PRELIMINARY ANALYSIS OF BILLFISH CATCH RATES IN THE INDIAN OCEAN

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ABSTRACT

Due to the general lack of targeted fisheries on billfish, the resource status of these species within the Indian Ocean has not been analysed in any previous study and currently remains unknown. Nevertheless, significant quantities of billfish are caught annually in the Indian Ocean and, being generally long lived, these species remain vulnerable to overfishing. In this paper preliminary indices of stock availability are presented for the main billfish species based on the catch and effort data pertaining to the Japanese and Taiwanese Indian Ocean longline fisheries. While the indices need to be treated with some caution (due to problems relating to the accuracy of the catch and effort data, and the fact that changes in catchability have not been factored into the analyses), the declines observed in the indices for black marlin, striped marlin and sailfish/spearfish warrant further investigation. In particular, further effort needs to the put into accounting for changes in targeting practices and the other changes in the fishing gears used.

RÉSUMÉ

La situation des ressources de poissons épée dans l'océan Indien n'a encore jamais été analysée et demeure inconnu en raison de l'absence de pêche dirigée sur ces espèces. Néanmoins, un nombre important de poissons épée sont pêchés tous les ans dans l'océan Indien et, puisqu'ils ont un cycle de vie long, ils sont vulnérables à la surexploitation. Cet article contient des indices préliminaires du statut des ressources des espèces principales, estimés à partir des données de prises et d'effort dans les pêcheries palangrières japonaises et taiwanaises dans l'océan Indien. Ces indices sont sujets aux incertitudes liés à la précision aléatoire des données de prises et d'effort et à l'absence d'intégration dans cette analyse de facteurs de capturabilité. Toutefois, les déclins dans les indices relatifs aux makaire noire, au marlin rayé, aux voiliers et aux makaires à rostre court exigent des recherches approfondies. Ces efforts doivent en particulier porter sur l'effet que pourrait avoir les variations de ciblage et de pratiques de pêche.

Introduction

The resource status of billfish within the Indian Ocean has not been analysed in any previous study and currently remains unknown (Anon, 1995a). This is due to a lack of a targeted fishery on these stocks and uncertainties in the data available. Nevertheless, significant quantities of billfish are caught annually in the Indian Ocean and, being generally long-lived, these species remain vulnerable to overfishing. In this paper, preliminary indices of stock availability are presented for the main billfish species based on the catch and effort data pertaining to the Japanese and Taiwanese Indian Ocean longline fisheries. The analysis assumes that the catch rates of a given species are a measure of the abundance and availability of that species to the fishery within a given region.

Note: The information in this paper is taken from the report "Synopsis of the billfish stocks and fisheries within the western AFZ and the Indian Ocean" (Campbell *et al*, 1998).

Billfish catches in the Indian Ocean

The estimated catch of tuna and tuna-like species of the tuna fisheries in the Indian Ocean more than doubled from 405,929 tonnes (t) in 1983 to 1,106,518t in 1995. During this same period the estimated catch of billfish nearly tripled, from 14,568t to 52,221t (Anon 1995b, 1997). This increase was mainly due to a substantial increase in catch in the western Indian Ocean (FAO Area 51) by Taiwanese longliners and coastal nations, in particular the Sri Lankan gillnet fishery.

The estimated annual catch of billfish in the Indian Ocean by species for Areas 51 and 57 between 1971 and 1995 is given in Tables 1 and 2. Note that the catches for 1995 are preliminary. The catch of billfish in the western region of the Indian Ocean is greater than that in the east (FAO Area 57) with 39,079t caught in Area 51 in 1995, compared to 13,142t in Area 57 (Anon, 1997). The western Indian Ocean catch statistics are mainly from longline catches of Japan, Taiwan and Korea; gillnetting by Sri Lanka and Taiwan and small troll, handline, purse-seine and unclassified gear catches from various coastal nations. The eastern zone catch estimates include the longline catches of Japan, Taiwan, Korea, Indonesia and Australia, along with gillnet catches by Taiwan. In Area 51, the unclassified billfish catch (BIL Not Elsewhere Included) is mainly due to Taiwanese, Korean and Indian longlining, and Pakistani gillnetting. For Area 57, unaccounted longline fishing is principally responsible for the unclassified catches, and to a lesser extent Indian unclassified gear and Korean longlining. A summary of the reported billfish catches between 1990 and 1995 by country is given in Table 3. Finally, plots of the annual catch by species for the entire Indian Ocean between 1985 and 1995, together with the annual catch of the principal fishing nations, are given in Figures 1a-f.

The above catch estimates are usually taken as being conservative. The catch of billfish is generally secondary to the catch of the principal tuna species or is a bycatch, and as such is often not well documented in logbooks. Billfish species are also sometimes lumped into single categories, misidentified or not recorded due to being discarded or used as "crew-share". Some industrial longline fleets are known to

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discard substantial numbers of billfish, and estimates of catch from these fleets are thought to be a poor reflection of actual catches. For example, longline vessels monitored in Colombo gave an estimated discard rate of 61 and 84 percent for black marlin and swordfish respectively, while for longliners monitored in Penang the estimated discard rate for various billfish species was 79 percent (Anon, 1997). Estimates of discard rates for Japanese longliners fishing within the western Australian Fishing Zone and in the fishery for southern bluefin tuna in the Indian Ocean are given in Table 4 (Campbell *et al*, 1998). These estimates have been obtained from onboard observers. Except for blue and black marlins, the discards rates are low in most instances. The higher discard rates for blue and black marlins are due to an agreement to release these species if still alive at the time of line retrieval. Discard rates for other distant water fishing nations remain unknown. On the other hand, since there is little processing or discarding in the coastal/artisanal fisheries, actual catches are considered to be close to the reported nominal catch. Likewise, purse-seine catches are frozen without processing. The IPTP strongly recommends that more information on bycatch and discards be collected either through logbook reports or observer programs (Anon, 1997).

The annual catch of tuna and tuna-like species of the industrial fisheries in the Indian Ocean was approximately equal to that of the coastal/artisanal fisheries during the decade up until 1995 (Anon, 1997). However, the distant water fishing nations generally caught more billfish than the coastal fisheries during the 1980s, but between 1990 and 1994 coastal nation catches of billfish were greater. This increase in coastal catches has been especially marked in the eastern side of the Indian Ocean, where coastal countries have been building up domestic or joint-venture longline fleets (Anon 1997; Somvanshi and John 1996).

All species of billfish, except striped marlin, have experienced an increase in catch since the mid-1980s. In most instances this increase is due to the increase in the catches taken by Sri Lanka and to a lesser extent by Indonesia and Taiwan. This increase is most evident in blue and black marlin and sailfish. Note that the large decrease in the catch of black marlin in 1994 and 1995 is mainly due to the decrease in the catch taken by Sri Lanka (taken by gillnetters). However, this decrease is offset by the increase to over 4,000t in the catch of unidentified billfish by Sri Lanka in 1995 (again taken by gillnetters). It is likely then that the total catch of black marlin has continued to remain high and has possibly increased. The low catch in 1994 appears to be anomalous and is likely due, in part, to incomplete data.

There has also been a dramatic increase in swordfish catch since 1990, corresponding to an increase in catch by Taiwan, and to a lesser extent Sri Lanka. To what extent these increases represent changes in targeting or simply improved reporting is unknown. The catch of sailfish (which is likely to also include shortbill spearfish as these two species are often not separately identified on logbooks) also shows a rapid increase over the past decade, again due to large increases in the catch by Sri Lanka. On the other hand, the catch of striped marlin has fluctuated around 2,500t since 1970, with most of the catch being taken by Taiwanese longliners. The Sri Lankan and Indonesian reported catch of striped marlin has not increased as it has with the other billfish species.

Catch rates as indices of stock abundance

The relationship between fishing effort, catch and stock abundance has long been of importance in the management of commercial fisheries. Annual comparisons of nominal catch rates (defined as total catch divided by total effort) are frequently used as an indicator of stock abundance over time. However, nominal catch rates tend to be biased as different spatial areas and temporal periods are not treated equally, but weighted by the effort distribution. Furthermore, the catch rates in any particular year are influenced by a number of other factors such as improvements in fishing gear and bait-type and the prevailing environmental conditions. Because of changes in these factors over time the comparison of catch rates between years is made more difficult, since the changes in catch rates may not be due only to changes in stock abundance. General linear modelling (GLM) is the standard method used to account for these biases and changes in the fishery. However, due to the limited availability of the necessary auxiliary information, a standardisation of this type could not be performed for the purposes of assessing the billfish stocks in the Indian Ocean. Instead, an index was produced by simply summing the area-weighted catch rates of a particular species over all individual areas considered to be within a core stock region of that particular species. The manner in which this index was derived is explained as follows.

From the catch equation it is assumed that the expected catch, C, is proportional to the average concentration of fish within a given fishing region, D, (i.e. number of fish per unit volume of water) and the amount of effort expended, E, (i.e. number of days fished or number of hooks fished). This relation can be expressed as follows:

$$C = q\,ED$$

where q is a constant known as the catchability coefficient. From this relation it follows that the expected catch rate is simply proportional to the average density of fish in that region:

$$CPUE = q\,D$$

Multiplying each side of this relation by the volume of the region fished, V, and using the fact that (Number of fish) = (Concentration of fish)*(Volume), one obtains an expression for the number of fish in that region, N, i.e.:

$$CPUE.V = q\,DV = q\,N$$

$$\Rightarrow \quad N = CPUE.V/q$$

If the spatial extent of the fishery is partitioned into a number of separate regions, then the total number of fish in the total fishery, N_T, is simple given by the sum of the number of fish in each region, i.e.

$$N_T = \sum CPUE_i.V_i/q_i$$

where the sum is over all the separate regions of the fishery.

Availability

The concept of measured abundance needs some elaboration. Of particular importance is the related concept of availability. The following definitions were proposed by Marr (1951):

Abundance is the absolute number of individuals in a population. Availability is the degree (a percentage) to which a population is accessible to the efforts of a fishery. Apparent abundance is the abundance as affected by availability, or the absolute number of fish accessible to the fishery.

As an example, consider a fish population that inhabits the waters above the thermocline and which is being fished by a longline fleet. Suppose that in the first year of the fishery the depth of the thermocline is 100m and the depth of the deepest longline hook is also 100m. During the second year of the fishery suppose that the depth of the thermocline increases to be 200m (due to changes in oceanographic conditions) while the depth of the deepest longline hook remains at 100m. If the fish population remains the same in the two years and is always evenly distributed in the water above the thermocline, then the number of fish available to the longline fishing gear during the second year will be half of that during the first year. As a consequence the apparent abundance during the second year will be half that of the first year. In response to this change in apparent abundance, the catch rates in the second year will also be half that obtained in the first year. This is despite the fact that the abundance of the population has remained constant for these two years.

If we let TB represent the true abundance of a fish population and let AB represent the apparent abundance of this same population, then we have the relation:

$$AB = aTB \qquad (2)$$

where 'a' represents the availability of the population. The expression given in equation (1) gives a measure of apparent abundance, as it is a measure of the population available to the fishery. From equations (1) and (2) it therefore follows that:

$$TB = \sum \frac{PCPUE_i V_i}{q_i a_i} \qquad (3)$$

Relating any measure of abundance obtained from CPUE to true abundance therefore not only assumes that changes in catchability, q_i, are adequately known, but that changes in the availability of fish, a_i, are also accounted for. At best, the variations induced by the fishery upon the size of the available population must be large relative to variations caused by fishery-independent factors. However, it is not always clear that such an assumption is entirely justified. When variations in availability are also large, the problem of relating changes in abundance to changes in fishing intensity becomes increasingly difficult.

Large-scale changes in oceanographic conditions from year to year can have a significant influence on the availability of a fish population to particular fisheries. This was clearly demonstrated in the example above. In a similar manner, inshore recreational strike rates in any season will be influenced by the distribution of fish between the inshore and offshore regions. However, while such changes will influence measures of apparent abundance from year to year, if these changes are random over time (e.g. there is no long term temporal shift in the environment) then the importance of these changes over the longer term is decreased. This is because the main objective of calculating indices of abundance is to discern trends over a given period of time. As such, short-term fluctuations due to inter-annual changes in oceanographic conditions can be seen as background noise over the long-term trend. However, if factors affecting fish availability change in a non-random manner through time, then this could introduce a temporal bias in any CPUE derived indices of stock abundance. A shift in targeting practices of a fishery over time is one obvious factor that could influence the availability of fish to the fishing gear in such a non-random manner.

For example, black marlin, together with yellowfin tuna, are generally believed to inhabit the upper 100-200m of the oceans. On the other hand, bigeye tunas are generally believed to inhabit the colder and deeper waters (Suzuki *et al*, 1977). If the target species of a longline fishery shifts from yellowfin tuna to bigeye tuna, then the amount of time the hooks spend fishing in the upper layers of the ocean will be reduced. This will result in the fishing gear becoming less available to the black marlin (and yellowfin tuna) population in these upper layers. As a consequence one would expect the catch rates, and apparent abundance, of these species to decrease as the targeting of bigeye tuna is increased.

Catchability

Fishing catchability relates to the fishing power or fishing efficiency of the fishery. That is, for a given concentration of fish in the water, how effective is the fishery at catching fish for a unit of effort? It is likely that if two boats expend the same fishing effort but use different fishing gears, then the CPUE for these two boats will most likely differ. It will be meaningless to relate the individual CPUEs to measures of localised abundance unless the effective levels of effort for the two methods can be standardised. By accounting for all differences between the two boats (skill of fishers, bait used, gears used, etc) one could ensure that the fishing mortality is equivalent per unit of fishing effort. However, the standardisation of differences in boat attributes is a complex issue, as all differences in the manner of fishing between the boats need to be fully understood and accounted for in the analysis. For similar reasons, standardising for changes in the catchability over the years of an entire fishery is also problematic.

Index of Apparent Abundance

From the forgoing discussion it is seen that unless one can account for changes in the availability of fish to the fishery, the only measure of abundance that one can measure is the apparent abundance of the fish population. From equation (1) the apparent abundance in year (i) and quarter (j) is given by the expression:

$$B_{ij} = \sum \frac{cpue_{ijk} V_k}{q_{ijk}}$$

where the sum is over (k), the index for all the individual spatial regions of the fishery. Assuming that in any year that q_{ijk} is the same in all quarters and regions, and if one partitions the fishery in regions of equal area (and volume) we can rescale the above expression to obtain the following index of apparent abundance:

$$B_{ij} = \frac{1}{q_i} \sum cpue_{ijk}$$

Finally, by taking the average of the index for each quarter, we can obtain an overall index for each year:

$$B_i = \frac{1}{4q_i}\sum_j \sum_k cpue_{ijk}$$

Three problems remain however. First, we need to account for changes in the catchability of the fleet between years. Unfortunately, the information needed for this is not available. Hence, in the following it is assumed that the catchability has remained constant over time. There is no further loss of generality by setting q_i=1. Second, we need to define the spatial extent of the fishery for a particular species. For example, while fishing effort is distributed across almost the entire Indian Ocean, southern bluefin tuna are only caught in the southern temperate regions. For the purpose of the following analysis, the Indian Ocean fishery was partitioned in regions of 5x5-degree blocks of latitude and longitude. (Note that while these regions are not all equal in size, due to the presence of land in some blocks and the convergence of the lines of latitude, these differences are ignored.) For each species the spatial extent of the 'core' fishery in each quarter was defined as consisting of those 5-degree blocks where the catch of that species was non-zero in over half of the years considered. Hence, only the catch rates in this set of 5-degree blocks were included in the calculation of the apparent abundance for that species in a given quarter.

The third problem relates to the fact that calculation of the apparent abundance across the entire fishery is reliant on all selected regions of the fishery being fished each year (so that a catch rate can be obtained in each region). Unfortunately, the spatial distribution of fisheries in the Indian Ocean may change from year to year. As a consequence, there is no catch rate information and hence no estimate of the density of fish in a number of areas of the fishery. In this situation we can make two assumptions. First, the catch rate of a particular species in those blocks not fished in any given quarter and year is zero. The index of abundance is then calculated as follows:

$$B_i^{\min} = \frac{1}{4}\sum_{j=1}^{4}\sum_{k=1}^{NF_{ij}} cpue_{ijk},$$

where $NF_{ij} \le NB_j$ is the number of fished blocks within the fishery for the i^{th} year and j^{th} quarter and where NB_j is the total number of blocks in the fishery for that quarter. If the spatial extent of the stock in each year and quarter actually coincides with the blocks fished in that year and quarter, then the above formula will give an index of abundance for the total stock. However, if the spatial extent of the stock is greater than the blocks that are fished, then the index above will underestimate the true stock abundance, and only give an indication of the relative stock abundance within the portion of the stock's range that is fished. The abundance beyond the fished blocks will in this situation remain unknown. Since it is unlikely that the distribution of the stock and the fishery will coincide in each year and quarter, the above index is likely to be a minimum measure of total stock abundance. For this reason the index is known as the B-minimum (B-min) index.

The second assumption that is used is to assume that the spatial extent of the stock remains constant over time and equal in extent to the entire core region identified above. The catch rate in the i^{th} year and j^{th} quarter for those blocks not fished but within the core region is then taken to be equal, on average, to the mean of the catch rates in those blocks that are fished for that year and quarter. The index of abundance then becomes,

$$B_i^{ave} = \frac{1}{4}\sum_{j=1}^{4}\left(\sum_{k=1}^{NF_{ij}} cpue_{ijk} + (NB - NF_{ij}).\overline{cpue_{ij}}\right),$$

where $\overline{cpue_{ij}}$ is the average catch rate in year (i) and quarter (j) for those blocks that are fished. The number of 5-degree blocks that are not fished but are within the designated core billfish area is (NB-NF_{ij}). This index is known as the B-average (B-avg) index.

While these indices may take account of large-scale shifts in area and time, they do not account for shifts on a finer scale. They also do not consider changes in environmental conditions, gear or targeting practices. Billfish are not the principal target species of the Japanese and Taiwanese fleets (except perhaps swordfish in more recent years), and so changes in targeting practices can unduly influence catch rates and therefore indices of abundance. As such, and due to all of the above assumptions, conclusions based on these analyses should be treated with some caution.

Data used in analyses

Yearly and quarterly effort (in hooks) and catch (in numbers) data were available on a 5-degree basis for the major billfish species (source IOTC) caught in the Indian Ocean. However, only the Japanese and Taiwanese data were used in the following analyses, as these data were the most extensive in terms of spatial and temporal coverage.

The available Japanese data covered the years 1952 to 1995, though due to the early decades being a period of exploration and expansion, only the years from 1970 were used in the following analyses. The annual catch and effort information since 1970 is given in Table 5. The greater proportion of the billfish catch has been taken in Area 51. However, as shown in Figures 1a-f the reported catch of billfish by the Japanese longline fleet has not been substantial since the late 1980s. The catch of swordfish increased from 1-2 % of the total catch in the early 1970s to over 5 % in the early 1990s. At the same time the catch of other billfish has decreased from over 7 % of the total catch in the early 1980s to under 3 % during the 1990s. Catches of the tunas have also changed as a proportion of total catch, with southern bluefin tuna decreasing, and bigeye increasing. The proportion of yellowfin tuna in the catch has also increased since the mid-1980s.

Likewise, the available Taiwanese data covered the period 1967 to 1994, though only data from 1975 onwards was used. The catch information in Table 6 shows a gradual trend away from albacore to bigeye and yellowfin tunas. Proportions of blue and black marlin have declined to less than 1 % of the catch, while striped marlin has decreased to just over 2 % from a peak of around 10 % in the late 1970s and early 1980s. After remaining at less than 5 % of the total catch from 1970 to 1987, swordfish catch increased to nearly 10 % of the total in 1992, and then after decreasing in 1993 increased dramatically in 1995 to nearly 19 % of the catch. There has possibly been a move to more southerly latitudes in recent years, as suggested by the increase in SBT and drop in yellowfin tuna. In 1993, the proportion of blue, black, striped marlin and swordfish caught in the east compared to the west was 20 %, 24 %, 15 % and 7 % respectively (source IPTP/IOTC). Note that there are some concerns about the accuracy of the Taiwanese data and inefficiencies in the compilation system. The fisheries management sector of Taiwan is currently attempting to improve logbook recovery and validation (Huang, 1996).

Results

Indices of abundance for black, blue, and striped marlin, swordfish and sailfish are shown in Figures 2b to 6b respectively. For comparison, indices from Japanese and Taiwanese catch and effort data are shown together. The quarterly core catch areas for each billfish species are shown in Figures 2a to 6a. As stated previously, a 5-degree block is included in the core catch area if a catch occurred in that block on more than half of the years considered in the catch rate analysis. For indices based on the Japanese data, a block was included if fished in over 13 years during the period 1970 to 1995. Similarly, a block was required to be fished in over 10 years during the period 1975 to 1994 for indices based on Taiwanese data. Note that these core catch areas are constrained by the spatial distribution of effort of each of the nations and so do not give a true indication of the potential range of the species.

Black Marlin

The reported Indian Ocean catch of black marlin increased gradually from below 500t in 1977 to nearly 3,500t in 1993. This increase was mainly due to Sri Lankan gillnetting and Taiwanese and Indonesian longlining. Catch by Japanese longline vessels has decreased since the mid-1980s and was less than 100t in 1994. The core catch areas for black marlin are mainly North of 15°S, with the exception of an area off eastern South Africa fished by Japanese vessels (Figure 2a). The core catch area shows its greatest spatial extent in quarters 1 and 4.

After a sharp drop in the early 1970s, the index of apparent abundance for black marlin from the Japanese fishery remained relatively stable through to 1986, after which the index declines markedly to 1990 (Figure 2b). From 1990 until 1995 the index remains at a low level, with no sign of increase. A similar decline in the index is seen in the Taiwanese catch and effort data, though with a delay of one year. After a stable period through the late 1970s and early 1980s, the index dropped markedly after 1987, and remained at depressed levels until 1994 when an increase is observed. As stated in the previous section, the relation between apparent abundance and true abundance is determined by the availability of the fish to the fishing gear. From equation (2) it is seen that a decline in apparent abundance can be the result of a decline in either the true abundance of the resource, a decline in availability, or both. Unfortunately, without further information it is difficult to resolve the contribution each of these factors to the pattern of changes in the above indices.

Changes in the fishery through time may account for some of the observed decline. For example, regulations regarding the release of all live black and blue marlin within the Australian Fishing Zone (AFZ) in 1987 would tend to decrease catch rates of black marlin if these are not reported. However, the release of live black marlin is not enforced on the high seas, and the AFZ provides only a fraction of the core area of black marlin (Figure 2a). It is known that some Japanese longliners did target black marlin within the AFZ during some years before the voluntary agreement came into place. Furthermore, the abundance of black marlin is often higher in coastal waters and the exclusion of longline fleets from these regions after the declaration of Exclusive Economic Zones has contributed to the decline in catch rates (Y. Uozumi, pers comm.).

Increased targeting of bigeye tunas by Japanese and Taiwanese longliners may have also reduced catch rates of black marlin due to the hooks fishing at depths greater than that preferred by this species. While the targeting practices of the Japanese (or Taiwanese fleet) remain unknown, information from the equatorial Pacific Ocean indicates that, after 1988, the Japanese longline fleet increased the number of hooks set between the buoys (Campbell, 1998). This increase may have been associated with setting the hooks deeper. If such a strategy was also followed in the Indian Ocean this may help explain the large decrease in catch rates after this time. However, without more information on these matters and a more in-depth analysis of the data the true reasons for the decreases in the catch rates for black marlin remain uncertain. Similar concerns regarding the decline in the observed catch rate of black marlin were expressed for the Pacific Ocean stock (Skillman, 1989; Suzuki, 1989).

Finally, the decrease in the indices for black marlin coincides with a large increase in the catch of this species by Sri Lankan gillnetters (cf. Figure 1a). Whether or not these two events are related remains unknown, but the increased catches by Sri Lanka may be impacting on the availability of black marlin in the wider Indian Ocean.

Blue Marlin

The reported catch of blue marlin increased gradually from approximately 3,000t in the late 1970s to nearly 9,000t in 1994. This increase is largely due to Sri Lankan gillnetting and Taiwanese and Indonesian longlining. The Japanese catch has decreased since the mid-1980s and was less than 500t in 1994. The core catch area of blue marlin shows a similar distribution to that of black marlin (Figure 3a), though the spatial extent of the core area expands further south in quarters 1 and 4 than that of black marlin, reaching approximately 25°S. There has been no stock assessment for blue marlin in the Indian Ocean, however assessments for the Pacific Ocean stock indicate that blue marlin may have been over-exploited (Skillman, 1989; Suzuki, 1989).

The indices of apparent abundance for blue marlin in the Indian Ocean for both the Japanese and Taiwanese data (Figure 3b) show similar trends to those for black marlin. A stable period through the 1970s and early 1980s is followed by a marked decline after 1987. Low levels continue until 1993 when signs of recovery are observed. The similarity of the trends in the indices for blue and black marlin lends some weight to the argument that the changes observed in these indices are due to changes in the fisheries and not solely due to changes in the true abundance levels of these species. Furthermore, as with black marlin, the voluntary agreement to release live blue marlin and the shift to deeper longlining may have affected catch rates and caused the observed declines. However, for the reasons already mentioned, this does not appear to fully explain the decline. As with black marlin, is also interesting to note that the decline in the blue marlin catch rates by Japanese and Taiwanese longliners again coincides with the large increase in the catch of this species by Sri Lankan gillnetters.

Striped Marlin

The Indian Ocean catch of striped marlin has fluctuated greatly since the 1970s, remaining between 2,000t and 4,000t per annum. Until the 1990s, the main nations catching striped marlin were Japan and Taiwan, however Indonesian longline vessels now catch more striped marlin than Japan (cf. Figure 1c). During quarters 1 and 4 the core catch area is predominantly North of 20°S, with the exception of an area off the East coast of South Africa (Figure 4a). In quarters 2 and 3 core areas are found North of 10°S and also in a band between 25°S and 35°S, this being mainly due to Taiwanese vessels. While no assessments of striped marlin exist for the Indian Ocean, Skillman (1989) and Suzuki (1989) conclude that stocks in the Pacific Ocean were either at or below optimal exploitation levels.

The indices of abundance for Indian Ocean striped marlin (Figure 4b) show an increase in the mid-1970s through to the early 1980s after which there was a substantial decrease. This was followed by a slight increase to 1986, and then a further decline through the 1990s. The Taiwanese index shows signs of recovery from 1993, whereas the Japanese index does not. The increase in the catch rates for the Taiwanese is likely to be due to spatial shifts in the fishery or changes in targeting practices. Striped marlin are considered to be the best among the billfish for marketing (Nakamura, 1985) and have been targeted for this reason. However, as before, the interpretation of these changes is difficult without a clearer understanding of the targeting practices of the fishing fleets. For example, striped marlin have higher abundance in coastal waters and the decrease in the Japanese effort in the coastal waters off Somalia and India may have contributed to the decline on catch rates of striped marlin observed for this fleet (Y. Uozumi, pers comm.).

Swordfish

Figure 5a shows that the core swordfish catch areas are found in northerly latitudes (North of 20°S in quarters 1 and 4, and North of 10°S in quarters 2 and 3) and off the West coast of Australia and the East coast of South Africa (Japanese vessels). In quarters 2 and 3 the central Indian Ocean shows no core blocks. However, as with striped marlin, a band forms in southern latitudes between 25°S and 40°S. This is likely to be due to vessels shifting their effort to southern waters in order to target southern bluefin tuna.

There have been no stock assessments of Indian Ocean swordfish (Anon, 1995a). Swordfish catches remained between 2,000-3,000t for the period 1970-84 but have since increased, with the catch reaching 18,000t in 1993. The recent increase in catches by Sri Lankan and Taiwanese fleets has instigated the IOTC to devote effort to monitoring catch and improving data collection procedures to assist stock assessments. The 6th Expert Consultation on Indian Ocean Tunas concluded that, while the stock status is unknown, the wide geographic distribution and low historical levels of catch indicate that the stock would not be adversely affected by increased exploitation (Anon, 1995a). Sakagawa (1989) concluded that Pacific Ocean stocks are in good condition. However, as noted by Campbell *et al*. (1996), swordfish have a slower growth rate, lower fecundity and a later age-at-maturity than the marlins and these biological factors should be considered when assessing the stock and estimating potential yields. As such, the large increases in the catch of swordfish in the Indian Ocean seen during the 1990s need to be viewed cautiously.

In general, the swordfish indices of apparent abundance remained stable through the 1970s and 1980s (Figure 5b). However, while the Taiwanese index shows a substantial increase in 1993 and 1994, the Japanese index continues to remains relatively stable. The observed increase in the index based on Taiwanese data is almost certainly due to a change in targeting practices or unreliable data, and not indicative of any change in stock abundance. Swordfish catch increased from approximately 6 % of the annual Taiwanese catch in the Indian Ocean in the late 1980s to nearly 19 % of the catch in 1995. This is indicative of a major shift in targeting practice. It is believed that this fleet started targeting swordfish by using surface longlines at night. As such the swordfish index for this fleet shown in Figure 5b is not a reliable estimator of the true temporal trend in stock abundance.

Sailfish/Spearfish

Taiwanese longline vessels are reported to have been largely responsible for the substantial yield of sailfish in Indian waters (John *et al*., 1996) where over 20 % of the total reported Indian Ocean catch of sailfish is reportedly taken. Unfortunately, the Taiwanese data provided by the IOTC does not include any reference to sailfish. Large increases in the catch of sailfish have occurred since 1984, with the majority of the catch being taken by Sri Lanka and Indonesia.

The reported catch of sailfish on Japanese longliners is combined with the reported catch of spearfish. As such it is only possible to analyse the combined data for these two species. The core catch areas of sailfish and spearfish for the Japanese longline fleet are in northerly latitudes and predominantly in quarter 1 (Figure 6a). The index of apparent abundance for these species from Japanese catch and effort data shows a dramatic decline from the early 1970s to 1992, after which a small increase is observed (Figure 6b). The reasons for this large decline remain unknown. However, as the catch of sailfish before the mid-1980s was generally small (less than 1,000t, cf. Figure 1e) this decline is more likely to be due to changes in the fishery than due to a large decline in the abundance of sailfish (and /or spearfish). As with some of the marlin species, higher catch levels of sailfish are also known to occur in coastal waters, close to islands and reefs and the move away from these areas would account for some of the declines seen in the Japanese catch rates. Indeed, at a recent meeting of the scientific committee for ICCAT (International Commission for the Conservation of Atlantic Tunas) it was decided not to use the Japanese data on sailfish for stock assessment purposes since the catch rate trend for sailfish from Japanese longliners is significant different from those of coastal fisheries off Africa. Since 1993 the Japanese have begun to report the catch of sailfish separately from that of spearfish (Y. Uozumi, pers comm). This will help to ascertain the distribution and catch of this species in the Indian Ocean in future years.

As with blue and black marlin, the catch of sailfish taken by Sri Lankan gillnetters increased in the late 1980s. However, unlike the indices for these other species, the decline in the index for sailfish began long before this increased catch occurred. Nevertheless, after being somewhat stable during the first half of the 1980s, the index again decreased after1986.

Conclusions

The purpose of this paper is to initiate discussion on the status of the various billfish species found in the Indian Ocean through the presentation of possible indices of apparent stock abundance based on the catch and effort data available at this time. While the indices need to be treated with some caution (due to problems relating to the accuracy of the catch and effort data, and the fact that changes in catchability have not been factored into the analyses), the declines observed in the black marlin, striped marlin and sailfish/spearfish indices are reason for some concern and warrant further investigation. In particular, further effort needs to the put into accounting for changes in targeting practices and the fishing gears used and possible long-term changes in environmental or oceanographic influences on fish availability. The possibility of large-scale interactions between different fisheries should also be investigated.

Knowledge of basic biological parameters and fisheries data also needs to be improved in order to provide the necessary information to assess the status of these species. At present, billfish statistics are hindered by the under-reporting, discarding and non-reporting of billfish catches by species. For example, in 1993 22 % of billfish catches were not reported by species, down from 40 % in 1989 (Anon, 1995a). The collection of accurate catch and effort statistics and improved biological data should therefore be a high priority for Indian Ocean billfish species. Until this is undertaken the status of billfish stocks in the Indian Ocean will remain largely uncertain.

Acknowlegdements

The authors wish to thank David Ardill and Claude Fernando of the Indian Ocean Tuna Commission for providing catch and effort data pertaining to the Indian Ocean. Naozumi Miyabe and Yuji Uozumi of the National Research Institute of Far Seas Fisheries, Japan, are also thanked for providing additional data and comments relating to Japanese catch and effort in the Indian Ocean.

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Table 1. The estimated catch (metric tonnes) of billfish in the western Indian Ocean (FAO Area 51). These estimates are seen as being conservative and some caution is needed in their interpretation. The catches for 1995 are preliminary. Note: BIL NEI = Billfish not elsewhere included. (Source IOTC).

YEAR	Black Marlin	Blue Marlin	Striped Marlin	Swordfish	Sailfish	BIL NEI	TOTAL
70	402	2085	2121	1264	600	740	7,212
71	229	1593	1020	857	700	1372	5,771
72	228	1790	1633	856	500	1622	6,629
73	74	842	1001	757	200	1307	3,265
74	82	762	2148	640	194	3712	7,538
75	29	1975	947	738	459	890	5,038
76	14	901	513	798	363	1476	4,065
77	68	1325	1181	838	165	1610	5,187
78	291	1754	1701	1236	150	2491	7,623
79	126	1498	1214	947	386	2893	7,064
80	127	1025	831	589	392	2237	5,201
81	165	1332	722	903	284	2878	6,284
82	205	1669	683	1370	324	5410	9,661
83	216	1983	578	1261	290	3836	8,164
84	340	1365	779	1041	257	5034	8,816
85	419	1725	2685	2019	1885	5116	13,849
86	962	2754	2382	2494	1173	5685	15,450
87	703	3484	1776	2595	1285	5623	15,466
88	1478	5216	1556	3704	3342	5447	20,743
89	929	3115	1001	2307	2299	8223	17,874
90	1099	4330	605	3169	2942	8110	20,255
91	886	5427	1144	4007	4250	6262	21,976
92	1665	5554	1402	8002	3639	6012	26,274
93	2976	4476	3119	8769	5091	6084	30,515
94	155	7307	1667	7168	7677	9417	33,391
95	171	440	2002	17928	5754	12784	39,079

Table 2. The estimated catch (metric tonnes) of billfish in the eastern Indian Ocean (FAO Area 57). These estimates are seen as being conservative and some caution is needed in their interpretation. The catches for 1995 are preliminary. Note: BIL NEI = Billfish not elsewhere included. (Source IOTC).

YEAR	Black Marlin	Blue Marlin	Striped Marlin	Swordfish	Sailfish	BIL NEI	TOTAL
70	342	1958	984	1126	200	157	4,767
71	319	1282	542	739	100	140	3,122
72	320	985	445	439	0	140	2,329
73	254	787	520	357	0	11	1,220
74	460	1304	690	617	51	31	3,153
75	274	1535	795	898	130	1221	4,853
76	108	1542	1429	694	132	778	4,683
77	105	823	1827	614	62	536	3,967
78	188	1225	3038	844	105	837	6,237
79	252	1761	1983	1023	160	1176	6,355
80	541	1749	3286	1052	187	1160	7,975
81	466	1213	3500	939	86	709	6,913
82	355	1009	1339	806	104	554	4,167
83	762	1465	1987	1327	123	740	6,404
84	882	2338	1891	1280	144	738	7,273
85	797	1759	2225	1464	103	1014	7,362
86	585	1309	2145	1266	107	1099	6,511
87	480	1174	1912	1546	47	935	6,094
88	516	1534	978	1898	370	933	6,229
89	505	1681	938	1965	362	3575	9,026
90	543	2518	644	1716	758	4314	10,493
91	428	1911	640	1131	611	3521	8,242
92	400	2143	669	1492	613	4196	9,513
93	411	2235	906	1436	765	4566	10,319
94	374	1905	752	2307	743	5604	11,685
95	417	1929	850	3700	746	5500	13,142

Table 3. Nominal catch of billfish in the Indian Ocean by country. (From Anon, 1997)

Country	Area	1990	1991	1992	1993	1994	1995
Australia	57		4	32	193	157	73
China(Taiwan)	51	3,411	5,237	8,423	7,055	4,998	15,856
	57	879	1,003	1,538	1,241	1,102	2,395
Comoras	51	678	678	327	327	386	386
France	51		8	100	218	218	453
Honduras	51	64	87	166	163	171	432
	57				681	1,127	878
India	51	1,010	766	1,060	1,199	1,458	1,383
	57	38	23	335	540	260	244
Indonesia	57	4,695	3,964	3,980	3,980	3,980	3,980
Iran	51		170	170	740	1,085	
Japan	51	891	675	1,448	799	1,703	1,208
	57	768	179	259	478	538	1,051
Kenya	51	212	292	224	241	241	241
Korea	51	2,427	1,006	1,724	2,274	3,118	2,179
	57	459	46	18	131		
Malaysia			1			3	3
Mauritius	51	228	172	264	194	227	196
Mozambique							312
Oman	51	774	251	808	694	563	973
Pakistan	51	1,932	3,357	3,398	2,976	3,787	3,594
Seychelles	51	23	13	7		2	
South Africa	51			1	2		
Spain	51				163	543	
Sri Lanka	51	6,424	7,783	6,543	11,437	14,027	11,126
Tanzania	51	454	288	300	531	670	580
United Arab E.	51	200	192	199	193	193	180
Not Elsewhere	51	1,527	1,001	1,112	1,309		
	57	3,654	3,022	3,351	3,075	4,518	4,518
Total		30,748	30,218	35,787	40,834	45,076	52,221

Table 4. Discarding and retention practices (expressed as a percentage of the total observed) for billfish caught by Japanese longliners fishing within the western Australia Fishing Zone (AFZ) and in the wider Indian Ocean.

Zone	Species	Discarded	Retained	Not Recorded	Number Observed
Western AFZ	Black Marlin	53	47	0	34
	Blue Marlin	40	60	0	20
	Striped Marlin	12	88	0	17
	Swordfish	14	80	6	708
	Sailfish	50	50	0	4
	Spearfish	56	40	4	25
Indian Ocean	Swordfish	5	91	4	191
	Spearfish	0	96	4	23

Table 5. Effort in millions of hooks and total catch in metric tonnes by Japanese longliners in the Indian Ocean east of 30°E. The figures for species are the proportion that each species represents in the total catch. (Adapted from data supplied by H. Okamoto and N. Miyabe).

Year	Hooks (million)	Total(t)	SBT	ALB	BET	YFT	BAM	BUM	STM	SWO
1971	83	51,166	35.7	5.7	21.9	27.2	1.6	2.0	2.0	1.9
1972	59	33,995	42.7	2.6	24.0	20.6	1.0	2.7	2.2	2.0
1973	65	31,289	55.5	5.2	17.1	14.7	0.8	2.0	1.7	2.1
1974	72	38,728	51.5	6.4	18.8	13.4	1.3	2.5	3.4	1.8
1975	86	35,202	47.8	3.2	23.5	16.6	1.4	2.1	2.5	2.3
1976	65	26,952	71.9	2.9	10.0	9.5	0.8	1.2	1.8	1.3
1977	53	24,891	64.3	1.0	19.4	10.1	0.7	1.2	2.1	1.0
1978	52	32,101	26.8	0.8	43.9	15.4	1.3	3.3	5.3	2.7
1979	50	18,905	46.8	1.0	26.2	14.5	1.0	2.4	5.6	2.1
1980	68	25,291	49.1	1.6	24.4	14.7	1.1	2.8	4.3	1.7
1981	63	23,742	42.6	3.7	26.8	16.3	1.0	3.3	3.8	2.2
1982	66	28,727	30.8	2.6	36.2	20.7	0.9	3.8	2.1	2.6
1983	95	42,964	33.6	2.7	40.0	15.4	0.8	3.7	1.4	2.2
1984	92	37,626	32.6	3.7	34.1	18.8	1.6	3.9	2.6	2.5
1985	110	45,723	29.6	4.3	36.2	19.8	0.9	3.2	2.1	3.6
1986	104	39,942	22.0	4.6	37.7	26.4	0.8	3.1	2.4	2.7
1987	91	34,665	22.2	4.7	42.5	21.8	0.8	2.7	1.9	3.2
1988	75	30,735	24.0	3.2	38.0	27.3	0.6	2.5	0.9	3.4
1989	60	18,003	32.7	3.2	37.7	19.6	0.5	1.9	0.7	3.4
1990	35	17,891	18.1	3.5	42.7	28.6	0.4	1.7	0.6	4.2
1991	45	14,805	13.1	5.4	48.3	26.0	0.4	1.5	1.0	4.2
1992	41	13,828	17.9	7.4	34.6	27.8	0.5	2.1	1.3	8.2
1993	38	14,644	7.9	6.3	50.2	26.1	0.4	2.0	0.7	6.4
1994	67	27,452	8.1	5.4	53.0	25.4	0.2	2.2	0.7	4.9
1995	80	26,863	8.4	6.6	55.2	22.3	0.3	1.6	0.8	4.6
1996	101	34,920	10.3	7.1	42.8	32.1	0.2	1.6	0.8	4.9

Note: SBT=Southern bluefin tuna, ALB=Albacore tuna, BET=Bigeye tuna, YFT=Yellowfin tuna, BAM=Black marlin, BUM=Blue marlin, STM=Striped marlin, SWO= swordfish

Table 6. Effort in millions of hooks and total catch in metric tonnes by Taiwanese longliners in the Indian Ocean. The figures for species are the percentage that each species represents in the total catch of tuna and tuna-like species. (Source IOTC).

Year	Hooks (M)	Catch (t)	SBT	ALB	BET	YFT	BAM	BUM	STM	SWO
1970	46.7	33,418	0.0	21.5	25.8	38.3	2.2	4.6	3.3	2.4
1971	44.8	25,620	0.2	27.2	18.6	39.8	2.1	5.0	2.2	2.3
1972	39.2	25,413	0.2	27.5	18.8	40.1	2.2	5.0	2.2	2.3
1973	32.6	22,377	0.0	53.4	15.3	21.9	1.5	3.7	1.8	1.9
1974	52.8	29,353	0.2	59.3	17.7	12.9	1.8	2.8	2.6	2.1
1975	37.1	17,976	0.1	35.5	25.7	22.2	1.7	3.8	3.0	3.4
1976	32.9	19,075	0.1	51.1	19.0	15.2	0.6	2.5	6.4	3.0
1977	33.9	25,630	0.1	38.2	20.9	27.2	0.7	2.5	8.0	2.2
1978	36.6	24,713	0.2	51.8	17.3	14.8	0.4	3.1	10.4	1.5
1979	57.8	28,031	0.2	53.5	22.8	11.4	0.5	3.2	5.5	2.6
1980	59.6	26,634	0.2	41.2	29.0	12.3	1.1	3.3	9.4	3.1
1981	51.9	26,455	0.1	46.6	22.4	13.4	0.9	3.1	10.7	2.7
1982	79.5	39,163	0.1	56.0	25.0	10.4	0.5	2.2	3.1	2.4
1983	86.3	36,118	0.1	47.0	27.1	13.3	1.3	3.1	4.6	3.4
1984	82.4	32,760	0.4	42.5	28.7	15.3	1.0	4.5	4.1	3.4
1985	65.0	27,738	0.0	22.2	38.0	21.3	1.5	4.8	7.1	4.7
1986	86.4	47,628	0.0	23.2	30.6	29.3	1.0	4.9	6.5	4.2
1987	109.0	55,197	0.2	23.8	27.6	33.3	1.1	4.2	5.0	4.4
1988	122.7	52,106	0.2	21.2	32.1	31.8	0.9	3.5	3.6	6.4
1989	133.3	43,899	0.4	16.2	33.9	34.7	0.8	2.8	3.2	5.8
1990	125.4	39,823	0.4	14.5	43.4	31.1	0.4	1.9	1.5	6.1
1991	146.5	45,908	0.2	28.5	38.8	18.7	0.4	1.9	2.6	6.6
1992	140.3	58,749	0.1	18.9	27.9	36.0	1.0	3.0	1.9	9.9
1993	341.0	131,551	0.5	9.0	26.0	57.6	0.1	1.6	2.3	1.6
1994	207.6	74,569	1.1	19.3	32.2	39.3	0.1	0.4	2.5	5.0
1995	NA	81,856	1.6	17.4	34.5	24.3	0.2	0.1	2.7	18.8

Note: SBT=Southern bluefin tuna, ALB=Albacore tuna, BET=Bigeye tuna, YFT=Yellowfin tuna, BAM=Black marlin, BUM=Blue marlin, STM=Striped marlin, SWO= swordfish

Figure 1a. The estimated total catch of black marlin in the Indian Ocean. Catches by the major fishing nations are also shown. Sri Lanka (SL), Indonesia (INDO), Taiwan (TAI) and Japan (JAP). Note that the data for 1994 may be incomplete. Source IPTP.

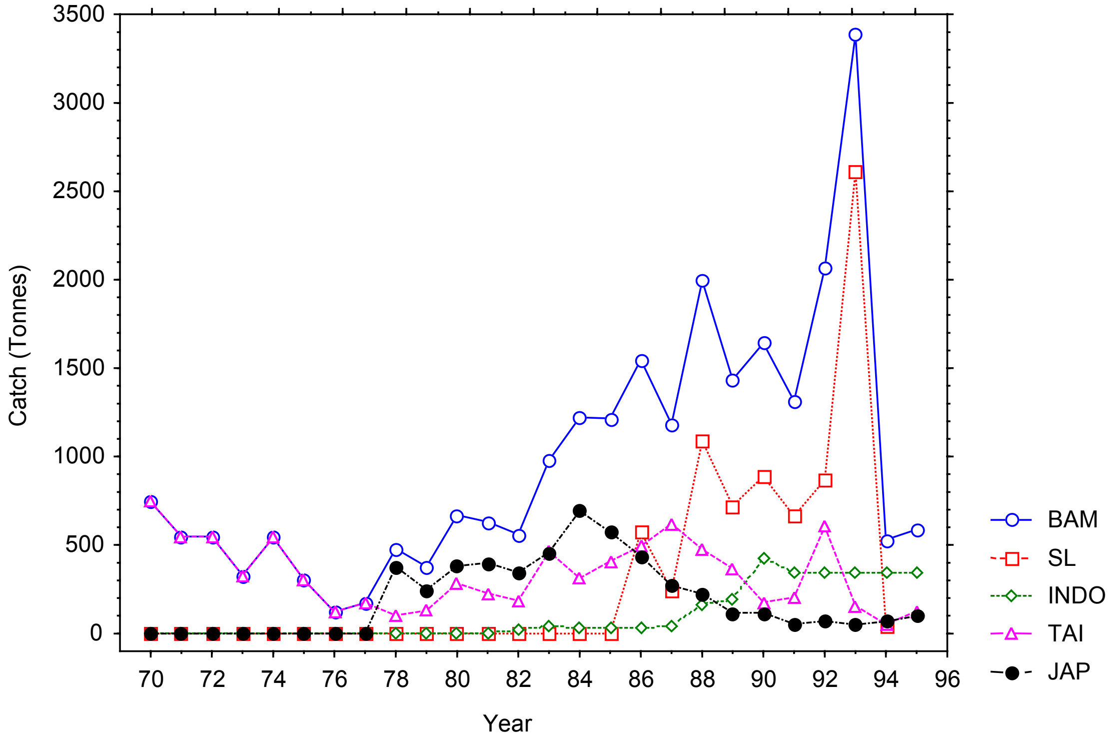

Figure 1b. The estimated total catch of blue marlin in the Indian Ocean. Catches by the major fishing nations are also shown. Sri Lanka (SL), Indonesia (INDO), Taiwan (TAI) and Japan (JAP). Source IPTP.

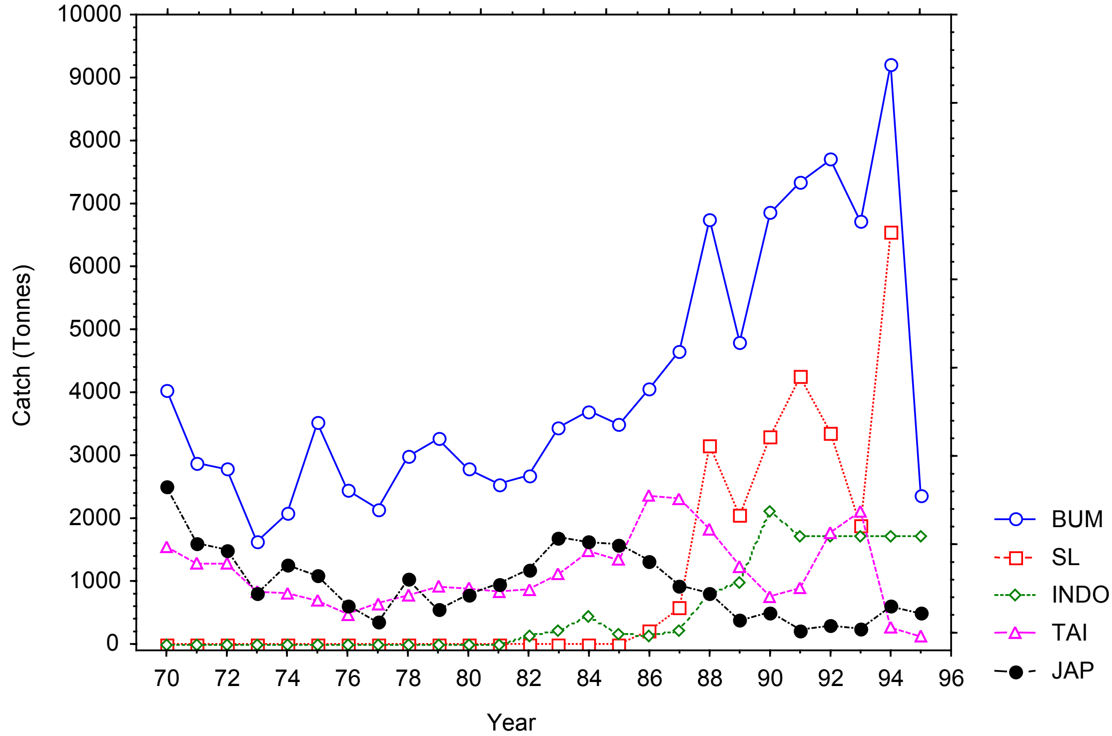

Figure 1c. The estimated total catch of striped marlin in the Indian Ocean. Catches by the major fishing nations are also shown. Sri Lanka (SL), Indonesia (INDO), Taiwan (TAI) and Japan (JAP). Source IPTP.

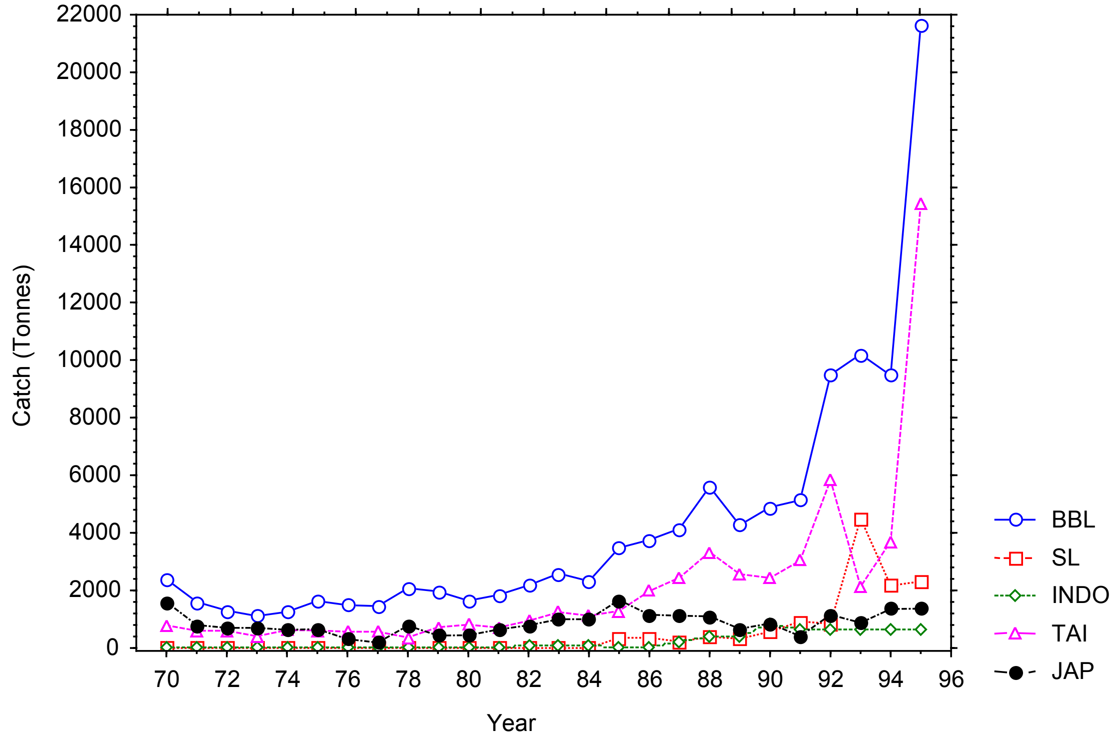

Figure 1d. The estimated total catch of swordfish in the Indian Ocean. Catches by the major fishing nations are also shown. Sri Lanka (SL), Indonesia (INDO), Taiwan (TAI) and Japan (JAP).). Note that the data for 1994 may be incomplete. Source IPTP.

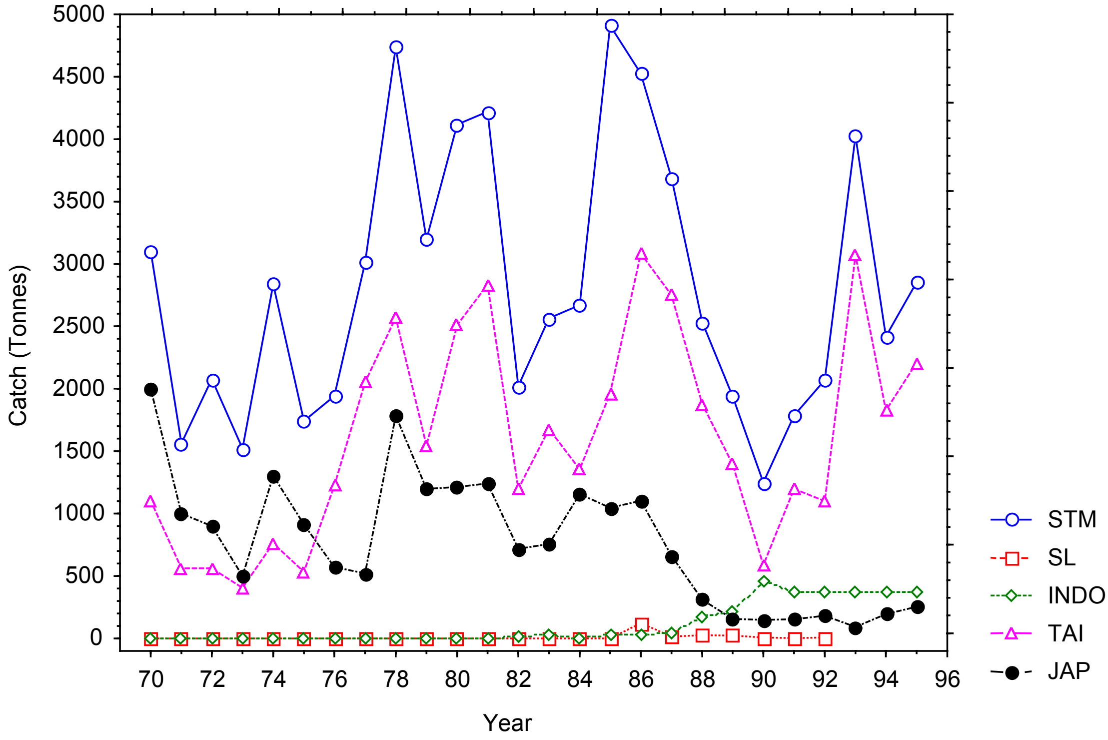

Figure 1e. The estimated total catch of sailfish in the Indian Ocean. Catches by the major fishing nations are also shown. Sri Lanka (SL), Indonesia (INDO), Taiwan (TAI) and Japan (JAP). (Source IPTP).

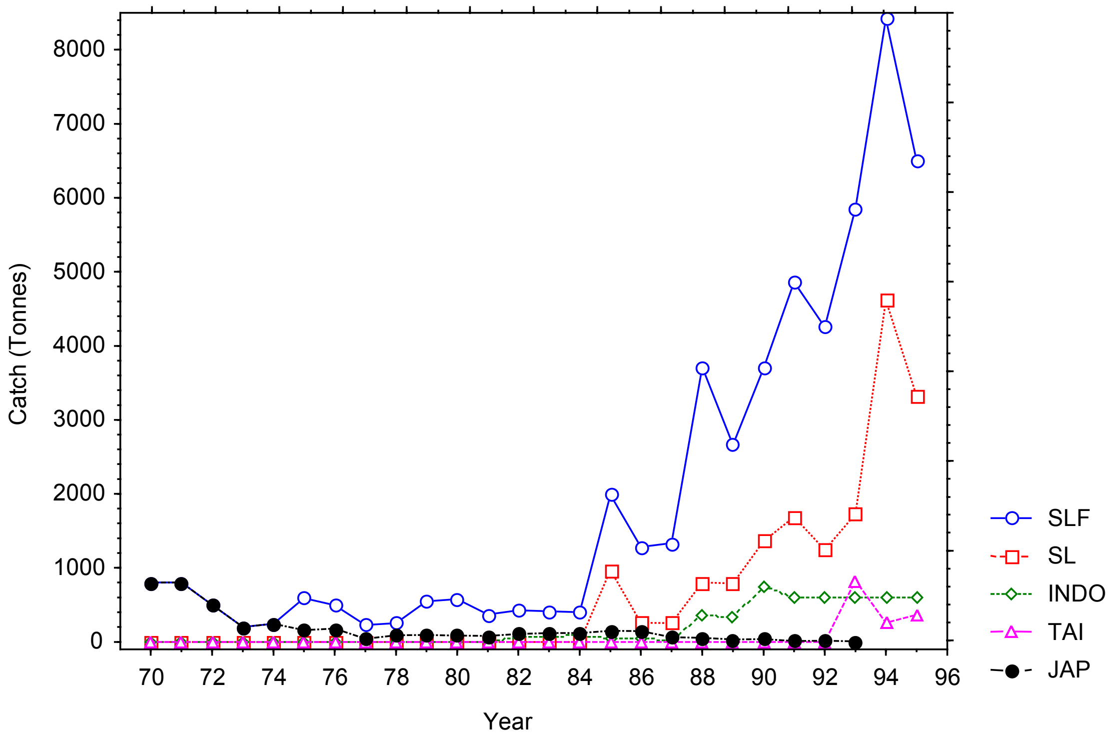

Figure 1f. The estimated total catch of billfish in the Indian Ocean NOT included in the individual species totals. Catches by the major fishing nations are also shown. Sri Lanka (SL), India, Korea (KOR), Pakistan (PAK) and Not Elsewhere In (NOT). (Source Anon, 1997).

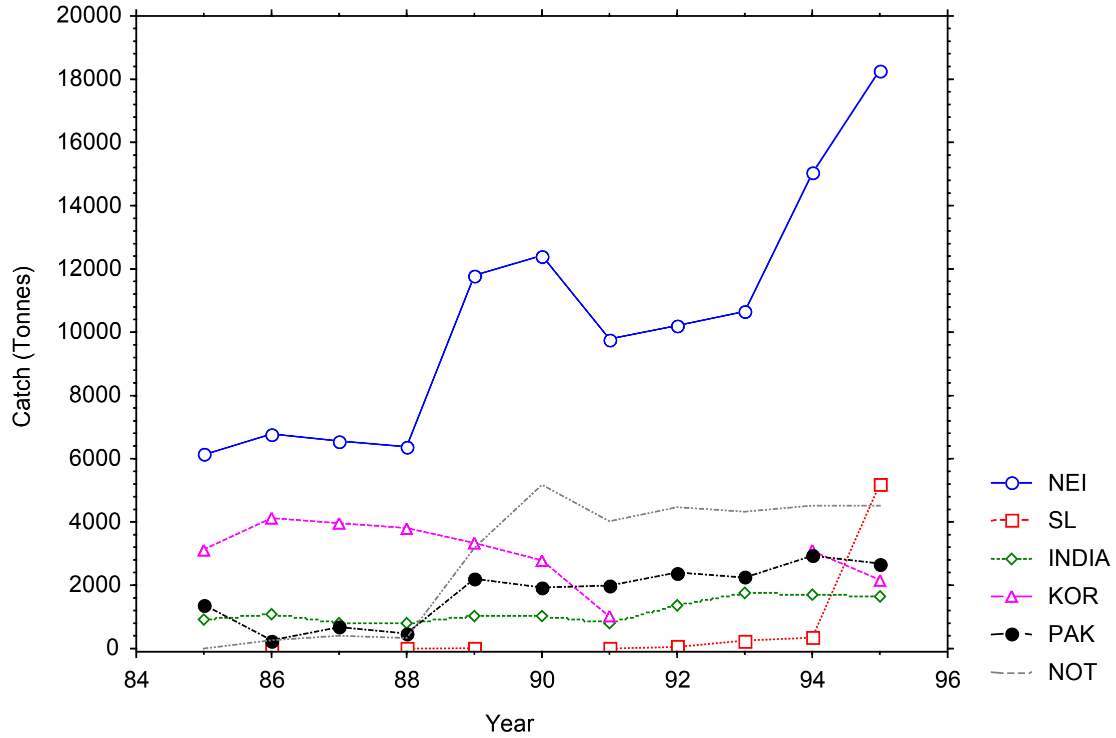

Figure 2a. The quarterly core catch areas of black marlin for the Japanese and Taiwanese longline fisheries in the Indian Ocean.

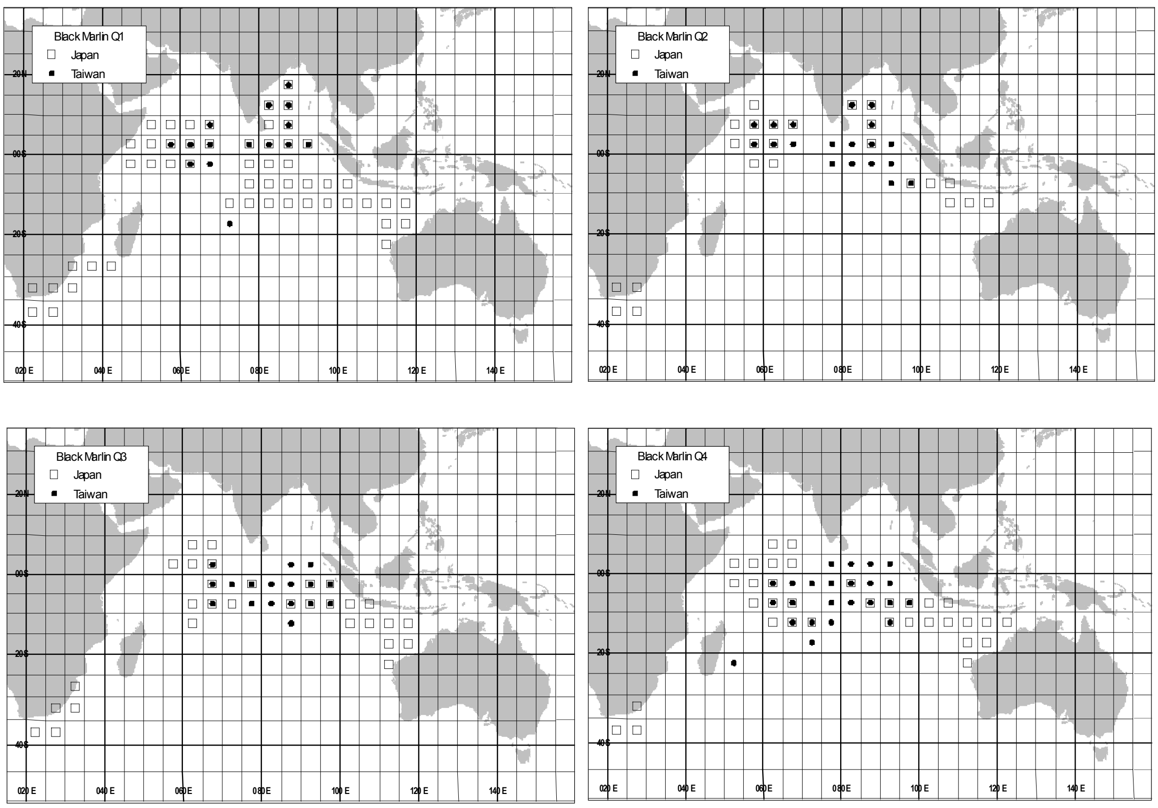

Figure 2b. Annual indices of apparent abundance of black marlin in the Indian Ocean from Japanese and Taiwanese longline data.

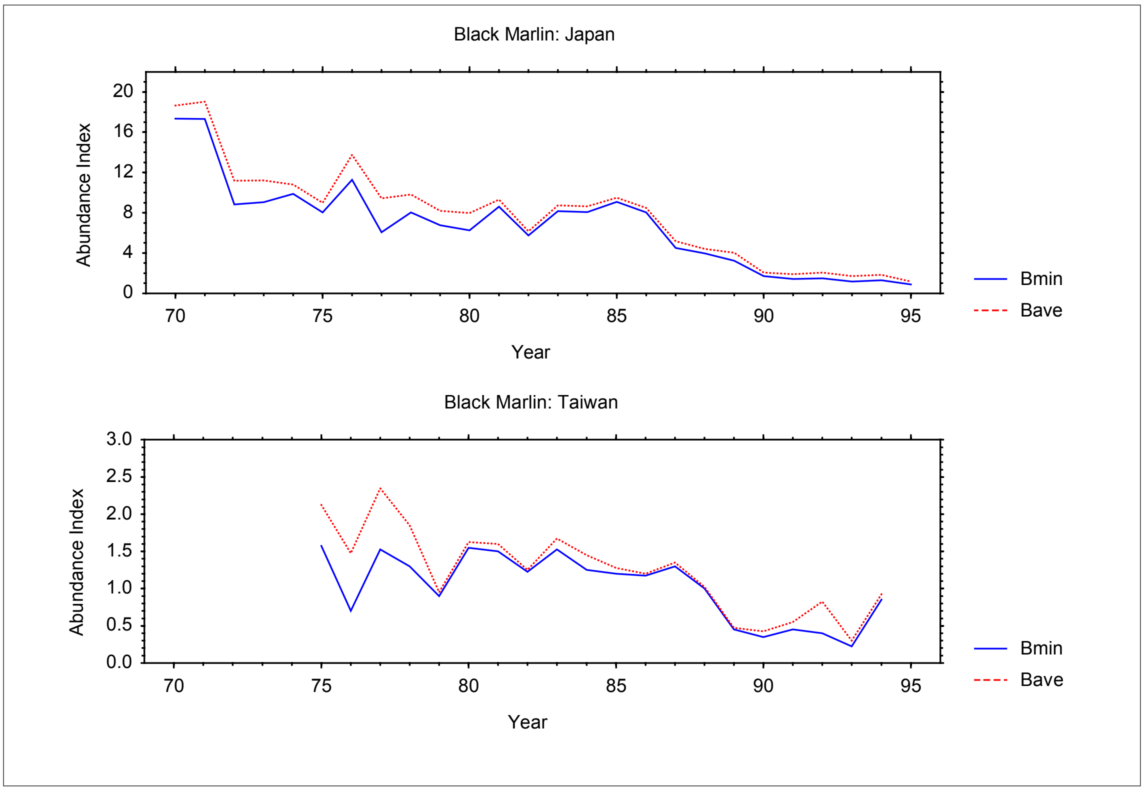

Figure 3a. The quarterly core catch areas of blue marlin for the Japanese and Taiwanese longline fisheries in the Indian Ocean.

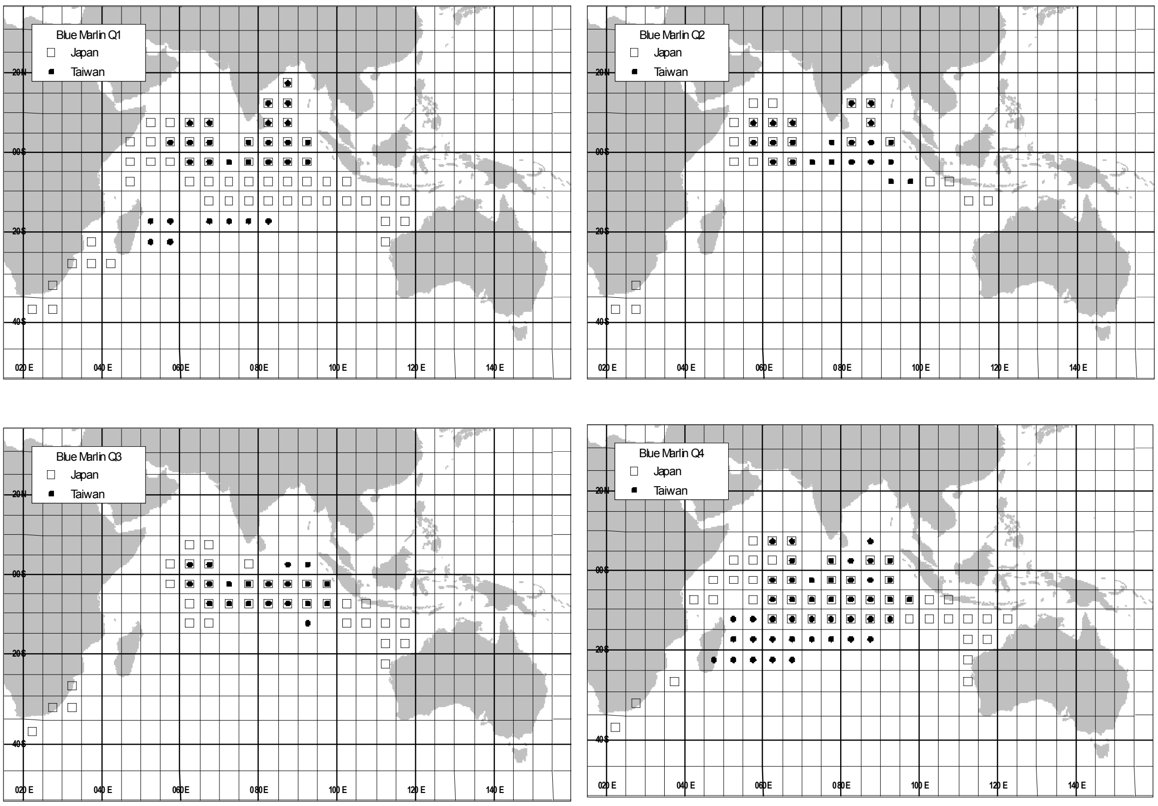

Figure 3b. Annual indices of apparent abundance blue marlin in the Indian Ocean from Japanese and Taiwanese longline data.

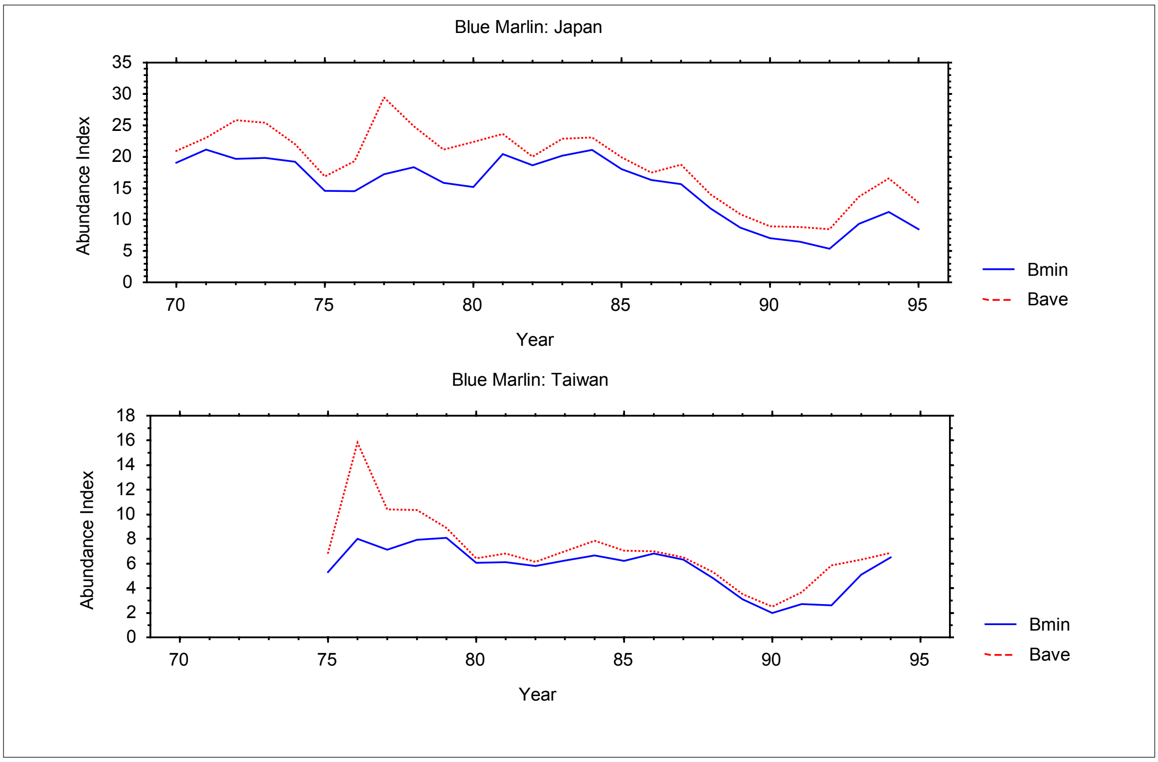

Figure 4a. The quarterly core catch areas of striped marlin for the Japanese and Taiwanese longline fisheries in the Indian Ocean.

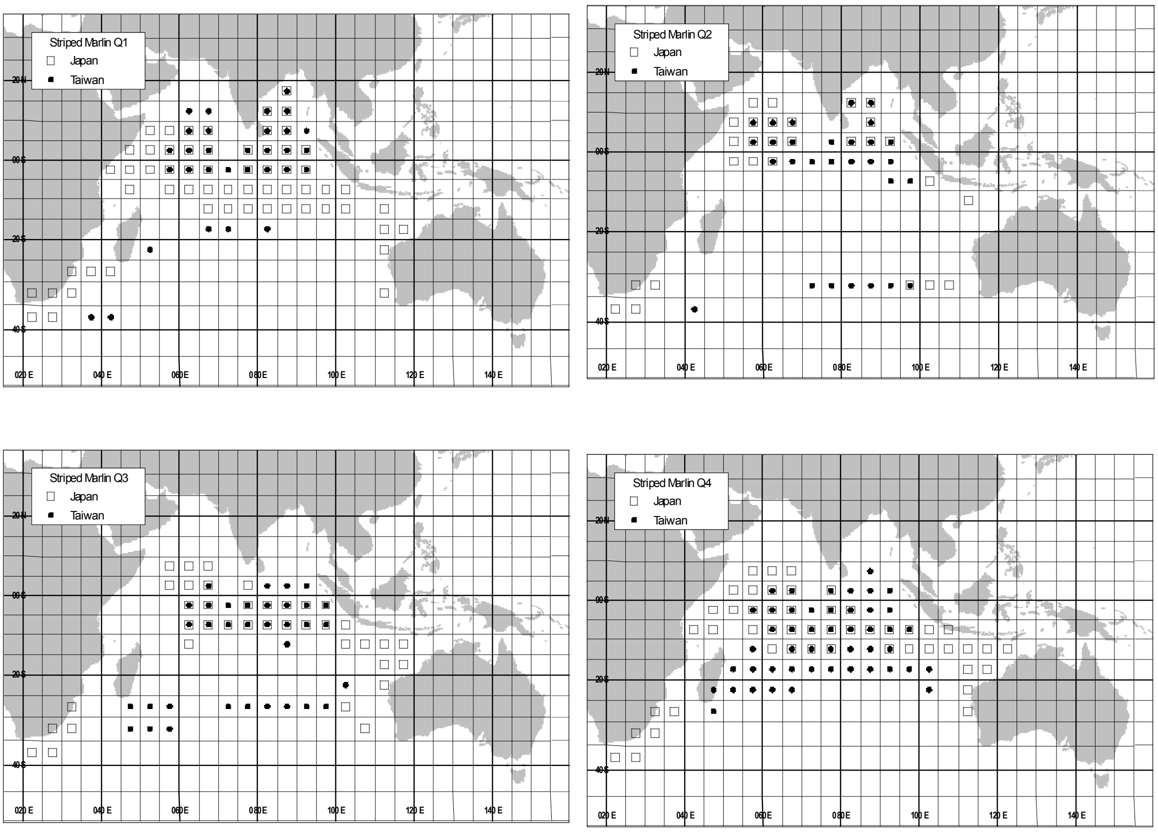

Figure 4b. Annual indices of apparent abundance striped marlin in the Indian Ocean from Japanese and Taiwanese longline data.

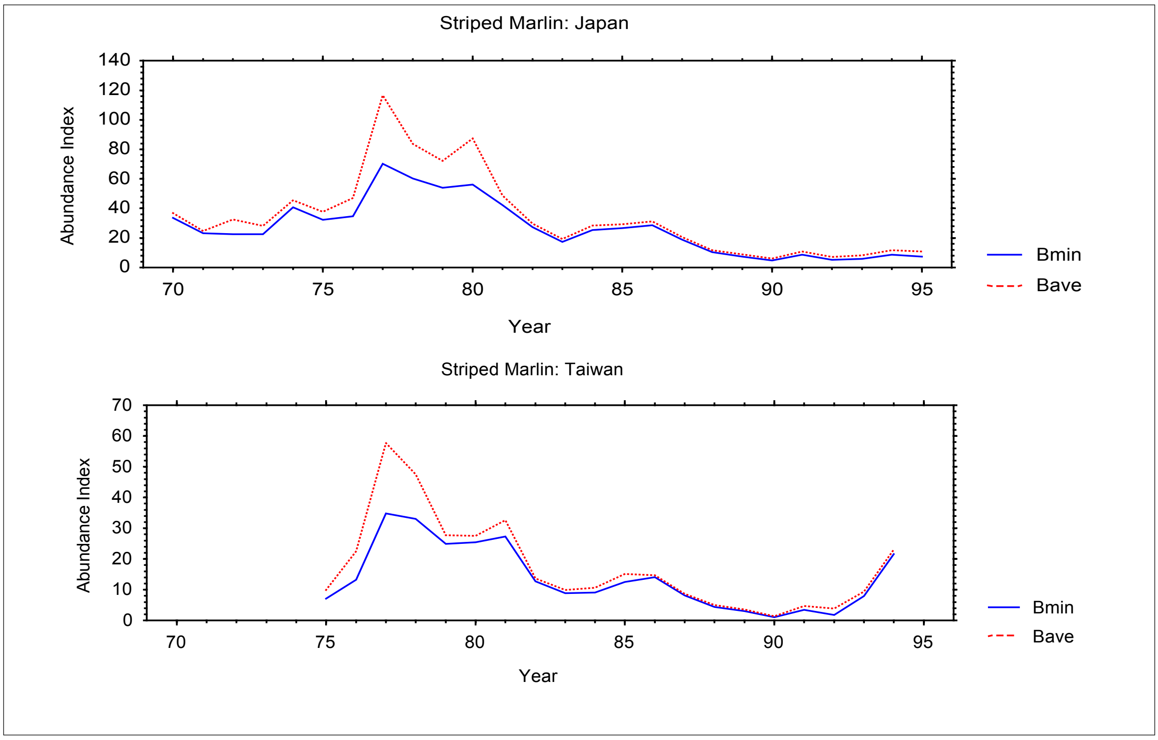

Figure 5a. The quarterly core catch areas of swordfish for the Japanese and Taiwanese longline fisheries in the Indian Ocean.

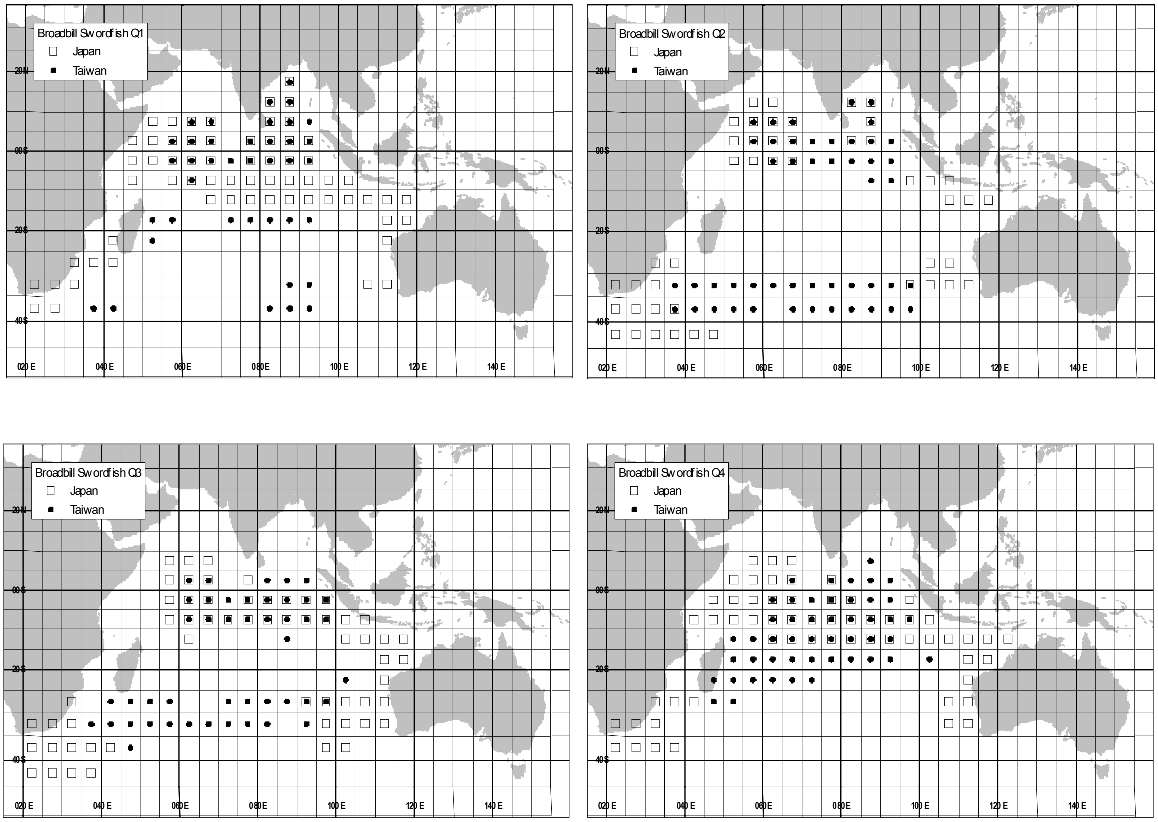

Figure 5b. Annual indices of apparent abundance swordfish in the Indian Ocean from Japanese and Taiwanese longline data.

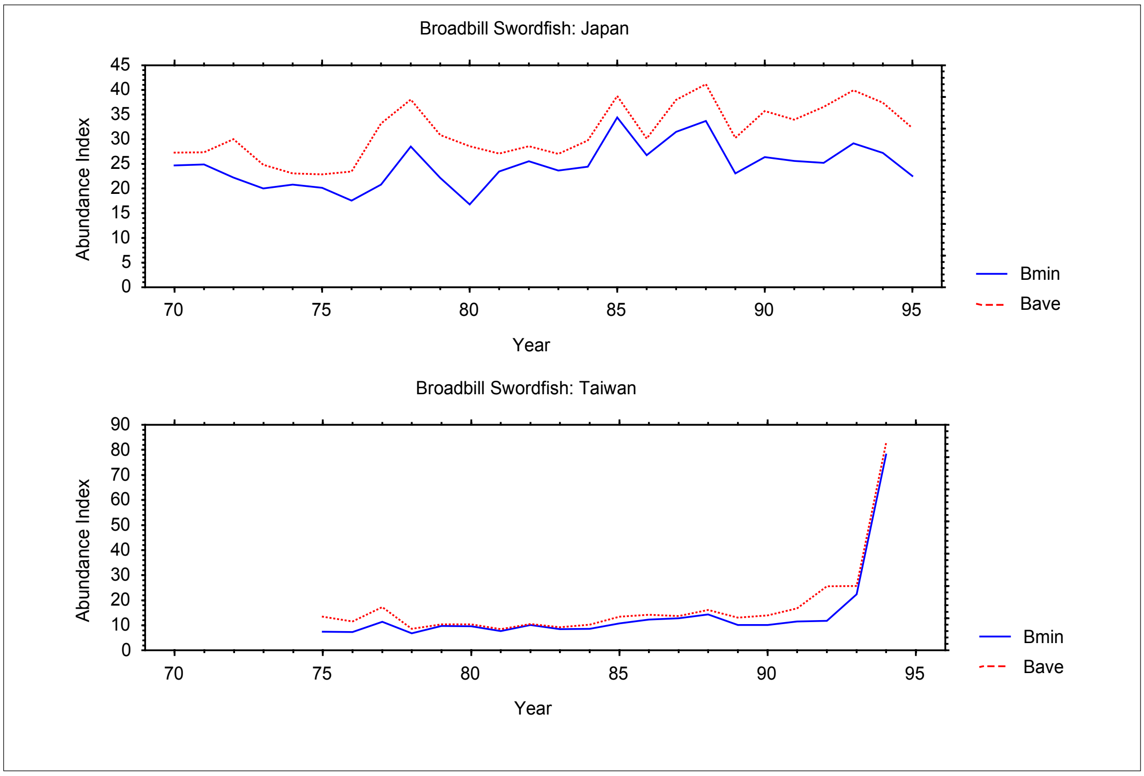

Figure 6a. The quarterly core catch areas of sailfish and spearfish combined for the Japanese longline fishery in the Indian Ocean.

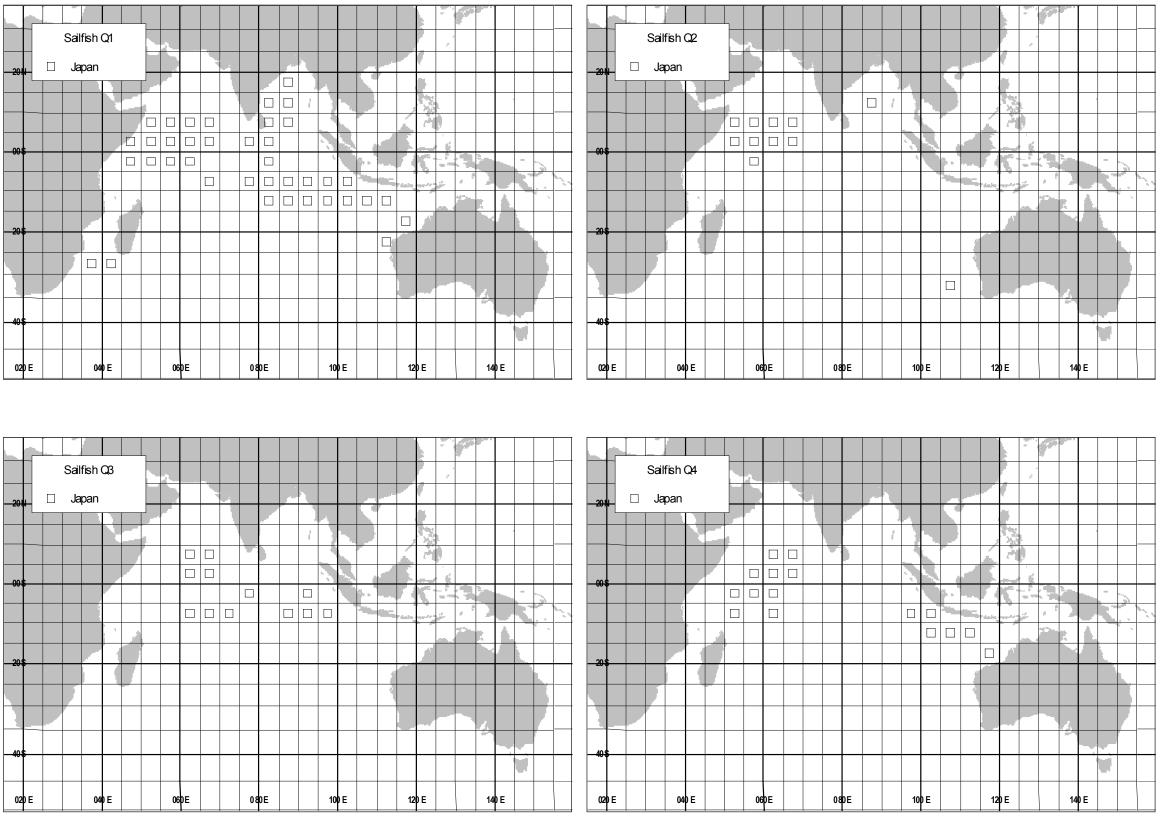

Figure 6b. Annual indices of apparent abundance of sailfish and spearfish combined in the Indian Ocean from Japanese longline data.