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Indian Ocean Tuna Commission
Commission des Thons de l'Océan Indien

Report of the 2nd Session of the IOTC Working Party on Billfish

St Gilles, La Réunion, November 5-8, 2001

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EXECUTIVE SUMMARY

The Second Meeting of the Working Party on Billfish took place in St Gilles, La Réunion on November 5th -8th , 2001, involving 21 participants. As instructed by the Scientific Committee in its Third Session, the WPB concentrated its efforts in assessing the status of the swordfish, and briefly reviewed the new information available for the other species.

The WPB recognised that there are still important gaps in data available on catches of billfish, due to various problems including aggregation and misidentification of species, underreporting of catches and lack of size-frequency data. In the particular case of the swordfish, the range of assessment techniques was severely limited by the lack of important data on catches by the longline fleet of Taiwan,China.

Some new information was presented on the biology of billfish, in particular, regarding growth, reproduction and feeding. The WPB recommended to continue with this work and to carry out research in the areas of stock structure, sex-ratio and movement patterns.

Given the restrictions posed by the limited data, it was not possible to conduct a formal stock assessment for swordfish. The WPB was able to improve significantly on the procedures to obtain indicators from other fisheries. These indicators show evidence of significant declines in the CPUE of swordfish for the Japanese fleet, particularly over the last decade, in areas of the SW Indian Ocean where swordfish are targeted by the Taiwanese fleet. There is also significant evidence for localised depletion of swordfish stocks around La Réunion.

The indicators suggest that the status of swordfish stocks in the Indian Ocean should be closely monitored. The Working Party considered that, until the Taiwanese data become available and a comprehensive stock assessment can be conducted, any increase in the catch of or fishing effort on swordfish should not be allowed. The judgement of the WPB is that, should further increases in catch and effort occur, it is likely that they will be unsustainable. Given the life history characteristics of swordfish it is also likely that it will not be possible to detect over-fishing in time to correct serious damage to the stock.

1. OPENING OF THE MEETING

The Working Party on Billfish (WPB) was convened in St. Gilles, La Réunion, at the invitation of IFREMER. The meeting, attended by 21 participants (list given as Appendix 1), was chaired by John Gunn (CSIRO, Australia). The participants were welcomed by Philippe Lemercier, Délégué Régional of IFREMER for the Indian Ocean.

The draft agenda was approved (Appendix 2) after allocating the papers presented to the meeting to the appropriate agenda items. The list of documents presented to the WPB is given in Appendix 3. A. Fonteneau (France) and D. Ardill (IOTC Secretariat) were nominated as co-rapporteurs of this meeting.

As instructed by the Scientific Committee in its Third Session, the WPB concentrated its efforts in assessing the status of the swordfish, and briefly reviewed the new information available for the other species.

2. REPORTS ON CATCH STATISTICS

The total billfish catches declined to 77,000 t in 1999 following a high of 85,000 t in 1998. The trends shown by the catches of each species are given in Figure 2 and Figure 3 for swordfish. The yearly catches declared by each country are given for the main species in Appendix VIII.

Four documents and various verbal communications in relation to billfish statistics were presented to the WPB.

Status of IOTC databases

The Secretariat presented a review of the status of data available on billfish (WPB-01-01). The main problems identified at the previous meeting of the WPB continued to affect the quality of the data available for these species, such as:

- A significant level of aggregation in the reporting of catches. Reporting from several fisheries, in particular artisanal fisheries continue to be as aggregates such as "Billfish" or "Tuna and tuna-like species". In part, this is due to the fact that these species are an incidental catch for most fisheries.

- Underreporting of discarded catches. As many of these species have relatively low commercial value, fish caught are discarded at sea and not reported in the logbooks. In some cases, catches are retained but are sold at local markets and never recorded in the statistics.

- Problems in the correct identification of the species. Some species are difficult to identify and this leads to reporting of catches under the incorrect name, underreporting or reporting under aggregates.

- A lack of representative size-frequency data for most of the catches of billfish. In the particular situation of swordfish, this is aggravated since it is a main target of vessels from Taiwan, China[1]. Taiwanese authorities have not submitted the available SF data despite continuous requests.

In spite of these pending issues, the Secretariat has completed been able to achieve improvements in various areas:

- Complete revision of the Nominal Catches database: catches of billfish species added to the IOTC DB especially for early years (1950-70) from a number of different sources, especially the FAO nominal catch database.

- Review of Indonesian longline catch series: New information was obtained on the development of this fishery, and consideration of this new data led to major changes in the estimates, especially for recent years (1995-2000).

- The collection of size frequency (SF) data on tuna and billfish species through the IOTC sampling programmes in Penang and Phuket continued throughout 2001,

- More accurate estimates of catches of IUU fresh tuna vessels, landed in Penang and Phuket was obtained from the IOTC sampling programmes.

- Improvement in the reporting from Sri Lanka in 1999. Sri Lanka reported the catches of billfish by species, rather than as a single aggregate as happened in earlier years. The Secretariat is in contact with Sri Lankan officials and a review of the complete data series is currently underway.

The Secretariat also prepared a new series of figures and tables that illustrate the situation of the fisheries and statistics. In particular, a series of catalogues have been produced that summarised the data stored in the IOTC database, as well as the quality of different data holdings.

The Secretariat also briefly reported on the progress of the sampling programmes that have been implemented in Phuket, Thailand and Penang, Malaysia, in cooperation with national institutions. The information collected from landings of small fresh-tuna longliners has been useful in improving the estimation of catches from non-reporting vessels and has provided good information on the size-frequency composition of the catch of this fleet.

The meeting recognised that the Secretariat has made significant advance in the last year and the document prepared by the Secretariat concerning the billfish statistics was considered highly valuable.

National reports on fisheries and statistics

Among the swordfish fisheries which are presently identified as being active in the Indian Ocean, only few relatively minor swordfish fisheries are well described and were reviewed by the WPB (Seychelles, South Africa, Japan and Australia), while the trends of major longline fisheries (for instance, Sri Lanka) were not described or reviewed by the WPB.

Five fisheries were examined by the WPB, through documents (Seychelles, La Réunion, South Africa), a formal presentation (Australia) or by a review of detailed statistical data

[1] This terminology refers to Taiwan province of China

recently submitted to the IOTC Secretariat (Spain) and presented by the Secretariat as working document WPB-01-08, upon request from the WPB. These five fisheries show various common characteristics including: recent development, a semi-industrial nature and limited geographical extension (these characteristics are quite different from the Japanese, Taiwanese and Korean longliners fleets which have been taking swordfish in various degrees throughout the entire Indian Ocean during long periods).

Document WPB-01-04 presented the trends in the recently developed longline fisheries from the Seychelles islands. Feasibility studies on the development of the semi-industrial fishery started in 1994 and commercial fishing started in 1995. The average number of hooks used for each set has decreased to 440 in 2000. Light sticks are used on every third hook and there is an average of 8 hooks per basket. Squid is used as bait for 85% of the trips and 75% of the sets are made at night. Logbook and landing data forms are received at SFA, with coverage of 75% and 96%, respectively. In 2000, about 16% of the trips were sampled. Since the fishery started in 1995, the number of active vessels increased from 2 to 11 vessels. In 2000, the fishing effort decreased to 400 000 hooks, 80% of the 1999 level. The total catch for 2000 was 380t, including 203t of swordfish. Catch rates for all species were 0.90 kg/hook in 2000, whereas catch rates for swordfish were 0.48 kg/hook (around 18 fish/1000 hooks). In 2000, predation by mammals on swordfish amounted to 15%. The length-frequency distribution of swordfish has remained quite stable (135cm fork length).

The longline fishery in Seychelles is still a free entry fishery with a small yearly entry of semi industrial longliners managed by Seychellois owners.

Document WPB-01-07 presented the trends in the La Réunion longline fisheries. The Indian Ocean swordfish longline fishery based in Réunion Island started operating in 1991. Since July 1998, IFREMER has been compiling information on the domestic longline fishery. Two of the main aims of this programme, financed by the European Union and Réunion Local Councils, are to follow the Réunion Swordfish fishery and to provide data requested by IOTC. The fleet was stratified into two classes of vessels: (1) less than 16 meters and (2) more than 16 meters. The number of vessels has been increasing since 1991. The number of vessels in class (1) is still increasing, whereas the number of large vessels has been decreasing since 1998. The landings of the two classes attained the same level in 1999. The effort (number of hooks) of the fleet has been increasing steadily, except in 1997. The longline catch of swordfish was 278t in 1991, increased to 2 076t in 1998 and then decreased to be an estimated 1 741t in 2000. The swordfish component of total longline landings (by weight) averaged 66%. The fishing grounds of the Réunion longliners are located to the west and south of Réunion. A spatial extension of the activity has been noticed from 1994 to 1998. In 1999, some of the larger boats stopped their activity and, as a result, the exploitation is now concentrated closer to Réunion Island. The monthly swordfish CPUE decreased between 1994 and 1996 and remained stable thereafter.

The WPB estimated that the decline in CPUE observed in the fishery was difficult to interpret in relation to the status of the overall swordfish stock, but it was detrimental for the economics of the local fishery. Further GLM analyses were conducted during the WPB which provided similar results (see Appendix 5).

J. Gunn made a presentation of the recent development of the Australian longline fishery targeting swordfish in the West Coast of Australia. The trend reported at the first WPB of increased effort and swordfish catch in the Australian longline fishery operating in the SE Indian Ocean continued in 2000. In 1997, this fishery consisted of 10 boats catching 10t of swordfish. In 2000 this has risen to over 60 vessels, fishing over 5 million hooks and catching approximately 1 500t of swordfish. A catch of two tonnes of striped marlin was also reported. An increasing number of these vessels operate outside the Australian EEZ on the high seas. Size data (mostly weight measurements with a small sample of length measurements) are now collected for over 50% of the catch of this fishery. It was also noted that, on the east coast of Australia, rapid expansion of a swordfish fishery in the 1990s appears to have resulted in significant localised depletion of swordfish stocks. The fishery began fishing inshore waters, with vessels using American-style monofilament gear and light sticks, with high catch rates of swordfish. However, within two years of initial swordfish targeting, catch rates in these inshore areas had declined significantly and fishermen began to move further offshore in search of higher catch rates. Over the last five years, there has been a reduction of catches rates in each area that has been fished for more than two years. The fleet has moved progressively offshore, and today a significant amount of the Australian effort is directed outside the Australian EEZ, in the high seas. This progression towards offshore fishing has led to a significant increase in capacity of the fleet as operators built bigger vessels capable of longer trips and carrying more catch.

The WPB was also informed that a domestic observer programme will begin on Australian tuna/swordfish longliners in 2002, at a coverage level yet to be determined, but likely to be in the order of 10%. The objective of the programme will be to collect data on longline by-catch and the validation of catch-and-effort data recorded on logbooks. Such an observer programme was considered as being of major interest in order to collect biological information on swordfish catches, with priority given to catch-at-size data by sex.

M. Griffith made a presentation of the recent development of the South African longline fishery targeting swordfish along the South African coast. Thirty experimental longline permits were issued towards the end of 1997 for targeting tuna in the South African EEZ. South African longline effort was focused within three broad areas from 1998 to 2001: along the shelf edge of the western Agulhas Bank and west coast (region 1); the east coast (region 2) and further offshore along the Walvis Bay Ridge in the eastern Atlantic (region 3). With the exception of region 2, fishing was conducted with American-style fishing gear (i.e. night sets with monofilament mainlines, light sticks and squid bait). Not surprisingly, swordfish comprised 50-60% of the combined tuna/swordfish catch. Nominal CPUE in region 1 declined from almost 4kg per hook (80 fish per thousand hooks) during the last quarter of 1997 to about 0.5kg/hook (10 fish per thousand hooks) during the first quarter of 1999 (a decline of 70% in just over a year). This trend was mirrored by recreational catch rates during an annual tournament in region 1; they fluctuated between 0.1 and 0.8 fish per outing between 1992 and 1998, crashed to zero in 1999 and have remained there ever since. Following the period of rapid decline, longline CPUE was fairly stable, at around 0.2-0.3kg/hook (4-6 fish per thousand hooks), between the last quarter of 1999 and the third quarter of 2001. Quarterly CPUE in region 3 showed no clear trend, with values fluctuating between 0.2 and 1kg per hook (4-20 fish per thousand hooks) during the period 1999 to 2001. Swordfish taken by the longline fishery in regions 1 and 3 were mostly large fish of between 120 and 240cm LJFL (mean = 170cm). Based on U.S. import data, the annual swordfish catch made by the South African experimental longline fishery is estimated to have been just over 1000t (dressed weight). The recent introduction of vessels with super freezers has, however, resulted in increased effort in the international waters of the Indian Ocean and catches are expected to increase.

Other billfish fisheries catching marlin and sailfishes

Only one document was submitted to the WPB (WPB-01-10) on the billfish fisheries catching marlins and sailfish, which are often, but not always, taken as by-catches. This lack of information is a critical limiting factor to follow the status of these stocks.

This document describes the experimental fishery and the biology of sailfish in the northwest of India. In India, sailfish are caught exclusively as by-catch of tuna fisheries. Tunas, billfishes and sharks are the three major groups caught in the longline gears, sailfish being the dominant billfish, representing 15% of the total longline catches in the area. The CPUE of sailfish in this seasonal fishery has shown a large increase since 1997. The spawning seasons have been studied, based on maturity stages of females. The average weight of sailfish caught was 27kg. The sailfishes are found to feed on a mixed food web of cephalopods, bony fishes and crustaceans.

REVIEW OF DATA ISSUES

Analysis of Taiwanese data

The Secretariat and the WPB made an extensive review of the statistical data (total yearly catches and catch and effort series by 5° and month, given in weight and in numbers). SF data have not been reported since 1989, and there are various unresolved inconsistencies concerning the CE data for the period 1990-1992 (see Figures 11 and 12). Although the Secretariat had requested a re-submission of the CE data for the period 1990-1992, there has been no positive response from authorities of Taiwan, China. Furthermore, the recent trends and changes in the swordfish CPUEs appear to be highly unrealistic (see Appendix VII).

The Taiwanese fishery is dominant in the Indian Ocean swordfish fishery (see Figure 5), catching more than 50% of swordfish landed and reported catches show a severe increasing trend in the 1990s (multiplied by a factor of 7), and it is of key importance for the assessment and conservation of this stock to correct the Taiwanese statistical files as soon as possible. Every possible method to correct the Taiwanese database should be explored, for instance through the IOTC Secretariat or by bilateral work between scientists of countries working on longline data.

Japanese longline statistics

In the WPB discussions, it was agreed that the CE data from the Japanese longline fleet provides the most comprehensive statistical series for swordfish and billfishes because of the large area fished (entire Indian Ocean) and because of the long period covered (nearly half a century). These statistical series are also of good quality and provide valuable information on hooks per basket, although the fraction of the catch sampled for size-frequency has been very small in recent years. Japanese CPUEs are presently the fundamental basis for all swordfish stock assessment (WPB-01-02).

It was noted, however, that because targeting is primarily for southern bluefin and bigeye tunas (with deep longline), the fishing areas of Japanese longliners were quite restricted during recent years; the limited extent of their fishing zones is a negative factor to obtain consistent abundance indices on tropical species, for instance on marlins and sailfishes which are primarily shallow subtropical species.

Predation by mammals

The high rates of predation by marine mammals (primarily by the genus *Pseudorca*) observed both in Seychelles and in other areas were discussed by the WPB. Fishermen have mentioned that predation seems to have increased over time (possibly because of learning by the marine mammals), but the data available are too scarce to provide firm evidence of this increase. This predation is a cause of serious concern for both fishermen (as this may have a severe negative impact on their profit) and scientists (as the lost fishes are not recorded in the IOTC database).

The IOTC programme for a predation survey, targeting an extensive collection of data on historical and present predation rates, may be the only way to clarify these uncertainties. This problem may significantly affect removals and the loss of fish linked with fishing mortality has not been taken into account in stock assessment.

Sex-ratio data

Sexual dimorphism is a biological characteristic which is most often observed in billfishes, where large individuals are almost always females. It is therefore of key importance to sample both the catch at size and the sex of billfishes simultaneously. The sex ratio by size is often highly variable across fisheries and strata, indicating that it is important that sex-structure be incorporated into the formulation of stock assessment models in future. It was suggested that the sex of processed individuals could be determined from sample tissues, and this potential should be further explored.

Sport fisheries

The catch rates of sport fisheries which are actively targeting billfish in various places of the Indian Ocean could provide useful indices of abundance, at least at a local scale. They could also provide an index of the sizes of fish taken which could be used as a potential indicator of stock status. It was noted that these data might well cover long periods of time. Such data set indices could probably be obtained from Mauritius, South Africa, Australia, Kenya and the United Arab Emirates.

Better species identification of marlins

The IOTC Secretariat report underlined that many artisanal and industrial fisheries have been reporting their catches as “billfishes” without species identification. This statistical problem is partly due to the difficulties faced in the identification of these species, especially when they are landed as processed carcasses. Australian scientists have recently developed identification sheets allowing a simple species identification of this group. The WPB recommended that the Secretariat obtain copies of these billfish identification sheets and circulate them to all statistical offices connected with billfish fisheries.

Proposal for a joint project IOTC-OFCF to improve the quality of statistics

The WPB was informed by the Secretariat of a proposal for a joint project between the Overseas Fisheries Cooperation Foundation (OFCF) of Japan and the IOTC. The WPB supported the project and recommended that various serious pending statistical problems faced in various Indian Ocean billfish fisheries be tackled under this project. The uncertainties about the catches from Indonesia, India, Sri Lanka and by various other artisanal gillnet fisheries are included in this category.

3. REVIEW OF NEW INFORMATION ON BIOLOGY, ECOLOGY AND FISHERIES OCEANOGRAPHY

Reproduction

Document **WPB-01-05** on swordfish reproduction in the La Réunion area was presented. The Indian Ocean swordfish longline fishery based in Réunion Island started operating in 1991. From May 1998 to January 2001, IFREMER compiled information on the domestic longline fishery in the French EEZ. Data are collected from logbooks, from regular at-sea and landing samples and from on-board scientists. During 52 cruises on commercial longliners (327 days at sea), scientists recorded length measurements of all swordfish caught. They also determined the sex and collected gonads and the anal fin. Some aspects of the reproductive biology of swordfish around Réunion Island were studied from a sample of 1727 gonads collected between May 1998-January 2001. They represent around 1.65% of the total number of swordfish landed by the domestic fleet. Spawning was estimated to take place mainly from October to April. The vitellogenesis was characterised by histological features and relations were made with a macroscopic maturation index. The first aspects of fecundity of swordfish were analysed. Batch fecundity was estimated around Réunion Island (between 19° and 25° South and 48° and 58° East). The individual batch fecundity fluctuated from 900 000 hydrated oocytes for the smallest ripe female measured 124cm lower jaw fork length (LJFL) to 4.19 million for a large female sampled (225cm LJFL).

The Working Group noted that although the batch fecundity was available, there was no estimate of spawning frequency. It was recommended to try to estimate the frequency of spawning events using the technique recently developed by Australian scientists. It was also suggested that Boins rather than Gilson solutions should be used for preservation of gonads.

The high variability of sex ratio observed in the area was noted by the WPB. This pattern of sex ratio by size is very different from the profiles observed in South Africa, Seychelles and Australia. These differences in sex ratio are quite typical of swordfish but they are still poorly understood. Sex specific migrations of swordfish may explain part of this variability of sex ratio. It was noted that mobile oceanic longline fisheries are probably able to target a given sex and size of swordfish in specific strata because of the spatial heterogeneity of swordfish sexes and sizes. This targeting can produce a wide variability of the average weights caught because of differing sex ratios. It was noted that, on the east coast of Australia, more mature females were taken inshore than offshore (>150nmi). It was suggested that this could be explained by the presence of a warm inshore current, rather than by distance from the coast.

Growth

Document **WPB-01-06** on swordfish growth in the La Réunion area was presented. This study on age determination of swordfish (*Xiphias gladius*) in the southwest Indian Ocean was based on the observation of growth marks in cross sections of the second anal fin spine. During this programme, carried out in close collaboration with fishermen, 1665 hard parts were collected and analysed. For 689 females and 445 males, annuli (or growth bands) observed on spine cross sections were counted, with the Vililog-TNPC 3.2 image analysis software. This study was carried out in collaboration with the LASAA (LAboratoire de Sclérochronologie des Animaux Aquatiques, an IFREMER/IRD laboratory). Power and linear relationships were obtained between the lower jaw fork length of fishes (LJFL) and the spine radius for both sexes. The best determination coefficients were obtained with power relationships. Von Bertalanffy growth curves were fitted to the data under the hypothesis of the formation of one annulus each year. Females seem to grow faster and reach larger sizes than males for each estimated age. In the Indian Ocean, swordfish seem to have a slower growth than in other oceans. Monthly evolution of the relative marginal increment did not confirm the annual nature of each annulus. Tagging operations with chemical markers appear necessary for the age validation of swordfish.

The WPB noted that the size of swordfish taken by the fishery was similar to swordfish taken by South African fisheries. It was also noted that the growth curve obtained in La Réunion still needs to be validated; some concerns were expressed about the young ages estimated for larger swordfish. Reports in the literature indicate that swordfish could live well over 10 or 15 years, e.g. ages never observed by the La Réunion age reading. The WPB considers that the non-validated age reading of spines may seriously underestimate the age of old individuals. It was suggested that re-analysis of the spine samples to determine the periodicity of the light-coloured rings at the margin of the spine could help determine whether rings were indeed annual. The growth variability observed may come from Réunion being a breeding ground, with fish coming from different feeding grounds

In discussing growth validation, it was recognised that injection of chemical markers would pose the same problems as for tagging. This might be possible using very short sets or the "Cuban" fishing method (individual lines with flares that are extinguished by a strike). This problem should be addressed to the tagging Working Party. It was also suggested that ageing could possibly be determined by the use lead/radium radio-nucleotide proportions.

Feeding

Paper **WPB-01-09** presents the status of data collection regarding trophic ecology studies on swordfish undertaken under the IRD *Thetis* programme. The data collection for billfish consists of stomach contents and muscle samples for determining the nitrogen-stable isotope composition (this indicates the trophic level of the individual). The results presented in this paper come from 26 stomachs taken during the first research longline trip in August 2001 in the Seychelles region. Two sub-areas, one purely oceanic and one close to the Seychelles plateau drop-off, were defined to investigate the coastal effect on feeding activity and diet composition. The proportion of empty stomachs was relatively low (average 12%) and did not vary significantly between the sub-areas. This might not reflect the average feeding activity, as regurgitation often occurs and the longline gear might select primarily hungry fish. The diet composition was dominated by fish (both sub-areas), followed by cephalopods and crustacea. This result is quite different from what is commonly admitted, i.e. cephalopods being the major forage category for swordfish. Surprisingly, squids dominated over crustacea in the drop-off sub-area, when the opposite pattern, exhibited in the oceanic sub-area, was expected. These differences cannot be further discussed because of the small sample size. However, data collection will continue until 2004 and regular re-analyses are planned during the programme.

The Working Party recommend 3-D plots of forage rather than IRI, but that if this index was used, it should be standardised to 100 % to enable comparisons. It was also suggested that it would be useful to compare consumption rates from different areas and to make studies of energetic needs of swordfish. The Working Party was informed that studies were being undertaken for a reference file of morphometric relationships between swordfish and their prey.

Climate variability

The climate variability in the Indian Ocean was addressed by an oral presentation given by F. Marsac. Emphasis was put on two areas where swordfish are exploited, an equatorial strip (5°N-5°S) across the Indian Ocean, and the southwestern area (South Mozambique Channel). In the equatorial zone, the ENSO cycle leads the changes observed in the epipelagic environment: strong positive sea surface temperature anomalies (SSTA) in the western part during a warm episode, with a significant remote forcing by stronger than normal easterly winds in the eastern part. The positive and negative SST anomalies are associated with similar sea level anomalies. An atmospheric variable, the Indian Oscillation Index (IOI), depicts SST variability in the western area more precisely than the well-known SOI. It is proposed that this index be used as a climatic factor in CPUE standardisation, whatever the species considered (tunas or swordfish). The pattern of variability in surface ocean conditions in the southern Mozambique Channel shows a very distinct response to climate forcing compared to the equator. No link can be identified with the ENSO cycle at the meso-scale level. The main features are a clear seasonal cycle in sea level anomalies (positive during the first semester, negative thereafter) and similar trends between SST anomalies and sea level anomalies (increasing temperature and sea level from 1994 to 1999). The south Mozambique Channel region is dominated by strong meso-scale heterogeneity due to eddies generated by the retroflection of the East Madagascar Current (and further south by the Agulhas Current retroflection). This active meso-scale dynamics should be taken into account to explain the catch variability in the southwestern area of the longline fishery.

This type of study was considered by the WPB to be potentially useful. It was emphasized that this study should be stratified by species, as tropical and temperate tunas are most often fished in different areas and show different biological and behavioural patterns; the causes of increased catches in relation with environmental heterogeneities should be better understood (increased catchability or increased biomasses?).

J. Gunn presented a recent fine scale analysis of swordfish abundance in Eastern Australia (biophysical environment relationships) conducted by Jock Young (CSIRO Marine Research). This research studies the links between apparent abundance of swordfish (estimated using nominal CPUE) in the SW Pacific Ocean and a range of environmental variables. It indicates that salinity, fluorescence, moon phase, nearness to frontal systems and season all significantly affect swordfish catches. The study used commercial vessels fitted with an innovative “underway sampler”. The sampler allows real-time collection and logging of salinity, fluorescence and temperature data from the engine water intake. As the real-time data are displayed on an on-board computer, fishermen quickly learned to use the data variability to target swordfish and tunas, and there is anecdotal evidence that interpretation of the data allowed significant improvement in catch rates. This was not tested however, as vessels were not actively directed to select fishing location on a random basis.

The WPB discussed this interesting work and considered that small-scale studies using similar equipment should be usefully developed in the Indian Ocean longline fisheries in order to better understand the small-scale distribution of swordfish as a function of its environment.

Local depletion of swordfish

Fast local depletion was observed in various Indian Ocean swordfish fisheries, with a quick decline of the CPUE after few years of high catch rates. This phenomenon seems to be typical of many swordfish fisheries. The fast decline of local abundance remains unexplained, but is probably in relation with the limited movement of some fractions of stocks (so-called viscosity of the stock), a hypothesis which has been proposed for some highly migratory species.

4. REVIEW OF STOCK INDICATORS

Catch trends

Catch trends are a major parameter in the analysis of fisheries, especially when these series can be associated with corresponding trends of estimated fishing efforts. The IOTC database permits estimates of the levels and trends of yearly catches by species, and these series are shown on Figure 2 for the various billfish species. In each of these figures, various curves were drawn in order to show statistical uncertainties due to the large amount of catches registered in the database as “billfishes”. These figures show the large increase in the catches of swordfish and sailfish catches, and the relative stability of catch trends for other species (striped marlin showing a large variability from year to year).

Changes in fishing zones

The changes in the geographical distribution of fishing zones and the sizes of the zones fished are key factors in the development of billfish fisheries. For instance, it was noted that the increase of swordfish catches is often linked with an expansion of fishing zones and with a concentration of fishing effort in the area of the highest fish densities. These changes are usually difficult to take into account in traditional stock assessment models, but it is always useful to map the changes of fishing zones of the major fisheries. This was done by 5 year period for the Taiwanese longline fishery (Figure 5).

Trends in CPUE

Document WPB-01-02 analyzes the distribution patterns of CPUE of swordfish caught by Japanese and Taiwanese longliners (5 year average by quarter) and compares them for the period of 1980-1999. The Japanese longline catch shows a roughly similar pattern throughout the entire period analysed. As for the Taiwanese longliners, unrealistic fluctuations of CPUE were observed at a basin scale. In 1995-1999, high CPUEs were observed in the southwest Indian Ocean. Distribution patterns of the catch composition by species were also analysed for Taiwanese longliners for the same period. A high catch ratio of swordfish was observed in the southwest Indian Ocean, mainly in the third and fourth quarters. The results of this analysis clearly indicate the existence of swordfish-directed operation of Taiwanese longliners in the 1990s in the southwest Indian Ocean. At the same time, unexpected large changes were observed of swordfish CPUE patterns for Taiwanese longliners, indicating the need to verify and correct the catch and effort data.

Document WPB-01-03 analyses the relationship between catch, effort, CPUE and local abundance for non-target species such as billfish, caught by Indian Ocean longline fisheries and for target species (such as tunas). The goal of this study is to evaluate the potential bias in the relationship between local CPUE and local abundance when the fishery is exploiting strata with a low or with a large local fishing effort. The paper first makes a global presentation of the Indian Ocean longline fisheries (tunas and billfish). The potential problem of local effort is first analysed, comparing specific CPUEs calculated in value, as this economic parameter is probably driving the behaviour of most longline fisheries. Results obtained from various GAM analyses are also presented and discussed. They tend to confirm the potential role of local effort in the statistical behaviour of the CPUE, but also show that annual, seasonal and geographical effects tend to be larger than local effects. Simulated exploitation of 5°-month strata was also conducted using an *ad hoc* migratory model built with a combination of a target and a non-target species, both increasingly fished. Both the resources and the fisheries are mobile in this simulated ocean. The model suggests that the CPUE of non-target species may be more heavily biased because of their status; this bias appears to be a function of the level of the profitability break-even point for the target species. The present conclusions are still provisional, but this study tends to confirm that total fishing effort should preferably be taken into account in order to estimate local densities, this prerequisite probably being more important for by-catch species such as billfish than for the target species.

The WPB agreed that the problem discussed in the paper was potentially important and should be further analyzed using other types of statistical methods. In particular, it was mentioned that re-analysing the data using a GLM (rather than GAM) could provide a better statistical framework in which to test the proposed hypotheses. For example, a GLM that models catch as a function of effort and other explanatory variables could be used to test whether the CPUE declines with effort through the inspection of the effort-related coefficient.

Document WPB-01-Inf.2 discusses a method for the standardization of swordfish longline CPUEs. The WPB expressed interest in the proposed method and encouraged the authors to report on the results of future analyses based on this method.

Review of CPUE trends

Recognizing the importance of the CPUE trends in the assessments of any species, even when the analyses cannot be done in the context of a formal stock assessment procedure, the WPB agreed that a small sub-group be dedicated to carry out additional analyses on the CE series available at the meeting, i.e.: the Japanese longline, Taiwanese longline and Réunion longline.

The analyses for the Japanese and Réunion data sets are described in detail in Appendices IV and V. Before doing the analyses, it was agreed that a common definition of areas would be applied to the Taiwanese and the Japanese data sets (see Figure 9). This definition of areas facilitates a comparison with the CPUE indices from Seychelles (assumed for area 1) and Réunion (area 2).

CPUE of the Taiwan, China fleet

During the meeting, a number of analyses were done on the CE data for the Taiwanese fleet available at the IOTC Secretariat (see Appendix VII). A major difficulty in the interpretation of this series is the sharp increase in CPUE that takes place simultaneously with the increase in catches in the early 1990s. These increases occurred throughout the Indian Ocean, but mostly in areas that were heavily exploited (see Figure 23 in Appendix VII). The fact that the increases in CPUE occurred simultaneously with an increase in the catches suggests that a change in targeting or in reporting practices are possible explanations for the observed CPUE trends.

Information about targeting practices of the Taiwanese fleet was not available, so an attempt was done to standardize by the observed species composition of the catch (see details in Appendix VII). Although the factor associated with the species composition explained an important part of the variability of the CPUE data, it failed to explain the large increases in CPUE in the early 1990s. Furthermore, the model diagnostics indicate that the performance of this model was not satisfactory. Given that these uncertainties (and those described in

WPB-01-02) could not be resolved during the meeting, the WPB decided to postpone further consideration of this dataset pending clarification of these issues.

CPUE for the longline fleet of Japan

A new CPUE index was calculated for the Japanese longline fleet on the basis of a GLM-based standardization. The analysis is similar to the standardization carried out in the previous WPB meeting on the same dataset. The main differences, fully described in Appendix VI, are in the definition of the areas and in the choice of hooks-per-basket levels.

An initial analysis showed large, unexplained increases in the area 7 that were considered a change in fishing practices. The CPUE in area 7 (West Australia) shows a drastic decline since the early 90s, but it appears that this decline is probably the consequence of the spatial heterogeneity of this area and the WPB estimates that this decline is not representative of the resource. One potential reason in this decline of swordfish CPUE may be the concentration of fishing effort observed in a very small area with low CPUE of swordfish and high CPUE of the target species, bigeye tuna. The WPB therefore decided to eliminate area 7 from consideration for the final version of the GLM analysis, which is described in Appendix VI.

The resulting indices show a decline in CPUE in the areas most heavily exploited of the western Indian Ocean, in particular areas 3 and 2. There is no clear trend in area 1, which shows higher CPUEs than the other areas.

CPUE for the longline fleet of Réunion

A similar GLM analyses was carried out on the data available from the longline fisheries of Réunion. The details of this analysis are shown in Appendix 5. Model diagnostics indicate no serious problems in this analysis, which used high-resolution data on individual boats and sets. This fishery has been routinely targeting swordfish in area 2, so the CPUE trend obtained can be compared with that for the Japanese fishery in area 2.

The standardized trend (Figure 19) suggests that a significant decline occurred in the CPUE after 1995-6, coincidental with a decline observed in the Japanese CPUE trend.

Overall comparison of CPUE trends

The three trends considered (standardized Japan and Réunion longline and nominal Seychelles longline) are consistent in that they show declines in areas where the swordfish resource has been more intensely fished. The Japanese and Seychelles trends offer no evidence of a decline in area 1, while both the Japanese and Réunion indices point to a decline in area 2.

Review of average size in the catch

The WPB made an extensive review of the statistical data (total yearly catches and catch and effort series by 5°-month in weight and in numbers) for the longline fleet of Taiwan, China. Since CE data has been reported in both weight and numbers, it was possible to calculate trends of average weight of swordfish by 5° square. These figures show a sharp increase of average weights after 1993, which is difficult to explain, in particular when the weights obtained from similar fisheries are considered (see Figure 12). The heterogeneity of the raising factors between the two statistical series of statistics is also a source of major concern, as these changes are very difficult to understand (Figure 11). The WPB considered that these changes are most likely the result of a change in processing or reporting practices for the fishery, as the processing procedure for the logbook data was revised after 1993. This was confirmed through informal e-mail contacts with Taiwanese scientists during the meeting.

The WPB also produced trends in average weight of the fish caught in the Japanese longline fishery for each of the seven areas used in the GLM analyses (Figure 13) and average length for the fleets of Réunion and Seychelles (Figure 14). There is no evidence of a strong long-term decline in the average size in the catch (as it has been observed in the Atlantic), suggesting that the stock has not yet been severely overexploited.

Tentative production modelling of swordfish

In absence of reliable size data for most of the catch of swordfish, it was not possible to conduct any size- or age-structured stock assessment. Therefore, an attempt was made to estimate the parameters of a production model. However, the trends in catches and effort observed in the swordfish fishery correspond to what has been described in the literature as a "one-way trip", that is, a continuous increase in catches and effort and a simultaneous decline in CPUE. Under this scenario, it becomes difficult to find reasonable parameter values.

To illustrate this problem, the parameters of a Schaefer model were estimated using the program ASPIC (Prager, 1995) which uses a non-equilibrium estimation procedure. The data used as input were the total annual catches and the CPUE index obtained from the Japanese longline fishery (results are listed in Table 1). Although the CPUE trend indexes numbers of fish, rather than biomass, the relatively constant average weight in the catch suggests that this apparent inconsistency of fitting a biomass model to an index of numbers does not represent a serious problem.

The results of the basic run indicated that, when the program is allowed to estimate all the parameters of the model, unrealistically high estimates of the intrinsic rate of growth are obtained. The estimate of MSY obtained from this procedure is in the order of 30 000t, similar to the current level of the catches. This coincidence between estimated MSY and recent catches has been reported in the literature as being a consequence of the difficulties of estimating parameters of the model under the "one-way trip" scenario.

These difficulties were further illustrated by running new estimations with ASPIC, this time fixing the parameter corresponding to the intrinsic rate of growth and allowing the other two parameters in the model (carrying capacity and catchability) to be estimated by the programme. The results are shown in Table 1 and illustrate the sensitivity of MSY to the various values of intrinsic rate of growth. For example, if we fix this parameter at the value of 0.30, the resulting MSY would be around 20 000t. As a reference value, the intrinsic rate of growth has been estimated at 0.27 for the north-Atlantic swordfish stock.

An alternative production model using the generalised production model of Pella-Tomlinson and Fox's equilibrium approximation as an estimation procedure (the software used is PRODFIT, Fox 1975) was also used to analyse the same catch and efforts series. Two runs of PRODFIT were conducted, based on the assumption that swordfish was exploited during a period of 8 and of 12 years (k parameter). This model provided estimates of MSY in a range between 24 000t (k=12) and 28 000t (k=8) and suggested that current effort is above the level of fishing effort corresponding to MSY (Figure 16).

These results are really meant to be interpreted as indicative analyses, but most probably current catches are above equilibrium for current levels of fishing effort, and it is possible that

Table 1. Results of trial runs of ASPIC on the data for the Japanese longline fleet.

B1-ratio	r	MSY	B-ratio	F-ratio
2	**0.05**	4871	0.808	8.077
2	**0.10**	8422	0.819	4.610
2	**0.25**	15420	0.845	2.449
2	**0.30**	17050	0.851	2.200
2	**0.50**	21690	0.871	1.700
2	**1.00**	27280	0.898	1.326
2	**1.50**	31330	0.930	1.136
2	**3.00**	33050	0.960	1.063
2	**5.00**	34650	1.017	0.984
2	15.93	31800	0.996	1.004

the current catches and effort in the swordfish fisheries are above the level corresponding to the MSY. Such a situation has been observed in other for a long-lived species such as swordfish, when fishing effort is increasing very rapidly (such as in the Indian Ocean fisheries).

However, it appears that the average weights of swordfish taken by most fisheries remain quite high and stable compared to those observed with the Atlantic swordfish fisheries. This could be interpreted as an indication that the Indian Ocean stock is not yet severely overfished.

After considering all the available indicators, the WPB agreed that the status of the swordfish cannot be consistently assessed with the current biological knowledge and fisheries data. Nevertheless, its status should be followed with great care by IOTC, because there are reasons to believe that current catches may not be sustainable and that the stock could already be overfished.

5. DISCUSSION OF STOCK ASSESSMENT APPROACHES SUITABLE FOR BILLFISH

Report from Working Party on Methods

The report of the Working Party on Methods held during April 2001 in Sète, France, was presented to the WPB. This report was considered highly relevant to the future work of the billfish WPB. The WPB strongly supported the recommendations proposed by the WPM and noted that several of these recommendation were put in practice in the CPUE analyses carried out during the meeting..

The WPB was particularly supportive of the development of an "operational model" which could serve as a benchmark for testing new procedures for analyses and assess the performance of management procedures based on pre-agreed decision rules. This approach also widely facilitates communication between managers and scientists and can provide very useful insight on the parameters that are the most important for the assessment and conservation of billfish stocks. These models are of general interest for the various species Working Parties, as it can be assumed that the same basic simulation model could be used, for example, for swordfish and bigeye tuna. As others tuna bodies are also interested in the development of these complex models, the WPB recommended that they be approached to benefit from their experience and to cooperate with similar efforts as possible.

General discussion concerning stock indicators

There was an extensive discussion during the WPB concerning the future use of stock indicators for assessing the status of the billfish stocks. The conclusion is that, given the existing data deficiencies, it will be difficult to conduct formal stock assessment and that the assessment of the status of these resources, at least in the near future, will have to rely on the consideration of various stock indicators. The need for such indices is illustrated by the major difficulties that "traditional" stock assessments faced, as discussed in earlier sections. It is difficult to envisage that in-depth stock assessment will be done on these stocks in the near future using traditional methods (such as Sequential Population Analysis) because of the lack of data and biological knowledge. In this context, the stock indicators may allow, if they are well selected, to monitor stocks and fisheries.

The list of potential indicators recommended by the WPB was listed as following:

1. An Index of average sizes or weight, preferably standardized through GLM analyses.

2. The size of the fish corresponding to a high percentile (e.g.: 95^{th}) of the size-frequency distribution in the catch, as an indicator of the presence of large fish in the catch.

3. Nominal and standardized CPUE global and by fishing area; the effective CPUE should incorporate proxies of hook depth, a key factor to interpret CPUE of swordfish and Istiophorids. CPUEs which are based on those obtained from various fisheries should give a proper statistical weight to each fishery. When CPUE indices are divergent in some strata, it is recommended that the reasons for such divergences be identified.

4. Catch per unit area by homogeneous ecosystems (such as Longhurst ecosystems).

5. The spatial components of fisheries should be followed by various indicators such as: 1) size of the areas fished (versus the estimated size of the species habitat), 2) frequency and levels of yearly catches in "hot-spot" areas (often in relation with topographic or environmental anomalies), where large catches can be observed, but often during short periods. The Gini index, proposed by Myers and Caligan 1995, could be a useful index in a fisheries context.

6. Biological indicators such as size and age at maturity and sex ratio by area should be followed.

7. Comparative worldwide analysis: Similar indicators obtained in similar fisheries active in other oceans (for instance in the better-followed Atlantic swordfish fisheries) should be obtained from the other Tuna Commission and made available to the WPB in order to allow comparisons of indicator trends between oceans. Priority should be given to simple indices.

The possibility that some biological characteristics of individual fishes, for instance, indices of liver condition or fat contents, may be indicative of stock status and of the potential stress was also discussed. Such potential indicators have not yet been identified for tunas and billfishes, but the potential for such indicators should be explored.

6. RECOMMENDATIONS

Recommendations concerning data

1) Taiwanese data: The major statistical deficiencies for swordfish and billfishes are due to the lack of cooperation of Taiwan Province of China, as this major fleet has not been reporting its fishery data according the minimal IOTC requirements, for instance, as size data are lacking and catch-and-effort data questionable. The validation of these data should be based on a detailed review of set-by-set data. There is an absolute need to obtain size data as well as information on gear configuration and time of setting used by the Taiwanese fishery.

The WPB strongly recommends that all possible direct or indirect actions be taken which could allow to reduce or to solve as soon as possible these major statistical uncertainties which severely hamper all present and future stock assessments.

2) Marlins and sailfishes: there is a critical lack of statistical data for this group of fishes. It is absolutely necessary to better estimate catches and discards by species and by gear, by size and sex.

3) Purse seine landings: It is strongly recommended that past and future catches of marlins taken as by-catches by purse seiners be estimated. The yearly landing of marlins by tropical purse seiners should be estimated, based on a analysis of the observer data, and landing data of this fleet should be well followed in the future (preferably by species and by size). It is also recommended to develop permanent observer programmes on these fleets, at least at a small scale, in order to better estimate by-catches of billfishes.

4) Sex ratio by size : It is necessary to sample the size of swordfish and marlins as a function of their sex simultaneously. Biochemical sex identification is being developed which might permit sampling at landing sites

5) OFCF project: The WPB strongly support the Japanese OFCF statistical project and recommends that priority should be given to sampling in countries which have substantial catches of swordfish and billfishes which are not properly monitored.

6) Written **statistical reports** should be obtained from scientists from each fishing country on all fisheries, even when this country cannot participate in Working Groups. The IOTC Secretariat should request these reports before WPB meetings.

7) Billfishes length measurements: Length data should be reported to the IOTC in a standard format to facilitate comparison of data from different countries. When these lengths are collected in a non-standard way, they should be converted to the standard form of reporting using well-described methods. The basic data used to establish these conversions should be kept by IOTC. The WPB strongly recommends that size measurements should be always taken in straight length, never in round length (this is because the condition factors and shapes of fishes are highly variable at a given size between time and area strata).

Research recommendations

1) Stock indicators

Further research is recommended concerning the definition and calculation of stock indicators that would be useful to follow the status of stocks. Special attention should be given to the choice of indicators which could well measure changes in abundance of older fishes (which are the first to disappear in case of overfishing) and changes in the geographical patterns of the fisheries. The various **stock indicators** recommended by the WPB should be calculated in advance of the WPB meeting in cooperation between scientists from fishing countries and the IOTC Secretariat; these indicators should be available at the beginning of the WPB meetings.

2) Swordfish stock structure and tagging of swordfish

The WPB considered tagging swordfish as being of key importance to determine realistic hypotheses concerning stock structures. Genetic results are clearly of great interest, but they cannot be used to make realistic hypotheses on movement rates between strata. It was recognized that tagging of swordfish is a difficult and expensive task. However, taking into account the absolute need to validate growth and to determine stock structure, the WPB strongly recommend conducting swordfish tagging in the IOTTP (as was planned in the original IOTTP).

Such tagging could be done in various ways such as:

1. Doing scientific tagging, primarily with electronic tags, using small rented longliners with short sets of few hooks; the good tagging results obtained by Carey are proof that swordfish tagging is feasible. This tagging could well be included in the feasibility tagging presently planned by IOTC.

2. Encouraging longline fishermen to tag small swordfish when they are still alive. Such tagging is already conducted in Australia and could preferably be done by observers. They would have limited goals but they could provide valuable information concerning swordfish movements.

3) Swordfish growth

Further research is recommended to improve knowledge concerning swordfish growth; it was recommended to try to validate the growth studies already done, and to conduct similar comparative studies in other areas.

4) Analysis of apparent movement of swordfish based on fishery data

The analysis of size specific CPUE by sex and by time and area strata may offer some potential to evaluate the apparent movement of swordfish. Such analyses, based on the various sizes and sexes taken seasonally by each fishery, could provide interesting hypotheses on swordfish movements.

5) Research on biology of Istiophorids

- Genetic studies of the main Istiophorid species should continue, concentrating on obtaining robust sample sizes from widely separated locations in the Indian Ocean. If genetic studies cannot commence in the near future, samples should still be collected and archived.

- Hard parts from billfish (marlin, sailfish) should be collected and archived for future age estimation studies. The third (largest) anal spine is probably best for this purpose, but this needs to be verified for each species (with respect to the extent of the matrix in larger fish).

- Popup satellite tagging experiments should be conducted on blue and black marlins to provide information on many aspects of their biology, including long-term vertical behaviour, movement and mixing rates.

- Increased tagging of billfish in the Indian Ocean should be encouraged on an opportunistic basis. This could be achieved as a 'by-product' of the longline-tagging component of the Tuna Tagging Programme, and also by instigating a coordinated, Indian Ocean wide sport fishery tagging programme.

- Improved catch and effort statistics should be collected for artisanal fisheries of coastal countries with the help of IOTC and of the OFCF project.

- Selected indicators of stock status should be better identified, selected and prepared before the next WPB meeting and be made available to the WPB allowing to evaluate stocks trends, independently of stock assessments analysis.

Stock status and Management recommendations

The Billfish Working Party concluded that it was unable to conduct a formal stock assessment for swordfish, largely because of serious deficiencies in the data available for analyses. The non-reporting of size data from Taiwanese fleet is of particular concern, as are the serious inconsistencies in the catch-and-effort data reported for the same fleet, as it continues to limit the range of possible analyses. Thus, the Working Party renews its recommendation that the Secretariat and IOTC Members, as a matter of urgency, take all necessary steps to rectify this situation.

The WPB was able to improve significantly on the procedures to obtain indicators from other fisheries. These indicators show evidence of significant declines in the CPUE of swordfish for the Japanese fleet, particularly over the last decade, in areas of the SW Indian Ocean where swordfish are targeted by the Taiwanese fleet. There is also significant evidence for localised depletion of swordfish stocks around La Réunion.

The indicators suggest that the status of swordfish stocks in the Indian Ocean should be closely monitored. The Working Party considered that, until the Taiwanese data become available and a comprehensive stock assessment can be conducted, any increase in the catch of or fishing effort on swordfish should not be allowed. The judgement of the WPB is that, should further increases in catch and effort occur, it is likely that they will be unsustainable. Given the life history characteristics of swordfish it is also likely that it will not be possible to detect over-fishing in time to correct serious damage to the stock.

7. ANY OTHER BUSINESS

M. Burgener, from the South-Africa base of the NGO TRAFFIC, made a presentation of the project planned by TRAFFIC concerning international trade of swordfish in the SW Indian and SE Atlantic oceans. This project is aimed to promote a better conservation and management of swordfish resources through an in depth follow up of trade data.

It was noted that such information could be of great value in order to validate and to improve the IOTC database and further cooperation and exchange of information between TRAFFIC and IOTC was encouraged.

APPENDIX I: LIST OF PARTICIPANTS

Alejandro Anganuzzi
Deputy Secretary
Indian Ocean Tuna Commission
P.O.Box 1011
Fishing Port
Victoria
SEYCHELLES
Tel: (+248) 225591, Fax: (+248) 224364
aanganu@seychelles.net

David Ardill
Secretary
Indian Ocean Tuna Commission
P.O.Box 1011
Fishing Port
Victoria
SEYCHELLES
Tel: (+248) 225494, Fax: (+248) 224364
iotcsecr@seychelles.net

Pascal Bach
Scientist
IRD-CRHMT
B.P. 171
Av. Jean Monnet
Sète CEDEX 34203
Tel: 499573202, Fax:
pbach@ifremer.fr

Julien Barde
IFREMER
BP 60
rue Jean Bertho
Le Port 97822 cedex
LA REUNION
Tel: 0262 42 03 40, Fax: 02 62 43 36 84
Julien.Barde@ifremer.fr

Rose-Marie Bargain
Industrial Fisheries Research Manager
Seychelles Fishing Authority
P.O. Box 449
Fishing Port
Victoria
SEYCHELLES
Tel: (+248) 224597, Fax: (+248) 224508
sfasez@seychelles.net

Markus Burgener
Programme Officer
Traffic East / Southern Africa
Private Bag x11, Parkview 2122
Johannesburg
SOUTH AFRICA
Tel: 27-11-486-1102, Fax: 27-11-486-1506
lpwg@ewt.org.za

Alain Fonteneau
Scientist
Institut de recherche pour le développement
P.O. Box 570
Victoria
SEYCHELLES
Tel: 22 47 42, Fax:
irdsey@seychelles.net

Jean-Marc Fromentin
IFREMER
BP 171
Bd. Jean Monet
sete 34203
FRANCE
Tel: 04 99 57 32 32, Fax: 04 99 57 32 95
Jean.Marc@ifremer.fr

Marc Griffiths
Senior Specialist Scientist
Marine and constal Management
Line Fish Section
Private Bay X2 Roggebaai 8012
Cape Town
SOUTH AFRICQ
Tel: 09 27 21 40 23 118, Fax:
mgriffit@mcm.wcape.gov.za

John Gunn
Senior Research Scientist
Commonwealth Scientific and Industrial
Research Organisation
P.O. Box 1538
Castray Esplanade
Hobart 7001
AUSTRALIA
Tel: 61-3-623 25 375 Fax: 61-3-623 25 012
gunn@marine.csiro.au

David Guyomard
PHD Student
BP 172
Sainte Clotilde 97490
LA REUNION
Tel: 0262 29 56 29, Fax: 0262 28 48 79
guyomard@univ-reunion.fr

Jean-Yves Le Gall
Faculty of Agronomy
65 Rue de St Brieuc
Rennes
FRANCE
Tel: , Fax:
legall@agrorennes.educagri.fr

Philippe Lemercier
Delegué
IFREMER
BP 60
rue Jean Bertho
Le Port 97822 CEDEX
LA REUNION
Tel: 02 62 42 03 40, Fax: 02 62 43 36 84
Philippe.Lemercier@ifremer.fr

Francis Marsac
Head "Thetis" Program
Institut de recherches pour le développement
B.P. 172
Ste. Clothilde CEDEX 97492
LA REUNION
Tel: 262 295629, Fax: 33-4-67 63-87-78
marsac@univ.reunion.fr

Dominique Miossec
Biologiste
IFREMER
BP 60
rue Jean Betho
Le Port 97822 CEDEX
LA REUNION
Tel: 02 62 42 03 40, Fax: 02 62 43 36 84
Dominique.Miossec@ifremer.fr

Renaud Pianet
Chairman of IOTC SC
IRD - Unité de Recherche no. 109 (THETIS)
B.P. 171
Av. Jean Monnet
Sète CEDEX 34203
FRANCE
Tel: (+33-4) 99 573239, Fax: (+33-4) 99 573295
pianet@ird.fr

François Poisson
Biologiste
IFREMER, Délégation de la Réunion
B.P. 60
Rue Jean Bertho
Le Port Cedex 97822
LA REUNION
Tel: 262-42-03-40, Fax: 262-43-36-84
francois.poisson@ ifremer.fr

Marc Taquet
Chef du Laboratoire Ressources Halieutiques
IFREMER, Délégation de la Réunion
B.P. 60
Rue Jean Bertho
Le Port Cedex 97822
LA REUNION
Tel: +262-42 03 40, Fax: +262-43 36 84
marc.taquet@ifremer.fr

Karine Vanpouille
Biologiste
281, Chemin de Combavas
Saint Paul 97411
LA REUNION
Tel: 0 2 62 44 39 48, Fax:
Karine.Vanpouille@wanadoo.fr

Kotaro Yokawa
Senior Scientist
National Research Institute of Far Seas Fisheries
5-7-1, Orido
Shimizu-shi 424-8633
JAPAN
Tel: 81-543-36-6035, Fax: 81-543-35-9642
yokawa@affrc.go.jp

APPENDIX II: AGENDA OF THE MEETING

1. *Official Opening and welcome to participants*

2. *Reports on Catch data and statistics*
    a. *Secretariat WP*
    b. *Informal reports on the nature and extent of data collection by members.*
    c. *Discussion of data requirements for stock assessment and actions required to achieve improvements in current situation.*

3. *Review of new information on biology, ecology and fisheries oceanography*
    a. *Reproduction*
    b. *Growth*
    c. *Feeding*

4. *Review of Stock Indicators*
    a. *CPUE Analyses WPs*
    b. *Size Data*
    c. *Future Directions in CPUE Analyses*
    d. *Report by special working group*

5. *Stock Status and Management Recommendations.*

6. *Discussion of stock assessment approaches suitable for use in billfish*
    a. *Report from Working Party on Methods*

7. *Review of research recommendations*
8. *Any other matters.*

APPENDIX III: LIST OF DOCUMENTS

WPB-01-01	Report on the Status of the Billfish statistics gathered at IOTC. *IOTC Secretariat*
WPB-01-02	Preliminary analysis of catch pattern of Japanese and Taiwanese longliners laying stress on swordfish. *Hirokazu Saito and Kotaro Yokawa*
WPB-01-03	Relationship between catch, effort, cpue and local abundance for non target species, such as Billfishes, caught by Indian Ocean long line fisheries. *Fonteneau, A. and Richard, N.*
WPB-01-04	Trends in the Seychelles semi -industrial longline fishery. *Bargain, R.M*
WPB-01-05	Sexual maturity, spawning season and estimation of batch fecundity of Swordfish (*Xiphias gladius*) caught by the Reunion-based pelagic longline fishery (SWOI). *Poisson F., Marjolet, Fauvel C.*
WPB-01-06	Etude de la croissance de l'espadon (*Xiphias gladius*). *Vanpouille K., Poisson P., Taquet M., Ogor A. , Troadec H.*
WPB-01-07	Country Report Reunion Swordfish Fishery (France). *Poisson F., Taquet .M,*
WPB-01-08	Note on the development of the Spanish surface longline fleet targeting swordfish in the Indian Ocean. *IOTC Secretariat*
WPB-01-09	On-going research activities on trophic ecology of swordfish (Xiphias gladius) in the Western Indian Ocean. *Marsac, F , Potier, M.*
WPB-01-10	Distribution, abundance indices and some biological characteristics of the Indo-Pacific Sailfish, *Istiophorus platypterus* (Shaw and Nodder, 1792) in the North Western Indian EEZ. *V.S.Somvanshi and S. Varghese*
WPB-01-I1	Size-weight relationships of the swordfish (*Xiphias gladius*) and several pelagic shark species caught in the spanish surface longline fishery in the Atlantic, Indian and Pacific Oceans. *Garcia--Cortes, B. & Mejuto, J.*
WPB-01-I2	Proposal for standardisation of cpue for Swordfish (*Xiphias gladius*) in the Indian Ocean; *Robert Campbell, Natalie Taylor*

APPENDIX IV: FIGURES REFERENCED IN THE TEXT OF THE REPORT

Figure 1: Average swordfish catches by flag declared to IOTC during recent years (1997-1999) in thousands of tonnes (catches decreasing clockwise); countries with reliable data are shown in light colours.

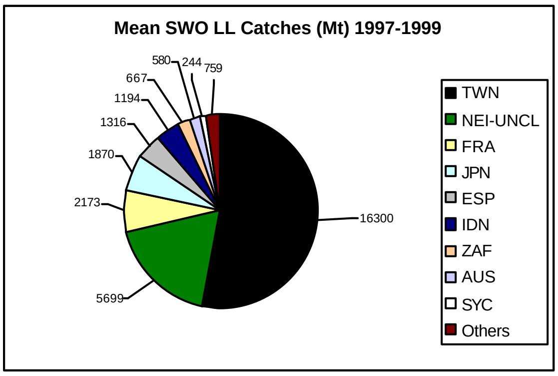
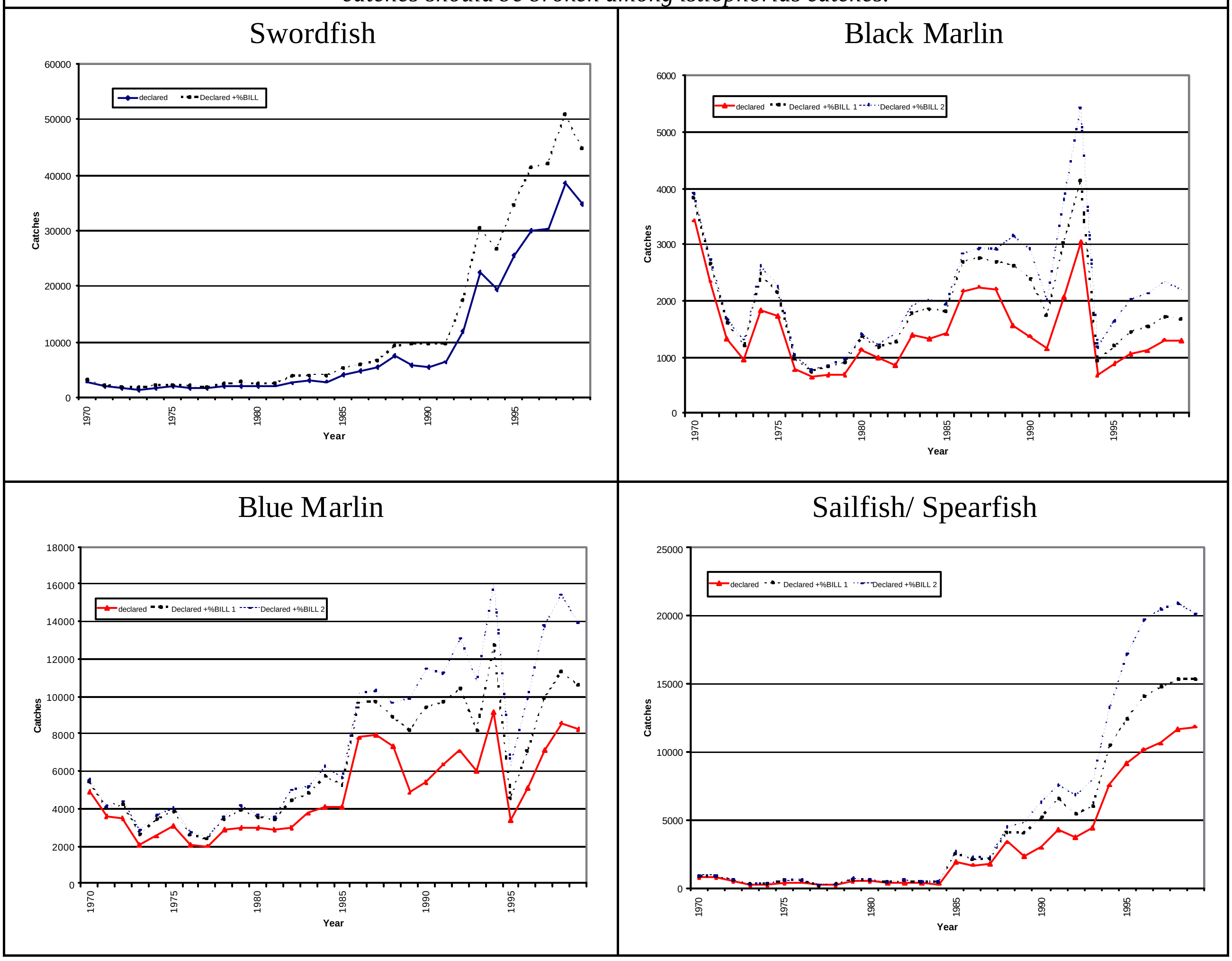


Figure 2. Yearly catches of swordfish, marlins and sailfish declared to the IOTC and estimated potential catches of the same species, assuming that catches submitted as « Billfishes » are in fact a mixture of SWO and BILL in proportion of each species catches, and assuming that SWO catches are well declared and that the same « Billfishes » catches should be broken among istiophorids catches.



Striped Marlin

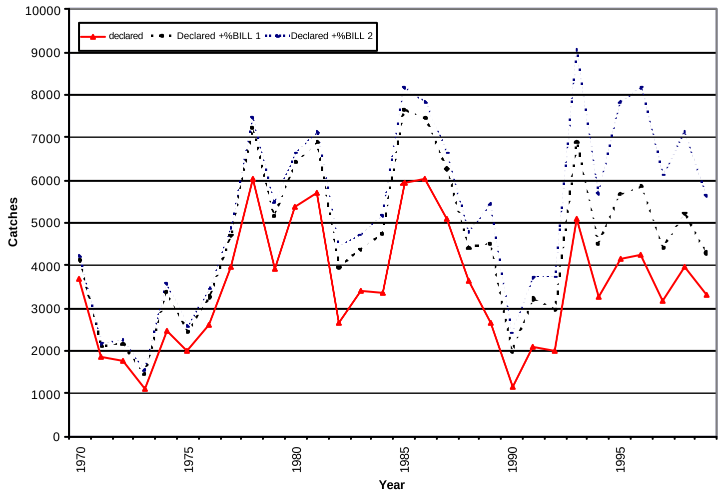


Figure 3. Catches of swordfish in the Indian Ocean for the period 1961-1999, in thousands of metric tons by gear and country/fleet

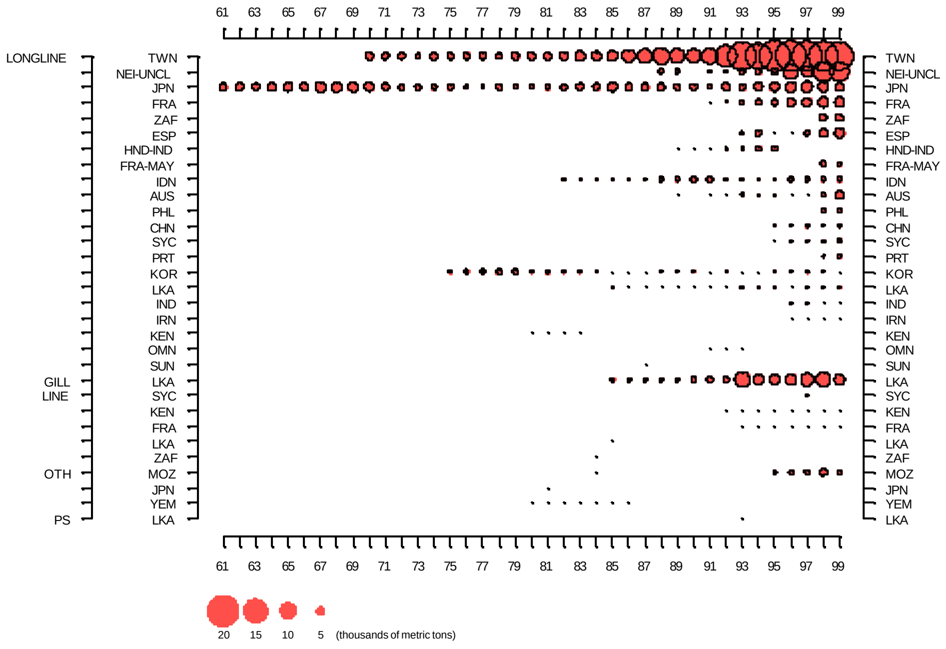


Figure 4. Nominal CPUE of swordfish for the fleet operating from Seychelles (left panel) and Réunion (right panel) in the western Indian Ocean.

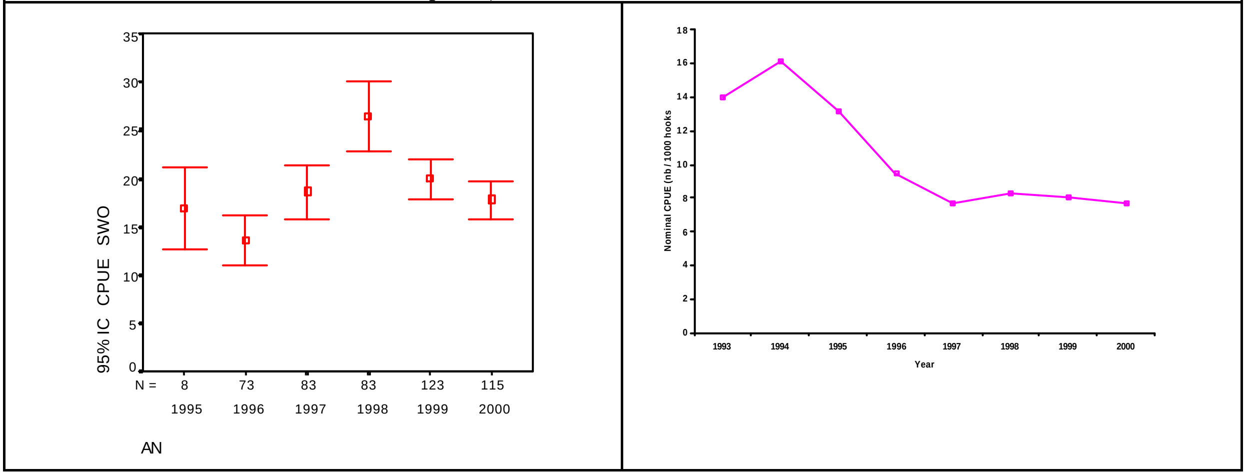


Figure 5 . Taiwanese LL SWO mean catches (Mt) for different time periods of 5 years (Mean catches:1980-1984: 1500 Mt, 1985-1989: 3700 Mt,1990-1994: 9100 Mt,1995-1999: 17000 Mt)

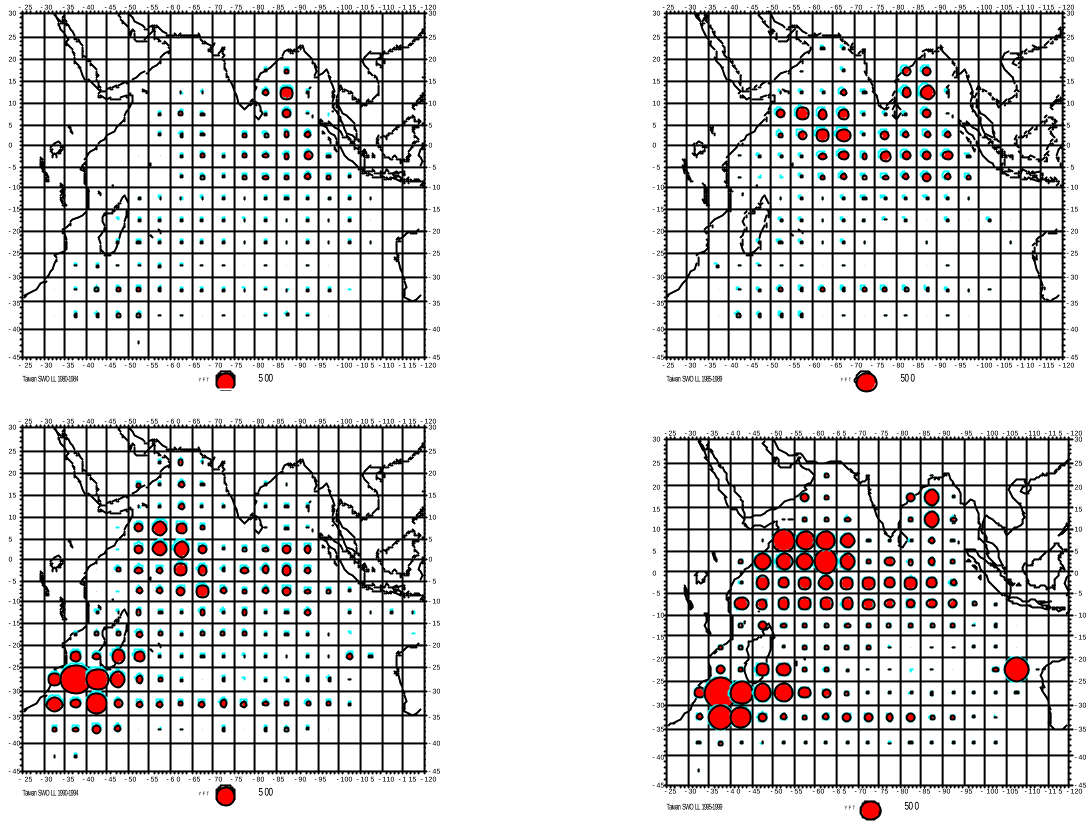


Figure 6. Time and space diagram of swordfish total yearly catches of oceanic longliners for the areas shown in figure ?? (areas derived from Longhurst ecosystems)

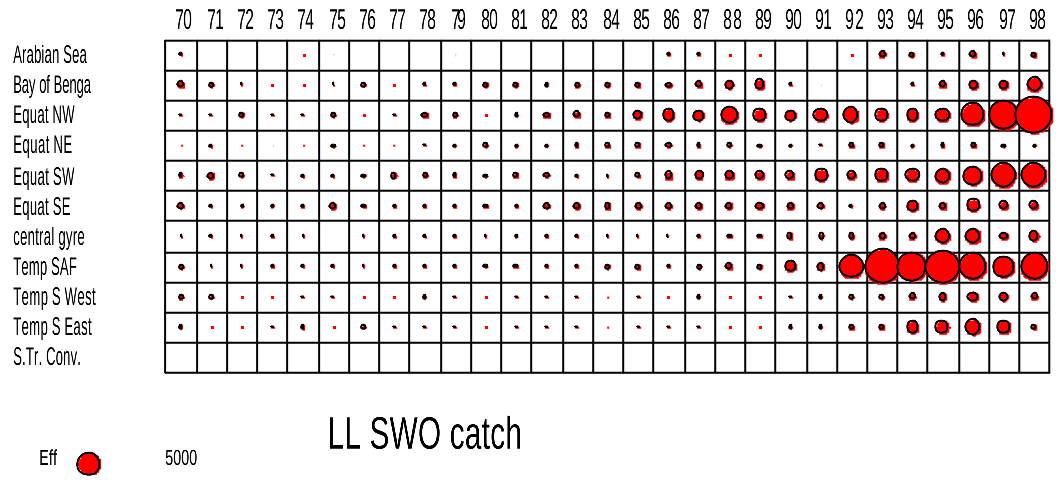


Figure 7. Time and space diagram of swordfish total yearly efforts of oceanic longliners by area.

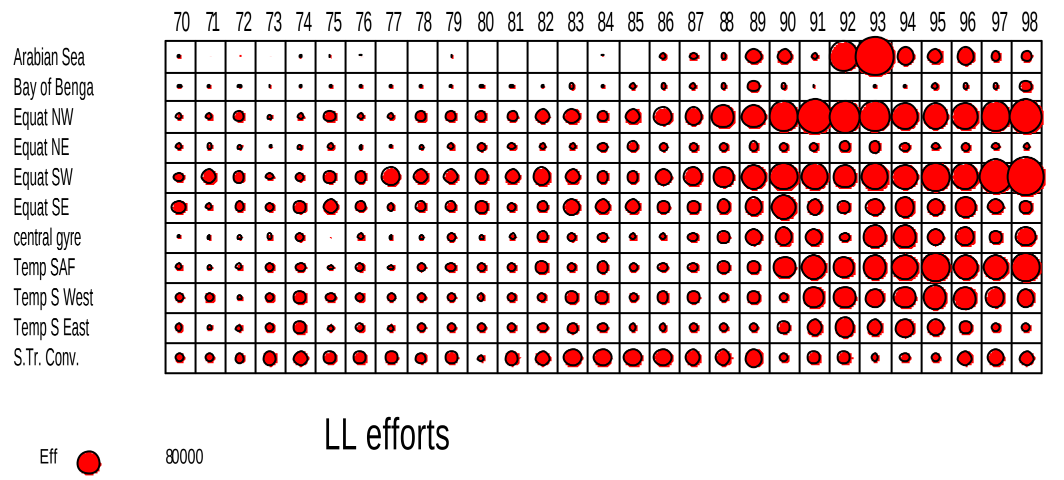


Figure 8. Fishing areas based on the pelagic ecosystems proposed by Longhurst (1998).

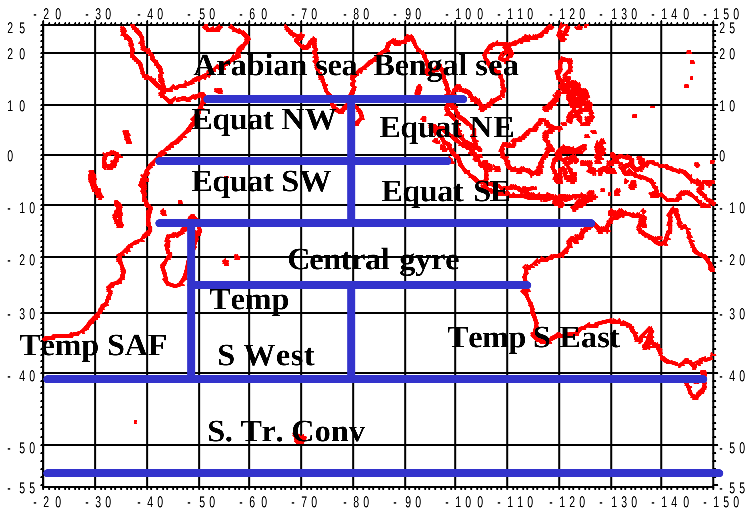


Figure 9 . Definition of the areas used in the standardization of the Japanese LL CPUE (see Appendix IV and the analyses in Appendix VI)

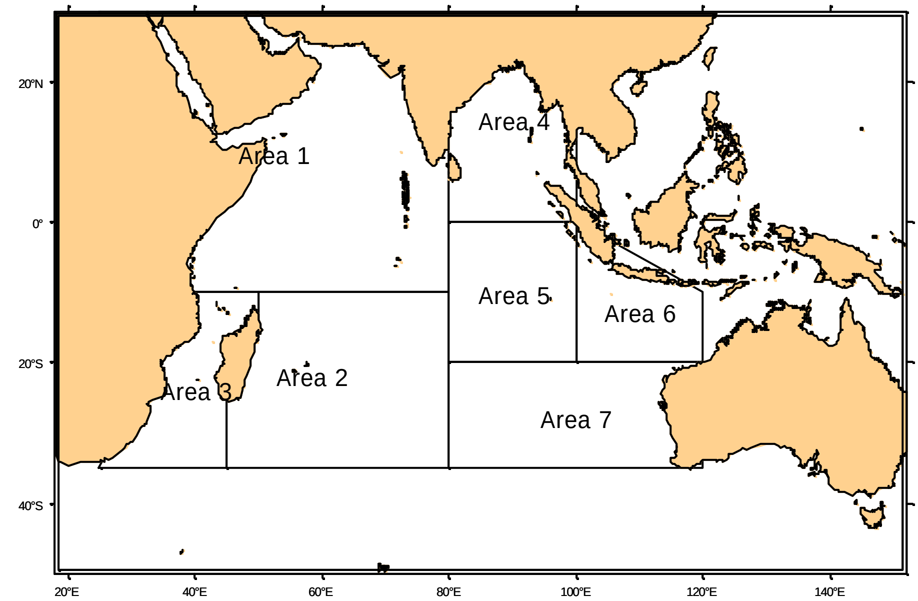


Figure 10. Average size distribution of swordfish taken during recent years by various longline fleets fishing in the Western IO.

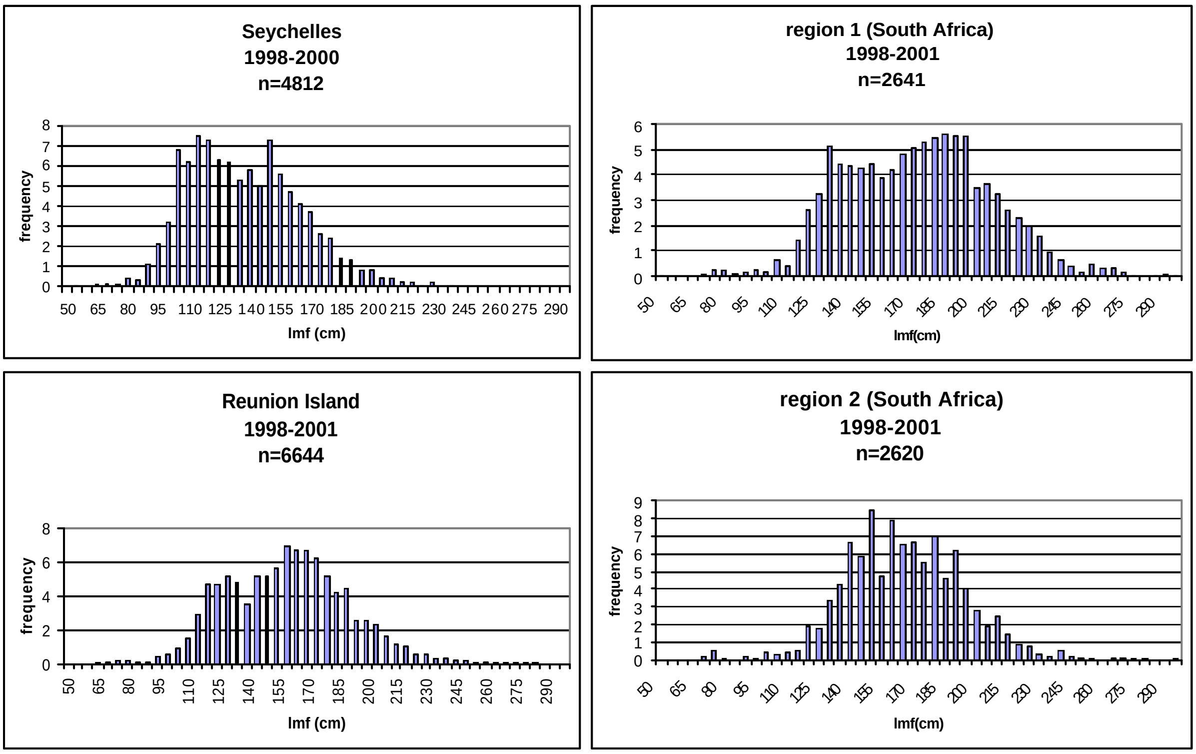


Figure 11. Catch of swordfish as reported in the nominal catches(NC) and catch-and-effort databases(CE) ,and the ratio between these two estimates for the Taiwanese longline fleet.

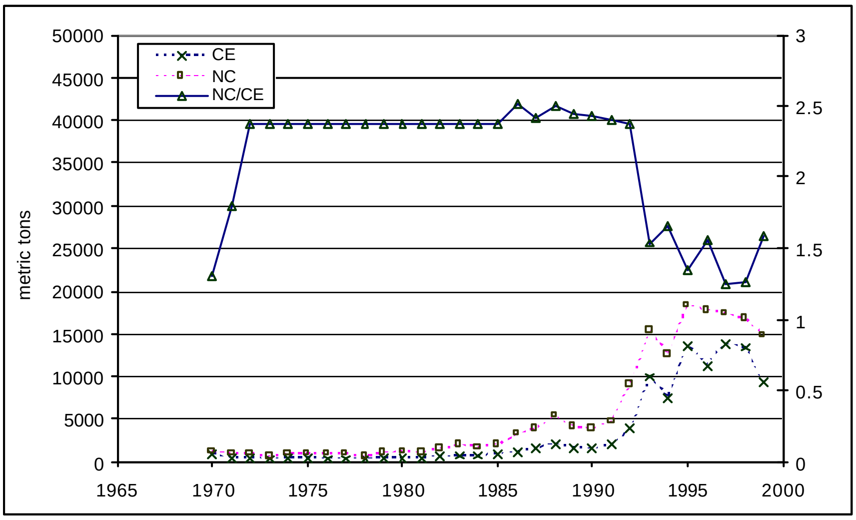


Figure 12. Average weight of swordfish in the catch of the Taiwanese longline fleet, as estimated from the CE data.

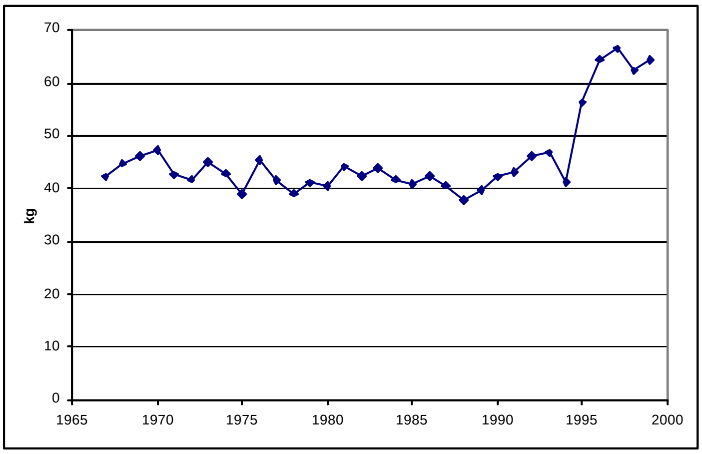


Figure 13. Average weight of swordfish caught in the Japanese LL fishery by the areas shown in Figure 9.

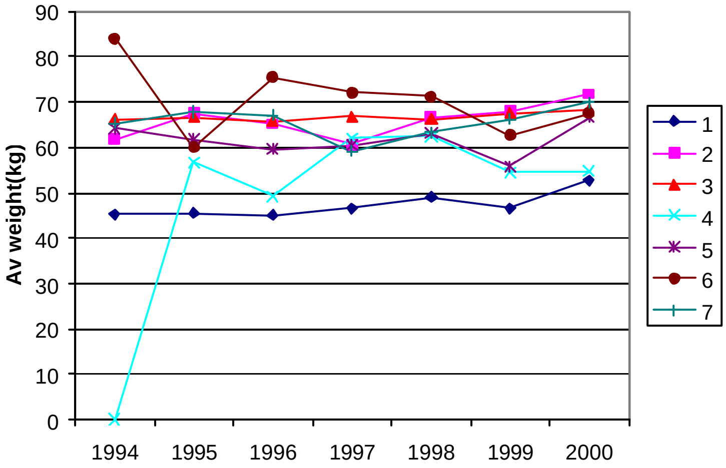


Figure 14. Average length of swordfish taken by the SWO LL fisheries operation around La Réunion and Seychelles, by year (left panel) and month (right panel).

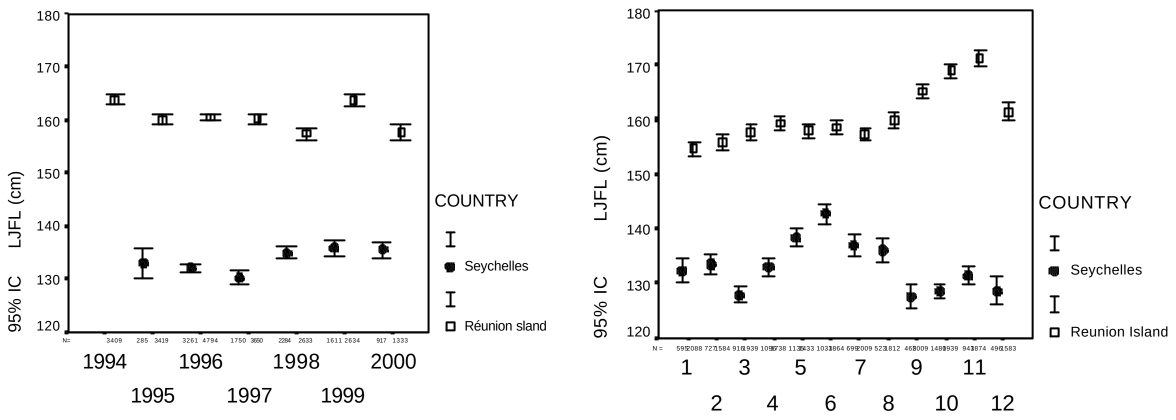


Figure 15: Effective fishing effort on swordfish, estimated as the ratio of total catches to the GLM index of abundance calculated for Japanese longliners.

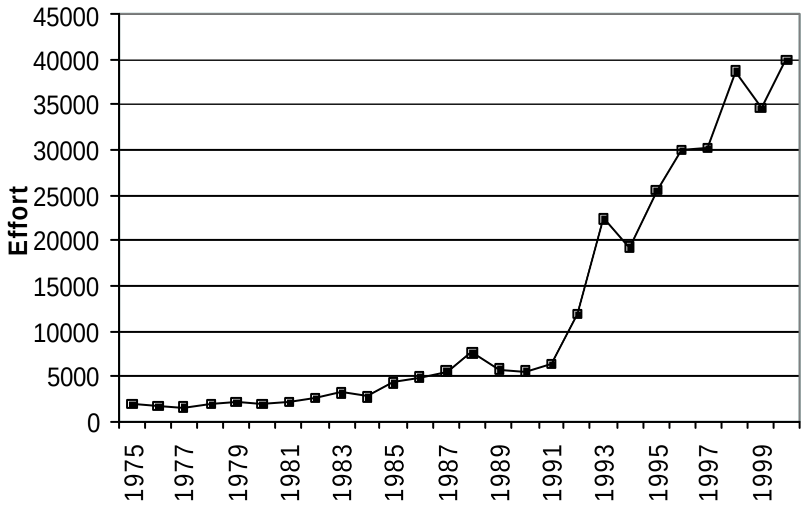
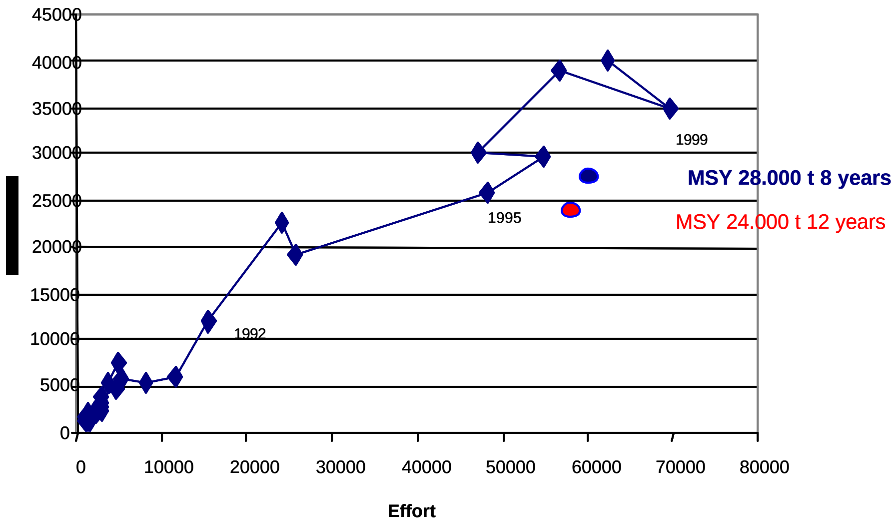


Figure 16: Plot of the relationship between yearly swordfish catches and corresponding effective fishing efforts. The MSY's shown are plausible values obtained in two different runs of the PRODFIT program



APPENDIX V: STANDARDIZATION OF THE CPUE INDICES FOR THE INDIAN OCEAN FRENCH LL FLEET

A preliminary analysis of the Indian Ocean French long liners data set has been made during the second IOTC billfish working group in order to compute a standardized CPUE index of swordfish. The aim of this exercise was firstly to compare trends in the French LL fishery, which targets swordfish, with that of the Japanese LL fleet, which does not target swordfish. The computation was restricted to area 2 (see figure Appendix IV), so that catches close to the Seychelles have been removed. Generalized Linear Models (GLM) have been used for the calculation.

The distribution of the dependent variable (i.e., the nominal CPUE = catch in numbers of fish divided by the numbers of hooks) did not appear normal. It appeared slightly more dispersed than a log-normal, so we decided to fit the log(CPUE) with a Gamma distribution and a link identity. Various variables were tested and the final model that was chosen, using the stepAIC function (Venables and Ripley 1999), was:

$$\log(CPUE) = f(boat + month + year + boat{:}year + setting + hauling)$$

The fit of this model is satisfactory as may be seen from the residuals plots. Though there is still some variability being not explained, the plot of the predicted values against the observed ones is also satisfactory. The anova revealed that the 'year' effect was the most important variable, followed by the 'month' effect and then by the interaction 'boat:year' and the 'boat' effect. Although being significant, the 'setting' and 'hauling' variables were of minor importance. The 'year' effect was plotted beside the nominal CPUE and confirmed that the major change in this fishery occurred around 1996-1997. From 1993 to 1996, the CPUE was around 11 fishes/1000 hooks (log(CPUE)=2.4) and then it suddenly decreased to about 6 to 7 fishes/1000 hooks in 1997, where it seems to stay since then.

In the near future, this standardized CPUE index should be improved by integrating the probable effect of the moon on the catchability of the surface long lines.

Figure 17. Frequency distribution of the CPUE observations, without any transformation (upper figures), and after applying a logarithmic transformation (lower figures).

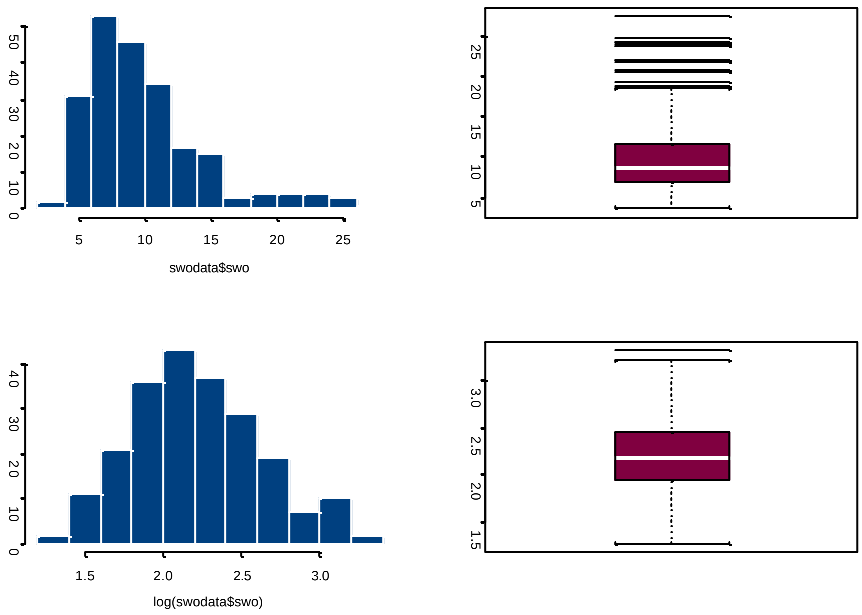


Figure 18. Standard diagnostic plots for the GLM analysis.

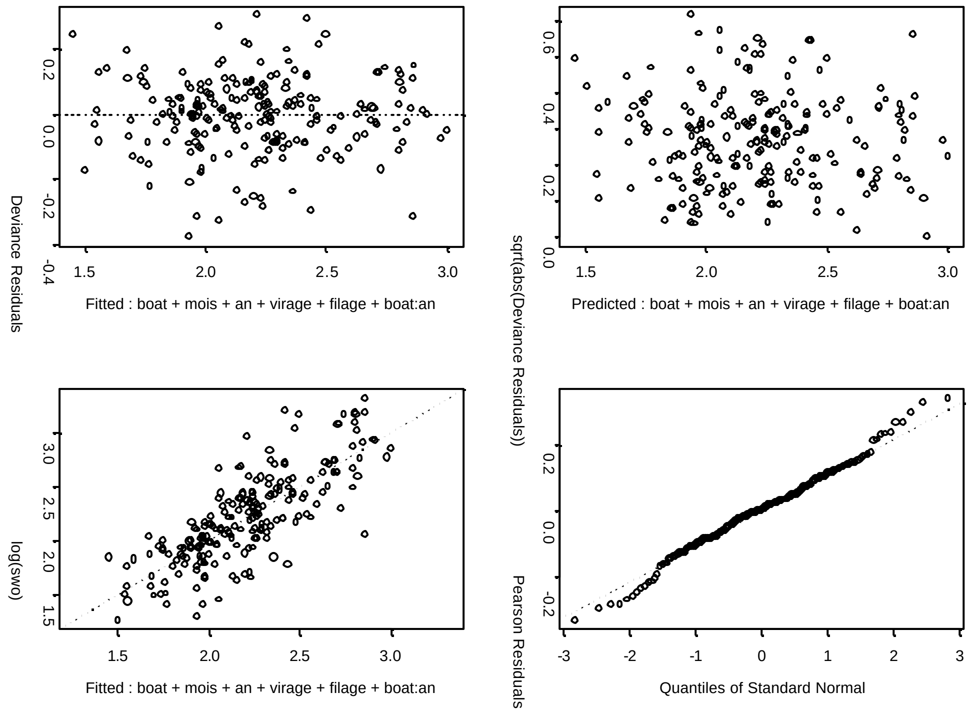
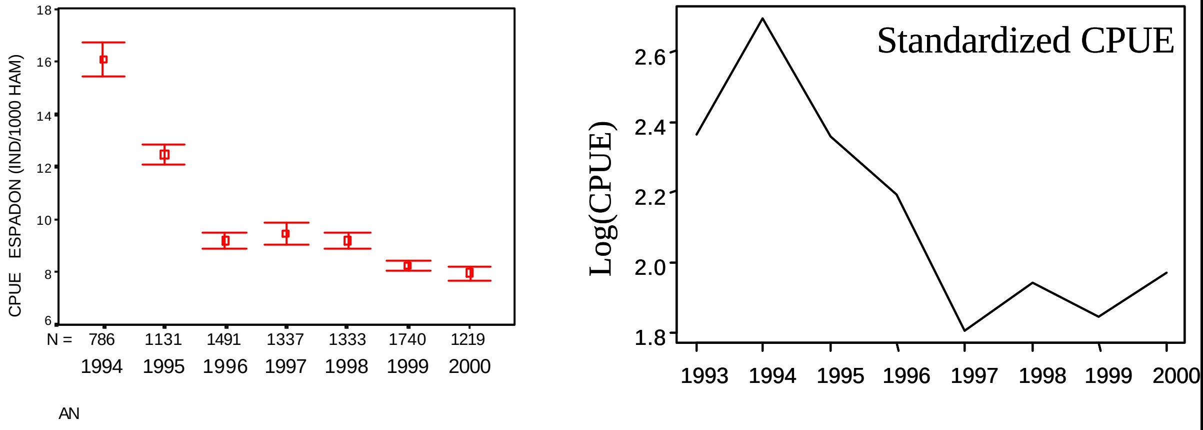


Figure 19.Nominal (left panel) and standardized (right panel) CPUE for the fleet operating froma La Réunion.



APPENDIX VI: CPUE ANALYSIS OF THE JAPANESE LL DATA

Data: Catch (in numbers of fish) and effort (in number of hooks) by 5º-grid and month for 1970-2000.

Model:

Log(CPUE + 0.1*mean(CPUE)) = f(Year + Areas + Quarter + Gear)

where

CPUE : Catch/(1000*Effort)

Year = Year (factor)

Areas = Areas 1 through 6 as defined during the meeting (factor with six levels)

Quarter = Quarter (factor with four levels)

Gear= Represents a proxy for targeting based on the number of hooks between floats. Gear is a factor with two levels: 'shallow fishing' (5-9 hooks between floats for years prior to 1994, 5-12 hooks after 1994); and 'deep fishing' (more than 10 hooks between floats prior to 1994, more than 12 hooks after 1994)

Constraints:

All observations with less than 5,000 hooks of effort were discarded.

Software used : SAS v 8.0

Results:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	179	14343.94862	80.13379	19.77	<.0001
Error	18612	75457.89549	4.05426		
Corrected Total	18791	89801.84411			

R-Square	Coeff Var	Root MSE	lcpue Mean
0.159729	-129.6948	2.013519	-1.552505

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yr	25	1297.317487	51.892699	12.80	<.0001
area	5	2348.394402	469.678880	115.85	<.0001
qt	3	252.286470	84.095490	20.74	<.0001
gear	1	465.858397	465.858397	114.91	<.0001
area*qt	15	990.814916	66.054328	16.29	<.0001
yr*area	125	2368.768108	18.950145	4.67	<.0001
area*gear	5	877.732462	175.546492	43.30	<.0001

Figure 20. Distribution of residuals from the GLM analysis.

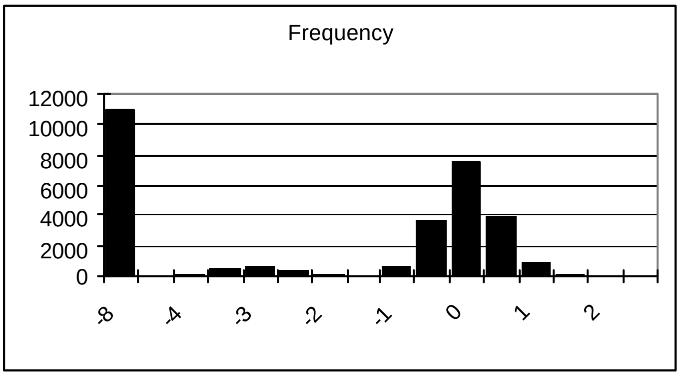


Figure 21. Standardized CPUE trend for the western (Areas 1-3) and eastern (Areas 4-6) Indian Ocean.

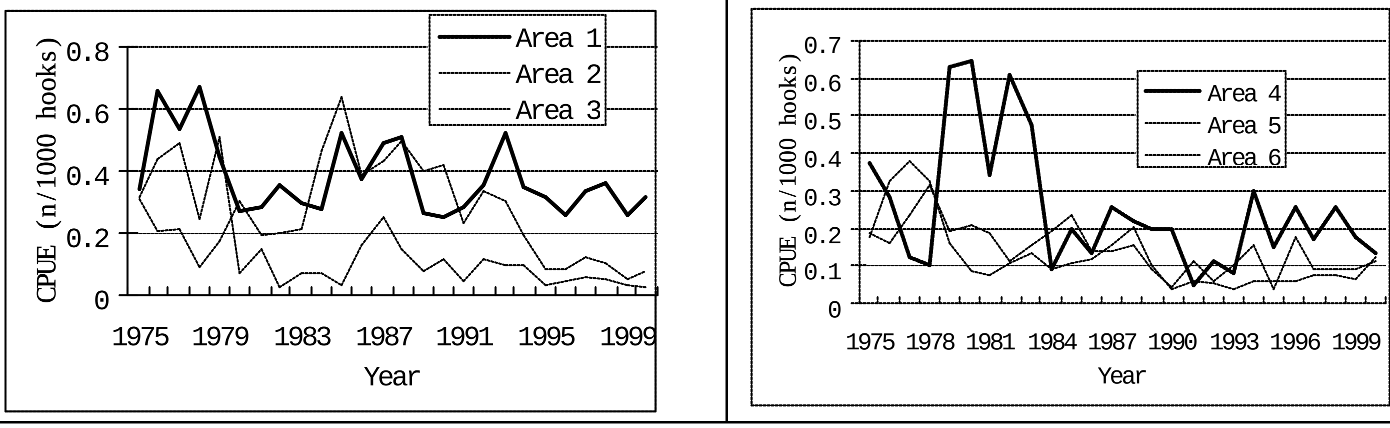
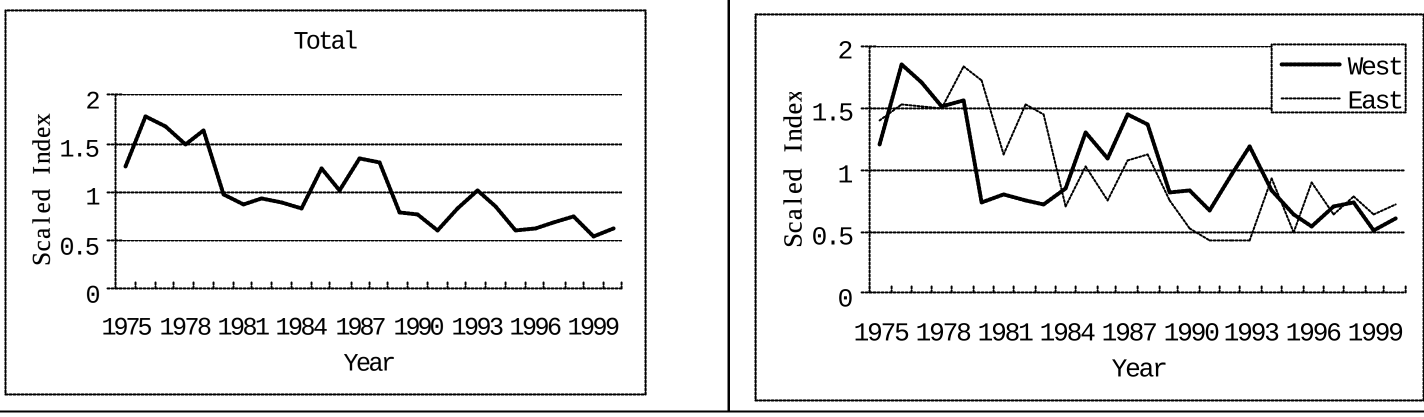


Figure 22. Standardized trends for the whole Indian Ocean (left panel) and by region (right panel). The combined indices were obtained using an area-weighted average of the CPUEs for the different areas.



APPENDIX VII. CPUE TRENDS IN THE TAIWANESE LL FISHERY

Data:

Catch (in numbers of fish) and effort (in number of hooks) by 5º-grid and month for 1967-1999.

Model:

Log(CPUE + 0.1*mean(CPUE)) = f(Year + Areas + Quarter + SWR)

where

CPUE : Catch/(1000*Effort)

Year = Year (factor)

Areas = Areas 1 through 7 as defined during the meeting (factor)

Quarter = Quarter (factor)

SWR = factor with two levels used as a proxy for targeting.

The procedure to obtain the factor was to compute the ratio

SWR =(SWO + BET)/(SWO + BET + SBF + YFT) for all observations.

Those records for which SWR > 0.2 were set to true.

Constraints:

All observations with less than 5000 hooks of effort were discarded.

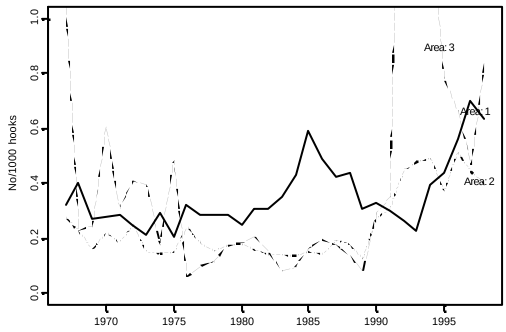
Software:

S-Plus 2000 release 3, glm procedure

Results

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Year	31	1858.91	59.9647	50.3307	0.0000000
Areas	6	951.74	158.6232	133.1385	0.0000000
Quarter	3	4.68	1.5584	1.3081	0.2698116
SWR	1	364.30	364.2953	305.7669	0.0000000
Year:Areas	184	1187.48	6.4537	5.4168	0.0000000
Residuals	15012	17885.52	1.1914		

Figure 23. Standardized CPUE for the western areas (Areas 1-3) and the eastern areas (Areas 4-7).



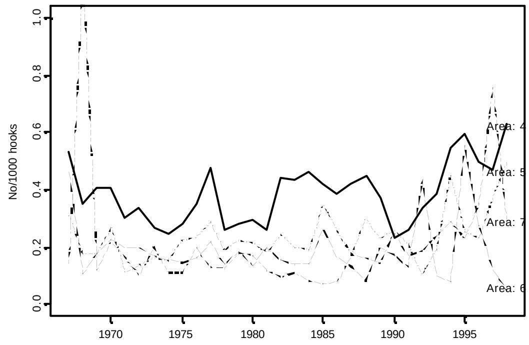
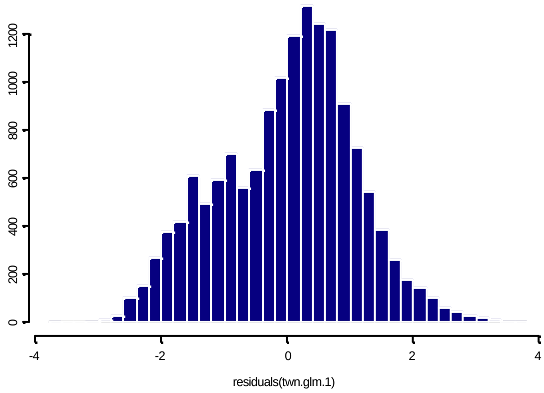


Figure 24. Distribution of residuals from the GLM analysis.



APPENDIX VIII. TABLES OF CATCHES FOR THE DIFFERENT BILLFISH SPECIES AND RELEVANT AGGREGATES.