the F-ratio during this period (as determined by a separable VPA with a flat-topped selectivity) was specified by 1.0, and F-ratios for 1978-82 and 1983-87 were estimated within the ADAPT framework.

- Bootstrapping was used to evaluate the variability of the fit of the indices to the catch-at-age through the VPA model and to incorporate the uncertainty of the 1988-95 F-ratio level (uniform distribution from 0.75 to 1.33).

Production Models

In the north Atlantic, the current base case non-equilibrium production model case used the ASPIC model (Prager, 1993a,b). The age-structured production model was attempted in 1996, but is still considered preliminary (Anon., 1997a). Non-equilibrium, generalized production models were also attempted, although the production function skew parameter was fixed rather than estimated. The base case ASPIC production model had the following inputs and specifications.

- total reported north Atlantic reported catch from 1950 to 1995, including discards (Table 1, Anon., 1997a)

- CPUE biomass index from 1963 to 1995 (Hoey et al., 1997; Table 5, Anon., 1997a)

- beginning in 1950 biomass was constrained to 1.75 * BMSY (equivalent to 0.875 * K)

Sensitivity Analyses

Sensitivity analyses have been used by the SCRS for many years and attempt to characterize the overall variability or model misspecification. They can indicate how much the model result is influenced by a change to a particular input or assumption. However, there has been a tendency to conduct sensitivity trials in the absence of clear experimental design or decision making rules. In recent years, a more rational approach has been used, in part following the guidelines of Restrepo and Powers (1995). Many of the sensitivity trials conducted for swordfish are related to our inability to reliably age swordfish, including the problem of sexually dimorphic growth (such as examination of the influence of the size of the plus group on the VPA result (Anon., 1995b), the influence of the assumptions about the F-ratio (Anon., 1995a, 1997a), an attempt to do a length-based analysis (Anon., 1994), and most recently a preliminary sex-specific VPA (Anon., 1997a)). Some sensitivity trials have to do with the length of the time series, the use of particular indices, and the use of particular years in the index series. Finally, other sensitivity trials have examined the impact of non-reporting of catches and the variability and accuracy of the CPUE distributions.

The various sensitivity trials are well detailed in the SCRS reports (see especially Anon., 1995a, 1997a). Because many of the sensitivity trials are related to our inability to reliably age swordfish and to the problem of sexually dimorphic growth, I will elaborate on what the SCRS sees as the next level of the base case analysis. In 1996 a preliminary sex-specific VPA for the north Atlantic was conducted as a sensitivity analysis. Past studies (Suzuki and Miyabe, 1991; Restrepo, 1991; Restrepo et al., 1992) have shown that the trends in the estimates from the VPAs were not strikingly different when sexual dimorphism was accounted for, but that some of the magnitudes were, and that much could be gained by incorporating differential growth by sex into the analyses. These findings were confirmed in the preliminary 1996 sex-specific analysis

(Anon., 1997a). The preliminary sex-specific analysis in 1996 had the following specifications (where they differed from the base case VPA).

- catch-at-age by sex from 1985-95—sum of males plus females, growth rate based on Ehrhardt et al., 1996
- calibrated using 13 indices (same as base case VPA without the Canadian sex-specific indices as they were not available) and 10 age groups
- F-ratios fixed to 1.0
- terminal fishing mortality rates all estimated

The sex-specific VPA was designated as a sensitivity trial due to the preliminary nature of the sexed catch-at-age. However, the SCRS recognizes that it is more biologically realistic to account for the sexually dimorphic growth patterns exhibited by swordfish when constructing the catch-at-age from length data. The SCRS recommended that the future base case VPA assessments be conducted on data derived in that manner. Differences in the catch-at-age, the treatment of the F-ratios and the length of the time series are felt to account for the difference between the sex-specific and base case analyses.

Yield Per Recruit

Yield-per-recruit models have been used in conjunction with assessment models to predict the effects of specific changes in fishing practices, relate spawning biomass per recruit relative to unfished levels and biological reference levels, and relate fishing mortality rates to common biological reference points. The effectiveness of the minimum size regulation was evaluated this way (Anon., 1995a; Anon., 1997a; Mace, 1995), and the conclusion is that increases in the effective minimum size offer the greatest opportunity for increasing long-term yields, whereas overall reductions in fishing mortality are required in order to achieve substantial increases in biomass per recruit (and ultimately the size of the spawning stock). The current fishing mortality rate estimates are well above common biological reference points.

Retrospective Analyses

Retrospective analyses have been conducted by stepping back through the years of available data and conducting tuning at each step, ignoring all data in subsequent years. The results indicate whether there is a pattern in the estimate of abundance of a particular age for a particular year which increases or decreases systematically as more data are added. These so-called retrospective patterns can arise for many reasons (e.g., unreported catches, misspecification of indices or natural mortality rates or growth). Although ad hoc adjustments can be made, it is unclear whether they are an improvement. Results of the most recent (1994) retrospective analysis for the north Atlantic swordfish did not show a strong pattern especially in recent years (Anon., 1995a). Stock sizes were not adjusted for retrospective patterns. No retrospective analysis was conducted during the 1996 assessment.

Projections

Projections have been used on both the nonequilibrium production model and the VPA. In 1996, managers requested a 15-year recovery plan, and projections used in the formulation of advice were conducted from the VPA (because of the nature of the recruitment assumptions). Specifications were as follows:

- bootstrapped VPA;
- assume total weight in catch in 1996 = 1995;
- two-line stock-recruitment relationship with CV of 0.4 was used: horizontal line computed from average of 1978-95, slope defined as line from origin to the lowest observed spawning biomass (there is little evidence of declining recruitment at recent levels of spawning biomass);
- selectivity from geometric mean of 1993-95 selectivities;
- MSY proxy = intersection of slope of R/S at Fmax and the horizontal portion of the stock-recruitment relationship (for each bootstrap iteration); and
- various harvest and F scenarios calculated (see Anon., 1997a).

The results indicate that large reductions in yield and F are required to rebuild the stock in the short and medium term. These 15-year projections, while very uncertain, provide the basis for a management strategy. These projections can be updated at each assessment to ensure that the management strategy is on target. The ICCAT Commissioners, until now, have tended to operate without clear management goals or time frames.

Uncertainty

It is useful to characterize the statistical uncertainties in the estimates of stock status, management references, and projections. This is done in the ICCAT swordfish stock assessments using bootstrapping techniques. It is important to note that although variation in as many quantities as possible has been incorporated (e.g., the indices, recruitment or F-ratio), there are other uncertainties which are not included, including sex-specific growth and non-reporting of catches (see sensitivity analyses above), technological advances which increase catchability, and mixing between the north and south Atlantic. It is likely that some of these unquantified uncertainties are systematic and not random, therefore they would result in a directional shift to some quantities of interest, rather than added variation. To the extent possible, these unquantified uncertainties have been described qualitatively and they should be kept in mind when interpreting the bootstrap results.

THE FUTURE

The three areas for improvement in the ICCAT stock assessments are the understanding of basic swordfish biology, reliability of catch and CPUE inputs, and types of models used. Before more advanced models can be used (e.g., more spatially explicit models), better basic data are required (e.g., quantitative documentation of migration). The quality and type of data available limit both the reliability of the present results and the type of models that can be used now and in the future.

Given the limited resources for gathering data, it is useful to take a broad perspective and determine how and where to focus research efforts. The era of conducting research in the absence of carefully planned and executed studies has passed. Designing specific experimental approaches to answer questions in support of stock assessment is the most efficient method. The ultimate goal is to improve stock status advice to managers and industry, and thus conservation. To do that we need to reduce uncertainty in our basic assumptions (i.e., stock structure, age, and growth), determine the most efficient way to accurately record and sample the catch and CPUE, and use models that are realistic and accommodating for the uncertainty in the data (e.g., explore length-based approaches) and that provide robust management advice.

In summary, I offer the following points of relevance to the Pacific swordfish group based on the ICCAT experience:

- Definition of management units. It is important to have basic research conducted to determine the most appropriate boundaries for management purposes. Select the most appropriate tools to address the problem within the limits of your resources. In ICCAT, there is still much uncertainty about the biological stock boundaries. Resources should be focused on specific methods to resolve this major source of uncertainty.

- Data collection. Ensure the collection of reliable and complete catch and CPUE data on as fine a scale as possible in a standardized format.

- Compatibility of data and models. Determine the attributes of your data and the available information on the biology of the species and choose the most appropriate model for stock assessment. If the data do not suit the model then improve the data, refine the model to accommodate the data, or find another model. For instance, for a species that is difficult to age, such as swordfish, perhaps length-based models should be explored more fully.

- Communication of results. For the results of stock assessments to be of any use to improve conservation, they must be presented to managers and the industry in a clear and understandable fashion, and in terms that can be implemented. Managers should be informed well in advance as to what they can realistically expect from stock assessment results (scientists confront many uncertainties and cannot provide all the answers), and the time frame for reporting. In ICCAT, there are no longer annual swordfish stock assessments; given the life history characteristics of swordfish, this is unnecessary. However, it would be useful for managers and scientists to balance the best use of resources to produce rigorous stock assessments. Given all the uncertainties in our basic understanding of swordfish biology, resources might be better spent on basic research than on frequent stock assessment reviews.

- Peer review. A very important component of rigorous stock assessment is peer review, as you are doing at this symposium. Constructive peer review is essential to maintain a high scientific standard. This is a shortcoming of ICCAT, though it will be improved in the near future.

ACKNOWLEDGMENTS

I thank my colleagues in ICCAT and the Canadian fishing industry for sharing their knowledge of swordfish with me. Jerry Scott, Rob Stephenson, Heath Stone, and Yuji Uozumi provided valuable comments on the manuscript.

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Table 1. Summary of ICCAT swordfish stock assessment methods adapted from Restrepo (1997a) and updated to 1996 (Anon. 1997). Swordfish were not assessed prior to 1977.

Year	Not assessed	Prod mod equil.	Prod mod noneq.	Prod mod age struct	Coh. anal untuned	VPA tuned	Yield/ recruit	Other	Stock status
1977	X						T		
1978	X								
1979									
1980	X						T		
1981	X								
1982	X								
1983									
1984					T				?
1985					T				SSB-60% from 1978
1986						T			SSB low
1987	X								
1988						N, S			F increasing
1989						N, NW, NE	N, NW, NE	Projections	Recrtmt increase, SSB decline in all
1990		N				N, NW, NE, T	N, NW, NE, T	Projections	$F>>F_{0.1}$
1991			N			N	N	Retrospect	$F>F_{msy}$
1992			N			N	N	Retrosp., projections	F_F_{msy}
1993	X								
1994			N			N	N	Retrosp., projections	$F>F_{msy}$
1995						M	M		$F>F_{0.1}$
1996			N, S, T	N		N	N	Projections	$F>F_{msy}$

Notes: An "X" in the second column indicates that no current, quantitative assessment was considered by the SCRS for any stock of swordfish in the corresponding year (sometimes the SCRS considers previous assessments and those are only listed for the year in which they were carried out). The subsequent columns contain a letter for the stock (E=East, W=West, N=North, S=South, M=Mediterranean, T=Total) or stocks that were assessed that year, by model type: equilibrium production models, nonequilibrium production models, age-structured production models, untuned cohort analysis or VPA, tuned VPA, yield-per-recruit computations, and "other" methods. The consideration given almost every year by the SCRS to relative trends in abundance indices or nominal CPUE is not included as an assessment in this table. The last column contains some implication or statement made by the SCRS concerning stock status and should be used only as a guide. For a complete description of the SCRS' perception of stock status, consult the SCRS reports.

ADAPT: A Practical Modeling Framework FOR FISHERIES STOCK ASSESSMENT

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HISTORY OF MODEL DEVELOPMENT

ADAPT is an age-structured, *adaptable* framework for estimating historical stock sizes of an exploited population. It is not a rigidly defined model in the mathematical sense, but rather a flexible set of modular tools designed to integrate all available data that may contain useful information on population size. The statistical basis of the ADAPTive approach is to minimize the discrepancy between observations of state variables and their predicted values. The observed state variables are usually (but are not limited to) age-specific indices of population size; e.g., from commercial catch-effort data, research surveys, mark-recapture experiments, etc. The predicted values are a function of a vector of estimated population size (age-specific) and catchability parameters; and standard population dynamics equations (usually Gulland's [1965]) VPA). Nonlinear least squares objective functions are generally employed to minimize the discrepancies.

The appellation *ADAPT* was introduced by Gavaris (1988). However, the foundation of the method was developed over the preceding decade under an umbrella of research generally referred to as *VPA tuning*. Although not generally recognized, Parks (1976) was the first to tune a VPA using auxiliary data and a least-squares objective function. He tuned VPA backcalculated fishing mortality rates (Fs) to Fs derived independently from tagging experiments. Gray (1977) suggested a least-squares approach to estimate mortality rates (both F and M) using a commercial catch-per-unit-effort (CPUE) index of abundance as auxiliary data. Doubleday (1981) used age-specific research survey indices of abundance as auxiliary data to estimate survivors in the terminal year for each cohort. This appears to have been the first attempt to utilize multiple indices of abundance in a least squares tuning procedure.

Parrack (1986) expanded upon Doubleday's work by integrating indices of abundance from widely diverse sources into the least-squares objective function. His formulation allowed indices from commercial fisheries, research surveys, larval surveys, etc. Indices could be either age specific or represent an age group and could be expressed in either population number or biomass. Indices were related to population size either linearly or through a power function. Variance estimates were made assuming linearity at the optimal solution. He also recognized that not all indices are of equal value in measuring population abundance. Some indices will always be inherently more variable than others, and some may be biased. He introduced detailed examination of residuals and correlation statistics as an acceptance/rejection filter that each index needed to pass through in order to be used in the final tuning. The tuning procedure described by Parrack (1986) is the kernel of the method today known as *ADAPT*, both in terms of the objective function employed and in terms of the underlying philosophy.

Gavaris' (1988) *ADAPTive framework* generalized Parrack's procedure in three ways. The adaptive aspects of the method were greatly enhanced through the use of a modular model structure and implementation in the APL programming language. This made it possible to modify the objective function significantly, as needed to rectify problems, even during the course of an assessment working group meeting. A Marquardt algorithm (Bard, 1974) was used for optimization of the least squares objective function. This allowed the simultaneous estimation of age-specific population sizes in the terminal year and catchabilities (Parrack estimated only the full F in the terminal year and relied on an input partial recruitment vector to complete the terminal year F vector). Additionally, the use of numerical derivatives in the Marquardt algorithm greatly enhanced the adaptive philosophy by making objective function modifications easy to implement. The more complete statistical model also allowed for improved diagnostics. In addition to residual analysis, availability of the full variance-covariance matrix (assuming linearization at the optimal solution) provided variance estimates of all parameters, correlation among parameter estimates, and in general a better sense of which parameters were estimable from the available information.

The integration of many diverse sources of information focused attention on objective procedures to account for differences in the quality of information. Collie (1988) suggested that all indices of abundance should be included in the least squares objective function rather than employing Parrack's acceptance/rejection criteria. He recommended weighting the indices by the inverse of their variances. Vaughn et al. (1989) used a Monte Carlo simulation to investigate the effect of weighting on the Fs estimated for bluefin tuna. They found that F estimates were unbiased only when the indices were weighted. Conser and Powers (1990) developed a more general weighting procedure that allowed for two-way effects; i.e., index and year. Gavaris and Van Eeckhaute (1991) employed a similar weighting procedure using an analysis of variance approach. Gassuikov (1990) suggested an alternative approach to weighting in ADAPT using the *moving check* procedure of Vapnik (1982). Weighting procedures continue to be examined in various stock assessment arenas. The International Commission for the Conservation of Atlantic Tunas (ICCAT) Bluefin Tuna Working Group has been especially active in this area of research.

It is noteworthy that all of the above cited work (with the exception of Gray [1977] and Gassuikov [1990]) was developed in conjunction with assessment working groups associated with either the ICCAT or the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC). This development environment has been influential in shaping the flexibility and the pragmatic nature of ADAPT. It differs from the Doubleday-Deriso catch-at-age models (Doubleday, 1976; Deriso et al., 1985; Kimura, 1989), developed over a similar period, in several ways. Although both employ least-squares objective functions and tune to auxiliary data,

(1) ADAPT does not assume separability (of fishing mortality and selectivity)
(2) ADAPT is more parsimonious in the number of parameters estimated
(3) ADAPT tends to be more interactive. It requires careful attention to diagnostics (e.g., residuals, correlations, etc.). This coupled with its flexibility (including objective function modifications) encourages iterative reruns of the model and rethinking some assumptions until all major problems are rectified.

ADAPT has been used for assessment of a wide variety of fish stocks in several different assessment arenas; e.g., ICCAT, CAFSAC, NAFO, and USA domestic assessments (Conser, 1993). It is currently the primary age-structured model used for stock assessments in the western north Atlantic (Canada and USA) and internationally for Atlantic tuna and swordfish assessments (ICCAT). A small sample of the extent of these applications is provided for interested readers—ICCAT (Conser, 1989; Nelson et al., 1990), CAFSAC (O'Boyle et al., 1988; Chouinard and Sinclair, 1988); NAFO (Baird and Bishop, 1989); USA domestic (SEFC, 1989, Conser et al., 1991); and many others.

DATA REQUIREMENTS AND ASSUMPTIONS

In a typical ADAPT application, required input data are as follows.

(1) Catch-at-age (in number) for each year in the analysis. Older ages may be aggregated into a 'plus group,' as necessary.
(2) Indices of abundance—typically derived from standardized CPUE data or from research surveys. Ideally, age-specific indices will be available for each year in the analysis, but missing data (year or age) are common. Aggregate groups of ages are also allowed; e.g., a spawning stock biomass index may be used. Multiple indices for some age/year combinations are common in practice; e.g., CPUE indices from different fisheries, abundance indices from research surveys, etc.
(3) Exogenous estimate of the instantaneous rate of natural mortality (M) for each age and year. In practice, M is usually assumed invariant with age and time.
(4) Initial estimates (starting values) for the parameters to be estimated in the model. Generally, one parameter is estimated for each incomplete cohort in the terminal year of the analysis (representing the number of survivors in that cohort), and one catchability coefficient is estimated for each index of abundance.

The above input data are needed for all applications of ADAPT, but additional input may also be required depending on the specifics of the analysis. For example:

(1) Mean weight-at-age estimates are needed if one or more of the indices is proportional to abundance in weight (rather than number).
(2) A maturity ogive is needed if one or more of the indices is proportional to spawning stock biomass.
(3) Exogenous estimates of partial recruitment for some ages in the terminal year may be needed if the full vector of survivors at the end of the terminal year is not estimable in the model.
(4) Objective function weighting factors may be needed when indices of abundance have greatly differing variances (see *Key Model Equations* section, below); e.g., inverse variance weights from sampling theory are sometimes used for weighting research survey indices.

Since VPA is a fundamental part of the infrastructure in most ADAPT applications, many of the assumptions of the ADAPT model are those associated with VPA. The key ADAPT assumptions are as follows.

(1) The instantaneous rate of natural mortality (M) is known over age and time (and usually assumed constant).
(2) Error in the catch-at-age estimates is negligible (relative to the error in the indices of abundance).
(3) The general shape of the partial recruitment function (e.g., flat-topped or dome-shaped) is known for all years prior to the terminal year. This information is needed to determine the survivors for each completed cohort (or equivalently, the fishing mortality rate [F] on the oldest age for each year prior to the terminal year).
(4) The catchability (q) associated with each index of abundance is constant over time. However with a sufficiently long time series (say, 10 or more years), it is sometimes possible to break a time series where a suspected q change has occurred, and then estimate separate qs (before and after the transition).

(5) The proper error structure for the indices of abundance is known. Errors are most often assumed to be log normal, but other error structures (e.g., normal) are also used in some settings.

Assumptions (1) through (3) are invoked in carrying out any VPA. Assumptions (4) and (5) result from the structural equations and parameter estimation in ADAPT.

KEY MODEL EQUATIONS

Due to the flexibility and adaptive nature of the model, both the structural equations and the statistical model used for parameter estimation can vary to some degree in various applications of ADAPT. The equations provided in this section describe the kernel of the model as usually implemented. VPA (Gulland, 1965) or VPA-like algorithms (e.g., Pope, 1972) usually form the basis of the underling structural equations. These equations are assumed to represent the population dynamics exactly; i.e., no process error (equation error) is generally allowed. Familiarity with VPA and VPA-like algorithms is assumed in this section. The detailed equations for these algorithms are not provided.

ADAPT, as generally implemented, is a measurement error model. The measured indices of abundance (I'_{iy}) are related to the *true* indices of abundance (I_{iy}) by

$$I'_{iy} = I_{iy} e^{\sigma_{iy}}, \tag{1}$$

where s_{iy} is a normally distributed random variable with mean 0 and variance s^2, representing the measurement error in the indices of abundance. Let K be the number of available indices and let Y_i be the number of years of available data in the i^{th} index. Then the nonlinear least squares objective function to be minimized is

$$SS(\theta) = \sum_{i=1}^{K} \sum_{y=1}^{Y_i} \lambda_{iy} \sigma_{iy}^2, \tag{2}$$

where the λ_{iy} are relative weighting factors for the various index-year terms and SS, the sum of squares, is a function of the set of parameters to be estimated (θ). Solving Equation 1 for s_{iy} and substituting into equation 2 gives the ADAPT objective function

$$SS(\theta) = \sum_{i=1}^{K} \sum_{y=1}^{Y_i} \lambda_{iy} \left[(\log_e I'_{iy}) - (\log_e \hat{I}_{xy}) \right]^2. \tag{3}$$

The estimate of the *true* value of the i^{th} index in year y ($\hat{I}_{iy}$) in Equation 3 is not actually a model parameter, but is derived from the structural equations (without process error) as follows:

$$\hat{I}_{xy} = \hat{q}_i P_{iy}, \tag{4}$$

where the $\hat{q}_i$ are parameters estimated in the model (catchability coefficients) and P_{iy} is the component of the population represented by index i in year y. For most indices used in practice, P_{iy} represents age-specific stock size in number; e.g., number of age 5 animals in 1990. However, depending upon the nature of the index being used, P_{iy} may also represent a group of ages (e.g., number of animals age 10 and older in 1990) or P_{iy} may represent a component of stock biomass (e.g., metric tons of spawning stock biomass at the beginning of the 1990 spawning season). More specifically,

$$P_{iy} = f_i\left(\mathbf{N}_{vpa}, \mathbf{W}, \mathbf{O}\right), \tag{5}$$

where the boldface symbols are matrices with dimension m x n (i.e., m ages by n years). $\mathbf{N}_{vpa}$ is the matrix of stock sizes in number (by age and year) from VPA. **W** is mean weight at age and year. **O** represents proportion mature at age (maturity ogive) and year. f_i is an index specific function that generates P_{iy} from typical VPA output and the other required input data, as needed. Finally,

$$\mathbf{N}_{vpa} = g_{vpa}(\mathbf{C}, \mathbf{M}, \hat{\mathbf{S}}_t), \tag{6}$$

where g_{vpa} is a generic function that carries out typical VPA calculations and returns $\mathbf{N}_{vpa}$. $\hat{\mathbf{S}}_t$ is the vector of survivors for the incomplete cohorts at the end of the terminal year of the VPA (i.e., year n). In practice, the function g_{vpa} often represents Pope's (1972) approximation to VPA (sometimes called cohort analysis). This approximation makes function evaluations faster and provides some conceptually simplicity. In general any algorithm, that can take the required inputs (**C** and **M**) and the parameter vector of survivors ($\hat{\mathbf{S}}_t$) and calculate $\mathbf{N}_{vpa}$, can be used.

The model parameters to be estimated are the K catchability coefficients (the $\hat{q}_i$) and the m elements in the survivor vector ($\hat{\mathbf{S}}_t$). Degrees of freedom (df) for the model are

$$df = \sum_{i=1}^{K} Y_i - (K + m). \tag{7}$$

In most implementations, all parameters are estimated simultaneously. However, as first described by Parrack (1986), optimization efficiency can be improved (sometimes greatly) by conditioning the $\hat{q}_i$ on the $\hat{\mathbf{S}}_t$, and solving for the $\hat{q}_i$ analytically (using the normal equations from simple linear regression). Because the $\hat{\mathbf{S}}_t$ are the highly nonlinear parameters in the model, the optimal solution vector is not affected by this modified procedure.

The objective function (equation 3) is straightforward and generally well behaved. With reasonable initial values for the parameters, it can usually be minimized efficiently using a Marquardt algorithm (Marquardt, 1963; Bard, 1974) without local minimum difficulties. Alternatively, in unusual cases where local minima are encountered, the more exhaustive but less efficient *simplex method* (Nelder and Mead, 1965; Press et al., 1986) can be employed.

EXTENSIONS OF THE MODEL

Variance estimates for all of the model parameters, as well as all management related state variables (e.g., fishing mortality rates, spawning stock biomass, etc.), are available via bootstrapping (see Conser [1994] for details) or via Monte Carlo simulation (Restrepo et al., 1991). Stochastic projection modules have also been developed that fully incorporate the uncertainty in terminal year stock sizes (from ADAPT bootstrapping) into forward-projected stock trajectories and their error bars (e.g., Brodziak et al., in prep).

Diagnostics have been fully incorporated into many model implementations. For example, CVs on parameter estimates, correlation among parameter estimates, residual analysis, and outlier leveraging are all available for critical analysis of model runs that may be candidates for the final, agreed-upon assessment.

Other areas of continuing research on the ADAPTive method include:

(1) Balancing the number of parameters estimated with the need to impose some model structure; e.g., the assumption of a partial recruitment pattern in years prior to the terminal year (e.g., Conser and Powers, 1990; Restrepo and Powers, 1991; Powers and Restrepo, 1992)
(2) Procedures for incorporating all components of variance into the ADAPT variance estimates of stock size and fishing mortality (e.g., Restrepo et al., 1991; Porch, 1996)
(3) Incorporation of movement and migration between stock areas (e.g., Butterworth and Punt, 1994; Porch et al., 1995)
(4) Adaptations of the model for length-based assessments (e.g., Mohn and Savard, 1989; Conser, 1995)

MANAGEMENT APPLICATIONS

Model output includes a wealth of population demographic information, including:

(1) population numbers (N) by age and year;
(2) fishing mortality rates (F) by age and year;
(3) population biomass (B) by age and year; and
(4) spawning stock biomass (SSB) by year.

These model results are quite useful in their own right for management purposes. However, when used in conjunction with the bootstrap results and stochastic projections (described in the previous section) it provides not only point estimates to fishery managers, but risk-based management advice as well. In several settings in which ADAPT is used as the primary assessment model, management advice is routinely given in terms of probability profiles; e.g., the probability that current SSB is below a management specified threshold or the probability that current F is greater than an established overfishing definition. Similar probabilities profiles can also be provided for future years based on stochastic projections and a suite of candidate management measures under consideration.

ADAPT was first used for Atlantic swordfish assessment in 1989 (Nelson et al., 1990) , and remains the primary age-structured model used for these assessments. It has also been used routinely for Atlantic bluefin tuna assessments over approximately the same period. The key issues at this symposium regarding its utility for Pacific swordfish will likely focus upon the following.

(1) Data, knowledge, and understanding of Pacific swordfish availability and abundance. These are integral issues in developing unbiased indices of abundance.

(2) The degree of confidence in Pacific swordfish catch-at-age estimates. The first issue is critical not only for successful implementation of ADAPT but also for any other assessment method that may be applied to Pacific swordfish. The second issue is more specific to age-structured models, such as ADAPT.

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ASPIC: A FLEXIBLE NONEQUILIBRIUM IMPLEMENTATION OF THE LOGISTIC SURPLUS–PRODUCTION MODEL

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INTRODUCTION

This paper describes the current state of the ASPIC computer program, an implementation of the logistic (Graham–Schaefer–Pella) surplus-production model. Comments on the use and data needs of ASPIC and a survey of past applications are also included. The information in this paper is largely abstracted from Prager (1994) and Prager et al. (1996), which describe in detail the theory underlying ASPIC and the statistical fitting methods used. This report, while summarizing some of that material, focuses on the more practical aspects of its use. Those interested in using the ASPIC computer program should also consult the ASPIC User's Manual (Prager, 1995).

Background Information

The use of an age-structured assessment model is often considered the benchmark of a state-of-the-art stock assessment. However, analysts increasingly accept that surplus-production models—which generally do not incorporate age structure—are also valuable tools for analysis of fish population dynamics. Production models are of particular value when the catch cannot be aged or cannot be aged precisely, and age-structured models cannot be applied. Surplus-production models are also used as complements to age-structured models, providing another view of the data. An appealing aspect of production models is their simplicity, which makes their properties easier to explore, and their results easier to present and understand (Barber, 1988).

The ASPIC computer program implements the logistic surplus-production model with a number of extensions. The logistic model (Lotka, 1924; Graham, 1935; Schaefer, 1954,1957) is the simplest form of production model, in that it assumes a symmetrical production curve with respect to biomass (Fig. 1). Other conceptual, computational, and practical properties of ASPIC include the following.

- It is a dynamic model; i.e., it does not use any form of "equilibrium assumption," in which observed yield is assumed to approximate the equilibrium yield.
- It is a continuous-time model.
- In many cases, ASPIC can accommodate data series with missing values.
- Statistical fitting can be conditioned on yield or on effort, at the user's option. However, more features are available when conditioning on yield because that is believed to be the more generally useful case.
- The fitting procedure can fix any parameter and fix or constrain the starting biomass.

- The user can specify that ASPIC should derive reasonable starting estimates for the parameter search.
- The program can analyze data from several simultaneous or sequential fisheries (e.g., gear types).
- When analyzing several fisheries, ASPIC can use iteratively weighted least-squares to estimate statistical weights for each series. This provides an approximate maximum-likelihood solution.
- Through bootstrapping, bias-corrected confidence intervals are estimated on many quantities including management benchmarks (such as MSY), trajectories of relative biomass, and fishing-mortality rate.
- An auxiliary program (ASPIC P) can read the ASPIC output and compute short-term projections under various management scenarios.
- The program prints several fitting diagnostics, including estimates of the C and N statistics of Prager et al. (1996).
- Output also includes printer plots of trajectories and residuals.
- The computer program is written in FORTRAN and is quite portable. It has been run successfully on DOS, OS/2, and Unix computers.

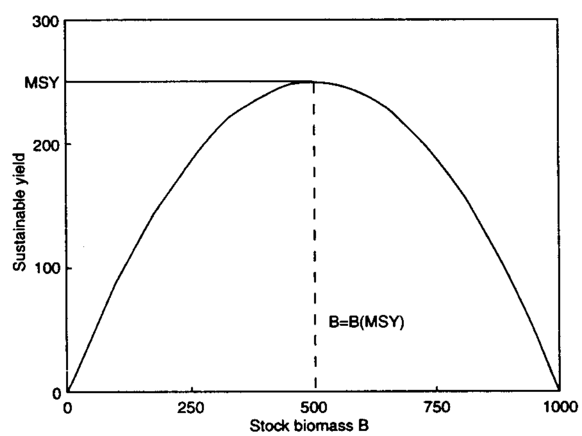

Figure 1. Parabolic production curve that results in logistic population growth. This relationship is the basis of ASPIC and other Graham-Schaefer-Pella surplus-production models.

The algorithm used for analyzing several fisheries is a rather simple one and assumes that each data series is a sample of the same population. Its greatest usefulness has been in testing for catchability changes, which can be accomplished by dividing the catch–CPUE series into several segments and comparing the estimates of catchability q. Where several fisheries have occurred simultaneously, it is usually preferable to introduce factors such as gear, area, or climate into a model of CPUE (or its logarithm) and develop a standardized abundance index before analysis with ASPIC or another production model. For example, age-specific indices for different age groups, as might be used in some age-structured analyses, should not be put separately into a production-model analysis that assumes each index is a measure of the same thing.

Applications to Date

ASPIC has been used for assessment of several species by the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT). These species are as follows.

- yellowfin tuna, *Thunnus albacares*
- bluefin tuna, *Thunnus thynnus*
- bigeye tuna, *Thunnus obesus*
- swordfish, *Xiphias gladius*
- white marlin, *Makaira albida*
- blue marlin, *Makaira nigricans*
- sailfish, *Istiophorus platypterus*

In the author's opinion, the applications to yellowfin tuna, bigeye tuna, bluefin tuna, and swordfish exhibited reasonably good fit and provided useful management information.

In the application to bigeye tuna, ASPIC produced plausible results that were in rough agreement with the results from other models. The SCRS believed that for this species it was more appropriate to apply a model that places B_{MSY} at smaller stock sizes, such as the model of Fox (1970). To the author's knowledge, there has never been a scientific investigation of this proposition, or of the more general question of whether much is lost by using a logistic model to estimate management benchmarks from a non-logistic population.

Applications to the billfishes (white and blue marlin, and sailfish) were hampered by poor data and the usefulness of ASPIC for assessment of these species is somewhat less certain. Nonetheless, plausible results were obtained in many cases, and the SCRS accepted several ASPIC assessments of these species. As the quality of data improves, it may be possible to acquire a better understanding of the utility of production models on the billfishes.

Applications of ASPIC have also been made to other species, with varying success. Application to data on skipjack tuna, *Euthynnus pelamis*, did not produce a solution (the algorithm did not converge). In this case the effort data had not been standardized, a major violation of the model's assumptions especially in light of known catchability changes in the fishery. The SCRS attempted to use ASPIC in several analyses of albacore, *Thunnus alalunga*, but the author does not have firsthand knowledge of these applications. It appears that an age-aggregated abundance index was not available, and fitting was attempted with various age-specific indices that were negatively correlated to one another, a severe violation of assumptions.[1]

The author has been involved in a few preliminary applications to more northern species, both pelagic and demersal, with mixed success. A recent application to Georges Bank yellowtail flounder seems to be giving useful results. However, data on northwest Atlantic cod proved resistant to interpretation by ASPIC. (The use of catch-at-age models on these cod stocks preceded severe management failure and stock collapse so that production models apparently

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[1] The current version of ASPIC will not attempt to fit series that are negatively correlated. It prints the correlation matrix, an error message, and stops.

were not alone in failing to provide reliable results. This leads the author to suspect that the data were deficient, and he has heard statements to that effect.) Simple production models may be least likely to succeed on stocks with large recruitment variations unrelated to stock size. In that case, a more complex production model incorporating exogenous factors might do better. The CLIMPROD model of Fréon et al. (1993) is a start in that direction.

ASPIC has been made available to other fishery scientists via the International Center for Living Aquatic Resource Management (ICLARM) and the American Fisheries Society (AFS) software library. The author has also distributed over 50 copies on request. He has received very little correspondence about ASPIC, and so cannot say how those copies are being used.

BASIC ASSUMPTIONS AND DATA REQUIREMENTS

Model Assumptions

The basic assumption is that population growth response follows the model (Fig. 1). This implies the following.

1. Exogenous sources of variation in population growth are small in comparison to modeled sources.

2. Age structure is of no importance to population dynamics.

3. The population growth rate responds instantly to changes in population size.

4. Model parameters are constant through time.

Assumption 4 seems to mean that the area covered by the stock and fishery should remain more or less constant, that there should be no major changes in gear, and that the environment should not cause major changes to the catchability, population growth rate, or carrying capacity. In practice, each of the enumerated assumptions is likely to be violated to a greater or lesser degree—but this is true of most models. Simulations studies can be used to examine the sensitivity of model results to violations of specific assumptions.

When conditioning on catch (the most common procedure), the fitting procedure used by ASPIC assumes the following.

1. Errors in the abundance index (or equivalently, effort series) are independent and identically lognormally distributed.

2. Errors in catch are small compared to the errors in effort or CPUE. This implies that the recorded catches are complete or a constant fraction of the true catch.

3. If several data series are used, the errors of each series are assumed to be of equal variance or it is assumed that the ratios of their variances are known; however, those ratios can be estimated with more or less precision by the program.

4. If several data series are used, the differences in abundance patterns among them are assumed to be due only to sampling error.

Data Requirements

The basic data requirements are a series of catches and a corresponding series of relative stock abundance estimates, both measured in biomass units. In practice, the abundance index is frequently a standardized CPUE series from the fishery, but any other abundance index can be used. If additional indices of abundance are available, the program can use them together with the primary index. As noted in the previous section, it may be preferable to develop a single standardized abundance index before applying ASPIC.

Sensitivity to Data Distribution and Noise

This topic requires more study. Hillborn and Walters (1992) include a general discussion and some examples, but their conclusions are necessarily limited. As with all models, reliable results are most likely to occur when the data include observations of the variables (yield, relative abundance) over a wide range of values. It also seems likely that MSY and related quantities will be estimated best if the data series includes observations of the stock biomass as it moves through B_{MSY}, the size at which MSY can be obtained. These concepts are included in two ad-hoc statistics computed by ASPIC.

Ludwig et al. (1988) found that autocorrelation was not particularly troublesome when their simulated data were analyzed by a production model. Punt (1988) examined over 100 methods of estimating parameters and uncertainties, but on only one scenario of population change. Unfortunately, that document is difficult to obtain. Polachek et al. (1993), in a Monte Carlo study, compared three statistical estimation methods and found that observation-error estimators like ASPIC were the least biased and most precise. Prager et al. (1996) found that mild changes in catchability and moderate age structure were not problematic for ASPIC when analyzing a simulated swordfish-like stock.

Some broad areas of knowledge are becoming clearer, but much remains to be learned. Simulation studies for specific cases will probably be the most useful way of approaching these questions in the near future.

GENERAL DERIVATIONS

Formulae

The model underlying ASPIC is developed from the basic differential equation

$$\frac{dB_t}{dt} = rB_t - \frac{r - qf_t}{K} B_t^2, \qquad (1)$$

where B_t and f_t are the stock biomass and rate of fishing effort, each at time t; q is the catchability coefficient; and r and K are additional parameters of the model. If N abundance indices are used, the vector of parameters $\{q_1, q_2, \ldots, q_N\}$ replaces the single q.

As is well known, r is often identified with the population's intrinsic rate of increase and K with its maximum attainable size, or carrying capacity. When $f_t = 0$ (i.e., when there is no fishing), the right side of equation (1) is simply the start of the Taylor expansion of an arbitrary dome-shaped function $\Phi(B)$ passing through the origin (Lotka, 1924). Assuming that $r > 0$, a population of any size will grow or shrink to eventually arrive at $B_t = K$, a stable equilibrium. If the population starts from a small size, the time trajectory of B_t will assume the S-shaped logistic curve.

By integrating equation (1) with respect to time, one can obtain model equations for projection of the biomass over time as well as the corresponding catch equations relating the yield in a time period to the starting biomass and the applied fishing effort. A detailed development is given in Prager (1994) and will not be repeated here. Equation (8a) in that paper contained a typographical error; the corrected equation is

$$F_r = \frac{\beta Y_t}{\ln\left[\dfrac{\beta B_t(e^{\alpha_\tau} - 1)}{\alpha_\tau} + 1\right]}.$$

Parameter Estimation

Here we present a brief summary of the concepts used by parameter estimation in the ASPIC computer program. The estimation procedure is given in more detail by Prager (1994), from which the following material is largely derived. Practical aspects of using the ASPIC computer program can also be found in Prager (1995).

Parameter estimation for production models can be accomplished by several methods. The one used by ASPIC is a slight modification of a forward-projection method originated by Pella (1967), later used by Pella and Tomlinson (1969) GENPROD program, and described as the "time-series method" by Hillborn and Walters (1992). Similar methods are used in fitting many assessment models, including the stock-synthesis model of Methot (1989, 1990).

Besides the three parameters described previously, it is necessary to estimate the starting population biomass B_1, so that the total set of parameters estimated is $\{B_1,r,K,q\}$, where q may be vector or scalar. Starting estimates of the parameter set allow a forward projection of the population through time to be computed. When conditioning on yield, a residual in the log of the abundance index is computed for each time period. The sum of squared residuals comprises the objective function. The parameter estimates are modified systematically until a minimum of the objective function is located. The algorithm used in ASPIC then perturbs the solution slightly to see if a better minimum can be found. Finding precisely the same answer three times in a row is required before a solution is accepted.

In fitting a linear regression, observation error in the predictor variables can cause inconsistency and bias in the parameter estimates (Thiel, 1971). The problems induced into nonlinear models are believed to be similar. Because yield in fisheries data is usually observed more precisely than relative abundance, it seems preferable to condition estimation on yield rather than effort.

For adjusting the parameter estimates while searching for a minimum, the simplex or "polytope" algorithm (Nelder and Mead, 1965; Press et al., 1986) is used in ASPIC for its robustness to starting values and difficult surfaces (e.g., many local minima). Although not as rapid computationally as some other methods, the simplex algorithm is reliable and can be manipulated (by restarts) to avoid many local minima (see Press et al., 1986, p. 292).

In some cases, it is difficult to locate a good minimum. The ASPIC computer program allows a Monte Carlo search of parameter space to be effected, either once or repeatedly. The author has occasionally found this helpful. More often, if a minimum is not found without the Monte Carlo search, the data do not support reasonable parameter estimates.

The fitting process provides estimates of B_1, r, K, and q, which define unique estimates of the stock biomass levels $\{B_2, B_3, \ldots, B_T\}$ and the stock's production during each period of time. The corresponding estimate of maximum sustainable yield (MSY) under the logistic model is $\widehat{\text{MSY}} = \hat{K}\hat{r}/4$. The logistic model implies that MSY can be attained as a sustainable yield only at one stock size, $B_{\text{MSY}} = K/2$. The instantaneous rate of fishing mortality that generates MSY at B_{MSY} is $F_{\text{MSY}} = r/2$; the corresponding rate of fishing effort is $F_{\text{MSY}} = r/2q$. Estimates of these benchmarks are obtained by $\widehat{\text{MSY}}$, $\hat{K}$, $\hat{r}$, and $\hat{q}$ substituting for their unknown true values in these expressions.

EXTENSIONS

A number of extensions are described in Prager (1994). Since that time, the ASPIC program has had no major additions. The printed output has been clarified in several respects, and two statistics have been added to the program output to help assess the usefulness of the fit. The estimated *nearness index* ($\hat{N}$) estimates how closely the biomass trajectory has approached B_{MSY}, and the estimated *coverage index* ($\hat{C}$) estimates how thoroughly the biomass has covered the region $[0, K]$. These are documented in Prager et al. (1996).

The author hopes to incorporate into ASPIC the generalized production model,

$$\frac{dB_t}{dt} = rB_t - \frac{(r - qf_t)B_t^m}{K}, \tag{2}$$

where the parameter m replaces the fixed exponent 2 in equation (1). Conceptually, this is not difficult; however, it is a substantial programming task and is now in progress.

MANAGEMENT APPLICATIONS

Management Advice Provided

The management advice provided by production models is fairly well known. The printed output from ASPIC provides the following.

- Several indicators of the likely success of the fitting procedure
- Estimates of the primary benchmarks MSY, B_{MSY}, and F_{MSY}
- Estimates of the model parameters q, r, K, B_1
- Estimates of additional benchmarks in biomass, yield, and effort, including a production-model form of $F_{0.1}$

- Estimates of stock status in the final year. These include estimates of the biomass, fishing effort rate, and yield in the final year, all relative to the values at $B = B_{MSY}$, as well as the equilibrium yield available in the following year as an absolute number and as a proportion of MSY.

- Estimates and printer plots of the time trajectories of relative biomass B/B_{MSY} and relative fishing mortality rate F/F_{MSY}

- Residual plots for each series of data

After a bootstrap run, several additional estimates are printed, some of which require running a simple projection program ASPICP.

- Bias-corrected estimates and nonparametric confidence intervals (at the 50% and 80% levels) on management benchmarks

- Bias-corrected estimates and printer plots of the trajectories of relative biomass and relative fishing mortality rate, both with 80% nonparametric bounds

- Short-term projections of stock status under user-specified management regimes, expressed either as specified fishing mortality rates (relative to the observed rate in the final year), specified harvests, or mixtures of the two

The quantity least well estimated in most ASPIC applications is the catchability coefficient q. When estimated biomass and fishing mortality rates are expressed relative to B_{MSY} and F_{MSY}, as is done in most ASPIC output, q cancels out and the estimates become much more precise. Absolute estimates of B and F are also printed, but their use is strongly discouraged, except for diagnosing possible program malfunctions.

The quantities estimated should be sufficient to guide management in increasing or decreasing allowable catch, even if the estimate of MSY is quite imprecise. Estimates from ASPIC, like those from any fisheries model, are best used in a heuristic way, in the context of other available information.

Applicability to Pacific Swordfish

Applicability to Pacific swordfish is obviously not known. As noted, ASPIC has been used successfully for Atlantic swordfish. Prager et al. (1996) found that, applied to simulated age-structured data on a stock like Atlantic swordfish, ASPIC was able to estimate MSY for the simulated stock well. There is no a priori reason why application of ASPIC to Pacific swordfish should not be attempted. The results will likely reflect the quality of the data.

Acknowledgments

The author gratefully acknowledges the support of the Virginia Sea Grant Consortium, the NMFS Southeast Fisheries Science Center, and the NMFS Southwest Fisheries Science Center for research on production modeling.

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DELAY-DIFFERENCE STOCK-ASSESSMENT MODELS: APPLICATION TO SWORDFISH

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The Deriso-Schnute delay-difference model (DSM; Hilborn and Walters, 1992) has been used to investigate the status of swordfish stocks in the eastern Pacific Ocean (EPO; Hinton and Deriso, 1999). We recommend that the reader consult Chapter 9 of Hilborn and Walters (1992) for a review of the model and its application to fisheries data. The principal reason that the delay-difference model framework is sometimes chosen for stock assessment is that it presents a method for fitting an age-structured population model to age-aggregated data. The fitted model can then be used, among other things, to estimate population structure, maximum sustainable yield (MSY), and MSY levels of effective fishing effort.

A short summary of the model is given here. Delay-difference models have as their basis the fact that the population biomass (B) at a given time t may be written as the sum of the biomass of individuals surviving from time t - 1 to t, plus the biomass resulting from growth of the survivors during the period from t - 1 to t, plus the biomass of individuals that enter the population at time t.

$$B(t) = B(\text{Survivors from } t-1,\, t) + B(\text{Survivors' growth over } t-1,\, t) + B(\text{Recruits at } t).$$

Incorporating process models for weight at age and recruitment, this may be written as

$$B(t) = \sum w(a)N(a,t) + w(k)N(k,t),$$

where $N(a,t)$ = number of individuals of age a at time t, $w(a)$ = average weight of an individual of age a, and k is the age of recruits at entry into the population.

The basic assumptions of the DSM are that (1) recruitment to the population occurs over a short size-interval (knife-edge recruitment), (2) the survival rate from natural causes (l) is constant for all fish recruited to the population, (3) spawning occurs at the start of each year, with fishing occurring after spawning and with natural mortality negligible during that period, and (4) the average weight at age is determined by a Brody growth model:

$$w(a+1) = w(a) + \rho[w(a) - w(a-1)],$$

where ρ is the Brody growth coefficient. We applied the simplified version of this model, which has the constraint $w(k-1) = 0$. We define $S(t)$ as the biomass of adults that survive the fishery and F_B as the biomass of recruits as a function of the adult biomass. Substituting the Brody curve solutions for the $w(a)$ and simplifying, the full model is given by

$$B(t) = (1+\rho)lS(t-1) - \rho l^2(S(t-1)S(t-2)/B(t-1)) + F_B(B(t-k)). \quad (1)$$

With F_B as defined, this formulation is for a closed population.

An alternative formulation would include an additional term, R, added to the right side of (1) to account for the net flux resulting from immigration and emigration of swordfish in the EPO, as described in Hinton and Deriso (1998). The following two models for recruitment were considered in their paper.

$$F_B(B(t-k)) = \alpha B(t-k)/(1+\beta B(t-k)), \text{ and}$$

$$F_B(B(t-k)) = \alpha B(t-k)/(1+\beta B(t-k)) + R,$$

where α and β are parameters of a Beverton-Holt curve. Recruitment was lagged by two years ($k = 2$) with respect to spawning stock biomass. The Brody coefficient $\rho = 0.9999$ (~1) was estimated for the application.

The parameters of the DSM were estimated in Hinton and Deriso (1999) by fitting model predictions of annual catch rates to "observed" rates (based on catch-per-unit-of-standardized-effort [CPUSE] and catch-per-unit-of-nominal-effort, [CPUNE]) for the 1962-87 period. The error structure for delay-difference models involves two sources. 'Process error' arises from the modeling of biological processes within the population dynamics model; i.e., error associated with using approximates for (true) growth, recruitment, and survival functions. 'Measurement error' arises from the independent estimates of catch rates [in this case the $CPUSE(t)$ and $CPUNE(t)$ data], against which the delay-difference model predictions are fitted during the estimation of model parameters. The process and the measurement errors are assumed to have log-normal distributions with parameters $(0, \sigma^2)$. Process errors were included in the model as multipliers of annual recruitment. Measurement errors are the difference between the log-transform of the observed and the predicted catch rates. We should note that the predicted catch rate follows the assumption of Hilborn and Walters (1992, p. 345) and others that $C/B = (1 - e^{-qE})$, where C is catch, B is biomass, q is the proportionality constant (catchability), and E is fishing effort.

Model fit was determined by maximizing the concentrated likelihood (CL): $CL = -(n/2)\ln(SSE) - u$, where n is the number of observations of process and measurement error, SSE is the sum of the squared process and the squared measurement errors (weighted by their assumed relative variance), and u is a constant.

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MULTIFAN CL: A LENGTH-BASED, STATISTICAL, AGE-STRUCTURED MODEL FOR FISH STOCK ASSESSMENT

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INTRODUCTION

Age-structured models are commonly used in the assessment of commercial fish stocks, with virtual population (or cohort) analysis (VPA) [see review in Megrey, 1989] being the technique most frequently applied. While computationally straightforward, VPA requires certain assumptions that are difficult to test or justify in many situations. Catch-at-age data are required and are usually assumed to be correct (unless ageing errors are incorporated using Monte Carlo simulations). The natural mortality rate and the fishing mortality rate for one age group of each cohort must be assumed. "Tuning" the analysis with catch per unit effort (CPUE) data or other abundance index time series is often employed to avoid the need to specify "terminal" fishing mortality rates for each cohort, but this invariably involves arbitrary assumptions about catchability. Additionally, VPA involves the computation of one fishing mortality rate for each non-terminal catch-at-age observation and the initial abundance for each cohort. The model is thus fully saturated (no degrees of freedom) and, apart from the statistical errors associated with the tuning procedure, there is no notion of statistical uncertainty in the results.

Statistical catch-at-age models (e.g., Doubleday, 1976; Paloheimo, 1980; Fournier and Archibald, 1982; Pope and Shepherd, 1982; Dupont, 1983; Deriso et al., 1985) can potentially avoid some of these assumptions. While catch-at-age data are still required, age- or time-related constraints on fishing mortality enable a statistical estimation of initial cohort sizes, fishing mortality rates or related parameters and—in theory—natural mortality rate, by minimizing an objective function based on a statistical criterion such as least squares. Variance estimates, and therefore confidence intervals, for the estimated parameters conditional on the catch-at-age data and the model can also be obtained.

Both VPA and statistical catch-at-age models rely on catch-at-age data. These are sometimes derived from the analysis of annuli on various body parts of individual fish. Perhaps more commonly, age composition is derived from length composition samples using an age-length relationship prior to the age-structured analysis taking place. In this type of sequential approach, the variability in length-at-age is often ignored.

In this paper, we describe a length-based, age-structured, likelihood model that circumvents many of the difficulties associated with sequential analyses such as VPA. The model incorporates the following features:

- Growth and age structure of the catch are estimated simultaneously with population parameters such as recruitment, selectivity, catchability and natural mortality. Approximate confidence intervals are therefore conditional not on catch-at-age, but on catch-at-length data.

- Missing data and data of different temporal resolutions are allowable and are internally managed by the model.
- Auxiliary data (such as tagging data) can be incorporated into the model, as appropriate.
- Various structural hypotheses, such as density-dependent growth, time-series trends in catchability, seasonal catchability and spatial structure, can be incorporated into the model and tested.

The main application of the model referred to in this paper is South Pacific albacore. Other applications of the model to date include western Pacific yellowfin tuna and Pacific cod.

DATA STRUCTURES

The fundamental data structure of the model is based on the notion of a fishery, which is thought of as a collection of fishing units which have similar catchability and selectivity characteristics. For example, in the South Pacific albacore analysis, we have defined fisheries according to gear type and latitudinal bands (regions) in the South Pacific as follows:

Fishery 1 (Region A):	DWFN longline, 0–10°S
Fishery 2 (Region B):	DWFN longline, 10–30°S
Fishery 3 (Region C):	DWFN longline, south of 30°S
Fishery 4 (Region B):	Domestic longline
Fishery 5 (Region C):	New Zealand troll
Fishery 6 (Region C):	STCZ troll
Fishery 7 (Region C):	Driftnet

Each occurrence of a fishery at a particular time is termed a fishing incident. In reality, fishing is more or less continuous, so the data for each fishery need to be aggregated over appropriate time intervals. In the albacore example, the longline fisheries (1–4) occur more or less continuously throughout the year, and quarterly time periods are sufficient to capture the seasonal variation. The surface fisheries (5–7) tend to operate during the summer months only, therefore monthly time periods are used for these fisheries.

Each fishing incident is associated with a data record, which is made up of an estimate of the total catch (in number of fish), the total effort, and a length-frequency sample. Effort and the length-frequency sample may be missing for some fishing incidents. A portion of the albacore data file is shown below.

```
# Lines beginning with # are comments
# Datasets  Length intervals  First length  Width  Factor
   591            80               40         1      1
#
#-------------------- Year 1962 Month 2 Fishery 1------------
#
# Year  Month  Week
   1      2      1
#
# Fishery  Catch    Effort
    1      58764   141140
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 1 0 1 4 2 6 12 15 18 48 50 51 57 62 70 48 40 40 29 14 10 6 6 6 1 3 0 0 0 0 0 0
 0 0 0 0 0 0 0
#
#-------------------- Year 1962 Month 2 Fishery 2------------
#
# Year  Month  Week
   1      2      1
#
# Fishery  Catch    Effort
    2     243310   86903
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 1 0 0 0 1 1 4 4 2 5 2 5 7 8 5 3 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
#
```

BASIC MODEL STRUCTURE AND ASSUMPTIONS

The Catch Equations

It is assumed for simplicity of notation that there is only one fishery in operation and that there is only one fishing incident per year. The model is designed to accommodate a variable number of different fisheries and fishing incidents each year; the equations that follow could easily be generalized in this way.

The catch equations relate the numbers of fish in the population to the numbers of fish in the catch of the fisheries. The form of the catch equations used in the model is described by the following relationships:

$$C_{ij} = \frac{F_{ij}}{Z_{ij}}\left[1-\exp(-Z_{ij})\right]N_{ij} \quad \text{for } 1 \le i \le n,\ 1 \le j \le r, \tag{1}$$

$$N_{i+1,j+1} = \exp(-Z_{ij})N_{ij} \quad \text{for } 1 \le i \le n,\ 1 \le j < r, \tag{2}$$

$$N_{i+1,r} = \exp(-Z_{i,r-1})N_{i,r-1} + \exp(-Z_{ir})N_{ir} \quad \text{for } 1 \le i < n, \tag{3}$$

$$Z_{ij} = F_{ij} + M_{ij} \quad \text{for } 1 \le i \le n,\ 1 \le j \le r, \tag{4}$$

$$C_{i\bullet} = \sum_j C_{ij}, \tag{5}$$

where

- n is the number of years of fishing,
- r is the number of age groups in the population,
- N_{ij} is the number of age group j fish in the population at the beginning of year i,
- C_{ij} is the catch (in number of fish) of age group j fish in year i,
- $C_{i.}$ is the total catch observed in year i,
- F_{ij} is the instantaneous rate of fishing mortality for age group j fish in year i,
- M_{ij} is the instantaneous rate of natural mortality for age group j fish in year i, and
- Z_{ij} is the instantaneous rate of total mortality for age group j fish in year i.

In this form of the catch equations the last (r th) age group consists of all the older fish in the population. This is useful when, as often occurs, the ageing estimates are especially inaccurate for the older age groups (Fournier and Archibald, 1982). For catch-at-length data it is useful to group the older age groups together after the fish reach an age where they essentially stop growing (Fournier et al., 1991).

Assumptions Relating to Constraints on Mortality Rate Variation

The essence of a statistical catch-at-age model is the creation of degrees of freedom by the imposition of reasonable constraints on the way in which the natural and fishing mortality rates are allowed to vary over time and among age groups.

Natural Mortality

To reduce the number of free parameters in the model, it is usually assumed that the instantaneous natural mortality rate is a constant, independent of time and age. We shall make this assumption initially and denote the instantaneous natural mortality simply by M. It should be noted that more realistic models of M variability can be posed and tested within the framework of the model. An example of this is given later.

Fishing Mortality

To further reduce the freedom of the parameters, we restrict the variation in the instantaneous fishing mortality rates F_{ij}. We do this by assuming that

$$\log_e(F_{ij}) = \log_e(s_j) + \log_e(q_i) + \log_e(E_i) + \varepsilon_i, \tag{6}$$

and

$$\log_e(q_{i+1}) = \log_e(q_i) + \eta_i, \tag{7}$$

where

- s_j is the selectivity for age group j (assumed constant over time);
- q_i is the catchability in year i;
- E_i is the observed fishing effort in year i;
- ε_i are normally distributed random variables representing large transient deviations in the effort–fishing mortality relationship; and

η_i are normally distributed random variables representing small permanent changes in catchability.

The notion, as implied in Equation (6), that fishing mortality consists of a "separable" age-dependent effect (selectivity), and a time-dependent effect (catchability) was first introduced by Doubleday (1976) and later elaborated upon by Paloheimo (1980) and Fournier and Archibald (1982). Details of the treatment of selectivity and catchability in the model are as follows:

Selectivity. It is sometimes possible to model selectivity as a function of age group, for example using a gamma function (Deriso et al., 1985). We preferred to allow the s_j to be separate parameters, but applied a smoothing transformation that essentially ensures relatively small differences in s_j between adjacent age groups having large overlap of their length distributions. This would be expected where selectivity is fundamentally a length-based, rather than an age-based process.

Catchability. Catchability is allowed to vary slowly over time. We assume that the q_i have the time series structure of a random walk (Equation (6)), which is the simplest statistical model of a slowly varying random quantity. The assumption that catchability has a time series structure was introduced by Gudmundsson (1994) for the analysis of catch-at-age data. Gudmundsson also included trend components in his time series formulation.

We make the prior assumption that the variance of η_i is small compared to ε_i; i.e., the ε_i represent relatively large transient effects (noise) while the η_i represent relatively small permanent changes in the catchability.

In this simple example of annual fishing incidents, η_i modifies catchability at each successive fishing incident. In general, each step of the random walk can be taken less frequently, as might be appropriate when multiple fishing incidents by one fishery occur within a year. In the albacore analysis (where the frequency of fishing incidents is quarterly for the longline fisheries and monthly for the surface fisheries), random walk steps are taken annually for all fisheries.

Assumptions About the Length-At-Age

The assumptions concerning the length distribution of the fish are as follows.

(1) The lengths of the fish in each age group are normally distributed around their mean length (see equation 8).
(2) The mean lengths-at-age lie on a von Bertalanffy growth curve (see Equation (10)) modified to include, where appropriate, sampling bias for the first age group (see Equation (11)) [other age groups are assumed to be randomly sampled without bias].
(3) The standard deviations of the lengths about the mean lengths-at-age are a simple linear function of the mean length-at-age (see Equation (12)).

The following symbols are used in the mathematical expression of these assumptions:

α subscript indexing the length frequency intervals.
N_I the number of length intervals in each length frequency data set.
S_i the number of fish in the i^{th} length frequency data set.

$f_{\alpha i}$ the number of fish whose lengths lie in the α^{th} length interval in the i^{th} length frequency data set.

$p_{ij\alpha}$ the probability that an age group j fish picked at random from the fish which were sampled to get the i^{th} length frequency data set has a length lying in length interval α.

Q_{ai} the probability that an animal picked at random from the fish which composed the i^{th} length frequency data set has a length lying in length interval α.

$\tilde{Q}_{\alpha i}$ the observed proportion of fish in the i^{th} length frequency data set having a length lying in length interval α.

μ_{ij} the mean length of the age group j fish in the i^{th} length frequency data set.

σ_{ij} the standard deviation of the length distribution of the age group j fish in the i^{th} length frequency data set.

x_i the midpoint of the i^{th} length frequency interval.

w the width of the length frequency intervals.

L_1 the mean length of the first age group on the von Bertalanffy curve in month 1.

L_r the mean length of the last age group on the von Bertalanffy curve in month 1.

K the von Bertalanffy K parameter.

r the Brody growth coefficient ($K = -\log_e(\rho)$).

b the coefficient of sampling bias in the first age group.

λ_1,λ_2 parameters determining the standard deviations $\sigma_{j\alpha}$.

$\xi_{i\alpha}$ parameters determining the relative variances of the sampling errors within the i^{th} length frequency data set.

τ parameter determining the overall variance of the sampling errors in all the length frequency data sets.

Assumption 1: Normal Distribution of Length at Age

If the lengths of the age group j fish in the α^{th} length frequency data set are normally distributed around their mean $\mu_{j\alpha}$ with standard deviations $\sigma_{j\alpha}$,. The $p_{ij\alpha}$ can be expressed in terms of $\mu_{j\alpha}$ and $\sigma_{j\alpha}$ by

$$p_{ij\alpha}(\mu_{j\alpha},\sigma_{j\alpha}) = \frac{1}{\sqrt{2\pi\sigma_{j\alpha}}} \int_{x_i-w/2}^{x_i+w/2} \exp\left\{\frac{-(x-\mu_{j\alpha})^2}{2\sigma_{j\alpha}^2}\right\} dx. \quad (8)$$

As long as $\sigma_{j\alpha} > w$, the integral can be approximated sufficiently well by setting

$$p_{ij\alpha}(\mu_{j\alpha},\sigma_{j\alpha}) = \frac{w}{\sqrt{2\pi\sigma_{j\alpha}}} \exp\left\{\frac{-(x-\mu_{j\alpha})^2}{2\sigma_{j\alpha}^2}\right\}. \quad (9)$$

This approximation has been used in the model.

Assumption 2: Relationship of Length to Age

Parameterization of von Bertalanffy Growth. If the mean lengths $\mu_{j\alpha}$ lie on a von Bertalanffy curve, then, using the parameterization given by Schnute and Fournier (1980)

$$\mu_{j\alpha} = L_1 + (L_{N_J} - L_1)\left[\frac{1-\rho^{j-1+(m(\alpha)-1)/12}}{1-\rho^{N_{J-1}}}\right] \tag{10}$$

where L_1, the mean length of the first age group, L_{N_J}, the mean length of the last age group, and r, the Brody growth coefficient, are the three parameters that determine the form of the von Bertalanffy curve, and m(α)-1 is the number of months after the presumed birth month of the fish in the αth length frequency data set.

Sampling Bias in the First Age group. For some length frequency data sets, the sampling procedure or the fishery does not fully select the smallest fish in the first age group. The effect of this size selectivity is that the mean length of the fish in the first age group in the length frequency data set is larger than the mean length of the fish in the population. If this sampling bias is not accounted for, biased parameter estimates may be produced. We assume that size-selective bias occurs only for fish in the first age group and that it decreases linearly with age until the fish reach the second age group, thus

$$\mu_{j\alpha} = L_1 + (L_{N_J} - L_1)\left[\frac{1-\rho^{(m(\alpha)-1)/12}}{1-\rho^{N_{J-1}}}\right] + \frac{b[12-(m(\alpha)-1)]}{12}, \tag{11}$$

where b is the sampling bias coefficient.

Assumption 3: Relationship of Standard Deviations in Length at Age to Mean Length at Age

The standard deviations $\sigma_{j\alpha}$ are parameterized as a simple function of length involving two parameters λ_1 and λ_2:

$$\sigma_{j\alpha} = \lambda_1 \exp\left\{\lambda_2\left[-1+2\left(\frac{1-\rho^{j-1+(m(\alpha)-1)/12}}{1-\rho^{N_{J-1}}}\right)\right]\right\}, \tag{12}$$

where the term enclosed in square brackets expresses the length dependency of the standard deviations independently of the numerical values of the parameters L_1 and L_{N_J} (Equation (10)). The two coefficients, λ_1 and λ_2, transform the rescaled length to the standard deviations. λ_1 determines the magnitude of the standard deviations, and λ_2 determines the length–dependent trend in the standard deviations. If $\lambda_2 = 0$, the standard deviations are length independent.

Maximum Likelihood Estimation

The parameters of the model are estimated by maximizing the log-likelihood function (or more generally by maximizing the sum of the log-likelihood function and the log of the density of the Bayesian prior distribution). The log-likelihood function consists of the sum of several components, the most important of which correspond to the length frequency data and the total catch estimates.

The Log-Likelihood Contribution for the Length Frequency Data

Because of the large variability in the length samples which occurs for real fishery length frequency data, the model employs a robust maximum likelihood estimation procedure. The motivation for using this procedure and the technicalities behind the procedure are described in Fournier et al. (1990) We shall not repeat this discussion here, but for convenient reference we briefly describe the form of the log–likelihood function employed.

If the $\tilde{Q}_{\alpha i}$ are derived from a random sample of size S_i, they would be random variables with means $\tilde{Q}_{\alpha i}$ and variances $(1-Q_{\alpha i})Q_{\alpha i}/S_i$. Two modifications have been made to this formula. If $Q_{\alpha i}=0$ the formula implies that the variance of $\tilde{Q}_{\alpha i}=0$. To decrease the influence of areas where no observations are expected we add a small number to the variance formula in such cases. To reduce the influence of very large sample sizes we assumed that sample sizes >1000 are no more accurate than sample sizes of 1000. We set $\xi_{i\alpha}=(1-Q_{\alpha i})Q_{\alpha i}$ and $\tau_i^2 = 1/\min(S_i, 1000)$. We also assume the variance of $\tilde{Q}_{\alpha i}$ is given by $(\xi_{i\alpha}+0.1/N_I)\tau_i^2$.

The likelihood function contribution for the length frequency data employed in the model is

$$\prod_{\alpha=1}^{N_A}\prod_{i=1}^{N_1}\left[\frac{1}{\sqrt{2\pi(\xi_{i\alpha}+0.1/N_1)\tau}}\left(\exp\left\{\frac{(\tilde{Q}_{i\alpha}-Q_{i\alpha})^2}{2(\xi_{i\alpha}+0.1/N_1)\tau^2}\right\}+0.01\right)\right]. \tag{13}$$

Taking the logarithm of Equation (13) we obtain the log–likelihood function for the length frequency data:

$$\begin{aligned}
&-1/2\sum_{\alpha=1}^{N_A}\sum_{i=1}^{N_I}\log_e(2\pi(\xi_{i\alpha}+0.1/N_I))\\
&-\sum_{\alpha=1}^{N_A}N_I\log_e(\tau)\\
&+\sum_{\alpha=1}^{N_A}\sum_{i=1}^{N_I}\log_e\left[\exp\left\{\frac{-(\tilde{Q}_{i\alpha}-Q_{i\alpha})^2}{2(\xi_{i\alpha}+0.1/N_I)\tau^2}\right\}+0.01\right].
\end{aligned} \tag{14}$$

Expression (14) is the contribution to the log-likelihood function for the observed length frequency data.

The Log-Likelihood Contribution for the Observed Total Catches

Assuming for simplicity that there is only one fishery per year, the log-likelihood contribution for the observed total catches is given by

$$p_c\sum_i(\log(C_{i.}^{obs})-\log(C_{i.}))^2, \tag{15}$$

where p_c is determined by the prior assumption made about the accuracy of the observed catch data.

The Log-Likelihood Contribution for the Bayesian Priors on the Effort-Fishing Mortality Relationship

The log-likelihood contribution for the Bayesian priors on the η_i and ε_i, (see Equations (6) and (7)) is given by

$$p_\eta \sum_i \eta_i^2 + p_\varepsilon \sum_i \varepsilon_i^2 . \tag{16}$$

The size of the constants p_η and p_ε are adjusted to reflect prior assumptions about the variances of these random variables.

Fitting the Model and Estimation of Approximate Confidence Intervals

The parameters of the model are estimated by maximizing the log-likelihood function (or posterior density in the Bayesian framework) as described above. The maximization was performed with a quasi-Newton function minimizing routine employing exact derivatives with respect to the model parameters. The derivatives were calculated using the C++ class library, AUTODIF, using an extension of the technique known as automatic differentiation (Griewank and Corliss, 1991). This approach is especially useful for models with large numbers of parameters. It also provides quick and accurate estimates of the Hessian matrix at the maximum, which can be used to obtain estimates of the covariance matrix and confidence limits for the parameters of interest.

A great advantage of an integrated model such as this is that the estimates of the uncertainty in the parameter estimates automatically take into account the effect of all of the model's assumptions, such as the uncertainty in the age at length, possibility of trends in catchability, effects caused by variability in the length frequency data, and errors in estimates of fishing effort. Confidence limits for the parameter estimates are calculated by employing the usual second order approximation to the posterior distribution at its mode. Let $\theta_1,\ldots,\theta_n$ denote a minimal set of n model parameters from which all model parameters can be calculated, and let $p(\theta_1,\ldots,\theta_n)$ be some parameter of interest, while $L(\theta_1,\ldots,\theta_n)$ is the logarithm of the posterior distribution. Then the estimated standard deviation p_σ for p is given by the square root of $\sum_{ij} \partial p / \partial\theta_i \partial p / \partial\theta_j \Lambda_{ij}$ where $\Lambda = (\partial^2 L / \partial\theta_i \partial\theta_j)^{-1}$ and the calculations are carried out at the mode of the posterior distribution. Then, 0.95 confidence limits for the p are given by $[p - 1.96 p_\sigma, p + 1.96 p_\sigma]$. These confidence limits are not invariant under reparameterization. To compensate somewhat for this the confidence limits for parameters which must be positive, such as estimates of biomass, are calculated by computing the confidence limits for the logarithms of these parameters and then transforming the confidence limits. This yields the confidence limits $[p\exp(-1.96 p_\sigma / p), p\exp(1.96 p_\sigma / p)$.

The above procedure provides approximate confidence for the model parameters (initial cohort size, selectivity and catchability coefficients, natural mortality rate, growth parameters, etc). For stock assessment purposes, it may be desirable to have confidence intervals for quantities of interest, such as adult biomass, that are functions of the model parameters. The variances (and hence confidence intervals) for such quantities may be determined using the delta method (Seber, 1982). However, note that confidence intervals derived in this way are conditional on the model structure used. It may be possible to define the best model from a finite range of alternatives for a particular set of data on the basis of the maximum likelihood criterion. However, there is never any guarantee that any given model is the best of all possible models. Uncertainty regarding what is the best model is not incorporated into the confidence intervals; therefore such confidence intervals will tend to understate the true uncertainty in the model parameters and other quantities of interest.

EXTENSIONS TO THE BASIC MODEL

It is frequently of interest in statistical modeling to add model structure in the form of one or more hypotheses concerning some process(es) of interest, and to observe the resulting change in model performance. This process can be thought of as attempting to define the "correct" model for a given set of data. The framework of MULTIFAN CL is ideally suited to the incorporation and testing of model hypotheses using the usual Frequentist approach: parameters representing a more complex model are added to the simpler model and the resulting improvement in fit is calculated. If this improvement in fit is large enough (as indicated by a likelihood ratio test, for example) the more complicated model is accepted. Otherwise the more complicated model is rejected and the simpler model is accepted as providing an adequate description of the data. Various more complicated models may be investigated in this fashion. Some of the hypotheses that have been tested in this way in the South Pacific albacore analysis are

- the number of (significant) age groups represented in the data;
- the existence of a length-dependent trend in the standard deviation of the distribution of the length at age around the mean length;
- the existence of a relative cohort strength component in the mean length at age of a cohort (density-dependent growth);
- the existence of age-dependency in M;
- the existence of spatial heterogeneity in various population parameters; and
- seasonal variation in catchability.

MANAGEMENT APPLICATIONS

MULTIFAN CL has been applied to South Pacific albacore, western Pacific yellowfin (in progress), and Pacific cod. The South Pacific albacore analysis is currently the best developed application. A variety of model structures have been tested, with most of the structural hypotheses listed in the previous section consistently proving to be significant. The results shown in Figures 1-6 demonstrate some of the features of the model discussed above, including

- fishery-specific selectivity coefficients (Fig. 1);
- fishery-specific catchability coefficients with time series trends and seasonal variation (Fig. 2);
- reasonable fits of the model to the length-frequency data (Fig. 3); and
- estimated time-series of derived population parameters of interest, such as exploitation rates (Fig. 4), population biomass (Fig. 5), and recruitment (Fig. 6), all with approximate 95% confidence intervals.

The model should be a useful tool for future management of the South Pacific albacore fishery. Two key uses come readily to mind and would require only minimal adaptation of the existing computer software. First, it would be relatively straightforward to cast the results of the model in a form suitable for comparison with limit or target reference points, as envisaged by the recent United Nations agreement on straddling and highly migratory fish stocks. This could be done by calculating the probability that a particular reference point would be violated under a particular fishing regime. Second, it is possible that the model could be a useful forecasting tool for both the surface and longline fisheries. Given some reasonable model for future recruitment (perhaps linked to large-scale environmental conditions such as *El Nino*), it would be possible to project the stock forward in time. Confidence intervals could also be determined for the projections to capture the uncertainty in future recruitment and the current population state. Such forecasting, if successful, would presumably assist both industry and management decision-making.

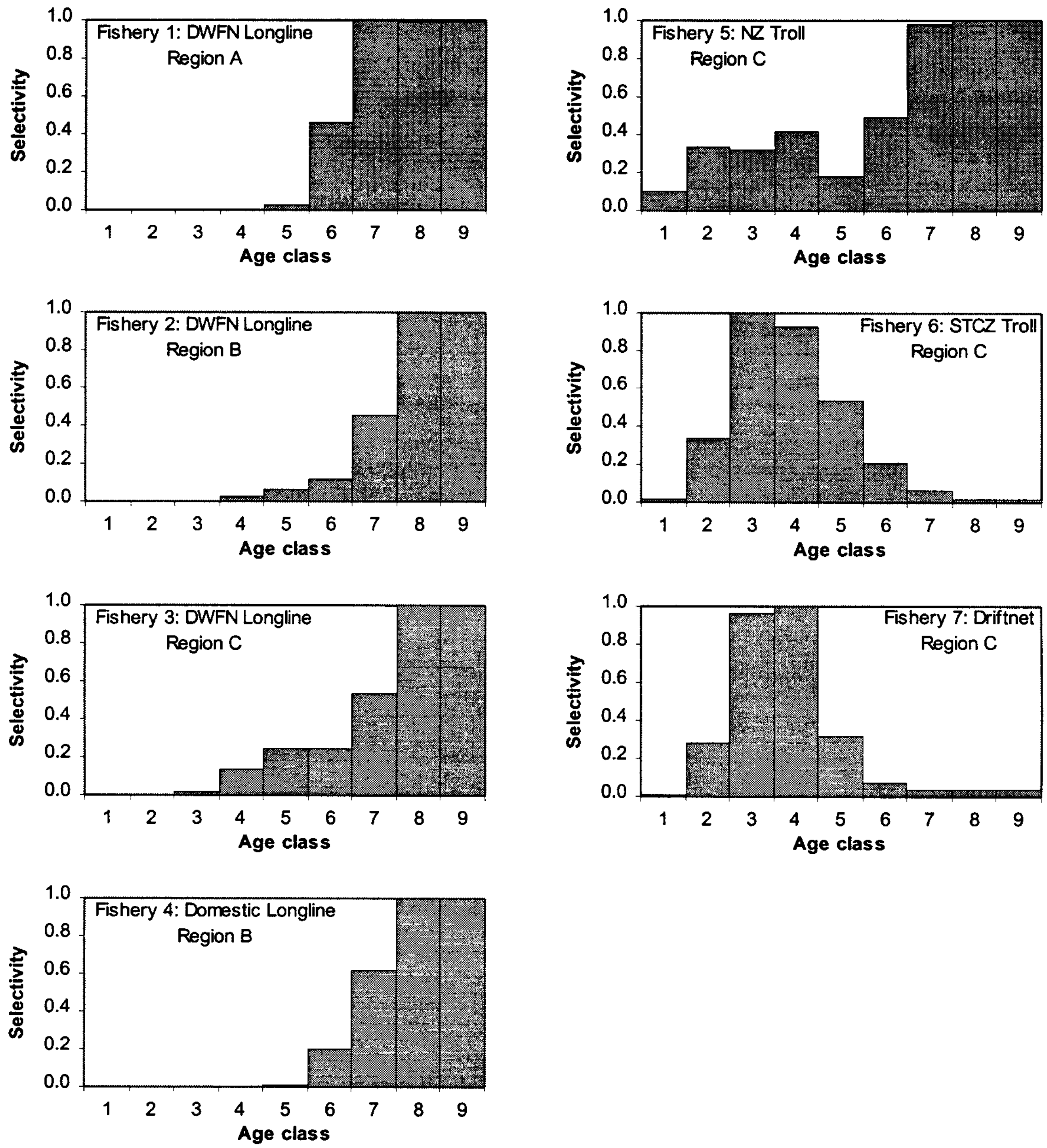


Figure 1. Estimated albacore selectivity coefficients for each fishery.

Figure 2. Estimated catchability (solid lines), which is assumed to change annually and seasonally, and deviations from the effort-fishing mortality relationship (dots), by fishery. The "***" indicate deviations beyond the scale of the figures.

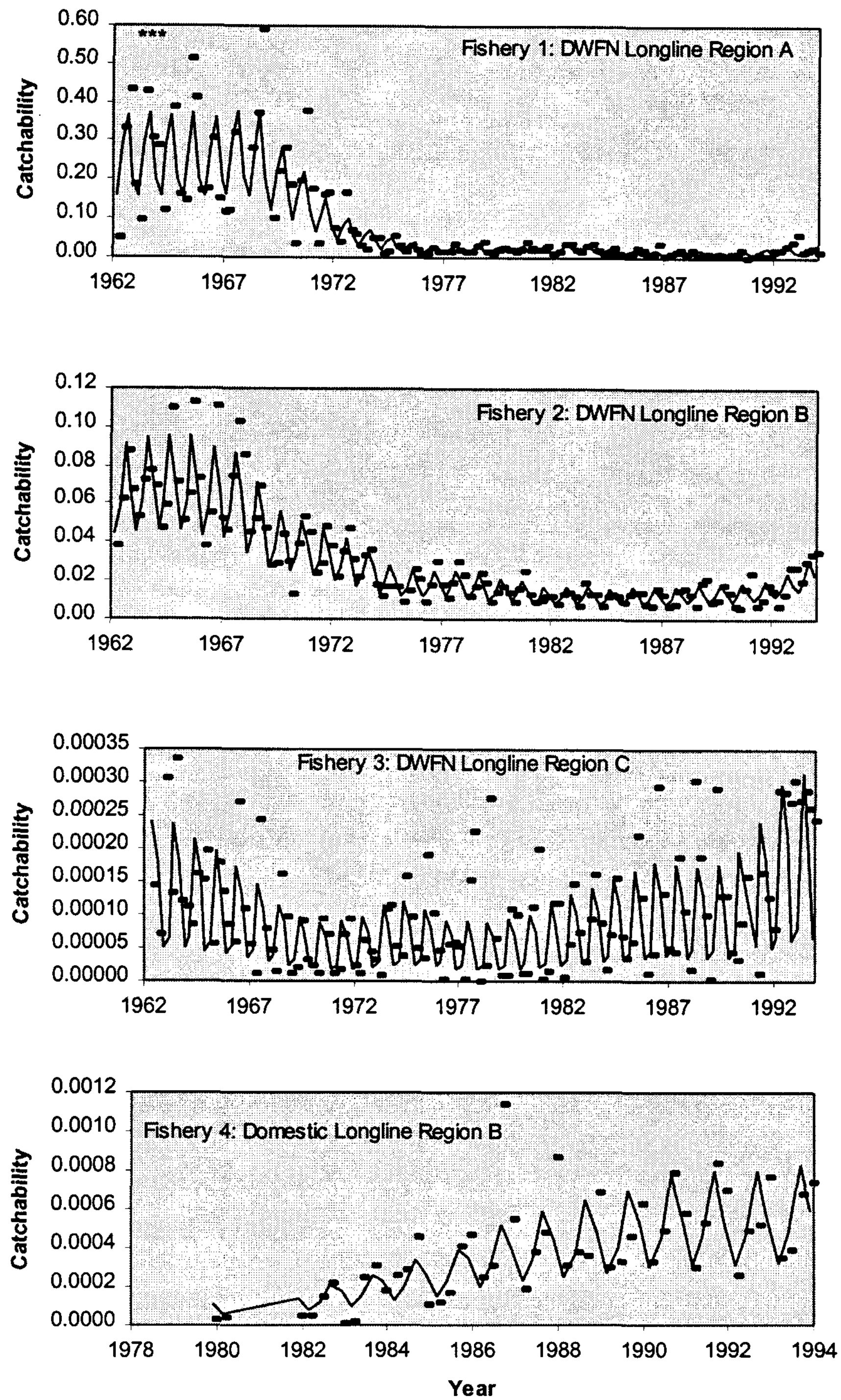


Figure 2. Estimated catchability (solid lines), which is assumed to change annually and seasonally, and deviations from the effort-fishing mortality relationship (dots), by fishery. The "***" indicate deviations beyond the scale of the figures.

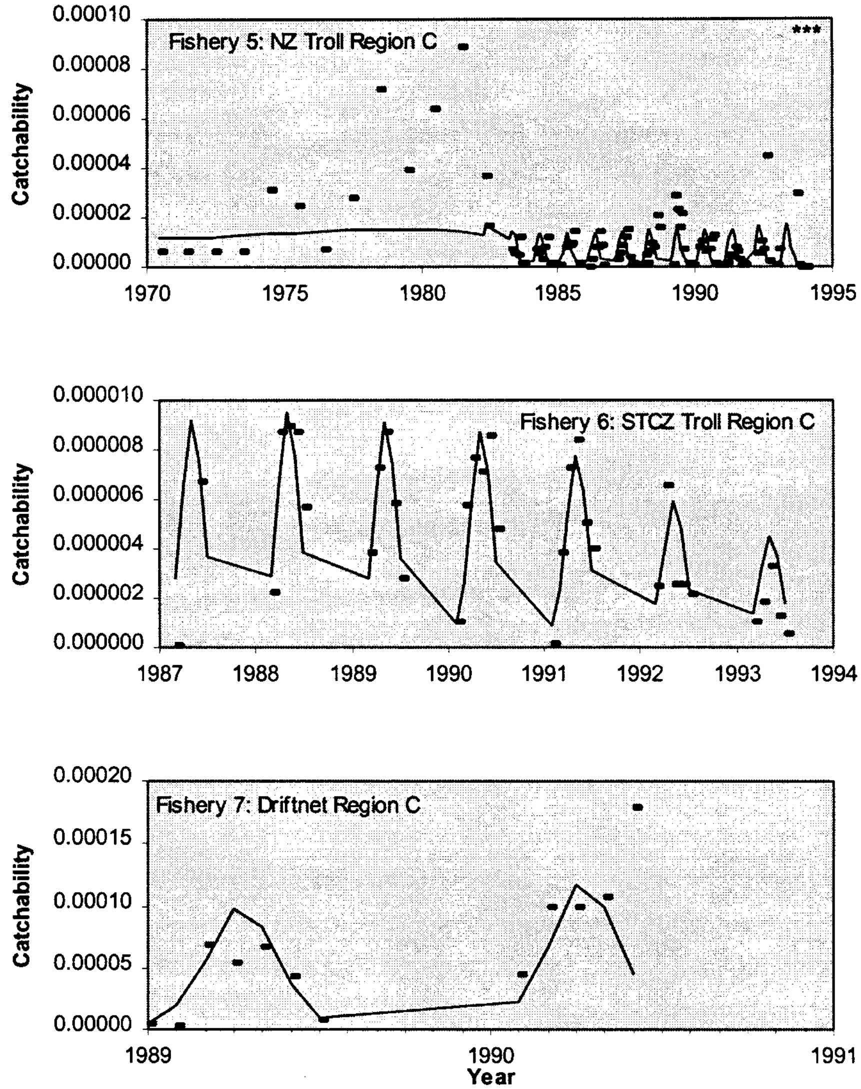


Figure 2. Continued.

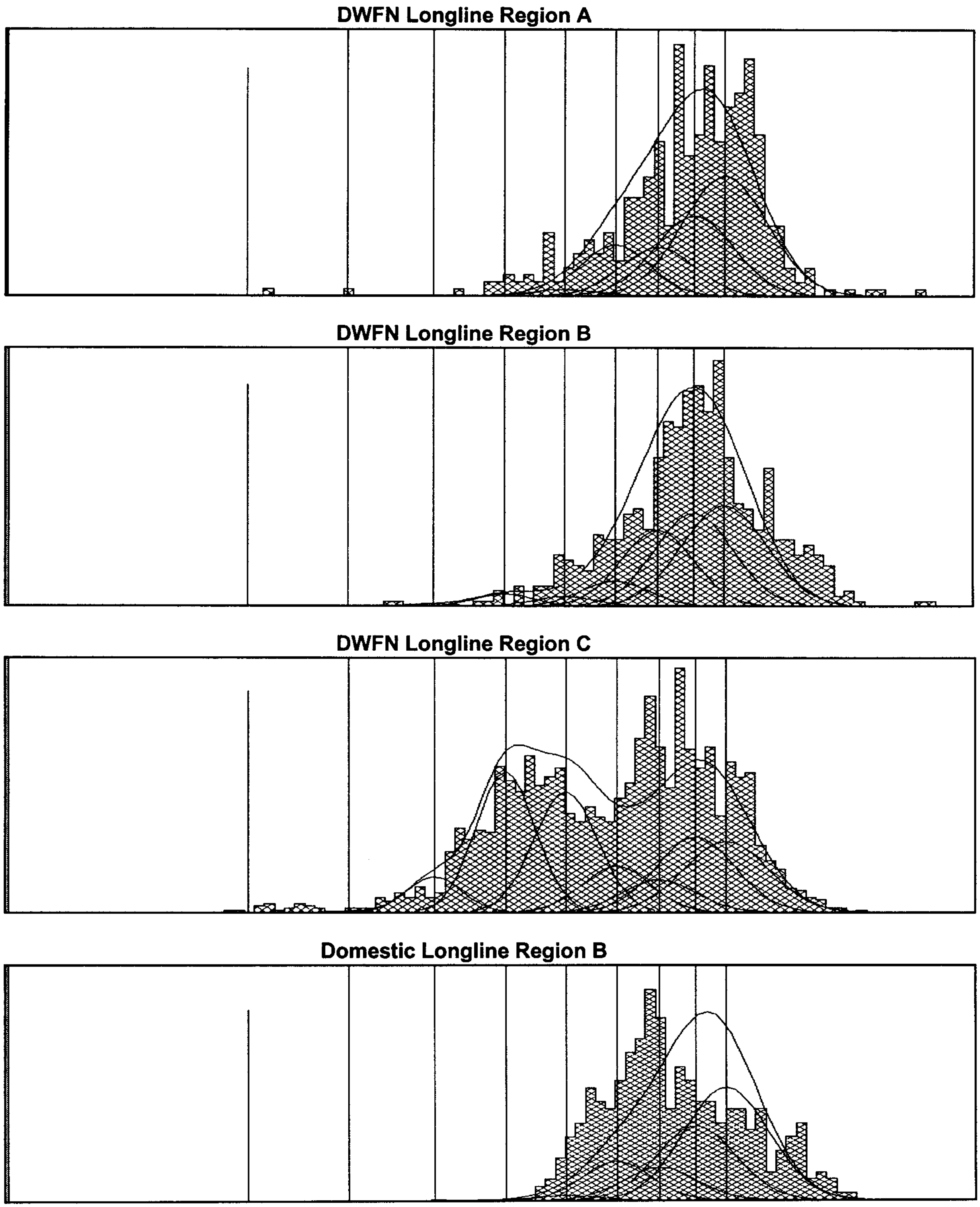


Figure 3. Examples of model fit to the length-frequency data. The vertical lines indicate estimated mean lengths at age. Both the estimated aggregate (upper line) and age-class specific length distributions are shown.

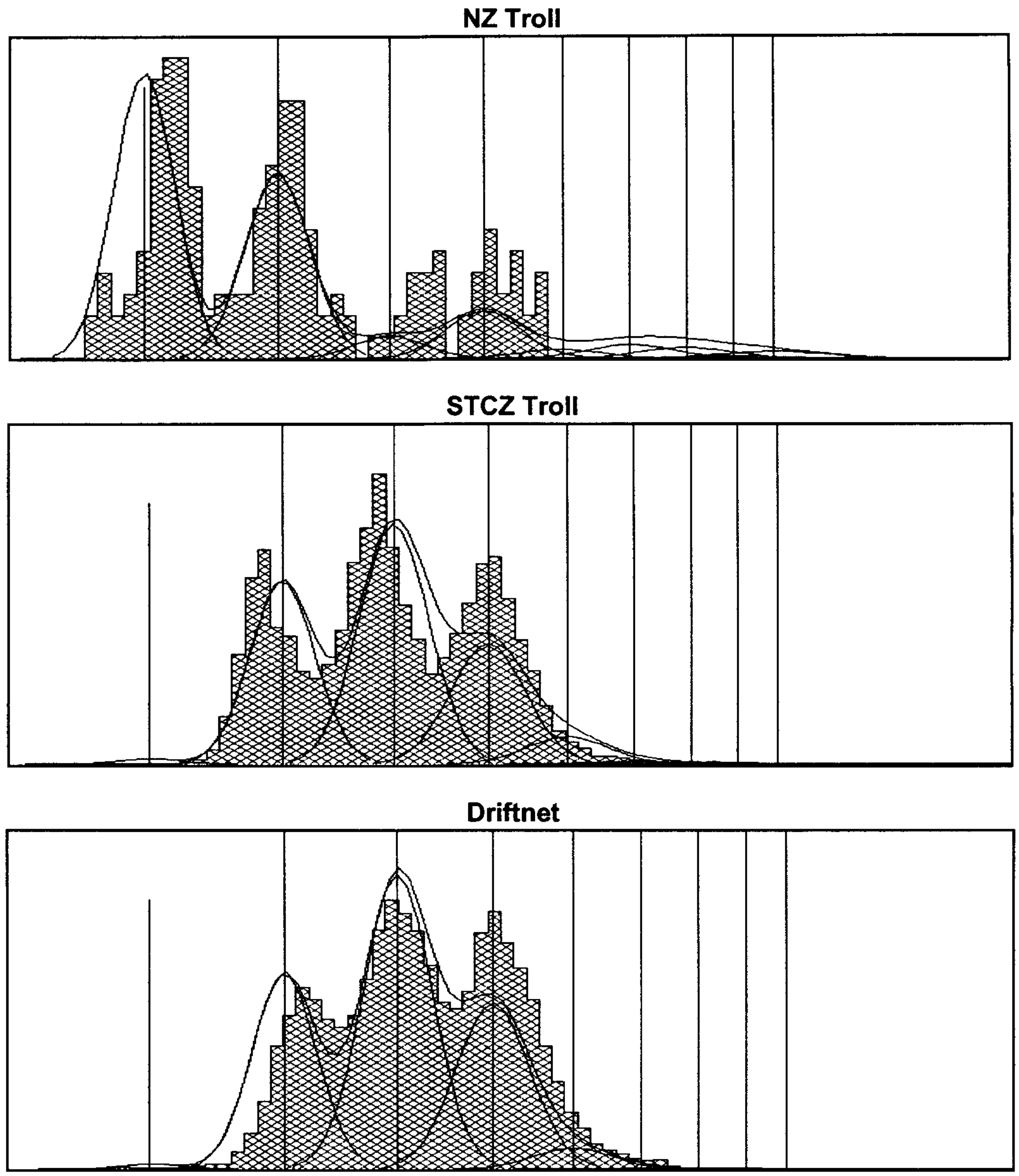
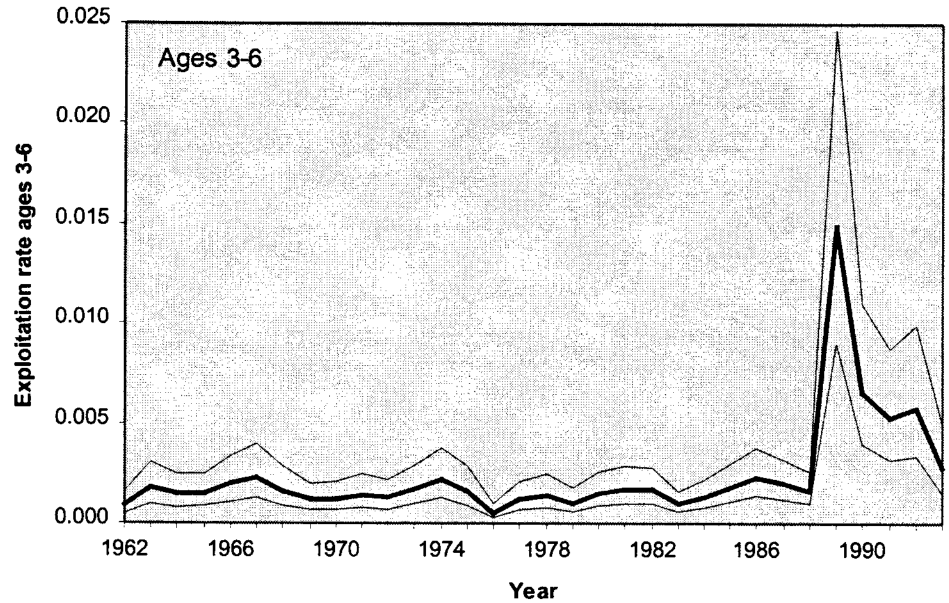


Figure 3. Continued.



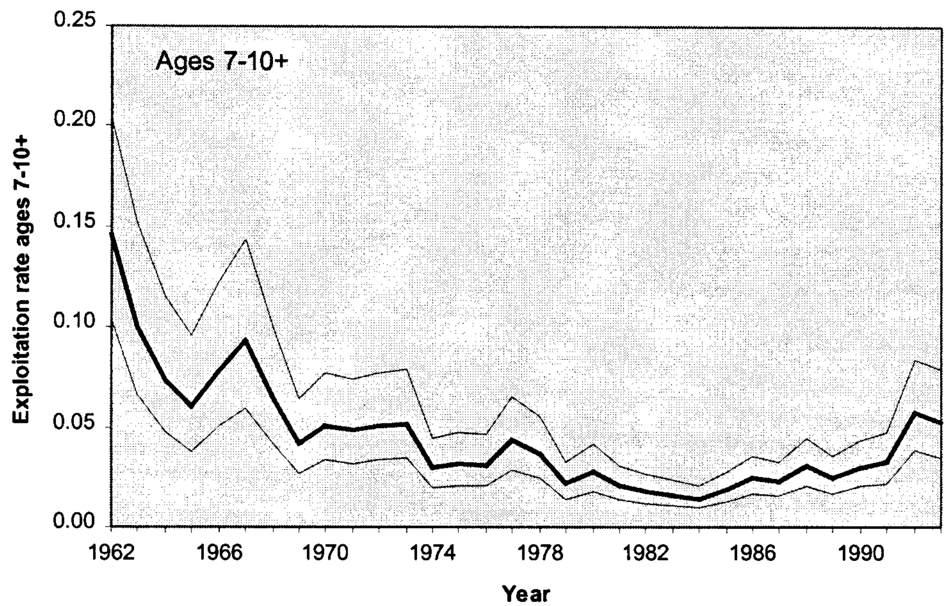


Figure 4. Estimated average annual exploitation rates (heavy lines) and their 95% confidence intervals (thin lines) of presumed ages 3-6 and ages 7-10+.

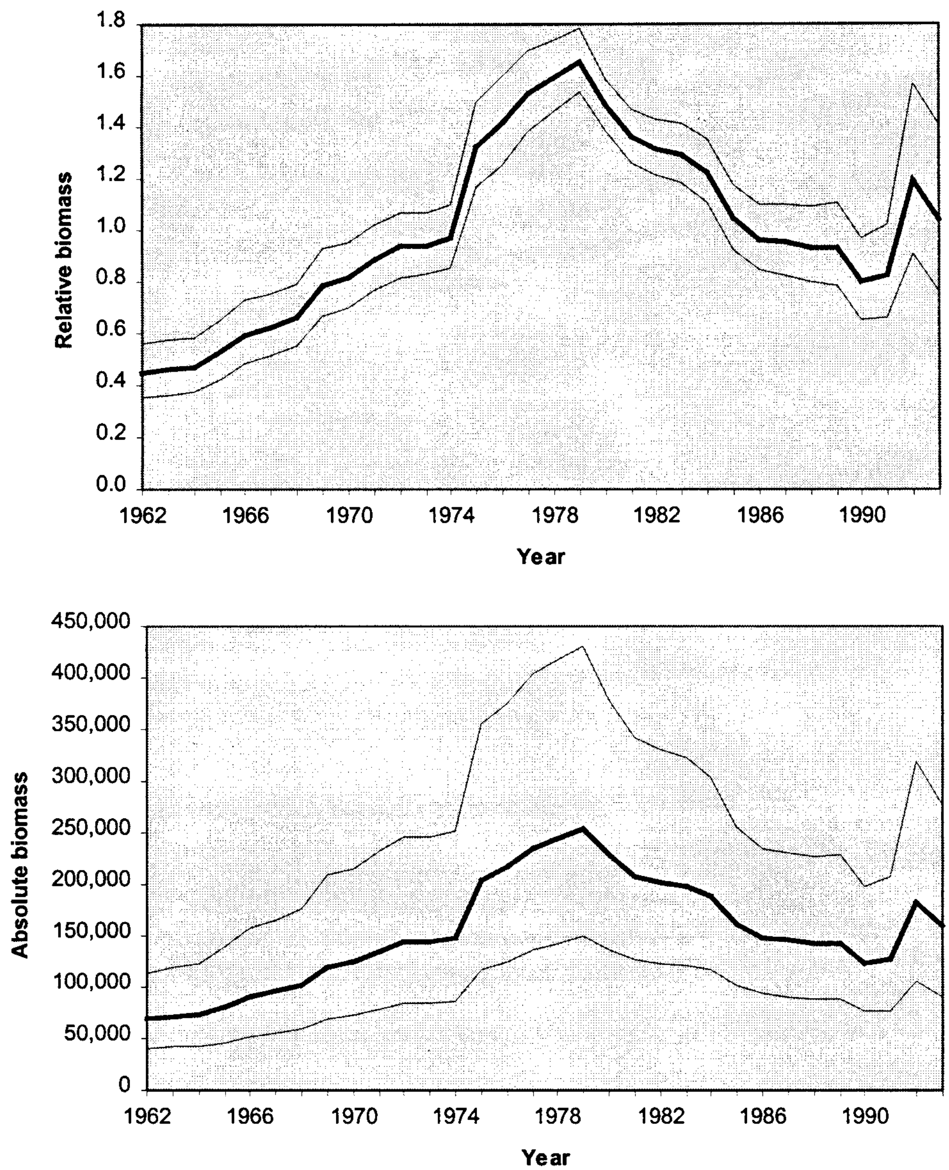


Figure 5. Estimated relative (scaled to the average) and absolute biomass, with 95% confidence intervals.

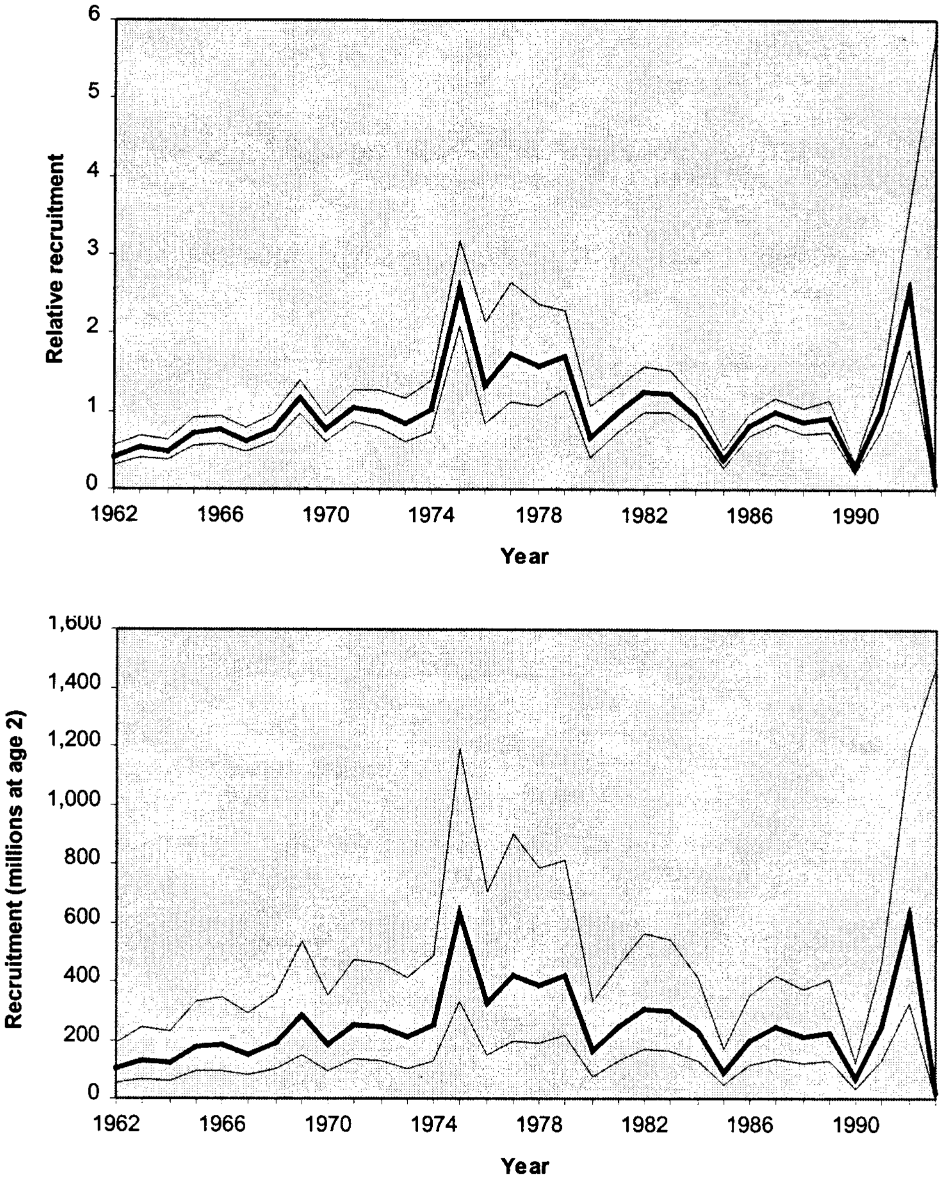


Figure 6. Estimated relative (scaled to the average) and absolute recruitment, with 95% confidence intervals.

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RECENT DEVELOPMENTS AND METHODS IN THE SOUTHERN BLUEFIN TUNA FISHERY ASSESSMENTS

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SOUTHERN BLUEFIN TUNA BIOLOGY

Age and Growth

Tagging Experiments

Extensive juvenile tagging programs were conducted in the 1960s and 1980s. From both periods some returns were recovered with times at liberty in excess of 10 years. The pre 1980s releases were used for analyses of growth rates (Lucas, 1974; Murphy, 1977; Kirkwood, 1983; Hearn, 1986; Hampton, 1991) that were input into stock assessment analyses before 1993. Hearn and Polacheck (1993) and Anon (1994a) showed that the southern bluefin tuna (SBT) growth was substantially greater in the 1980s than in the 1960s and that the growth model is different between adult and juvenile SBT.

The 1994 SBT Trilateral Workshop (Anon, 1994a) adopted a two-stanza von Bertalanffy growth equation with separation at a critical length l^*, and the Fabens (1965) fitting procedure. In each step of this procedure the expected growth increment for the two-stanza model was estimated using the technique of Bayliff et al. (1991). Results are presented in Table 1.1.

Table 1.1. The parameter estimates of the two stanza von Bertalanffy growth model (Anon, 1994a, Table 6), with the number of tag returns for each estimation (n).

		First stanza			l^*	Second stanza		
Period	n	K	L_∞	t_0		K	L_∞	t_0
1960s	701	0.289	134.6	-0.817	102	0.203	175.1	-0.214
1980s	1500	0.109	311.9	-0.780	86	0.180	183.9	-1.323

Previous to 1993 it was assumed that a 55 cm SBT was about 2 years old, but evidence from otolith daily rings in 1993 showed fish of this length were about 1 year old, and this was used to estimate the t_0 parameters. Hearn (1994) constructed the year-class age-at-length curves which assumes a continuous change during the transition period 1970 to 1980 (e.g., Table 1.2). There is considerable variation in growth of juveniles according to the season of the year (Hearn, 1986; Caton, 1991).

Introduction of the improved growth curves in the stock assessment in 1993 and 1994 made little difference in the estimates of the parental biomass, but reduced the recent estimates of recruitment (Anon, 1993, 1994b).

Table 1.2. Estimates of SBT length-at-age on January 1 for selected years and ages.

	Age (years)									
Year	1	2	4	6	8	10	12	15	18	21
1965	55.0	75.0	101.2	125.5	142.1	153.1	160.4	167.1	170.8	172.7
1970	55.0	75.0	101.2	125.5	142.1	153.1	160.4	167.1	170.8	172.7
1975	55.0	77.8	106.6	127.9	142.9	153.9	161.5	168.4	172.2	174.2
1980	55.0	80.9	111.6	132.1	146.6	156.6	163.6	170.7	174.8	177.0
1985	55.0	81.5	113.4	134.7	149.1	159.0	166.1	172.8	176.8	179.2
1990	55.0	81.5	113.4	134.7	149.6	159.9	167.1	173.8	177.7	180.0
1995	55.0	81.5	113.4	134.7	149.6	159.9	167.2	174.2	178.1	180.4
2000	55.0	81.5	113.4	134.7	149.6	159.9	167.2	174.2	178.2	180.6
2005	55.0	81.5	113.4	134.7	149.6	159.9	167.2	174.2	178.2	180.6

Hard Part Analyses

Until recently the principal sources of information on the age and growth of SBT were a major study of scale annuli (Yukinawa, 1970) and tagging studies. From these, recruitment to surface fisheries in the Australian Fishing Zone was thought to be at age 2 years, age at maturity age 7 years, and longevity around 20 years. The longevity estimate was derived from a tag returned 18 years after release on a 2-year-old fish.

These estimates were used within the assessment process for over two decades until the early 1990s, but it was widely acknowledged that the lack of validated ages had a significant impact on stock assessments. Consequently a three-year study was begun in 1992 to develop techniques for directly estimating age and use these estimates to determine the age distribution of the catch (Gunn et al., 1995).

Daily increments in sagittal otoliths were used to examine the age of fish up to 50-60 cm. These fish are 300-400 days old, significantly younger than the 2 years accepted previously. Microincrement-based estimates of age were supported by estimates based on "annual" banding patterns.

Age estimates of fish larger than 60 cm were based on bands in both vertebrae and otoliths. The two structures provided similar estimates of size-at-age up to age 6. However, above this age/size, otoliths and vertebrae from the same fish produced significantly different counts. The maximum age estimated from otoliths was 43 years while for vertebral counts it was only 22 years. Similar differences have been observed in other bluefin tunas.

A large tagging experiment was begun in 1991, with tagging of 1-3 year olds to validate the ring counts. This has so far allowed validation of annual banding in otoliths of 1-6-year-old SBT. Age validation for older fish used the levels of bomb-radiocarbon within the inner parts of otoliths to estimate the year in which fish were spawned (Kalish et al., 1996). The age estimates derived from bomb-radiocarbon analyses agree closely with otolith band counts of sister otoliths. It is concluded that the otolith band counts provide the most accurate estimate of age in SBT older than 6 years and that vertebral counts significantly underestimate age in these year classes.

The otolith band-count data have been used to estimate size-at-age throughout the exploited size range (Fig. 1.1) and the birth-date distribution of Japanese longline catches in the Australian

Fishing Zone (Fig. 1.2). A high proportion of the catch is of fish older than 20 years, and there is a significant increase in representation of year classes spawned since the introduction of catch quotas in 1984.

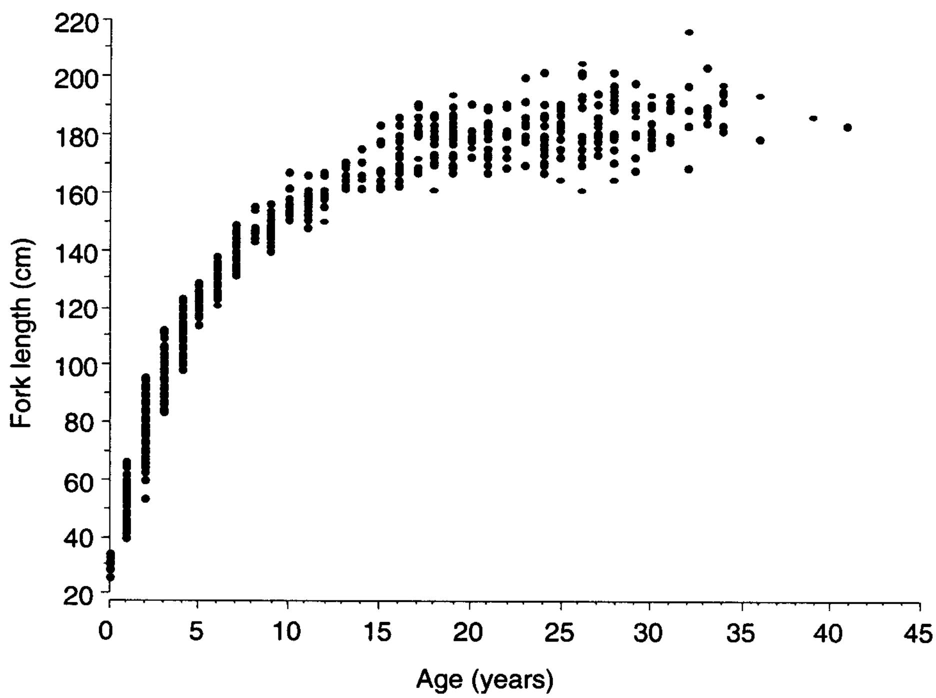

Figure 1.1. Length-at-age estimates for SBT based on interpretation of otolith banding ($n = 1131$).

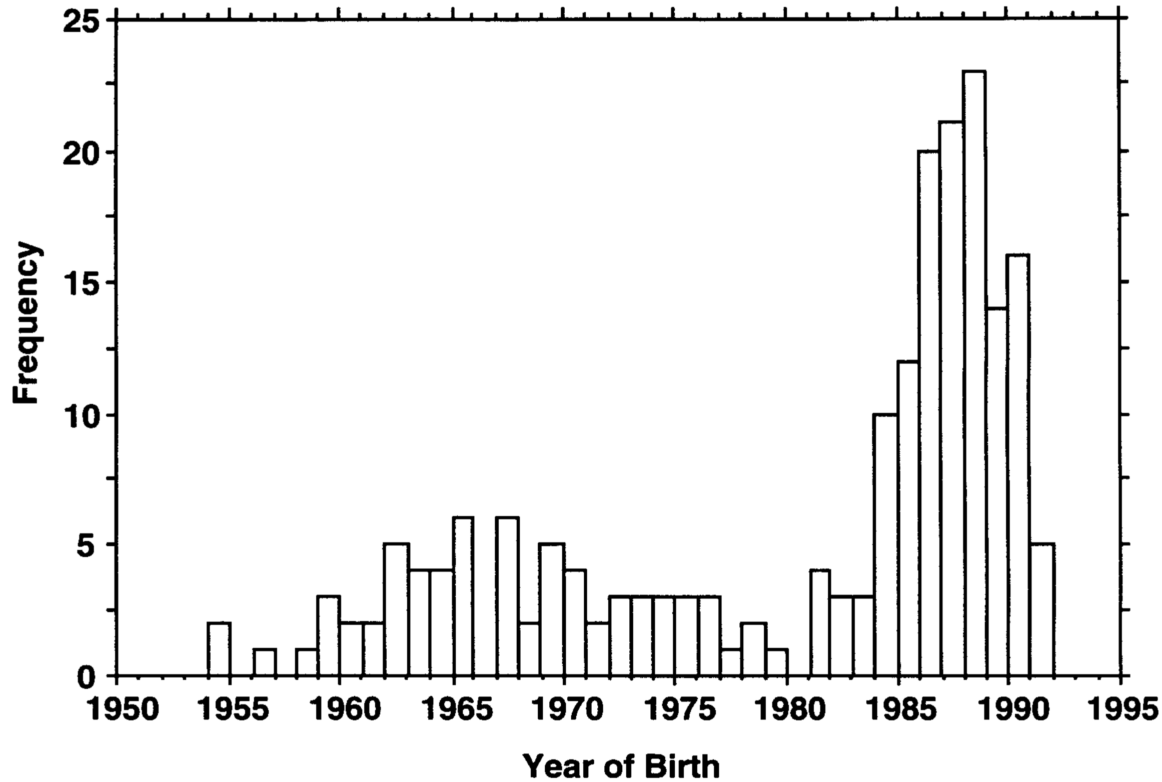

Figure 1.2. Distribution of cohorts in the Japanese longline catch off Tasmania during the 1990-94 fishing season, derived from estimates of otolith age of a random subsample of the catch.

Size and Age at Maturity

SBT spawn in an area south of Indonesia (the "Oka" fishing ground or statistical area 1, 10-20°S, 100-130°E) which was first fished by the Japanese in 1952. Fishing extended to the "Oki" fishing ground (statistical area 2, 20-35°S, 80-120°E) in 1958, which is south of the spawning ground and thought to be the stageing ground.

Warashina and Hisada (1970) considered that SBT on the spawning grounds reached maturity at 130 cm. Reanalysis (Anon., 1994a) of their data showed that this was the smallest size at which SBT matured and that the mean size at maturity was in the range 150-160 cm.

In area 1 the mean length and apparent mean length at maturity of SBT has progressively increased since the 1960s (Anon., 1994a and Table 1.3). This could be explained by the change in growth rate if maturity is age dependent. However, it might also be due to a shift in the distribution of age groups on the spawning ground.

Table 1.3. Mean length and mean length at maturity of SBT in statistical area 1 between the years 1965 and 1989.

Years	Number	Mean length in area 1	Standard deviation	Mean length at maturity
1965-69	3060	158.7	10.5	146.3
1970-74	696	161.4	10.3	149.4
1975-79	1026	161.0	10.6	148.5
1980-84	1357	162.5	10.3	150.4
1985-89	745	165.7	10.1	153.9

Davis (1995) examined ovary samples from the southeast Indian Ocean (28-44°S, 90–118°E), south of the Oka and Oki fishing grounds but on the spawning migration route. Two criteria for maturity were used, gonad index (GI) [Kikawa, 1964; Shingu, 1970] and oocyte diameter. The GI indicated a mean size at first maturity of 162 cm. Mean size at maturity using oocyte diameter was 152 cm (Davis, 1995).

There is a problem with these estimates of mean size at maturity based on individuals caught well south of the spawning grounds. Small fish may mature but not actually migrate and spawn in that season. These smaller fish do not reach the central and northern parts of the spawning ground as SBT caught there by the Indonesian fishery are all 147-222 cm (Davis et al., 1996; Farley and Davis, 1998). The poor representation of SBT <170 cm on the spawning ground relative to off the spawning ground is incompatible with Davis's (1995) mean size at maturity of 152-162 cm. Factors other than a larger mean size at maturity might explain the observed length frequency distribution on the spawning ground and were addressed by Gunn et al. (1996a). However, none of these factors were considered likely, and the most probable explanation was that the mean size at maturity is somewhat larger than 152-162 cm.

The distributions of SBT ages on the spawning grounds during the 1994/95 and 1995/96 spawning seasons (Davis et al., 1996) were compared with a combination of the ages of fish caught on and off the spawning grounds (Gunn et al., 1996a, 1996b). The resulting catch-at-age distributions for catches on and off the spawning grounds are compared in Figure 1.3. The lack of 7-11 year old fish on the spawning ground is not due to a lack of these aged fish in the general population. On the basis of data available, 12-13 years seems a more appropriate estimate of mean size at first spawning than the previous estimate of 10-11 years for the age at first maturity (Davis, 1995), or the estimates of 7-9 years used in the 1993 Council for the Conservation of Southern Bluefin Tuna (CCSBT) workshop.

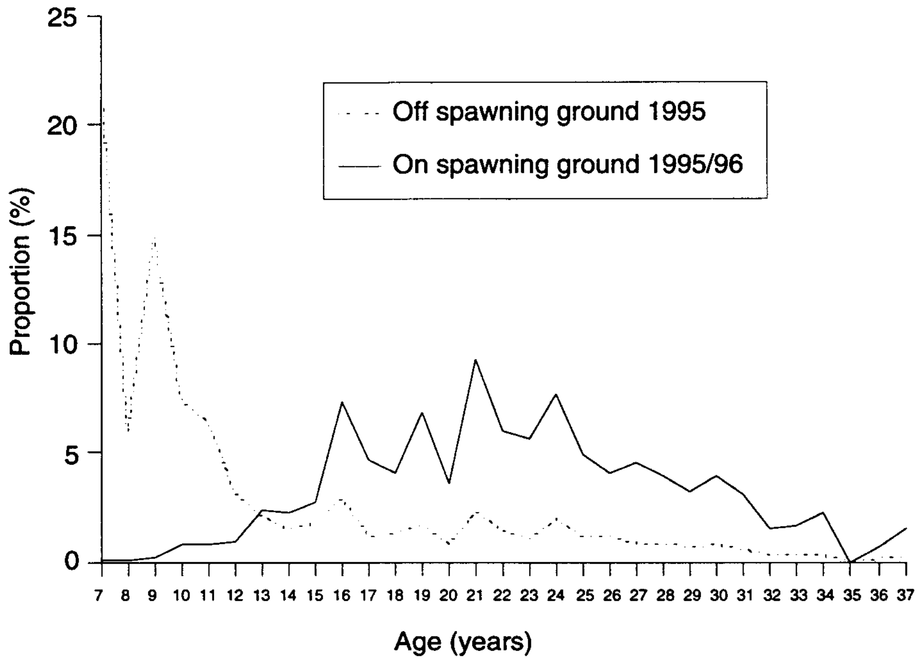

Figure 1.3. Age distribution on the spawning grounds during the 1995/96 spawning seasons and age distribution of Japanese catch data in 1995.

Fecundity and Spawning

Farley and Davis (1998) show that SBT are on the spawning ground every month except July, although relative abundance is low from May to August. February and October are the peaks of abundance on the spawning ground. Although the spawning season was protracted, individuals did not spawn over the whole season, with turnover of spawners on the spawning ground throughout the season. Females spawned on average every 1.1 days with an average batch fecundity of 6.0 million oocytes or 57 oocytes per gram of body weight.

Movements

The data obtained from archival tags, available since 1992, have provided a very different picture of the movement of juvenile SBT compared to those derived from over three decades of conventional tagging. The new perspectives include large-scale cyclic migrations of 2-4 year-olds from the summer feeding grounds on the continental shelf of Australia, out into the Indian Ocean during winter, and very rapid return journeys during spring. A smaller proportion of fish undergo an eastward winter migration. This is in contrast to the reported conventional tag returns, which indicated that many more SBT moved east than west.

ANALYSIS OF CATCH AND EFFORT DATA

Indices of SBT abundance based on Japanese longline catch and effort data provide indicators of stock status and are used to 'tune' virtual population analyses (VPA). Aggregated 5x5-degree/monthly catch and effort data ('coarse-scale' data) has been used routinely and since 1992, daily 1x1-degree catch and effort data ('fine-scale' data) have also been used.

Standardization of Catch Rates

Standardization methods follow the work of Robson (1966) and Allen and Punsley (1984), and use a general linear model (GLM). For example, a model of the mean catch rate which accounts for year (Y), seasonal (S) and area (A) effects together with gear (G) and environmental (E) effects is

$$E(CPUE_{ijkab}) = (Y_i S_j A_k G_a E_b) q_o D_o, \tag{1}$$

where q_o is the catchability for the standard gear under the standard environment, and D_o is the density of fish within the standard year, season, and fishing area. Assuming CPUE has a log-normal distribution then

$$\begin{aligned} E(z_{ijkab}) &= E(\ln CPUE_{ijkab}) \\ &= \ln(q_o D_o) + \ln Y_i + \ln S_j + \ln A_k + \ln G_a + \ln E_b \\ &= d_o + y_i + s_j + a_k + g_a + e_b. \end{aligned} \tag{2}$$

The right side of this equation is the linear predicator.

A model based on this approach and used in the SBT analyses includes interactions between year, season, area, and has the form:

$$E(z_{ijkab}) = d_o + y_i + s_j + a_k + (y \cdot s)_{ij} + (y \cdot a)_{ik} + (s \cdot a)_{jk} + e_a + g_b. \tag{3}$$

Two other model structures have also been used in the SBT analysis. The first assumes a gamma distribution for the catch rate and uses a log link function to relate the linear predictor to the expected catch rate (Hearn et al., 1994, 1995). The second assumes a Poisson error structure on the observed catch with a log link function between the linear predictor and the expected catch (Nishida et al., 1994; Nishida and Hiramatsu, 1995). Plots of the variance-mean relationship in the residuals after fitting each of the models (Anon., 1996) indicate that a gamma or log-normal distribution is more realistic than the Poisson.

Indices of Annual Stock Abundance

After standardizing for gear types and environmental conditions, the expected value of the standardized log(CPUE) in the i^{th} year, the j^{th} quarter and the k^{th} fishing region can be found by setting the value of the gear and environmental parameters, g and e, to zero:

$$E(\ln CPUE_{ijkoo}) = d_o + y_i + s_j + a_k + (y \cdot s)_{ij} + (y \cdot a)_{ik} + (s \cdot a)_{jk}.$$

Given that $CPUE_{ijkoo}$ has a mean μ and variance σ^2, the expected catch rate for the standardized catch is (Aitken et al., 1989)

$$\begin{aligned} E(CPUE_{ijkoo}) &= \exp(\mu + \sigma^2 / 2) \\ &= q_o D_o \exp(y_i + s_j + a_k + (y \cdot s)_{ij} + (y \cdot a)_{ik} + (s \cdot a)_{jk}) \exp(\sigma^2 / 2). \end{aligned} \tag{4}$$

The expected catch rate is proportional to the density of fish within the area fished, so a local index of abundance, B_{ijk}, can be obtained by multiplying the spatial size, f_k, of each fishing area by the expected value of the standardized CPUE:

$$B_{ijk} = f_k E(CPUE_{ijkoo}).$$

A total index of abundance for the i^{th} year, I_i, can then be obtained by summing over all fishing areas and taking the average over all seasons in that year. Either the arithmetic or geometric mean can be used, with the later being scale invariant. That is

$$I_i = \frac{1}{N}\sum_{j=1}^{N}\left[\sum_{k=1}^{R} f_k E(CPUE_{ijkoo})\right] \quad \text{or} \quad I_i = \sqrt[N]{\prod_{j=1}^{N}\left[\sum_{k=1}^{R} f_k E(CPUE_{ikjoo})\right]}, \qquad (5)$$

where N and R are the number of seasons and fishing areas in the model.

Equation (5) highlight the fact that the index is the product of fish density within spatial areas and the size of those areas. The common practice of reducing the index to a function of the year effect alone potentially ignores information on the spatial dynamics of the fishery which may be highly relevant to correct interpretation. For example, Equation (5) will give indices of total stock abundance if the spatial extent of the fishery coincides with, or is greater than, the spatial extent of the stock. If the spatial extent of the fishery is less than the spatial extent of the stock, then these equations will give an index of abundance for only a portion of the stock.

Interpretation of the CPUE indices of abundance is made difficult when the spatial extent of the fishery changes between years. For example, the spatial extent of a fishery might decrease over time because of (1) a decrease in the spatial extent of the stock over time (e.g., density dependent habitat selection; MacCall, 1990); (2) reduced effort in the fishery, possibly due to the introduction of quotas or other regulations that limit the spatial reach of the fishery; (3) increasing knowledge of the fishing grounds and a selection of higher catch rate regions; (4) some combination of the previous factors. The interpretation of CPUE in each situation can be quite different and without auxiliary information uncertainty will remain as to which interpretation is correct. Two indices of abundance have been developed to approximately bound our interpretation within each year. To focus on spatial issues these are described here, ignoring seasonal effects.

Constant Squares Index. It is assumed that the spatial extent of the stock remains constant between years and it coincides with the maximal extent of the fishery (i.e., the union of all areas ever fished). For individual fishing areas the density of fish in the sub-areas fished in any year is assumed to be representative of the density over the whole area, and the average density of fish in areas not fished is assumed to be the same as in the fished areas. That is

$$I_i(\text{constant\_squares}) = \sum_{k=1}^{R} f_{k,\max} E(CPUE_{ik}),$$

where $f_{k,max}$ is the maximal spatial extent of the k^{th} area and is a constant from year to year.

Variable Squares Index. It is assumed that the spatial extent of the stock varies and coincides with the extent of the fishery each year. In regions with no effort, the abundance is assumed to be zero. The resulting index is

$$I_i(\text{variable\_squares}) = \sum_{k=1}^{R} f_{ik,fished} E(CPUE_{ik}),$$

where $f_{ik,fished}$ is the size of the k^{th} area fished in the i^{th} year.

Analysis of fine scale data allows examination of fishery targeting and can help with interpretation and selection of assumptions. However, use of fine-scale data may also result in greater interannual variation in spatial coverage at that finer scale, increasing the problem of extrapolating densities to unfished areas. Simulations have been used to investigate how abundance indices are influenced by changes in the levels of data aggregation and the statistical balance of the data sets (Campbell, et al., 1995). These showed

(1) where there are data for all spatial regions in the fitted model for all years, but the number of observations varies from region to region, a weighted analysis is necessary so 'equal weight' is assigned to each region; and
(2) where the spatial extent of the fishery changes from year to year, so that there are regions with no data for some years, the estimates are biased.

The bias in the second case results from the GLM imputed values in missing cells. These imputed values depend in a complex manner on the structure of the model and the data, and it appears in some situations that there is basic mismatch between the model structure and the data structure so that interpretation is possible only with further assumptions (Campbell and Polacheck, 1993; Campbell et al., 1995; Hearn and Bradford, 1996). Simulations also showed that bias results if data are aggregated to a scale larger than the scale of fishery targeting.

Spatial Targeting Within the SBT Fishery

Between the early 1950s and the late 1960s the fishery expanded spatially but was not fully developed until 1970 (Shingu and Hisada, 1971; Warashina and Hisada, 1974).

The number of 1x1-degree squares fished by the Japanese fleet is shown in Figure 2.1. From a high in 1971, the spatial extent of the fishery remained relatively constant until the mid 1980s. It subsequently contracted coincident with the introduction of catch quotas. Spatial concentration of fishing effort has always been a feature of the SBT longline fishery (e.g., approximately 50 percent of the effort is expended in 10 percent of the squares), but prior to 1980 the targeted areas were in general not areas with higher catch rates. This situation changed in the 1980s, and since 1986 there has been stronger targeting of high CPUE areas.

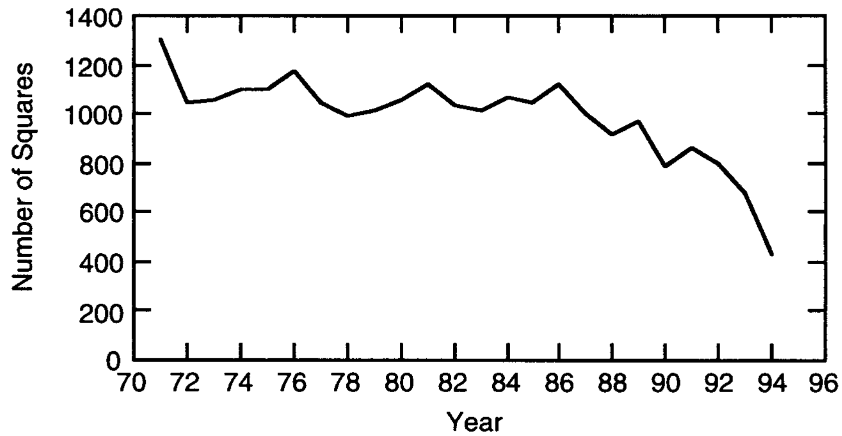

Figure 2.1. Number of 1x1-degree squares fished each year by Japanese longliners between 1971 and 1994 within the SBT Statistical Areas 4 to 9.

Southern Bluefin Tuna Data Analysis

A detailed description of the analysis is given in Campbell et al. (1995). The analysis was restricted to statistical areas 4 to 9 and quarters 2 and 3 because of data limitations. Total catch was converted to catch-at-age using size information aggregated by 5x10-degrees and by quarter, because this was the scale at which the data was collected prior to 1987. Three indices were calculated:

- B_{avg}—associated with implementation of the constant square type interpretation
- B_{min}—associated with implementation of the variable squares type interpretation
- B_{ratio}—associated with intermediate interpretation assuming that the spatial extent the stock and fishery coincide each year

The model given by equation (3) was fitted to the data where season is taken to be quarter of the year, fishing areas are 5x5-degree blocks, and the following gear and environmental effects are modeled—vessel size, bait type, hooks per basket, combined bycatch of other tunas, moon phase, sea-surface temperature (SST) for a given month and 1x1-degree square (Reynolds and Smith, 1994), Southern Oscillation Index (SOI) for a given month, and the strength of the westerly winds (WWI) in the mid-troposphere at mid-latitudes for a given month (Pook, 1992).

Separate analyses were carried out on the individual age groups 4, 5, 6, 7, and 8 years old, and on the combined age groups 4-5, 6-7, 8-11 and 12+ y. The standardizing effects of vessel size, bait type, hooks per basket, and moon phase were fitted as factors while the effects of bycatch, SST, SOI, and the WWI were fitted as covariates. Because there were different numbers of catch rate observations in each 1x1-degree square, a weighting was used as described by Punsley (1987). Although the area effect used in the model is a 5x5-degree block, the weighting of the data at the 1x1-degree square level accounts for spatial targeting at the 1x1-degree scale. Fine scale effects are also introduced into the model through the use of the 1x1-degree SST. Similarly the SOI and the WWI implicitly model month and year by month effects, while moon phase models daily effects.

Indices of stock abundance were calculated using Equation (5). The size of each 5x5-degree block was the number of 1x1 cells fished in that block. This size can vary between quarters, but the process of balancing the data ensures that the area fished in each 5x5-degree block is the same across all years; i.e., the entire fishery has the same spatial extent for all years, though this size can be different between quarters. The resulting yearly indices of stock abundance obtained for each age group are shown in Figure 2.2. A full analysis of residuals was also undertaken for these models, and no major misfits between the assumptions underlying the models and the observations were found.

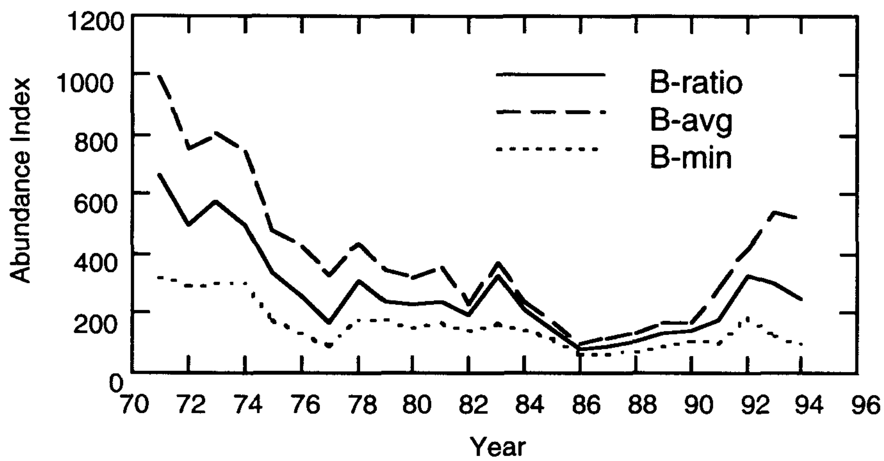

Figure 2.2a. Standardized indices of SBT abundance for age groups 4 and 5.

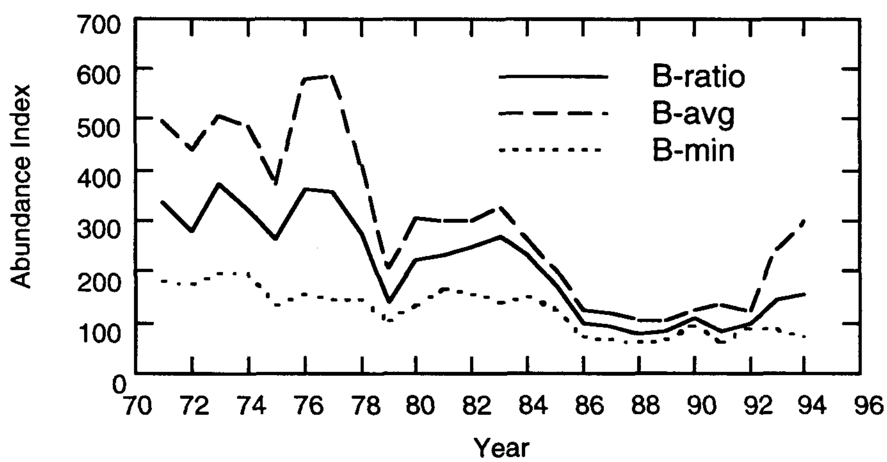

Figure 2.2b. Standardized indices of SBT abundance for age groups 6 and 7.

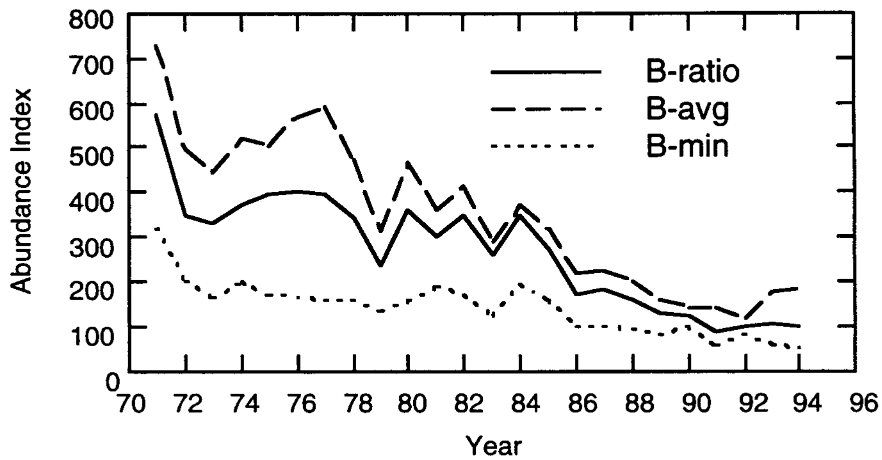

Figure 2.2c. Standardized indices of SBT abundance for age groups 8 to 11.

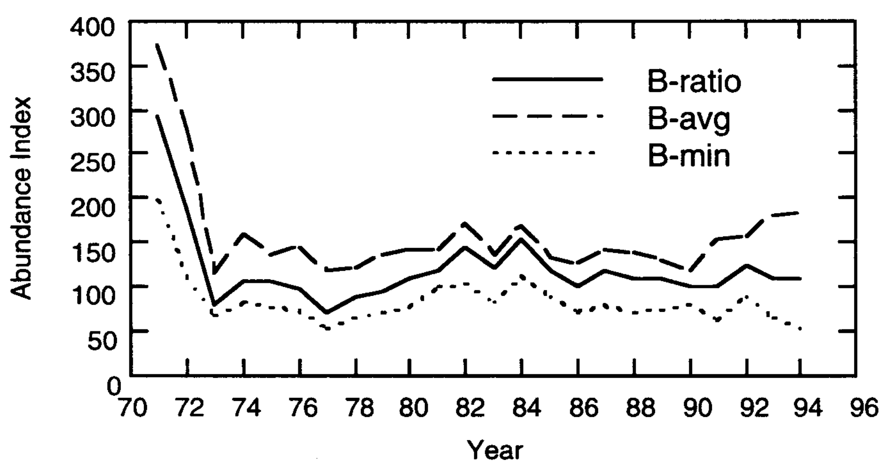

Figure 2.2d. Standardized indices of SBT abundance for age groups 12+.

Discussion

Many problems can arise with the use of catch and effort data to estimate abundance of fish populations (see Gulland, 1974; Paloheimo and Dicke, 1964). These problems relate to inadequate data coverage of the spatial extent of the stock and whether data from a commercial fishery that attempts to maintain a high catch rate reflect stock abundance. Both these issues seem to have been of relevance in the recent collapse of the North Atlantic cod fishery, where the 'fleet was fishing a smaller and smaller area of ocean' and 'the fishermen were catching more fish per hour ... because they were going to ... where they knew cod were (Anon., 1995). The extent to which this is happening with SBT is unknown, but given the available data the possibility of occurring cannot be excluded. Conversely the possibility of significant quantities of fish in unfished areas cannot be excluded. The key point here is that the range of CPUE interpretations provided by the different indices reflect the uncertainty in scientific interpretation.

Finally, while attempts have been made to account for a number of factors which may influence catch rates within the SBT fishery, many other factors which can and do influence catch rates have not been included. These factors include changes in the operational and technological aspects of the fishery, many of which have been shown to be important in other fisheries. Attempts to document the changes in the SBT fishery (Whitelaw and Baron, 1995) and, where possible, to include these factors in future analyses of catch and effort data are underway.

POPULATION ASSESSMENT

The information base available for assessing the status of the SBT resource is relatively rich compared to that available for most large pelagic fishery resources. Reasonably complete and detailed catch, effort, and size statistics are available for the entire history of exploitation. In addition, all available information indicates that SBT come from a single stock with a single breeding ground in the tropical Indian Ocean.

Since the early 1980s, the stock assessment has been primarily based on a combination of CPUE analyses, a set of qualitative fishery indicators and virtual population analyses (VPA). Until about 1990 these different approaches yielded consistent results indicating declines in recruitment since 1979 and a continuous long-term decline in spawning stock biomass.

Beginning in 1985 catch quotas were imposed under informal management arrangements involving Australia, Japan, and New Zealand. These management measures quickly resulted in a reduction in the juvenile catches from the surface fisheries around Australia, but it was not until 1989 that the quotas were restrictive for the Japanese high-seas longline fishery. With the imposition of restrictive quotas, the task of assessing the status of the stock has become increasingly more difficult. The question was no longer simply was the stock declining? The questions became—was the rate of decline decreasing and were the catch reductions sufficient to allow recovery? In addition, the catch rates from the fishery no longer provided a clear signal about recent trends. In recent years, conflicting results about the most recent stock trends can be obtained from VPA assessments using different portions of the available cpue information in combination with alternative hypotheses about natural mortality rates, selectivity, and methods for estimating the size of the plus group.

With the refined focus and conflicting results from the SBT assessment, increased research effort was given to many of the biological and modelling assumptions embedded in the assessment. Areas of improved biological information included estimation of changing growth rates, direct ageing, longevity, age of maturity, and age specific natural mortality rates. Superficially, this increased information base had the ironic consequence of increasing rather than decreasing uncertainty in the assessment. This was because the increased data clearly indicated that a number of the previous simple assumptions were inappropriate. Consequently, a wider range of generally more complex hypotheses were needed to provide results that were both consistent with the actual data and reasonably reflected the actual uncertainty. The increased information base did not really increase the true uncertainty. The previous assessments were artificially precise for their true accuracy because they were based on an overly restrictive set of hypotheses, and the new information exposed this.

The ADAPT framework for tuning VPAs (Garvaris, 1988) has been used for SBT assessments since 1990 (Ishizuka and Tsuji, 1990, 1991; Polacheck et al., 1996). The ADAPT tuning procedure is an "integrated approach" (Anon., 1985) based on developing models and then finding the set of parameter estimates which provides the best "statistical" fit to the available data. The advantage of these approaches is that they can accommodate a wide variety of different data, they are not necessarily restricted to VPA based models, and they provide "objective" measures to evaluate the parameter estimates.

Data

The fishery for SBT is complex and comprises several components (see Caton, 1991; Polacheck, 1994). The catch-at-age data are estimated from the size distribution of the catch using a knife-edge partitioning procedure (Majkowski and Hampton, 1983). Partition points are calculated from two-stanza von-Bertalanffy growth models derived from tagging data (Anon., 1994).

Complications and uncertainties in calculating the catch at age matrix include (1) poorly documented catches for non-CCSBT countries; (2) major changes in sampling procedures for the Japanese longline catches, including a substantial portion of the size data having been derived from weight measured at sea; (3) changing discard practices (4) change in growth over time; and (5) misclassification of the catch into cohorts by the cohort slicing procedure (See Polacheck et al., 1996 for more detail).

The results from tagging and direct ageing indicate that natural mortality is age dependent (Gunn et al., 1996; Polacheck et al., 1996). However, the exact form of the dependency is not well characterized, so eight different natural mortality vectors were considered in the most recent assessment (Polacheck et al., 1996).

CPUE indices of abundance are the main measures of relative abundance available for tuning the VPA. In the most recent assessment, five different sets of CPUE indices were used (Campbell et al., 1996; Hearn and Polacheck, 1993). The different sets of tuning indices represent alternative hypotheses about the interpretation of CPUE.

Estimation Procedure

Standard backwards VPA was used to estimate numbers at age and the ADAPT framework (Gavris, 1988) was used to tune the VPA (i.e., to estimate terminal fishing mortality rates). The common VPA approach has been extended to estimate the terminal fishing mortality rates for the oldest age group (11 years), as well as the rates in the most recent year for younger ages. This extension is necessary because the selectivity pattern among the older age groups of SBT has significantly changed over time (Polacheck and Klaer, 1991).

A wide variety of data are used to tune the VPA. The advantage of the ADAPT structure is that all these different data sources can be incorporated into the estimation procedure and the residuals used to explore robustness and sensitivity of the results. Tuning indices included in the most recent assessment included (1) age-specific cpue time series, (2) estimates of spawning numbers from cpue analyses from the spawning grounds (Hearn et al., 1995), (3) longline fishing effort in relationship to fishing mortality rates for the older age groups, (4) relative abundance of juveniles from recent fishery independent aerial surveys (Cowling et al., 1996), (5) fishing mortality rate estimated from tagging experiments in the 1990s, (6) direct ageing estimates of the age composition of the spawning stock and plus group in 1995 and 1996 (Gunn et al., 1996), and (7) estimates of total mortality rates from tagging experiments in the 1960s. In addition a term was included in the ADAPT objective function to ensure reasonable continuity in the fishing mortality rates among the three oldest age groups between years.

The method of estimation of the plus group is a major source of uncertainty in the current SBT assessment. Basically two approaches are used based on forward VPA projections from the numbers in the terminal age group and the catches from the plus group. One makes no assumption about the selectivity pattern between the plus group and the terminal age group but requires that the size of the plus group in the first year of the VPA be specified (from equilibrium assumptions). The other makes assumptions about the selectivity between the plus group and the terminal age group but allows the initial size of the plus group to be directly estimated.

A large number of different VPAs were performed over a wide range of values for the VPA input parameters, relative weightings of different sets of tuning indices, and different structural features in the VPA model. For example, the range of uncertainty explicitly considered in 1996 by the scientific committee of the CCSBT gave 216 VPAs, each relating to a specific combination of hypotheses (Anon., 1996). Relative weights were assigned to each hypotheses by the various groups of scientists involved so as to give overall summary means of important stock status measures—such as the ratios of the most recent spawning stock biomass to the 1960 level, the 1980 level, and to the level of the year before.

Results

Figure 3.1 shows typical output from an ADAPT fit to the input data, from which the adequacy and consistency of interpretation can be examined. Figure 3.2 shows typical population assessment results, and their sensitivity to different weightings across the age specific CPUE indices

Although a wide range of alternative hypotheses and weights on these hypotheses have been incorporated into the assessments, they give remarkably similar estimates of the key measures of the present population. For example, across all the different groups of scientists involved at the 1996 CCSBT Scientific Committee (Anon., 1996), the range of weighted means were:

1995 spawning biomass as a percentage of 1960 level = 5-8%
1995 spawning biomass as a percentage of 1980 level = 25-39%
1996 spawning biomass as a percentage of 1995 level = 104-109%.

However while the uncertainties in the 1996 assessment do not greatly affect these measures of present stock condition, some have significantly different implications for future population status. The prospects for stock rebuilding are quite sensitive to details of recent population trends, and these details are difficult to resolve accurately. The difficulties come from two main sources:

The first is that a relatively wide range of alternative hypotheses appear to be consistent with (or at least not clearly rejectable by) the available data. Ongoing research is focused on approaches to clarify this, both by developing better methods for objective hypothesis testing and by examining options for collecting auxiliary data that would make a significant difference to the assessment (including an experimental fishing program).

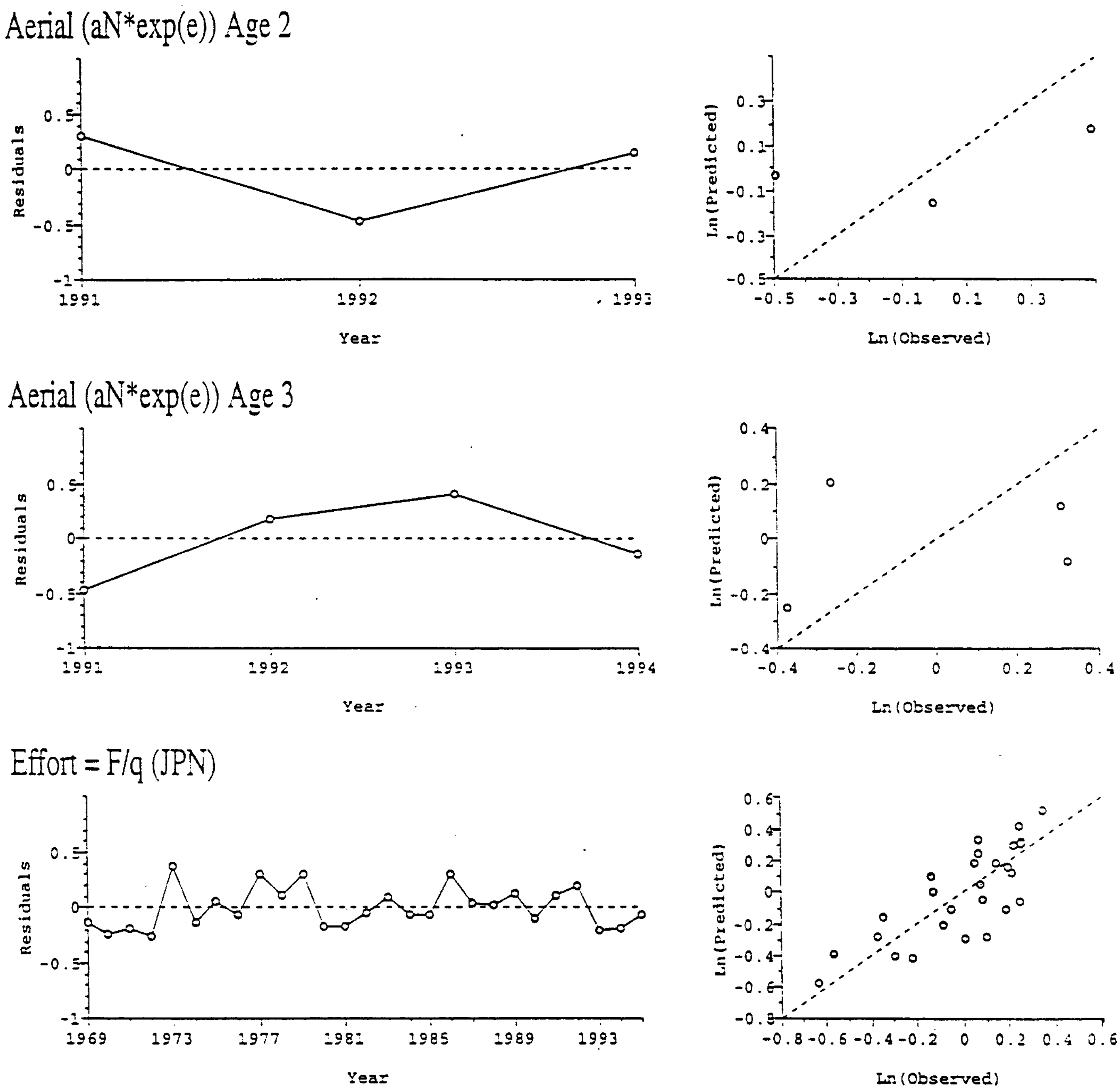

Figure 3.1. Residual plots for VPA.

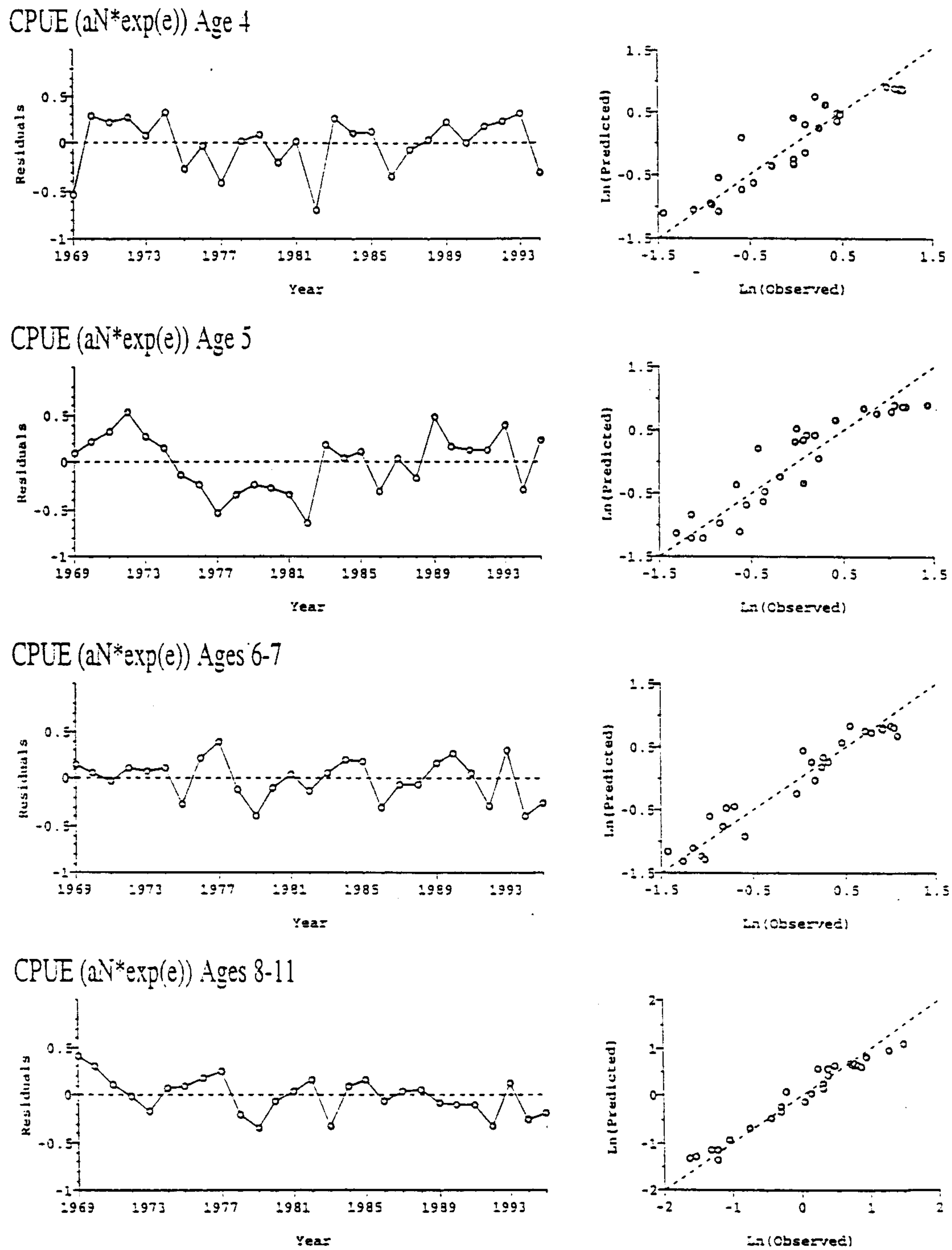

Figure 3.1. Continued.

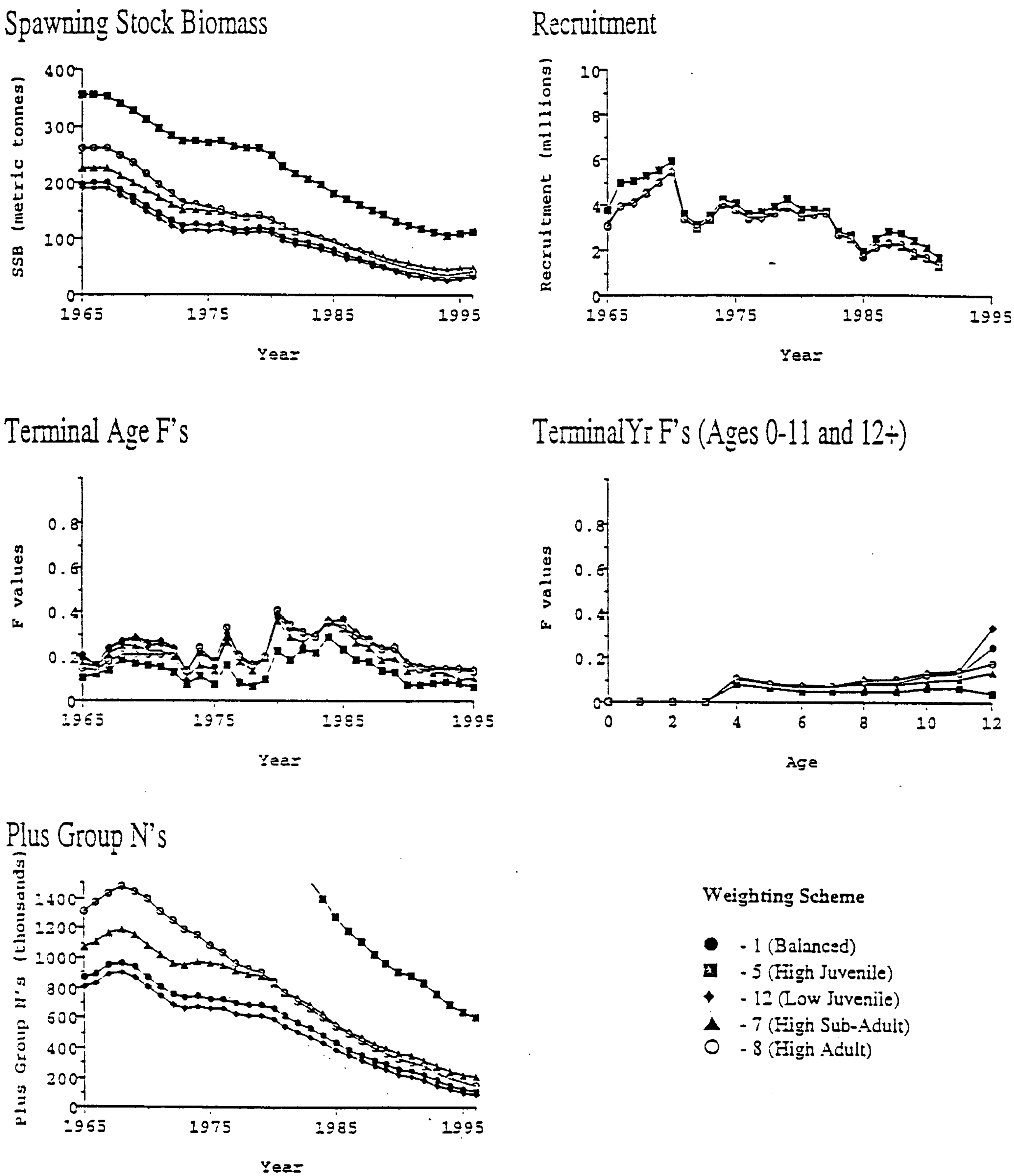

Figure 3.2. Typical VPA results and sensitivity to CPUE weight.

The second relates to inconsistencies between different data sets, which point to some more fundamental misunderstanding in either the dynamics of the stock or the data sets (the 'observation process') that is not captured by the existing range of hypotheses (see Polacheck et al., 1996 for more detail). For example the VPAs have difficulty fitting the recent rapid increase in juvenile catch rates while maintaining good fits to the other data. Perhaps the main inconsistency is the inability of the models to simultaneously fit both the plus group CPUE index and the other age-specific indices. The plus group catch rate declined only slowly over a long period, whereas the catch rates of younger fish declined substantially over that same period, and this decline would be expected to have affected the plus group by now. Possible explanations for these inconsistencies are as follows:

- Errors in the catch at age matrix, including incorrect age determination and changing biases because of changed sampling and measuring practices.
- Changing catchability, including changed fishing operations and technology, density-dependent catchability in the plus group, and recent targeting of young juveniles. The underlying problem here is the almost total reliance on interpretation of commercial CPUE to provide trends in abundance. It is widely recognized that such information alone is usually not sufficient for reliable assessment because of the difficulties in separating the effects of industry development and fleet dynamics from stock dynamics.

General Implications

The SBT results demonstrate the value and importance of integrating all available data into a single assessment framework which can be used to test for consistency of the information with respect to the status of the resource. They also demonstrate the power of the ADAPT framework to perform this integration within a VPA context.

When unresolved inconsistencies are found, their implications for both the assessment and management should be examined. It is not appropriate to use results based on only a portion of the data or to attempt to derive a single interpretation based on some sort of "averageing" of the input data or the VPA results.

The main problem in the SBT stock assessment is not the resolution of different models and methods, although these issues are significant. Rather, problems involve fundamental issues of the quality, resolution, and meaning of the basic input data. The scientific challenge for the SBT stock assessment, and for pelagic assessment in general, is to devise data collection and research schemes that would allow accurate estimates of the catch by age from the fishery and indices of stock abundance. These challenges are no different in kind from those facing the assessment of other fishery resources. However, for large pelagic fish the combination of large spatial scales, movements, shared management jurisdiction, and a long life span make this a more difficult problem.

Real improvements in catch data will require long-term commitment by management bodies and the cooperation of industry. Scientists need to develop innovative and practical approaches for obtaining indices of abundance. In the SBT context use of aerial surveys and tagging is being explored. Tagging appears to have considerable potential but requires sufficient resources, and industry cooperation to ensure high and estimable reporting rates. In the meantime there is a need to develop management strategies or procedures which are robust to the levels of present uncertainty, and which are flexible enough to respond to future information.

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SESSION REPORTS

SIZE-AT-MATURITY AND RELATED REPRODUCTIVE BIOLOGY

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SUMMARY

The major issues in swordfish reproductive biology that are relevant to age-structured stock assessment include (1) size-at-sexual maturity, (2) temporal and spatial characteristics of spawning, (3) egg production, and (4) sex ratio (sex-specific size composition) of catches.

The following briefly summarizes the information for Pacific swordfish and makes relevant comparisons with swordfish elsewhere.

Maturity

Several studies have estimated size-at-maturity for Pacific swordfish. Yabe et al. (1959) estimated size at maturity as 150-170 cm eye-to-fork-length (EFL) for female swordfish in the western North Pacific, based on macroscopic appearance of ovaries. Kume and Joseph (1969), Shingu et al. (1974), Miyabe and Bayliff (1987), and Nakano and Bayliff (1992) provided first approximations of size at maturity for female swordfish in the eastern Pacific based on a simple gonad index (ovary weight standardized by length-cubed) and various assumed relationships between gonad index and maturity. At present the best documented size-maturity relationship for Pacific swordfish is that of Sosa-Nishizaki (1990, figure 30), who evaluated swordfish caught throughout the Pacific during 1968-85. These data suggest that females mature at about 140-180 cm EFL. Unfortunately this estimate is not exact because it is based on gonad indices (as defined above, unadjusted for reproductive state) for specimens collected during both spawning and non-spawning periods. Sosa-Nishizaki (1990) provided no data on size at maturity in males. Hinton et al. (1997) recently attempted to validate gonadal indices with egg developmental stages as a means of estimating body size at maturity for swordfish from the Straits of Florida, but as yet no analogous study exists for Pacific swordfish.

Some information exists for size-at-maturity of swordfish in other oceans. Arocha et al. (1994) and Arocha and Lee (1995) have reported on size at maturity of swordfish sampled from the northwest Atlantic fishery where swordfish appear to reach 50% sexual maturity at 179-189 cm and 119-129 cm lower-jaw-to-fork-length (LJFL) for females and males, respectively. Taylor and Murphy (1992) observed similar differences between sexes of swordfish from the Straits of Florida (females: 182 cm; males: 112 cm LJFL). Based on the LJFL-EFL relation provided by Taylor and Murphy (1992), the equivalent EFL values for Arocha and Lee's (1995) and Taylor and Murphy's (1992) respective LJFL estimates are 158 and 161 cm EFL for females and 112 and 96 cm EFL for males. The values for Atlantic female swordfish are within the range of values estimated for female swordfish by Yabe et al. (1959) and Sosa-Nishizaki (1990) in the Pacific.

Spawning

The temporal and spatial spawning patterns of Pacific swordfish are poorly understood based on the distribution of reproductively active adults. Uchiyama and Shomura (1974) observed a large proportion of imminent spawners near the Hawaiian Islands in late spring. Several studies have described Pacific swordfish as spring-summer spawners north of the equator, winter spawners south of the equator, and year-round spawners at equatorial latitudes, with spawning bounded between 25-30°N and 10°S and absent east of 100°W (Kume and Joseph, 1969; Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992).

Recent studies have been consistent in documenting the absence of spawning in the coastal eastern Pacific. Weber and Goldberg (1986) found that all 90 swordfish (23 females, 67 males; range: 133-218 cm EFL) caught off southern California during August-November 1978 were mature but reproductively inactive. The most recent data on reproduction of Pacific swordfish are those of Ramon and Castro-Longoria (1994), who observed no cases of actively spawning fish among 1,696 specimens sampled from the U.S. (California-Oregon) and Mexican drift gill net fishery. These data suggest that the swordfish caught by the two fisheries are reproductively inactive. Although specimens were mostly of adult size (range 80-220 cm, with many fish >180 cm EFL), Ramon and Castro-Longoria's evaluation was limited to specimens caught during July-January because this driftnet fishery is closed during February-June (D. Ramon, NMFS, La Jolla, pers. comm. October 1996).

Larval distribution data provide additional insights into the spawning patterns of Pacific swordfish. Swordfish larvae are most prevalent in equatorial waters west of 120°W at surface water temperatures exceeding 23-24°C (Matsumoto and Kazama, 1974; Nishikawa and Ueyanagi, 1974; Nishikawa et al., 1978, 1985), which suggests a large center of spawning in the tropical west Pacific.

Egg Production

Information on the fecundity of Pacific swordfish is limited. Yabe et al. (1959) estimated that there were 3-4 million eggs in the ovaries of a single, 186-cm EFL female. Fecundities (based on estimated numbers of the largest size class of oocytes present in ovaries) ranged from 3 to 6 million eggs for eight fish weighing 80-200 kg caught near the Hawaiian Islands (Uchiyama and Shomura, 1974).

Arocha et al. (1994) and Arocha and Lee (1995) describe fecundity-LJFL relations for northwestern Atlantic swordfish. For 29 fish ranging between 165 and 245 cm LJFL (145-219 cm EFL) batch fecundity (estimated by the hydrated oocyte method) varied from about 1 to 9 million eggs, and averaged about 4 million eggs for a median-sized (220 cm LJFL, 196 cm EFL) female (Arocha and Lee, 1995, figure 4a). Arocha and Lee (1995) also estimated the spawning frequency of female individuals as once every 3 days over a period of 7 months. However, in their estimate the number of imminent spawners (those fish whose ovaries contained unovulated hydrated oocytes) was standardized by the total number of females in advanced vitellogenesis, which could overestimate frequency of spawning.

Sex Composition and Identification of Sex in Catch

There are few data describing the sex ratios of swordfish from commercial catches in the Pacific or elsewhere. The larger swordfish caught tend to be female, both in the Pacific (Kume and Joseph, 1969; DiNardo and Kwok, in press) and Atlantic oceans (Lee and Arocha, 1993). Hence, sex ratios are increasingly female biased for larger size classes in swordfish catches.

Larger swordfish may be disproportionately female for several reasons: (1) Females may grow larger at a faster rate than males because females have a longer period of relatively fast growth as immatures. Male growth begins decelerating sooner because males mature earlier. (2) Larger female size may also reflect greater longevity, but longevity of swordfish is poorly understood because of the great difficulty in obtaining and ageing rare, extremely large fish. (3) There is also the possibility that female and male swordfish differ in growth rates because of sexual differences in migration patterns and energy budgets (Ehrhardt et al., 1995). Resolving these three nonexclusive possibilities would also greatly aid our interpretation of swordfish age and growth.

A key prerequisite to adequately describing the sex-specific size composition of swordfish catches is developing the capability of sexing dressed carcasses ex-vessel. However, data on sex composition of swordfish caught by the Hawaii-based longline fishery (for example) are presently limited to fish sampled at sea aboard commercial vessels by NMFS observers, and these fish represent 5% or less of total swordfish landings in Hawaii. Once landed, dressed carcasses are unsuitable for sexing by conventional means, and a novel biochemical approach is needed.

In 1994-95 the Honolulu Laboratory funded an initial chemical assay to determine whether vitellogenin (VTG, a protein precursor of oocyte yolk) was present in swordfish muscle tissue and could be used to identify the sex of dressed carcasses. The results of the partially successful preliminary test using polyclonal antibodies are described in an unpublished Administrative Report of the Honolulu Laboratory (DeMartini and Specker, 1996). There are plans to extend this initial study by testing swordfish muscle tissue against a monoclonal antibody (mAB) assay that has been recently developed to teleost VTG (Heppel et al., 1995).

SUMMARY OF CONTRIBUTIONS

Six papers were presented in the session. Two pairs of papers on body size at sexual maturity and on size and sex-composition of catch were presented by Drs. Nelson Ehrhardt and Edward DeMartini, for swordfish in the northwest Atlantic and central North Pacific, respectively. In the concluding paper of the session, Dr. DeMartini reported on ongoing attempts by the NMFS, Honolulu Laboratory, to develop biochemical assays of sex for landed swordfish carcasses. The major findings of each of these papers can be summarized as follows.

Dr. Ehrhardt first summarized results-to-date on size-at-maturity and related reproductive studies of swordfish in the Northwest Atlantic. Patterns were described based on extensive samples (>14 thousand fish) collected throughout the northwest Atlantic from latitude 5°-55°N during 1990-95. Areas of swordfish collection were stratified into three geographic regions—temperate, subtropical, and tropical based on latitude and surface water temperature. The temperate-subtropical boundary was defined as latitude 35°N; the subtropical-tropical boundary was set at ≥23°C. Sexual maturity was assessed based on a compound gonadal measure for fish of each sex. For females, sexual maturation was defined as occurring at an oocyte diameter of 1 mm and a relative gonad index (RGI, gonad weight/body weight) of about 28. Sexual maturity of males was less exactly defined based on testes maturation state and RGI. Based on the incidence of actively spawning females, spawning is seasonal in the subtropics but year-round in the tropics (although primarily January-March, with a February peak). Males are reproductively competent year-round. Female swordfish in the northwest Atlantic have a batch fecundity of 3-9.5 million eggs and are multiple-spawners, with a spawning frequency (estimated from the incidence of hydrated oocytes) of once every 2.4-2.6 days, equivalent to about 80 spawnings per reproductive season. Sexual maturity in females occurs at an estimated median body size (L_{50}) of 175 cm LJFL (equivalent to 154 cm EFL) and an average age of 5 years. The L_{50} of male swordfish in the Northwest Atlantic is an estimated 128-135 cm LJFL. Dr. Ehrhardt's estimates of L_{50} were derived using nonlinear regression fits to the logistic model.

In the question-and-answer session following his talk, Dr. Ehrhardt acknowledged a comment from the audience that the present main spawning center (the Sargasso Sea) of swordfish in the northwest Atlantic may reflect the fishing down of formerly large spawning centers in the Straits of Florida and Gulf of Mexico.

Dr. DeMartini next reported on analogous estimates of median body size at maturity for swordfish taken by the Hawaii-based longline fishery. Swordfish caught by this fishery were sampled at sea aboard fishing vessels by observers of the NMFS, Southwest Region (SWR). Observers sampled about 5,000 (5.5%) of an estimated 89,000 swordfish caught during March 1994-July 1996, primarily between latitude 22°-39°N and longitude 145°-175°W. About 3,500 fish were visually sexed while fish were dressed aboard ship. For 1,017 of the fish for which gonad specimens were collected, sex was verified (shipboard determinations had a 1.5% error rate) and maturation state assessed histologically using standard tissue staining, sectioning, and slide preparation and analysis techniques at the Honolulu Laboratory. For fish of each sex, percentage mature within 5 cm EFL classes was fit to the logistic model using weighted nonlinear regression. Body size at 50% sexual maturity (L_{50}) was estimated as about 80 cm EFL for 416 males (EFL range 57-219 cm) and 143 cm EFL for 601 females (range 63-249 cm). Dressed body weight at L_{50} differed more than sixfold between males (7 kg) and females (45 kg).

Also presented was a table comparing sexual differences in size at maturity for swordfish from the Pacific with analogous estimates for swordfish from the Northwest Atlantic (Arocha et al., 1994; Arocha and Lee, 1995) and Straits of Florida (Taylor and Murphy, 1992). Female-to-male ratios in body weights at sexual maturity ranged from about 3 to 6 among fish from these three regions. For all regions, estimates based on EFL, the standard length metric used in Pacific fisheries, were cross-referenced with LJFL estimates which is the standard in Atlantic fisheries.

New evidence was also presented that swordfish caught by the Hawaii-based longline fishery spawn to a disproportionate extent near (within several degrees of latitude) the Hawaiian islands. Active spawners (those fish that have either spawned within the past several days or that are about to spawn within about a day, as indicated by the presence of hydrated oocytes or post-ovulatory follicles [POFs] in ovaries) were shown to be more numerous in catches near the islands than mature but inactively spawning fish, during the peak spawning period of May-June.

In the question-and-answer session that followed, it was suggested that the incidence of POFs be further evaluated as a measure of spawning frequency in swordfish. It was noted, however, that quantifying POFs aged 1-day and younger would require an assumption of constant ovarian temperature (or data on the variable environmental temperatures experienced by ovaries) while POFs degenerated, which is unlikely (or unlikely to become available).

Dr. Ehrhardt then followed with a description of the sex and size composition of swordfish catches from the Northwest Atlantic. Patterns of spatial and temporal dynamics were again described using the extensive series of catches used to estimate size-at-maturity and reproductive patterns. The same spatial subdivisions (temperate, subtropical, and tropical regions) were used. Females were found to predominate in the temperate region at latitude ≥ 35°N, but only in the summer; neither sex predominates in the subtropical zone. Males and females in general segregate inshore-offshore. Female swordfish in the northwest Atlantic appear to stratify spatially by body size, with larger females farther north and offshore and smaller females to the south and inshore. Larger females also occur in the Sargasso Sea spawning center during the breeding season. Although females are the generally larger sex in all regions, the proportions of females in catches increases monotonically with body size only in the temperate and tropical regions. In the subtropical region, the proportion of females in catches is bimodal, with females predominating only among juveniles and (especially) large adult fish. The sex ratio of swordfish catches thus fluctuates greatly both spatially, temporally, and with body size, although temporal dynamics are less in the tropical versus the temperate region. Dr. Ehrhardt emphasized that the spatially and temporally dynamic size and sex composition of swordfish catches in the northwest Atlantic has major implications for standardizing CPUE and that catches must be correctly stratified by size, sex, and season in stock assessments.

Because of a lack of time, there was no question-and-answer session following Dr. Ehrhardt's second talk.

Dr. DeMartini next summarized available data on sex-specific size composition of swordfish catch for the Hawaii-based longline fishery. Patterns of size and sex composition were inferred using the same series of data used for size-at-maturity estimates, collected by NMFS, SWR observers during the 30-month period from March 1994 to July 1996, for catches made primarily between 22°-39°N and 145°-175°W. The maturity, sex, and size composition of the catch varied seasonally and spatially, particularly with latitude. As noted in Dr. DeMartini's prior talk on size at maturity, most actively spawning female swordfish were caught north of, but relatively near, the Hawaiian Islands at 22°-26°N during April-July. The overall sex composition of catches was indistinguishable from unity (0.495 males: 0.505 females) throughout the range of the fishery during the entire period. Sex ratios (males as percentage of total fish) decreased with latitude of capture; sex ratios were female biased (0.46) north of 26°N, but male biased (0.62) at and below 26°N. Swordfish body size also was positively correlated with latitude, and relatively more large (≥180 cm EFL, ≥94 kg) fish of both sexes (68% females) were caught between 29°-39°N latitude during October-March. Overall sex ratios were male biased at sizes less than 140 cm EFL, equivalent for 140-150 cm EFL fish, and female biased at body lengths greater than 150 cm EFL.

These observed distributions of swordfish size and sex are consistent with two mutually nonexclusive hypotheses: (1) that most small (male) swordfish aggregate at lower latitudes where spawning occurs, and (2) that larger adult (mostly female) swordfish make more extensive feeding migrations into higher latitude waters of the central North Pacific. Another alternative hypothesis (that longline catches are biased for small [male] swordfish at latitudes below 26°N where tunas are targeted by longlines fished during the day at greater depths) cannot explain the geographic patterns in sex ratio. If reanalysis is restricted to swordfish-targeted sets only, sex ratios persist as female biased (0.46) north of 26°N and male biased (0.61) at and below 26°N.

Because of time limitations, the session proceeded to the next talk without discussion.

Dr. DeMartini concluded the session with a talk reviewing past and pending attempts at developing biochemical assays that would allow identification of the sex of landed swordfish. (Identifying the sex of billfish and tuna carcasses is problematic in the Hawaii-based longline fishery, and an innovative biochemical assay is necessary because muscle is the only tissue available from dressed fish.) Vitellogenin (VTG), a glycolipophosphoprotein precursor to oocyte yolk in lower vertebrates, has been extensively described as varying with sex and state of sexual maturation in fishes. Based on prior successful results at identifying the sex of tilapia and striped bass from the VTG present in blood and skin mucus, a collaborative pilot assay of swordfish specimens was conducted in 1995 with Dr. Jennifer Specker (University of Rhode Island).

Observers of the NMFS, SWR, present aboard commercial longline vessels, visually sexed and collected gonad specimens for swordfish marked for subsequent individual recognition at the Honolulu fish auction. Dressed carcasses were stored aboard ship for an average of 10 days at 1-2°C before off-loading. As fish were "tailed" at the auction, both red and white muscle tissues were collected from the caudal peduncle region. About 50 swordfish of a range of body sizes and both sexes, half of which were collected during peak spawning season (May-June) and half during the non-spawning period of January-February, were sampled. Sex was later verified by histological examination of gonads. Tissues were frozen until laboratory analyses.

An initial test determined that tilapia (*Oreochromis mossambicus*) muscle tissue reacted positively to a polyclonal antibody (pAB) previously developed to react to oocyte yolk VTG of tilapia. Chemical reactivity in this and subsequent tests was evaluated using an enzyme-linked immunosorbent assay (ELISA). Reactivities of swordfish muscle tissue antigens were then tested against tilapia VTG antisera. Reactivities differed qualitatively between male and female swordfish. Serial dilutions of extracts from known spawning males did not displace tilapia VTG, but serial dilutions from known spawning females did in a dose-dependent manner. Overall results, however, were only partly successful. Nine of 27 males and 13 of 23 females were misclassified based on the assay. Several factors likely contributed to these results. First of all, variability was inherently large because both immature and mature fish of both sexes, in breeding as well as non-breeding condition, were used. Perhaps more importantly, the antibody used had been developed for another species, and VTGs are known to differ among species. Also, the antibody was polyclonal rather than monoclonal, and polyclonals are by definition more cross-reactive with other proteins.

To resolve these problems, a follow-up study is planned to collect male and female swordfish tissues on a 1997 Honolulu Laboratory research cruise. Blood plasma and serum will be collected in addition to muscle tissues (the latter cold-stored to mimic conditions aboard a commercial vessel). A monoclonal antibody (mAB) specific to swordfish VTG will be developed, and swordfish muscle antigens will then be directly tested against this mAB. The assays will be developed in Dr. Nancy Denslow's laboratory at the Interdisciplinary Center for Biotechnology Research, University of Florida at Gainesville.

Extensive comments and questions were raised at the end of this talk. It was acknowledged that, although mAB assays have the potential to provide very efficient, near-real-time tests, assays for very large protein molecules like VTG must overcome the possibly large (but unknown magnitude) problem of molecule degradation in stored carcasses.

When asked whether the muscle tissues of tilapia control fish were stored so as to mimic shipboard conditions for stored swordfish, Dr. DeMartini explained that they were not because doing so would have had to assume that tilapia and swordfish muscle tissues have equivalent degradabilites.

Dr. DeMartini acknowledged the comment that, because swordfish above a threshold body size (e.g., 210-220 cm EFL) are almost entirely female, body size might be used as another variable when identifying sex, together with polyclonal test results, using multivariate discriminant analysis.

In another comment, it was noted that training cooperating fishers to visually sex swordfish at sea could provide a practical alternative to a biochemical assay for expanding the database on sex-specific catch. This was feasible, it was argued, because observers were able to visually sex swordfish with excellent (98.5%) accuracy, and interested fishermen should be equivalently trainable.

GENERAL DISCUSSION POINTS

In a brief discussion following the session's talks, there was a general concensus that the spatial scale of size-at-maturity characterizations for swordfish in the Pacific should be expanded (e.g., to include the western North Pacific). Despite this need for greater spatial coverage, it was noted that existing size and sex composition data should not be extended to inappropriately large spatial scales (e.g., extrapolating observations for swordfish caught by the Hawaii-based longline fishery to the western North Pacific).

Both Drs. Ehrhardt and DeMartini wanted to emphasize, and all working group participants concurred, that the size and sex composition of swordfish catches are highly dynamic both spatially and temporally and that this general fact has important implications for stock assessment in the Pacific and elsewhere.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

For swordfish in the northwest Atlantic as well as the central North Pacific, the sex and size composition of catches are spatially heterogeneous and temporally (seasonally, etc.) variable. These dynamics need to be explicitly incorporated in stock assessment models. For this reason, it is imperative that future research focus on identifying the important spatial and temporal strata to be used when partitioning catches by size and sex so as to minimize the variances of estimated catch rates. Identifying important spatial strata necessarily includes evaluating a spatially expanded database on the size and maturity composition of Pacific swordfish catches. Obtaining and analyzing data for swordfish caught in both the western and eastern North Pacific should be high priorities.

Future research should also evaluate the influences of the observed dimorphic body sizes at sexual maturity on sexual differences in average and maximum body sizes and (perhaps) growth rates and longevities. The reproductive and growth biologies of organisms are clearly interrelated; swordfish and other billfishes, because of their extreme sexual dimorphisms, likely represent some of the most important cases where these two types of information need to complement one another when interpreting the fishery implications of life histories.

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AGEING SWORDFISH USING OTOLITHS

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INTRODUCTION

Swordfish otoliths have not been widely used for age estimation because they are not susceptible to resorption; they grow isometrically as fish grow; and they undergo little alteration once formed. As a result, they reflect the fish's response to its physical and biological environment.

Previous work on swordfish otoliths suggested that external features might be useful for age estimation, but results have been inconsistent. Internal morphology of Atlantic swordfish otoliths yielded more consistent results, but sample sizes are small and, as yet, validation has not been accomplished. In general, there has been poor correspondence observed between external ridges and internal structures suggesting that external features are not useful for age determination.

In a recent study by Megalofonou et al. (1995), young-of-the-year (YOY) swordfish were aged from presumed daily increments on their otoliths. Back-calculated birthdates fell within the known spawning season for Mediterranean swordfish, suggesting that this technique is useful for ageing juveniles.

Studies in which otolith ageing has been compared to age estimates from other hard parts have suggested that fin ray ageing and internal morphology of sagittal otoliths generally yield consistent results, at least for young swordfish (Wilson and Dean, 1983; Castro-Longoria and Sosa-Nishizaki, in press; Uchiyama et al., in press).

Presentations

Results of ageing YOY swordfish from the northwest Atlantic were presented by Charles Wilson. Apparent daily growth increments have been counted in transverse sections of sagittal otoliths. Although the daily periodicity of these increments has not been validated, implied growth rates derived from the assumption that they are deposited daily have yielded reasonable results (approximately 6 mm/day over the first 100 days). Based on daily age estimates of fish less than 1 year old, back-calculated hatch dates indicated that spawning occurred year-round with a peak in March and April. Spawning appeared to progress from south to north during spring and summer. As is often the case in daily growth increment counts, the number of daily rings counted between apparent annuli was always less than 365 and generally fewer than 200.

Robert Humphreys presented the preliminary results of otolith microincrement counts on sagittae from 15 juvenile Pacific swordfish (26-154 cm lower-jaw-fork length [LJFL]). In contrast to other studies, the rostral path was utilized for increment enumeration. Rather than sectioning or grinding and polishing, the otolith was prepared by acid etching until the increments were exposed to the surface: a very tedious procedure. Increments were examined via SEM. Results indicated an age of 31-37 days at 26 cm LJFL, 1 year at 114 cm LJFL, and 1.5 years at 131-154 cm LJFL. An average growth rate of 7.1 mm/day within the size range 51-74 cm LJFL exceeds the daily growth rate recently reported for Mediterranean swordfish in this size range.

Richard Radtke presented updated results of otolith ageing and microchemistry. Up to 300 increments were counted between presumed annuli, giving more credence to the daily periodicity of these marks. Strontium-calcium ratios are known to vary with environmental factors including temperature. Thus, it may be possible to use the ratio of strontium to calcium in swordfish otoliths to determine regular annual cycles, such as migrations from low to high latitudes, that might be useful to corroborate otolith ages (Figure 1). Preliminary results from a single fish aged at 14 yrs from otolith internal morphology also had 14 peaks in strontium-calcium ratio.

John Gunn presented the results of radiocarbon ageing of southern bluefin tuna, a technique that utilizes carbon 14 ($_{14}C$) nuclear fallout signatures from bomb testing in the late 1950s and early 1960s to determine the year in which calcified structures were formed. By taking the core areas of otoliths from very old, large southern bluefin and determining the $_{14}C$ level, the date of birth could be reliably fixed. Ages thus determined were much older than previously thought and confirmed otolith age estimates that indicated maximum ages of greater than 40 yrs, rather than 20 yrs as previously determined from vertebrae and tag-recapture age estimates. It is noteworthy that tagging data and vertebral ageing data were in agreement with each other and with otolith data for the first 5 years or so. Tagging data could not resolve the uncertainty of maximum age because long-term recaptures are rarely made.

Steve Campana presented another paper on the use of nuclear fallout signatures to determine the absolute age of fish. Radiocarbon activity in the world's oceans roughly doubled between 1950 and 1970 as a result of the atmospheric testing of nuclear weapons. Through comparison with the $_{14}C$ time series reconstructed from atmospheric measurements and marine carbonates, it is now possible to use the $_{14}C$ activity measured in fish otolith cores as a means of confirming the annulus-based age estimates for those fish. Results for haddock and black drum were reported, which again showed the great utility and power of this technique to determine the absolute age of long-lived fish or fish whose otoliths have been archived so that dates of birth fall on the steeply ascending portion of the $_{14}C$ concentration curve that occurred in the 1960s and 1970s. In both cases, absolute age could be determined to within 1-2 years up to age-22 for haddock and up to age-42 for black drum. These results support the statement that no other age validation technique can confirm the absolute age of long-lived fish species with comparable levels of accuracy.

LOCAL-SCALE SWORDFISH FISHERIES OCEANOGRAPHY

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Frontal systems are hydrodynamic singularities that separate water masses with different thermohaline characteristics and where the spatial-temporal scales at which physical forces operate are in resonance with the scales relevant for biological processes (Fernandez and Pingree, 1996). Temperature fronts are important oceanographic features often targeted by fishermen because they result in high swordfish CPUE. For example, in the western north Atlantic very high catch rates for swordfish occurred frequently within 40 km of temperature fronts associated with the edge of the continental shelf (Podesta et al., 1993). There has been considerable work toward understanding the link between the physical characteristics of fronts and the subsequent impact on plankton biomass and production in oceanic frontal systems, particularly in the north Atlantic associated with the Gulf Stream and the subtropical system (Olson et al., 1994; Fernandez and Pingree, 1996). Observations and models of fronts extending from boundary currents such as the Gulf Stream or the Kuroshio Extension indicate that fronts enhance plankton biomass and production by providing regions of both divergence (upwelling) and convergence (Olson et al., 1994). Specifically, the fronts are characterized as zonal meanders with divergent sites which upwell nutrients leading to enhanced phytoplankton which is advected to convergent sites to support enhanced zooplankton populations (Olson et al., 1994). It is hypothesized that the enhanced zooplankton concentrated at the convergence sites serves as a basis for an enhanced trophic web consisting of micronekton, squid, swordfish, and ultimately the fishery.

The local-scale swordfish fisheries oceanography session focused on two issues. The first was related to the problem of how the fish uses the ocean environment and the corollary issue of how the fishery provides a view into the fish's world. The second addressed the question of how further knowledge about physical-biological-fishery linkages are beneficial to resource management. Both of these themes engendered much discussion. This flow of ideas will be pursued more or less in the manner in which they were laid out at the meeting. Therefore, our treatment starts with swordfish and their oceanic environment, then discusses the issue of how the fishery operates within this same environment, and finally, the thorny issue of how to make use of knowledge in fisheries management.

SWORDFISH AND THE OCEANIC ENVIRONMENT

The talk by D. Olson presented ideas on how swordfish use the ocean environment. Both fronts and topography can be shown to produce aggregation in both the tertiary producers that swordfish prey rely on for food and in the swordfish prey themselves. The conclusion is that it is advantageous for swordfish to find these regions because of increases in available forage. The available thermal, optical, and biotic clues that may allow a sword to seek out fronts were summarized. Most of the ideas can be found in Olson et al. (1994). Some of the ideas have been tested in simple behavior models and are consistent with the available fisheries data. One issue is that as aggressive, acoustically active fish, swordfish may possibly have a large-scale social network that is important for understanding their use of an environment. In other words, swordfish, while avoiding direct contact with each other, may still have a loose network that aggregates them on fronts or along topography. This discussion was illustrated by examples of swordfish tracking by Carey and Robison (1981) in topographic cases in the Gulf of California and in the Gulf Stream front. The talk concluded by considering the types of frontal and topographic environments that are available to swordfish in a basin. Using the North Atlantic longline effort as a proxy for swordfish migrations, the different frontal environments and their characteristics were described. The problem in testing these ideas with fisheries data was the topic of the second talk by G. Podesta and coauthors J. Browder, J. Cramer, and D. Olson. They showed a correlation between high CPUE and proximity to fronts. There is also an apparent relationship between CPUE and canyons, but the frequency of canyons and the resolution of set data make the statistics significant only in the highest quartile. The data available over the early 1990s in the Atlantic does show a definitive set of sets and catch on both the topography; i.e., the shelf break off New England, and in the Gulf Stream.

The two Atlantic presentations were followed by a discussion of the physical setting of the Hawaiian longline fleet by R. Lynn. The frontal geometry north of the Hawaiian islands involves three sets of fronts. From south to north these are the Subtropical Front, northern Subtropical Front, and Subarctic Front. The nature of the two branches of subtropical front and their connection to the Kuroshio to the west are uncertain. The high gradient region of the Subtropical Front commonly includes the 18°C winter isotherm; the 16°-17°C and the 15°C or lower are included in the northern Subtropical and Subarctic Fronts, respectively. The fronts are even more obvious in salinity with the Subtropical Front corresponding to 34.8, the northern Subtropical to 34.4, and the Subarctic to 33.8.

Lynn outlined considerable variability between years in these fronts to the east of Hawaii with a very weak Subarctic Front in 1974. It would be interesting to consolidate data sets including the new World Ocean Circulation Experiment data to consider the temporal variations in these important large pelagic habitats.

The overview of the fronts north of Hawaii was followed by a pair of presentations by M. Seki and J. Polovina on the detailed structure of the Subtropical Fronts in relation to the presence of swordfish north of Hawaii. Both of these talks focused on the nature of mesoscale variability and the distribution of swordfish catches. Seki concentrated on meanders and eddies embedded in the northern Subtropical front. The conclusion, from recent NOAA ship *Townsend Cromwell* cruises, is that the large thermohaline front at 29°N is a site of subduction where cooler more dense transition zone water is subducted below warmer less dense subtropical water. Corresponding to the edges of the fronts a shoaling of the deep chlorophyll maxima from 100 m to 75 m, enhanced surface nitrate values, and high zooplankton abundances are present. The association with swordfish and their primary forage, the squid *Ommastrephes bartramii*, needs to be understood further to complete an understanding of the distribution of swordfish in these frontal regimes.

The second talk by Polovina introduced the use of TOPEX/POSEIDON altimetry to describe the distribution of swordfish in relation to the frontal features. In general there is a relation between CPUE and geostrophic velocities derived from the altimeter data. In particular, high CPUEs occur in proximity to eddies and meanders which constitute the frontal zone. The long-term coverage with the altimeter also provides another tool for considering interannual changes in the frontal zones. As shown by B. Qiu, there is an apparent rise in eddy kinetic energy associated with the fronts over the time frame of the GEOSAT mission in the late 1980s. TOPEX/POSEIDON results suggest a decrease in the mid-1990s to a low in 1996. There are some indications that these changes are associated with variations in the Kuroshio flow. The data suggest that a weakening of the Kuroshio extension may weaken the fronts and the southward flows north of Hawaii and that these conditions correspond to lower swordfish CPUEs. This discussion ended with a short comment on the importance of sorting out swordfish-seamount interactions as a factor that could greatly modify the distribution of populations in regions where there are both seamount and fronts.

In an attempt to quantify the relationship between swordfish and the ocean environment K. Bigelow performed an analysis of swordfish CPUE against nine environmental variables and one fishery variable (number of light sticks). The environmental variables include SST and change in SST, a frontal index and the local temporal change in frontal index, latitude, moonlight, wind, and bathymetry. These were considered in the context of both general additive models (GAMS) and generalized linear models (GLMS). The GAMS analysis was preferred given the nonlinear relationships and it explained 43% of the CPUE variance. The results show that the best catches occur at cooler SST (14°-16°C) corresponding to the region between the fronts discussed above. Catch also increased with increased frontal activity. Best catches followed frontal formation or frontogenesis by around one week. Moonlight led to a increased catch rates while high winds or greater depths corresponded to decreases. The talk ended with a presentation of a reconstructed CPUE time series. This lead to a comment by R. Deriso that one "doesn't want to standardize away some environmental effects because they may correspond with actual changes in the population." This comment on the very significant analysis of CPUE on environmental variables formed one of the major discussion points in the meeting as described further below. Bigelow also briefly discussed similar GLM and GAM analyses of blue shark CPUE concluding that there were major interannual changes and a clear seasonality to CPUE were explained, in part, by environmental and fisheries variables. These comments have interesting interpretation in the presentations of the two speakers who discussed the commercial fishing community.

The next two talks by J. Cook and M. Travis addressed the topic of how Hawaii longliners operate. Travis began with a overview of how fishermen find swordfish. Temporally the effort is seasonal and tied to lunar phase with the first two quarters of the year with full moons traditionally being preferred. The location of sets is typically determined by the experience of previous trips, the positions of other vessels, large-scale SST, and weather. Fishing typically follows the passage of cold fronts in terms of weather. Locally, the fishermen use trial sets, SST sensors on high-tech boats, fish finders, and—on high tech boats—computerized NMARSAT receiver combinations for information handling. The best sets are on temperature breaks consisting of a 5° to 6°F step for a good break. The set is typically on the cold side of the break where the water moves more slowly, dragging the line over the warm water. Travis stated that the consensus is that there have been fewer good breaks in recent years.

Cook's presentation began with the statement that "fishermen are pragmatic and will fish where things work." He then pointed out that the nature of the fishery is highly constrained by regulation in the sense that originally it was concentrated on the topography around the islands, but had to move because of regulations aimed at protection of monk seals. Practical factors also influence the fishery in the fronts to the north. The blue sharks discussed by Bigelow, for example, cause damage by attacking hooked swordfish and ruining them. Therefore, the northwest sectors and the later quarters of the year are avoided by some of the fleet. Cook also said that the problem of squid taking baits increases to the northwest. This problem is also on the increase, perhaps a result of the end of the Japanese drift-net fishery to the west that concentrated on squid. Finally, Cook discussed the issue of high-tech boats and changes in targeting within the fleet. The issue is that the most capable boats often fish only the peak conditions and then switch to another fishery such as the albacore fishery.

The last three talks concentrated on swordfishing along the eastern margin in the Pacific and the southern Indian Ocean. The California Current and Chilean coastal were discussed by J. Svejkovsky and M. Angela Barbier. In both the California and Peru current system swordfish seem to be tied to warm intrusions into the coast. Bottom topography is particularly an issue off California but apparently less so off Chile. Catch maxima occur off capes where warm water approaches Cape Mendocino off California. In the Chilean case, catch depends on position in the banded frontal structure found off the coast with catches ranging from SST of 13° to 20°C with a maximum CPUE between 14° and 18°C. Off Chile the peak in CPUE versus SST shifts seasonally. Around Reunion Island in the Indian Ocean the oceanography is complex with frontal structures associated with the East Madagascar Current and the Agulhas Current. F. Rene discussed their efforts to describe the oceanography around Reunion Island with satellite imagery.

The meeting ended with a general discussion of the goals of fisheries oceanography. J. Cramer restructured R. Deriso's early comment by stating the quandary: if environmental factors are primarily effecting catchability, then CPUE can be adjusted to provide a better stock estimate, and if environmental variations are driving changes in stock density the previous conclusion, is of course, invalid. These questions were probably the most difficult of the meeting. What are we discovering about the fish or the fishery with the data available? R. Parrish questioned how we should think about population model verification in terms of the available data within these questions. One question that seemed to arise is whether the goal in terms of fishery management was a total population assessment or a local fishery impact assessment. In other words, is it important to have a global versus a local assessment when it comes to management?

Throughout the session there was discussion of numerous physical processes and their impacts on the biology and fishery. Dr. Guillermo Podesta helped summarize many of these points by considering temporal scales from seasonal to decadal (Table 1).

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Table 1. Physical variation for a range of temporal scales with biological and fisheries impacts.

Scales	Physical issues	Biological issues	Fishery issues
Synoptic	Frontogenesis	Forage aggregation catchability	Higher CPUEs near fronts?
	Frontolysis		Proportion of sets near fronts?
	Thermocline depth		
Seasonal	Seasonal warming/ cooling	Migration timing/routes	Proportion of habitat fished
	Wind onset/decay	Forage production	Distance to home ports
	Thermocline depth		Top-catching boats moving in and out
Interannual	Changes in Kuroshio Extension strength	Habitat shifts	Proportion of habitat exploited
	Strength of fronts	Changes in availability, catchability	Advances in gear/technology
Decadal +	Regime shifts	Habitat shifts	Change in MSY and spatial distribution
		Carrying capacity change	

BASIN-SCALE SWORDFISH HABITAT ASSESSMENT AND FISHERY DYNAMICS

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INTRODUCTION

Swordfish in the Pacific Ocean have an extensive distribution that ranges from latitude 50°N to 50°S (Nakamura, 1985; Bartoo and Coan, 1989) but exhibit a preference for waters of a considerably narrower range. For example, swordfish reportedly favor areas with a thermal regime of 18° to 22°C and waters in the vicinity of frontal zones, which coincidentally are also regions where the major fisheries tend to operate (Sakagawa, 1989). Unfortunately, beyond the basic descriptive spatial distribution and abundance information gleaned from commercial fishery data, we know little about the dynamics of swordfish populations over the large scale.

Basin-scale assessments of the dynamics of migratory pelagic species involve the incorporation of a myriad of parameters (e.g., biological, environmental, ecological, etc.) both on the spatial and temporal scale. With recent advances in remote sensing technology, large-scale synoptic measurements of physical environmental parameters are easily obtained; biological data, however, still tend to be collected on time and space scales much smaller than what basin-scale analyses require. Analysis of basin-scale dynamics for pelagic fishes fundamentally entails garnering an understanding of the large-scale movement (migration) and stock structure for the species. This working session focused particularly on the former and attempted to address the influence of the environment and the ecology; i.e., the habitat of swordfish on large-scale movement and observed distribution and abundance patterns.

PRESENTATIONS

Swordfish habitat is principally governed by reproductive and ontogenetic strategies, food availability and feeding ecology, and the influence of the prevailing climate and hydrographic conditions on these biological and ecological parameters. Embedded may be large-scale temporal (e.g., interdecadal) variation in the environment that may impact biological and ecological parameters such as spawning and juvenile habitat, carrying capacity, level of sustainable yield, and distribution and abundance patterns of predators and prey and thus require consideration. Recent analyses of historical datasets have provided insight to some of these relationships (e.g., Polovina et al., 1994; Parrish and Mallicoate, 1995). Overview and present status of available information pertaining to these large-scale habitat issues were the focus of the invited presentations.

The session opened with a presentation by Richard Parrish on "Regime scale climatic variations in the North Pacific and implications for highly migratory species." Interdecadal-scale climatic regime shifts were identified for the periods 1966-76 and 1977-88 in the North Pacific. These regime shifts occur in response to the behavior of the Aleutian (atmospheric) low pressure system and are evidenced in winter wind stress patterns over the northwestern and central Pacific Ocean. Regimes associated with the intensification of the Aleutian low (e.g., 1977-88) are characterized by southerly shifts of the maximum wind stress curl, increased recirculation into the interior, cooler sea surface temperatures (SSTs) in the central Pacific, and warmer SSTs in the eastern Pacific. A shift back to the less productive conditions of the prior regime has been observed since 1988 in the western and central Pacific. Albacore catches appear in phase with these long-term climatic regimes.

The Hawaii-based swordfish longline fishery generally operates in the North Pacific Transition Zone (NPTZ), particularly in the vicinity of its associated frontal boundaries. The NPTZ is physically characterized by pervasive mesoscale fronts and eddies (Roden, 1991) and biologically by a distinct regional nektonic fauna that exhibit broad latitudinal migrations (Mishima, 1991; Pearcy, 1991). The interplay between the ecosystem, swordfish population, and the fishery is not clear but undoubtedly is a critical piece of the puzzle in developing our understanding of the swordfish resource dynamics. The two ensuing presentations by Michael Seki, "Diet and role of feeding ecology in observed North Pacific swordfish distribution and catch patterns" and William Pearcy, "Assessment of species associations with swordfish from large-scale driftnet fishing operations" provided insight into the ecosystem structure and the role of swordfish in the ecosystem from a basin-scale perspective.

Seki presented evidence supporting the a priori hypothesis that the seasonal cycle of peak swordfish catches by the fishery during the winter-spring months in the vicinity of the Subtropical Frontal Zone (STFZ) may be a consequence of increased swordfish catchability caused by increased food availability in the form of spawning aggregations of seasonally migrating NPTZ nekton, such as the flying red squid, into the region (e.g., Gong et al., 1993; Murata and Hayase, 1993). Support for this argument came in the form of comparative catch and distribution patterns of swordfish from the concurrently operating 1990-91 commercial Asian high-seas driftnet fisheries and the Hawaii longline fishery, preliminary results of ongoing swordfish diet studies which identified flying squid and pomfrets as principle prey species, and catch and distribution patterns of flying squid and pomfret from the aforementioned driftnet fisheries. Additionally, seasonal north-south movement patterns of the prey species that hypothetically set the framework for the swordfish forage base were reviewed.

Pearcy reported on broad scale species associations among common epipelagic nektonic North Pacific fish and squid species with an emphasis toward relationships involving swordfish. Commercial driftnet fisheries data and gillnet catches from Hokkaido University research vessels were subjected to a multivariate statistical approach (detrended correspondence analysis [DCA]) to identify associations. Overall, distinct north-south trends in species composition were evident but did not exhibit any abrupt faunal changes across regions; i.e., a spatial continuum of species composition exists latitudinally. Swordfish in general were taken in very low numbers and catches were dispersed over the broad expanse of the area sampled. The DCA analysis did not reveal any strong associations, a result not unexpected for an opportunistic apex predator possessing broad ecological requirements. In the analysis of the smaller meshed (mesh size $<$ 130 mm) squid targeting fisheries and the Hokkaido research data, swordfish appeared oriented with species favoring warmer water, lower latitudes, and to a degree, more western longitudes. Not surprisingly, species associated in this grouping included subtropical species such as striped marlin, shortnose spearfish, albacore, skipjack tuna, and dolphin fish (mahimahi). In contrast, swordfish were most removed from the subarctic resident salmonid fishes. In the large mesh fisheries (mesh size $\geq$ 130 mm) that targeted billfishes and tuna, swordfish did not exhibit any strong patterns; DCA scores tended toward the center of the ordination.

The "Status of the U.S. tag-and-release program and swordfish movement" was updated by Christofer Boggs and John Gunn. A total of 422 swordfish have now been tagged and released by the Hawaii-based longline fleet in waters north of Hawaii. There have been four recoveries, two within 400 nmi of their release point, and two about 900 nmi or more ENE toward the U.S. West Coast. Interestingly, the two former fish recaptured in relative close proximity to their release site were also recaptured within nearly a week to the year of their tag-and-release. The latter recaptures in the eastern Pacific were tagged later in the fishing season and recovered "out of cycle" several months removed from time of tagging. These limited data lend support to the concept that pelagic fishes possess an inherent homing capability that allows them to return to the same general vicinity on annual cycles (e.g., Pepperell, 1990). Future efforts in the tagging program will concentrate on increasing the number of conventional fish taggings and continuing the development of and ultimately the employment of archival tags. Gunn briefly presented the core package of an archival tag. Putting together an archival tag package basically consists of three parts: a good anchor [for the tag], hydrodynamics, and the building of the unit.

To gain insight into the distribution of immature juveniles, Jean Cramer and Donald Kobayashi reported on the catch of undersized, subadult swordfish in commercial pelagic longline fisheries. In "The effect of environmental variation on the density of swordfish discarded by U.S. longline fishermen," Cramer examined longline catch data from commercial vessels that landed swordfish in the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico during 1991-95. The data set includes information on swordfish discarded by reason of suboptimal size (i.e., juvenile) or due to shark damage. Maps depicting areas of highest encountered discard levels illustrated the relationship between topography and oceanography on discard density. Highest discarding tended to occur around the canyon dropoffs in the Gulf of Mexico, in the area of the Gulf Stream off the southeast Florida coast, and in the vicinity of the Charleston Bump where a quasi-stationary, cyclonic eddy tends to exist.

In the companion presentation, "Subadult catch, discard, and damage of swordfish in the Hawaii-based longline fishery: a preliminary investigation of spatiotemporal patterns and environmental relationships," Kobayashi examined swordfish discards as documented in the Hawaii-based longline fishery logbook and observer programs. Concurrent analysis of the two data sets enabled differentiation of discarded fish damaged by sharks from the total discard, thereby allowing an estimation of the total percent of subadult discard. A dichotomous relationship in the subadult proportional composition of total swordfish catch was also noted between nighttime sets employing light sticks and daytime sets without light sticks. Subadult swordfish make up about 71% of the total swordfish caught in nighttime sets as compared to only 19% of the total swordfish in daytime sets. Areas of high catch rates of subadults generally corresponded with areas of high overall catch-per-unit-effort (CPUE).

Distributions of xiphiid larvae and sexually mature fish with developed gonads provide clues toward regions which may be targeted for spawning. For example, although a broad band from about latitude 31°N to 25°S in the Pacific is generally classified as reproductive habitat, smaller, seasonally variable, localized regions of heightened spawning activity can be identified (Kume and Joseph, 1969; Nishikawa and Ueyanagi, 1974; Uchiyama and Shomura, 1974; Grall et al., 1983; Nishikawa et al., 1985; Sosa-Nishizaki, 1990). In the final presentation of the session, Robert Humphreys rendered a "Review of larvae and juvenile distributions with inference towards swordfish spawning habitat."

As Humphreys reported, most young stages of swordfish have historically been collected with plankton nets, surface dip nets, or from the stomachs of larger predators. Successful captures with nets generally are made at the ocean surface, specifically in the upper 30 cm (e.g., neuston) surface layer during daylight hours and adjacent to areas of steep temperature and salinity gradients. Early life stages appear bound by a minimum SST of 24°C, but otherwise may be caught in a broad 24°-29°C temperature range. Year-round spawning in the tropical-subtropical western Pacific is supported by the capture of newly hatched larvae in regions such as off northwest Australia, north of Papua New Guinea east of Mindanao, and the central equatorial region throughout the year. In other regions such as in the central North Pacific and around Hawaii spawning appears seasonal, namely in the spring and summer. A conundrum exists in the eastern Pacific where there has been a total void in the collection of swordfish early life stages.

SUMMARY

The scope of this session was to spotlight these large-scale habitat issues with an ensuing discussion focusing on means to better grasp the habitat requirements for reproductive, ontogenetic growth, foraging strategies and the role each plays in basin-scale swordfish movement, distribution, and abundance. Open discussion of the working group reinforced the idea that we need to think in basin scale when assessing swordfish habitat issues. There is limited use in local or regional studies, especially when such results are used to generalize over the larger swordfish population. International gatherings, such as this meeting, provide a good vehicle towards maintaining and achieving the goal of a large-scale assessment.

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STOCK STRUCTURE

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INTRODUCTION

Knowledge of stock structure is essential for the assessment and management of swordfish in the northern Pacific and elsewhere. At least six different types of evidence are potentially suitable for stock identification, (1) spatial and temporal patterns of CPUE, and (2) direct evidence of spawning grounds based on the distribution of adult spawners (e.g., near the Hawaiian Islands for swordfish taken by the Hawaii-based long line fishery: data presented by Dr. Edward DeMartini in the Reproductive Biology session) or on collections of larvae and juveniles (discussed by Robert Humphreys in the morning joint Biology-Oceanography session). Other types of evidence include (3) various indirect evidence of different birthplaces (elemental body composition related to chemically different environments, meristic counts that reflect, for example, different water temperatures during early development); (4) morphometric evidence for genetic differences; (5) biological (parasite) or man-applied tags as indicators of past locations and movements (findings to date for man-applied tags summarized by Dr. Christofer Boggs in the morning joint session); and (6) evidence quantifying extent of genetic differentiation. While genetics can theoretically provide the most direct evidence of stock structuring, the other types of evidence are still relevant and potentially useful (Pawson and Jennings, 1996).

A brief summary of the information available for swordfish in the Pacific follows. For comparison, I mention findings for swordfish in other oceans.

CPUE

Sakagawa and Bell (1980), Bartoo and Coan (1989), and Sakagawa (1989) first acknowledged the possibility of multiple swordfish stocks in the Pacific associated with fishing grounds in the western-central North Pacific, eastern Pacific, and western South Pacific. Sosa-Nishizaki and Shimizu (1991) subsequently described in detail four centers of abundance for swordfish in the Pacific (off Japan, Baja California, western South America, and eastern Australia-northern New Zealand), on the basis of spatial and temporal patterns of CPUE from the Japanese longline fishery for the period 1952-85. Sosa-Nishizaki and Shimizu (1991) suggest that these four catch foci could be centers of unit stocks.

Catch data for swordfish elsewhere also suggest stock structuring. Swordfish in the Atlantic apparently comprise two (eastern and western) stocks, distinct from another stock in the Mediterranean (ICCAT 1987). Prior to recent genetics studies, evaluations for Atlantic and Mediterranean swordfish were based on a combination of tag-recaptures and the distributions of longline catches, spawning adults, and larvae (Skillman, 1989).

Elemental Composition

Since the recent development of sophisticated techniques like inductively coupled plasma mass spectroscopy ICPMS, the elemental composition of sagittal otoliths has been successfully characterized for a small, but phylogetically diverse, number of fisheries species (Kalish, 1990; Edmonds et al., 1991, 1992; Gunn et al., 1992; Camapana et al., 1994, 1995). "Elemental fingerprints" are the chemical signatures of individuals that reflect their location of origin (birthplace) or subsequent movements. Application to pelagic species may be limited, however, by reduced scope for differences in chemical signals throughout species' migratory routes that, although broad, span chemically homogeneous environments. To date, the only pelagic species that has been examined with any success is skipjack tuna, *Katsuwonus pelamis* (Ianelli, 1993).

Meristics

Meristics (discrete counts of repeat elements such as fin rays) has been successfully used to distinguish fish stocks based on either genetic or environmentally induced traits, but usually the latter (Pawson and Jennings, 1996). For swordfish, preliminary data indicate differences in dorsal and anal fin ray counts between fish longlined on Honolulu Laboratory research cruises in the equatorial versus north central Pacific. These differences in meristics likely reflect different water temperatures during early development (and perhaps different spawning areas) because fin ray counts in larval swordfish are established at body lengths < 1.5 cm (Potthoff and Kelley, 1982). Like studies of elemental composition, however, observations of meristic dissimilarities cannot refute the possibility that fish with geographically divergent birthplaces are members of a single stock, as is likely the case for highly migratory pelagic fishes.

Morphometrics

Morphometrics (the measurement of continuous morphological variables) has been used to differentiate among fish stocks (reviewed by Campana and Casselman, 1993). An excellent recent example is the study of hoki (*Macruronus novaezelandiae*) by Livingston and Schofield (1996), in which two stocks were identified by multivariate analyses of head and otolith shapes. Successful application of morphometric measures assumes a significant genetic component to the observed variation, however, and may have limited use for pelagic species if the phenotypic component of variation is overwhelmingly large.

Tagging

Fewer than 500 swordfish have been tagged and released in U.S. Pacific fisheries; to date only six fish have been recaptured. Some large displacements have been observed, and these include several fish that traveled from the central to the eastern North Pacific (D. Holts, NMFS La Jolla Lab., pers. comm., January 1997). To date, too few recaptures have been made to justify speculation on movement patterns. The difficulty and present high cost of tagging sufficiently large numbers of viable swordfish may prevent describing the stock structure of swordfish in the Pacific based solely on empirical movements data.

Tag-recapture data for swordfish from the harpoon and longline fisheries in the western North Atlantic indicate broad latitudinal movement north and south, but no trans-oceanic movements (Beckett, 1974; Miyake and Rey, 1989).

Parasites

The use of natural body parasites as tags has great theoretical, but lesser practical, value for widely dispersed pelagic species because of difficulty in studying the geographic distribution and ecology of parasites in open-ocean environments (Lester, 1990). The successful parasite tag studies by Speare (1994, 1995) on black marlin and sailfish off Queensland, Australia, however, suggest potential applications in billfish.

There are few data on parasites as tags of swordfish in other oceans. The relative abundance of two congeneric species of monogene trematodes (*Tristoma* spp.), parasites with direct (single host) life cycles that are abundant on the gills of North Pacific swordfish (Frost, 1993), appears to be the most promising parasite to use as an aid in distinguishing among swordfish caught in the western, central, and eastern Pacific. Personnel of the Honolulu Laboratory are presently conducting a feasibility study.

Genetics

Using restriction fragment length polymorphism (RFLP) analysis of the control region of mitochondrial DNA (mtDNA; cytoplasmic DNA that is maternally inherited), Chow (1994) was unable to distinguish haplotype frequencies between western (Japan) and eastern (Baja California) Pacific swordfish. Based on an independent RFLP analysis of mtDNA, Grijalva-Chon et al. (1994) suggested that North Pacific swordfish represent a single genetic stock. A recent study of swordfish allozymes (enzyme products of genes), however, suggests that some stock structuring may exist within the North Pacific (Grijalva-Chon et al. 1996).

Some data exist for stock structuring within the Atlantic Ocean. On the basis of a detailed examination of the mtDNA control region, swordfish are apparently well mixed within the North Atlantic (Alvarado Bremer et al., 1995), but differ between the North and South Atlantic Ocean at latitudes below 5°N (Alvarado Bremer et al., 1996).

Genetics studies on a larger spatial scale indicate stock structuring among major oceans (Alvarado-Bremer et al., 1996). The most recent appraisal of the worldwide stock structure of swordfish, using a specific subregion of the mtDNA control region, has confirmed that genetic dissimilarities exist among swordfish in the Pacific, Atlantic, and Mediterranean (Rosen and Block, 1996). Recent mtDNA research on Mediterranean and eastern Atlantic swordfish (Magoulas et al., 1994; Katoulas et al., 1995) has documented the existence of separate tropical Atlantic and Mediterranean stocks.

The qualitatively different results of past genetics studies on Pacific swordfish might reflect differences in methodologies, sample sizes (precision), or the inherent power (ability to detect real differences) associated with specific statistical tests. It might be informative to compare the results of allozyme, mtDNA, and nuclear DNA analyses within individual fish for swordfish in the Pacific and elsewhere.

There are no published studies of patterns of variation in biparentally inherited, nuclear DNA for swordfish. These might be particularly informative if migration patterns differ between the sexes (Ehrhardt et al., 1995, figure 7), and if this has resulted in different rates of dispersion for maternally and biparentally inherited genes throughout populations.

SUMMARY OF CONTRIBUTIONS

Five papers were presented in the Stock Structure session. The first paper by Dr. Oscar Sosa-Nishizaki reviewed Dr. Sosa-Nishizaki's and others' early studies of swordfish stock structure based on CPUE patterns. Dr. Steven Campana followed with an illustrative sampler of recent research on finfish stock structure using trace element analyses. Dr. Edward DeMartini next described a case study comparing the meristics of swordfish collected in the central North Pacific versus South Equatorial Pacific. The last two papers (by Dr. Seinen Chow and by Drs. Carol Reeb and Barbara Block) dealt with complementary aspects of recent genetics research on swordfish. The major findings of each paper are summarized as follows.

Dr. Sosa-Nishizaki's review of spatial and temporal patterns of swordfish CPUE expanded upon the catch data patterns provided by Sosa-Nishizaki and Shimizu (1991) and incorporated additional unpublished data on spawning patterns summarized in Sosa-Nishizaki (1990). Spawning patterns were deduced from occurrences of larvae and spawning adults (the latter based on the incidence of ripe females with gonadal indices greater than or equal to a defined threshold value). Spawning pattern data reinforced prior conclusions (based on CPUE patterns alone) that there are four apparent stocks in the Pacific: one in the western North Pacific between 25-50°N, east to 140°-150°W; one in the eastern North Pacific off Baja California-mainland Mexico; another in the eastern South Pacific off Chile, centered at 20°S; and a fourth east of Australia-New Zealand to 180°E at 20°-40°S.

In the second talk, Dr. Campana began by documenting the occurrence and environmentally influenced variability of myriad trace elements in fish otoliths (Sagittae). He argued how trace element signatures in these acellular, metabolically inert structures can provide evidence of stock structure, especially when used in conjunction with chemical proxies of temperature history, either with or without qualitatively different types of evidence such as genetics. Dr. Campana then proceeded to describe a number of applied case studies where different types of trace element analyses were used to test specific null hypotheses relating to stock structure. In the first study, whole cod (*Gadus morhua*) otoliths were dissolved and analyzed by solution-based, inductively coupled plasma mass spectroscopy (ICPMS) to provide a trace element spectrum that was then subjected to principal component analysis to reduce dimensionality. Four distinct North Atlantic cod stocks were identified using discriminant function analysis even though gene flow was sufficient to prevent genetics techniques (using allozymes and mtDNA) from discriminating the stocks.

In the second example, trace element data were used to reinforce evidence of stock structuring based on PCR amplified microsatellite (nuclear) DNA fingerprinting for Atlantic cod. Patterns of a single element (Mn) provided evidence for stock sub-structuring that was a temporally stable, hence consistent biological tracer.

In another study attempting to delineate the stock structure of American shad (*Alosa sapidissima*), an anadromous species, among three Atlantic river systems, genetics was unable to resolve river of birth, but elemental composition of otoliths could.

Other (laser-based) trace element analytical techniques were identified as applicable when the specific hypotheses require microscale spatial resolution within individual otoliths. Two recently developed beam-based techniques (ICPMS and particle-induced X-ray emission [PIXE]) are best for microscale trace element analyses. Two types of electron microprobes (energydispersive [ED-EM] and wavelength-dispersive [WD-EM]) are now somewhat dated, although WD-EM is the current method of choice for non-trace element analysis. A case study of Atlantic croaker (*Micropogonias undulatus*) was used to illustrate the successful application of LA-ICPMS for testing a hypothesis of inshore seasonal migration suggested by natural history observations. By sampling otoliths across a transect spanning the first year of growth, a history of trace element composition was detected that was consistent with ontogenetic shifts from coastal to estuarine-riverine environments.

Dr. Campana further suggested that either the solution-based (whole otolith dissolution) or the laser-ablation approaches could be applicable to swordfish studies, depending on which method was required to answer the question being asked. In an answer to a specific question, Dr. Campana explained how differences among putative nursery areas (particularly those in coastal waters) might be detected in young swordfish otoliths using whole otolith dissolution techniques such as ICPMS. Conversely, laser-ablation techniques could be used to evaluate patterns of movement history using individual otoliths of larger swordfish in a less sensitive analysis with greater microspatial resolution. In responses to other questions, Dr. Campana explained how laser-ablation techniques could be used to examine otoliths for evidence of different feeding versus spawning areas, such as in a mixed-stock analysis. The potential intractabilities of very highly migratory populations were acknowledged. Also recognized was the as-yet-unresolved problem of disentangling chemical versus temperature effects on trace element incorporation by otoliths.

Dr. DeMartini's talk on swordfish meristics compared counts of rays in the first dorsal and first anal fins of mostly older young-of-the-year (YOY)-sized (60-90 cm eye-to-fork length) fish of the 1994 and 1995-96 year-classes. Fish of the 1994 year-class were collected in October 1994 from the South Equatorial Current at latitude 2°N, longitude 165°W (about 5° west of the Line Islands) by a Honolulu Laboratory research vessel. Fish of the 1995-96 year-classes were collected by cooperating fishermen of the Hawaii-based longline fishery during October-November of 1995 and 1996 at 21-25°N, 151-162°W. Both dorsal and anal fin ray counts differed between fish from the two regions, as predicted if counts were related to temperature during larval development (i.e., in a manner consistent with different surface water temperatures during development at different latitudes). Modal fin ray counts for South Equatorial Current swordfish were lower (dorsal: 38-40, anal: 11) compared to the respective counts for central North Pacific fish (43 and 14; both $P < 0.001$, K-S tests). Dr. DeMartini emphasized that these comparisons were based on only several dozen specimens for each region, represented only a single series of collections, and need to be repeated on larger temporal and spatial scales. Also noted was that a complementary genetics evaluation, using matched meristics-genetics samples, needs to be continued to resolve whether meristic differences have a genetic component indicative of distinct spawning populations.

The underlying theme of several specific questions and comments was that non-genetic evidence such as meristics has the potential to provide important corroboration of primary (genetic) evidence for stock structuring. It was acknowledged that interpreting such secondary types of evidence can be difficult, especially if inconsistent with genetics findings, but that successful applications exist.

In his presentation, Dr. Chow described recent results of ongoing studies using both mtDNA and nuclear (microsatellite) DNA techniques to evaluate the global population structure of swordfish. Using restriction pattern analysis of D-loop mtDNA, Chow was able to reaffirm previously reported Mediterranean-Atlantic and North-South Atlantic differences. However, even though both mtDNA and nuclear DNA are polymorphic relative to allozyme gene loci, mtDNA has little power to resolve population-mixing hypotheses compared to nuclear DNA. mtDNA thus was unable to detect within-Pacific heterogeneities that become apparent using nuclear DNA data. Using microsatellites, a unique genotype (excessive AA homozygote) discovered in the western South Atlantic off Brazil was temporally unstable (present in one season but not another). This genotype might represent an isolated genetic stock or a transient mixture of fish from the Atlantic and Indian Oceans. Dr. Chow emphasized that additional samples are needed to resolve this issue.

In response to a comment, Dr. Chow acknowledged the distinction between relative frequencies of polymorphisms and the statistical power required to detect a difference in polymorphism frequencies when interpreting the relative usefulness of nuclear DNA and mtDNA.

Drs. Reeb and Block's paper also utilized information from both nuclear (microsatellite) DNA and mtDNA. Analyses of mtDNA was able to demonstrate Atlantic-Pacific differences, with two clades present in the Atlantic but only a subset of one of these clades present in the Pacific. Although mtDNA data were unable to resolve stock structuring within the Pacific, results using nuclear DNA indicated genetic heterogeneities within the Pacific that were temporally variable. Pacific swordfish were described as having maintained less genetic diversity through time than Atlantic swordfish, perhaps because of a founder effect and genetic drift subsequent to a relatively recent bottleneck when swordfish recolonized the Pacific from the Atlantic through the Indian Ocean (the "Out of the Atlantic" hypothesis). Greater genetic differences were observed for swordfish sampled farther east in the Pacific. Swordfish collected from the eastern South Pacific (off Chile) may represent a stock that has genetically diverged from the rest of swordfish in the Pacific. Alternatively, swordfish caught off Chile may be a mixture of migrants from the eastern tropical and western Pacific. Dr. Reeb emphasized the need for replication of nuclear DNA samples to assess the temporal stability of genetic patterns, and for empirical data on fish movements to help distinguish between genetic differentiation and stock mixing for swordfish caught in the eastern South Pacific.

Several comments specific to Dr. Reeb's talk questioned the directionality of stock expansion between Atlantic and Pacific. Dr. Reeb responded that the observed pattern of greater genetic diversity in the eastern Pacific is consistent with evolutionary expectations based on dispersal from the western to eastern Pacific. Also acknowledged was the need to examine sex differences in genetic patterns for swordfish within Pacific regions, a refinement that is now possible to evaluate because nuclear DNA comprises both paternal and maternal contributions.

It was further noted that, like swordfish, a pattern of two Atlantic and one Pacific clade exists for other pelagic fish like bigeye tuna.

GENERAL DISCUSSION POINTS

As initially outlined in the guidelines to session participants, the general discussion focused on (1) assessing the relative benefits and limitations of using other than genetic evidence (principally elemental otolith composition and meristics) as evidence of stock structuring. To a limited extent the discussion also considered (2) the reliability of genetics results (e.g., what statistical power is attainable with typical sample sizes and frequently used tests like heterogeneity Chi-square and "Analysis of Molecular Variance").

Regarding (1), there was a general consensus that the most relevant issue identified—whether the observed genetic heterogeneities between Chilean and other Pacific swordfish represent stock mixing or distinct stock structure—can best be tested using nuclear DNA analyses, complemented by data on elemental otolith composition and meristics, to be provided by matched (same fish) samples. Although the issue of cost required to do so was raised, it was acknowledged that collecting and archiving otoliths for potential future analyses was cost effective.

Regarding (2), incomplete discussion revealed that the relative resolving power of microsatellite DNA (versus mtDNA) is partly attributable to the greater numbers of polymorphic nuclear (versus cytoplasmic) DNA loci available for analysis. Both microsatellite and mtDNA analyses share other, fundamental limitations of sample size (number of fish individuals examined) and the types of statistical tests used.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

To be successful, studies of swordfish stock structure must be multidisciplinary. It is clear that many types of evidence, perhaps none individually conclusive, are required to produce a coherent picture of swordfish stock structure. This appears to be most true for swordfish in the Pacific, where many factors such as great size of the water body and related diversity of oceanographic regimes appear to have resulted in a complex stock structure relative to swordfish elsewhere in the world's oceans.

First of all, additional nuclear DNA studies are necessary. Temporally replicated nuclear (microsatellite) DNA sampling and analyses are needed for swordfish from select regions (the South Equatorial Pacific, the eastern South Pacific off Chile) in order to test whether patterns observed to date are temporally stable. As suggested by Dr. Reeb, using complementary tagging data to describe movements might resolve the issue of whether Chilean swordfish are a mixed or a unique stock.

Extending nuclear DNA studies to early life history stages could prove invaluable. An evaluation of microsatellite DNA patterns is clearly needed for larval swordfish, which represent localized spawning products, for comparison with analogous patterns thus far based primarily on fishery-sized fish. These latter (mostly subadults and adults, plus a minority of YOY and older juveniles) include varying fractions of fish on spawning and feeding migrations, depending on fishing area, in a highly migratory pelagic species like swordfish. A comprehensive evaluation of nuclear DNA patterns in catchables and larvae collected from the South Equatorial versus eastern South Pacific (plus western and eastern North Pacific) could obviate the need for tag-recapture data to distinguish between stock structure and mixing hypotheses for eastern South Pacific fish. A full comparison of nuclear DNA patterns for larvae and catchables also might be used to estimate the amount of mixing among older fish on the fishing grounds.

Secondly, laboratory analyses complementary to nuclear genetics studies are needed. Several types of trace (and non-trace) element analyses, together with meristics and nuclear (microsatellite) DNA studies, appear to comprise the most useful combination of methods. Meristics data have the great advantage of being easy (inexpensive) to collect, and could be used to flag specimens (e.g., from the South Equatorial Pacific and off Chile) for nuclear DNA analyses. If complementary analyses are matched within individual fish, the resulting gain in information would exceed the sum over each analysis.

One logical application of ICPMS technology for helping to describe Pacific swordfish stock structure is solution-based analyses of whole otoliths for pooled YOY juvenile specimens from different Pacific regions. Such an analysis could be used to test whether YOY derive from localized birthplaces.

Another promising application of elemental composition analysis would be the use of electron and laser-ablation microprobes for sampling ontogenetic transects across individual otoliths. The microconstituent tracers of water masses thereby revealed could be used to describe patterns of migratory movement. Microprobe methods are cost effective because they have the added benefit of concurrently testing hypotheses related to age and growth rate validation. Microprobe samples taken at seasonal (within-year) frequencies in hyaline and opaque growth bands could provide information on chemical and temperature signals that are both due to the environment and the physiological state of individual fish. For example, microsampled analyses of isotopic 18O (Kalish, 1991) and elemental Na and K (Fuiman and Hoff, 1995) within hyaline and opaque bands formed at different times of year could, together with marginal increment analysis, resolve whether "annuli" are formed more than once yearly as separate responses to temperature and spawning stress.

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FISHERY STATISTICS AND STOCK ASSESSMENT

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INTRODUCTION

This session addressed current availability and quality of basic fishery data required to assess the status of swordfish resources of the Pacific Ocean; reviewed resource assessment models and recommendations for collection of data, including environmental, in light of available data; and reviewed recent assessments of the swordfish resources of the Pacific.

Various sophisticated stock assessment methods are available to be applied to swordfish; however, only a few have been applied to Pacific swordfish. The most appropriate methods, given available data and information, have yet to be identified.

Presentations at the 1995 meeting of the Working Group for the Collection of Statistical and Biological Information on Pacific Swordfish and the 1996 meeting of the Interim Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean highlighted data requirements of various stock assessment models, identified current shortcomings in various components of these data as applicable to swordfish in the Pacific Ocean, and made recommendations for improvement of data collection and quality. Results of these meetings generally may be summarized as follows.

Catch and Effort

Catch and effort data for some fisheries appear incomplete. Total catch in round weight and in numbers of fish and the associated fishing effort measures are needed from all fisheries harvesting swordfish. These totals should include not only fish landed but also separately identifiable information on discards. In some cases, the reporting strata for catch and effort data are not sufficiently detailed to allow use of various stock assessment techniques. The goal should be to obtain information of sufficient resolution to identify stock structure, estimate catch and effort at such resolution, and estimate the abundance of individual stocks. Information on fleet dynamics, operational and design characteristics of fishing gear, and general environmental features in the region being fished and those influencing set position should be obtained.

Size and Sex Composition of the Catch

Data on the size and sex composition of the commercial catch are rarely collected. Lack of these data precludes use of models that require detailed information on age structure of the population and mortality rates. When possible, length-frequency data should be collected with the temporal and spatial resolution to the date and position of capture and the data collected should include the sex of the individuals.

Biology

Knowledge of the biology of swordfish in the Pacific, including information required to identify stock structure and to estimate basic population parameters required by various stock assessment models, is limited. Examples of this information include such as morphometric measurement data, genetic and reproductive data, and data on aging and growth. Some of these data, such as morphometric data, may be obtained at relatively low cost while obtaining size data. Other data is relatively more costly to obtain, but nonetheless of significant value to fisheries research and stock assessment. Every effort should be made to obtain data so identified.

PRESENTATIONS

Six presentations were made during this session.

(1) Report on the First Meeting of the Working Group for the Collection of Statistical and Biological Information on Pacific Swordfish (Michael G. Hinton)

This presentation reviewed the report of the working group, which is available from Hinton (editor).

The objectives of the working group were to (1) review the current form and status of data collected by various agencies and organizations with interest in fisheries harvesting Pacific swordfish, (2) develop recommendations as to the requisite data for study and stock assessment of Pacific swordfish, and (3) develop standardized data collection procedures designed to obtain these data, which include biological as well as fishery data.

Report recommendations on data/information to be collected were detailed. Fishery data recommendations dealt with catch and associated effort, operational information, technological information, environmental needs, and size data. Several recommended actions by the Working Group were reviewed.

(2) Size Composition of Swordfish in the Pacific (Koutarou Yokawa)

This presentation reviewed the available swordfish length frequency data collected by Japan. There are three sources of information for size data of swordfish caught by Japanese longline vessels: measurements taken at unloading sites; sales slips (weight only) from wholesale dealers at major unloading ports; and onboard measurements undertaken by commercial, training, and research vessels. Coverage rates tended to be low, and prior to 1986, data by sex were sparse. After 1986 about 70 percent of the size measurements were by sex. Length frequency sampling in both the North and South Pacific by research vessels is increasing; however, sampling of the commercial catch is needed.

(3) An Assessment of the Pacific Swordfish Resource Using Stratified CPUE (Norman Bartoo and Atilio Coan)

This presentation reviewed an assessment based on longline CPUE using data from 1952 to 1980. A yearly stratification of the data was employed to select 15% of the 5 x 5 degree squares with the highest CPUE values. The rationale for this stratification was that the high abundance squares represented targeted fishing for swordfish and are repeated year after year. The actual squares used shifted slightly in each year, presumably owing to environmental effects. It was concluded that CPUE has remained in a level trend from 1965 to 1980.

(4) Stock Structure and Assessment of Swordfish Resources of the Eastern Pacific Ocean Using Standardized Catch Rates and Delay Difference Methods (Michael Hinton and Richard Deriso)

This presentation gave evidence of existence of a swordfish stock with its distribution centered in the southern eastern Pacific Ocean (EPO). It was not clear if there was a stock in the northern EPO, but this region was shown to be frequented by individuals which move across the westerly boundary (150°W) of the study. A stock assessment using a delay-difference model indicated that average maximum sustained yield (AMSY) was less than 8,400 mt and that catch rates were above those expected when stocks are at AMSY. The standardized catch rates used in the assessment were developed using fishery catch and effort data and selected environment and oceanographic data.

(5) CPUE Standardization of Pacific Swordfish Using the Data Based on New Format Logbook (K. Uosaki and Yukio Takeuchi)

This presentation showed the results of a General Linear Model (GLM) application to logbook data to identify factors contributing the highest variation which can be used to "standardize" the data. In addition to catches of sharks, tunas, and swordfish, the data contained operational information on main and branchlines, such as number of hooks per basket, bait, etc. Results indicated that swordfish sets were shallower than those for tunas and used squid for bait. Different data transformations were tested. Results indicated that the parameter of number of hooks per basket was sufficient to identify swordfish targeted effort.

(6) Standardizing CPUE of Swordfish in the Pacific-Wide Japanese Longline Fleet Using General Additive Models (Pierre Kleiber and Norman Bartoo)

This presentation showed the result of an examination of the potential of using the relative catch of swordfish and other species as an indicator of targeting when standardizing CPUE data in the Japanese longline data set. Highly significant results were obtained when the results of the ratio of swordfish to tuna in the catch was used. A simulation model was used to investigate if the "targeting" function could be forced to yield false trends in CPUE under conditions where the population of tunas sustained a decreasing or increasing trend over time. The conclusion reached was that under some conditions of increasing or decreasing trends in tuna population, the use of proportions of swordfish to tunas in the catch as an indicator of targeting gave suspect or inaccurate results.

SUMMARY AND FUTURE DIRECTIONS

The participants discussed the importance of the collection of catch (production) data, fishing effort and resultant catch data, length frequency data, and sex ratio data. These data should be collected on as fine a scale as possible because they will be applied to stock level assessments.

The participants recognize the value of the work of the "Working Group for the Collection of Statistical and Biological Information on Pacific Swordfish." The participants would like to see more emphasis on the collection of sex ratio data, as swordfish have sexually dimorphic growth and distribution. The group also encourages future studies to examine sampling protocol including design and sample sizes.

Several catch per unit of effort analyses were presented. It is clear that for future analyses of operational and technical (e.g., gear configuration) data should be collected on as fine a scale as possible (e.g., by set).

It appears that significant advances in assessments of the condition of swordfish stocks (or reductions in the confidence intervals about estimates) obtained using conventional or traditional models will be dependent on improvements in basic data collections. Every effort should be made to get on with the improvement efforts. Significant advances in assessments can always come from "breakthroughs" in methodology.

CRITIQUE OF ASSESSMENT METHODS AND MODELS—IDENTIFICATION OF DATA COLLECTION AND RESEARCH NEEDS

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INTRODUCTION

The aim of this session was to review stock assessment practices as they have been or might be applied to swordfish and to suggest possible approaches to overcome inadequacies in current practice. There were no presentations during this session. In approaching the session's goal, we reviewed characteristics of swordfish and its fisheries that present a challenge to any stock assessment. We then considered the strengths and limitations of various stock assessment methods in relation to swordfish and in relation to the existing limitations in available data on swordfish and swordfish fisheries. Finally, we elaborated a list of suggested improvements to stock assessment models, data, and data gathering practices which, if implemented, should improve our understanding of swordfish population and fishery dynamics and thus lead to more robust stock assessments as well as more wise and prudent fishery development or management decisions.

Characteristics of the Swordfish and its Fisheries

Some characteristics of swordfish carry special implications and challenges for stock assessment:

- Swordfish are mobile and widely distributed, both vertically and horizontally, and it is not clear how different locations are interconnected.
- Swordfish are long lived, and it is difficult to determine age (especially in large/old fish).
- Swordfish live in a complex environment with a potentially complex habitat structure that influences movements, spatial distribution, and productivity.
- Swordfish show sexual dimorphism in at least growth and behavior.
- Possibly there is a complex stock structure.
- The timing and spatial distribution of spawning is complex, with spawning apparently being widespread and nearby continuous in equatorial regions but localized and seasonal in more temperate regions.
- Swordfish are largely unobservable except through the fishery and so they are difficult to survey.
- Characteristics of the fisheries for swordfish also have a major bearing on stock assessment and data collection.

- Fisheries are multinational and include both high-seas and within-economic-zone activities. This results in a mixture of data types and qualities across the range of the swordfish population, and a mixture of management questions that range from local (e.g., local depletion, interactions between nearby fisheries) to population wide.

- Fisheries are multispecies. Swordfish is mostly a significant bycatch in fisheries targeting other species. Even where swordfish is targeted the age/size groups targeted varies, and fishing operations are significantly affected by the catch of other species (e.g., blue sharks).

- Processing of the catch at sea (e.g., gill-gutting, finning, and filleting) limits the usefulness of port and market sampling to obtain biological samples and catch information.

STRENGTHS AND WEAKNESSES OF ASSESSMENT TECHNIQUES

Age-Aggregated Production Models

Strengths:

(1) Relatively limited data requirements (at a basic level total catch and an abundance measure).

(2) Conceptually simple and easily explained.

Weaknesses:

(1) Sometimes do not use all of the available information and so can miss signals.

(2) Cannot account for age/size structure effects, including those related to movements, natural mortality, fishing selectivity, and reproductive output.

(3) Simple models are likely to be misspecified. This is a generic problem and not just limited to production models as age-structured models are also relatively simple (e.g., assume constant natural mortality). Just increasing model complexity will not necessarily solve this problem; there also need to be sufficient data available to support the more complex models.

Age-Based Assessment Methods

Strengths:

(1) Age-based methods have a long history of application, so there is extensive scientific background for their application. Most of the "traps" and weaknesses are well known, even if that does not always allow the detection and correction of some kinds of problems as they occur.

(2) There is great flexibility, and many different types of information can be used in frameworks such as ADAPT.

(3) Age-specific effects can be explicitly included.

(4) Catch-at-age analysis can be applied to length data using the "cohort slicing" technique based on a growth curve rather that direct ageing. This does introduce additional uncertainties, but it can be done and its reliability across known or expected uncertainties tested.

(5) Experience with the Atlantic swordfish assessments shows that age-structured and production models both give similar results. This convergence is encouraging, although it is recognized that both are being driven by the same abundance indices and that the plus group in the age-structured model is very large (i.e., the age-structured and production models have similar conceptual structure) and so reasonable convergence in results is expected.

Weaknesses:

(1) A high level of information and sampling is required to get reliable catch-at-age estimates, and ideally this would include intensive and representative collection of samples for age determination.

(2) Application of age-structured models to Atlantic swordfish required use of a very large plus group (age-5 and older). This has two main negative effects: it reduces the model's ability to explicitly deal with age-structured effects (as in the age-aggregated models), and the numbers at age in the terminal years, which feed into the plus group each year, strongly rely on assumptions about selectivity and are generally not well estimated. This is a very good example of limitations in the data-driving limitations in the model and ultimately the assessment. The Atlantic assessment must use a plus group starting at age-5 because the data are not separated by sex and sexually dimorphic growth is significant beyond that age. If the catch data were separated by sex then the model could use a plus group beginning at age-10 and greatly reduce the problems mentioned above. A simple change in the data available would make a big difference to the quality of the assessment.

Length-Based Methods

There appears to be very limited scope for application of presently available length-based assessment methods to swordfish because of the basic biological characteristics of the species. There is very little information on stock dynamics in the swordfish length frequency distribution alone, and significant auxiliary data (for example, extensive tagging programs or direct determination of length at age) would be needed for successful application of length-based methods.

Spatially Structured Models

A dubious assumption intrinsically built into standard assessment models that do not admit spatial structure is that movements are so fast that all influences are transmitted throughout the population without lags. Current development of spatially structured models promises to overcome that assumption and furthermore to better allow consideration of local depletion effects as well as fishery interaction concerns. The problem with such models is the need for spatially disaggregated fishery data and quantitative understanding of fish movement behavior.

Stock Assessment for Management

A major point of discussion of the adequacy stock assessment models focused on their use in a management context. Assessment models are frequently used as management operational models, so the point estimates of their output are used to directly determine catch levels. Stock assessment models are not derived for, or typically tested for, their performance in providing direct management advice that will lead to achieving desired management objectives. Two related points here are the need to report and present stock assessment advice in a more probabilistic way, so that the uncertainty is more fully recognized, and to develop specific management operational procedures that interface with the scientific output (e.g., the use of reference points and the management actions that should be triggered by them to achieve management objectives). A further step down the path toward robust management strategies is identification and use of management instruments that are in themselves more robust to the details of stock assessment methods, such as limiting fleet catching capacity and use of fish refugia (i.e., fish protection areas or times). The effectiveness of such management measures, or the conditions for their effectiveness, has not been well shown and examination of this would be a good use of the basin-scale models currently being developed in a number of places. Indeed, a repeated theme in discussion was the utility of whole population, basin-scale models as a "test bed" for evaluation of assessment methods and their appropriate structure, complexity, and robustness. This includes determining the most appropriate way of bringing environmental data into the assessment and balancing the opposing risks of missing important environmental effects on the stock versus incorporating them incorrectly or incorporating the wrong ones.

SUMMARY

Discussion of recent experience with assessments in some other fisheries identified the crucial importance of the interpretation of data from the fishery as a measure of population abundance--be it local or overall abundance. It is particularly important to have data covering the whole range of the stock and to utilize all the available fishery information to get this coverage, if possible. Information from all the various parts of the fishery should be included, not just those parts that give the cleanest data. There is reasonable confidence from a variety of studies that most assessment methods will work reliably if these crucial input data correctly reflect fish abundance, and they will not work reliably if the data do not. In the case of swordfish it was recognized that there are significant challenges in achieving the desired level of interpretation of the fishery data. Targeted fishery data are not available across the range of the species, and are likely never to be. The interpretation of fishery data from fisheries targeting other species is always difficult. Moreover fisheries economics, practices, and strategies are very dynamic in the region, and further rapid changes in targeting practices are expected in the future. Thus, there is little prospect of a time series of constant catchability data from the fisheries. From the outset it is recognized that swordfish assessments will involve more assumptions in the interpretation of abundance trends from fishery data than is the case when fisheries are more economically stable, specifically targeted, and cover the range of the species.

Future Directions

In considering possibilities for improvements in swordfish stock assessments, discussion examined both improvements to models and data, but it was repeatedly emphasized that the biggest problem, and consequently the greatest opportunity for improvement in assessments, would be with the data.

Suggested Improvements to Assessment Models

There should be better treatment of spatial structure. All the various model classes of model can be applied in a spatially structured manner, but this is not routinely done despite spatial interactions being a critical issue in swordfish assessment.

There was discussion of the possibility of developing very broadly based, average stock indicators from information taken across the whole stock (i.e., looking to estimate the overall mean rather than a spatially or otherwise disaggregated measure). However, it was recognized that even if possible, this would not address some of the critical management issues that relate to local dynamics and depletion.

There should be better and more objective treatment of model misspecification. Two related issues are involved here. The first is that model misspecification is a significant source of uncertainty, but it is not represented in the usual calculations of confidence intervals. Usual (e.g., bootstrap) confidence intervals are actually conditional on the specified model being correct, but it is highly unlikely that the model is correct. The second issue is the need to incorporate a reasonable range of alternative hypotheses (models) into the assessment, and the challenge is to develop a scientific framework for allowing this objectively. Bayesian methods may provide some approaches for this.

Modeling assumptions made in the absence of adequate data need to be closely examined in that they can result in inadequate, and often over-optimistic, interpretations in many fisheries; for example, the assumptions that natural mortality is constant (rather than age dependent), that movements very rapidly transmit local fishing effects globally (rather than with a spatially structured lag), that fishing catchability is constant (rather than changing with trend), and that all processes are stationary. There is a need to develop more objectively based hypotheses that encompass a reasonable range of possibilities for use when specific data are absent or limited.

The explicit consideration and modeling of fleet dynamics and fisherman behavior was recognized as providing insight into two important areas of the stock assessment. That is, the interpretation of commercial vessel catch rates and prediction of future stock status. Commercial vessel catch rate is strongly affected by the choices made by fishermen as to where, when, and how to fish. Similarly, future prediction of population status is often sensitive to the future age/size-specific selectivity of the industry, and at present most projections simply assume that the future selectivity will be the same as the present selectivity (even though selectivity has clearly not been constant in the past for many pelagic fisheries).

It was also recognized that most pelagic fisheries are essentially multispecies, and they should be assessed in that context. This is particularly relevant in the case of swordfish, which is a significant bycatch rather than a targeted species across most of its range. Fishing operations are targeted in a multispecies environment, and there is increasing development in some important areas of targeting strategies to optimize across a mix of species, rather than the catch of just one species. Moreover, fishing in the pelagic ecosystem is simultaneously taking predators, competitors, and prey, and there is little understanding of what effect (if any) this is having on swordfish population dynamics. It was thought that the most effective approach to this issue in the short term was through the exploration of possible multispecies effects in basin-scale simulation models. The objective would be to determine the conditions under which such effects would be significant for stock assessment and the manner in which significant effects might occur.

A very important issue to emerge from discussion was the need for adequate review of scientific methods and analysis before they are used as the basis of assessment advice. There is a need to follow the general scientific procedure of peer review before acceptance, but in the stock assessment processes of many organizations the time or independent views are not available. There is a balance to be struck between over-hasty acceptance and decision making versus the creation and ossification of dogma. However, it was agreed that a good review process is needed, that time and resources should be allowed for that in assessment processes, and that evaluation/review of methods should include simulation testing with respect to the available data and reasonable alternative interpretations.

There was considerable discussion about how to bring environmental information into stock assessments. It was recognized that this information was important and potentially critical but that incorporating it in an incorrect manner (e.g., false causative explanations, incorrectly specified models) could make assessments worse. It was suggested that these data should be brought into assessments where there was reasonable evidence to support their inclusion but that in doing so two principles should be followed: 1) the mechanisms/ hypotheses involved should be explicitly stated, and 2) the consequences of alternative hypotheses with similar plausibility with respect to the available data should also be brought into the assessment. For example, if an interpretation is provided based on the hypothesis that sea surface temperature affects local vulnerability then, in the absence of information to the contrary, alternative hypotheses, such as the environment causing stock mortality or immigration (i.e., effecting local availability), should also be included.

Suggested Improvements to Swordfish Data

The assessment of swordfish is essentially data limited, and there was hope that the recent U.N. High Seas and Straddling Stock Agreement could be used to improve data coverage and quality, especially through the use of Vessel Monitoring Systems and procedures for improved and verifiable catch and effort data collection. There was also a recognition that developments in tag technology, and especially the use of satellite communicating data-logging tags, could allow practical study of swordfish movements, whereas conventional tags were limited by practical difficulties and low recovery rates.

Detailed specifications of the statistical requirements of fisheries data generally, and the Pacific swordfish fishery in particular, have been provided previously, and these are accepted here (i.e., FAO Fish. Report No. 500 for general requirements and pages 17-24 of the 1995 Working Group for the Collection of Statistical and Biological Information on Pacific Swordfish (M. Hinton, ed.)). Very generally, the data requirements are for all data to be on a fine spatial/temporal scale and to include

(1) Catch and catch-effort
- total catch (including discards)
- fishery operational details
- environmental details

- fish weight in whole weight
- a standard minimum set of data from all fisheries

(2) Size data
- statistically meaningful catch length-frequency sampling
- lengths separated by sex
- specific studies with multiple measurements on the same individuals to intercalibrate different measurement practices
- specific studies to determine morphometrics for stock structure considerations

(3) Tagging
- costly but potentially valuable
- needs a basin-wide program to be effective
- needs good and verifiable recovery program to be effective

(4) Inter-fleet calibration
- a specific study should be mounted in areas where the Japanese and U.S. fleet operations overlap to help standardize catch rate and other interpretations

(5) Ageing
- hard parts for ageing should be collected now, even in advance of certain methods to analyze them
- collection strategies must be statistically meaningful
- mechanisms for the archiving of samples are necessary

Index of Abundance

There is a need to develop and apply methods for fishery-independent indices of abundance. There is a certain fatigue factor in this topic, as it is a need that has been recognized for many years but no solution has yet been found. However, it remains probably the most important uncertainty and the key cause of fishery assessment failures. Consideration of improved data for assessments must include exploration of the value and feasibility of various approaches to development of fishery-independent indices of abundance, while also recognizing that the basic data collection from the fisheries must also occur. Some possible approaches for the development of fishery independent indices of abundance are

- tagging, including use of pop-up data-logging tags,
- surveys based on novel methods (e.g. LIDAR, active and passive acoustics)
- surveys using the fishery (e.g., a fraction of the effort is expended on a statistically based design to provide a more standardized catch rate series, recognizing that this would imply a high level of verification of vessel location and catch).

Basin-Scale Simulation Model

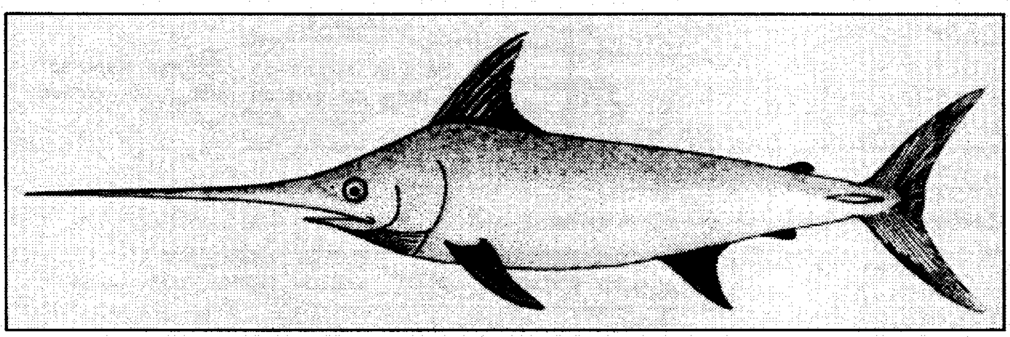
It was strongly suggested that a basin-wide swordfish simulation model be constructed. The model should incorporate spatial structure with movement of both swordfish as well as the more usual population dynamics. The purpose of the model would be testing the adequacy and robustness of stock assessment models and methods as well as the adequacy of temporal and spatial resolutions of data acquisition schemes. The model might also be a platform for pre-testing the likely effects of proposed fishery developments or fishery management actions.

APPENDIX

SECRETARÍA DE MEDIO AMBIENTE, RECURSOS NATURALES Y PESCA

P E Z   E S P A D A

LA PESQUERIA DEL PEZ ESPADA EN MEXICO. UNA ALTERNATIVA DE DESARROLLO.



INSTITUTO NACIONAL DE LA PESCA

FEBRERO DE 1997

LA PESQUERIA DEL PEZ ESPADA (*Xiphias gladius*) EN MEXICO. UNA ALTERNATIVA DE DESARROLLO.

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El pez espada se encuentra todo el año en aguas mexicanas y su pesca se realiza principalmente en la costa occidental de BC. siendo el puerto de Ensenada BC el principal puerto de recepción de las capturas. El periodo de pesca para la flota mexicana comprende de octubre a febrero obteniendo las mejores capturas en noviembre-enero. El recurso se desplaza hacia el sur siendo inaccesible a la flota después de esta temporada. En el pacifico centro-sur de la ZEEM se obtienen capturas de pez espada de manera incidental en las actividades de pesca de atún con palangre aunque actualmente solo opera un barco palangrero en esta zona. Se considera que existe un solo stock del pez espada en el pacifico norte, evidencia sustentada por un pez marcado en el noreste de Hawai y recuperado en California.

La composición de las capturas registradas en redes agalleras en el sur de la península de B.C. indican una mayor proporción de hembras adultas alrededor del 70-80% con una longitud media de 164 cm. y un rango de 6 a 245 cm. (Sosa-Nishisaki *et al.* 1992). Se estima que la composición de edades en la captura comercial de la flota mexicana se encuentra en el rango de 1-9 años (Castro-Longoria R., y Sosa-Nishisaki O. 1994.) correspondiendo alrededor del 80% hembras maduras, las cuales de acuerdo a la condición de las gónadas observadas no desovan en esta zona de captura ya que buscan aguas más calientes para su reproducción . De muestras de tallas de pez espada analizadas por investigadores del Centro Regional de Investigaciones Pesqueras de Manzanillo Col. del Instituto Nacional de la Pesca a bordo de embarcaciones palangreras dirigidas a la pesca de tiburón que operaron en el Océano Pacífico Centro-Sur de México en los años 80`s, indican una talla promedio de longitud furcal de 267 cm. con un rango de 128-334 cm.

A partir de 1983 se prohibe el uso del palangre para la captura de picudos al ser reservados a la pesca deportiva siendo esta una causa de esta disminución, así como la exclusión de la pesca de estas especies en una franja de 50 millas a partir de la línea de costa. Existen otros factores que intervienen en esta disminución de capturas tales como la gran sensibilidad de esta especie a los cambios ambientales como la presencia del fenómeno del El Niño al provocar desplazamientos hacia el norte dejando inaccesible el recurso a nuestra flota, otro factor importante es el esfuerzo de pesca ejercido por las flotas extranjeras fuera de la ZEEM que pudiesen afectar las abundancias del recurso en la zona de pesca de la flota mexicana. A diferencia del manejo biológico de los recursos, que produce un impacto positivo en la condición biológica de las poblaciones explotadas, la mayoría de las medidas aplicadas al pez espada y marlin rayado del Pacífico nororiental han sido el resultado de acciones de grupos políticos, impulsados por la pesca deportiva en un intento de restringir las operaciones de las pesquerías comerciales.

Con estas restricciones nacionales la FAO reporta en 1990 incrementos en la captura de pez espada en el Pacífico ya que siguen operando embarcaciones japonesas fuera de las 200 millas de ZEEM aprovechando el recurso que México esta protegiendo.

El pez espada constituye un recurso nacional cuya explotación debe fomentarse con base en las estimaciones de abundancia y rendimiento sostenible, empleando para ello los equipos, métodos y regímenes de pesca que, de acuerdo con la experiencia nacional e internacional, permitan una alta producción de este recurso y sean ecológicamente sanos.

Este tipo de regulaciones, mejor definidas como manejo para objetivos sociales y económicos, han repercutido en los sectores productivos con poco efecto en el estado de los stocks de picudos del Pacífico.

A partir del mes de mayo de 1995 se han recibido en el Instituto Nacional de la Pesca las solicitudes de 10 empresas, que cuentan con 15 embarcaciones para pesca múltiple que solicitan concesión por 20 años para la explotación comercial del pez espada. Algunas de ellas solicitan autorización para continuar empleando la red agallera de deriva, mientras otras prefieren cambiar al uso del palangre de deriva, en busca de mejores oportunidades comerciales en el mercado exterior.

Esta alternativa es más viable de instrumentar considerando la presión mundial sobre el uso de redes de deriva debido a la mortalidad incidental de otros organismos, incluyendo mamíferos marinos y tortugas. Además se esta trabajando para la modificación de la regulación de la pesca deportiva para excluir al pez espada del resto de los picudos considerando la insignificancia de sus capturas en esta actividad.

La Pesquería de pez espada en el Océano Pacífico

La pesquería de pez espada en México se ha desarrollado principalmente en dos etapas, una a través de la pesca con palangre que inició en 1964 y la otra con redes de deriva que inició en 1986. La captura de pez espada en las actividades de pesca deportiva es poco significativa alrededor de 30 organismos al año.

Palangre.

La pesquería palangrera japonesa de picudos ha sido, por mucho, la más importante del Océano Pacífico Oriental (OPO) en cuanto a su duración, cobertura geográfica y volúmenes obtenidos (Nakano y Bayliff, 1990). Las exploraciones japonesas en busca de estos recursos del OPO comenzaron alrededor de 1956 y para 1968 las actividades de pesca se extendían a la mayoría de las áreas tropicales y subtropicales, incluyendo la actual Zona Económica Exclusiva de México (ZEEM).

En 1963 una gran parte del esfuerzo se desplazó hacia el noreste del OPO, donde las exploraciones habían revelado altas concentraciones de marlin rayado (*Tetrapturus audax*), pez vela (*Istiophorus platypterus*) y pez espada, junto con pequeñas proporciones de marlines azul (*Makaira nigricans*) y negro (*M. indica*) (Joseph, 1972). Las mayores tasas de captura para el pez espada se obtuvieron entre las Islas Revillagigedo (19° Lat. N) y la parte sur del Golfo de California, además de la costa occidental de Baja California Sur hasta Bahía Magdalena.

La zona más importante para la pesca de pez espada con palangre en aguas mexicanas comprende el noroeste del extremo sur de la península de Baja California y la boca del Golfo de California, en invierno y primavera (Figura 1). De hecho, en esta zona se han registrado las mayores tasas de captura en el Pacífico nororiental para el pez espada y también las abundancias más elevadas de los Océanos Pacífico e Índico en el caso del marlin rayado, por lo que algunos autores la denominan "área núcleo" (Squire y Au, 1990). Durante el verano y otoño la captura de pez espada descendía y el área de operación se extendía entonces hacia el sur en busca de marlin rayado, desde Bahía Magdalena y Cabo San Lucas, hasta las Islas Revillagigedo.

El esfuerzo pesquero comenzó a ejercerse de manera sustancial dentro del área núcleo en 1964 y mantuvo continuidad en su magnitud hasta 1976. A lo largo de ese lapso la CPUE del pez espada se comportó relativamente estable (Gráfica 1a).

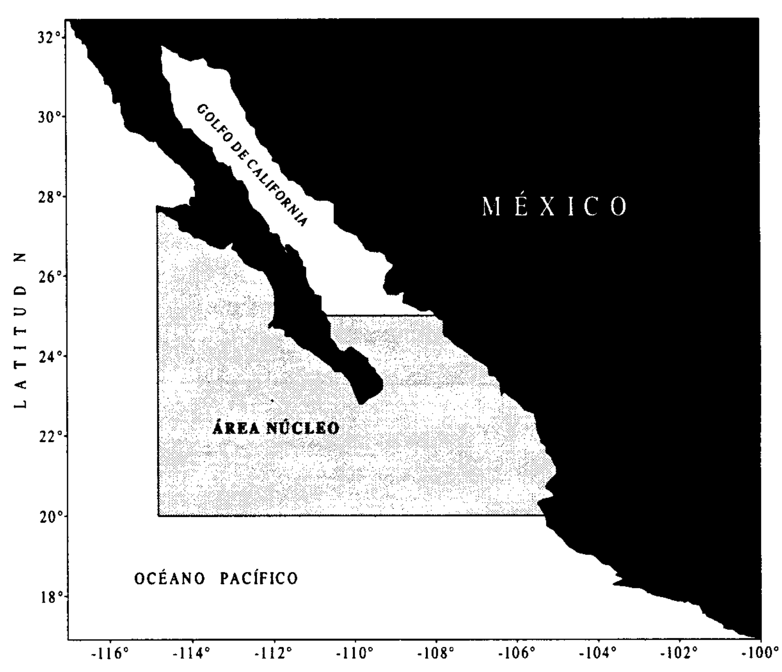
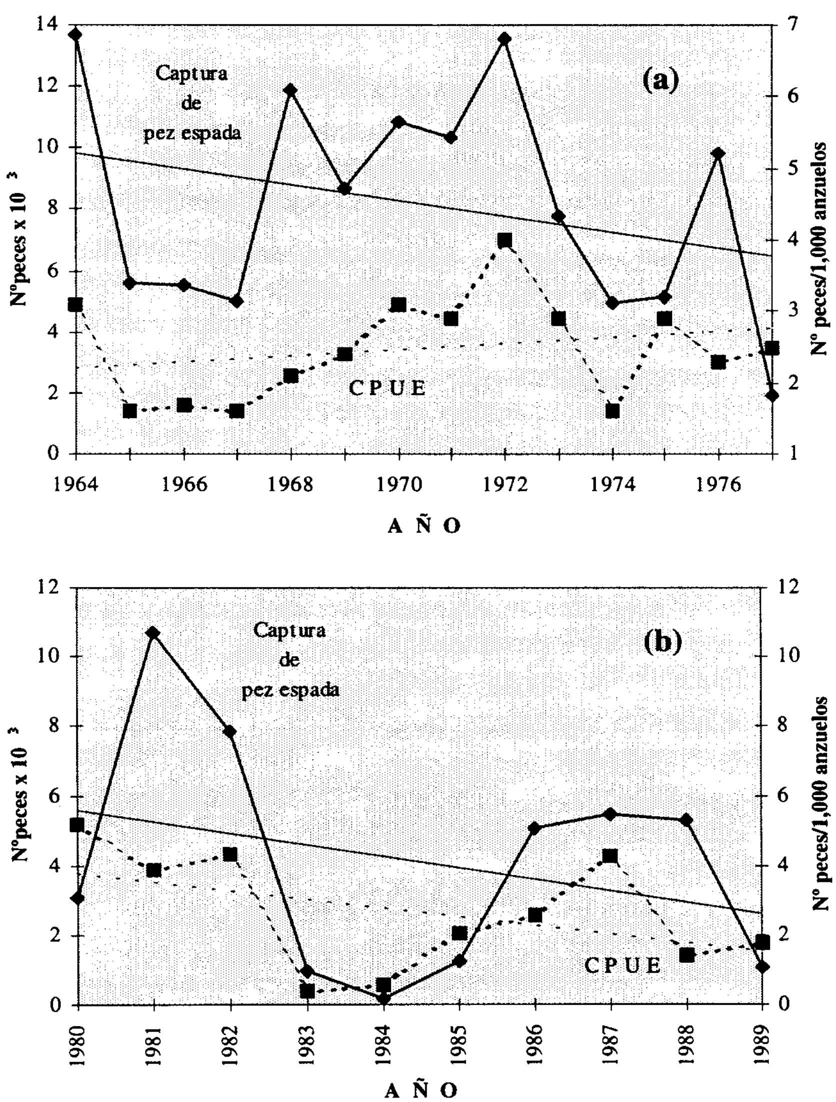


Figura 1. Área núcleo de mayor abundancia de pez espada en el Pacífico nororiental (modificado de Squire y Au, 1990).

En la siguiente etapa de la pesquería, entre 1980 (cuando se iniciaron las empresas de coinversión) y 1989, el esfuerzo de pesca dentro de la ZEEM presentó grandes fluctuaciones, con un máximo de 3,757,060 anzuelos calados en 1988, capturando 48,022 marlines rayados, 17,750 peces vela y 5,313 peces espada. Esas capturas de marlin y vela constituyeron un récord para el periodo 1980-1989, pero la máxima captura anual de pez espada se dio en 1981 con 10,677 ejemplares (Gráfica 1b).

El Gobierno de México restringió en 1983 el uso del palangre en el Océano Pacífico al decretar la exclusividad de la pesca de picudos a las actividades de pesca deportiva dentro de una franja costera de 50 millas vigente hasta la fecha, lo que provocó el inicio de una nueva pesquería de pez espada utilizando como arte de pesca la red agallera de deriva.



Gráfica 1. Captura de pez espada, CPUE y sus tendencias. (a) Flota palangrera japonesa, área núcleo al sur de Baja California. (b) Flota palangrera de coinversión, ZEEM.

Red agallera de deriva.

La pesquería con redes agalleras en California, cuyas capturas están integradas fundamentalmente por tiburones y pez espada, ha presentado una incidencia anual media de 550 marlines rayados y proporciones imprecisas de marlin negro (Hanan *et al.*, 1993).

La flota agallera mexicana que opera frente a la costa occidental de la península de Baja California desde finales de 1987 obtiene una captura incidental desconocida de marlines (Squire y Muhlia, 1992). Las estimaciones al respecto establecen que la captura total se compone de tiburones (25%), especies varias sin importancia comercial (25%), pez sol (*Mola* sp., 19%), atunes (*Thunnus* sp., 19%) y el restante 12% corresponde al pez espada, que es la especie objetivo de esta pesquería (Sosa *et al.*, 1992).

El uso de las redes agalleras de deriva es una innovación relativamente reciente en la pesca mexicana de picudos. Las restricciones impuestas en 1983 al uso del palangre dentro de la ZEEM y finalmente la cancelación de este tipo de permisos en 1990, promovieron el desarrollo de la actual pesquería mexicana con redes agalleras de deriva, que inició su actividad en 1987.

En 1992 la flota agallera mexicana estaba integrada por 27 embarcaciones con permiso, de las cuales operaron 24 y en 1995 esta cifra descendió a 22 barcos. Un factor en esta reducción es la tendencia a la baja de los precios en el mercado exterior para el pez espada capturado con redes agalleras de deriva, en comparación al que se pesca con palangre (Sakagawa, 1994). Las embarcaciones son de tipo camaronero y atunero con las adaptaciones propias para esta pesquería.

La flota opera a lo largo de la costa occidental de la península de Baja California, entre las latitudes 21° 30' N y 32° 20' N, es decir, básicamente en las mismas zonas antes frecuentadas por los palangreros. Aparentemente la mayor actividad pesquera se realiza de septiembre a enero en 2 áreas, una al sur de Punta Eugenia hasta los 23° N y la otra desde el paralelo 30° N hasta el límite norte de la ZEEM (Castro *et al.*, 1995).

Estimaciones publicadas sobre la producción de esta pesquería difieren ampliamente entre sí. Castro *et al.* (1995) reportan una captura mínima de 100 tm en 1988 y una máxima en 1993 de 700 tm. Sin embargo, Squire y Muhlia (1992) presentan datos que oscilan entre 900 y 1,080 tm de producto en presentación de filetes, equivalentes a un rango de 1,170 a 1,404 tm de peso entero.

La incertidumbre en el monto del esfuerzo pesquero y de las capturas totales, aunado al desconocimiento de su composición específica relativa, impide la estimación de la mortalidad por pesca causada al grupo de especies que integran la porción mayoritaria de las capturas (tiburones, atunes y otros escómbridos, istiofóridos, peces varios) y consecuentemente se dificulta evaluar el impacto ecológico sobre sus poblaciones.

Pesca deportivo-recreativa.

La pesca deportivo-recreativa que se realiza desde el sur de California hasta Perú obtiene una captura de picudos de magnitud indeterminada. En el OPO se presentan también capturas incidentales de picudos en la pesquería de atún con red de cerco. De acuerdo a datos de las bitácoras de observadores a bordo de la flota cerquera del OPO, aproximadamente el 9% de los lances efectuados frente a Centroamérica han registrado capturas de picudos (Squire y Muhlia, 1992).

El pez espada es uno de los trofeos de pesca deportiva más buscados, sin embargo el número capturado anualmente en la ZEEM es muy escaso y similar al reportado para la región sur de California, que en promedio es de 29 peces espada por año (Anónimo, 1981).

Monitoreo de la Pesquería

La colecta de información se lleva a cabo a través de avisos de arribo de las embarcaciones de pesca una vez que concluyen cada viaje de pesca en el cual se incluyen datos sobre días de pesca, captura de organismos en peso y número tanto de peces espada como otros organismos.

Se iniciará un programa de observadores a bordo de las embarcaciones de pesca con la finalidad de obtener mayor información sobre esta pesquería.

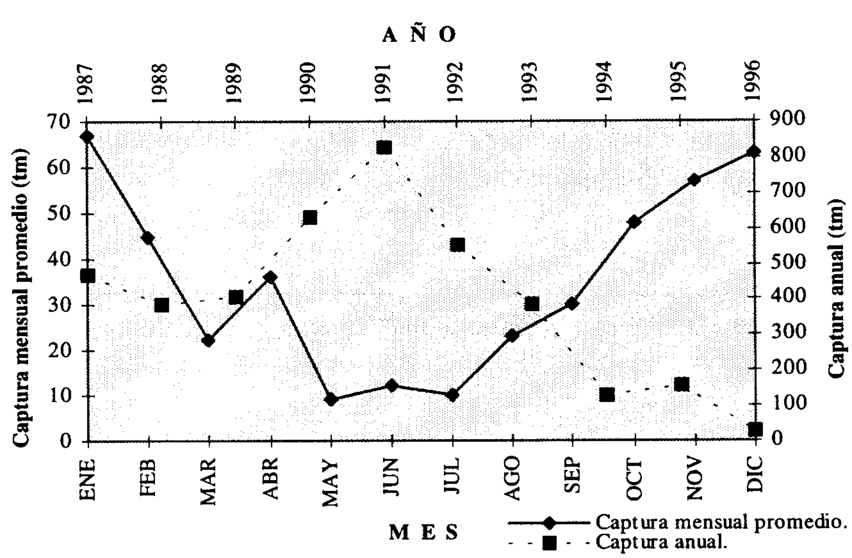
Existe también como fuente de información las bitácoras de los patrones de pesca en donde se lleva un registro diario de las actividades de pesca en cada uno de sus viajes.

Algunas Instituciones académicas realizan investigaciones diversas sobre especies de pico a bordo de embarcaciones comerciales y de ellas generan información relevante sobre el conocimiento y biología de estas especies.

CAPTURAS

La pesquería registra capturas irregulares a lo largo de su historia que inicia en 1964 a través de empresas de coinversión México-Japón utilizando el palangre como arte de pesca permitido, presentando las máximas capturas en 1964 y 1972 con 13,519 y 13,677 individuos respectivamente. En 1976 se capturaron 9,821 peces y a partir de esa fecha inicia una marcada disminución en las capturas (Gráfica 1a).

En 1986 reinicia la actividad de pesca de pez espada, ahora con redes agalleras de deriva obteniendo un pico de captura en 1991 con alrededor de 828 toneladas, estas capturas han ido declinando registrando 131 y 154 toneladas en 1994 y 1995 respectivamente (Gráfica 2).



Gráfica 2. Captura mensual promedio (1987-1995) y captura anual de pez espada de la flota agallera mexicana (1996: datos preliminares enero-junio).

CPUE

Palangre

El pez espada del Pacífico oriental ha mostrado una CPUE estable desde 1965 y se estima que tiene capacidad para mantener un rendimiento anual de 35,000 peces, equivalentes a 2,800 tm (Bartoo y Coan, 1989; Joseph, 1981). Ciertos porcentajes de esta cantidad han sido capturados en los años recientes por las flotas agalleras de México y los Estados Unidos, sobre una población aparentemente común.

En el periodo 1964-80, la pesquería palangrera japonesa capturó un promedio anual de 7,273 peces espada dentro del área núcleo de abundancia (Figura 1), con CPUE media de 2.48 peces/1000 anzuelos (Gráfica 1a).

Entre 1980 y 1989, las empresas de coinversión capturaron un promedio anual de 4,090 peces espada en aguas de la ZEEM, con CPUE media de 2.51 peces/1000 anzuelos (Gráfica 1b), valor muy semejante al obtenido por los palangreros japoneses durante 1964-80.

Estos resultados muestran que el palangre es un arte de pesca poco selectivo para la captura de pez espada. Los promedios de producción de 360-640 tm (4,090-7,273 peces) al año, resultan bajos al compararlos con los datos disponibles de la pesquería con redes agalleras de deriva (Gráfica 2).

Sin embargo, conviene recordar que entre 1971 y 1976 la flota palangrera japonesa capturó un promedio anual de 35,000 peces espada en todo el Pacífico oriental, cifra equivalente al rendimiento sostenible estimado. El 26% de esta captura (9,100 peces/año) fueron capturados en aguas de la actual ZEEM, con CPUE promedio de 2.7 peces espada/1,000 anzuelos, con un máximo de 3.9 en 1972.

El esfuerzo de pesca se incrementó de 5 millones de anzuelos en 1961, a 91 millones en 1973, cuando el esfuerzo ejercido dentro de 200 millas náuticas (mn) de la costa de México fue aproximadamente 4 millones de anzuelos, 5.1% del total del OPO en ese año. Se estima que durante el periodo 1971-79 el esfuerzo en la actual ZEEM representó sólo un 7% del aplicado en todo el OPO. No obstante la producción de picudos fue sustancial, superando varias veces la que se esperaría con un nivel de esfuerzo de 7%. Durante 1971-76, los años previos al establecimiento de la ZEEM, la pesquería japonesa obtuvo de esta área el 56% de sus capturas de marlin rayado en el OPO (Joseph, 1981).

El esfuerzo palangrero declinó rápidamente en 1976-77 al establecerse la ZEEM y sólo se incrementó después de 1980, con el otorgamiento de permisos de pesca para empresas de coinversión México-Japón. El esfuerzo frente a la costa de los Estados Unidos fue menor que en aguas de México y principalmente con fines exploratorios (Anónimo, 1980).

Red agallera de deriva.

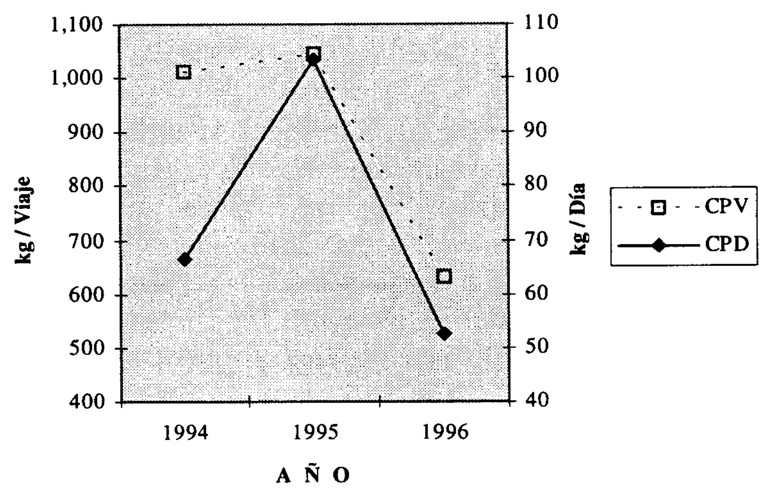
Datos generales publicados sobre la pesquería agallera de México indican que la captura está dominada en un 88% por tiburones, especies varias sin importancia comercial, pez sol y atunes, contribuyendo el pez espada con 12% (Sosa *et al.*, 1992).

Esta selectividad para el pez espada es baja y refleja poca eficiencia en la captura de este recurso.

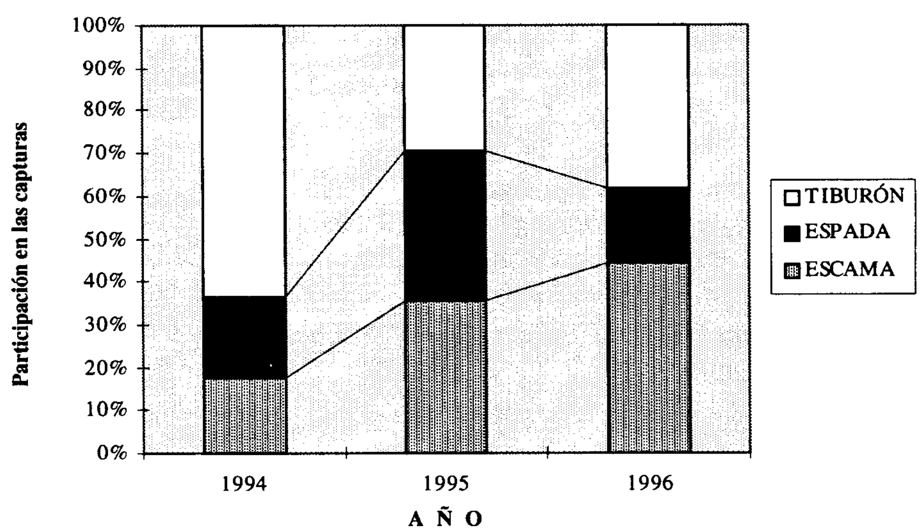
De manera general se puede estimar de acuerdo a la información disponible que en los últimos tres años (1994-1996) se obtuvo una CPUE promedio de 882.16 kg. por viaje de pesca y 71.82 kg. por día de viaje. Es un estimado muy grueso pero se desconoce el número de lances efectivos de pesca (Gráfica 3).

Composición de la captura

Las redes agalleras de deriva causan un impacto de mayor o menor escala sobre las poblaciones de mamíferos y tortugas marinas presentes en las zonas de pesca. Es importante conocer las magnitudes de estos tipos de captura fortuita en la pesquería mexicana. En la Gráfica 4 se muestra la composición relativa de las capturas mexicanas en los años recientes, agrupadas en 3 categorías principales.



Gráfica 3. Captura por unidad de esfuerzo de pez espada (1996: datos preliminares enero-junio). Flota agallera mexicana.



Gráfica 4. Composición relativa de las capturas de pez espada , agrupadas en 3 categorías principales (1996: datos preliminares enero-junio). Flota agallera mexicana.

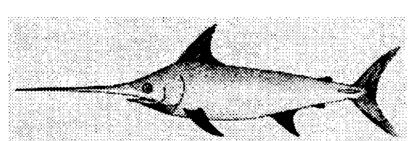
En las capturas de la redes agalleras de deriva predominan los tiburones oceánicos, de los que se sabe poco respecto a la condición biológica que guardan sus poblaciones. Esto es motivo de preocupación porque a nivel mundial las pesquerías de tiburones han mostrado ser frágiles, tendiendo a declinar marcadamente o colapsarse de manera súbita (Compagno, 1990). Existen ejemplos de las formas en que las redes agalleras de deriva pueden afectar a los stocks de tiburones. La mayoría de los tiburones makos y zorros capturados en el sur de California eran juveniles y la talla media de estos últimos disminuyó 21% entre 1982 y 1991. El tiburón azul formaba parte de las capturas, pero al ser descartado en el mar sin registrarlo en las bitácoras, se ignora cuál haya sido su mortalidad por pesca (Hanan *et al.*, 1993).

La red agallera de deriva, al ser un arte de pesca pasivo que opera interceptando el paso de las especies que captura, presenta el riesgo potencial de causar lo que se denomina "pesca fantasma", ya que las redes extraviadas o fragmentos de ellas tienen la capacidad de continuar capturando por un tiempo indeterminado, mientras permanezcan en la columna de agua.

Recomendaciones

Se requiere poner en marcha un sistema de recolección de datos en los viajes vía la pesca de la flota agallera de bandera mexicana, con objeto de dar seguimiento a las operaciones y resultados de pesca y estar en posibilidad de realizar la investigación sobre aspectos primordiales de la pesquería como son, entre otros, distribución geográfica y temporal del esfuerzo pesquero, volumen y composición de las capturas, captura por unidad de esfuerzo y estructura poblacional de las especies principales. Lo anterior permitirá conocer la evolución de la condición biológica de las poblaciones locales y en su caso, adoptar oportunamente las decisiones pertinentes para el manejo de los recursos.

Se requiere la presencia de observadores científicos a bordo de la flota, autorizados por la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, para dar seguimiento a la pesquería y obtener la información biológico-pesquera y tecnológica, que permita hacer un aprovechamiento del recurso a largo plazo y obtener el máximo beneficio social de la actividad, con el menor impacto ambiental adverso.



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SECOND INTERNATIONAL PACIFIC SWORDFISH SYMPOSIUM
Agenda

Sunday, March 2

1830-2000 Registration

Monday, March 3

0730-0830 Registration

0730-0830 Breakfast

Plenary Session
Chair: Gerard DiNardo *(NMFS, Hawaii, USA)*

0835 Welcome

0900 General Recent Trends in the Pacific Swordfish Fisheries
Oscar Sosa-Nichizaki *(CICESE, Ensenada, Mexico)*

0920 Recent Status of the Japanese Swordfish Fisheries and Research Topics
Yuji Uozumi *(NRIFSF, Shimizu, Japan)*

0940 Swordfish Fishery in Mexico (1987-1996): Development alternatives
Pablo Arenas Fuentes *(Instituto Nacional de la Pesca, Mexico)*
Presenter: Pedro Ulloa Ramirez *(Instituto Nacional de la Pesca, Mexico)*

1000 Tea and Coffee

1020 U.S. Swordfish Fisheries of the North Pacific
Russell Ito* *(NMFS, Hawaii, USA)*
Atilio Coan, Jr. *(NMFS, California, USA)*

1040 Swordfish Fisheries of Chile
Maria-Angela Barbieri *(Instituto de Fomento Pesquero, Valparaiso, Chile)*

1100 Swordfish Fisheries in the Philippines
Reuben Ganaden *(Bureau of Fisheries and Aquatic Resources, Quezon City, Philippines)*

1120 The Development of the Reunion Longline Swordfish Fisheries: Evaluation and Trend, Market and Trade
Francois Renä *(IFREMER, Reunion, France)*

*Presenter

1140 Swordfish Fisheries in the Eastern Australian Fishing Zone: An Update of Development during 1996
Peter Ward (*Bureau of Resource Sciences, Kingston, Australia*)
Wade Whitelaw (*CSIRO, Hobart, Australia)*

1145 Lunch

1300 Perspective on Atlantic (and Mediterranean) Swordfish Fisheries and Assessments: The ICCAT Experience
Julie M. Porter (*Department of Fisheries and Oceans, New Brunswick, Canada*)

Expert Panel Discussion
Moderator: Raymond Conser (NMFS, Oregon, USA)

1400 ADAPT: A Practical Modelling Framework For Fisheries Stock Assessment
Raymond Conser (*NMFS, Oregon, USA*)

1425 ASPIC: A Flexible Nonequilibrium Implementation of the Logistic Surplus-Production Model
Michael Prager (*NMFS, California, USA*)

1450 Tea and coffee

1510 Delay-Difference Stock-Assessment Models: Application to Swordfish Session
Richard Deriso* and Michael Hinton (*Inter-American Tropical Tuna Commission, California, USA*)

1535 MULTIFAN CL: A Length-Based, Age-Structured Model For Fish Stock Assessment
John Hampton (*SPC, Noumea, New Caledonia*)

1600 Recent Developments and Methods in the Southern Bluefin Tuna Fishery Assessment
Keith Sainsbury, T. Polacheck, N. Klaer, J. Gunn, R. Campbell, W. Hearn, T. Davis, A. Betlehem, A. Preece, and A. Cowling (*CSIRO, Tasmania, Australia*)

1625 Audience Participation - Question and Answer

1900 Reception

*Presenter

Tuesday, March 4

0730-0830 Breakfast

Working Group 1 - Biological Input to Stock Assessment

Session Topic: Size-At-Maturity and Related Reproductive Biology
Chair: Edward DeMartini *(NMFS, Hawaii, USA)*

0840 Review of Background Information
Edward DeMartini *(NMFS, Hawaii, USA)*

0850 Size at Maturity Estimates for Swordfish in the West Atlantic
Nelson Ehrhardt (*Univ. Miami, Florida, USA*)

0905 Size at Maturity of Swordfish in the Hawaiian Longline Fishery
Edward DeMartini (*NMFS, Hawaii, USA*)

0915 Sex-Specific Size Composition of Catch in the West Atlantic
Nelson Ehrhardt (*Univ. Miami, Florida, USA*)

0925 Sex and Size Composition in the Hawaiian-Based Longline Fishery
Edward DeMartini (*NMFS, Hawaii, USA*)

0935 Recent and Pending Chemical Assays to Determine the Sex of Processed Swordfish
Edward DeMartini (*NMFS, Hawaii, USA*)

0940 General Discussion

1000 Tea and Coffee

Session Topic: Ageing Swordfish Using Otoliths
Chair: Oscar Sosa-Nishizaki *(CICESE, Ensenada, Mexico)*

1020 Review of Background Information
Oscar Sosa-Nishizaki (*CICESE, Ensenada, Mexico)*

1030 Ageing Juvenile (YOY) Swordfish-The Atlantic Experience
Charles Wilson (*Coastal Fisheries Institute, Baton Rouge, Louisiana, USA*)

1050 Ageing Juvenile (YOY) Swordfish-The Pacific Experience
Robert Humphreys (*NMFS, Hawaii, USA*)

1110 Recent Developments on Micro and Macro Structure for Ageing Adult Swordfish
Richard Radtke (*HIGP, Univ. Hawaii, Hawaii, USA*)

1125 Radiocarbon Ageing of Southern Bluefin Tuna
John Gunn (*CSIRO, Tasmania, Australia*)

*Presenter

1140 The Use of Nuclear Fallout Signatures in the Determination of Absolute Fish Age
Steve Campana (*Bedford Institute of Oceanography Nova Scotia, Canada*)

1200 Lunch

1300 General Discussion - Interpretation, Validation, and Recent Techniques in Swordfish Ageing Using Otoliths

1445 Tea and Coffee

1500 General Discussion (*continued*)

Session Topic: Ageing Fish Using Other (non-otolith) Hardparts and Size Frequencies
Chair: Nelson Ehrhardt *(Univ. Miami, Florida, USA)*

1500 Review of Age and Growth Based on Methods Other Than Using Otoliths
Nelson Ehrhardt (*Univ. Miami, Florida, USA*)

1515 Use of Fin Rays For Swordfish Ageing - The Atlantic Experience
Nelson Ehrhardt (*Univ. Miami, Florida, USA*)

1530 Use of Fin Rays For Swordfish Ageing - The Pacific Experience
Edward DeMartini* and James Uchiyama (*NMFS, Hawaii, USA*)

1545 Can Swordfish Age be Determined From Radiocarbon in Vertebrae?
John Kalish* (*Australian Natl. Univ., Australia)*; Rodger Sparks and Nicola Redvers-Newton (*Institute of Geological and Nuclear Sciences, New Zealand*); and Edward DeMartini (*NMFS, Hawaii, USA*)

1600 Age Validation
Nelson Ehrhardt (*Univ. Miami, Florida, USA*)

1630 General Discussion - Reabsorption in Fin Rays, Validation and Value of Corroborative Evidence, and Growth Modeling

1800 Poster Session

1900 Symposium Banquet

*Presenter

Working Group 2: Fisheries Oceanography

Session Topic: Local-Scale Swordfish Fisheries Oceanography
Chairs: Don Olson (RSMAS, Univ. Miami, Florida, USA)
Jeffrey Polovina *(NMFS, Hawaii, USA)*

0840 Introduction
Jeffrey Polovina (*NMFS, Hawaii, USA*)

0850 Large Pelagics in Frontal Zone Environments
Don Olson* (*Univ. Miami, Florida, USA*), X.Humston; and Guillermo Podesta, *Univ. Miami, Florida, USA)*

0910 Aspects of Swordfish Oceanography in the Atlantic
Guillermo Podesta (*Univ. Miami, Florida, USA*)

0930 Oceanography of Fronts and Other Meso-scale Features in the North Pacific
Ron Lynn (*NMFS, California, USA*)

1000 Tea and Coffee

1020 Coupling of Physical and Biological Processes in Response to Mesoscale Environmental Heterogeneity at the North Pacific Subtropical Frontal Zone
Michael Seki (*NMFS, Hawaii, USA*)

1040 The Oceanographic Features of the Swordfish Fishery Grounds in the Central North Pacific Based on Satellite Altimetry
Jeffrey Polovina (*NMFS, Hawaii, USA*)

1100 Influence of Environmental Factors on Swordfish Catch Rates
Keith Bigelow (*South Pacific Commission, Noumea, New Caledonia*)

1120 How Fishermen Find Swordfish
James Cook* (*Pacific Ocean Producers, Hawaii, USA*)
Michael Travis* (*NMFS, Hawaii, USA*)

1140 Update on Swordfish Fisheries Oceanography From Other Regions: Eastern Pacific
Jan Svejkovsky* (*Ocean Imaging Corporation, CA, USA*)

1200 Lunch

1300 Update on Swordfish Fisheries Oceanography From Other Regions: Indian Ocean
Francois Rene (*IFREMER, Reunion, France*)

1315 Update on Swordfish Fisheries Oceanography From Other Regions: Chile
Maria Angela Barbieri* (*Instituto de Formento Pesquero, Chile*)

1330 Discussion and Summary

*Presenter

1445 Tea and Coffee

Working Group 3: Resource Assessment and Monitoring

Session Topic: Fishery Statistics and Stock Assessment
Chair: Norman Bartoo *(NMFS, California, USA)*

0830 Opening Remarks/Objective of Session
(Norman Bartoo (*NMFS, California, USA*)

0845 Report on the First Meeting of the Working Group for the Collection of Statistical and Biological Information on Pacific Swordfish
Michael Hinton (*Inter-American Tropical Tuna Commission, California, USA*)

0915 Size Composition of Swordfish in the Pacific
Kotaro Yokawa (NRIFSF, Shimizu, Japan)

0945 General Discussion

1000 Tea and Coffee

1020 General Discussion *(continued)*

Session Topic: Review of Current/Recent Assessments of Pacific Swordfish
Chair: Michael Hinton *(Inter-American Tropical Tuna Commission, California, USA)*

1100 An Assessment of the Pacific Swordfish Resource Using Stratified CPUE
Norman Bartoo* and Atilio Coan *(NMFS, California, USA)*

1130 Stock Structure and Assessment of Swordfish Resources of the Eastern Pacific Ocean Using Standardized Catch Rates and Delay Difference Methods
Michael Hinton* and Richard Deriso *(Inter-American Tropical Tuna Commission, California, USA)*

1200 Lunch
1300 CPUE Standardization of Pacific Swordfish Using the Data Based on New Format Logbook
K. Uosaki and Yukio Takeuchi* (*NRIFSF, Shimizu, Japan*)

1330 Standardizing CPUE of Swordfish in the Pacific-wide Japanese Longline Fleet using General Additive Models
Pierre Kleiber* (*NMFS, Hawaii, USA*)
Norman Bartoo (*NMFS, California, USA*)

1400 General Discussion

*Presenter

1445 Tea and Coffee

Joint Session - Working Groups 2 (Fisheries Oceanography)and Working Group 3 (Resource Assessment and Monitoring)

Session Topic: Uses of Environmental Data in Assessment and Management of Swordfish
Chair: Gerard DiNardo *(NMFS, Hawaii, USA)*

1500 Environmental Variations and the Validity of Stock Assessment of Highly Migratory Species
Richard Parrish (*NMFS, California, USA*)

1530 Uses of Environmental Data in Assessment and Management of Highly Migratory Species
Jeffrey Polovina (*NMFS, Hawaii, USA*)

1600 General Discussion

1800 Poster Session

1900 Symposium Banquet

Wednesday, March 5

0730-0830 Breakfast

Concurrent Sessions

Joint Session - Working Groups 1 and 2

Session Topic: Basin-Scale Swordfish Habitat Assessment and Fishery Dynamics
Chair: Michael Seki *(NMFS, Hawaii, USA)*

0830 Introduction
Michael Seki (*NMFS, Hawaii, USA*)

0900 Regime Scale Climatic Variations in the North Pacific and Implications for Highly Migratory Species
Richard Parrish (*NMFS, California, USA*)

0920 Diet and Role of Feeding Ecology in Observed Swordfish Distribution and Catch Patterns in the North Pacific
Michael Seki (*NMFS, Hawaii, USA*)

*Presenter

0940 Assessment of Species Associations with Swordfish From Large-Scale Driftnet Fishing Operations in the North Pacific
William Pearcy (*Oregon State Univ., Oregon, USA*)

1000 Tea and Coffee

1015 Status of Tagging Programs and Swordfish Movement
Christofer Boggs* (*NMFS, Hawaii, USA*)
John Gunn* (*CSIRO, Tasmania, Australia*)

1025 The Effect of Environment Variation on the Density of Swordfish Discarded by U.S. Longline Fishermen
Jean Cramer* (*NMFS, Florida, USA*)
Don Kobayashi* (*NMFS, Hawaii, USA*)

1050 Review of Larvae and Juvenile Distributions with Inference Towards Spawning Habitat
Robert Humphreys (*NMFS, Hawaii, USA*)

1110 General Discussion

1200 Lunch

Session Topic: Stock Structure
Chair: Edward DeMartini (*NMFS, Hawaii, USA)*

1330 Introduction
Edward DeMartini (*NMFS, Hawaii, USA)*

1340 Stocks Inferred from Spatial and Temporal CPUE Patterns
Oscar Sosa-Nishizaki, (*CICESE, Ensenada, Mexico*)

1350 Stock Identification and Reconstruction of Migration Patterns Using Otolith Elemental Fingerprints
Steven Campana (*Bedford Institute of Oceanography, Nova Scotia, Canada*)

1415 Some Suggestive Meristics Data for Evaluating Swordfish
Edward DeMartini (*NMFS, Hawaii, USA)*

1425 Discussion

1445 Tea and Coffee

1500 An Attempt to Clarify Genetic Stock Structure of Swordfish Using Nuclear Gene Markers
Naritoshi Cho, (*NRIFSF, Shimizu, Japan*)

1515 Genetic Analysis of Pacific Swordfish Populations Using mtDNA and Microsatellite Markers
Carol Reeb* and Barbara Block (*Stanford Univ, California, USA*)

*Presenter

1545 General Discussion

1800 Dinner

Working Group 3 - Resource Assessment and Monitoring

Session Topic: Critique of Assessment Methods and Models; Identification of Data Collection and Research Needs
Chair: Pierre Kleiber *(NMFS, Hawaii, USA*

0830 Review Characteristics of Swordfish and Swordfish Fisheries That Challenge Traditional and Modern Stock Assessment Techniques - Group Discussion

0900 What Are The Features of Stock Assessment Models and Techniques That Could Cause Swordfish Assessments to be Questionable - Group Discussion

1000 Tea and Coffee

1020 To Minimize Dangers of Mis-Assessment, What Changes Could be Made to Swordfish Stock Assessment Models - Group Discussion

1200 Lunch

1330 What Research Projects Should be Conducted to Address Questions Concerning Swordfish Stock Assessments - Group Discussion

1445 Tea and Coffee

1500 Group Discussion (*continued*)

1800 Dinner

Thursday, March 6

0730-0830 Breakfast

Plenary Session
Reports from the Workshop, Pacific Perspective, Announcement of Next Meeting
Chairs: Gerard DiNardo *(NMFS, Hawaii, USA)*
Yuji Uozumi *(NRIFSF, Shimizu, Japan)*

0830 Workshop Report of Biological Input to Stock Assessment Working Group Sessions

0930 Workshop Report of Fisheries Oceanography Working Group Session

1000 Tea and Coffee

*Presenter

1020 Workshop Report of Fisheries Oceanography Working Group Session *(continued)*

1100 Workshop Report of Resource Assessment and Monitoring Working Group Sessions

1200 Lunch

1300 Pacific Perspective in Swordfish Research Where Do We Go From Here?

1400 Discussion and Announcement of the Third International Symposium and Farewell

1800 Dinner

*Presenter

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