YELLOWFIN TUNA
- TECHNICAL SYNOPSIS OF FISHERIES AND RESOURCE STATUS IN THE WESTERN-CENTRAL PACIFIC OCEAN

I. DATE OF SYNOPSIS: JULY 2001

II. DESCRIPTION OF FISHERIES (INCLUDING RECENT DEVELOPMENTS)

The catch of yellowfin in the WCPO has doubled since 1980 with catches in recent years peaking at over 400,000 mt. The catch of yellowfin is the second largest component (23% in 1999) of the total catch of skipjack, yellowfin, bigeye and albacore tunas in the WCPO. They are harvested with a diverse variety of gear types, from small-scale artisanal fisheries in Pacific Island and Southeast Asian waters to large, distant-water longliners and purse seiners that operate widely in equatorial and tropical waters. Purse seiners catch a wide size range of yellowfin tuna, whereas the longline fisheries catch mostly adult fish.

- **Fleets and gears**

i) Purse Seine
Fifteen countries have reported purse seine catches of yellowfin tuna in the WCPO (Lawson, 1999), though the bulk of the catch is taken by the four DWFNs - Taiwan, Korea, Japan and the United States. The major Pacific Island fleets are from FSM, PNG, Solomon Islands and Vanuatu.

Japanese purse seiners have been operating in the tropical areas of the WCPO since the late 1960s, mainly targeting skipjack and yellowfin and mostly fishing on schools associated with drifting logs. Since the early 1980s the number of large vessels (>200GRT) operating has been relatively stable at around 35 (mostly 340-500 GRT) though the number of smaller vessels operating near Japan has decreased from over 50 to around 20 during this period (Miyabe et al 2000). Several group seiners operated until around 1990. In recent years over half the sets have been made on log-associated schools. Matsumoto et al (2000) and Shono et al (2000) give a description of gears used and developments over time.

Two Korean purse seiners began operating in the WCPO in 1980. The number of vessels peaked at 39 in 1990 then decreased steadily during the 1990s with 26 vessels fishing in 1999. The dimensions of Korean purse-seine nets have not changed significantly, but mesh size has increased from 5 in (12.7cm) to 8-10 in (20.3-25.4 cm) and pursing speed has increased. Log sets declined to represent 28 percent of the Korean purse seine catch by 1989, then fluctuated between 20 and 50 percent of the annual catch. Until the mid-1980s about 20-25% of vessels carried helicopters but this increased after 1986 with between 70-90% of vessels carrying helicopters in the 1990s. Helicopters are sometimes used cooperatively between several vessels in the Korean and other fleets. Some Korean purse seiners are still using payao-like artificial logs to aggregate tunas. There has been irregular observer coverage of this fleet (see Hwang et al, 1999).

Taiwan started purse seining in the Pacific in 1982, with 42 vessels fishing during 1999 (the same as in recent years). Between 1996 and 1999 the percentage of sets in any year deployed on different schools types has varied considerably, through there appears to be a general increase in sets on logs, increasing from 25% to 67% during this period.

The number of US purse seiners operating in the WCPO in the period 1995-99 has varied between 35 and 44. Itano (2000) gives a description of gears used and developments over time.

ii) Longliners

Twenty-two countries have reported longline catches of yellowfin tuna in the WCPO (Lawson, 1999), though the bulk of the catch is taken by the three DWFNs - Japan, Taiwan and Korea. There has been a steady and significant increase in the number of Pacific Island domestic longline vessels in the fishery over the past decade.

Statistics on the number of Japanese longline vessels fishing in the Pacific are available since 1953 when 1,733 vessels were registered (Miyabe et al, 2000). The total number of longline vessels peaked at 2,685 in 1960 and by 1999 had declined to 1,395. However, the number of vessels greater than 200 GRT remained relatively constant at around 640 after 1971 until 1999 when there was a 20% reduction. Small Japanese longliners use shorter branchlines and floatlines, so that their longlines fished shallower than those of larger longliners. These differences were not reflected in the number of hooks-per-basket reported in logbooks.

Taiwanese distant water longliners have been fishing in the Pacific Ocean since 1963 with around sixty-five vessels (mostly 150-250 GRT) operating during 1999. Most vessels target albacore for canning, but some also target yellowfin and bigeye for the Japanese frozen sashimi market. Major fishing grounds are in the South Pacific (south of 10^{o}S) though in recent years the north Pacific has become more important as vessels start to target on northern albacore. Taiwan also has a large offshore longline fleet consisting of around 1700 vessels that operate in both the Pacific (since 1988) and Indian Oceans. These vessels traditionally limited their operations to coastal and offshore waters of Taiwan targeting yellowfin and bigeye tunas, but in recent years some vessels have been operating in a manner similar to DW longliners.

In 1999, 171 Korean longliners operated in the WCPO, the highest number since 1991 when 220 vessels operated. Most vessels are in the size range 300-500 GRT and operate in the central tropical regions between 20^{o}S and 20^{o}N. Between 1988-1994 the mean number of hooks per basket showed little change (varying between 11.7 and 12.6) but by 1997 had increased to 14.5, mainly due to the increased use of sets using 18-19 hooks per basket (Moon et al, 1999). Since 1988, Korean longliners have also gradually changed the materials used for branchline leaders (snoods) from wire to monofilament, so that 90% of vessels now use monofilament (though some vessels are believed to use a combination of the two). Such leaders supposedly improve yellowfin and bigeye CPUE while lowering that of sharks and billfishes. A variety of baits are used.

iii) Pole-and Line

Thirteen counties have reported pole-and-line catches of yellowfin tuna in the WCPO (Lawson, 1999), though the bulk of the catch is taken by Indonesia, Japan and the Solomon Islands. The major target of these fisheries is skipjack.

The number of vessels in the Japanese pole-and-line fleet peaked at 6,533 in 1958, though most of these vessels (~92%) were small (<20 GRT). By 1994 the fleet had declined to 2,015 vessels including 48 vessels of size >200 GRT. There was a sharp reduction in the number of small vessels in the fleet the following year, reducing the total fleet to 654 vessels. The fleet consisted of 543 vessels in 1998 (including 46 large). Small vessels concentrate fishing effort in the Japanese coastal areas north of 25^{o}N, while in 1998 the larger vessels mainly fished in the northern equatorial regions west of 180^{o}E.

There has also been a reduction in most other pole-and-line fleets during the 1990s. The Solomon Island pole-and -line fleet (which was established in the early 1970s) consisted 26-31 vessels between 1995-1999. Fisheries formerly operating in Palau, PNG and Kiribati are no longer active, and only one of two vessels is now operating in Fiji. Several vessels continue to fish in Hawaii and the French Polynesia bonitier fleet remains active.

- **Distribution of Effort**

Purse seine effort is usually limited to the western equatorial Pacific between 10^{o}N and 10^{o}S. However, the geographical extent of purse seining is linked with ENSO patterns and their associated effects on sea surface temperatures and ocean productivity. In El Nino years, purse seining extends eastwards to 150°W, where purse seiners target free-swimming schools of large yellowfin.

- **Targeting practices**

i) Purse seine
Mixed schools of skipjack and yellowfin are more common for associated sets, with large yellowfin tending to form pure free-swimming schools. Yellowfin tuna attracts higher prices at canneries than skipjack and, as such, is often targeted by purse seiners, especially as unassociated schools. For example, during 1998 54% of the Japanese purse seine catch of yellowfin (and bigeye) came from the 23% of sets which were pure schools of yellowfin (and/or bigeye) (Takayuki et al, 1999)

Drifting FADs, or enhanced logs, have been used by purse seine vessels for many years, but have become much more sophisticated in recent years and now represent the dominant purse seine fishing method used in the WCPO by some fleets. During 1999, the US fleet made 90% of sets on drifting FADs, compared to 20-30% during the 1996-97 period, while Japan and Taiwan made 40% and 30% of 1999 sets on FADs.

There have been several developments in the purse seine fleets to improve the success rate of sets. These include (i) electronic equipment, e.g. GPSs and satellite imagery, to reduce searching time and time locating FADs, (ii) chumming, (iii) greater use of drifting FADs in fishing strategies, (iv) larger, deeper and lighter nets, (v) more powerful winches providing faster pursing and hauling speeds, (vi) faster sacking-up procedures and brailling equipment, (vii) increased storage capacity with improved refrigeration systems, and (viii) reduction in port unloading time and maximising time on the fishing grounds through onboard processing and transhipment. Additionally, the use of support vessels that can rapidly visit and check the fish concentration under FADs, has increased the catching power of Indian Ocean purse seiners by about 50%. Owners are more likely to upgrade or add new equipment when commercial performance is good. Many innovations are considered trade secrets, and are thus difficult to document and measure.

Before 1991, Korean logbook data did not distinguish between school and associated purse-seine sets. Interviews with captains indicated that prior to 1991 purse seiners mostly set on logs, and rarely used FADs. However, they occasionally deployed payao-like structures.

ii) Longliners
Longlines generally catch a range of species simultaneously and the composition of the catch often does not indicate what the target species was. Before the mid-1970s Japanese longliners generally targeted yellowfin tuna and deployed shallow sets using around 5 hooks-per-basket.

With the shift to targeting bigeye after the mid-1970s, there was a shift to deploying deeper longlines with the number of hooks-per-basket generally increasing to between 10 and 15.

iii) Pole-and Line
The main target species of these fisheries is skipjack tuna.

- **Data Issues**

Bigeye are not usually distinguished from yellowfin in purse seine logsheet reports. Consequently, bigeye-yellowfin ratios derived from species composition sampling are used to adjust logsheet estimates of yellowfin and bigeye (eg. Bigelow, 1999; Coan and Miyabe, 1999). These ratios vary with set type and fish size, and possibly also with area and vessel nationality. At present there is port sampling only for the US and Japanese fleets and estimates for the remaining fleets are based on the assumption that the proportions of bigeye in associated and unassociated sets are similar to those for the US fleet. However, there is some concern with the use of this assumption as bigeye proportions may differ between fleets due to a number of operational factors (Anon, 1998). For example, the proportion of bigeye from associated sets by U.S. purse seiners increased from the 1989-95 average of 13% to 41% in 1996, due to a change in targeting and the use of deeper nets. All fleets need to commence or continue port sampling programs to provide an accurate breakdown of the bigeye and yellowfin composition of purse seine catches.

The timing of data submissions is often a problem, with data for distant water longline fisheries often not available for two or more years after the fishing year. The year for which catch data was last reported from each fishing nation and gear is indicated in Table 1. Data have not been provided for the Indonesian longline and pole-and-line fisheries since 1994.

III TRENDS IN CATCH

- **Overview**

Since 1990 the total yellowfin catch has ranged between 320,000 mt (1996) and 458,000 mt (1997). The history of yellowfin catches in the WCPO is shown in Figure 1 while a summary of the most recently reported catch by fishing nation and gear type is given in Table 1.

- **Recent Developments**

The 1997 yellowfin catch in the WCPO was the largest on record and followed the lowest catch for 10 years in 1996, a result of greatly reduced purse seine catches. The catch in 1998 was 407,000 mt and in 1999 the catch was just under 400,000 mt, the third highest level ever. The decrease from 1998 and 1997 was mainly attributable to the decrease in purse-seine catch as experienced in previous La Nina years (1995/96).

In 1998, very large catches were recorded in the archipelagic waters of the Philippines and eastern Indonesia and in equatorial waters around 180°. Equatorial catches shifted mainly to the west of 180° in 1998 after being mainly to the east of this longitude in the El Nino period of 1997-1998.

- **Catch by Gear-Type**

Purse seiners harvest the majority of the yellowfin tuna catch (57% by weight in 1997–1999), with the longline and pole-and-line fisheries comprising 14% and 3% of the total catch, respectively. For most of the DW fleets, yellowfin tuna usually represent approximately 20–25% of the overall purse-seine catch and may contribute higher percentages of the catch in individual sets. Purse seine catches taken by Pacific Island nations increased to around 10% of the total purse seine catch by the late 1990s.

Between 1995-98 yellowfin tuna comprised 28% of the total catch (by weight) retained by Japanese longliners, while between 1995-99 yellowfin tuna comprised around 31% of the total catch of Korean longliners and around 5% of the Taiwanese longline catch. Longline catches of yellowfin in recent years (52,000–77,000 mt) are well below catches in the late 1970s to early 1980s (which peaked at 117,000 mt), presumably related to changes in targeting practices by some of the larger fleets towards bigeye tuna. The 1999 longline catch of yellowfin of 52,580 mt was the lowest for nearly 30 years and was influenced by a 20% reduction in the Japanese distant-water fleet during this year.

During 1999 the catch from the pole-and-line fisheries was 13,643 mt. Catches in the 'Other' category shown in Figure 1 amounted to around 100,000 mt in 1999 and largely come from the Philippines and Eastern Indonesia where a variety of gear types (eg ringnet, bagnet, gillnet, handline and seine net) are used. Catches in this 'Other' category have increased steadily over the past decade.

- **Spatial distribution of catch**

The spatial distribution of the yellowfin catch in the WCPO, between 1988 and 1998, is shown in Figure 2. The majority of the yellowfin catch is taken by purse seine vessels in equatorial areas of the WCPO (between 10^{o}S and 10^{o}N) and in the Indonesian and Philippines fisheries. The east–west distribution of catch is strongly influenced by ENSO events, with larger catches taken east of 160°E during El Niño episodes.

- **Size composition by gear type**

Purse seiners catch a wide size range of yellowfin, while longline fishery takes mostly large adult fish (>100 cm).

Length frequencies for the Japanese purse seine fishery are estimated by landing or port sampling data. During 1997, purse seine caught yellowfin ranged between 30 and 140 cm in fork length. Two large modes were observed at lengths around 45 and 75 cm. In 1998 many more small fish (<60cm) and significantly fewer medium sized fish (60-100 cm) were observed.

Size composition for yellowfin caught by longline has not shown any discernible change over 28 years, suggesting that there have not been significant changes in the size structure of the yellowfin stock despite large increases in catch.

IV TRENDS IN NOMINAL CATCH PER UNIT OF EFFORT

i) Purse seine

Annual yellowfin purse seine CPUE (shown in Figure 3) has varied without trend since the 1980s, though is characterised by strong inter-annual variability, and in many years differences amongst fleets. Most of the interannual variability is a result of variation in fishing success on free-swimming yellowfin schools, which is generally higher during El Nino episodes. This is believed to be related to increased catchability of yellowfin tuna due to a shallower surface mixed layer during these periods. Trends in nominal CPUE for most fleets have been similar since 1995, displaying a significant decline in 1996, recovering in 1997 and 1998 before declining again in 1999. This convergence in trends across fleets in recent years may be related to a convergence in fishing practices (perhaps associated with the increased used of FADs).

Catch rates in the Japanese pole-and-line catch rates are influenced in a similar manner. ENSO variability is also believed to impact the size of yellowfin and other tuna stocks through impacts on recruitment.

ii) Longline
Nominal yellowfin CPUE for several longline fleets operating in the WCPO is shown in Figure 4. CPUE for Japanese longliners shows a substantial decline and leveling off following a peak in 1978, which is believed to be at least partly related to increased targeting of bigeye by that fleet. Catch rates for longline fleets over the past few years have remained near their historical lows. The trend in recent data is mixed, with some fleets showing a flat trend and others showing a slightly downward trend since 1988, but these trends may have been affected by changing fishing practices. During 1996-1999, yellowfin catch per unit effort (CPUE) in tropical waters declined considerably for the fleets of Federated States of Micronesia, Japan and Taiwan, although it remained stable for the Chinese fleet. The longline data available for the first three-quarters of 2000 indicate that yellowfin CPUE increased for all four fleets.

V. BIOLOGICAL INFORMATION

- **Distribution**

Yellowfin tuna (*Thunnus albacares*) are found in all oceans, inhabiting the tropical and sub-tropical regions between about 40^{o}N and 40^{o}S, though their distribution is usually limited to those regions where the water temperatures are greater than 15^{o}C. Recent studies indicate that this limitation is due to the inability of yellowfin tuna to increase their heart rate at or below this temperature (Anon, 1997a). They are often caught in frontal regions, characterised by strong gradients in oceanographic conditions such as temperature, as prey species are often abundant in these regions.

Adults have a much wider distribution than juveniles, covering the whole area between 40^{o}N and 40^{o}S in the western Pacific and becoming narrower latitudinally toward the central Pacific. On the other hand, juvenile appear to be distributed in the higher latitudes in the western Pacific as far north as the coastal areas of southern Japan (about 30^{o}N) and as far south as 23^{o}S along the Australian coast (Higgins 1967, Suzuki 1994).

Several key physiological differences and less demanding metabolic requirements allow yellowfin tuna to exploit a greater range of habitat than skipjack tuna. The progressive development of a swim bladder with age and longer pectoral fins provide greater buoyancy and hydrodynamic lift (allowing maintenance of hydrostatic equilibrium at slower basal swimming speeds). With somewhat lower oxygen requirements, yellowfin can also 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 tuna appear to spent most of their time in the mixed layer above the thermocline. Studies of yellowfin tuna in Hawaii using ultrasonic depth sensitive transmitters found that these fish spend most of their time in water shallower than 120 meters (Holland et al, 1990).

- **Stock Structure**

Hypotheses regarding the stock structure of yellowfin have been constructed from many sources, including morphometric comparisons, catch rates analyses, tagging experiments, and population genetics studies (see Suzuki (1994) for a review).

Tagging data in the western Pacific show extensive zonal movements between 120°E and 170°W, with some fish moving more than 1000km or more over a 12-month period. To date, no yellowfin tagged west of 170°W have been reported as recaptured in the eastern Pacific purse seine fishery though several recoveries have been reported by longliners operating east of 150°W (Anon, 1997b). Furthermore, 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 two stocks within the Pacific - eastern Pacific and western-central Pacific stocks. A Pacific-wide population genetics study supports this view (Ward et al, 1994).

The level of sub-population structure, if any, within the western-central Pacific stock remains uncertain. Morphometric studies tend to show heterogeneity in several areas in the Pacific ranging from very limited area extent (eg. Royce 1964) to ocean-scale (eg. Schaefer 1991). A recent study, using otolith microchemistry analysis, has attempted to determine stock relationships between fish caught off eastern Australia and other regions of the WCPO. Whilst significant differences were found among the sites for most of the elements probed, samples from the first year showed no significant differences between fish caught in the Coral Sea and off the NSW coast, or between the Coral Sea and the Solomon Islands. Results from the second year of samples indicated a different pattern of similarities between sites, suggesting that the pattern of recruitment into eastern Australia is likely to display inter-annual variation, so that the regions from which yellowfin tuna recruit to the southern Queensland/NSW fishery may vary from year to year. Genetic differences among 6 sites in the WCPO were also found to be significant, but not consistent across years, indicating either changes in gene flow between the regions, or a single gene pool across the populations.

- **Spawning and Size/age at maturity**

Yellowfin spawn throughout the tropical and equatorial Pacific. Spawning may occur throughout the year in equatorial waters, but it is limited to the summer months in the higher latitudes as water temperatures need to be between 25-26°C for spawning to occur (Kikawa 1966, Ueyanagi 1969). While the occurrence of larvae is continuous across the equatorial Pacific, three areas of higher larval density have been tentatively recognised: 130-170°E, 180-160°W and east of 110°W. In the north-western Coral Sea mature fish often form spawning aggregations during periods of the full moon in October and November. El Nino events extend the spawning area in the eastern Pacific and could create better conditions than during La Nina events for recruitment to this area.

Early studies indicated the size at 50% maturity to be in the range 100-120 cm (Yuen and June 1957, Kikawa 1962). However, these studies did not include histological examinations. A large scale study of the reproductive biology and spawning activity of yellowfin tuna in the central and western Pacific has, however, recently been completed by the University of Hawaii (Itano, 2000). This study found that for tuna caught within 10 degrees of the equator, that 50 percent of fish reached sexual maturity at 105 cm in fork length (approximately 25kg and two years in age) while

90 percent reached sexual maturity at 121 cm (approximately 35kg). Like other members of the tuna family, yellowfin tuna are serial spawners that release several batches of eggs throughout the year. Results also indicate that regular and repeatable seasonal patterns to reproduction in the equatorial regions may not exist but vary with productivity and environmental conditions peculiar to each year.

- **Sex ratios**

The sex of yellowfin tuna <35-40cm can rarely be distinguished but it is generally agreed that the sex ratio (ratio of female to male) is about 1 until a length of about 120 cm is reached (Suzuki 1994). Subsequently, the ratio of females decreases steadily for larger yellowfin in the WCPO. A study off eastern Australia during the late 1980s found no significant difference between the ratios of males to females in either the domestic longline or pole-and-line or Japanese longline fisheries. However, female yellowfin tuna were significantly less common in the larger size classes, with no females larger than 70kg total weight recorded during the study.

- **Growth rates**

Like skipjack, yellowfin are very productive (in terms of growth and reproduction) and reach approximately 50 cm fork length (5 kg) in their first year and approximately 100 cm (15-30 kg) by their second year. Yellowfin tuna are believed to rarely live beyond 8 years of age. However, in reviewing studies undertaking up until 1990 relating age and growth of yellowfin tuna in the Pacific, Suzuki (1994) found significant differences between the implied growth curves. In a large study undertaken more recently, otolith increment data and tagging/recapture data from the SPC Regional Tuna Tagging Project have been used to estimate age and growth parameters (Lehodey and Leroy, 1999). Initial validation results supported the hypothesis of daily deposition of growth increments in the western Pacific, which agrees with studies from other regions. The results also indicate that there is no sexual dimorphism in growth, though fish larger than 170cm (70kg) are usually male.

The von-Bertalanffy model did not satisfactorily describe the growth of yellowfin over the entire size range. The growth rate appears to decrease early in life with a maximum decrease between ages 0.5 to 1 year (45-70 cm FL). This decrease may be linked with ecological or physiological changes such as onset of maturity or the behaviour associated with the development of a gas bladder. This result also supports an earlier conclusion reached by Yamanka (1990) that a significant physiological change occurs when yellowfin attain a size between 35-50cm. MULTIFAN-CL results also suggest a reduced growth rate for one-year-old yellowfin. A modified von Bertalanffy growth model in which K varied according to a normal distribution was found to give a better fit to the otolith readings and tag data (see Table 2). The results indicate a rapid growth rate to age 3, followed by a leveling-off of growth and lower asymptotic size compared to the results of the tagging analysis. The results also differ significantly from previous studies, with proposed lengths at ages 1 and 2 of 65 and 115cm respectively. Increments laid down during the first few days of life may be sub-daily or daily in nature. The analysis assumed sub-daily deposition, which would artificially shift the growth curve to the left if they were actually daily. It should be noted that many previous growth curves were based on an analysis of length-frequency data as opposed to otolith data.

- **Length-Weight relation**

Length and weight relationships are available for Philippine waters (Ronquillo 1963), Hawaiian waters (Tester and Nakamura 1957), central Pacific (Nakamura and Uchiyama 1966) and western and central Pacific (Kamimura and Honma 1959, Morita 1973). Some of these relationships are given in Table 2.

- **Mortality (F, Z, M, other sources)**

Early studies gave estimates of the annual natural mortality of between 0.3 and 2.5 (see Suzuki 1994), though the study by Ishii (1968) using a sequential-recruitment model with the catch-at-age data gave an estimate of 0.9 for fish older than 3 years.

Natural mortality estimates from MULTIFAN-CL indicate a basal level of around 0.6 per year for sub-adults, somewhat higher for smaller yellowfin and significantly higher for adult yellowfin. Overall fishing mortality is estimated to have increased since the mid-1990s but estimates of fishing mortality-at-age remain considerably smaller than the corresponding estimates of natural mortality-at-age.

- **Movement patterns**

Until the advent of large scale tagging programs, migration patterns of yellowfin tuna were inferred from changes in seasonal fishing grounds together with information on the size of fish caught. These changes indicated fairly clear seasonal movement along the Kuroshio and the East Australia Currents, moving to the higher latitudes in the warmer months and returning to the lower latitudes in the colder months (Suzuki et al 1978). Yellowfin tuna tagged as part of the SPC Regional Tuna Tagging Program (undertaking between 1989-91) indicate that juvenile yellowfin (mostly between 30-60 cm) show a greater tendency to move east-west than north-south. Furthermore, while migrations of over 1,000 were demonstrated, many fish were recaptured close to their tag positions. The former observation support the hypotheses that yellowfin migrate extensively from the western to central Pacific (Kamimura and Honma 1963) while the second lends support to the hypothesis that most yellowfin stay within a range of several hundred miles throughout their life (Royce 1964).

A tagging project has been undertaken in recent years to study the movement patterns, gear interactions and exploitation rates of yellowfin and bigeye tuna around the Hawaiian Islands and within the central Pacific region. As of 30 April 2000, 7,427 yellowfin (and 7,552 bigeye) have been tagged and released throughout the Hawaiian EEZ. Recapture rates for yellowfin are 12.54% driven largely by the high number of short term recaptures at the point of release on seamounts and FADs (Itano and Holland, 2000).

- **Environmental Influences**

Preliminary results concerning ENSO impacts on yellowfin based on a time series analysis showed that rising and vertical extension of the yellowfin temperature habitat in the west during El Nino would increase the catchability by the surface fishing gears (Lehodey, 2000). There is also a potential ENSO effect on recruitment, but further studies are needed to confirm these results.

VI. STOCK ASSESSMENTS

- **Abundance Indices**

i)Purse seiners

The introduction of innovative fish-finding equipment together with improvement in gear technologies and the increased use of FADs during the 1990s is likely to have had a significant impact on the efficiencies of purse seine vessels and needs to be accounted for when standardising CPUE. For example, the use of helicopters, bird radar, sonar, radio beacons on logs or FADs, distance between schools, number of schools sighted and number of FADs deployed are all important factors that need to be taken when ascertain a meaningful measure of effort in any purse seine fishery. Discrimination of school modes (e.g. log associated or free swimming) is also essential. Equipment on board purse-seine vessels has been well documented by regional observer programs and Japan has recently compiled a database of equipment associated with individual vessels over time. (see Itano 2000, Matsumoto et al 2000 and Shono et al 2000)

Japanese purse-seine CPUE has been standardised using a GLM to account for time/area strata, boat and the use of various gears (Shono et al, 2000). Relative CPUE based on the use of purse winch, mesh size, power block, net size, tele-sounder and GPS were calculated, as were trends in nominal and standardised CPUE for associated and free-swimming schools. The purse winch and the mesh size of the net influence operating speed, especially on surrounding the fish, and have a positive effect on fishing efficiency. Larger estimates of standardised CPUE for associated sets at the end of the time series were probably attributable to the use of FADs in areas where logs are uncommon, while smaller values occurred with reduced use of FADs. However, disentangling the effects of FADs and areas fished is seen as problematic.

U.S. purse seine CPUE has been standardised against vessel specifications, including GRT, vessel length, net length, net depth, block pull and line pull (Anon 1999). Loess fits to the relationship between CPUE and various categories of the six variables revealed no significant trends in CPUE, although CPUE increased with block and line pull. Errors in vessel specification data may have affected the results. The analysis also implied that tuna encounters increased with net depth. It was suggested that the study be repeated with a time series of vessel specification data.

For Philippine purse seiners owned by large companies, days of fishing is an inappropriate effort unit for estimating CPUE, since from the 1990’s several payaos have been towed together, combining the tuna aggregating under each.

A proposal has been put forward to use either standardised purse seine free-swimming school set CPUE, or CPUE involving captains with a long, continuous history in the fishery, as an index of stock abundance. However, standardisation would still be an issue since some boats set on associated schools in the mornings and then search for free schools. Another complication is that yellowfin is often a bycatch in skipjack sets. A process-oriented model using detailed operational data collected by observers may be a way to standardise the CPUE data.

ii) Longline

As longliners target larger fish, the CPUE time series should be more indicative of adult yellowfin tuna abundance. However, as with purse-seine CPUE, the interpretation of longline CPUE is confounded by various factors, such as themocline depth, depth of hooks, hooking time, start and end times of sets, gear structure and line materials. Changes in fishing practices will have changed the effectiveness of longline effort with respect to yellowfin tuna, and such changes need to be accounted for if the CPUE time series are to be interpreted as indices of relative abundance.

Sun and Yeh (2000) used GLMs to standardise the Taiwanese distant-water and offshore longline fleets for the period 1964-98 and 1980-99 respectively. The models account for year, month, WPYF area and bigeye catch rates (plus albacore catch rates and a spawning season-area term for the DW model) plus two-way interactions among main effects except year. For the DW fishery, standardised CPUE declined in stages while the trend for the offshore fishery was highly variable with no overall trend. The under-reporting of catch for the DW fishery prior to 1992 makes the interpretation of these results difficult.

Bigelow et al. (1999) use a procedure to account for the effects of changes in targeting as well as the variation in environmental parameters that define yellowfin tuna habitat. They calculated 'effective' longline effort as an estimate of the numbers of longline hooks fishing in the mixed layer above the thermocline, which is believed to define yellowfin tuna habitat. The estimates take into account the time and spatial variability in the depth of the mixed layer (using oceanographic databases) and variation in the fishing depth of longliners as indicated by distributions of the numbers of hooks between floats. The effective effort estimates were derived at 5°-month resolution separately for the Japanese, Korean and Taiwanese distant-water longline fleets. The estimates were then summed across these fleets and raised to represent the total longline catch by 5°-month. Nominal CPUE declined sharply from 1978 to 1991, and at least part of this decline is attributable to the change in targeting behaviour of the longline fleet; consequently the standardised CPUE does not exhibit as strong a decline over this period. Over the entire time series, standardised CPUE had low points in the mid-1970s, 1991 and 1997–1998. While these most recent points are the lowest observed standardised CPUEs in the history of the longline fishery, they are not much lower than those observed in the mid-1970s. Nevertheless, this indicator suggests that the portion of the yellowfin tuna population available to the longline fishery has been at a relatively low level in recent years. It should also be noted that these 'effective' effort estimates do not account for any technological advances (e.g. in fish location) that may have been adopted by the longline fleet. If such advances have occurred, then the standardised CPUE may err on the optimistic side to some extent.

Off eastern Australia, standardised yellowfin CPUE based on Japanese longline data shows large interannual variation, with catch rates after 1985 generally higher than for the period 1971-1984. Years of high catch rates followed by years of sequential decline in catch rates were seen in the time series. Standardised Japanese catch rates in the equatorial regions were generally lower after 1986 compared to the previous decade. The analyses suggest that changes in CPUE were not correlated between the two regions, with the declines in the tropical region not as apparent in the eastern Australian region. One explanation is that mixing between the regions may not as high as would be expected if the two regions were part of a single, homogeneous stock. Changes in the spatial distribution of catch rates may be a result of the large increase in purse seining in the 1980s.

- **Tagging**

As with skipjack tuna, tagging experiments have provided valuable information on the status of the yellowfin tuna stock in the WCPO. During the RTTP, special efforts were made to tag and release substantial quantities of yellowfin tuna; 40,075 were tagged, from which 4,950 (12.4%) have been recaptured and the tags returned to SPC. A tag-attrition model has been fitted to these data yielding a total attrition of 0.16 per month and exploitation rate of 0.20 (95% confidence intervals 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. There appears to be a strong signal in the data regarding variation of natural mortality and fishing mortality by size class. Exploitation levels from the early 1990s are low to moderate, at catch levels at that time slightly below those in recent years. 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, which would minimise the effects of catching very small yellowfin on catches of larger fish. Fishing mortality rates decline with increasing size, suggesting that exploitation rates on large yellowfin are modest.

- **Integrated Population Dynamics Models**

i) MULTIFAN-CL

The MULTIFAN-CL model has been applied to yellowfin tuna in the WCPO. The spatial structure used in the analysis consists of the seven areas of the WCPO and the time period covered by the analysis is 1962–1999. Catch, effort and size data, stratified by quarter, for 16 fisheries (7 longline, 2 Philippines domestic, 1 Indonesia domestic, and 6 purse seine fisheries classified by set type) were used in the analysis. Tagging data from the RTTP were also incorporated into the analysis. The model structure adopted includes: quarterly recruitment, 20 quarterly age classes, independent mean lengths for the first 8 age classes with von Bertalanffy growth constraining the mean lengths for the remaining age classes, structural time-series variation in catchability for all non-longline fisheries, age-specific natural mortality and age-specific movement among the model regions. A more detailed description of the data, the model structure employed for the analysis and the complete set of results is given in Hampton and Fournier (2000)

Main conclusions of the analysis to date are:

1. The growth estimates are consistent with estimates from otolith analysis and in general agreement with length-increment data from tagged yellowfin.
2. Estimates of natural mortality are strongly age-specific, with higher rates estimated for young fish and fish approaching maturity. The basal rate is similar to values commonly used in yellowfin assessments in other regions.
3. Recruitment shows considerable variation at several different time scales. The high-frequency variation appears to be seasonal, although the phase is not always consistent. This could be due to growth variability, resulting in errors in the ageing of some length-frequency modes. The low-frequency variation might be correlated with decadal-scale environmental variation. Lehodey (2000) hypothesised that El Niño conditions in the WCPO should generally be favourable for yellowfin tuna (and skipjack tuna) recruitment because high primary and secondary productivity north of Papua New Guinea and the Solomon Islands would enhance spawning and larval survival. The higher recruitment estimates for 1976–1997 (a period of high-frequency El Niño events) are consistent with this hypothesis. Similarly, the decline in recruitment during the last 2–3 years may be related to persistent La Niña conditions since 1998. However, whether these estimates are indicative of a real decline in stock productivity is uncertain at this stage, because the most recent recruitment estimates are subject to the greatest statistical uncertainty.
4. Both total and adult biomass peaked in the mid-1980s and have been trending downwards since that time. The decline during the most recent years is particularly strong and is related to the decline in recruitment. The impact of fishing on the total biomass has increased over time, and catches and fishing mortality have increased. In the early 1990s, the biomass is estimated to have been reduced by 20-25% compared to the level it would have been in the absence of fishing (which is consistent with the earlier tag-based assessment). In recent years, the estimated impact of fishing has increased to 50%.
5. Fishing mortality has increased strongly in recent years for all age groups except yellowfin tuna >4 years of age. Increases have been particularly strong since 1996. These increases are

related to the decline in recruitment and possibly the increased use of FADs which may have increased the vulnerability of small fish. Fishing mortality is estimated to be particularly high for the youngest age group, which are caught by the Philippine and Indonesian domestic fisheries.

6. While fishing mortality has increased recently, the fishery is not considered to be overfished.

Despite the good fit of the model to the longline data, there is concern that data coverage from other fisheries may be relatively poor. Also, the large number of estimated parameters and the constraints placed on some of these during estimation prevent a ready understanding of model sensitivity to various assumptions, suggesting that it is important to quantify uncertainty in the parameter estimates.

ii) A-SCALA

A new, age-structured statistical catch-at-length analysis (A-SCALA) stock assessment model, based on the MULTIFAN-CL method used by SPC, has been developed by IATTC to assess the tuna stocks in the EPO (I-ATTC, 2000). The model fits to catch and length-frequency data conditioned on effort, includes environmental data to explain variation in recruitment and catchability, and uses priors and penalties to constrain the estimation procedure. The population is modelled from 1975 to 1999 on a quarterly time step and for 16 fisheries. Results indicate that there have been two productivity regimes, with low productivity before 1984 and high productivity subsequently. A positive correlation between recruitment and sea surface temperature was found. Recruitment to the fishery was estimated to be very high in 1998 and low in 1999. However, there is uncertainty in these estimates due to the short time period for which these cohorts have subsequently been observed in the length-frequency data.

- **Environmental models**

Modelling environmental effects on the availability of yellowfin tuna indicate a strong correlation with ENSO events. Model results suggest that shallow mixed layer depths, and hence yellowfin habitat, during El Nino years are associated with higher yellowfin tuna catches by purse seine. There also appears to be a beneficial impact of El Nino on yellowfin tuna recruitment. Indeed, if a relationship is assumed between recruitment and El Nino, then the predicted fluctuations in yellowfin abundance seen in the MULTIFAN-CL and A-SCALA models in the WCPO and EPO respectively show relatively good correlation with El Nino events.

- **Other modelling approaches**

A multi-species, multi-gear, multi-gear, age-structured simulation model was applied to the estimation of fishery interaction. The simulation model attempts to place available information on aspects of tuna biology and fisheries in a simulation framework. The model has not been formally parameterised, but had been roughly tuned to total catch data for the fisheries considered. Interaction was investigated by varying the effort levels of the fleets and observing the resulting impact of catches of other fleets. Generally, significant levels of interaction, and these low to moderate, were observed only when effort in the largest fisheries, such as the purse-seine fishery, was manipulated. Small interactions in terms of changes in catches can translate into significant impacts on the economics of a fishery, and a similar model has been used to estimate bio-economic characteristics of the fishery interactions.

- **Fisheries independent indicators**

Acoustic methods were used around French Polynesia to characterise the pelagic habitat and then to make a direct estimate of tuna abundance (Bertrand and Josse, 1999). A density of 1.33 fish per km^2 was estimated, such that the biomass of tunas (yellowfin, albacore and bigeye) targeted by longliners in French Polynesia was estimated to be about 100,000 mt in the French Polynesian EEZ (surface area 2,900,106 km^2). Although the uncertainty in these estimates cannot be quantified, the study shows a means of obtaining fishery independent estimates of abundance, although species recognition is not presently possible. However, data are likely to provide only a snapshot of conditions in local areas, and moreover, such surveys currently very expensive to conduct. Additionally, results should only be interpreted as the amount of tuna available to longline fisheries, since fish in the surface layers are not adequately surveyed. It would also be necessary to design a separate acoustic investigation of how tunas relate to seamounts.

- **Reference points**

The A-SCALA results were interpreted with respect to reference points. Average weight of fish caught is lower than the critical weight, indicating growth overfishing. However, the use of critical size, derived from yield-per-recruit analysis, as knife-edge indicator of growth overfishing was questioned. Since it is impossible to expend all fishing effort at the theoretical critical point, the average size of fish caught would be expected to be below the critical size. Spawning biomass is estimated to be above, and effort close to, the level that would support MSY. Due to the flat-topped yield curve, a reduction in effort would produce yield curves close to MSY while increasing the biomass level. Different MSY levels could potentially be achieved by different fisheries, and a simulation study could be used to determine maximum yield. The B_{MSY} was estimated from the results of the model and reflect the conditions in the fishery. If a stock-recruitment relationship was assumed, the estimate of B_{MSY} could increase due to density dependence. From the perspective of MSY, the fishery is close to optimum-current biomass.

VII. STATUS OF STOCK SUMMARY

The various fishery indicators examined are mostly stable, indicating that fishery performance has been sustained over a long period of time. The possible exception to this is the decline in standardised longline CPUE in 1997 and 1998. The longline catch and effective effort estimates have a considerable impact on the results of the MULTIFAN-CL analysis. In particular, the analysis suggests declines in biomass and recruitment in recent years consistent with the recent decline in longline CPUE. In addition, fishing mortality rates are estimated to have increased recently, particularly for juvenile yellowfin tuna. This increase is at least partly due to increased catchability, probably resulting from the now widespread use of deployed FADs by purse seiners. The impact of fishing on the stock is therefore estimated to have increased strongly in recent years, from a 20-25% impact on biomass in the early 1990s to a 50% impact in 1999. If the MULTIFAN-CL estimates are accurate, the WCPO yellowfin tuna stock is probably close to fully exploited at present. At the same time, we should note that these most recent estimates are subject to high uncertainty, particularly in view of the lack of longline fishery data for 1999. Data for the years 1999 and 2000 are urgently required from all fisheries to update this assessment. (taken from Hampton et al, 200)

VII. RESEARCH REQUIREMENTS AND WORK PLAN

- Further documentation of changes in gear technologies for both purse seine and longline fleets. In particular, need to define current state of drifting FAD technology.

- Quantification of changes in fishing power on catch rates. Empirical studies involving the calibration of the performance of old technology with new technology are also required.

- Further research is required on tuna behaviour and the relationship between FAD aggregation and abundance. Detailed information on natural logs and FADs, including location and abundance, is also required.

- The relationship between the distribution of habitat and the distribution of fish needs to be better understood. In particular, the change in volume of habitat versus the density of hooks and whether fishing behaviour changes in response to changes in oceanographic conditions require further study.

Research tasks from the 2000 SCTB were:

1) Conduct studies on age and growth to more accurately determine ages in the catch, and report on the use of otoliths for aging.
2) Conduct studies on changing sex ratio with length/age for input into the understanding of sex-specific natural mortality.
3) Conduct studies on food habitats in order to understand trophic and ecosystem dynamics.
4) Conduct studies on stock identification, and report on the use of otolith micro-chemistry for stock identification.
5) Conduct studies on process mechanisms (physiology, behaviour etc.) related to temperature, depth and oxygen preferences by sex and age for development of habitat models.
6) Continue studies designed to evaluate, validate and improve capabilities of emerging stock assessment models, such as MULTIFAN-CL, A-SCALA, habitat-based, SEPODYM, etc.
7) Build a stock projection capability into MULTIFAN-CL, and to conduct cross-analyses with differential models and simulations to evaluate model behaviour.
8) Develop research ideas and plans for obtaining fishery-independent or semi-independent data for indexing stock abundance and/or for critical parameters of the new assessment models.

VIII REFERENCES

An and Kim (2000) *Scientific observations for Korean tuna purse seine fishery in the western and central Pacific Ocean*. RG-6 SCTB 13.
Anon (1997a) *How tuna physiology affects tuna movements and distribution*. Pelagic Fisheries Research Program Newsletter, 2(4) 3-6.
Anon (1997b) *Yellowfin tuna biology and fisheries in the Pacific*. Research Program Newsletter, 2(4) 6-8.
Anon (1998) *Report of the 11th meeting of the Standing Committee on Tunas and Billfish*, 28 May - 6 June, 1998, Honolulu, Hawaii. Oceanic Fisheries Program, Secretariat of the Pacific Community, Noumea, New Caledonia. 108pp.
Anon (1999) *Report of the 12th meeting of the Standing Committee on Tunas and Billfish*, 16 - 23 June, 1999, Papeete, Tahiti, French Polynesia. Oceanic Fisheries Program, Secretariat of the Pacific Community, Noumea, New Caledonia. 126pp.
Bertrand and Josse (1999) *Acoustic estimation of longline tuna abundance*. YFT-4 SCTB 12
Bigelow (1999) *Estimating bigeye composition in the purse seine fishery*. SWG-3 SCTB 12.

Bigelow, Hampton and Miyabe (1999) *Effective longline effort within the yellowfin habitat and standardised CPUE*. YFT-3 SCTB 12

Coan and Miyabe (1999) *Comparisons of areas fished by Japanese and US purse seine fleets in the central-western Pacific*. SWG_4 SCTB 12

Coan, Childers, Ito, Kikkawa and Hamm (2000) *Summary of US fisheries statistics for highly migratory species in the cental-wstern Pacific*, 1995-1999. NRF-21 SCTB 13.

Hampton and Fournier (2000) *Updated MULTIFAN-CL based assessment of yellowfin tuna*. YFT-1 SCTB 13

Hampton, J. A. Lewis and P. Williams (2000) The western and central Pacific Tuna Fishery - 1999: Overview and status of stocks. Oceanic Fisheries Program, Secretariat of the Pacific Community, Noumea, New Caledonia. 61pp

Higgins (1967) *The distribution of juveniles of four species of tunas in the Pacific Ocean*. Proc. Indo-Pac. Fish. Coun., 12(2): 79-99.

Holland, Brill and Chang (1990) *Horizontal and vertical movements of yellowfin and bigeye tunas associated with fish aggregating devices*. Fish. Bull, 88:493-507.

Hwang, Park and Moon (1999) *Scientific observations for Korean tuna purse seine fishery in the western and central Pacific Ocean*. RG-5 SCTB 12.

Ishii, T. (1968) *On population parameters of yellowfin and bigeye tunas in the Pacific*. In: Proceedings of the Japanese Tuna Conference (Showa 42 nendo), Shimizu, pp72-76.

Itano (2000a) *Current status and recent developments in the WCPO purse seine fishery*. RG-9 SCTB 13.

Itano. D. (2000b) *The reproductive biology of yellowfin tuna (Thunnus albacares) in Hawaiian waters and the western tropical Pacific Ocean: Project summary*. SOEST 00-01, Pelagic Fisheries Research Program, Honolulu, Hawaii.

Itano and Holland (2000) *Hawaii tuna tagging project*. RG-8 SCTB 13.

Kaminmura, T. and M. Honma. (1963) *Distribution of the yellowfin tuna (Neothunnus macropterus) (*Temminck and Schlegal*) in the tuna longline fishing grounds of the Pacific Ocean*. Rep. Nankai Reg. Fish. Res. Lab., (17) 31-53.

Kikawa, S. (1962) *Studies on the spawning activity of Pacific tunas, Parathunnus mebachi and Neothunnus macropterus, by the gonad index examination*. Occas. Rep. Nankai Fish. Reg. Lab., (1) 43-56.

Kikawa, S. (1966) *The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in tun longline grounds in the Pacific*. Rep. Nankai Fish. Reg. Lab., (23) 131-208.

Kim (2000) *Korean tuna fisheries in the western Pacific Ocean*. NFR-11 SCTB 13.

Lawson (1999) *Estimates of annual catches of target species in tuna fisheries of the western and central Pacific Ocean*. SWG-2 SCTB 12

Lehodey (2000) *Impacts on the El Nino Southern Oscillation on tuna populations and fisheries in the tropical Pacific Ocean*. RG-1 SCTB 13.

Lehodey and Leroy (1999) *Age and growth of yellowfin tuna (Thunnus albacares) from the western and central Pacific Ocean as indicated by daily growth increments and tagging data*. YFT-2 SCTB 12

Lewis and Williams (2000) *Overview of the western and central Pacific Ocean tuna fisheries - 1999*. GEN-1 SCTB 13

Matsumoto, Ogura, Miyabe and Shono (2000) *Creation of a database to identify factors affecting CPUE of the Japanese equatorial purse seine fishery*. RG-7 SCTB 13.

Miyabe, Ogura, Matsumoto and Nishikawa (2000) *National tuna fisheries report of Japan as of 1999*. NRF-9 SCTB 13.

Moon, Park and Hwang (1999) *Effect of different longline materials on catch rates of the species caught by Korean tuna longliners in the Pacific Ocean*. RG-6 SCTB 12.

Morita, Y. (1973) *Conversion factors for estimating live weight from gilled-and-gutted weight of bigeye and yellowfin tunas*. Bull. Far Seas Fish.Res. Lab., (9) 109-122.

Ronquillio, J.A. (1963) *A contribution to the biology of Philippine tunas*. In Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fish. Rep., 6(3), 1683-752.

Royce, W.F. (1964) *A morphometric study of yellowfin tuna, Thunnus albacares* (Bonnaterre). Fish Bull. US. Fish. Wildl. Serv, 63(2), 395-443.

Schaefer, K.M. (1991) *Geographic variation ion morphmetric characters and gill raker counts of yellowfin tuna, Thunnus albacares, from the Pacific Ocean*. Fish. Bull. NOAA-MNFS, 89(2), 289-97.

Shono, Matsumoto, Ogura and Miyabe (2000) *Preliminary analysis of effect of fishing gears on catch rate for the Japanese purse seine fishery*.RG-3 SCTB13.

Sun and Yeh (2000) *Updated CPUE of central and western Pacific yellowfin tuna from Taiwanese tuna fisheries*. YFT-4 SCTB 13.

Suzuki, Z. (1994) *A review of the biology and fisheries for yellowfin tuna (Thunnus albacares) in the western and central Pacific Ocean*. In. Shomura, R.S., Majlowski, J. and Langi, S.(eds.) Interactions of Pacific tuna fisheries. Proceedings of the First FAO Expert Consultation on interactions of Pacific Tuna Fisheries, held 3-11 December 1991. Noumea, New Caledonia. Vol. 2. Papers on biology and fisheries. FAO Fisheries Technical Paper 336/2.

Suzuki, Z., P.K. Tomlinson and M. Honma. (1978) *Population structure of Pacific yellowfin tuna*. Bull. I-ATTC., 17(5) 273-441.

Suzuki, Z., Y. Warashina, and M. Kishida. (1977) *The comparison of catches by regular and deep tuna longline gears in the western and central equatorial Pacific*. Bull. Far Seas Fish. Res. Lab., (15) 51-73.

Takayuki, Miyabe and Ikehara (1999) *Fishery indicators form the Japanese tuna fisheries in the western central Pacific, as of 1998*. RG-4 SCTB 12.

Tester, A.L. and E.L.Nakamura. (1957) *Catch rate, size, sex, and food of tunas and other pelagic fishes taken by trolling off Oahu, Hawaii, 1951-55*. Spec. Sci. Rep. US. Fish. Wildl. Serv (Fish), (250), 25p.

Ueyangi, S. (1969) *Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, Thunnus alalunga*. Bull. Far Seas Fish. Res. Lab., (2) 177-256.

Wang, Chang and Kuo (2000) *Tuna fishery of Taiwan in the Pacific region during 1995-1999 period*. NFR-19 SCTB 13.

Ward, R.N., N.G. Elliot, P.M. Grewe and A.J. Smolenski (1994) *Allozyme and mitochondrial DNA variation in yellowfin tuna (Thunnus albacares) from the Pacific Ocean*. Mar. Biol. 118. 531-539.

Yuen, H.S.H. and F.C. June. (1957) *Yellowfin tuna spawning in the central equatorial Pacific*. Fish. Bull. US. Fish. Wildl. Serv., 57(112), 251-64.

Figure 1. WCPO yellowfin catch (mt) by gear.

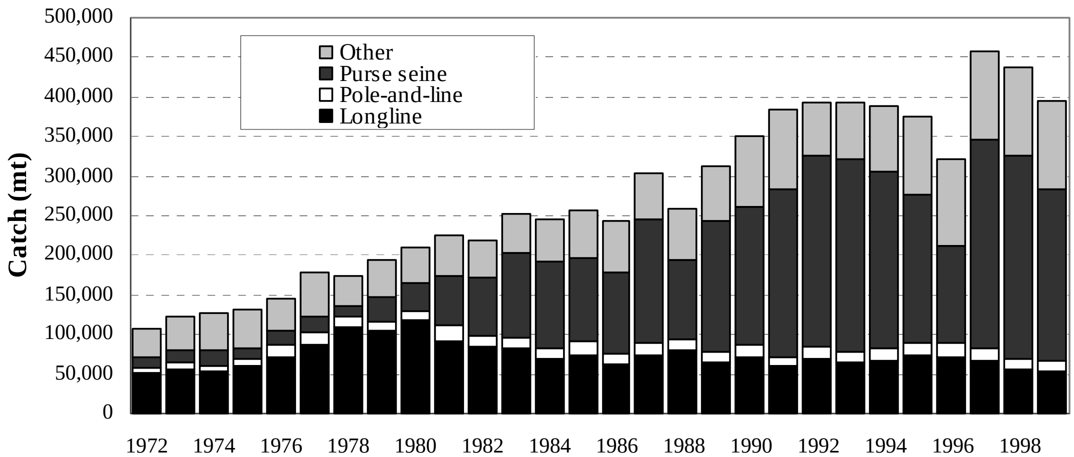

Figure 2. Distribution of yellowfin catch in the WCPO, 1988–1998.

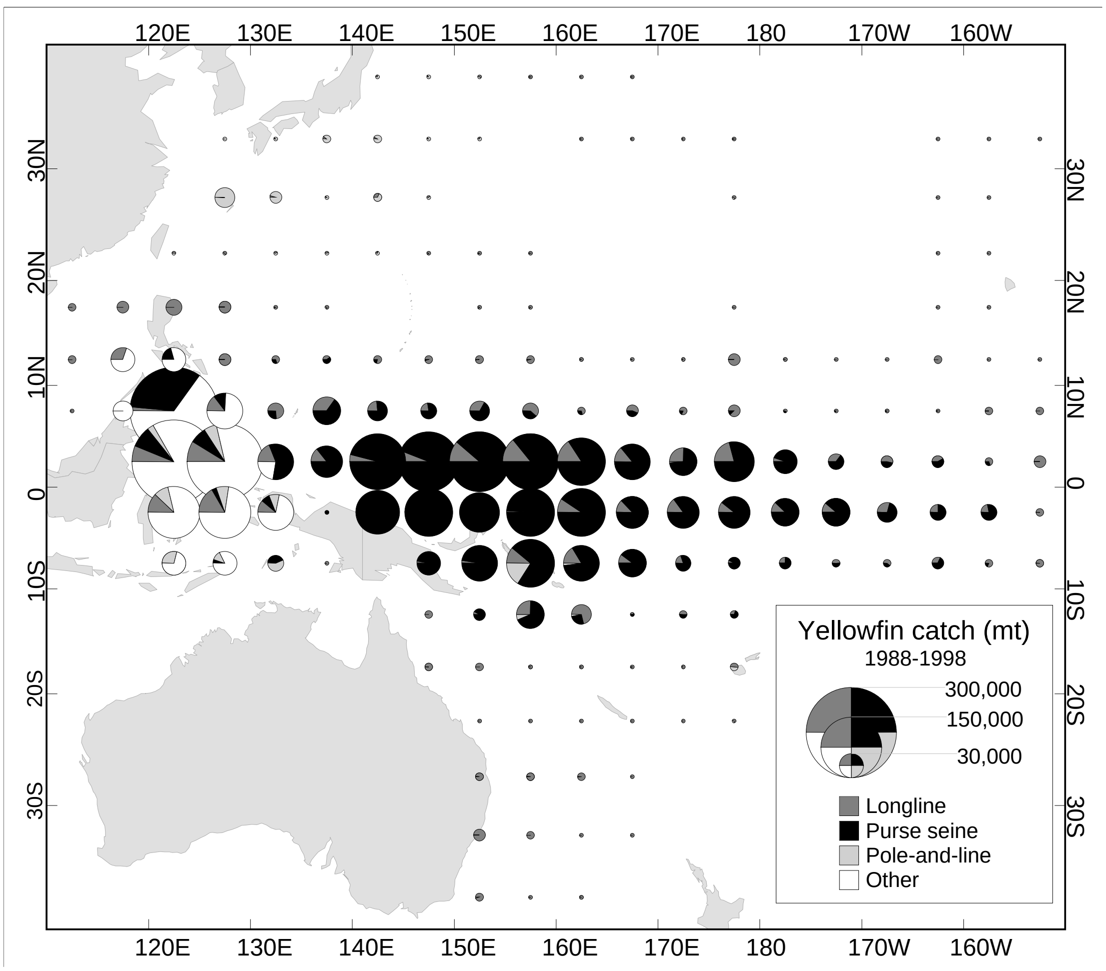

Figure 3. Nominal yellowfin CPUE for the four main purse seine fleets in the WCPO (1999 is preliminary).

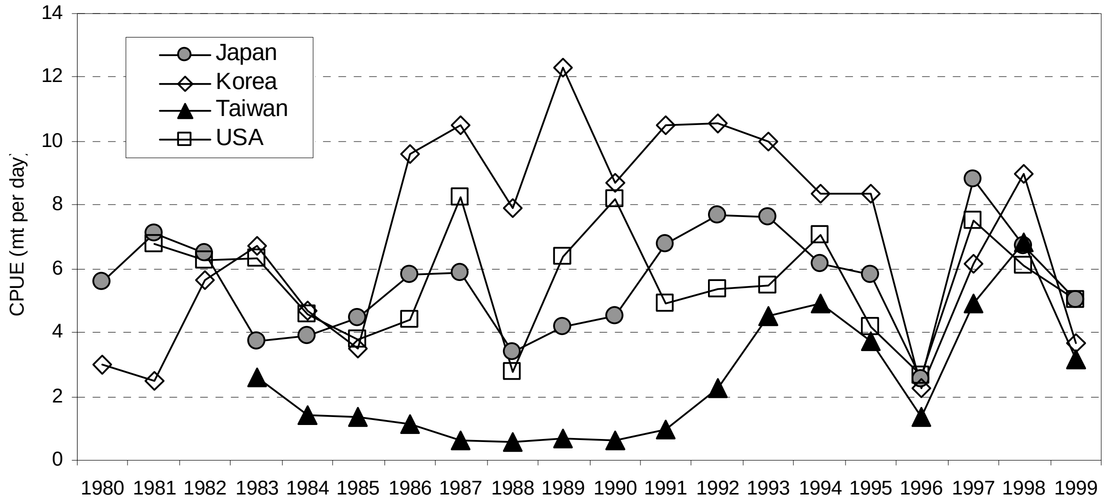

Figure 4. Nominal yellowfin CPUE for selected longline fleets operating in the WCPO.

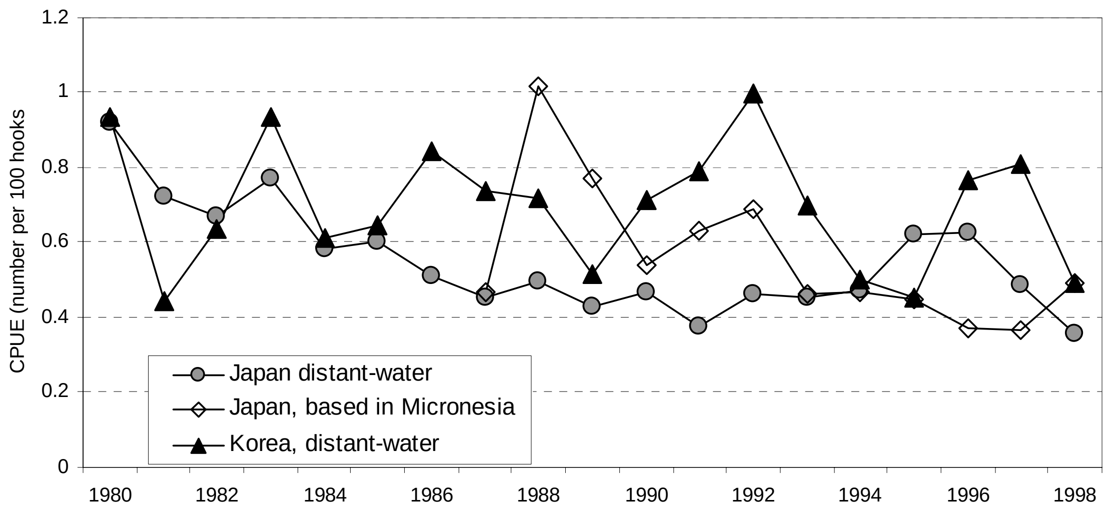

Table 1. Catch summary of Yellowfin Tuna in the western and central Pacific Ocean.

Country	Longline				Pole-and-Line				Purse seine			
	Last Catch Reported	Year	Maximum Catch	Year	Last Catch Reported	Year	Maximum Catch	Year	Last Catch Reported	Year	Maximum Catch	Year
America Somoa	34	1998										
Australia - Dom	2,150	1998			0	1998	75	1996	0	1998	26	1989
- DW									362	1993	1,237	1991
China	969	1998	5,871	1995								
Cook Islands	7	1996	23	1995								
FSM	456	1998							1,326	1998	4,299	1994
Fiji	343	1998	1,177	1996	36	1998	823	1986				
French Polynesia	480	1998			118	1998	472	1981				
Indonesia	4,204	1994	8,841	1988	5,247	1994			4,410	1994		
- DW									2,195	1989		
Japan Coastal	6,079	1997	8,452	1992	492	1997	503	1995	8	1997	6,975	1962
- Offshore/DW	17,988	1997	63,289	1980	3,639	1997	12,920	1985	36,960	1998	57,891	1993
Kiribati	0	1996	5	1995	41	1995	848	1989	698	1998	2,000	1997
Korea	9,623	1998	22,795	1980					55,212	1998		
Marshall Islands	18	1995	69	1993								
Mexico									2,070	1985		
New Caledonia	185	1998	839	1995	25	1983	41	1982				
New Zealand	164	1997			0	1997			0	1997	170	1985
Palau					14	1992	2,480	1981				
Papua New Guinea	300	1998	442	1997	930	1985	8,563	1976	9,533	1998		
Philippines	1,341	1997	3,449	1987					14,806	1997	17,109	1991
- DW									10,389	1998	11,154	1992
- Ringnet									3,835	1997	5,595	1985
Russia									3,412	1994		
Samoa	424	1998	2,125	1997								
Solomon Islands	658	1998	2,271	1996	1,235	1998	4,159	1994	7,659	1998		
Taiwan DW	904	1998	6,939	1971					63,100	1998		
- Offshore Micro	857	1998	3,473	1990								
- Off Taiwan	14,069	1998	22,629	1979								
Tonga	47	1996	81	1982								
Tuvalu					2	1992	90	1987				
United States	827	1998	1,249	1997	1	1998	114	1986	36,231	1998	56,426	1994
Vanuatu	113	1998	306	1997					6,112	1998		
Total	62,215	1997	117,423	1980	10,768	1998	19,322	1981	250,279	1998		

Table 2 Life-history parameters for yellowfin tuna.

Quantity	Values	Reference
Growth parameters		
- Male: L_∞	146.7	Lehodey and Leroy, 1999
K	0.805	
t_o	-0.049	Modified Von Bertalanffy
t_m	0.923	growth curve where
σ	0.326	K = K-N(t)
a	0.178	and
- Female: L_∞	177.1	
K	0.511	$N(t) = \frac{a}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(t-t_m)^2}{2\sigma^2}\right]$
t_o	-0.167	
t_m	0.891	
σ	0.278	
a	0.065	
- Combined: L_∞	151.7	
K	0.728	
t_o	-0.085	
t_m	0.936	
σ	0.380	
a	0.164	
Length-Weight[1], $W=aL^b$	$a=6.44x10^{-6}$, b=3.1878 $a=1.4769x10^{-5}$, b=3.0583 $a=2.512x10^{-5}$, b=2.9396	Kamimura and Honma, 1959 Nakamura and Uchiyama, 1966 Morita, 1973
Weight-at-age, $W=aA^b$ $\tilde{a}$ $\tilde{b}$	$2.1355\ 10^{-5}$ 2.902	
Dressed-to-Whole Weight r = whole/dressed	*log* r = 0.5707 -0.2445 *log* L *1.32* *1.18* *1.09*	Morita, 1973 70-80 cm 110-120 cm 150-160 cm
Length-at-50% maturity	105 cm	Itano, 2000
Natural mortality - *M*	~0.6 yr^{-1} But variable with age	MULTIFAN-CL

1. Fork length (L) is in cm and weight (W) is in kg. Weight is whole weight except for Kamimura and Honma who measured gilled and gutted weight.