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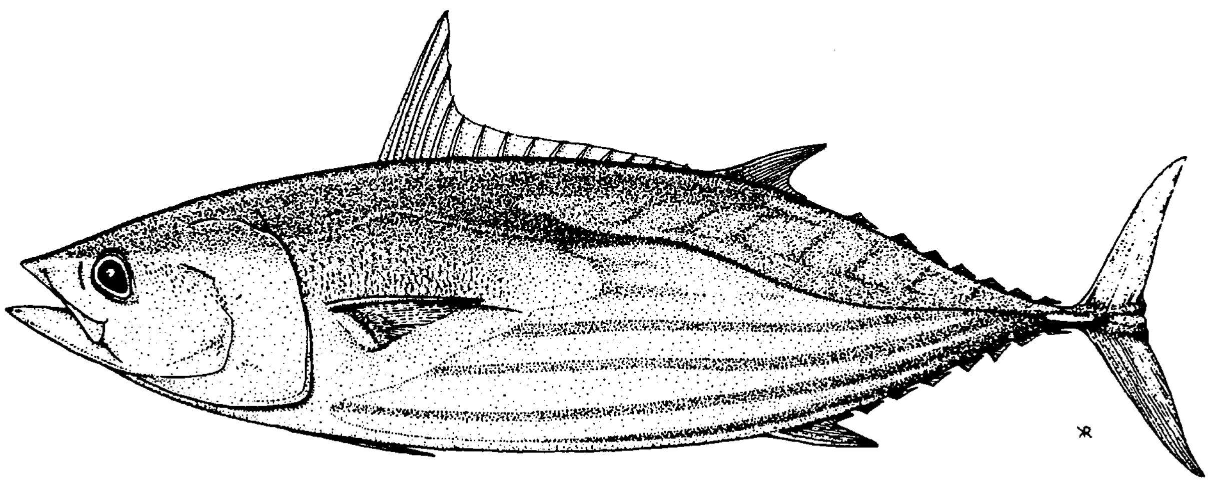
STATUS OF TUNA STOCKS IN THE WESTERN AND CENTRAL PACIFIC OCEAN



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1. INTRODUCTION

The Oceanic Fisheries Programme of the South Pacific Commission prepares an annual report on the status of tuna stocks in the western and central Pacific Ocean (WCPO), for consideration by various regional and international fora. This edition of the report has been prepared for consideration by the Second Multilateral High-Level Conference on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific.

The primary objective of the reports is to provide a summary of current information on the status of stocks of the four main market species of oceanic tunas in the western and central Pacific Ocean – skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), bigeye (*T. obesus*) and albacore (*T. alalunga*). By way of background information, we first provide overviews of basic biological information (distribution, spawning and stock structure) on these species (section 2) and their fisheries in the region (section 3). The most recent information on status of the stocks is presented in section 4. Conclusions and fisheries outlooks are presented in section 5.

2. TUNA STOCKS OF THE WESTERN AND CENTRAL PACIFIC

Distribution

Skipjack, yellowfin, bigeye and albacore are distributed throughout the Pacific Ocean between about 45°N and 45°S. Key elements of the distribution of each species are as follows:

Skipjack is the most tropical of the four species, occurring in large surface schools year round in the equatorial zone (10°N–10°S). During summer, the distribution extends into the higher latitudes, particularly off the coasts of eastern Australia, New Zealand and Japan. The horizontal distribution of skipjack is approximately limited by the 15°C isotherm, with the result that the distribution extends seasonally into temperate waters. Within these overall limits, oxygen concentration and the availability of forage are the key determinants of vertical and horizontal distribution. Skipjack have the highest metabolic requirements of all the tunas (Brill 1994) and are thus limited to oxygen-rich waters near the surface and to productive areas where baitfish, small crustaceans and other prey are available. A schematic distribution of skipjack in the Pacific Ocean is shown in Figure 1a.

Yellowfin have a similar distribution to skipjack as small juveniles (<70 cm FL), and frequently occur in mixed schools with skipjack of the same size. Yellowfin have less demanding metabolic requirements than skipjack. Unlike skipjack, they develop a swim bladder and large pectoral fins at larger size, which affords them greater buoyancy and hydrodynamic lift. Slower basal swimming speeds are therefore possible. With somewhat lower oxygen requirements, yellowfin can inhabit deeper water, particularly as adults, where their large size and some ability to physiologically thermoregulate provides a buffer against the lower ambient temperatures. However, yellowfin appear to spend most of their time in the mixed layer above the thermocline. Yellowfin tend to increase in average size from west to east. A schematic distribution of yellowfin in the Pacific Ocean is shown in Figure 1b.

Bigeye have similar overall distribution limits as yellowfin. Little is known of the distribution of small juveniles. They are caught in relatively small quantities by most surface fisheries in the region, and are reasonably common in catches of smaller tuna associated with floating logs and fish aggregation devices (FADs). Adult bigeye (>100 cm FL) have the lowest dissolved oxygen tolerance and lowest water temperature preference (11–15°C) of the four species considered in this review. They therefore tend to be found deeper in the water column during the day, although there appears to be regular movement towards the surface at night (Holland *et al.* 1990). A schematic distribution of bigeye in the Pacific Ocean is shown in Figure 1c.

Albacore are the most temperate of the four species in their distribution. They have a discontinuous distribution across the equator, with the discontinuity widening to the east. In the South Pacific, the distribution is essentially Pacific-wide, and may be continuous across the Southern Ocean and into the Indian Ocean. Juvenile albacore (<80 cm FL) tend to occur in temperate waters of 16–20°C, while adults have a wider temperature range of 13–25°C. Concentrations of juveniles are found in the subtropical convergence zone (35–40°S) east of New Zealand to at least 130°W. Adults have a more subtropical distribution, with the largest concentrations at 15–30°S. Albacore probably have similar oxygen requirements to yellowfin. In the area 10°N–10°S, water within the temperature preference range of juvenile albacore can only be found at considerable depths, however the oxygen content of this water is generally below the minimum requirement. This provides a barrier to movement of juvenile albacore across the equator. Movement of adult albacore through the equatorial zone is possible because of their greater temperature tolerance, but may be still be limited to a great extent. A schematic distribution of albacore in the South Pacific is shown in Figure 1d.

Spawning

Skipjack spawning occurs year round in the equatorial zone, with seasonal extensions to the north and south limited by the 25°C surface isotherm (Figure 2a). The density of skipjack larvae appears to decrease from west to east across the Pacific, although recent sampling by the Inter-American Tropical Tuna Commission has revealed considerable spawning activity in waters off central America.

Yellowfin spawning appears to be Pacific-wide and bounded in its northern and southern extremes by the 26°C surface isotherm (Figure 2b). While the occurrence of larvae is continuous across the equatorial Pacific, three areas of higher larval density have been tentatively recognized: 130–170°E, 180°–160°W and east of 110°W. Spawning occurs year round, possibly with a peak in the November–April period. Some data also suggest different spawning seasons for areas east (March–September) and west (November–April) of 180°. Recent data collected by the University of Hawaii indicate that adult yellowfin can attain spawning condition rapidly, possibly in response to food supply.

Bigeye larvae have been found between 30°N and 20°S in the western Pacific and between the equator and 20°N in the eastern Pacific (Figure 2c). Higher concentrations are found in the western and eastern Pacific, with a lesser concentration in the area 180°–150°W.

Albacore spawn in subtropical waters of the North and South Pacific, with little or no spawning occurring in the equatorial region. In the South Pacific, the main spawning area is

15–25°S (Figure 2d). Spawning is concentrated in the summer months (Ramon and Bailey 1996).

Stock Structure

Skipjack tagging data indicate unrestricted zonal movement between 120°E and 160°W, as well as seasonal movements into and out of the higher latitudes (Figure 3). Despite the large amount of tagging carried out in the WCPO over the past 15 years, no recoveries of these fish have been recorded from the eastern Pacific purse seine fishery. Similarly, few eastern-Pacific-tagged skipjack have been recaptured west of 150°W. It had been previously believed that skipjack in the eastern Pacific originate mainly from spawning in the central and/or western Pacific; however, recent sampling of skipjack gonads in the eastern Pacific by the IATTC suggests that considerable spawning may also occur in this region. Gene frequency data are inconclusive regarding Pacific-wide skipjack population structure. However, given the likelihood of restricted exchange, it is probably appropriate to consider skipjack in the WCPO, i.e. west of 150°W, as a single stock for assessment purposes.

Yellowfin tagging data in the western Pacific show extensive zonal movements between 120°E and 170°W (Figure 4). To date, no yellowfin tagged west of 170°W have been reported as recaptured in the eastern Pacific purse seine fishery, although several recoveries have been reported by longliners operating to the east of 150°W. No yellowfin tagged in the eastern Pacific fishery have been reported as recaptured west of 150°W. This and the distribution of yellowfin larvae is considered to be consistent with at least eastern and western/central Pacific stocks. A recent Pacific-wide population genetics study tends to support this view (Ward *et al.* 1994). The Pacific-wide distribution of GPI-F* allele frequencies showed significant heterogeneity between eastern Pacific samples and western-central Pacific samples (Figure 5), leading Ward et al. (1994) to conclude that "there are at least two genetically different groups of yellowfin in the Pacific Ocean, one comprising eastern Pacific fish (California, Mexico, Ecuador) and the other western/central Pacific fish (Philippines, Coral Sea, Kiribati, Papua New Guinea, Hawaii)". No significant heterogeneity was found among the western-central Pacific samples. For stock assessment purposes, we define the WCPO stock to range from the Philippines and eastern Indonesia to 150°W. This eastern boundary is chosen on the basis that it is consistent with the available biological data on spawning and movements, and it neatly separates the eastern and western Pacific surface fisheries.

Bigeye tagging in the Pacific has been relatively limited, and therefore the data on long-distance movements are not as extensive as for skipjack and yellowfin. A number of movements of >1000 nmi. have been observed (Figure 6), including two recent recoveries of Coral Sea-tagged bigeye by longliners fishing in the main bigeye fishing area to the east of French Polynesia. Stock assessments carried out to date have generally assumed a Pacific-wide stock structure, however in the absence of additional data, other stock structure hypotheses, such as separate eastern and western stocks, could not be ruled out. Preliminary results of a population genetics study carried out on Pacific bigeye are now available to clarify this issue. The preliminary results of this work, which will be finalized in mid-1997, suggest that there is little genetic differentiation across the Pacific basin, thus favouring the Pacific-wide stock structure hypothesis.

Albacore are believed to constitute separate stocks in the North and South Pacific, based on a clear discontinuity in longline CPUE between 10°S and 10°N, separate spawning areas in the North and South Pacific, centered around 20° of latitude and few records of trans-equatorial movement of tagged albacore[1].

Within the South Pacific, albacore are capable of extensive zonal and meridional movements, as evidenced by tagging data (Figure 7). Most albacore have been tagged in the surface fishery operating in the subtropical convergence zone at 35–45°S, 140–160°W. From this area, movements to the east, west and north have been observed. Exchange between the central Pacific, New Zealand coastal waters and the Tasman Sea has also been demonstrated. These data suggest that albacore should be treated as a single stock in the South Pacific. This conclusion is supported by genetic data. Albacore sampled at five South Pacific locations (Tasmania, New Zealand, New Caledonia, Fiji, and French Polynesia) did not show significant heterogeneity among locations for any of the screened loci.

3. OVERVIEW OF THE FISHERIES

Fisheries for the four major tuna species in the WCPO (in which we include the domestic fisheries of the Philippines and eastern Indonesia) have undergone significant expansion in the past decade. Total catches in the SPC Statistical Area have increased from about 540,000 t in 1980 to peak at more than 1.4 million t in 1991 (Lawson 1996). The total catch has exceeded 1 million t since 1989.

Much of the increase in catch resulted from development of the purse seine fleet, which increased from 14 Japanese vessels at the start of 1980 to almost 200 vessels, from mainly Japan, United States, Korea, Taiwan and Philippines, in 1992. The increases, therefore, have mainly been in the catches of skipjack and yellowfin. Albacore and bigeye catches have remained stable, apart from an increase in albacore catch in the late 1980s associated with driftnetting. Albacore and bigeye catches are a minor component of the total catch, at least in terms of weight.

In compiling estimates of the total catch by species, it is necessary to define areas which, ideally, represent stock boundaries. While considerable uncertainty still exists for some species on where the boundaries should be, preliminary boundaries based on the distribution of the fisheries and various biological information can be defined. The following preliminary boundaries are defined for the purpose of compiling fisheries statistics and stock assessment information, and should not be viewed as constituting final management units.

Skipjack	45°N–45°S, Asian Pacific coast (including South China Sea and eastern Indonesia) and Australian east coast to 150°W
Yellowfin	45°N–45°S, Asian Pacific coast (including South China Sea and eastern Indonesia) and Australian east coast to 150°W

[1] One recovery of an albacore tagged in the South Pacific was recently reported by a longliner fishing north of the equator in the Marshall Islands.

Bigeye	45°N–45°S, Asian Pacific coast (including South China Sea and eastern Indonesia) and Australian east coast to the west coasts of the United States, Central and South America
Albacore	Equator to 50°S, 145°E to the west coast of South America

Skipjack

Skipjack catches have more than doubled since 1980, with a peak catch of one million tonnes recorded in 1991 (Figure 8). Since 1991, the annual catch has remained between 800,000 and 1,000,000 t.

Pole-and-line was originally the dominant gear type, with a large fleet of Japanese vessels as well as fleets based in Papua New Guinea, Palau, Solomon Islands, Fiji and Kiribati. The Japanese fleet has been steadily reduced over the past ten years for economic reasons, while the Palau and Papua New Guinea operations terminated in the mid-1960s and early 1980s, respectively, also for economic reasons.

Most of the catch is now taken by the international purse seine fleet, which comprised 180 vessels (15 locally based) in 1994. The largest fleets are from the United States, Japan, Korea and Taiwan. Purse seine skipjack catches increased steadily between 1980 and 1991, and have since varied between 600,000 and 700,000 t per year (including purse seine and ring net catches in Philippines waters).

The domestic fisheries of Philippines and eastern Indonesia have also increased since 1980, comprising 20–25% of the total WCPO catch in recent years. These fisheries are prosecuted by many small operators using a variety of gear types, including ringnet, purse seine, gillnet and handline in the Philippines, and pole-and-line and purse seine in Indonesia. In both cases, fishing is based on FADs (payaos) and the sizes of fish are generally small compared to skipjack caught by large purse seiners in the WCPO (Figure 9).

Yellowfin

Yellowfin catches in the WCPO have almost doubled since 1980, peaking at approximately 400,000 t in 1993 (Figure 10). Catches were dominated by longliners (mainly Japanese) prior to 1980. Since then, longline catches have fallen, while the purse seine fishery, for which yellowfin is a target species (along with skipjack), has taken over as the major producer of yellowfin in the WCPO. As with skipjack, catches of yellowfin in the Philippines and eastern Indonesia have also increased substantially. Yellowfin catches by pole-and-line fleets have remained a minor component of the total catch.

Yellowfin are caught at a variety of sizes by the various gear types (Figure 11). Longliners land mainly fish >100 cm FL, while purse seiners target both small (40–60 cm FL) and large fish. Set type is the major determinant of the size of yellowfin caught by purse seiners – log sets catch almost exclusively smaller fish, while unassociated sets are made on free-swimming schools of both small and large yellowfin. As with skipjack, the domestic fisheries of Philippines in particular catch large quantities of very small FAD-associated yellowfin. A substantial handline catch of adult yellowfin, currently of the order of 35,000 t per year, also occurs around FADs in the Philippines.

Bigeye

Total catches of bigeye in the Pacific have fluctuated between 80,000 and 160,000 t per year (Figure 12), with most of the catch attributed to longliners. Reported catches by the surface fisheries (purse seine and pole-and-line) are small by comparison, as most purse seine fleets in the western Pacific routinely record both yellowfin and bigeye catches as "yellowfin". Sampling programmes indicate that the proportion of bigeye in the catch recorded as "yellowfin" may be of the order of 5–10% and the fish are mostly of small size. Similar mis-classification of catches is likely to have occurred in the domestic fisheries of Philippines and Indonesia. A recent analysis of sampling data for 1988 to 1995 indicated that bigeye catches by the western Pacific purse seine fishery have been approximately 10,000-18,000 t per year since 1990 (Hampton et al. 1996). Similarly, bigeye catches in the domestic fisheries of the Philippines and eastern Indonesia are estimated to have been 10,000-14,000 t per year. These new estimates of bigeye catch by surface gear have been incorporated into Figure 12. For the area of the Pacific west of 150°W, the total bigeye catch since 1990 is estimated to have been 70,000-85,000 t per year.

Purse seine catches of bigeye in the eastern Pacific increased sharply in 1994 to nearly 30,000 t, with approximately 32,000 t taken in 1995. These vessels are targeting small to medium-sized bigeye (average weight approximately 11 kg) aggregated under floating logs, using specialized techniques such as deeper nets, lights, and bait to chum the fish close to the surface. As the fishing area is fairly close to the main longline fishing area for bigeye, some effects of these surface catches may, over the next two years, be seen in longline catch rates.

There have been recent reports of increased bigeye catches by purse seiners in the WCPO. These increased catches appear to have resulted from the use of deeper purse seine nets in conjunction with drifting FADs.

The size distributions of bigeye catch by gear (Figure 13) are similar to those for yellowfin, although large bigeye are less common in purse seine catches in the WCPO.

Albacore

Total albacore catches in the South Pacific have remained fairly stable since 1980, although its distribution among gears has varied (Figure 14). Longline (mainly Taiwanese) catches of mostly larger albacore have varied between 20,000 and 40,000 t per year. Catches were at the lower end of this range during 1989–1991 after which there has been a steadily increasing trend. Taiwanese longline data indicate that effort by this fleet has been increasing strongly since 1985, with the level of effort in the most recent year of data (1994) being a record high (Figure 15).

Surface fisheries for albacore using troll and driftnet gear and targeting juvenile albacore (Figure 16) developed during the 1980s, with the driftnet fishery expanding rapidly in the late 1980s. Driftnetting is no longer carried out, but troll fishing in New Zealand coastal waters and along the subtropical convergence zone in the central South Pacific continues.

Troll catches in the central South Pacific area in the 1992–93 and 1993–94 seasons were apparently poor, although catches in New Zealand coastal waters in 1994 were greater than usual. Better catches were recorded in the central Pacific troll fishery in 1994–95; the fishery again fared poorly in 1995-96 and better catches were reported in 1996-97.

4. STATUS OF STOCKS

In this section, we examine available information on the status of stocks of the four species in the areas described earlier. We first examine fishery indicators (CPUE trends) for any evidence of persistent changes in the stocks that might have been due to fishing activities. The indicators used are derived primarily from those fleets from which reliable data are currently available – the various Japanese fleets (pole-and-line, purse seine and longline) and the United States purse seine fleet. We then review various analyses of data (tag-recapture models, age structured models, surplus production models) that have been carried out over the past few years.

Skipjack

Fishery Indicators

Since the late 1970s, skipjack CPUE by Japanese purse seiners has varied between 15 and 20 t per day (Figure 17), with a slightly increasing trend. Skipjack CPUE by United States purse seiners increased consistently between the early 1980s and early 1990s, and its pattern of variability has closely resembled that of the Japanese fleet.

Skipjack CPUE by the Japanese pole-and-line fleet has tended to increase over the past decade (Figure 18). CPUE has generally been higher, but more variable, in the equatorial fishing area than in the northern area. The increases in CPUE have coincided with substantial effort reduction; this is likely to have been the result of technological advancements such as bird radar and changes in the fleet profile (retirement of less efficient vessels). CPUE for the major Pacific Island pole-and-line fleet, the Solomon Islands fleet, has shown no consistent trend over the past 15 years. This fleet has not changed a great deal over the years and may better represent variation in skipjack abundance, at least in the Solomon Islands area, than the Japanese fleet.

There is no evidence from these time series that the fisheries have impacted the skipjack population to the extent that their CPUE has been adversely affected. However, interpretation of surface fishery skipjack CPUE is difficult without a good understanding of the relationship between CPUE and abundance. It is clear that technological advances in the location and capture of skipjack have occurred for the major DWFN fleets, and that these are probably responsible for the increasing CPUE trends in the major fisheries.

Tag-Recapture Models

The South Pacific Commission has undertaken two major tag recapture studies, the Skipjack Survey and Assessment Programme (SSAP) 1977–1982 and the Regional Tuna Tagging Project (RTTP) 1989–1992. During the SSAP, approximately 140,000 skipjack were tagged and released, from which approximately 6,000 (4%) were recaptured and the tags returned. During the RTTP, 92,376 skipjack were tagged for 10,738 returns (11.6%). These experiments, undertaken at very different times during the development of the fishery, have thus provided a valuable database with which to assess the current impact of fishing on the skipjack stock.

Tag attrition models have been fitted to both data sets (Kleiber et al. 1987; SPC 1994). For the SSAP data set, the total attrition rate (analogous to total mortality rate) was estimated to be 0.17 per month, with an exploitation rate (proportion of total attrition due to fishing) of 0.04. While the accuracy of the exploitation rate estimate was limited by a lack of reliable information on the reporting rate of tags, the results nevertheless imply that the effect of fishing on the skipjack stock during the late 1970s and early 1980s was very small; the total annual catch of skipjack at this time was of the order of 400,000 t.

For the RTTP data set (Figure 19), more information was collected on tag reporting rates and other sources of tag loss and these were incorporated into the analysis (Hampton 1997). A similar estimate of total attrition was obtained (0.16 per month), but the estimated exploitation rate had increased to 0.20, reflecting an increase in the average annual skipjack catch during the RTTP to around 950,000 t. This analysis also incorporated an explicit estimate of reporting rate (0.59 overall) derived from tag seeding experiments. Another feature of the RTTP analysis was the incorporation of various sources of uncertainty into the analysis, resulting in estimates of 95% confidence intervals on all parameters. The estimated 95% confidence intervals for the exploitation rate were 0.16–0.25. These results indicate that the impact of the fisheries on the WCPO skipjack stock has increased as would be expected with the increases in catch that have occurred. Kleiber et al. (1987) noted that skipjack exploitation rates up to about 0.7 should be possible on yield-per-recruit grounds, but Patterson (1992) presented empirical evidence for over-exploitation of small pelagic species at exploitation rates greater than 0.4. Using the lower level as a conservative benchmark for skipjack, we would conclude that current catches represent a low to moderate level of exploitation on the skipjack stock.

There is strong evidence in the skipjack tag return data of strongly variable natural mortality rate (*M*) by size. A size structured tag attrition fit to the RTTP data indicates that small skipjack (of the size typically caught in the Philippines fishery) have about 6-8 times the *M* of larger skipjack (Figure 20). However, fishing mortality (*F*) is relatively low for all size classes. The implication of this size-dependency of *M* is that there is unlikely to be a significant impact of large catches of small skipjack (e.g. in the Philippines) on fisheries that target larger-sized skipjack. However, the economic impact of such catches is currently unclear.

Surplus Production Models

No surplus production modeling of WCPO skipjack has yet been undertaken.

Age Structured Models

No age structure modeling of WCPO skipjack has yet been undertaken.

Yellowfin

Fishery Indicators

CPUE trends for both purse seine and longline vessels are available to serve as fishery indicators. Purse seiners catch mainly juvenile yellowfin, with a smaller component of adult fish. Longliners catch predominantly adult yellowfin.

Nominal catch per day fished by Japanese and United States purse seiners has fluctuated a great deal since 1981 (Figure 21), but with no evidence of a persistent declining trend. For the United States fleet, yellowfin CPUE was relatively low in 1995 and 1996. CPUE for the Japanese fleet was also relatively low in 1996. These recent declines in CPUE may be related to the switch from a protracted *El Nino* to a *La Nina* period around 1995. *El Nino* periods tend to result in good fishing conditions for yellowfin because of a shallower mixed layer in the ocean. Conversely, *La Nina* periods tend to result in poor yellowfin fishing conditions because of a deeper mixed layer.

Various standardized CPUE time series have been constructed using General Linear Models (GLMs). These are not strikingly different from the nominal CPUE trends. In one analysis (Miyabe 1995b), standardized CPUE for small yellowfin showed no long-term trend, but standardized CPUE for large yellowfin showed an upward trend (Figure 22). Updating of these analyses with recent data should be undertaken as soon as possible.

A long time series of yellowfin CPUE by Japanese longliners is also available (Figure 23). Three regions have been defined for the purpose of examining trends – 10°N–10°S, where most of the catch and the highest CPUEs are recorded, 10–40°N and 10–40°S. For the 10°N–10°S region, CPUE declined steadily from 1962 to 1975, possibly a fishing down process characteristic of most longline fisheries during their developing stages. CPUE increased sharply between 1975 and 1978. Since 1978, CPUE has declined steadily, although the preliminary estimate for 1995 is the highest in several years. CPUE in the northern region shows a similar pattern until the early 1980s. CPUE was stable from 1982 to 1991, but appears to have increased somewhat in recent years. In the southern region, CPUE declined to 1976, increased to 1981, and has varied around this increased level since that time.

The interpretation of the longline CPUE time series is confounded to some extent by operational changes that have taken place in the fishery. Most important of these is a transition since the mid-1970s towards deeper longline sets targeting bigeye. It is possible that this change in setting behaviour could at least be partly responsible for the post-1978 decline in CPUE in the equatorial area. Miyabe (1995b) used a GLM to standardize Japanese longline CPUE in the WCPO between 20°N and 20°S for changes in targeting, the effects of bigeye and albacore by-catch and area-season effects. The standardized time series is shown along with the nominal time series in Figure 24. The standardized time series indicates a flatter time series of yellowfin abundance since the early 1980s than that suggested by the nominal CPUE data.

Although the start of the more recent decline in longline CPUE pre-dates the development of the WCPO purse seine fishery, the possibility of an interaction effect of the purse seine fishery on the longline fishery should be acknowledged. Some local interaction effects have been inferred from changes in the size composition of longline catches in areas of high purse seine effort (Anon. 1994).

Tag-Recapture Models

During the RTTP, special efforts were made to tag and release substantial quantities of yellowfin; 33,523 yellowfin were tagged, from which 3,476 (10.4%) have been recaptured and the tags returned to SPC.

As with skipjack, a tag attrition model has been fitted to these data (Figure 25) and similar estimates to those obtained for skipjack were derived – total attrition of 0.16 per month and exploitation rate of 0.20 (0.16–0.25).

A size-structured model has also been fitted to the yellowfin tagging data, resulting in a significantly improved fit over the standard attrition model; as with skipjack, there appears to be a strong signal in the data regarding variation of natural mortality (in particular) and fishing mortality by size class. As for skipjack, estimated natural mortality rates in the two smallest size classes (20–30 and 30–40 cm) are much higher than in the other size classes (Figure 26), which would tend to minimize the effects of catching very small yellowfin on catches of larger fish. Fishing mortality rates tend to decline with increasing size (apart from the smallest size class, for which F is low) suggesting that exploitation rates on large yellowfin are modest.

Surplus Production Models

Suzuki et al. (1989) presented surplus production model fits to longline catch and effort data for the WCPO; estimates of maximum sustainable yield (MSY) of 70,000–110,000 t were obtained. These fits were obtained using an equilibrium model, which has generally proven unreliable in estimating MSY and other management parameters for many fish stocks (Hilborn and Walters 1992). It is clear that these results underestimated total surplus production, as the total catch, and even the catch of "longline-sized" yellowfin, has now far outstripped the MSY estimates with no signs of the stock collapse that would have been predicted by these models.

Sun and Yeh (1994) analyzed nine CPUE time series from all WCPO purse seine, pole-and-line and longline fisheries for yellowfin using a surplus production model employing a time-series fitting procedure (which allows the equilibrium assumptions to be relaxed). Apart from the technical superiority of the method, the catch data analyzed represent the total WCPO yellowfin catch rather than just the longline catch used in previous studies. The important estimates from the analysis were as follows:

MSY	670,700 t
Biomass at MSY	900,000 t
1992 biomass	1.53 million t
Fishing mortality at MSY	0.062 per month
1992 fishing mortality	0.022 per month

The estimates are reasonably consistent with the tagging analysis (where the size-aggregated estimate of fishing mortality was 0.032 per month) in suggesting low-moderate current exploitation. It should be noted, however, that this production modeling approach is at a preliminary stage for WCPO yellowfin and many more fits to the data are required in order to assess the reliability of the results.

Age Structured Models

The development of a length-based age-structured model for WCPO yellowfin is currently in progress. The model will include spatial structure and will be based on a likelihood fitting procedure. The model will make extensive use of available catch, effort, size composition and tagging data. It is anticipated that the results of this project will be available for inclusion in next year's report.

Bigeye

Fishery Indicators

While small quantities of bigeye are caught by surface fisheries in the WCPO, detailed information on CPUE is lacking because bigeye catches are recorded as yellowfin by most fleets. The only available fishery indicator is longline CPUE; as Japanese longliners dominate the longline catch, data from this fleet are considered to be the most useful fishery indicator.

Standardized bigeye CPUE by Japanese longliners for the entire Pacific and for areas east and west of 150°W (Miyabe 1995a) is shown in Figure 27. CPUE declined in both areas, particularly in the eastern Pacific, between 1955 and 1970. Since 1970, CPUE has continued to decline steadily in the eastern Pacific, but has been essentially constant in the western Pacific. Analyses of standardized longline CPUE in the eastern Pacific undertaken by the IATTC suggest a less obvious decline in relative abundance since 1975 (Tomlinson 1996).

Tag-Recapture Models

Tag-attrition models have recently been applied to Pacific bigeye for the first time (Hampton et al. 1996). Using the available tagging data, it was possible to estimate the exploitation rate of juvenile bigeye by purse seiners in the western equatorial Pacific in the early 1990s. The estimate of 0.23 is similar to the estimates for skipjack and yellowfin. Significantly higher exploitation rates were estimated for the Philippines domestic fishery. As with skipjack and yellowfin, size-dependent natural mortality also seems to be evident for bigeye.

Surplus Production Models

Several attempts have been made to fit surplus production models to Pacific bigeye data (reviewed by Miyabe 1993). These analyses, which have generally used equilibrium assumptions in the fitting procedure, have estimated Pacific-wide MSYs of 100,000–170,000 t. Miyabe (1995a) used a time-series fitting procedure, obtaining an MSY of 120,000 t under a single Pacific-wide stock hypothesis. A separate western and eastern stock hypothesis gave MSY estimates of 39,000 t and 76,000 t for the western and eastern stocks, respectively. Under the single-stock hypothesis, the current biomass is estimated to be approximately equal to the biomass at MSY, indicating full exploitation. For the two-stock hypothesis, the biomasses of both stocks are considerably below those at MSY, indicating over-exploitation. Note that these estimates of MSY were obtained using data sets in which bigeye catches by surface fisheries were under-estimated. Re-analysis of the data using catch estimates that include reasonable estimates of surface fishery catches is urgently required.

The IATTC has also undertaken production model analysis of bigeye in the eastern Pacific (Tomlinson 1996). These results differ significantly from those of Miyabe (1995a) - levels of total effort (standardized to longline effort) up to 1994 were found to be less than optimum (the MSY level).

Age Structured Models

Virtual population, or cohort analysis has been applied to Pacific bigeye by several authors (Miyabe 1993). Miyabe (1989) used virtual population analysis (VPA) assuming natural mortality rates of 0.4 and 0.6 per year. The analysis was tuned to the Japanese longline CPUE time series. For the analysis using M=0.4 per year, there is no clear trend in population numbers at age, but the estimated fishing mortality rates are relatively high, about 0.3–0.6 per year for the fully recruited age classes. For the analysis using M=0.6, the fishing mortality rates are lower (0.2–0.4 per year), but the estimated numbers at age 1 show a declining trend. Miyabe (1989) considered these results to be preliminary, but concluded that the level of catch in the late 1980s was sustainable.

The IATTC has carried out VPA for bigeye in the eastern Pacific (Tomlinson 1996). Estimates of M of 0.4, 0.6 and 0.8 per year were used in these analyses. Biomass was estimated to have declined since the mid-1980s, with greater declines for the lower assumed values of M. Recruitment appeared to be stable regardless of the M assumed. However, the impact of the recent high surface fishery catches on the longline fishery is strongly dependent on the value of M - strong interaction was estimated assuming M=0.4 per year, but a weak interaction at M=0.8 per year. Similarly, the results of yield per recruit analyses were strongly dependent on the level of M assumed. The 1994 effort (which resulted in high surface fishery catches) is greater than optimum assuming M=0.4 per year, but substantially less than optimum assuming M=0.8 per year.

Albacore

Fishery Indicators

The longline fleet fishing in the South Pacific consists mainly of Japanese, Korean and Taiwanese vessels. Of these, the Taiwanese fleet is the most important and is the only one to have consistently targeted albacore over a long period. The CPUE of this fleet is therefore generally used for examining trends in apparent abundance. Albacore CPUE (expressed in number of fish per 100 hooks) varies according to latitudinal zone, increasing from the equator towards the subtropical convergence zone (Figure 28). Albacore size also varies latitudinally, with smaller fish predominating in the more southerly areas. CPUE declined sharply in all areas between 1986 (when record high CPUEs occurred) and 1990, but has since increased in all areas. However, CPUE remains low relative to most of the time series.

Tag-Recapture Models

Since the early 1980s, 17,297 albacore have been tagged in the South Pacific by various research agencies. Of these, 160 (0.93%) have been recaptured and the tags returned, mostly by longliners. These data have provided useful information mainly on movements and growth. Bertignac et al. (1996) recently made the first attempt to estimate mortality rates from the tagging data. Over a range of possible reporting rates (0.1-1.0) the estimated exploitation rates ranged from 0.11 to 0.01, with estimates of natural mortality of 0.38-0.44 yr^{-1}.

Surplus Production Models

Various authors (reviewed by Murray 1993) have attempted to fit surplus production models to longline catch and effort data, usually using equilibrium models. MSYs for a longline fishery, operating in the presence of a small surface fishery, of 31,000–37,000 t have been estimated. Given the uncertainties in methodology, these estimates should be treated with caution. Further analysis of the available data using the time-series fitting procedure could usefully be undertaken.

Age Structured Models

An age structured model for application to South Pacific albacore has been developed by SPC and Otter Research Ltd, in cooperation with the South Pacific Albacore Research (SPAR) group. The model is an integrated statistical catch-at-age model in which fishing mortality for a particular gear is parameterized in terms of age-dependent selectivity and time-dependent catchability. The age structure of the catch is derived from length frequency samples. For the most recent analysis of the albacore data, spatial structure has been added to the model in the form of three regions - 0-10°S, 10°-30°S and 30°-50°S. Distant-water longline fisheries were defined for each of these regions, as well as a "domestic" longline fishery in region 2. The surface fisheries, the New Zealand coastal troll fishery, the central South Pacific troll fishery and the driftnet fishery, all occur in region 3. This gives a total of seven region-specific fisheries. The model has been fitted to catch, effort and length frequency data for each fishery, and preliminary results are now available. Data up to and including 1993 have been incorporated into the analysis.

The model outputs of most interest in a stock assessment context are the time series of recruitment and relative population biomass. The estimated recruitment time series (Figure 29, lower panel) shows considerable variability, with several very high and very low recruitments. Recruitment generally is estimated to be at significantly lower levels during the second half of the time series. Relatively low estimates of recruitment are obtained for 1985 and 1990. Assuming that the age of recruitment is approximately two years, the spawning seasons corresponding to the low recruitments match well with the occurrence of *El Nino* episodes (negative values of the Southern Oscillation Index) in the Pacific Ocean (Figure 30). The high recruitments resulting from spawning in the mid-1970s and 1989-90 also seem to correspond to *La Nina* events (positive values of the Southern Oscillation Index). The relationship is not as good over the first half of the time series, but recruitment variability during this period may not be well estimated because of the absence of fisheries directed at small albacore.

The biomass estimates (Figure 29, upper panel) show a strongly increasing trend up to the late 1970s and a decreasing trend thereafter until about 1990. The estimates of biomass in the most recent years are similar to the estimates at the beginning of the time series. It is clear that the biomass trends are essentially recruitment driven, with little apparent impact of the fisheries on the stock.

The exploitation rate is an index of the impact of the fishery on the stock. Exploitation rates for juvenile fish (primarily taken by surface fisheries) had been very low prior to the mid-1980s, but increased rapidly with the development of surface fisheries, particularly the driftnet fishery (Figure 31, upper panel). With the cessation of driftnetting, the juvenile albacore exploitation rates fell to around 0.04. For adult albacore (primarily exploited by longliners) exploitation rates have increased since the mid-1980s in line with increases in longline effort (Figure 31, lower panel). The current exploitation rate for adult albacore is estimated to be in the region of 0.12. These estimates are generally consistent with the range of estimates obtained from tagging data.

5. CONCLUSIONS AND FISHERY OUTLOOKS

Skipjack

There is no indication from CPUE time series that the fisheries have significantly impacted the WCPO skipjack stock, but as noted, changes in purse seine technology complicate the interpretation of CPUE as an index of abundance. Most of the information on fishery impacts comes from the SPC tagging experiments. These suggest that the current level of exploitation is low to moderate, in spite of large increases over the past 15 years (to current catches of up to one million tonnes per year).

It is expected that skipjack CPUE will continue to vary in the range 15–25 t per day. The *El Nino* that persisted between 1991 and 1994 switched back towards *La Nina* conditions in 1995 and 1996, resulting in a concentration of fishing effort and higher catch rates in the PNG-FSM-Solomon Islands area. It is possible that the prolonged *El* Nino could have impacted skipjack reproductive success (there are no data currently available to support this; however such impacts have been suggested in other areas); skipjack recruitment may therefore be lower than normal for several years. Recent climatic data suggest that the *El Nino*-Southern Oscillation (ENSO) cycle is beginning to revert once more to *El Nino* conditions. If this trend continues, we would expect some eastwards shift of surface fishery productivity to again occur.

Yellowfin

The above comments for skipjack are largely appropriate for yellowfin also. Surface fishery CPUEs are variable but show no evidence of persistent stock declines. Low CPUE in 1995 and 1996 could be related to reduced yellowfin vulnerability associated with the switch from *El Nino* to *La Nina* conditions, although reduced yellowfin recruitment following the most recent *El Nino* is also a possibility. The status of the adult portion of the stock is more uncertain, given the decline in longline CPUE. Tagging data indicate moderate exploitation rates overall, and preliminary results from a size structured analysis of the tagging data do not suggest that exploitation rates are particularly high for any individual size class. If the tagging results are generally applicable to the yellowfin stock, it is unlikely that the decline in longline CPUE is primarily the result of increases in purse seine catch. However, further analyses of the tagging data to test the effects of possible differential reporting of tags among purse seine and longline fleets are required.

Similar purse seine catch rates to those of recent years (4–10 t per day) can be expected in the short term. As with skipjack, concentration of the fishery in the PNG-FSM-Solomon Islands area occurred in 1995 and 1996 following the switch to *La Nina* conditions, but may once again shift to the east if the recent trend back towards *El Nino* conditions persists. As with skipjack, effects of the recent *El Nino* on current yellowfin recruitment may result in below average catch rates for several years.

Bigeye

Longline CPUE for bigeye shows quite different trends in the eastern (decreasing) and western (stable) Pacific. Indices of abundance based on these data show similar trends, although there are some differences in the results of analyses carried out by Japanese and IATTC scientists for the eastern Pacific. Some surplus production model fits to the data suggest that recent catch levels are in the region of, and possibly exceed, the estimated MSY, while others (for the eastern Pacific) suggest that total effort levels are less than that corresponding to MSY. There has been some recent progress in better defining important bigeye population and fishery parameters; however, many information gaps remain. In particular, the lack of more precise estimates of natural mortality rates for bigeye complicate the interpretation of results of age-structured models such as VPA. The status of Pacific bigeye continues to be highly uncertain. Greater research and monitoring efforts leading to the application of more informative stock assessment models are urgently required.

The outlook for longline fishery catch rates of bigeye depends on the impact of increased surface catches in both the western and eastern Pacific. If the natural mortality rate is in the region of 0.4 per year or lower, significant impacts can be expected. The response of longline CPUE over the next several years to these increased surface fishery catches should provide new information about the dynamics of the bigeye stock.

Albacore

Considerable improvements have been made in albacore stock assessment over the past year. The conclusions of a recent meeting of the South Pacific Albacore Research Group were as follows:

"Total catches of South Pacific albacore have been stable over the past several years, although the success of the troll fishery in the STCZ has been variable. Longline CPUE has been stable or increasing in recent years, and there is no evidence from these data that the current levels of fishing are adversely affecting the stock. Nor is there any indication that the driftnet catches of the late 1980s and early 1990s have had a significant impact on the stock or on the longline fishery. Analyses of tagging data and a length-based age-structured model provide reasonably consistent estimates of growth and mortality rates, which suggest that albacore are slow growing and long lived relative to the tropical tunas. The fisheries potential of albacore is therefore more restricted by comparison with these species. The tagging and age-structured models also provide a preliminary indication that the current exploitation rate is relatively low, probably less than 10% per year. This provides further evidence that the current level of fishing can be sustained."

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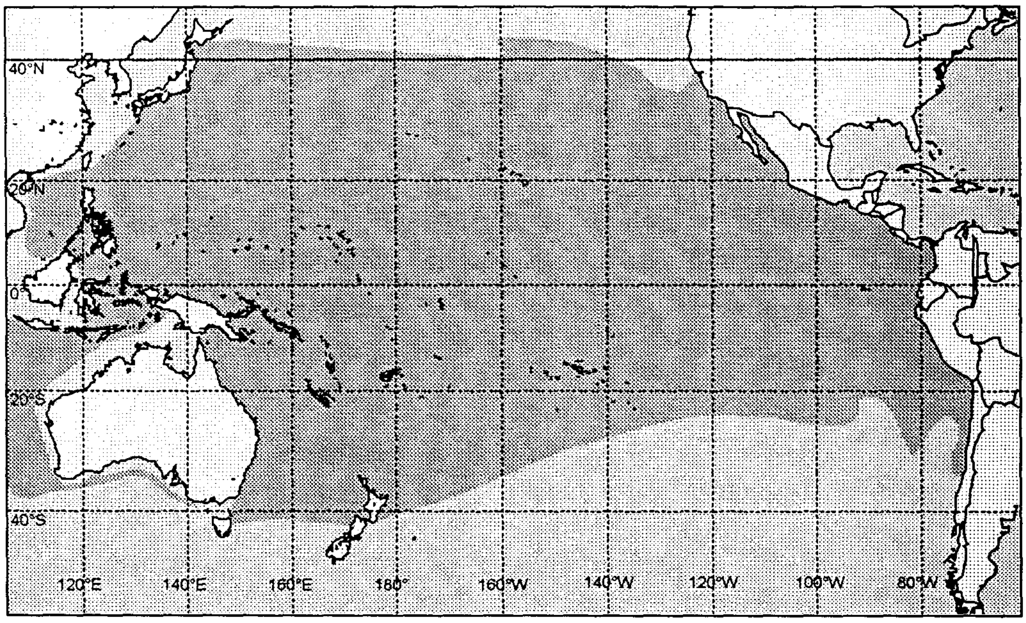

Figure 1. Schematic distributions of tuna stocks in the Pacific Ocean. (a) skipjack.

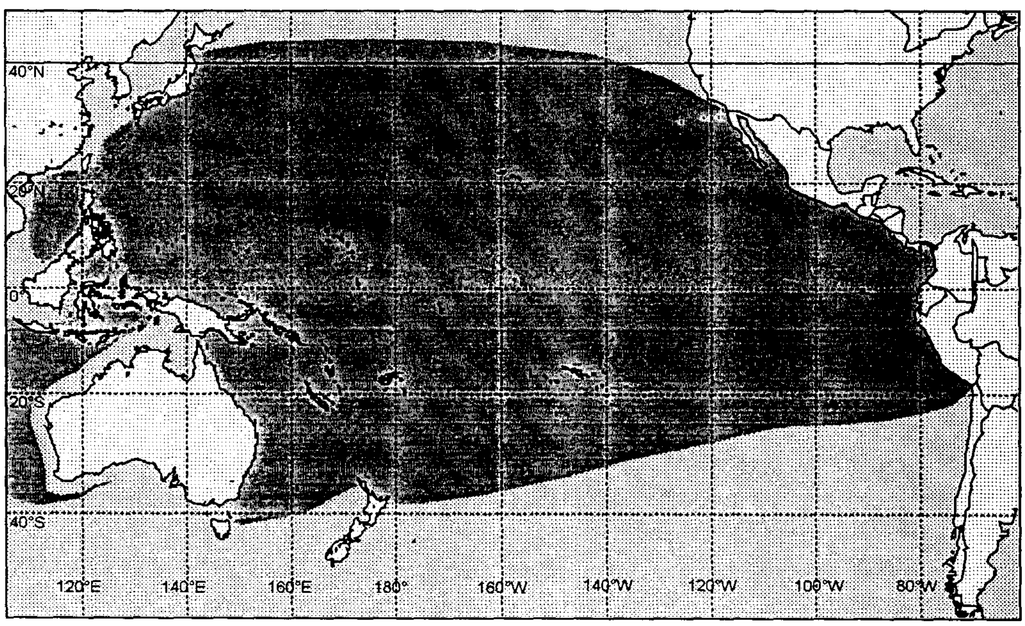

Figure 1. Schematic distributions of tuna stocks in the Pacific Ocean. (b) yellowfin.

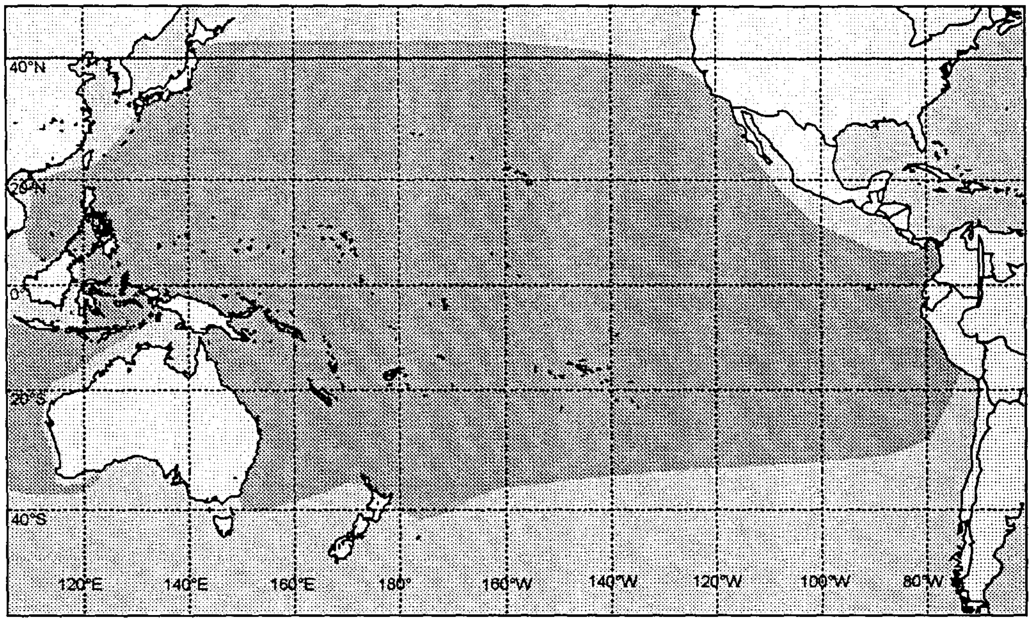

Figure 1. Schematic distributions of tuna stocks in the Pacific Ocean. (c) bigeye.

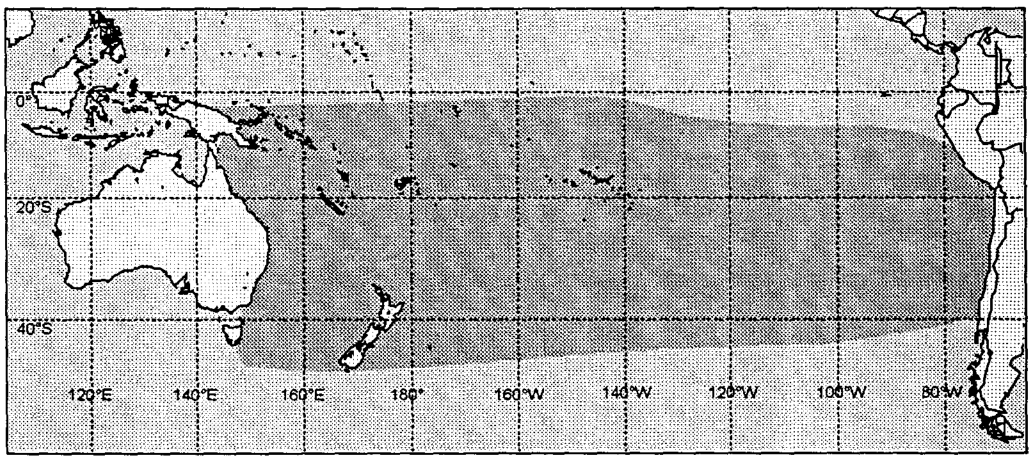

Figure 1. Schematic distributions of tuna stocks in the Pacific Ocean. (d) South Pacific albacore.

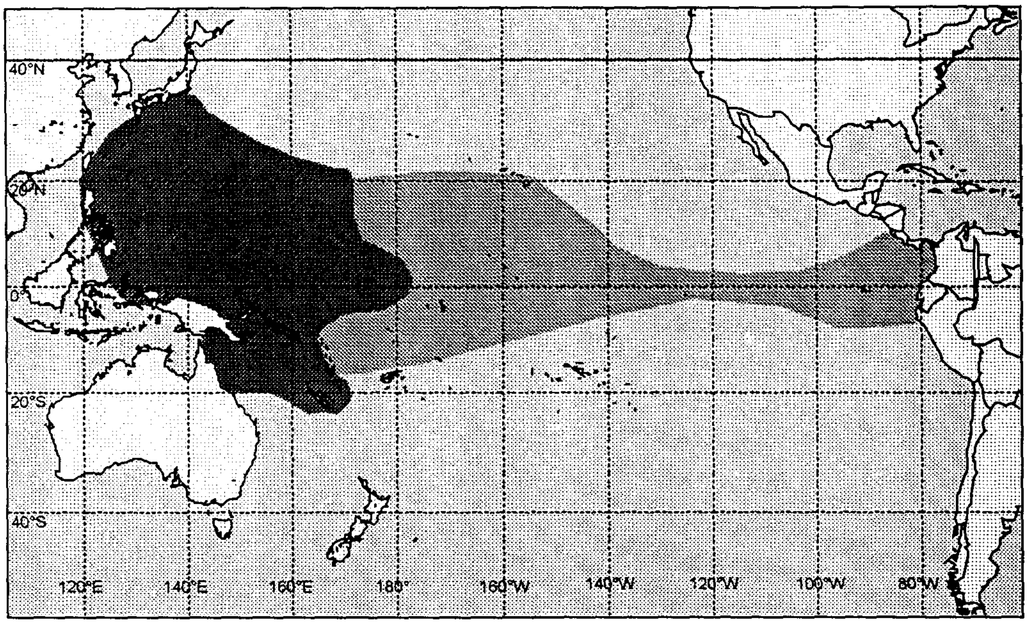

Figure 2. Schematic distributions of tuna larvae in the Pacific Ocean. (a) skipjack. The darker region indicates probable higher larval densities.

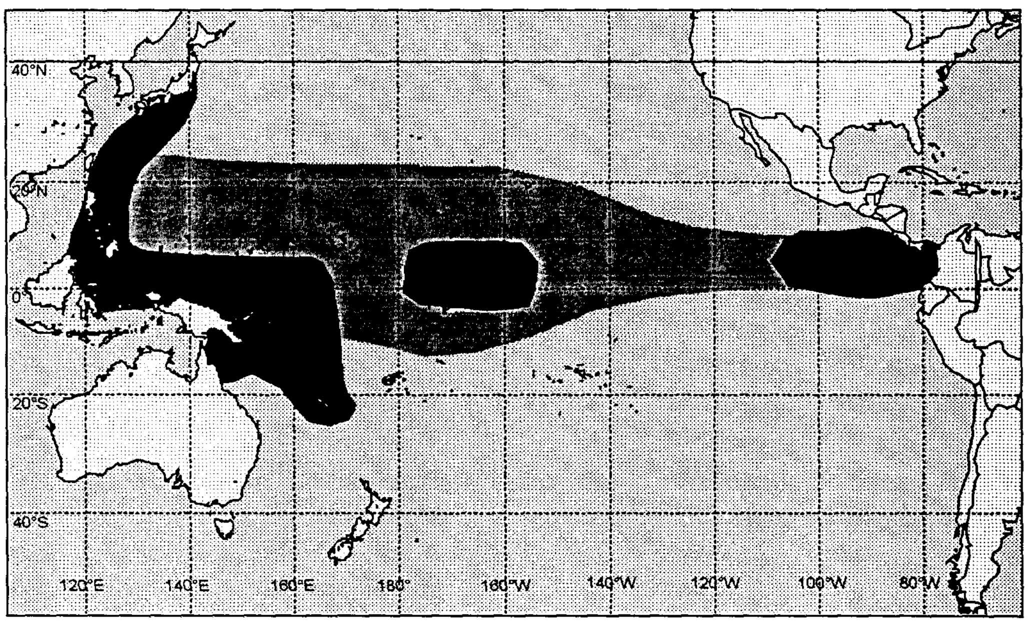

Figure 2. Schematic distributions of tuna larvae in the Pacific Ocean. (b) yellowfin. The darker region indicates probable higher larval densities.

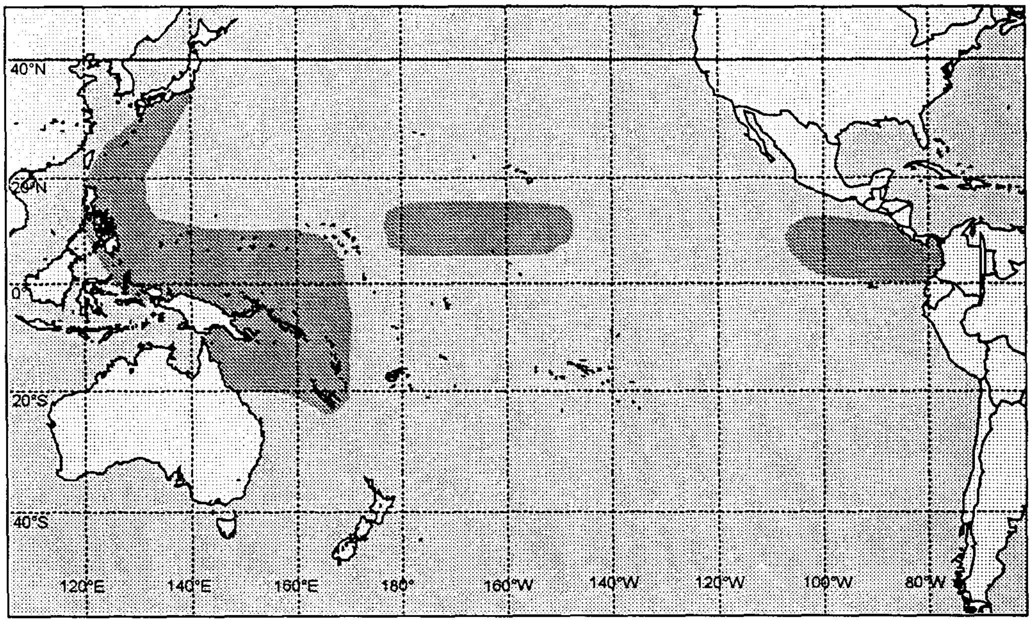

Figure 2. Schematic distributions of tuna larvae in the Pacific Ocean. (c) bigeye.

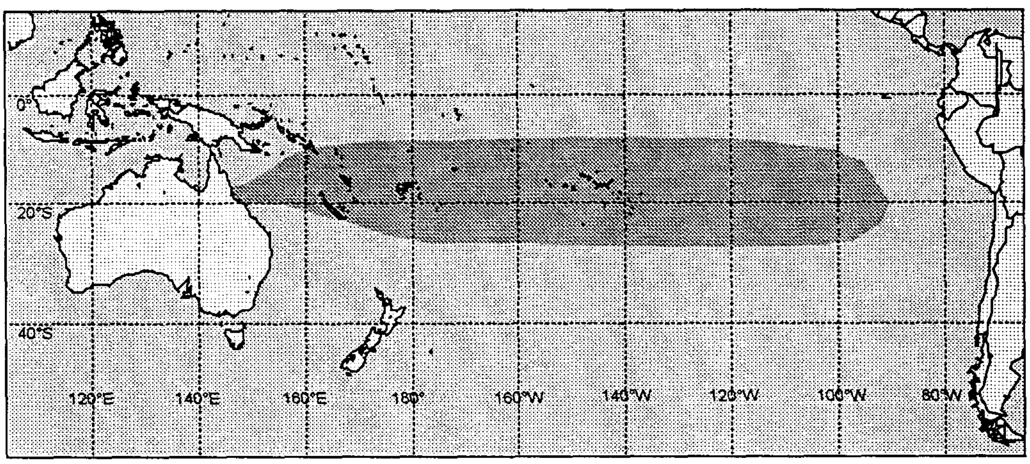

Figure 2. Schematic distributions of tuna larvae in the Pacific Ocean. (d) South Pacific albacore.

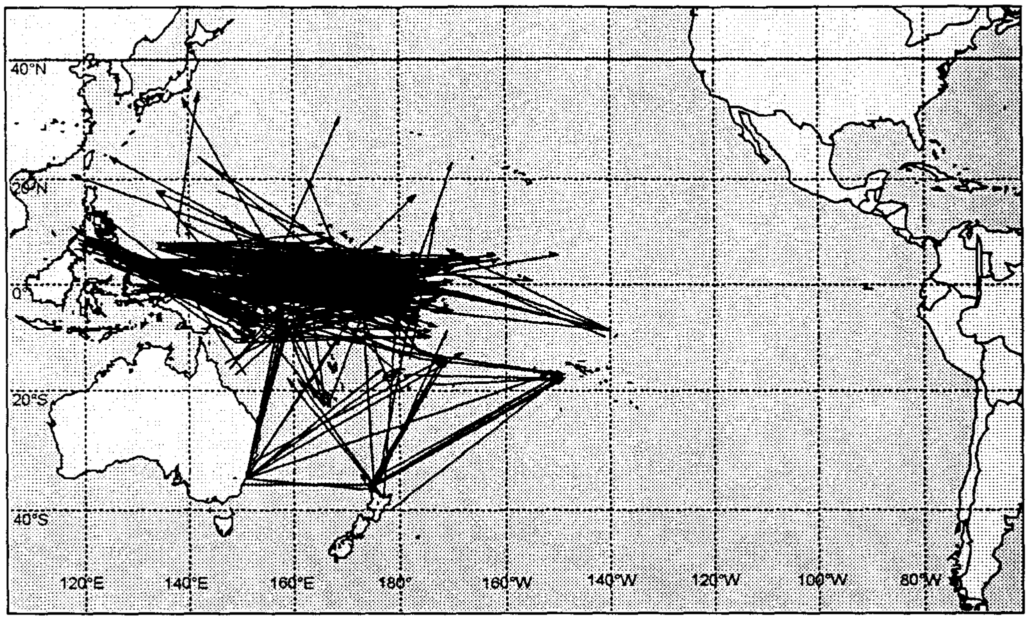

Figure 3. Tagged skipjack displacements >1,000 nmi. (SPC releases).

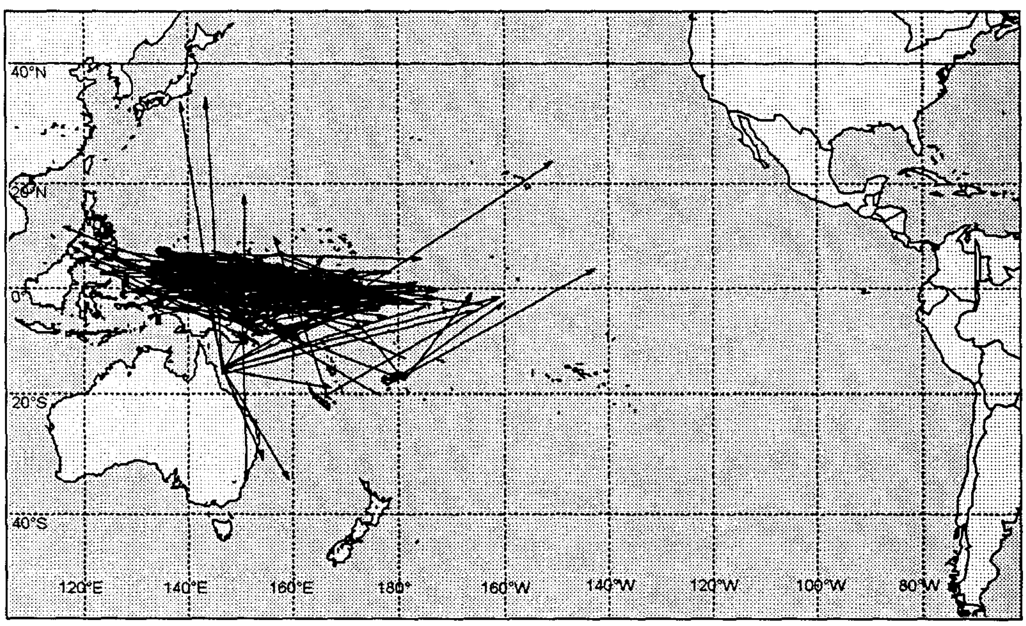

Figure 4. Tagged yellowfin displacements >1,000 nmi. (SPC releases).

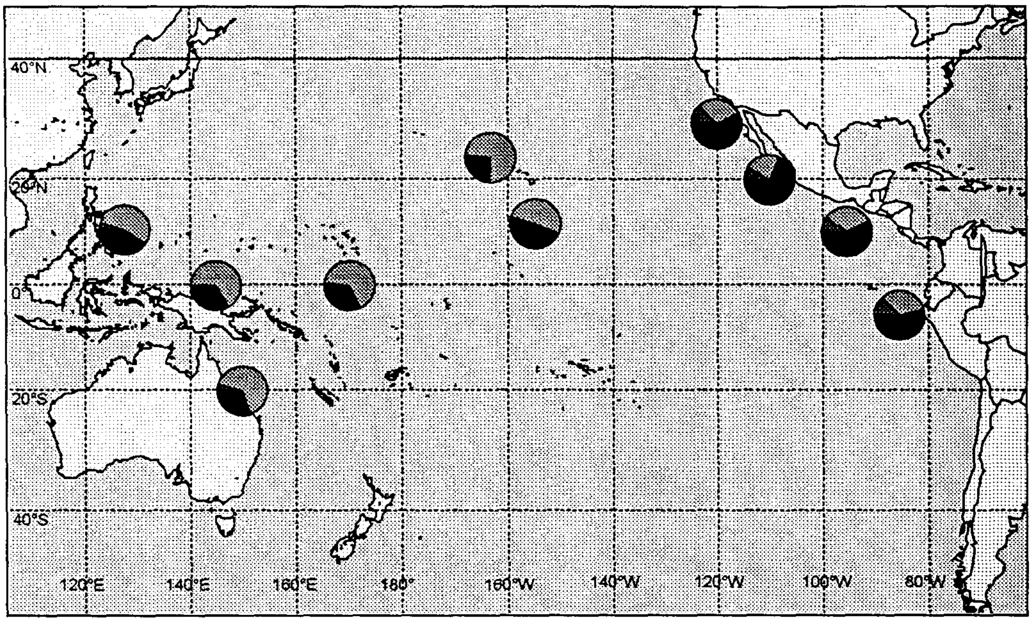

Figure 5. Distribution of yellowfin GSI-5* allele frequencies in the Pacific Ocean. [Reproduced from Ward et al. 1994]

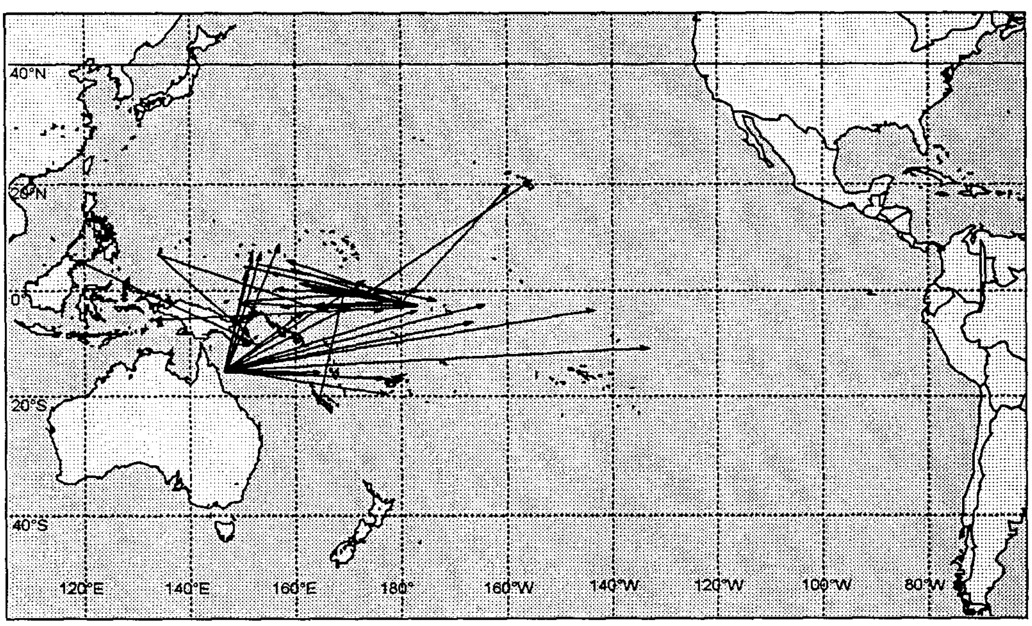

Figure 6. Tagged bigeye displacements >1,000 nmi. (SPC releases).

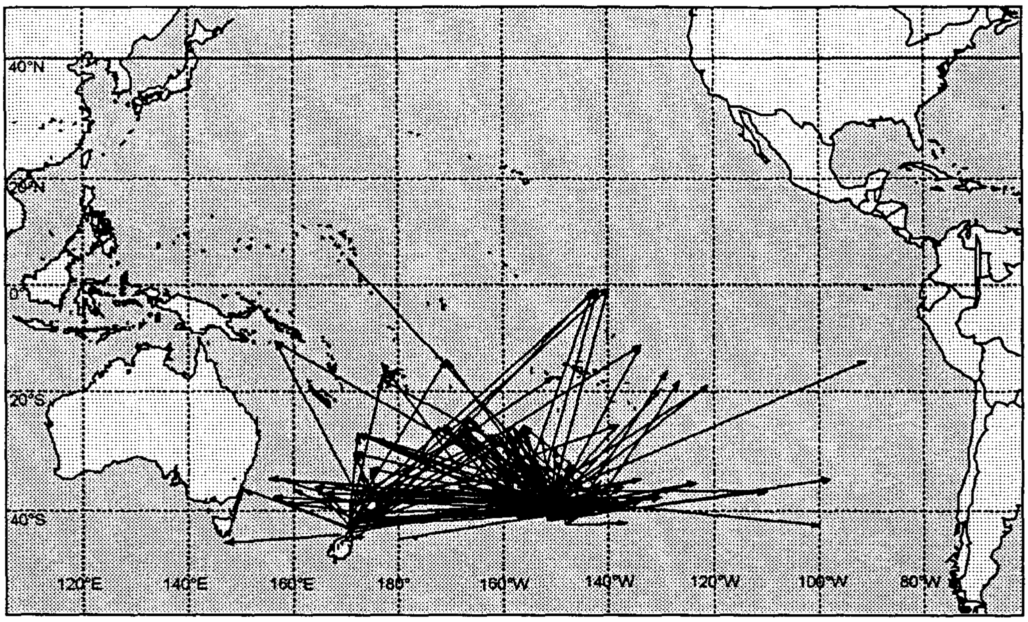

Figure 7. Tagged South Pacific albacore displacements (SPAR tagging database).

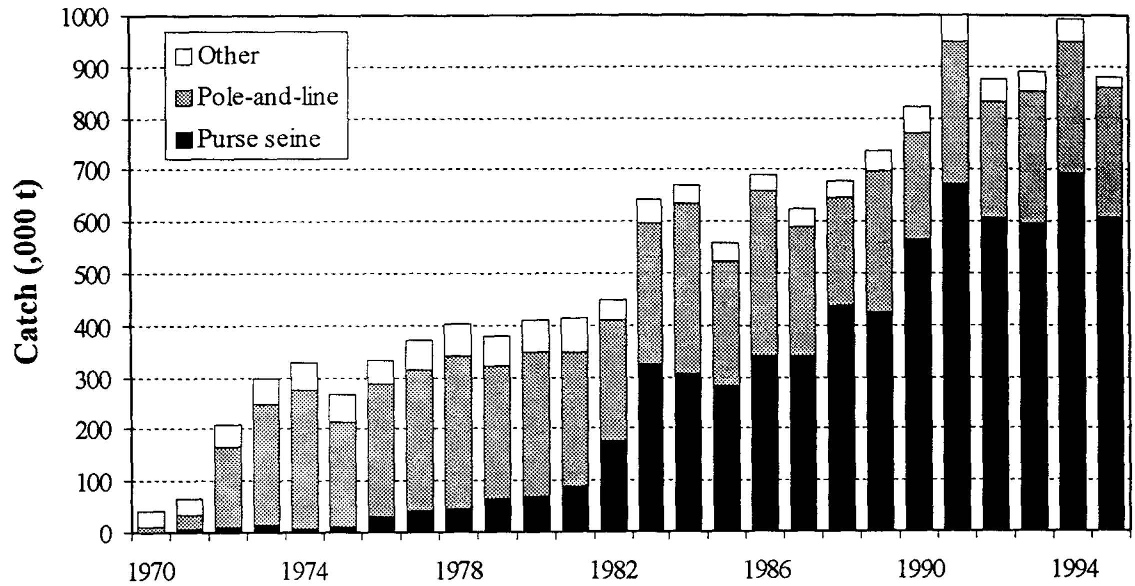

Figure 8. Skipjack catch by gear type in the WCPO. "Other" includes unclassified catches by the domestic fisheries of Philippines and eastern Indonesia. Source: WPYRG 1995 and Lawson (1996).

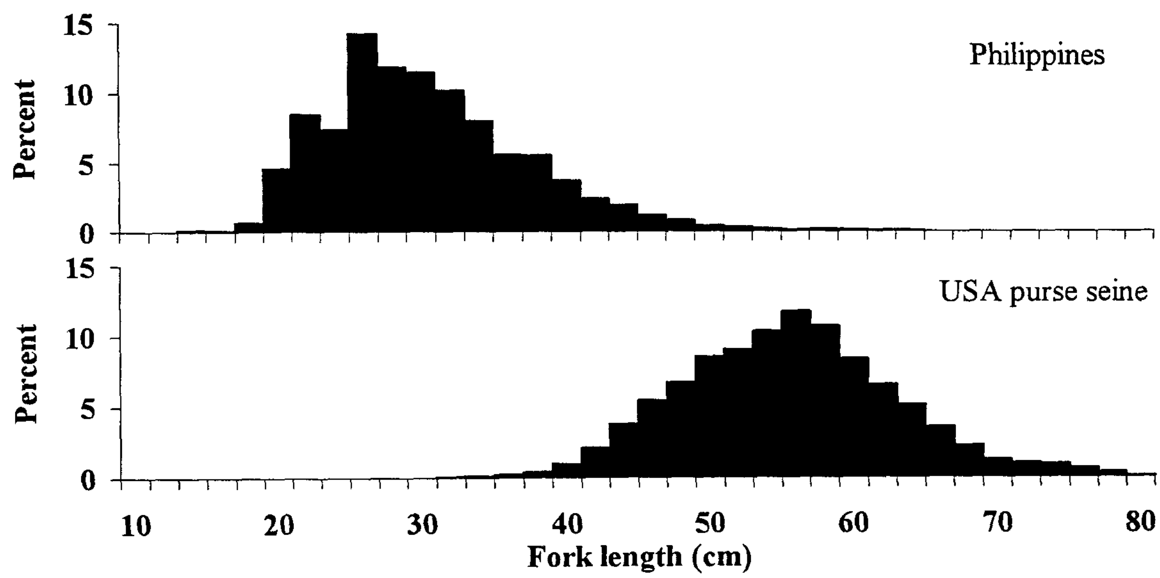

Figure 9. Size composition of skipjack caught in the Philippines domestic fishery and by USA purse seiners in the WCPO.

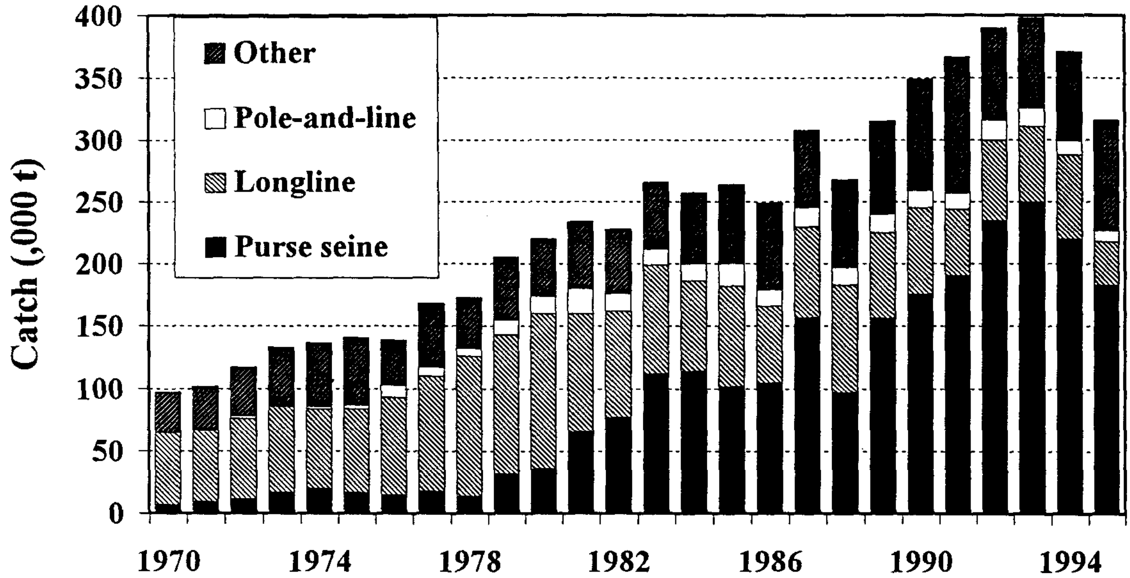

Figure 10. Yellowfin catch by gear type in the WCPO. "Other" includes unclassified catches by the domestic fisheries of Philippines and eastern Indonesia. Source: WPYRG 1995 and Lawson (1996).

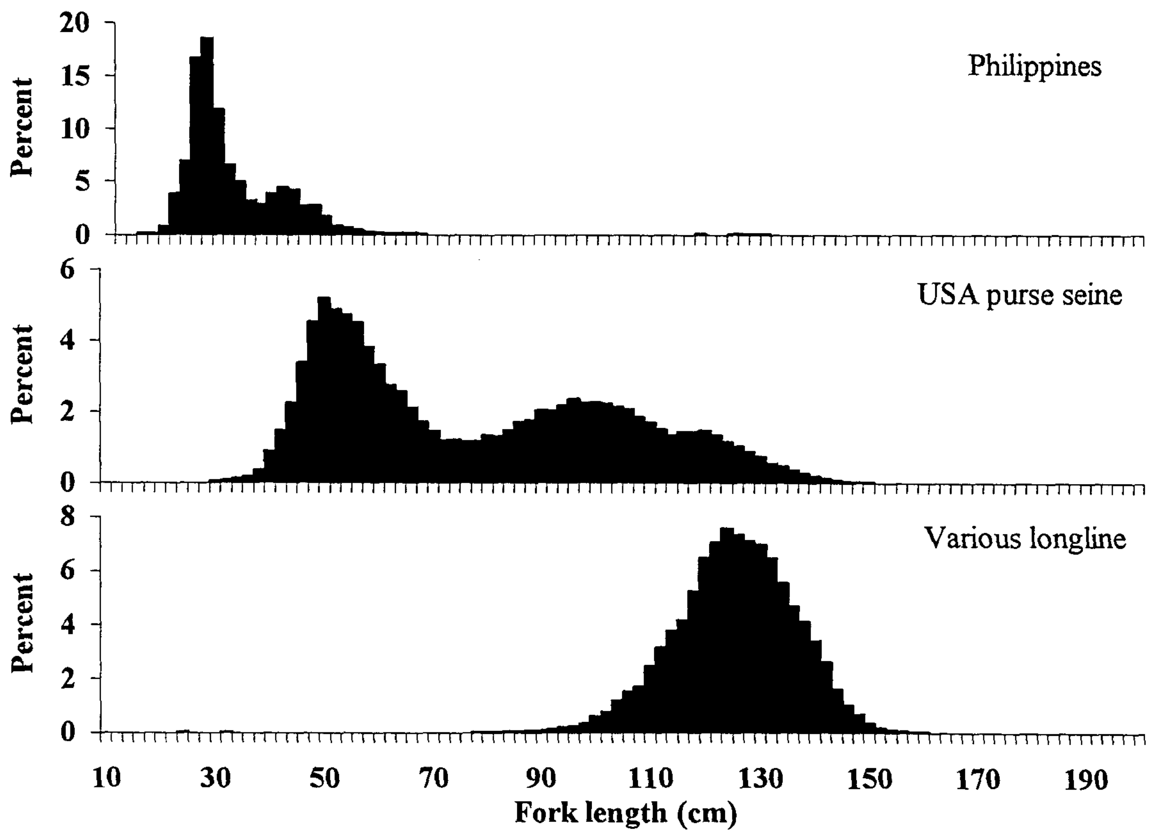

Figure 11. Size composition of yellowfin caught in the Philippines domestic fishery, by USA purse seiners and by longliners in the WCPO.

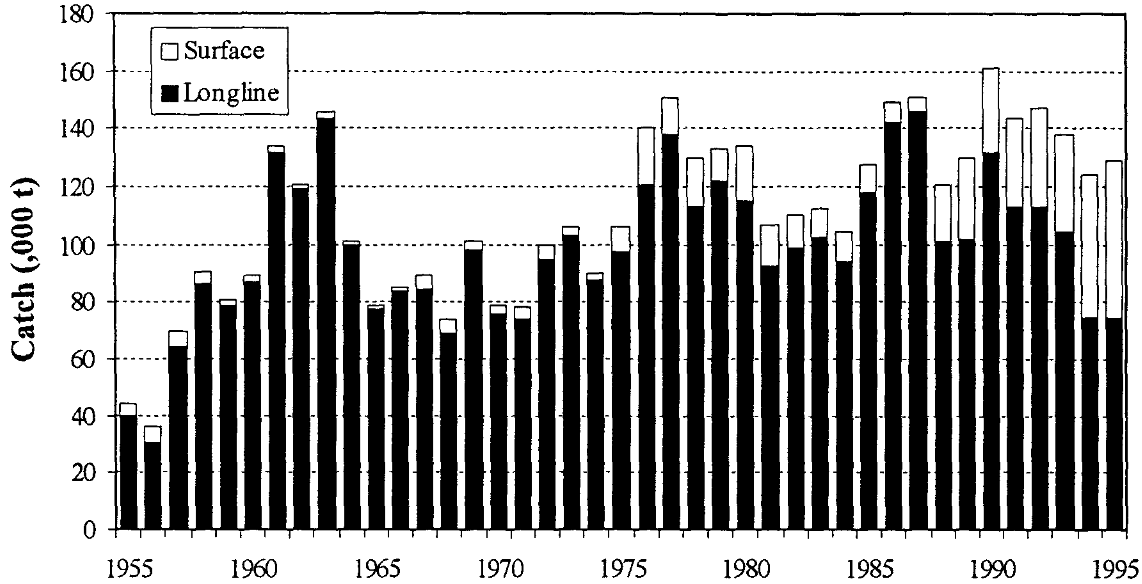

Figure 12. Bigeye catch by longline and surface fisheries in the Pacific Ocean. Surface fishery catches may be under-estimated prior to 1988. Source: Miyabe (1995a) and Hampton et al. (1996).

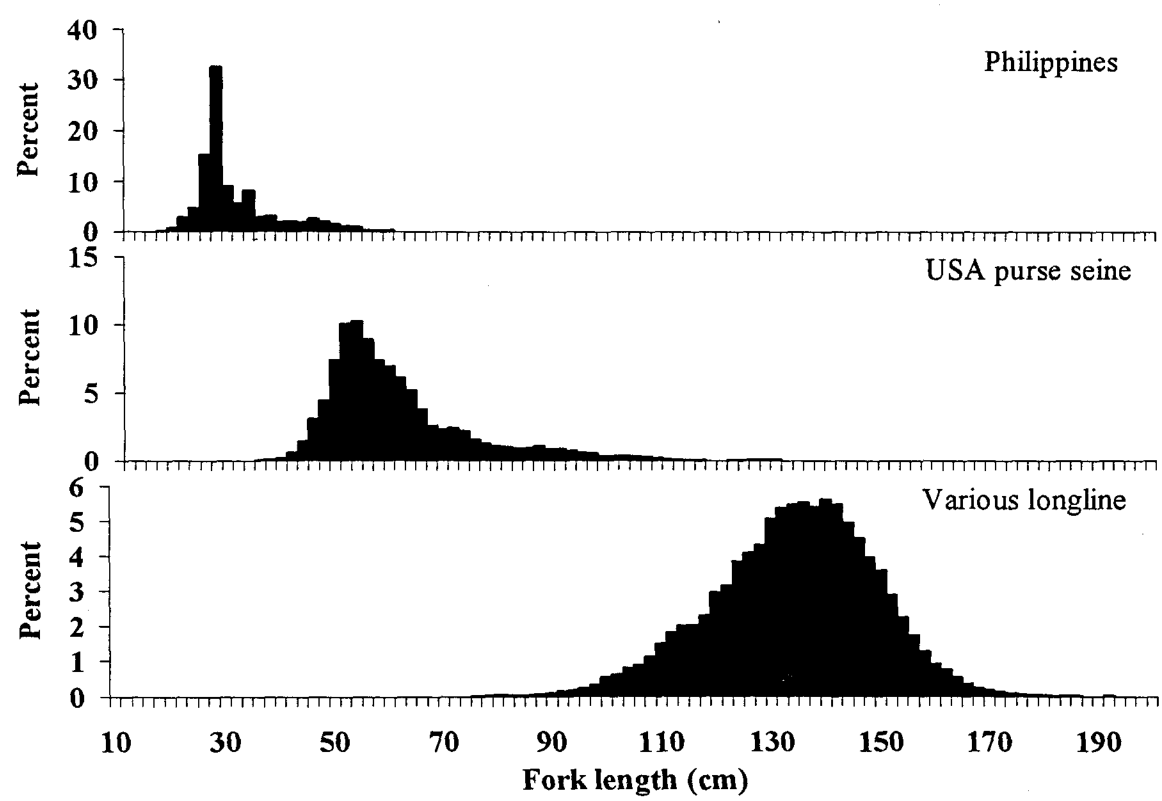

Figure 13. Size composition of bigeye caught in the Philippines domestic fishery, by USA purse seiners and by longliners in the WCPO.

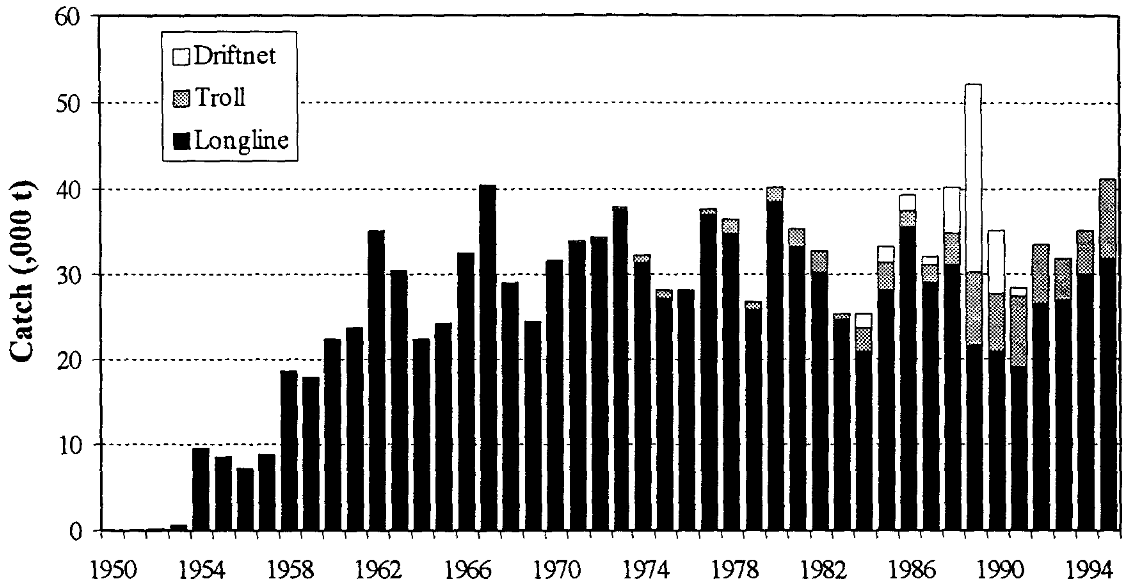

Figure 14. Albacore catch by longline, troll and driftnet fisheries in the South Pacific Ocean. Source: SPAR Workshop 1996.

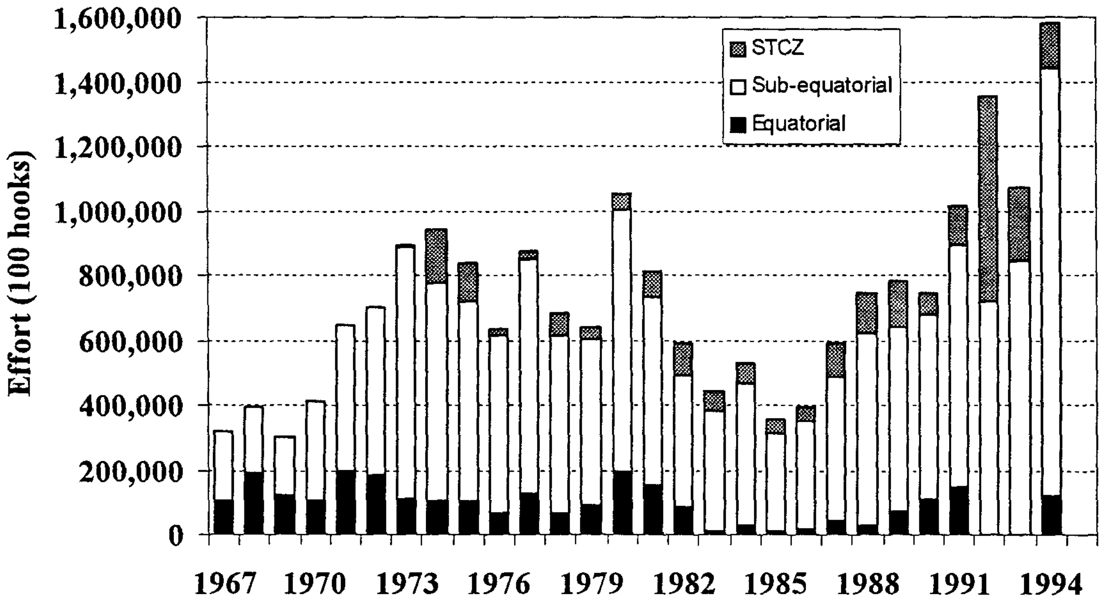

Figure 15. Effort by Taiwanese longliners. The areas referred to are: Equatorial: 0–10°S; Sub-equatorial: 10–35°S; STCZ (subtropical convergence zone): 35–50°S.

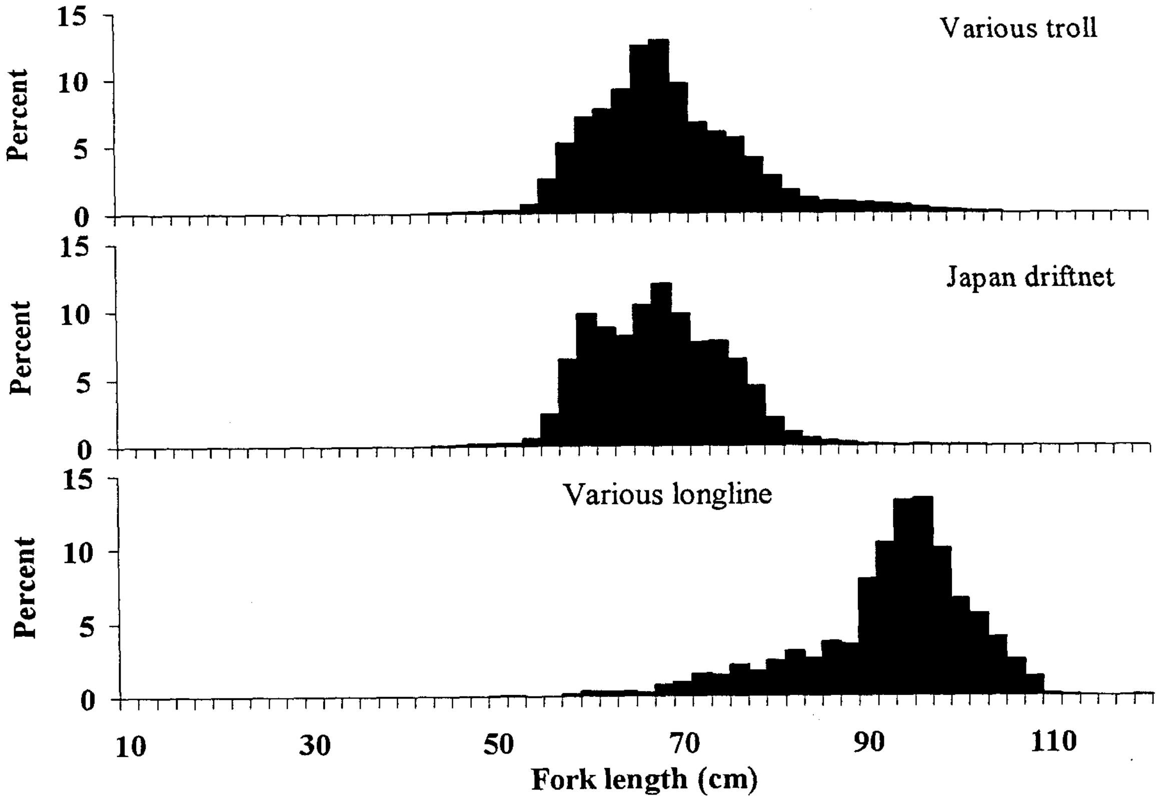

Figure 16. Size composition of albacore caught by troll, driftnet and longline in the South Pacific Ocean.

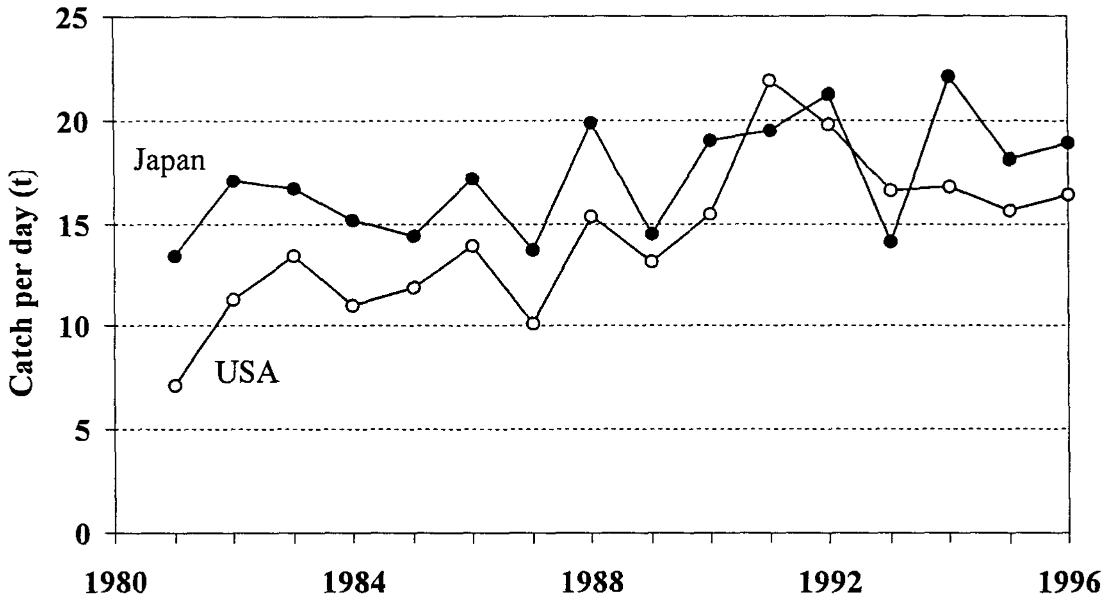

Figure 17. Skipjack CPUE by Japanese and USA purse seiners. 1996 data are preliminary.

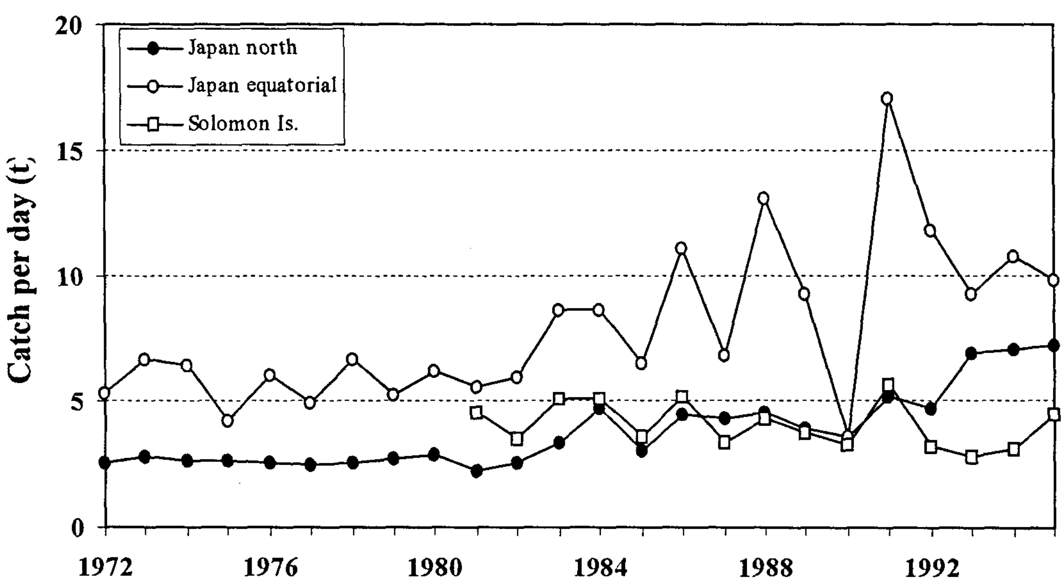

Figure 18. Skipjack CPUE by Japanese pole-and-line vessels. The equatorial area refers to 10°N–10°S. The northern area refers to 10–40°N. 1995 data are preliminary.

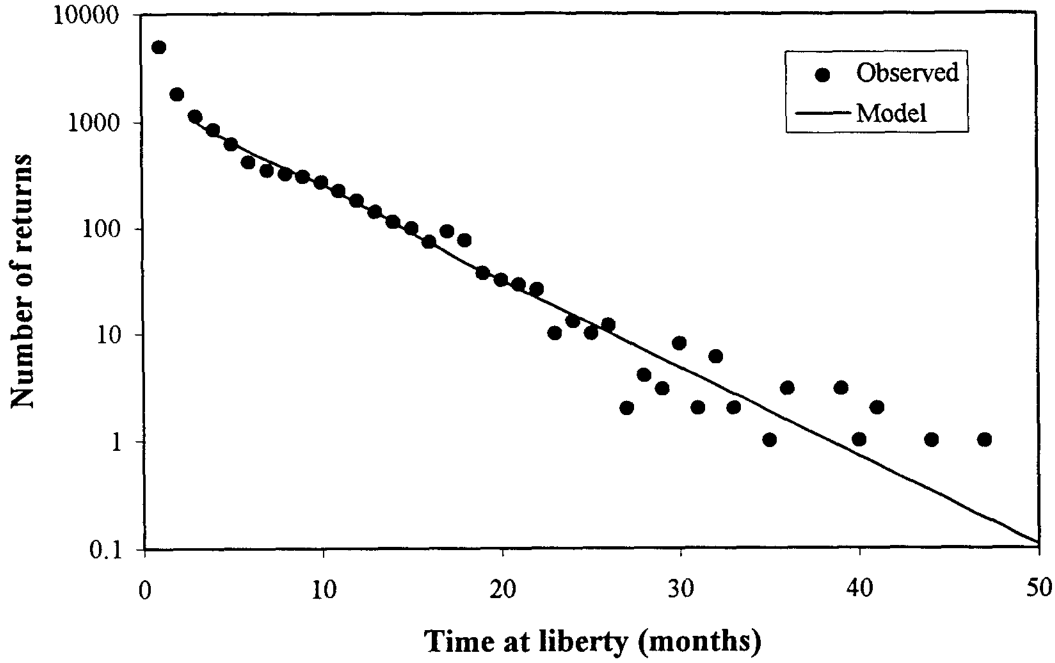

Figure 19. Observed and predicted skipjack tag attrition, based on RTTP data. The model used for the predictions was a size-structured tag attrition model.

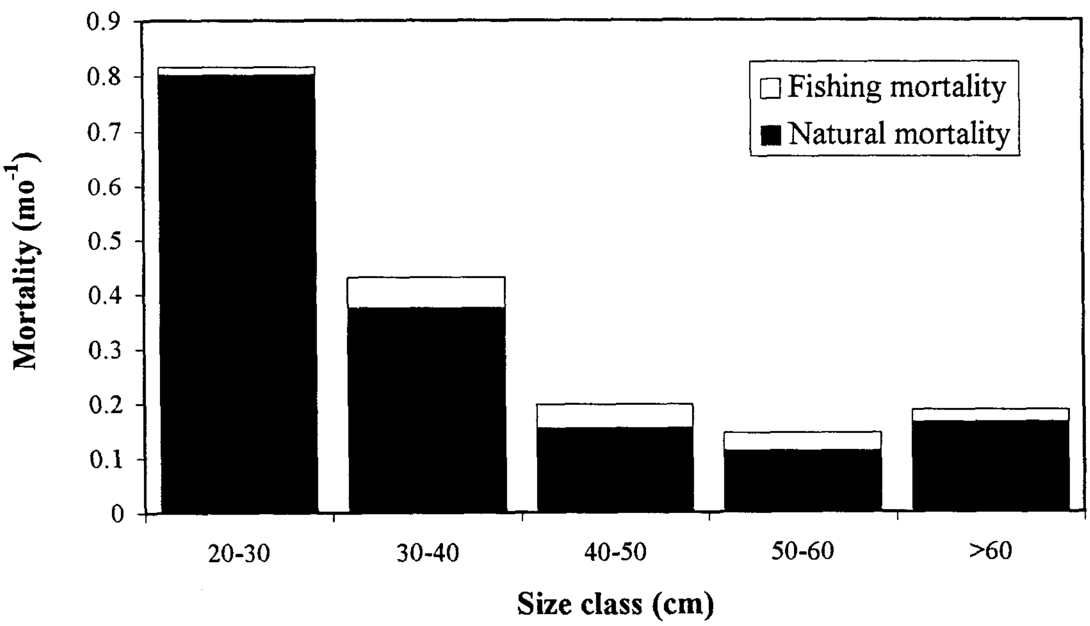

Figure 20. Total mortality, natural mortality and fishing mortality of skipjack, by size class, estimated from RTTP tagging data.

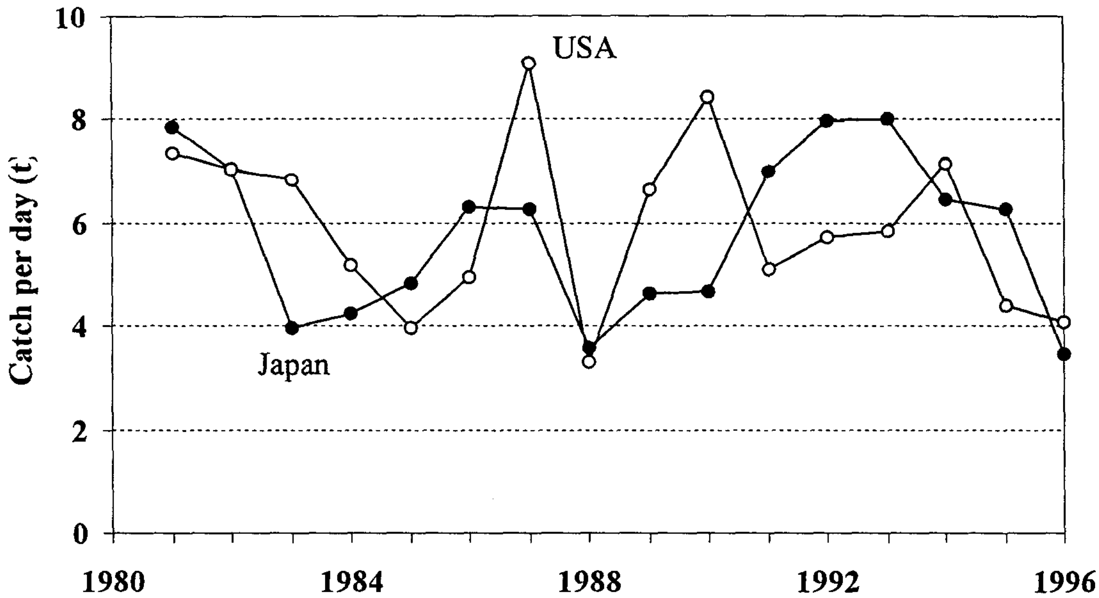

Figure 21. Yellowfin CPUE by Japanese and USA purse seiners. 1996 data are preliminary.

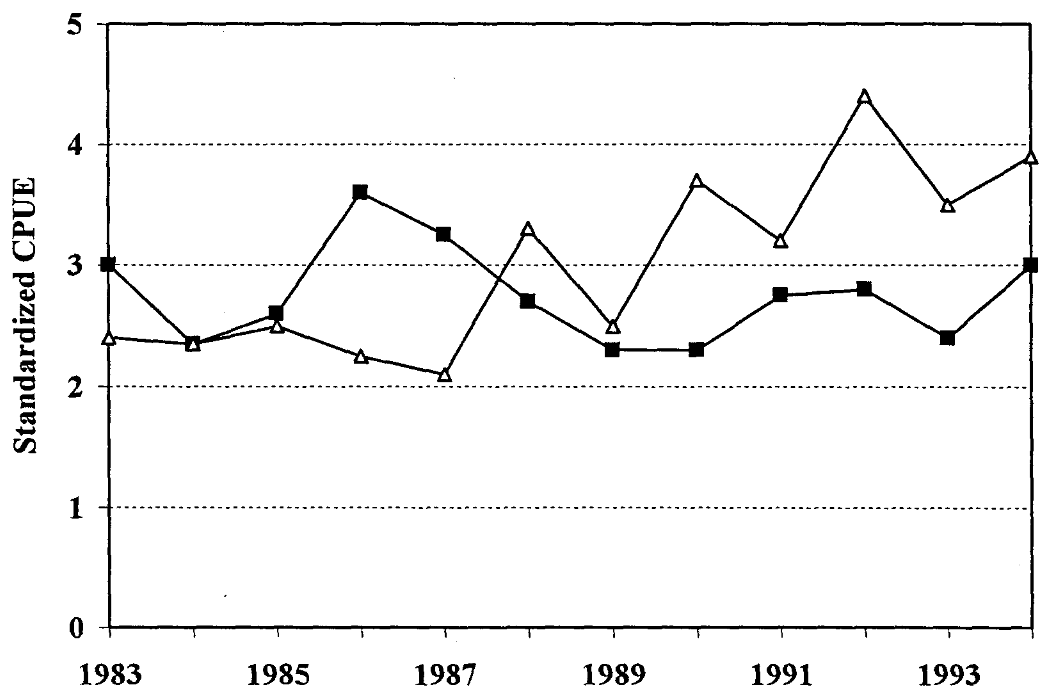

Figure 22. Small and large yellowfin abundance indices based on Japanese purse seine CPUE. After Miyabe (1995b).

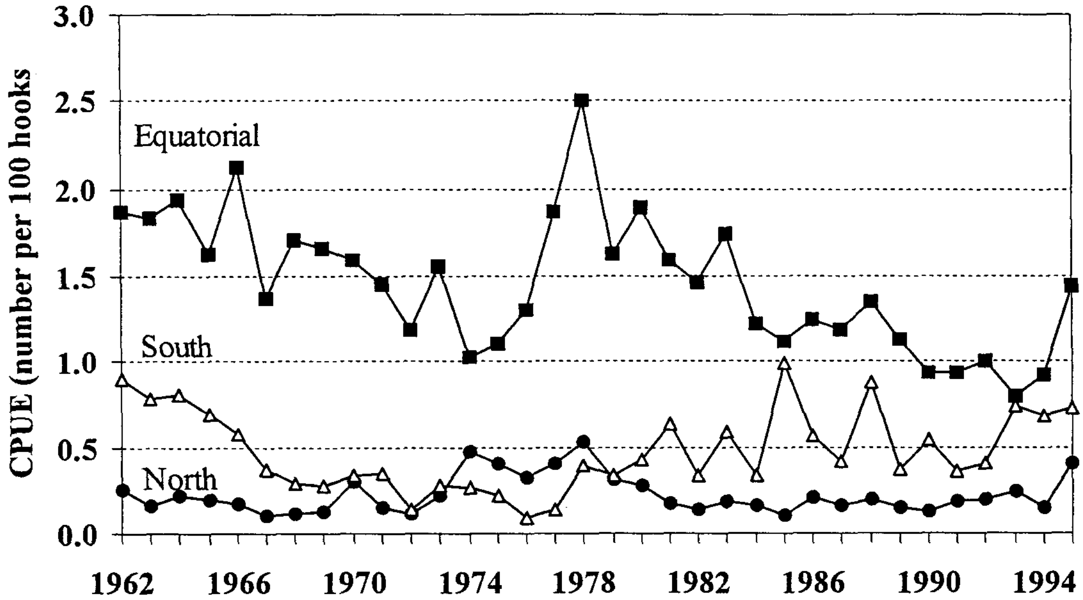

Figure 23. Yellowfin CPUE by Japanese longliners. The areas referred to are: Equatorial – 10°N–10°S; South – 10–40°S; North – 10–40°N. 1995 data are preliminary.

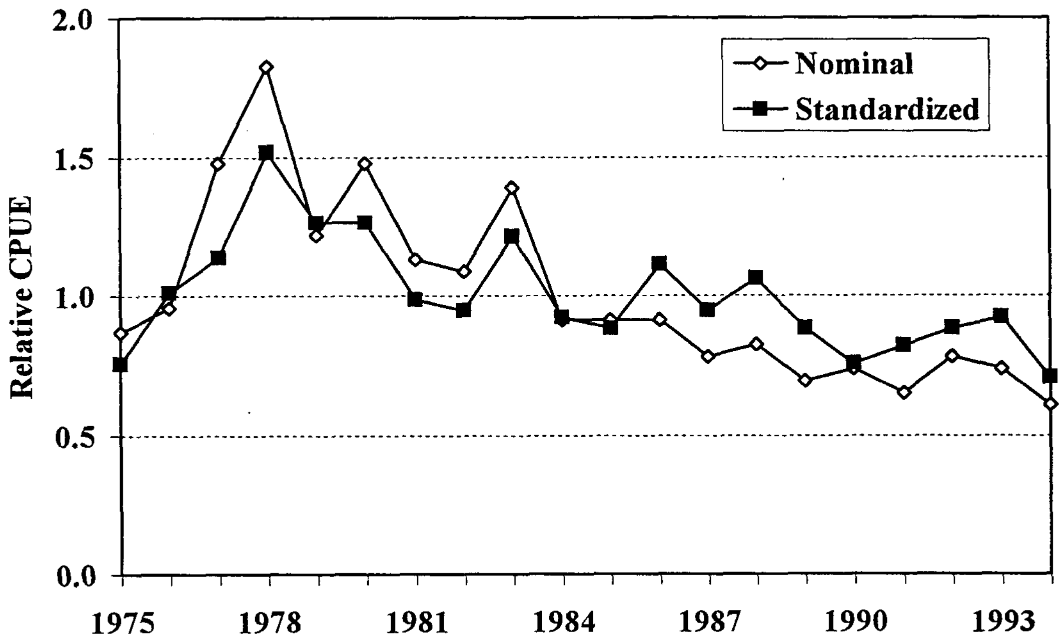

Figure 24. Nominal and standardized yellowfin CPUE by Japanese longliners in the area 20°N–20°S.

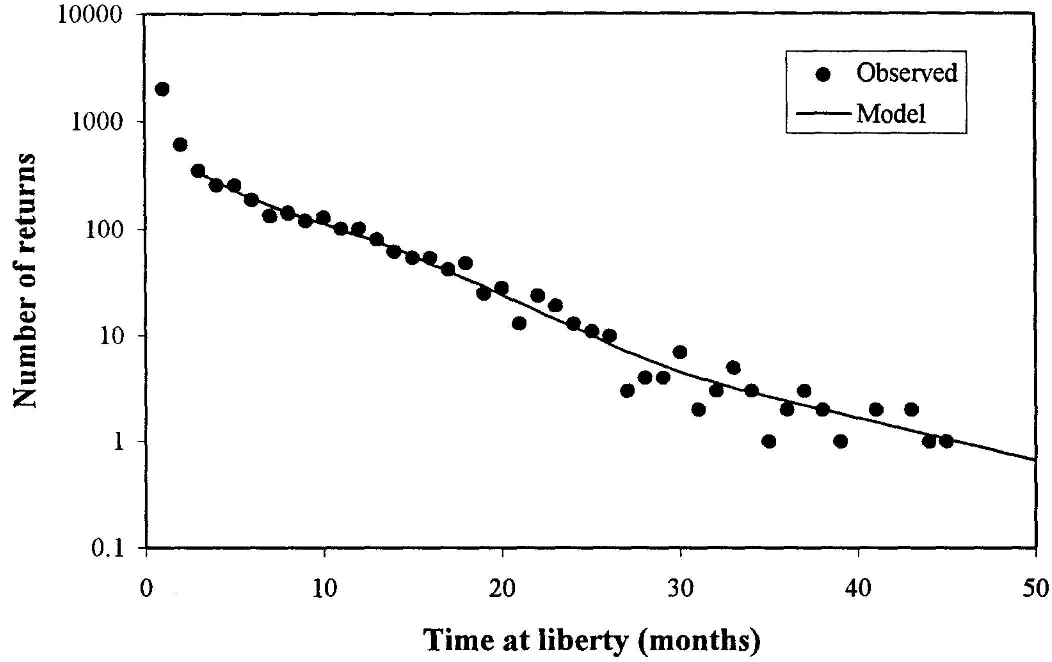

Figure 25. Observed and predicted yellowfin tag attrition, based on RTTP data. The model used for the predictions was a size-structured tag attrition model.

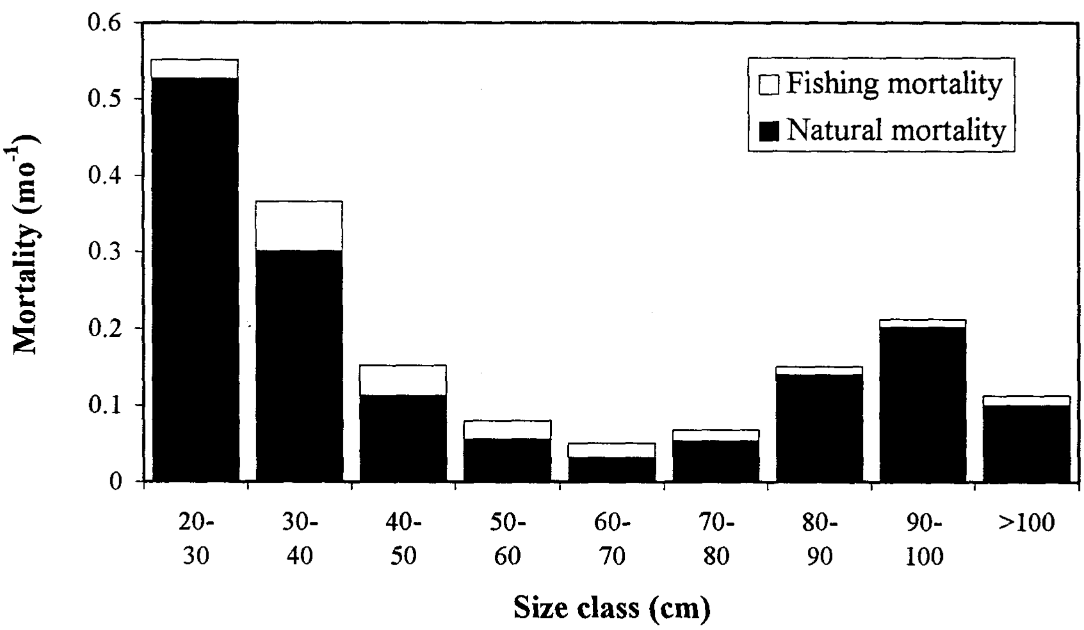

Figure 26. Total mortality, natural mortality and fishing mortality of yellowfin, by size class, estimated from RTTP tagging data.

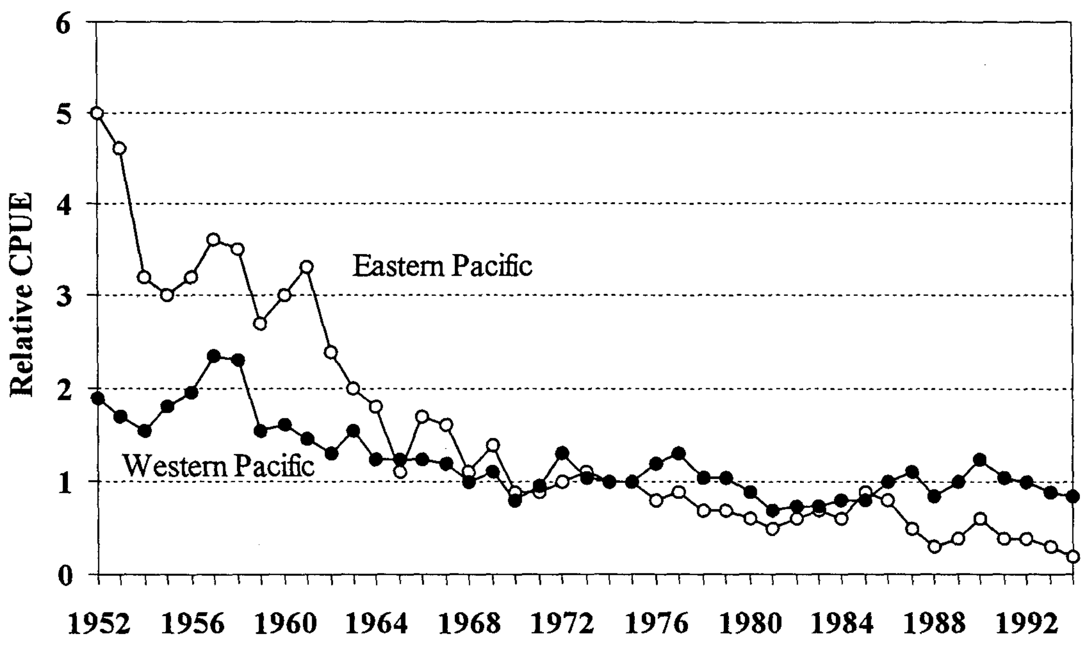

Figure 27. Bigeye abundance indices based on CPUE by Japanese longliners. Eastern and western Pacific refer to areas east and west of 150°W. After Miyabe (1995a)

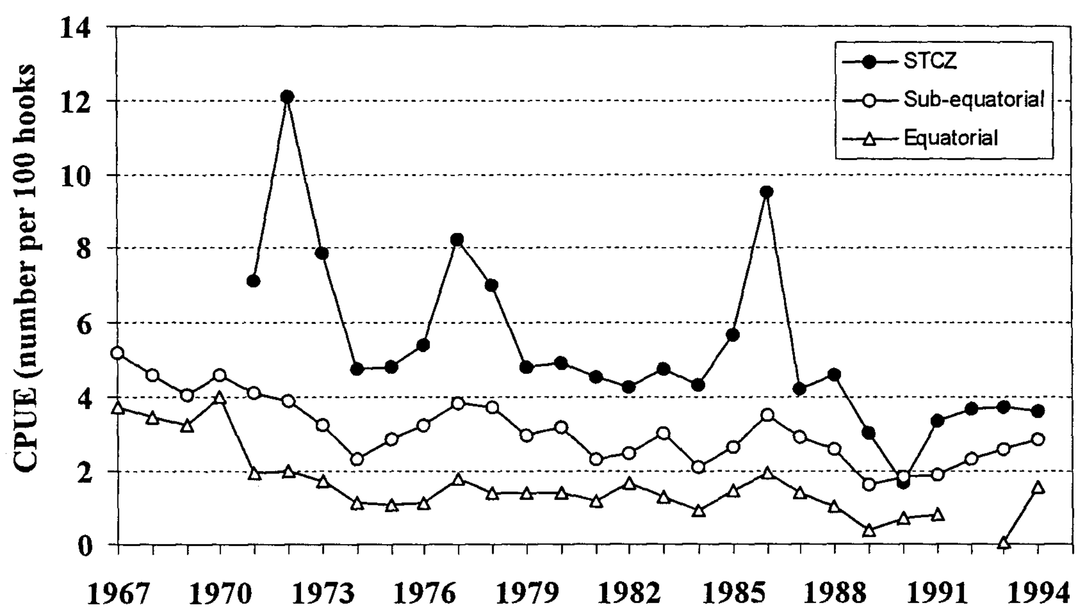

Figure 28. Albacore CPUE by Taiwanese longliners. The areas referred to are: Equatorial: 0–10°S; Sub-equatorial: 10–35°S; STCZ (subtropical convergence zone): 35–50°S.

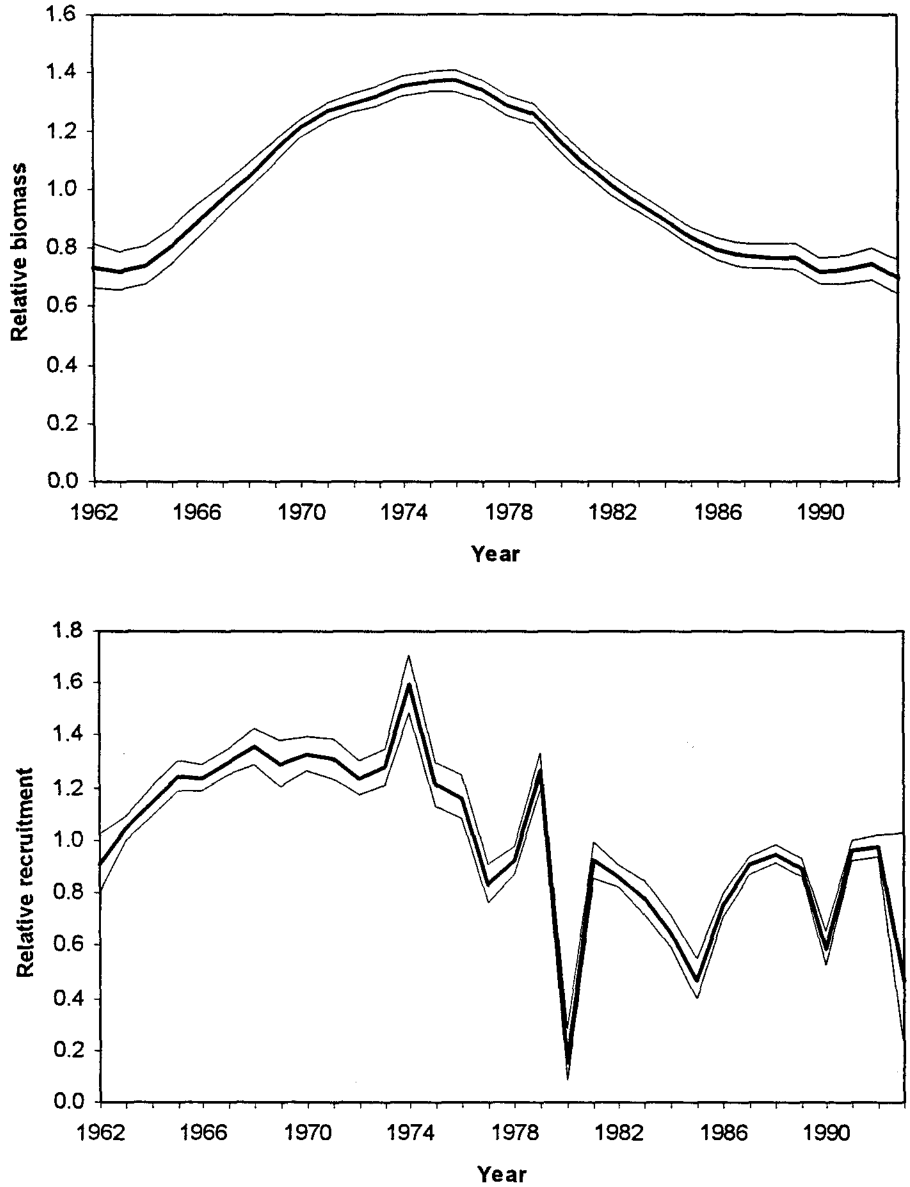

Figure 29. Estimated trends in relative biomass (upper) and recruitment (lower) for South Pacific albacore. The outer lines indicate the 95% confidence intervals about the estimates.

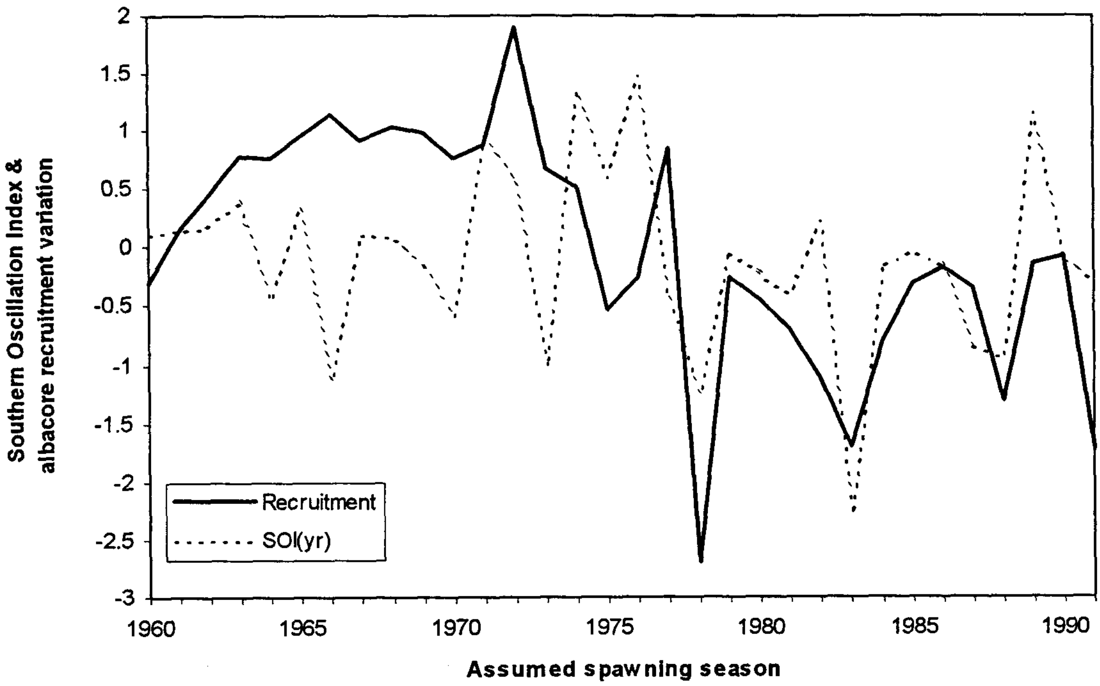

Figure 30. Estimated South Pacific albacore recruitment, by assumed spawning season, and the Southern Oscillation Index.

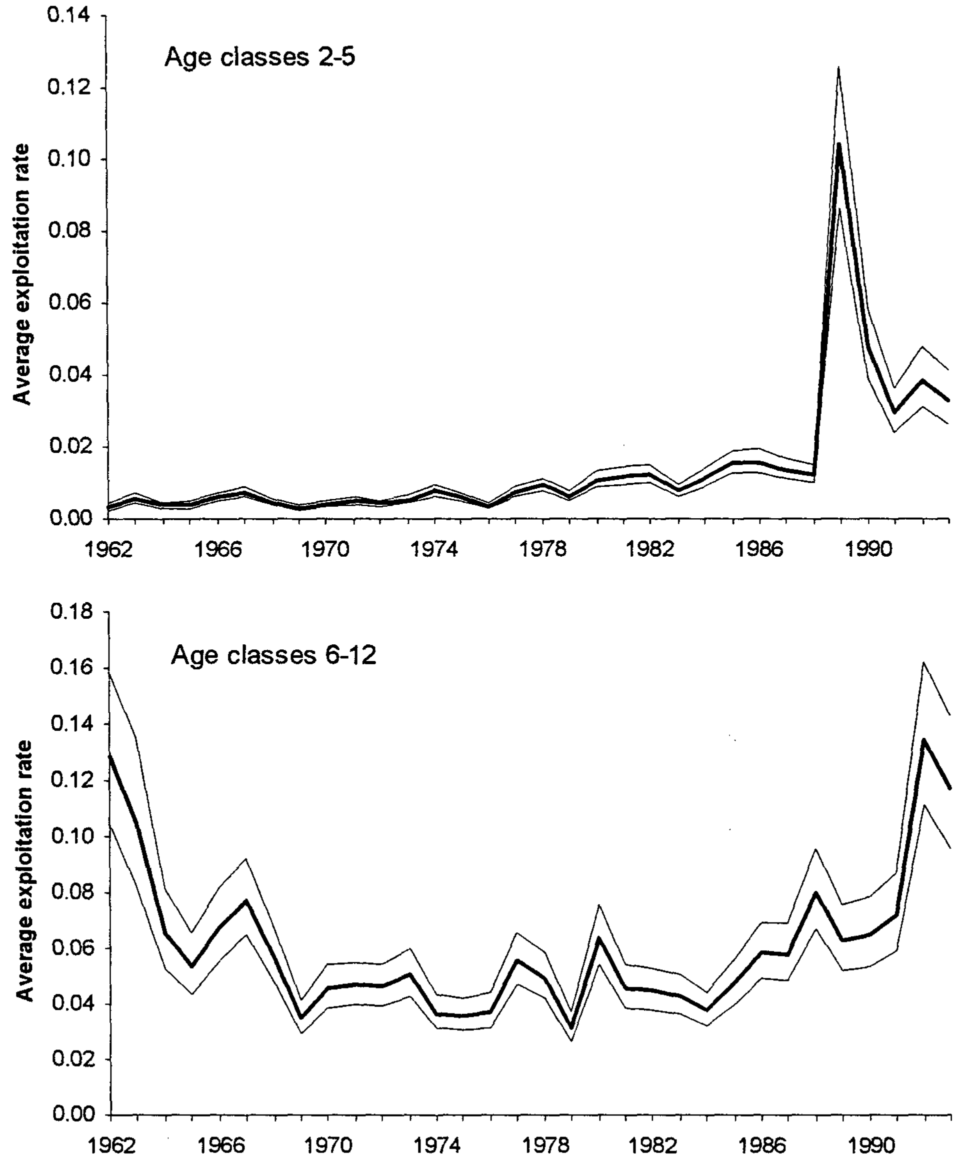

Figure 31. Estimates of exploitation rates, and 95% confidence intervals, for South Pacific albacore. The upper panel refers to juvenile albacore and the lower panel to adult albacore.