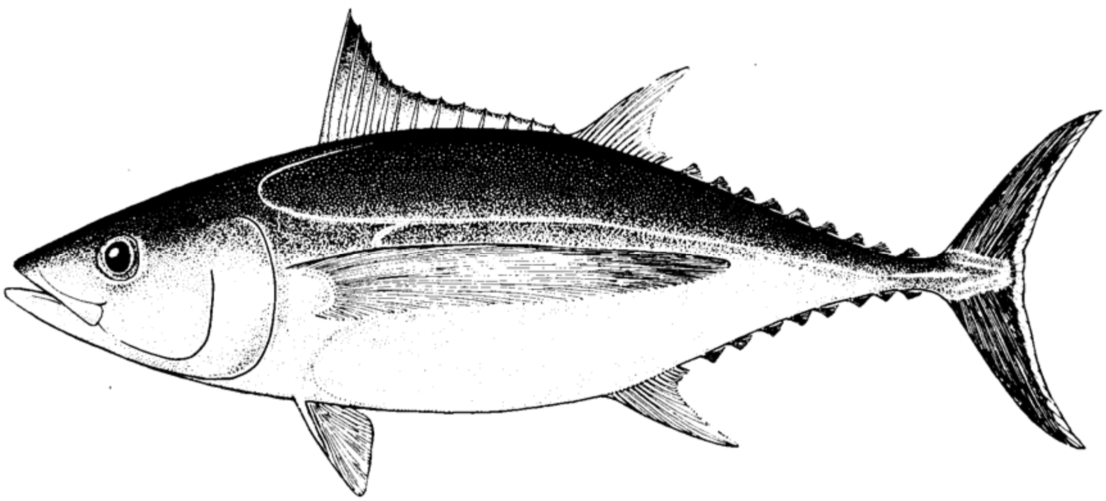
THE SOUTH PACIFIC ALBACORE FISHERY: A SUMMARY OF THE STATUS OF THE STOCK AND FISHERY MANAGEMENT ISSUES OF RELEVANCE TO PACIFIC ISLAND COUNTRIES AND TERRITORIES.

Adam D. Langley



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Abstract

The purpose of this report is to provide a summary of recent studies on South Pacific albacore and highlight the key issues for PICTs to consider in the management of their domestic longline fisheries. The current (2005) stock assessment for South Pacific albacore concluded that there are no sustainability concerns regarding the overall stock and substantially higher yields could be taken from the fishery. However, this conclusion does not adequately address the management issues faced by the domestic longline fleets in PICTs. The PICT fisheries principally catch larger, older (7–12 years) albacore. These age classes represent a relatively small proportion (about 30%) of the total adult biomass of albacore. Recent levels of fishing effort from all fisheries combined have reduced the level of biomass available to the PICT domestic longline fisheries by approximately 30% compared to unexploited levels. At a regional level, increases in fishing effort in the PICT domestic longline fisheries will result in declines in CPUE due to a decline in exploitable biomass. These impacts are likely to be considerably greater than the impact of large increases in the level of fishing effort by the distant-water fleet in the south-eastern area of the fishery. Catch rates in domestic longline fisheries exhibit strong seasonal trends. For the longline fisheries in Fiji and French Polynesia, these trends appear directly related to seasonal fluctuations in the oceanographic conditions. Seasonal trends in fisheries in adjacent waters are likely to be influenced by similar variations in oceanographic conditions. Inter-annual variation in albacore catch rates is also evident in most of the PICT fisheries. The sustained period of low catch rates that commenced in late 2002 appears to be attributable to inter-annual variation in oceanographic conditions. At a local scale, very high levels of fishing effort appear to be capable of causing localised depletion of albacore tuna. This is principally an issue for domestic longline fleets where fishing effort is concentrated in a relatively small area, largely due to operational constraints of the fleet. The scale of the local depletion effect is likely to vary seasonally and inter-annually as the rate of exchange of fish with adjacent waters varies. Indications from the Fiji longline fishery is that, on average, catch rates may be reduced by about 20% at high levels of fishing effort. Management objectives of the PICT domestic fisheries need to balance levels of fishing effort with the availability of fish to the fishery to ensure economic sustainability of the fleet.

Résumé

Le présent rapport résume les récentes études sur le germon du Sud et met en relief les principaux points que les États et Territoires insulaires océaniens doivent prendre en considération dans la gestion des flottilles locales de palangriers. L’évaluation des stocks actuels (2005) de germons conclut à la viabilité de l’exploitation de la ressource et confirme que l’activité pourrait offrir des rendements nettement plus élevés. Toutefois, elle n’aborde pas, comme elle le devrait, les problèmes de gestion auxquelles les flottilles locales de palangriers des États et Territoires insulaires océaniens sont confrontées. En effet, les prises sont principalement constituées de germons âgés (7 à 12 ans) et d’assez grande taille. Ces tranches d’âge représentent une proportion relativement faible (environ 30 %) de la biomasse totale des germons adultes. Les activités récentes de toutes les flottilles confondues ont réduit la biomasse disponible dans les États et Territoires insulaires océaniens d’environ 30 % par rapport au niveau intact de la ressource. L’accroissement des activités des flottilles nationales de palangriers, à l’échelle de la région, entraînera des diminutions des prises par unité d’effort (PUE) en raison de la résorption de la biomasse exploitable. Ces impacts seront sans doute beaucoup plus importants que ceux des activités, pourtant bien plus intenses, des flottilles de pêche hauturière dans la partie sud-est de la zone d’activité. Les taux de prise des flottilles nationales de palangriers se caractérisent par des cycles saisonniers très marqués. Aux Îles Fidji et en Polynésie française, ces derniers semblent directement liés aux fluctuations saisonnières des conditions océanographiques. Dans les eaux

adjacentes, ils sont susceptibles d'être influencés par des variations semblables des conditions océanographiques. La plupart des activités de pêche dans les États et Territoires insulaires océaniens reflètent clairement des variations interannuelles des taux de capture de germons. La longue période de faible taux de capture, qui a débuté à la fin de l'année 2002, semble s'expliquer par la variation interannuelle des conditions océanographiques. À l'échelle locale, des activités de pêche très intenses pourraient entraîner un épuisement localisé du germon. Le problème se pose principalement aux flottilles nationales de palangriers qui concentrent leurs activités sur une zone relativement restreinte en raison, notamment, des contraintes opérationnelles inhérentes à ce type de flottilles. L'ampleur des effets de cet épuisement local est susceptible de varier de saison en saison et d'année en année au gré des déplacements des stocks en provenance ou à destination des eaux adjacentes. Selon les informations des professionnels fidjiens de pêche à la palangre, les taux de capture peuvent être en moyenne de 20 % inférieurs lorsque l'activité de pêche est particulièrement intense. Les services des pêches des États et Territoires insulaires océaniens doivent se fixer des objectifs de gestion visant à instaurer un équilibre entre le niveau d'activité et la disponibilité de la ressource, afin de garantir la viabilité économique des flottilles.

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List of Abbreviations

$\tilde{B}_{MSY}$	Equilibrium total biomass at MSY
CPUE	catch per unit of fishing effort
DWFN	Distant water fishing nation
EEZ	Exclusive Economic Zone
$F_{current}$	Average fishing mortality-at-age for 2000–2002
F_{MSY}	Fishing mortality-at-age producing the maximum sustainable yield (*MSY*)
FL	Fork length
GLM	Generalised linear model
MSY	maximum sustainable yield
MULTIFAN-CL	a length-based, age-structured computer model used for fish stock assessment
OFP	Oceanic Fisheries Programme of the Secretariat of the Pacific Community
PICTs	Pacific Island Countries and Territories
$SB_{current}$	Average current (2000–2002) adult biomass
$S\tilde{B}_{MSY}$	Equilibrium adult biomass at MSY
SPC	Secretariat of the Pacific Community
SST	Sea surface temperature
STCZ	Sub-Tropical Convergence Zone
WCPFC	Western and Central Pacific Fisheries Commission

1. INTRODUCTION

Since the early 1990s, there has been a substantial development of domestic tuna longline fisheries within the subequatorial region of the South Pacific. Domestic fleets have developed in many of the Pacific Island Countries and Territories (PICTs) within the region, most notably Fiji, Samoa, American Samoa, New Caledonia, French Polynesia, Tonga, and the Cook Islands. These domestic fleets are typically composed of smaller vessels operating within their national waters and adjacent areas. The catch is fresh chilled and generally discharged at the vessel's home port.

For most of the domestic fleets, a high proportion (up to 80%) of the tuna catch (by volume) is comprised of South Pacific albacore (*Thunnus alalunga*). Many of these fleets have a relatively limited range and/or are effectively limited to fishing within waters of their national jurisdiction. Consequently, the fleets are largely dependent on the local abundance of tuna species, in particularly albacore, to maintain catch rates at or above economically sustainable levels.

During late 2002, many of the domestic longline fleets experienced a substantial decline in catch rates, principally of albacore. The low catch rates persisted for at least a year in most of the fisheries and for some fisheries catch rates have not recovered, notably French Polynesia, Cook Islands, and Tonga. This has resulted in considerable economic hardship for many of the operators in the fishery.

Over the last few years, considerable work has been undertaken by OFP to improve the assessment of the South Pacific albacore stock and to understand the dynamics of the albacore fishery, including the influence of prevailing oceanographic conditions and local-scale fishery impacts (local depletion). The results of these analyses are documented in a number of technical reports or reports to individual SPC member countries. The purpose of this report is to compile the key results from the separate analyses in a single document to provide a general overview of the status of the South Pacific albacore stock and the key management issues in the fishery, particularly those relevant to the Pacific Island domestic longline fisheries. The paper is intended for general readership by fisheries managers, operators, and other stakeholders.

2. REGIONAL OVERVIEW

2.1. Albacore biology

Albacore tuna comprise a discrete stock in the South Pacific Ocean. Mature albacore (greater than 80 cm fork length, FL) spawn in tropical and sub-tropical waters between about 10°S and 25°S during the austral summer. Spawning success appears to be related to the prevailing oceanographic conditions with stronger recruitment occurring during La Niña conditions (i.e., positive Southern Oscillation Index).

Juvenile albacore recruit to surface fisheries in New Zealand coastal waters and in the vicinity of the sub-tropical convergence zone (about 40°S) in the central Pacific about one year later, at a size of 45–50 cm (FL). Fish reach the size of first maturity (about 80 cm FL) at approximately 5 years of age and growth attenuates over the subsequent years.

The natural mortality rate (M) for albacore is considered to be in the range of 0.2–0.4 yr^{-1}(per annum), i.e., 20–40% of fish die each year due to predation, disease, and senescence (old age), although significant numbers of fish reach an age of 10 years or older. The most recent stock assessment estimated that natural mortality was towards the upper limit of this range (0.35)

(Langley & Hampton 2005). The longest period at liberty for a recaptured tagged albacore in the South Pacific is currently 11 years. Maximum recorded length is about 120 cm (FL).

2.2. Fishery Summary

The South Pacific albacore fishery developed in the early 1950s and over the following decade catches increased to about 30,000 mt per annum (Figure 1). Until the early 1980s, annual catches fluctuated about this level and were exclusively taken by longline. During the 1980s, annual catches increased due to the development of the troll fishery and, more notably, the drift net fishery in the late 1980s, with catches peaking at 22,000 mt in 1989 (Figure 1). Drift net fishing ceased in the early 1990s, while the troll fishery has continued to catch approximately 10,000 mt per annum (Figure 1).

Longline catches of albacore remained at about 30,000 mt per year up to 1998 and increased to approximately 50,000 mt in 2001 largely due to the development of small-scale longline fisheries in PICTs (Figure 1). The longline fishery catches albacore over a large proportion of their geographic range (Figure 2). However, the fishery can be clearly subdivided into three main sectors based on the spatial and temporal distribution of fishing activity and the size composition of fish caught: (1) the PICT domestic longline fisheries, (2) the distant-water longline fisheries operating in the subequatorial waters, and (3) the distant-water longline fisheries operating in subtropical waters.

The Pacific Island longline fisheries essentially operate throughout the year in waters of national jurisdiction and/or in adjacent waters. Catches from this sector are dominated by large (older) fish (Figure 3). Distant-water longline fleets of Japan, Korea and Taiwan have historically targeted albacore and the Taiwanese fleet continues to account for a substantial component of the longline catch. These fleets generally target/targeted albacore in the more southern latitudes (south of 30° S) during late summer and autumn and operated further north in the subequatorial waters during the remainder of the year. The size composition of the DWFN catch differs considerably between the subtropical and subequatorial areas with a high proportion of juvenile fish (age 3 and 4 years) in the catch from southern waters (Figure 3). Catches of albacore by the DWFNs operating in the subequatorial region (north of 30°S) were generally comprised of slightly smaller fish than caught by the Pacific Island longline fleets (Figure 3).

The troll fishery for juvenile albacore operates in New Zealand coastal waters and in the central Pacific in the region of the STCZ (Figure 2). Troll catches are relatively small, generally less than 10,000 mt per year with the catch dominated by 2 and 3 year old fish (Figure 3).

The driftnet vessels from Japan and Taiwan targeted juvenile albacore in the central Tasman Sea and in the central Pacific near the STCZ during the 1980s and early 1990s (Figure 2). Catches by this fleet were dominated by fish in the 2–4 year age classes (Figure 3).

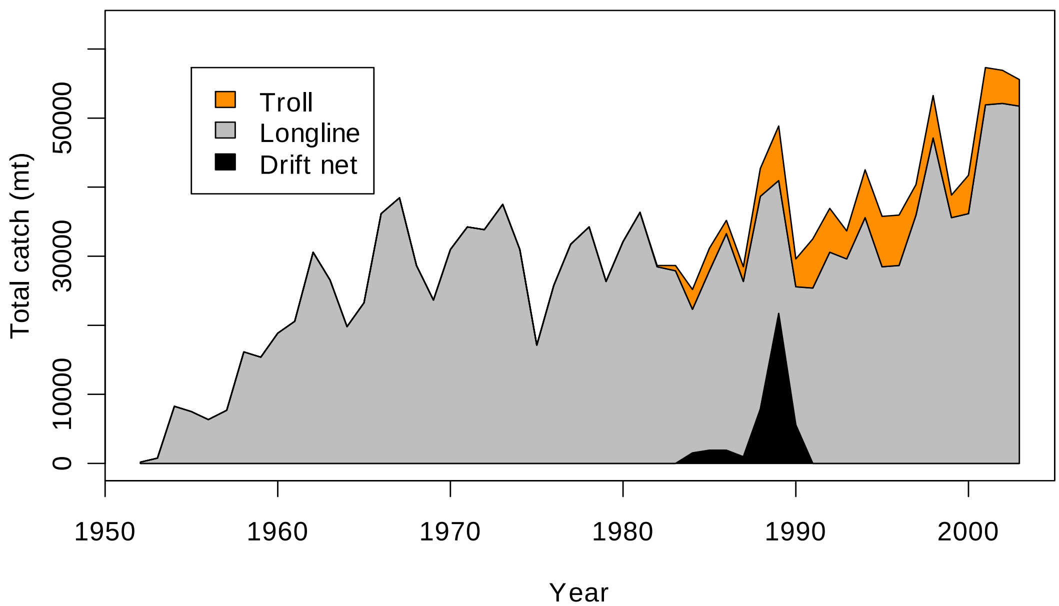

Figure 1. Annual catches of South Pacific albacore from 1952 to 2003 by fishing method.

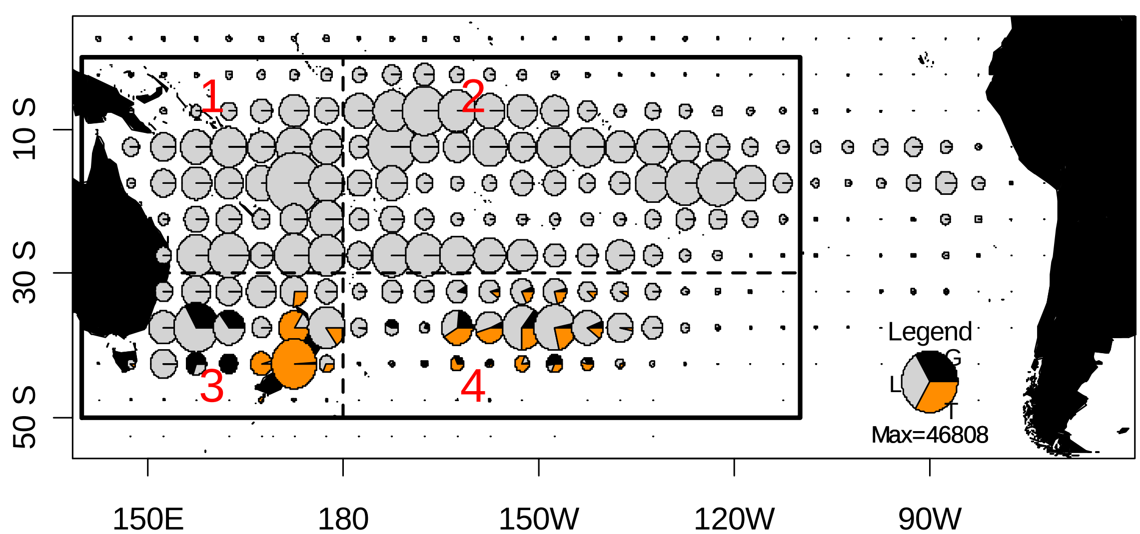

Figure 2. Total catch from 1960 to 2003 by 5 degree squares of latitude and longitude by fishing gear: longline (L), driftnet (G), and troll (T). The area of the pie chart is proportional to the total catch. The boundary of the stock assessment area is delineated by the black line and regional boundaries are delineated by the grey lines.

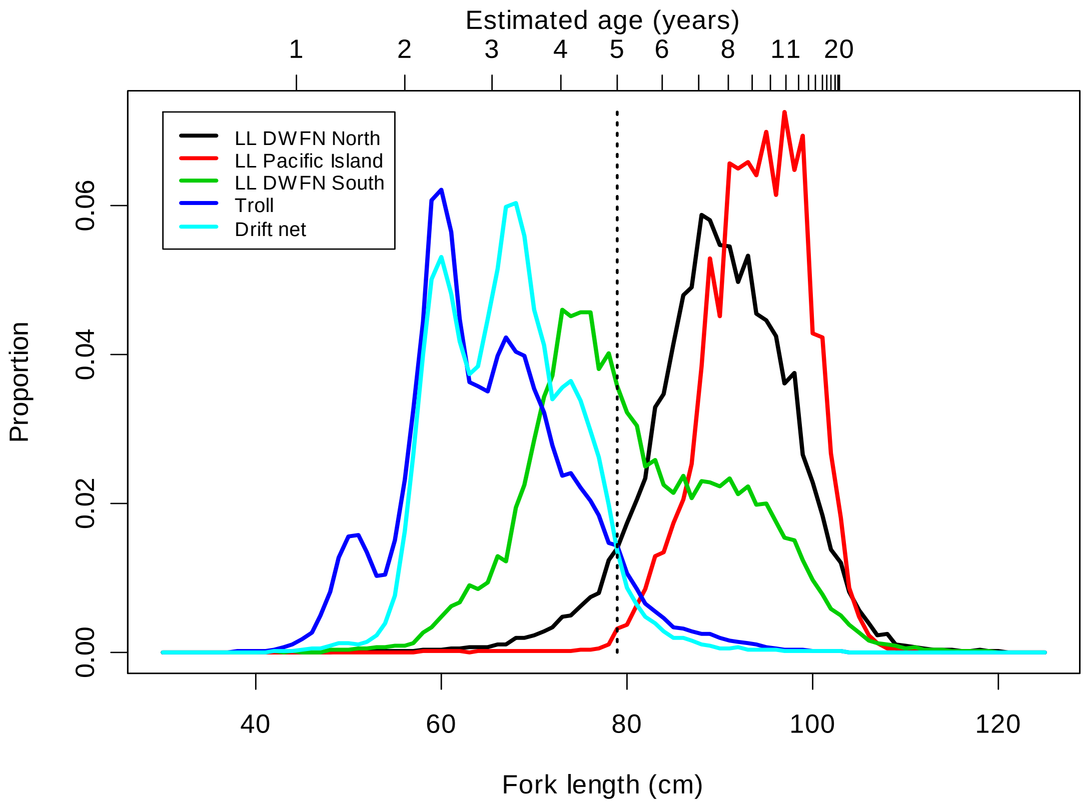

Figure 3. Cumulative length compositions of the South Pacific albacore catch from the main fisheries (all years combined). The corresponding estimated age at length is displayed on the top axis. The dashed vertical line represents the length/age when 50% of the population is assumed to reach sexual maturity.

2.2.1 Longline fishery

The relative abundance of albacore varies between areas (spatial variation) and within an area over time (temporal variation) both seasonally and inter-annually. Spatial variation in abundance relates to the underlying distribution of the species.

There is considerable seasonal variation in the spatial distribution of albacore, as inferred from the catch rates from the longline fishery (Figure 4). There is also considerable change in the seasonal distribution of the distant-water longline fleet, partly attributable to this change in the distribution (and/or availability) of albacore. During the first quarter of the year, higher albacore CPUE (greater than 20 kg per 100 hooks) is generally restricted to within the 10–25°S latitudinal band — the area of operation for most domestic Pacific Island fleets. In the second quarter, the area of higher CPUE extends southward and eastward, while the overall magnitude of CPUE also increases. Through the last half of the year, there is a general northward contraction of the area of higher CPUE back to the subequatorial latitudes (Figure 4).

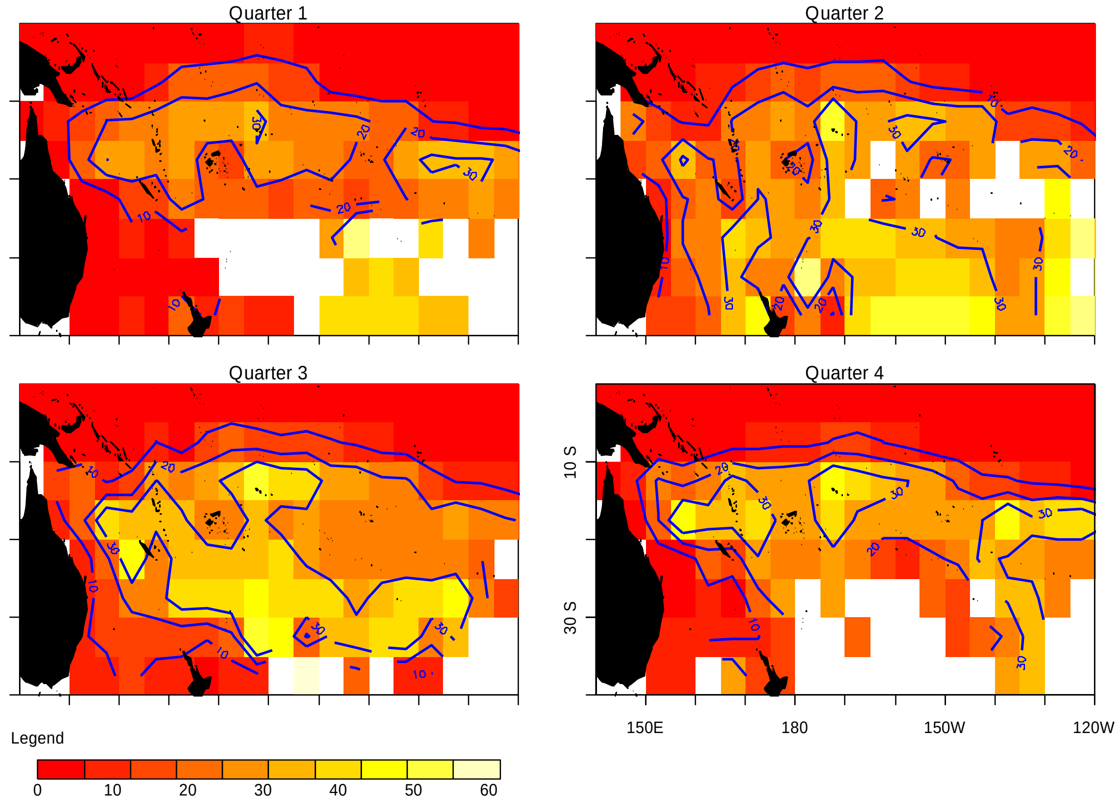

Figure 4. Average quarterly albacore catch rate (kg per 100 hooks) by the longline fishery (all fleets combined) in the southwestern Pacific for the years 1970 to 2003 combined. The blue lines represent contours of albacore CPUE at 10, 20, and 30 kg per 100 hooks.

The seasonal trend in the distribution of albacore presented in Figure 4 represents the average trend over many years. However, between years there is considerable variation in both the timing of the operation of the fishery in the subtropical waters (south of 25°S) and the location and spatial extent of the areas of higher CPUE. The reasons for these variations are discussed in detail in a latter section of this paper.

2.3. Stock assessment

The most recent assessment of South Pacific albacore was presented to the Scientific Committee of the WCPFC in August 2005 (Langley & Hampton 2005). The assessment was conducted using a length-based, age structured population model (MULTIFAN-CL) that incorporated catch and effort data, size data, and tagging data from the fishery. The main outputs of the stock assessment model are trends in stock biomass (fish abundance, expressed in weight) over time and estimates of potential yields (i.e. catches) from the stock.

The model was structured to include the main fisheries within the region, segregated by gear type and area fished. Specific fisheries were defined for the distant-water and main domestic longline fleets. This enables an examination of historical and recent trends in the level of biomass available to these fisheries. Further, the impact of different levels of future fishery-specific effort on the biomass available to individual fisheries can be examined via forward projections (based on specific assumptions regarding future levels of recruitment).

The current stock assessment estimates that the adult biomass of South Pacific albacore increased in the 1960s and was at a high level during the 1970s. The level of biomass is estimated to have declined during the 1980s and again since the late 1990s (Figure 5). These trends in adult biomass generally follow trends in estimated recruitment for the stock — recruitment has been estimated to have declined steadily over the last decade, hence the subsequent decline in the adult biomass since the late 1990s (Langley & Hampton 2005).

Overall, the current levels of exploitation are estimated to be having a relatively small impact on the level of adult biomass, reducing the biomass by approximately 10% in recent years (Figure 5). However, levels of fishery impact have increased in the last decade as the overall level of catch has increased and the level of adult biomass has declined.

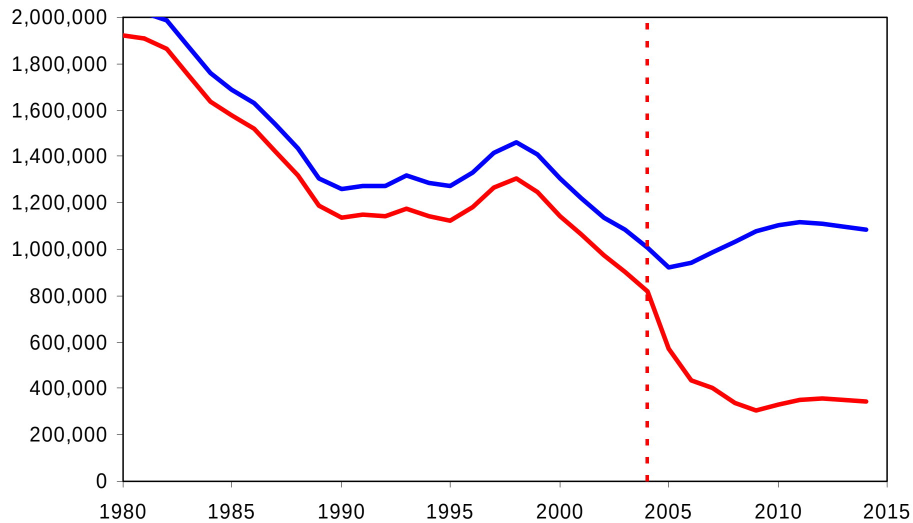

Figure 5. Adult biomass (mt) of South Pacific albacore with (red line) and without (blue line) fishing. From 2004 (vertical dashed line), effort is presumed to occur at the F_{MSY} level.

Further, the level of fishery impact on the component of the stock vulnerable to the PICT domestic longline fisheries has been considerably higher (25–30%) than for the adult biomass (Figure 6). This is illustrated by the example of the Fiji longline fishery that shows a greater difference between the level of vulnerable biomass under 'exploited' conditions (i.e. fished, red line) and 'unexploited' conditions (i.e. unfished, blue line) (Figure 6).

This is because the PICT domestic longline fisheries principally catch large, older fish which represent a relatively small proportion of the total stock compared to the total adult biomass. This component of the stock has accounted for a higher proportion of the total catch in recent years and, hence, exploitation rates of this component of the stock have been higher in recent years.

The PICT longline exploitable biomass is also impacted by the cumulative effect of fishing by other fisheries on the age classes prior to recruitment to the PICT fisheries, although the current assessment indicates this has been relatively low in recent years. This is evident from the very low impact on the juvenile component of the stock harvested by the New Zealand troll fishery and the relatively low impact on the biomass vulnerable to the Taiwanese longline fishery in the southern area of the region (Figure 6). The latter fishery harvests smaller fish than the PICT longline fisheries and the recent impact due to fishing on this component of the stock is estimated to be about 10%.

Overall, the stock assessment indicated that the South Pacific albacore stock is well above established biological reference points; current adult biomass is substantially higher than the adult biomass at the level corresponding to Maximum Sustainable Yield (*MSY*) (i.e. $SB_{current} > SB_{MSY}$) and current exploitation rates are much lower than the fishing mortality rate required to produce the *MSY* (i.e. $F_{current} < F_{MSY}$). Therefore, the stock is not overfished and overfishing is not occurring.

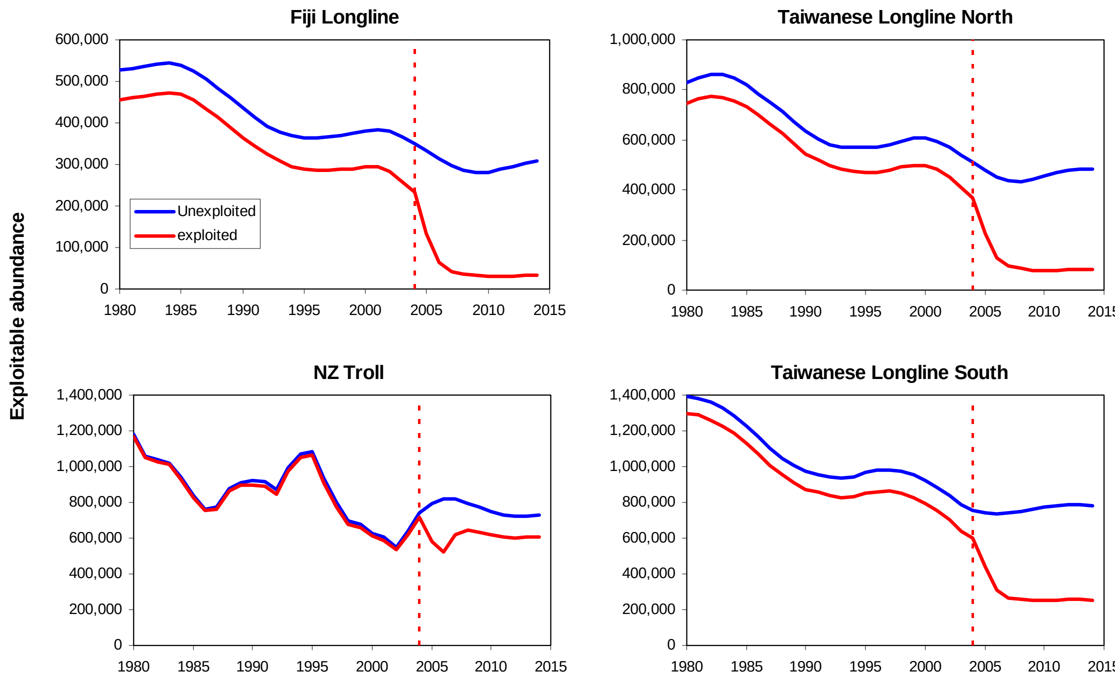

Figure 6. Exploitable abundance (which is proportional to CPUE) of selected South Pacific albacore fisheries with (red line) and without (blue line) fishing. From 2004 (vertical dashed line), effort is presumed to occur at the F_{MSY} level.

The stock assessment also indicates that substantially higher long-term sustainable yields could be taken from the stock — *MSY* is estimated to be about 180,000 mt, approximately three times the level of recent annual catches (about 55,000 mt). However, given the current distribution of fishing effort, effort by all fisheries would have to increase by 19-fold to achieve the *MSY* (i.e. F_{MSY}). The resulting reduction in biomass (to B_{MSY}) would result in a reduction in catch rates in all fisheries, although the magnitude of the decline in vulnerable biomass and the corresponding reduction in CPUE would vary between fisheries.

Model projections were conducted to examine the fishery-specific impacts of increasing exploitation rates to the F_{MSY} level, i.e. increasing effort to 19 times the average 2000–2002 effort in all fisheries (Hampton et al. 2005)(see Figure 6). For the longline fisheries in the subequatorial region, including the PICT domestic fisheries, exploitable biomass is estimated to be reduced to about 15% of the level in the late 1990s, with a corresponding reduction in catch rate (Figure 6).

The model estimates of *MSY* and the corresponding level of exploitation rate (F_{MSY}) are very uncertain. The principal conclusion of the assessment is that current yields are below the *MSY*, although the magnitude of the reference yield is unknown. The F_{MSY} projections presented in Figure 6 should be considered as theoretical and the reference level of fishing mortality is not promoted as an appropriate management target for the fishery. Instead, the projections serve to illustrate the impact that excessively high levels of effort are likely to have on the various components of the fishery, in particular the PICT domestic longline fisheries.

Further such increases in fishing effort are highly unlikely to be achievable, based on the current fishery configuration, and clearly uneconomic given the magnitude of the associated declines in CPUE. A range of more plausible scenarios for future levels of fishing effort are considered in Section 3.3.

3. THE PACIFIC ISLAND DOMESTIC FISHERIES

This section examines recent trends in the PICT domestic longline fisheries and provides an analysis of the key results of the stock assessment of relevance to these fisheries. For two of the fisheries (Fiji and French Polynesia) the results of a detailed analysis of the effects of oceanographic conditions on albacore catch rates are presented. These two fisheries were also examined to investigate the impact of localised fishing effort. The fisheries were selected because of the relatively high level of fishing activity in the EEZs and the availability of a good time-series of catch and effort data from the fishery.

3.1. Recent trends

The domestic longline fisheries in the South Pacific developed from the early 1990s and rapidly expanded during the following decade (Figure 7). During this period, catches of albacore by PICT flagged vessels increased from a negligible level to 20–25,000 mt per annum, representing approximately 40% of the total South Pacific albacore catch by all methods. The largest component of the recent PICT catch was taken by Fiji (40% of the 2003 and 2004 catch combined), American Samoa (19%), French Polynesia (13%), and Vanuatu (8%) flagged longline vessels (Figure 7).

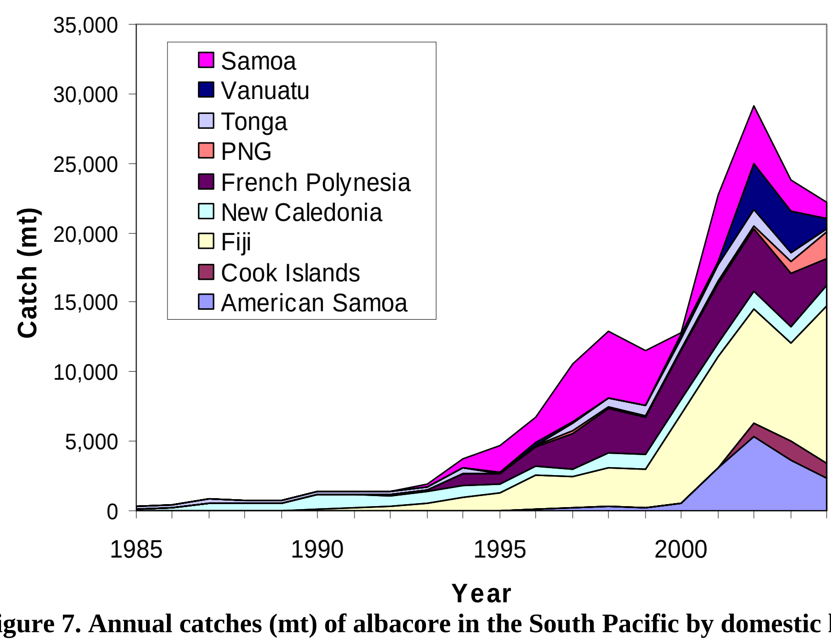

Figure 7. Annual catches (mt) of albacore in the South Pacific by domestic longline fleets of PICTs from 1985 to 2004.

There is considerable spatial variation in the catch rate of albacore between PICT's EEZs (Figure 8). In recent years, highest catch rates were recorded in American Samoa, Samoa, and the northern waters of the Cook Islands EEZ. Catch rates in Papua New Guinea (southern waters) were very low prior to 2003.

Most fisheries exhibit strong seasonal variation in albacore catch rates, particularly those fisheries operating in the more western EEZs of the South Pacific Ocean (i.e., New Caledonia and Fiji). The timing of the seasonal peak(s) in catch rates varies between EEZs although catch rates are generally highest during late autumn and winter (May–July) (Figure 8). Catch rates in Fiji, Tonga, New Caledonia, and Vanuatu also have a second peak in early summer (December–January).

There is also considerable inter-annual variation in albacore catch rates and, in general, catch rates in most fisheries were relatively low between late 2002 and late 2004 (Figure 8). The exception was the longline fishery in southern PNG that exhibited a considerable increase in albacore catch rates from early 2003 onwards.

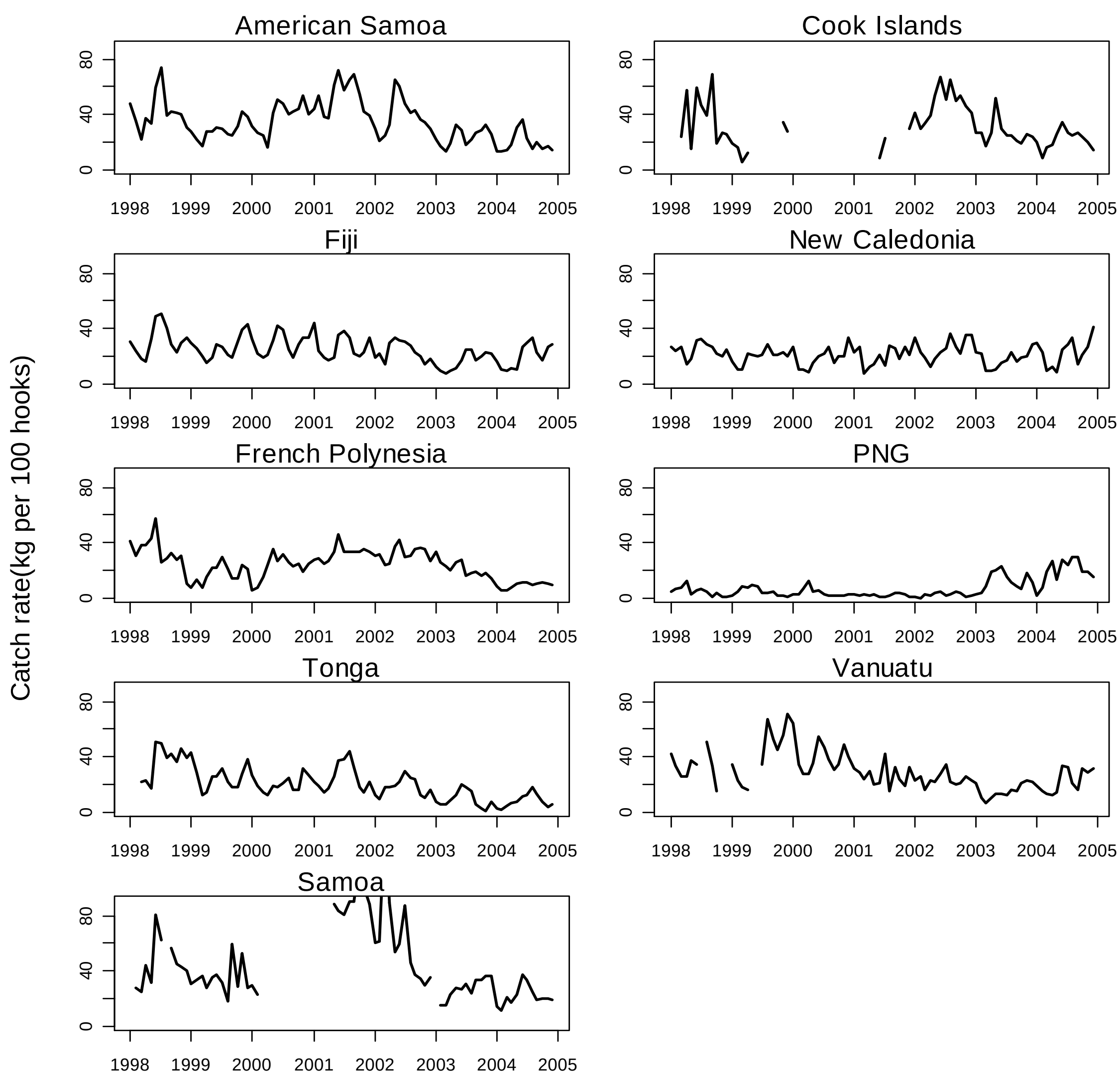

Figure 8. Monthly albacore catch rates (kg per 100 hooks) of the Pacific Island domestic longline fleets (within national EEZs) from 1998 to 2004.

3.2. Albacore availability to the fleet — a conceptual model

The temporal variation in abundance of albacore in an area, such as a country's EEZ or principal fishing ground, is influenced by the following main factors:

- ***Total stock size***, particularly the proportion of the stock of the size vulnerable to the fishing method. The overall stock size is related to the overall level of exploitation of the stock and recent trends in stock recruitment.
- ***The prevailing oceanographic conditions***. In general terms, the variation in species distribution due to oceanographic conditions may be approximated by the seasonal trends in the distribution of the species. However, oceanographic conditions deviating from the norm may result in substantial changes in the seasonal distribution of the species.
- ***Local depletion effects.*** In areas where fishing effort is high and catches exceed the rate of replenishment from outside the area, the level of biomass (abundance) in the area will be reduced by the effect of fishing. If this effect is severe, then catch rates by the fleet in the area may be significantly reduced.

These three factors interact to determine the abundance of albacore in a specific area. The effects are summarised in the following schematic diagram (Figure 9). For a domestic longline fleet limited to a relatively small area of operation, these effects will directly impact on the albacore catch rates achieved by the fleet. For the distant water fleets, the impacts of oceanographic conditions and localised depletion are minimised as the vessels have a much larger operational range.

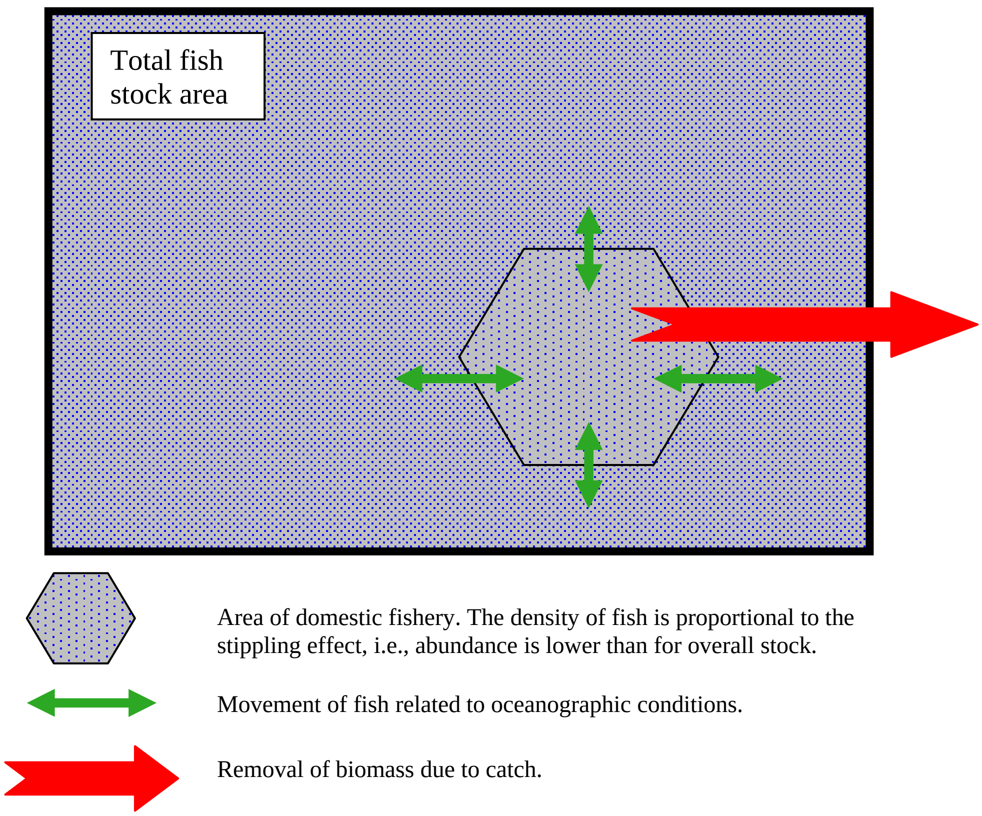

Figure 9. Conceptual model of the availability of fish to a specific area within the stock boundary.

3.3. Application of the stock assessment results to the PICT domestic fisheries

The PICT domestic longline fisheries principally catch large, older albacore (see Figure 3). Albacore are assumed to reach sexual maturity at a considerably smaller size than that selected by the PICT longline fisheries. Consequently, the proportion of the stock exploited by the PICT longline fisheries represents a relatively small proportion of the total adult biomass — approximately 25% by weight (Figure 10). This is due to the cumulative effects of natural mortality (M) and fishing mortality reducing the number of fish in the older age classes vulnerable to the PICT longline fisheries.

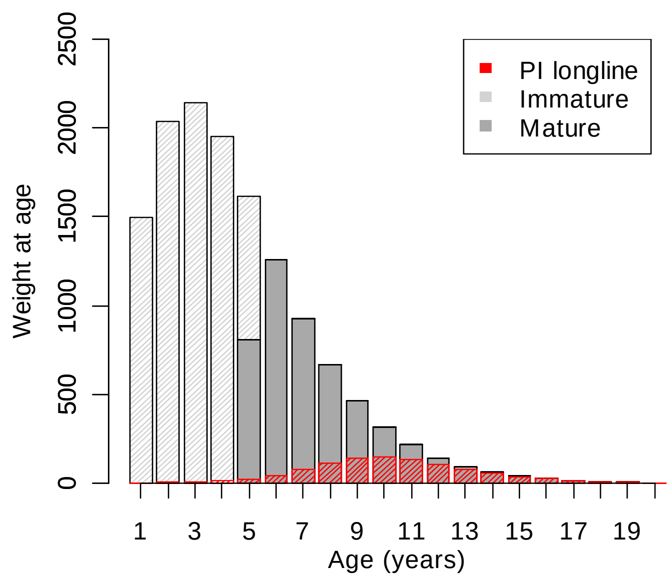

Figure 10. The composition of a theoretical cohort (weight at age): immature (light grey), mature (dark grey) and vulnerable to the PICT longline fisheries (red). In this example, natural mortality is assumed to be 0.35 and fishing mortality is zero.

Overall, the current stock assessment indicates the level of albacore biomass available to the PICT domestic fisheries is relatively modest; i.e. of the order of 300,000 mt distributed over an ocean area of approximately 14.5 million sq km (5.5. million sq m) (10–28°S, 160°E to 140°W).

The current stock assessment indicates exploitation rates on this component of the stock have increased considerably over the last 15 years (Figure 11) consistent with the increased catches taken by the PICT domestic longline fisheries. The stock assessment also attributes the increase in fishing mortality rates to an overall decline in the biomass of older fish (greater than 7 years) in the population following a decline in recruitment during the late 1990s (see Langley and Hampton 2005).

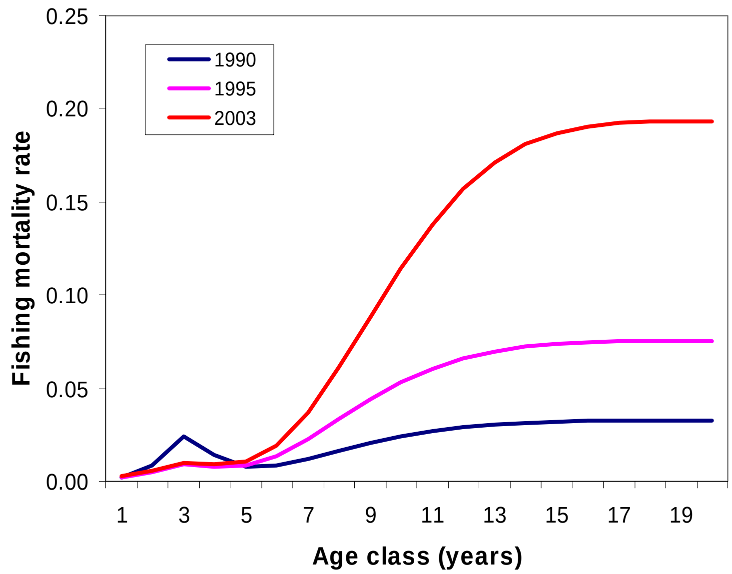

Figure 11. Estimated fishing mortality rates of albacore by age class for three time periods (1990, 1995, and 2003) from the 2005 stock assessment (Langley & Hampton 2005).

While exploitation rates have increased substantially over the last 15 years, overall exploitation rates for the stock are low relative to established biological reference points (i.e. F_{MSY}) and the current level of exploitation does not impact on the sustainability of the stock.

Nevertheless, increasing exploitation rates of the age classes vulnerable to the PICT domestic fisheries will result in a reduction in the level of biomass available to these fisheries and, consequently, an overall reduction in the level of CPUE achieved by the fisheries.

To investigate the potential impact on PICT fisheries of future increases in fishing effort, a number of scenarios for the potential expansion of the South Pacific albacore fishery were considered in the framework of the current stock assessment. The approach used by Hampton et al (2005) was applied to estimate future levels of albacore biomass under different effort scenarios, assuming future recruitment is equivalent to long-term average recruitment. The scenarios considered were:

- A five-fold increase (relative to the average of the fishing effort level during 2000–2002) in fishing effort by the Taiwanese distant-water longline fleet operating in the south-eastern area of the fishery (south of latitude 30° S and east of longitude 180°) ("TWDW 5x"). Effort in all other fisheries held constant.
- A doubling of the level of effort in the PICT longline fisheries from the level of the 2003 year ("PICT 2003 2x"). Effort in all other fisheries held constant.

These two scenarios were compared to a baseline projection ("base") with fishing effort in all fisheries remaining constant at the average of the fishing effort level during 2000–2002. Projections were conducted for a 10-year period (up to 2014).

The assessment indicates that the PICT longline exploitable biomass declines sharply from 2000 to 2004, largely due to the decline in estimated recruitment in the late 1990s (described above) (Figure 12). This decline in biomass continues into the projection period of the model and is greatest for the scenario with high effort in the PICT fisheries (*PICT 2003 2x*). For all scenarios, there is a gradual increase in PICT longline exploitable biomass from about 2007 due to projected recruitment being higher than recruitments immediately prior to the projection period (Figure 12).

Over the projection period, the impact of the increased fishing effort in the PICT longline fisheries is substantially greater than the impact of increased Taiwanese fishing effort in the south-eastern area (relative to the baseline projection). Overall, the doubling of fishing effort in the PICT fisheries resulted in a 25–30% reduction in the level of exploitable biomass, while a 5-fold increase in Taiwanese fishing effort in the south-eastern area resulted in only a minimal (about 5%) impact on the biomass available to the PICT longline fisheries (Figure 12).

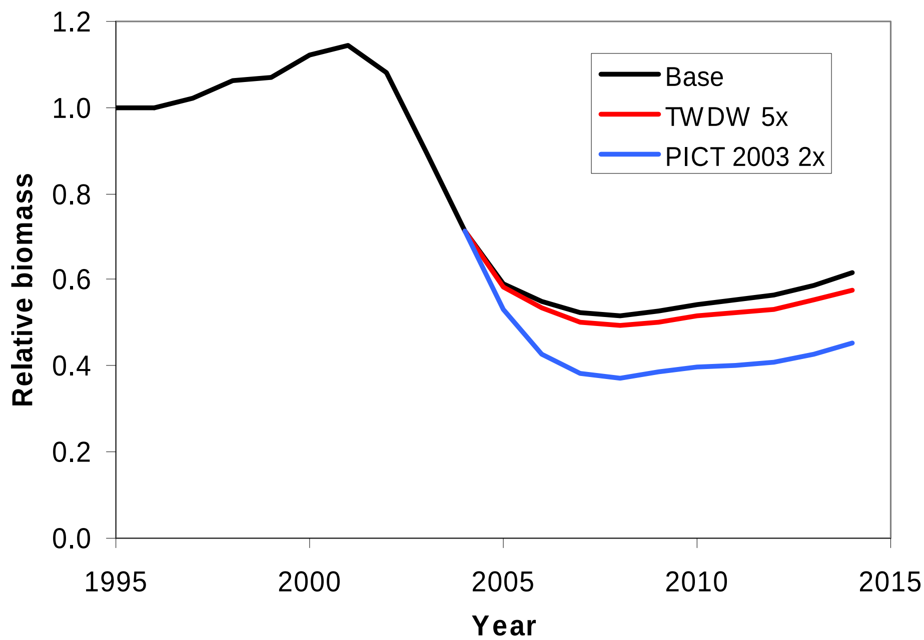

Figure 12. Comparison of the <u>projected</u> longline exploitable biomass available to the PICT domestic fleets under three potential effort scenarios defined in the text. The biomass is plotted relative to the exploitable biomass level in 1995. The projection period is 2004 to 2014.

The lower impact of the increased Taiwanese effort on the PICT longline component of the stock is largely attributable to the differences in the size selectivity of the two fisheries. Catches from the Taiwanese fishery in the south-eastern area are dominated by relatively young fish that are not vulnerable to the PICT longline fisheries (see Figure 3). Consequently, the impacts of these catches do not directly affect the level of biomass available to the PICT longline fisheries and the overall impacts of the increased catches are small relative to the level of natural mortality.

In contrast, increased effort in the PICT fisheries will directly increase exploitation rates and increase removals of the vulnerable component of the stock, thereby reducing the level of exploitable biomass. The decline in exploitable biomass will result in a reduction in CPUE in these longline fisheries. The decline in CPUE would be proportional to the decline in exploitable biomass if there was complete mixing of the stock. However, this assumption is unrealistic and CPUE declines may be higher due to localised depletion effects resulting from the concentration of fishing effort in local areas (see Section 3.5).

3.4. Oceanographic conditions

The rapid and coincidental decline evident in the catch rates from most domestic longline fisheries from late 2002 is suggestive of regional scale effects influencing albacore availability. The decline is too immediate to be attributable to a decline in albacore biomass and there is no indication of a protracted period of very low recruitment in the preceding years. Instead, it seems more plausible that the availability of albacore to the domestic fleets was reduced due to a substantial change in the prevailing oceanographic conditions either shifting the main distribution of albacore beyond the range of the domestic fleets and/or reducing the catchability of the albacore on the local scale.

For the key domestic longline fisheries, statistical models have been developed that relate albacore catch rates to a range of oceanographic variables, including sea temperatures at a range of depths, chlorophyll-a concentration (sea colour), and current flows (Langley 2004). These models have generally been able to approximate the observed monthly trends in albacore catch rates from the main fisheries, at least over the seven year period examined.

On that basis, the modeling approach was successful and it also identified the oceanographic variables most likely to be influencing albacore catch rates. These included the magnitude of the east-west current flow and temperature at depth (150 m). However, the models are rather complex (including at least four main variables) and there are strong correlations between most of these variables so that it remains unclear how the variables interact to explain the catch rate of albacore. Further, the models do not provide an understanding of the underlying mechanism that may be driving the change in albacore availability to the individual fleets.

Further work has recently been undertaken to develop a simpler approach to understanding the relationship between oceanographic conditions and albacore catch rates. For many of the domestic albacore longline fisheries, there is a strong seasonal trend in albacore CPUE (Figure 8) and many of the fisheries have two strong peaks in albacore catch rates during the year, for example the Fiji fishery.

The subequatorial waters where these domestic fisheries operate are characterised by a high level of contrast in sea temperatures through the latitudinal range, with sea surface temperatures ranging by about 6°C between latitudes 15° and 25°S (Figure 13). There is also a strong seasonal trend in sea temperatures within this region as warmer waters extend further south during summer and retreat northwards in autumn. This is evidenced by the seasonal south/north movement of the 25°C sea surface temperature isotherm which migrates from about latitude 20°S in winter to 28°C in summer (Figure 14 and Figure 15).

An examination of the seasonal trends in catch rates from a number of the domestic fisheries revealed that highest albacore catch rates generally coincide with the periods of greatest contrast in oceanographic conditions or immediately following these changes. For example, albacore catch rates from the Fiji domestic fishery typically increase sharply during March to June coinciding with the period of rapid northward movement of the 25°C sea surface temperature isotherm, i.e., the period of rapid cooling of waters within the Fiji EEZ (Figure 14). Catch rates then decline during the winter months (August and September) when oceanographic conditions are relatively stable. This is followed by a second increase in catch rates during October to December, again coinciding with a period of substantial change in oceanographic conditions with the strong southward movement of warmer water indicated by the southern movement of the 25°C sea surface temperature isotherm (Figure 14). During January–March, catch rates are generally low, while there is limited variation in the latitude of the 25°C sea surface temperature isotherm.

For the French Polynesian fishery, there is generally a single seasonal peak in albacore catch rates following a strong increase in CPUE from May to July (Figure 15). This increase also coincides with the period of strong seasonal change in oceanographic conditions as water temperatures rapidly cool during autumn as indicated by the northern shift in the location of the 25°C sea surface temperature isotherm. The peak in catch rates is maintained for a short period (1–2 months), although moderate catch rates are generally maintained throughout the winter months. Catch rates tend to decline sharply in early summer, reaching a low level in February–March. This decline in catch rates tends to coincide with the warming of water temperatures in the area as indicated by the southern movement of the 25°C sea surface temperature isotherm (Figure 15).

For both the Fiji and French Polynesia fisheries, the seasonal trends in albacore catch rate can be generally linked to strong seasonal trends in oceanographic conditions. This may be explained by the following two simple mechanisms:

1. The movement of albacore through the waters of the EEZ following the seasonal change in the distribution of the preferred habitat of the species, as indicated by water temperature preference.
2. The effect of "environmental forcing" whereby the seasonal movement of warmer/cooler water southward/northward compresses the distribution of the species at the boundary of the temperature front. The higher density of fish at the boundary results in an increase in catch rates while fishing at the vicinity of this area.

In fact, both these factors are likely to act together to some extent. Longer-term trends in catch rate (lasting several years) are more likely to be attributable to substantial shifts in the underlying distribution of the species (1).

It is hypothesised that the very strong seasonal changes in catch rate observed in these fisheries during period of strong shifts in oceanographic conditions are more likely to be attributable to the forcing effects described above (2). To this end, two simple variables were calculated from the available sea surface temperature data in an attempt to quantify the magnitude of the forcing effect in each month:

a) The rate of change (delta) in the latitude of the 25°C sea surface temperature isotherm between successive months. [This variable quantifies the degree of change in the water temperatures in the area between months. Higher values are considered to represent a higher level of "environmental forcing" as the oceanographic conditions are more dynamic.]
b) The distance between the 23°C and 25°C sea surface temperature isotherms in the month. [A lower value of this variable equates to a higher degree of compression of the preferred habitat and, therefore, a higher level of "environmental forcing".]

The two temperature values were chosen as they represent the range of sea surface temperatures in the main area where albacore fishing occurs. The indices thus derived should be interpreted as indicators of overall oceanographic processes, rather than the actual preferred temperature range of albacore. Other temperature values could be chosen although the trends in the temperatures are highly correlated and the resulting oceanographic indicators would be similar.

These indicator variables were computed for the two EEZ areas (Fiji and French Polynesia) and related to the observed trends in monthly albacore CPUE from the two fisheries from 1998 to 2004.

3.4.1 Fiji

For the Fiji fishery, monthly trends in catch rate were generally well correlated with the rate of change in the latitude of the 25°C sea surface temperature isotherm prior to late 2002 (as previously described) (Figure 14). High catch rates tended to coincide with periods of greatest change in oceanographic conditions.

However, from late 2002 onwards, this relationship is not maintained and catch rates are generally low. There is evidence of a change in oceanographic conditions in late 2002 with the 25°C sea surface temperature isotherm not extending as far south as in other years (Figure 14). This may be correlated with a weakening of the environmental forcing effect as quantified by the shorter periods when there was a strong movement of the 25°C sea surface temperature isotherm and, in particular, longer periods where there was a wider distance between the 23°C and 25°C sea surface temperature isotherms. The higher values for the latter variable in 2003 and 2004 suggest there was a weaker forcing effect during this period, possibly explaining the substantially lower CPUE (Figure 14).

3.4.2 French Polynesia

The situation is more complex for French Polynesia. Seasonal trends in oceanographic conditions are generally characterised by a latitudinal trend in water temperature as described above. However, during summer there is also an eastwards extension of the warm pool and a subsequent westward contraction during late autumn (Figure 13). This extension of the warm pool influences the oceanographic conditions in the waters encompassing the French Polynesia EEZ and is illustrated by the seasonal fluctuation in the longitude of the 28°C sea surface temperature isotherm (Figure 16). Consequently, consideration of oceanographic conditions influencing French Polynesia must also consider the longitudinal dimension of the oceanographic conditions as well as the latitudinal component that almost exclusively dominates the fishery in the Fiji EEZ (as an example).

During 1998 to 2002, there was a sharp increase in catch rates during autumn that coincided with the rapid decline in water temperatures, as indicated by the strong northern movement of the 25°C sea surface temperature isotherm (Figure 15). This is suggestive of the environmental forcing processes described for the Fiji fishery or it may represent a broader shift in the distribution of albacore into the area of the French Polynesian fishery during that period when waters are cooler.

There is also a clear inverse relationship between catch rates and the eastern extent of the 28°C sea surface temperature isotherm (Figure 16). Catch rates are generally higher in the winter months when the isotherm is located further west and is within the longitudinal range of the main French Polynesian fishery for a sustained period. During summer, the isotherm is displaced eastwards, east of the main fishery area, coinciding with periods of low catch rates.

Since late 2002, the 28°C sea surface temperature isotherm was further eastwards (by approximately 10° longitude) during winter than in the previous period and exhibited much weaker seasonal oscillations (Figure 16). This coincided with the sustained period of low catch rates from the fishery. This suggests that since late 2002, the prevailing oceanographic conditions have shifted the distribution of albacore eastwards of the area of the main French Polynesian fishery and the weaker seasonal oscillations during the subsequent years have been insufficient to replenish the abundance of albacore in the area of the main fishery.

There is additional information from the French Polynesian longline fishery to support this hypothesis. There is a temporal and spatial trend in the catch rates within the longline fishery with higher catch rates in the eastern area of the fishery preceding the increase in catch rates in the western area of the fishery during the autumn months. The converse is also evident, with the decline in CPUE during summer first occurring in the western area of the fishery and then later in the eastern area. This is indicative of fish moving eastwards out of the fishery area during early summer and returning westwards during autumn.

Further, during the period from late 2002 to the end of 2004, when catch rates were low throughout the area of the French Polynesia fishery, catch rates were generally higher in the eastern area than in the western area. This is contrasted with the earlier period when the relative difference in CPUE fluctuated from east to west. The recent trend is suggestive of the main abundance of albacore being displaced eastward during recent years.

These two examples, illustrate how oceanographic conditions may directly influence the abundance of albacore in the waters fished by the domestic longline fleets. The mechanisms proposed differ between the two fisheries, reflecting the different geographical location and, consequently, the different effect of variation in oceanographic conditions on the availability of albacore to the domestic fisheries. Similar oceanographic effects are likely to impact the performance of the longline fisheries in waters adjacent to these two EEZs.

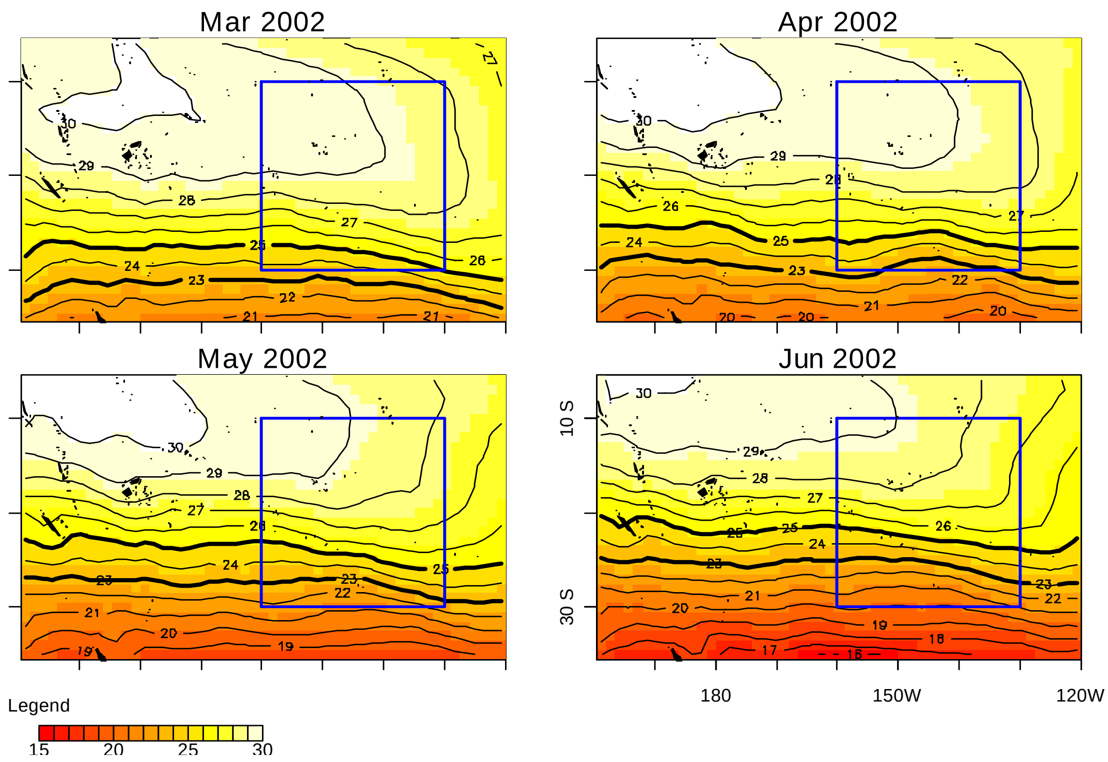

Figure 13. An example of monthly trends in the sea surface temperature (degrees Celsius) of waters in the South Pacific Ocean from March to June 2002. The black lines represent SST isotherms. The blue box approximates the area of French Polynesia.

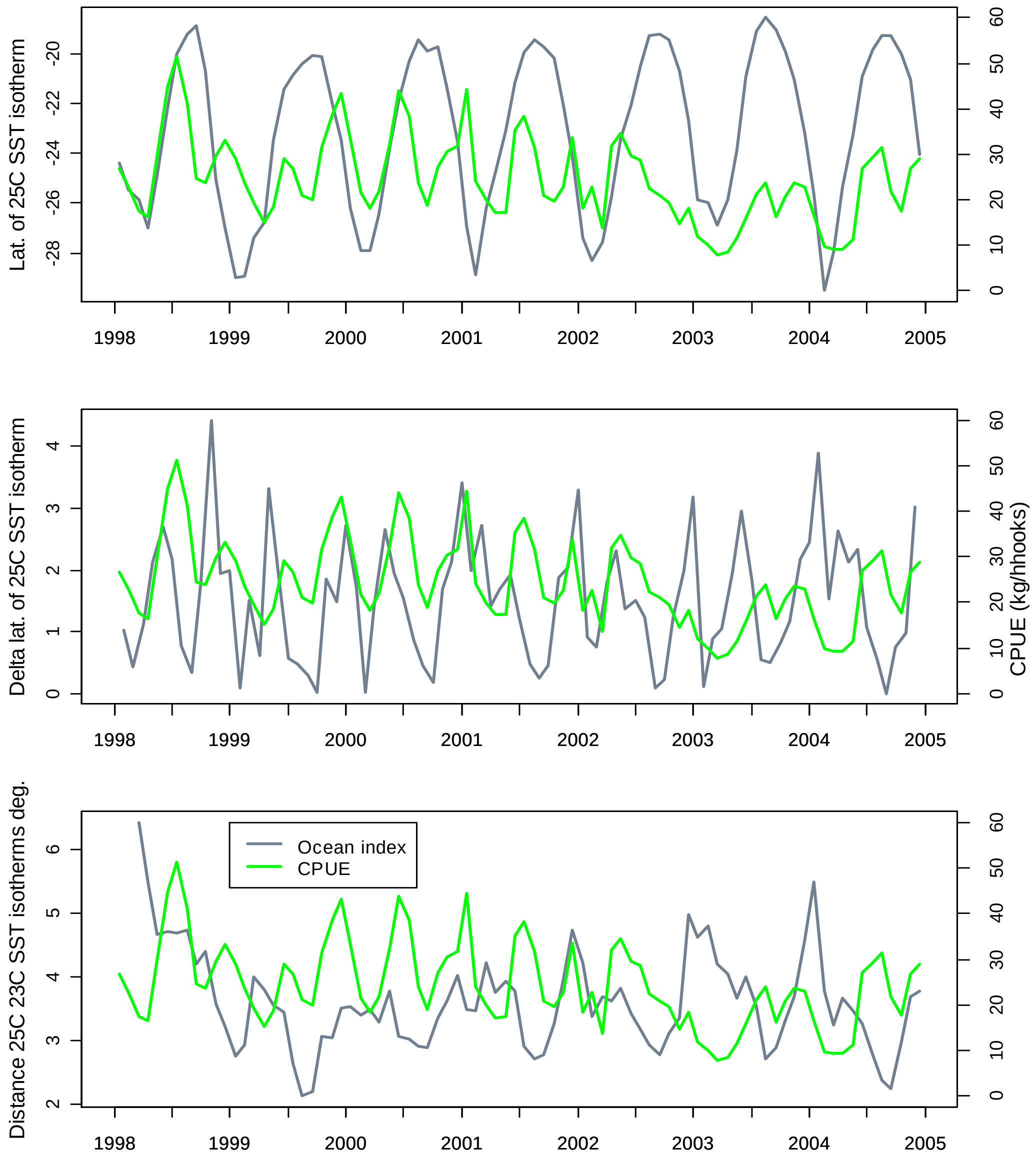

Figure 14. A comparison of monthly albacore catch rates (green) from the Fiji domestic longline fishery and three oceanographic variables (grey) derived from the area of the Fiji EEZ from 1998 to 2004. The oceanographic variables are the latitude of the 25°C sea surface temperature isotherm (top), the change (absolute) in the latitude of the 25°C sea surface temperature isotherm (middle), and the distance (in degrees of latitude) between the 23°C and 25°C sea surface temperature isotherms (bottom). A detailed description of the oceanographic variables is provided in the main text.

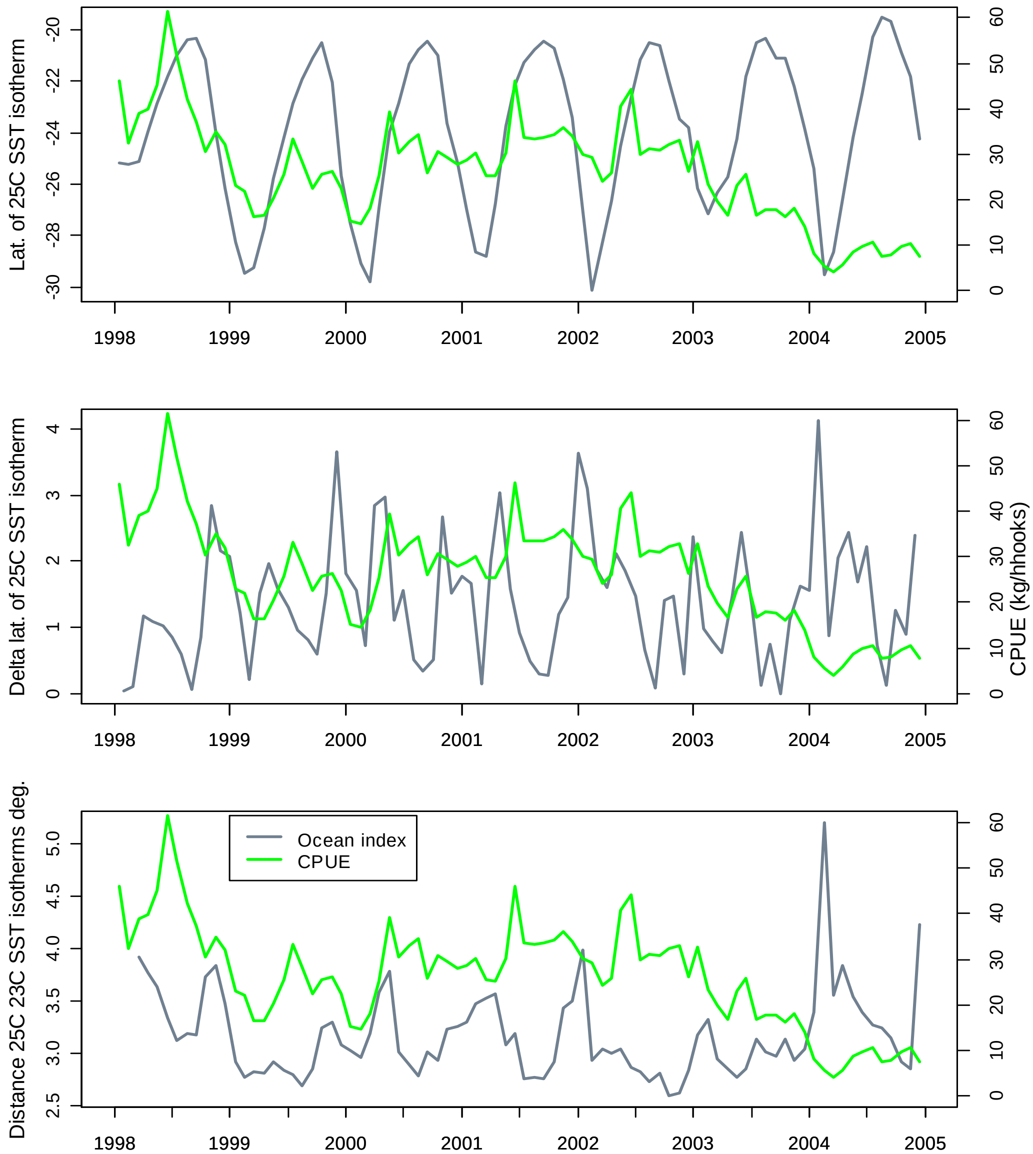

Figure 15. A comparison of monthly albacore catch rates (green) from the French Polynesia domestic longline fishery and three oceanographic variables (grey) derived from the area of the French Polynesia EEZ from 1998 to 2004. The oceanographic variables are the latitude of the 25°C sea surface temperature isotherm (top), the change (absolute) in the latitude of the 25°C sea surface temperature isotherm (middle), and the distance (in degrees of latitude) between the 23°C and 25°C sea surface temperature isotherms (bottom). A detailed description of the oceanographic variables is provided in the main text.

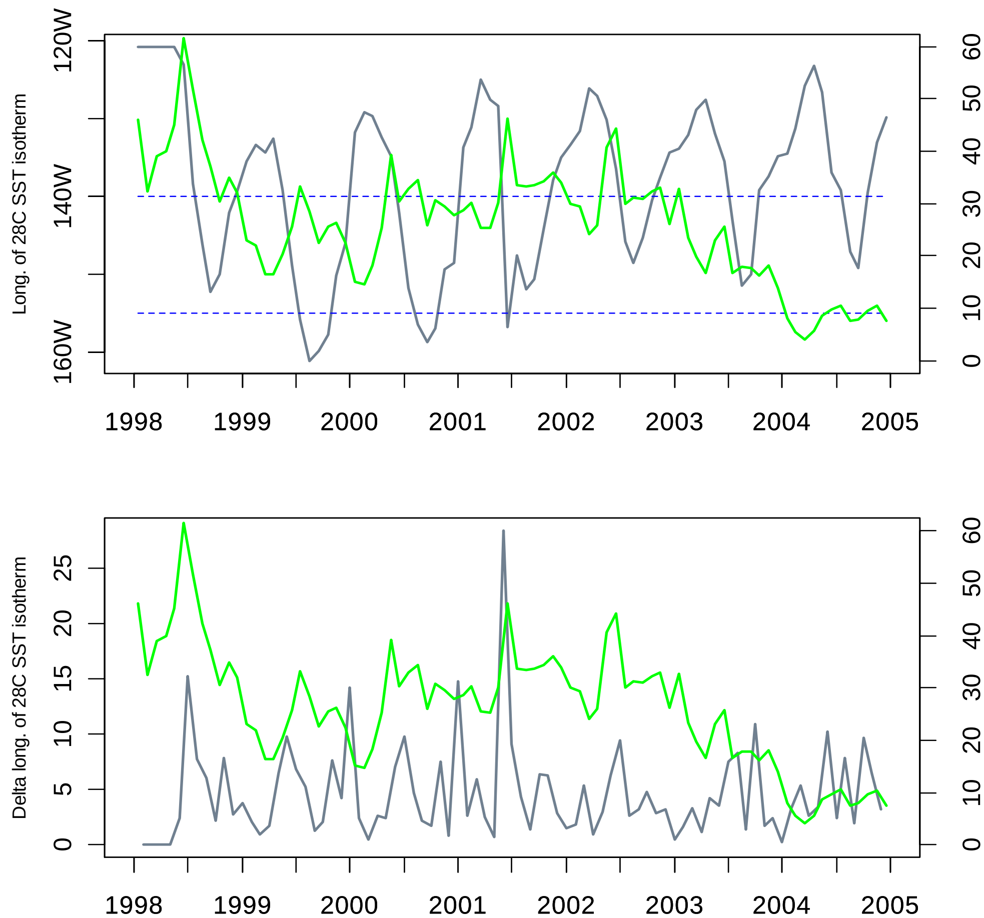

Figure 16. A comparison of monthly albacore catch rates (green) from the French Polynesia domestic longline fishery and oceanographic variables (grey) derived from the area of the French Polynesia EEZ from 1998 to 2004. The oceanographic variables are the maximum longitude of the 28°C sea surface temperature isotherm (top) and the change (absolute) in the maximum longitude of the 28°C sea surface temperature isotherm (bottom). A detailed description of the oceanographic variables is provided in the main text. The blue dashed line represents the longitudinal range of the main area of the fishery within French Polynesia.

3.5. Local depletion effects

Local depletion can be defined as the reduction in fish abundance directly attributable to the impact of fishing. The removal of fish due to fishing will result in a reduction in the density of fish in an area and a concurrent reduction in fishery catch rates.

For a migratory species such as tuna, these local depletion events may be transitory as the abundance of fish in the area is replenished by the diffusion of fish into the area from adjacent waters. Further, large-scale fishing vessels are unlikely to remain in an area of lower fish density and have the flexibility to move to other areas supporting higher catch rates. However, domestic longline fleets are more restricted in their area of operation and, consequently, localised areas may continue to attract a high level of fishing effort. Such is the case in the Fiji longline fishery where fishing effort is concentrated in the central area of the Fiji EEZ (Figure 17). Similarly, most of the fishing effort in the French Polynesia fishery is concentrated north-east of the Society Islands (Figure 17).

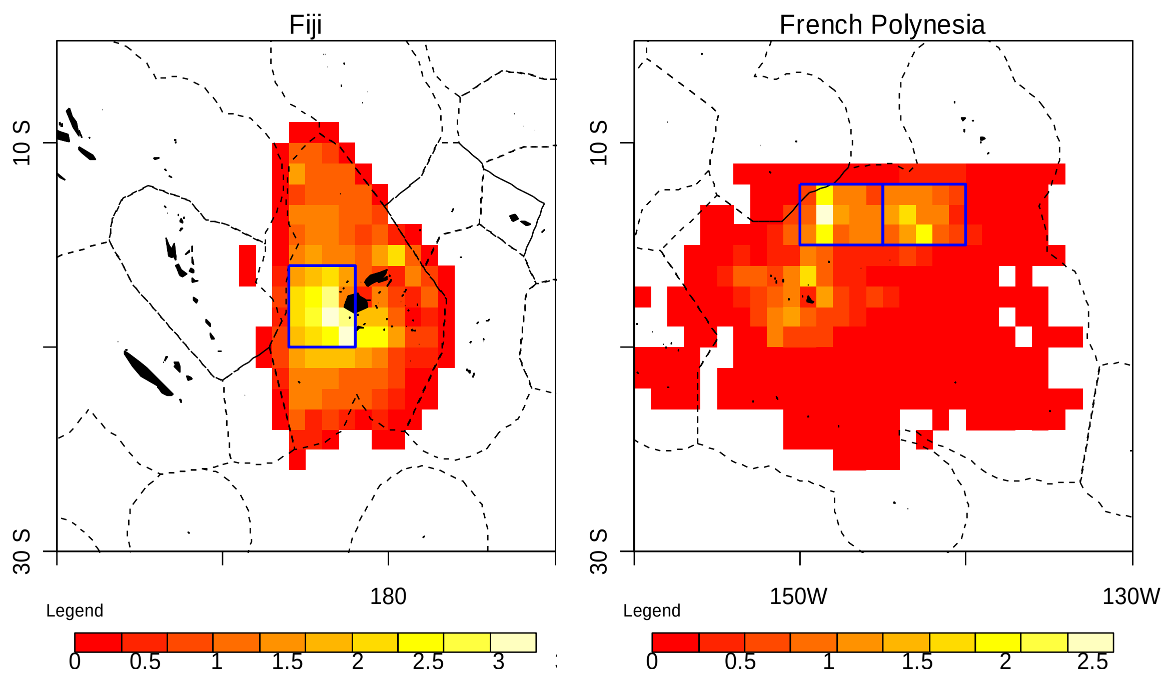

Figure 17. Spatial distribution of total longline fishing effort (millions of hooks) in the Fiji (left) and French Polynesia (right) longline fisheries from 1998 to 2004 by degree of latitude and longitude. The blue boxes define the boundaries of the areas of highest fishing effort during the period.

For these two fisheries, the sustained high level of fishing effort in these small areas may result in local scale depletion of tuna within the area, with the levels of catches from these areas exceeding the net movement of fish into the fishing areas. This effect may be particularly extreme when there is limited replenishment of fish into these areas, such as occurs during periods of adverse oceanographic conditions.

To examine this effect in more detail, trends in the longline catch rate of albacore from the three core areas identified in Figure 17 were examined. For each area, the difference in catch rates between successive 10-day periods was calculated and related to the amount of catch taken during the previous 10-day period. The presumption is that if there is a significant local depletion effect then there should be a greater decline in CPUE over the 10-day periods when cumulative catches are highest.

For each of the three areas, there is a high degree of variation between the magnitude of catch and the change in catch rate of albacore (Figure 18). This variation is likely to be strongly influenced by the underlying seasonal variation in catch rates described in previous sections of this paper. These seasonal effects will dilute the local scale impacts of fishing due to variations in the rate of exchange of albacore with adjacent waters.

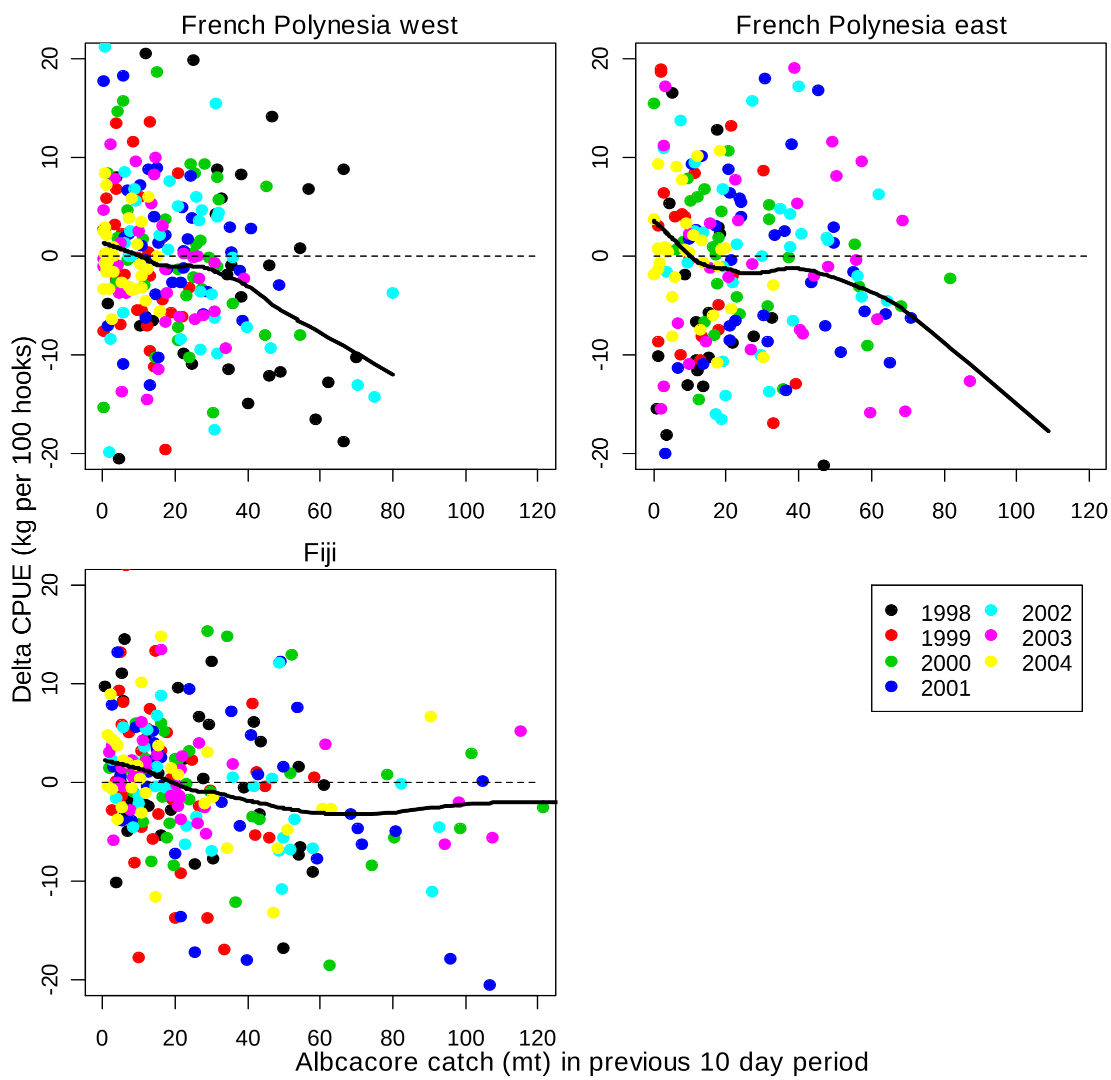

Figure 18. Changes (delta) in albacore catch rates (kg per 100 hooks) in relation to albacore catches by 10-day period for the domestic longline fleets operating in three areas of high fishing effort during 1998 to 2004. Data from each year are plotted as a separate colour. The black line represents a smoothed fit to the data points.

Nevertheless, for each of the three areas, there is also evidence that high levels of catch are resulting in local scale depletion effects, as indicated by the general decline in catch rates with increased levels of albacore catch (Figure 18). Generally, when catches are low (less than 10 mt per 10-day period) there is no decline in catch rates or catch rates may increase as catches are lower than the rate of net migration of fish into the area. At higher levels of catch, exceeding 40 mt per 10 day period, there is a significant reduction in catch rates in each of the three regions examined. This indicates that the higher levels of catch are reducing the overall abundance of albacore in the area, i.e. catches are exceeding the replenishment rate of fish in the area.

As mentioned above, this observation relates to "average" conditions and does not consider the additional effect of season and oceanographic conditions on fish density. In periods of higher abundance, the areas may sustain higher catches without unduly impacting on the subsequent catch rates. However, the converse is also valid and during periods of lower abundance, local depletion effects may be more extreme for an equivalent amount of catch taken.

A more robust statistical approach (GLM) was applied to the data from the Fiji fishery to incorporate some of the seasonality in the change in catch rates. The GLM model related the natural logarithm of albacore CPUE at time *t+1* to the natural logarithm of CPUE and catch during the previous 10-day period (*t*) and the season. Season was defined by the 37 10-day periods within the year and included in the model as a factorial variable.

The model accounted for 70% of the observed variation in CPUE in the Fiji fishery. Catch rates were predicted to increase following higher CPUE in the previous 10-day period, although this trend is mediated by the strong seasonal trend in CPUE (Figure 19). The model also indicates CPUE will decline with increased catch taken in the previous 10-day period. For example, a catch of about 75 mt in the 10-day period is predicted to reduce CPUE by approximately 20% (Figure 19). This is highly suggestive of a localised depletion effect, although the magnitude of such an effect may not be well estimated by the model. This is because the catch and CPUE in the previous 10-day period (*t)* are positively correlated and the model can explain the data by different parameterisations of these two variables.

A similar model was investigated for the French Polynesia fishery, although the fit to the data was poor (adjusted R^2 26%). The poor fit to the data is likely to be attributable to the higher variability observed in this fishery, largely driven by variation in the prevailing oceanographic conditions.

The areas examined from the two domestic fisheries are subjected to some of the highest levels of longline fishing effort in subequatorial waters of the South Pacific. Consequently, local depletion effects are likely to be greatest in these areas compared to many other EEZs in the region where the intensity of fishing effort is substantially lower. Nevertheless, a number of other domestic longline fisheries have a high concentration of fishing effort in a relatively small area, most notably within the Samoa and American Samoa EEZs and in the eastern area of the Vanuatu EEZ. A detailed analysis of fishery performance in these areas could be undertaken once a strong time-series of detailed catch and effort data is available from the respective fishery.

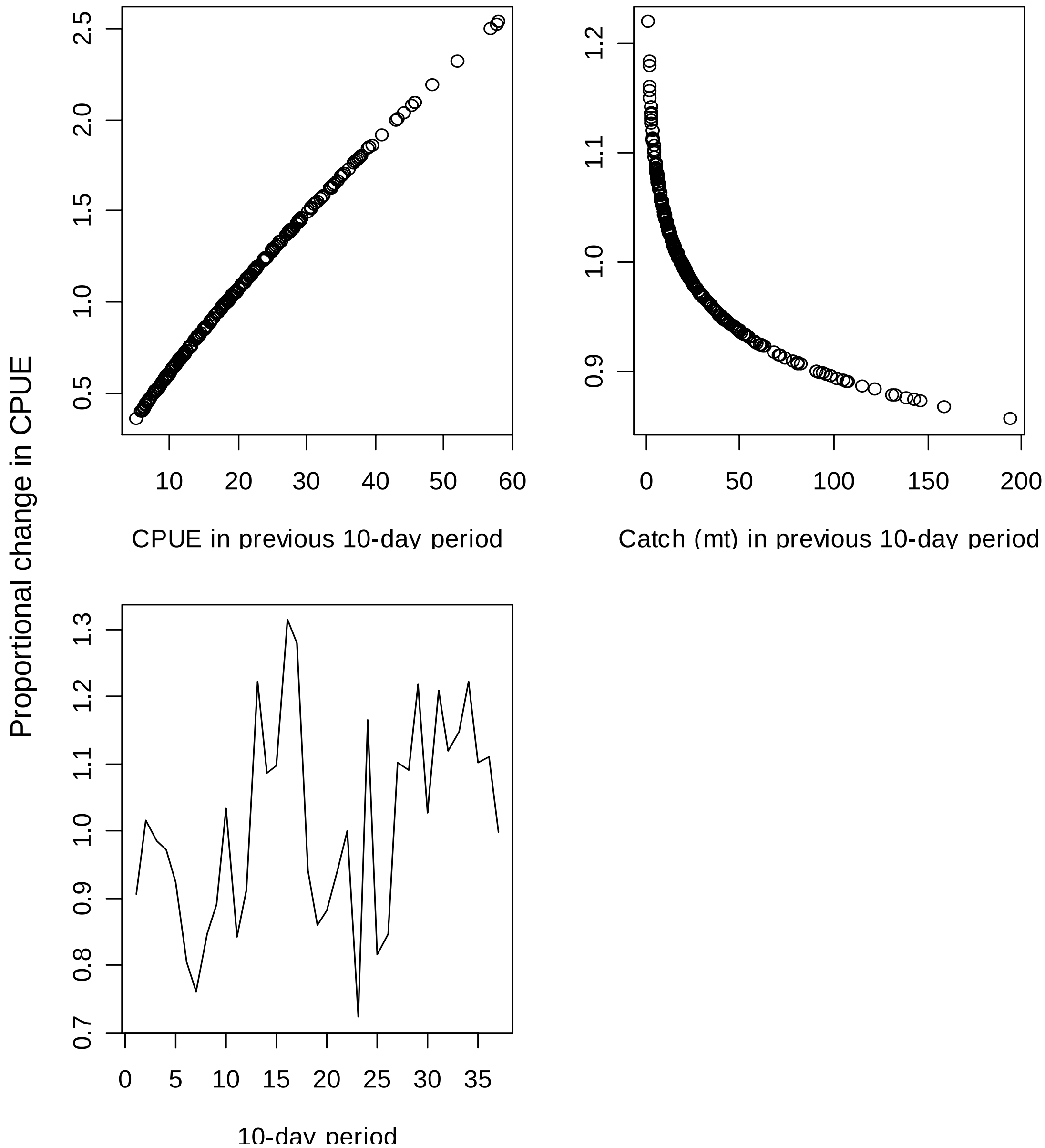

Figure 19. Predicted proportional change in albacore CPUE between successive 10-day periods for each of the three variables included in the GLM model for the Fiji longline fishery operating in the core area of the fishery from 1998 to 2004.

4. SUMMARY AND CONCLUSIONS

The purpose of this report is to assimilate the results of a number of recent studies on South Pacific albacore and highlight the key issues for PICTs to consider in the management of their domestic longline fisheries. The main conclusions of the paper are summarised as follows:

1. The current stock assessment for South Pacific albacore indicates that there are no sustainability concerns regarding the overall stock. Substantially higher yields could be taken from the stock without impacting on the biological sustainability of the stock.
2. The domestic longline fisheries of the subequatorial region of the South Pacific catch larger, older albacore. These age classes represent a relatively small proportion (about 30%) of the total adult biomass of albacore.
3. Overall, the current stock assessment indicates the level of albacore biomass available to the PICT domestic fisheries is relatively modest; i.e. of the order of 300,000 mt distributed over an ocean area of approximately 14.5 million sq km (5.5. million sq m) (10–28°S, 160°E to 140°W).
4. Recent levels of fishing effort from all fisheries combined have reduced the level of biomass available to the domestic longline fisheries by approximately 30%. At a regional level, increases in fishing effort in the PICT domestic longline fisheries will result in declines in CPUE due to a decline in exploitable biomass. For example, a doubling of domestic longline fishing through the region is predicted to result in approximately a further 25–30% decrease in longline exploitable biomass. These impacts are considerably greater than the impact of large increases in the level of fishing effort by the distant-water fleet in the south-eastern area of the fishery.
5. Catch rates in domestic longline fisheries exhibit strong seasonal trends. For the two fisheries examined, these trends appear directly related to seasonal fluctuations in the oceanographic conditions. Seasonal trends in fisheries in adjacent waters are likely to be influenced by similar variations in oceanographic conditions.
6. Inter-annual variation in albacore catch rates is also evident in a number of fisheries. The sustained period of low catch rates that commenced in late 2002 was attributed to inter-annual variation in oceanographic conditions. Different mechanisms are proposed as to how the regional change in prevailing oceanographic conditions impacted the fisheries in Fiji and French Polynesia. Similar mechanisms are likely to have affected the fisheries in adjacent PICT waters that also exhibited strong declines in catch rates during this period.
7. At a local scale, very high levels of fishing effort appear to be causing localised depletion of albacore tuna. This is principally an issue for domestic longline fleets where fishing effort is concentrated in a relatively small area, largely due to operational constraints of the domestic fishery. The scale of the local depletion effect is likely to vary seasonally and inter-annually as the rate of exchange of fish with adjacent waters varies. Indications from the Fiji longline fishery is that, on average, catch rates may be reduced by about 20% at high levels of fishing effort.

The continued development and long-term economic sustainability of the domestic longline fisheries operating in PICT EEZs are largely dependent on the maintenance of catch rates of albacore above an economic threshold. The threshold, expressed either as albacore CPUE (kg per hook) or economic return (revenue per hook), will vary between countries dependent on the operating costs of the individual fishing fleets.

The economic fragility of many of the operators in the PICT fisheries was highlighted by the impact caused by the sustained period of lower catch rates that occurred from the end of 2002.

This decline in catch rates was attributed to a change in the prevailing oceanographic conditions. While such processes are beyond the control of fisheries managers and operators, they serve to highlight that the economic performance of the fishery needs to be strong enough to sustain the fishery through periods when catch rates are lower. This may result in management measures that limit the level of total effort and/or catch to ensure higher catch rates are achieved. This may result in some loss in total yield from the fishery, at least in the short-term, but will aid the establishment of a long-term and stable domestic longline fishery. Hopefully, this approach will minimise the boom-bust cycles evidenced in the development of other domestic longline fisheries within the region.

In conclusion, the establishment of appropriate levels of target effort and/or catch for a domestic longline fishery requires a consideration of the three key elements to ensure viable catch rates of albacore are achieved by the domestic longline fleet:

1. The overall level of abundance of the proportion of the stock vulnerable to the PICT longline fisheries and the availability of albacore within the area of the specific fishery.
2. The magnitude of any negative impact on catch rates attributable to changes in oceanographic conditions, including the likely frequency and duration of such events.
3. The extent of any local scale depletion effects attributable to different levels of fishing effort in the area of the fishery.

This information can be incorporated within a simple model, with the inclusion of economic data from the fishery, to estimate levels of effort that correspond to sustainable yields from the fishery over the medium term. This simple approach could be applied to most of the PICT domestic longline fisheries once a sufficient baseline (5–10 years, depending on observed variation in CPUE) of high quality catch and effort data has been collected from the fishery.

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