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TRENDS IN SIZE COMPOSITION OF LONGLINE-CAUGHT ALBACORE IN THE SOUTH PACIFIC

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Trends in size composition of longline-caught albacore in the South Pacific.

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Executive summary

Size of albacore (nominal mean weight from logsheets and median lengths from length-frequency data supplied through observer and port sampling programmes), revealed trends in the size of albacore by domestic fleets of sub-equatorial EEZs. The impacts of domestic fisheries, changes in recruitment strength and the influence of variable oceanography are all likely to interact and influence the size of albacore captured by domestic fleets. However, trends in size data appear closely related to trends in total longline effort within individual EEZs. Not only did median size of albacore decline as many domestic fleets developed and increased in size and total effort, stabilisation or increases in median size were reported in several EEZs after reductions in domestic longline effort. In fisheries where there were increases in effort, median albacore size has continuously declined. Similar trends are also observed when the proportion of large albacore (greater than 95 cm FL and 100 cm FL) in catches are examined.

Changes in median size in relation to effort suggest that management at the scale of individual EEZs (i.e. within the scope of national fisheries management agencies) can influence the size distribution of albacore (and catch rates) captured by domestic longline fisheries in the sub-equatorial WCPO. This may be a result of local populations of large albacore having longer residency times and/or shorter movement than currently assumed. An extensive albacore tagging programme is required to provide improved estimates of movement and residency of longline-vulnerable albacore than currently exist, and such a programme is currently being planned. In addition, management at the scale of sub-regions would also be likely to influence albacore size in catches and catch rates by domestic fisheries.

Finally, the information presented in this paper highlights the importance of length-frequency data collected by observer programmes and port-sampling programmes in the WCPO. While size data are important inputs to stock assessment models, length-frequency data may also assist in the interpretation of the impacts of longline effort at the level of individual EEZs and sub-regions.

Introduction

South Pacific albacore tuna are an important component of the tuna catches in the WCP-CA (Figure 1 and Figure 2), with recent catches approaching 60,000 mt (Figure 3). Albacore are captured by longline and troll method fisheries (Figure 2 and Figure 3) with approximately 90% of recent catches attributable to longline-method fisheries.

Adult albacore are targeted by domestic longline fisheries of sub-equatorial Pacific Island Countries and Territories (PICTs) and distant water fleets (dominated by Taiwanese vessels, but also Japanese and Korean fleets) (Langley and Hampton 2005). Albacore are critical to the development and maintenance of domestic longline fisheries in sub-equatorial EEZs of the WCP-CA (Figure 4 and Figure 5).

Stock assessments for albacore tuna have been undertaken since 2001 (Hampton and Fournier 2001) using MULTIFAN-CL (Fournier et al. 1998). The most recent stock assessment for south Pacific albacore (Langley and Hampton 2005[1]) and an update (Langley and Hampton 2006[2]) concluded that the current level of fishing mortality (i.e. effort) is well below that estimated to achieve maximum sustainable yield (MSY) (i.e. $F_{current} < F_{MSY}$). Therefore the stock is not experiencing overfishing, nor is it in an overfished state (i.e. $B_{current} > B_{MSY}$ and $SB_{current} > SB_{MSY}$). Langley (2006) estimated that an increase of approximately 19 times the current level of fishing effort was required in order to achieve MSY (approximately 180,000 mt per year). The estimated MSY is significantly higher that the recent estimated longline catches of albacore from the southern WCP-CA.

Catches in domestic sub-equatorial longline fisheries typically consist of albacore older than approximately five years, a relatively small proportion of the overall stock of south-Pacific albacore (Figure 6). Thus, while overall impacts of fishing are relatively minor on the albacore stock as a whole, the impacts of fishing on the longline–vulnerable proportion of the albacore stock have reduced this component of the stock by approximately 30% (Figure 7, Langley 2006). Increasing the fishing mortality (effort) on the longline-vulnerable proportion of the stock would likely reduce albacore catch rates in sub-equatorial longline fisheries, while the stock would remain biologically healthy (i.e. $F < F_{MSY}$ and $B > B_{MSY}$).

Nonetheless, some domestic fisheries in sub-equatorial PICTs have recorded significant reductions in catch rates and catches of albacore since the early 2000s (Figure 8), with limited recovery in catch rates evident in some EEZs despite significant declines in longline effort (e.g. Tonga, French Polynesia). In addition, there are anecdotal reports from domestic fisheries of some PICTs of reductions in the size of albacore captured in sub-equatorial longline fisheries. These issues have led to the robustness of the recent albacore stock assessment being questioned by fishers in domestic fisheries of sub-equatorial EEZs, although a decline in albacore size is consistent with the stock status in the most recent assessment.

This paper will briefly review size data available for south Pacific albacore captured by longline fisheries, in order to explore recent trends in this important tuna fishery of the WCP-CA. The paper focus on size data from domestic fisheries within sub-equatorial fisheries of the WCPO and the Taiwanese distant water fleet operating in the region.

Data sources

Two main types of data were examined: operational-level logsheet data supplied to SPC, and size data suppled from regional observer and port sampling programmes. Logsheet data reports a range of operational variables for each longline set (e.g. set position information, time, number of hooks) and the catch of albacore (and other species) in both numbers and kilograms. From logsheet data, a range of variables describing catches and catch rates can be calculated (e.g. nominal catch rate (kg and numbers) per hundred hooks, the mean weight of retained albacore per set).

Observers and port samplers report the size of individual fish captured within each observed longline set or trip. However, there are significantly less observer and port sampling data

[1] For the 2005 assessment, the ‘current’ level for the estimation of MSY based reference points were estimates of fishing mortality and biomass data for the period 2000–2002 (Langley and Hampton 2005).

[2] For the 2006 update, the ‘current’ level for the estimation of MSY based reference points were estimates of fishing mortality and biomass data for the period 2002–2004 (Langley and Hampton 2006), although the model included some fishery data from 2005.

available compared to logsheet data. In addition, most observer and port sampling data are only available since the early 1990s.

Albacore size data from logsheets the length-frequency database (i.e. observer and port sampling data) were examined for the model region for the south Pacific albacore. Data were examined within each of the four sub-regions of the 2005 assessment (Figure 2), and also at the level of individual EEZs and main flags where possible. The amount of data available varied among EEZs, flags and model sub-regions, with limited or no data available for some flags (e.g. no observer data for Taiwanese longline fleet in the south Pacific Ocean).

From logsheet data, mean nominal size of albacore per set (i.e. total kilograms/total number) was calculated and temporal trends examined. Temporal trends in median albacore size from the length-frequency database were also examined and compared among flags and EEZs within each sub-region of the model. Data were examined on monthly and/or quarterly scales. Limited operational-level logsheet data exist for Japanese and Korean longline vessels operating in the southern Pacific Ocean and the limited size data for these fleets were not included in this paper.

Results

Logsheet data

i. Regional catch rates

Relatively high catch rates (kg.hhooks^{-1}) were reported over extensive areas of sub-regions 1 and 2 in the second and third quarters during the period 1978–2003(Figure 9 and Figure 10). The exception was a large area of sub-region 2 encompassing large areas of the French Polynesia and Cook Islands EEZs. Areas of relatively high catch rates were reported immediately to the east of the French Polynesia EEZ and immediately south of sub-equatorial EEZs. Catch rates were also high in sub-region 4 in the second and third quarters. Low catch rates were reported between the equator and 10°S in the first and last quarters of the year. In sub-region 3, the highest catch rates of albacore are reported during quarter 2, although catch rates are generally lower than those from sub-regions 1 and 2. However, a proportion of vessels operating south of 38ºS within sub-region 3 are likely to be targeting southern bluefin tuna and not albacore. Similar patterns were observed since 2003 (Figure 10), although there was a smaller spatial extent of relatively high catch rates in areas of the model north of 30°S, especially in sub-region 2 in the second and third quarters.

Broadly similar patterns are observed when catch rates are expressed as number of albacore per hundred hooks (Figure 11, Figure 12). The higher catch rates observed in southern sub-regions are due to smaller (and younger) fish in these sub-regions, relative to the larger (and older) fish in more northern regions, a result of the ontogenetic shift in distribution of albacore throughout their life-cycle.

ii. Domestic CPUEs

Domestic longline fleets have developed in many sub-equatorial PICTs since the early 1990s (Figure 4 and Figure 5), with most of these fleets targeting albacore (Williams and Reid 2006). Much of the development occurred during the late 1990s and high catch rates (kg.hhooks^{-1}) were initially reported by domestic fleets in many sub-equatorial EEZs (Figure 8). However, catch rates subsequently declined from during 2002/3. This is most clearly observed in sub-regions 1 and 2 (Figure 8).

Similar trends and levels of catch rates have been reported from all EEZs in sub-region 1 of the albacore model since 2003, with somewhat higher catch rates reported by the longline fleet in the New Caledonia EEZ. Lower catch rates are observed for the longline fleet operating in the northern areas of the Australian EEZ (north of 30ºS). However, catch rates in this part of the Australian EEZ have increased since 2003 as some vessels in this fleet have commenced targeting albacore in this sub-region. Catch rates by the Taiwanese fleet have also followed a similar trend to most other fleets in sub-region 1 since the mid 1990s, with a decline in catch rates in recent periods.

Catch rates in many EEZs in sub-region 1 increased after 2003 or 2004 (Figure 8), with subsequent catch rates of 20–40 kg.hhooks^{-1} reported from most areas. In sub-region 2, catch rates also increased after 2003 to between 20–40 kg.hhooks^{-1} for longline fisheries within American Samoa, Samoa and the Cooks Islands-North. However, albacore catch rates from French Polynesia and Tonga EEZs and the Cook Islands-South, while improving, have remained below 20 kg.hhooks^{-1} since 2003. Taiwanese catch rates have followed a similar trend to the catch rates of the EEZs of French Polynesia, Tonga and the Cook Islands-South.

Catch rates (kg.hhooks^{-1}) in sub-region 3 have been much lower than those in sub-regions 1 and 2 due to the smaller size of albacore in this region (Figure 8). Catch rates by the longline fleet operating in the New Zealand EEZ have fluctuated at 10–20 kg.hhooks^{-1} since 2000, lower than the catch rates reported during the mid to late 1990s. Catch rates by the longline fleet in the Australian EEZ within sub-region 3 have been relatively stable throughout the time period. Few data were available from the New Zealand EEZ in sub-region 4 of the albacore model but displayed an increase in CPUE since the mid 1990s. The Taiwanese fleet in this sub-region has shown similar fluctuations and magnitudes of catch rates to those of the New Zealand fleet.

The Taiwanese distant water fleet targeting albacore operates in all four sub-regions of the albacore model. Nominal catch rates (both in kg and numbers.hhooks^{-1}) by this fleet followed broadly similar patterns to other fleets within each sub-region. Catch rates of albacore by the Taiwanese fleet in sub-region 1 declined slightly in the early 2000s as a proportion of the fleet switched to targeting bigeye tuna, before albacore catch rates increased 2003 (Figure 13). In sub-region 2, catch rates by the Taiwanese fleet declined rapidly until 2003, and have increased only since 2005. Limited data were available for the Taiwanese fleet operating in sub-region 3 of the model. In sub-region 4, catch rates fluctuated between 1998 and 2003, before stabilising.

iii. Size data

Nominal mean weights of albacore captured by longline fleets in sub-region 1 have ranged between 14 kg and 18 kg since 1998, with the exception of smaller fish captured by the Australian fleet (Figure 14). Trends in nominal weights for the fleets of Fiji, Papua New Guinea (PNG) and Vanuatu have displayed a slight but steady decline in mean nominal size since 2002. Heavier albacore have been generally reported by the domestic fleet of New Caledonia than by other fleets in sub-region 1 in recent years, although there has been a decline in mean size from the New Caledonia EEZ since 2005. The longline fleet operating in the Australian EEZ within sub-region 1 of the model displayed much lower mean weights than other fleets between 1998 and late 2004, after which mean weights increased rapidly to be similar to the mean weights reported by other fleets in the sub-region since the 1990s, a result of the recent switch to targeting albacore by components of this fleet. With the exception of the Australian fleet, the mean weights of albacore captured by the Taiwanese fleet operating in sub-region 1 since 1990 were slightly lower than those of the domestic fleets in the sub-region. The mean sizes of albacore reported by all fleets in this sub-region have converged since 2005, with slightly large albacore captured by the New Caledonia fleet.

The mean nominal sizes of albacore estimated from logsheet data from most longline fisheries in sub-region 2 have displayed similar trends (Figure 14). The average weight of albacore from sub-region 2 for most fleets has varied between 15 kg and 20 kg, slightly larger than the average weights from sub-region 1. There has also been a slow but steady decline in mean nominal weight in all fisheries from the early 2000s. The mean weights estimated from logsheet data for the Taiwanese fleet in sub-region 2 are similar to the mean weights for most other EEZs in the sub-region. The exception is the trend in mean weights estimated from logsheet from the domestic fleet of French Polynesia and the fleet of Cook Islands-South. The mean weights from these two fleets have been relatively stable and 2–4 kg higher than mean weights estimated from logsheet of other domestic fleets late in the time-series

The nominal mean weights of albacore estimated from logsheet of fleets operating in sub-region 3 have been much smaller than the average weights from sub-regions 1 and 2, fluctuating around 8 kg to 12 kg for most of the series (Figure 14). This is a result of the spatial distribution of albacore by size, where smaller (and younger) fish are located in the southern areas of the model region. The longline fishery in the Australian EEZ recorded slightly larger sized fish (~ 10 kg) than the domestic New Zealand fleet until 2003, after which the size of albacore captured in both EEZs converged. The Taiwanese fleet operating in sub-region 3 captured slightly larger albacore than either domestic fleet between 2001 and 2005 before sizes converged for all three fleets.

Data for the Taiwanese fleet in available from sub-region 4 recorded albacore of a similar size to those reported in sub-region 3 (~11 kg) until 2001 (Figure 14). Subsequently, the nominal average size of albacore captured by this fleet has increased to approximately 13–14 kg, approaching the nominal mean weights of albacore captured by fleets in sub-region 1. This may be due to the more northerly operation of this fleet within the sub-region, to areas where older and larger albacore are more available. Limited data from the New Zealand longline fleet in sub-region 4 displayed a similar nominal mean albacore size to the Taiwanese fleet for most of the 1990s, after which the nominal mean size displayed a decline. This may be a result of this fleet targeting other species (e.g. swordfish) and operating in more southerly and western areas of the sub-region compared to the Taiwanese fleet.

Observer data and port sampling data for longline fisheries

The albacore length-frequency data base has length records collected by observers for more than 600,000 individual albacore from the assessment region. The size-frequency distributions of albacore captured by longline fisheries from within the four sub-regions have displayed remarkable consistency within each sub-region among years (Figure 15).

Larger fish are recorded in sub-regions 1 and 2 in most years (Figure 15). A strong mode between 90 cm and 100 cm FL is observed in these two sub-regions for most years since 1993, corresponding to ages of 5–7 years or greater (Figure 16). Relatively few albacore smaller than 80 cm FL or larger than 100 cm FL have been reported from these sub-regions in since 1993. However, modes at small sizes are observed in the length data for sub-region 1 in some years (e.g. 1995, 2003).

In contrast, a strong mode is observed between 70 cm and 80 cm FL in sub-region 3 in most years, with evidence of modal progression among years (e.g. 1995–2000, 2003–2006, Figure 15). The size data from sub-region 4 show a range of small or large modes among years, although the data are limited compared to the other regions, as effort in this sub-region is dominated by the distant water fleet of Taiwan and lacks port facilities, limiting observer and port sampling activities.

The trend in quarterly median size of albacore from sub-region 1 has fluctuated at approximately 95 cm FL throughout the time series (Figure 17) with larger fish recorded during the second quarter of each year. This peak may represent larger fish moving northward through the sub-region and the main fishing areas during the second quarter of each year, likely as water temperatures decrease during the austral autumn (Langley 2006). Smaller median sizes were most often recorded during the middle of each year before sizes increased in the third quarter, as large fish move southwards again. However the seasonal peaks in median size have reduced in recent years, while the median size has tended to increase.

A slight decrease in the long-term median size of albacore was observed from sub-region 2 since 2000, although the reduction in median size was only 2–3 cm FL (Figure 17). A seasonal pattern of larger median sizes were reported in the first quarter of most years, with smaller median sizes reported during the third and fourth quarters. Again this is likely in response to movement patterns, although the peaks in modal size differ in timing from those in sub-region 1.

Much more variability in quarterly regional sizes were observed in sub-regions 3 and 4 (Figure 17), due to a combination of smaller sample sizes and the wider range of fish sizes in these sub-regions (Figure 15). Larger median sizes were generally reported in the first and last quarters of each years from sub-region 3, likely a response of larger fish moving south from sub-region 1 (and 2) as water temperatures increase. In addition, the long-term quarterly trend in median size increased between 1993 and 2000, and declined between 2000 and 2006. The median size of fish at the start (1993) and end (2006) of the time series are similar.

The relatively small amount of length data available from sub-region 4 has shown some major changes through time (Figure 17), likely driven by the relatively small sample sizes. The long-term trend in median size has included a range of approximately 5 cm FL and has increased in recent years. The median size is generally smaller than those from sub-regions 1 and 2, but larger than the median size of albacore from sub-region 3.

The median fork length of albacore captured by all flags in sub-region 1 (Figure 18) have remained between 90 cm and 100 cm FL. Taiwanese and Vanuatu flags have reported smaller fish relative to other flags in the sub-region, potentially due to the wider range of operations by these two fleets. Median size of albacore from the other fleets have followed a similar trend, with increasing albacore size reported during the late 1990s, and declines in median size from 2001 onwards. The Australian fleet has reported a fluctuating median size of albacore from sub-region 1, which likely reflects changes in targeting towards albacore by some vessels within this fleet in recent times. Overall, the median size range of albacore from all flags in sub-region 1 has not exceeded 7 cm since 1993, with the sizes of albacore from all fleets converging in recent years. However, the New Caledonia fleet has maintained consistently larger fish than other fleets in the sub-region since 2002.

For all flags, the median size range varied by less than 5 cm in sub-region 2 between 1993 and 2001 (Figure 18), with the median size being relatively stable between 94 cm and 97 cm FL. However, many flags reported a reduction in median size from the 2000–2002, with most fleets reporting median sizes of approximately 92 cm FL in 2005 and 2006. Of interest is that the decline in fish size was recorded first by the Taiwanese fleet (late 1990s), which tends to operate in more southern and eastern areas of sub-region 2 than other fleets.

As with the logsheet data, the fleet of French Polynesia has reported albacore of a consistently larger median size than other fleets in sub-region 2 for most of the time series (since 1993) (Figure 18), despite major changes in catch rates (Figure 13). While the median size has declined slightly since 2002, fish captured from French Polynesia remain approximately 5 cm FL larger than fish captured by other fleets in the region. The exceptions are the fleet of Tonga, which has reported an increasing median size since 2003, and the Cook Islands-South, which has reported the largest median sizes of albacore from this sub-region. These three fleets have also reported relatively low catch rates since 2003 (Figure 8).

Less data were available for fleets operating in sub-regions 3 and 4 and trends (Figure 18). Median sizes of albacore from the three fleets in sub-region 3 have been smaller than median sizes of fish from sub-regions 1 and 2. Size data for the fleets of Australia and New Zealand displayed a declining trend in median size from 2001 onwards, with both fleets reporting fish with a median size of less than 80 cm FL late in the time series. In contrast, the Taiwanese fleet has reported a trend of increasing median since 2001.
The Taiwanese fleet in sub-region 4 has reported albacore of a similar size to those captured in sub-region 1, but slightly smaller than those in sub-region 2 (Figure 18). A declining trend in median length of albacore is observed since the mid 1990s for albacore from this sub-region, although the decline has been less than 4 cm FL since 1994. Limited data were available for the New Zealand fleet in sub-region 4 but revealed smaller fish than captured by the Taiwanese fleet in sub-region 4.

Similar trends are observed for albacore captured from sub-regions 1 and 2 when length-frequency data were examined by EEZ (Figure 19). In sub-region 1 the median size of albacore from the New Caledonia EEZ have been consistently larger than from other EEZs since the late 1998s. In contrast, the median size of albacore from Vanuatu has steadily declined since 2000 when size data became available. Median albacore size from the PNG EEZ has also declined rapidly, reducing by approximately 5 cm FL since 2000. Median size data from the Fiji EEZ was higher in the mid 1990s before declining, although the median size of albacore from this EEZ has stabilised since 2003. The median size of albacore from the Solomon Islands EEZ has also been stable at approximately 92 cm FL since 1997.

Median size data for the Australian EEZ in sub-region 1 shows two distinct phases. The median size of albacore was stable between 1993 and 1998, likely due to the main distant water fleet operating in the northern EEZ (Japan) targeting other species of tuna (bigeye). Since 1997/8, only Australian vessels have operated in the EEZ, a proportion of which are targeting albacore; the median size of albacore increased since 1997 and has followed a similar trend to other EEZs in sub-region 1.

The median size of albacore from the EEZ of French Polynesia have generally been larger than those from other EEZs in this sub-region, with the exception of the median size of albacore from the Tonga EEZ since 2004 and the Cook Islands-South (Figure 19). However, the median size of albacore from the French Polynesia EEZ has declined slightly since 2005. The median sizes of albacore from Samoa and Cooks Islands-North have declined by approximately 4 cm FL since the early 2000s. The median size of albacore from Samoa, the Cook Islands-North and American Samoa EEZs are the smallest for this sub-region.

The median sizes of albacore from the EEZs of Australian and New Zealand within sub-region 3 have shown downward trends late in the time series (Figure 19). Since 1993, there has been a reduction in median size from approximately 85 cm FL to less than 80 cm FL. Data from the New Zealand EEZ in sub-region 4 show a decline in median size from the late 1990s before an increase since 2001.

Trends in median albacore size from the length-frequency database are broadly similar within each region whether examining size data by flag (Figure 18) or EEZ (Figure 19) as most domestic fleets mainly operate within their EEZ. The major discrepancies were with the New Zealand fleet (Figure 14 and Figure 19) and are likely due to a combinations of changes in targeting, vessels operating in high seas areas outside the New Zealand EEZ and the introduction of a quota management system.

The proportion of large albacore (greater than 95 cm FL or 100 cm FL) in catches were examined at the level of each sub-region (Figure 20). The proportions of albacore greater than 95 cm FL has been stable since 2001, with a slight decline in the proportion of albacore greater than 100 cm FL. The proportion of albacore greater than 95 cm FL in longline catches has steadily declined in sub-region 2 since 2002 (Figure 20), while the proportion of albacore greater than 100 cm FL has remained stable at approximately 0.20. The proportion of large albacore has been stable at very low levels in sub-region 3, a result of the this region being dominated by small, juvenile fish. The proportion of large albacore in catches from sub-region 4 has increased rapidly since 2002, although data are limited.

Large differences in the proportion of large albacore in catches are observed among EEZs within sub-regions (Figure 21 and Figure 22). The proportion of albacore greater than 95 cm FL increased in the mid 1990s in the EEZs of Fiji and New Caledonia, likely a result of improved targeting of albacore. This is supported by the increase in the proportion of albacore greater than 95 cm FL in the late 1990s within the Australian EEZ in sub-region 1, as this fleet commenced exploiting albacore within the EEZ. In contrast, strong declines in the proportion of albacore greater than 95 cm FL are observed in the EEZs of Papua New Guinea, and Fiji late in the time series. A mild decline in the proportion of albacore greater than 95 cm FL is observed in the New Caledonia EEZ since 2003. Similar trends are observed for the proportion of albacore larger than 100 cm FL in sub-region 1 (Figure 22).

An increase in the proportion of albacore greater than 95 cm in catches by most fleets in sub-region 2 is observed at the start of most data series, after which the proportion reduces (Figure 21). The exception is the increasing proportion of albacore greater than 95 cm FL in the Tonga EEZ. In general, there appears to be larger fish in the south-western EEZs of sub-region 2 (i.e. Tonga, Cook Islands-South and French Polynesia), as highlighted by the proportion of fish greater than 100 cm FL in catches from these EEZs (Figure 22).

As expected from the distribution of albacore by size and age, the proportion of fish greater than 95 cm FL has been relatively low for sub-regions 3 and 4 of the assessment model (Figure 21 and Figure 22).

The Taiwanese fleet operating in the model region has shown trends in the proportion of large albacore in catches similar to those shown by most fleets within each sub-region (Figure 23). The Taiwanese fleet in sub-region 1 recorded reductions in the proportion of large albacore since 2002. A decline in the proportion of albacore greater than 95 cm FL has been recorded by the Taiwanese fleet in sub-region 2. The Taiwanese fleet in sub-regions 3 and 4 have shown increases in the proportion of large fish in catches since about 2002, although data are limited.

Discussion

The median size of longline-caught albacore reported by most fleets and most EEZs has declined since the late 1990s in sub-equatorial sub-regions (sub-regions 1 and 2) of the albacore assessment model. These declines in size are observed in nominal mean weights derived from logsheet data. However, nominal mean weights represent the average weight of retained albacore within each set as recorded on logsheets and may suffer from inaccuracies due to the difficulties of estimating weight data at sea.

In comparison, length-frequency data collected by observers are more precise as lengths of individual fish are measured. From length-frequency data, trends are generally similar if data are examined by fleet (flag) or EEZ, as most vessels of each flag operate almost exclusively within their home EEZs. The exceptions are the fleets of Fiji, Vanuatu and Taiwan which operate over much greater spatial areas. In addition, trends varied for the New Zealand data if examined by fleet or EEZ, likely due to changes in targeting (e.g. a shift towards swordfish), the potential for sectors of this fleet to operate in areas of high seas (i.e. outside the New Zealand EEZ) and the introduction of quota management system. Nonetheless, trends in median size data vary among fleets and EEZs within each model sub-region.

There are several possible processes that may account for the variations in size trends.

Fishing effects

The effects of fishing may account for the trends observed within each EEZ of the sub-equatorial regions. Albacore captured by longline fisheries in sub-regions 1 and 2 are relatively old (at least 5 years with a mode at approximately 8-9 years of age). Given the natural mortality rate (M=0.343, Langley and Hampton 2005) and the rapid increases in fishing mortality rate of the longline-vulnerable proportion of the stock since in the 1990s (Figure 7), it is likely that fishing has reduced the proportion of older fish contributing to recent catches in these two sub-regions.

This is supported when the proportion of large fish (greater than 95 cm FL and 100 cm FL) are examined for each sub-region (Figure 20) and for individual fisheries within each of sub-regions 1 and 2 (Figure 23, Figure 21, Figure 22). For example, there have been steady declines in the proportion of albacore greater than 95 cm FL in sub-regions 1 and 2 (Figure 20, Figure 21) since late 2001. Similar declines were also observed in the proportion of albacore greater than 95 cm FL and 100 cm FL estimated for the Taiwanese longline fleet (Figure 23), with the decline occurring earlier in sub-region 2 (2000) than in sub-region 1 (2002).

The proportion of large albacore in the catches by EEZ in sub-regions 1 and 2 have also tended to decline, although there are differences in the timing and magnitude (Figure 21 and Figure 22). As domestic fleets developed, CPUEs were initially relatively high (Figure 8), declining as each fishery developed further. This pattern is likely due to each domestic fleet initially fishing on lightly exploited local populations of albacore, containing relatively large proportions of older fish. As these older fish were removed, catch rates reduced and stabilised as catches were supported by slightly smaller, but more abundant albacore. The differences in timing of the periods of high and low catch rates, and the declines in catch rates, median size and proportion of large albacore in catches are likely due to the differences in timing of development of individual fleets, with the largest and fastest declines in median albacore size and proportion of large albacore reported in catches in fisheries that expanded relatively rapidly (increased effort fastest).

Overall, increasing longline effort (millions of hooks) appears correlated with reductions in the median size of albacore and the proportion of large albacore in catches within EEZs of sub-region 1 (Figure 24). All EEZs examined within this sub-region have shown a negative correlation between changes in effort and changes in median size and proportion of large fish. This suggests that increasing effort within an EEZ reduces the abundance of larger albacore.

For example, in Vanuatu between 1997 and 2005, effort increased from 6.7 million to more than 25 million hooks per year, with albacore catches increasing from 2,800 mt to 6,800 mt over the same period (Table 1). During this period, the proportion of albacore greater than 95 cm FL in catches reduced from approximately 0.6 in 2000 to 0.4 in late 2005 (Figure 21). The proportion of fish greater than 100 cm FL in the Vanuatu EEZ declined from 0.3 to 0.1 over a similar period, with the median size declining from approximately 96 cm FL to 92 cm FL. Thus the Vanuatu fishery is being supported by smaller and younger fish.

The domestic fishery in the PNG EEZ also displayed a rapid decline in median size (Figure 9) and the proportion of large fish in recent catches (Figure 21). Components of this fishery have recently (early 2000s) switched to targeting albacore in the southern areas of the EEZ, as highlighted by the rapid increases in catch rates (Figure 8). The relatively rapid rate of decline in the proportion of large fish in the catches by the PNG longline fleet (Figure 21) are likely due to the expected low relative abundance of albacore in this northern EEZ. This is similar to the Australian fleet operating in the Australian EEZ in sub-region 1, a proportion of which have recently switched to targeting albacore, resulting in a decline in median size (Figure 19) and a reduction in the proportion of large fish in catches (Figure 21 and Figure 22).

In contrast, the median size of albacore from the New Caledonia EEZ (bordering the western side of the Vanuatu EEZ) has been higher than the median sizes of other EEZs in the region since at least 2001. The domestic fishery has expanded in the New Caledonia EEZ since the mid to late 1990s, although to a lesser extent than many other domestic fleets. For example, recent levels of effort in the New Caledonia EEZ have only recently exceeded 6 million hooks per year, with annual albacore catches only recently exceeding 1,500 mt. The decline in proportion of albacore greater than 95 cm FL in the New Caledonia EEZ has also been relatively modest, with the proportion declining from approximately 0.6 to 0.55 between 2002 and 2006 (Figure 21), a much higher proportion than reported by other domestic fleets in this sub-region.

In sub-region 2, only the EEZs American Samoa and the Cook Islands-North show negative correlations between changes in levels of effort and median albacore size or the proportion of large albacore in catches (Figure 25), similar to those described for sub-region 1 (Figure 24) and expected if local fishing is impacting on the size of albacore. However, other EEZs in this sub-region (Tonga, Samoa, Cook Islands-South and French Polynesia) show positive correlations. These positive correlations are in EEZs where there have only ever been relatively low levels of total effort (Cook Islands-South) and/or where there have been major declines in longline effort late in the time series (Tonga, Samoa and French Polynesia). With declines in effort, levels of fishing mortality within each EEZ are expected to be reduced, increasing the likelihood of albacore within local populations growing through to larger sizes, increasing the median size and proportion of large albacore in catches over time. In addition, at least some sectors of the fleets of Tonga, Cook Islands-South and French Polynesia have shifted targeting from albacore to other species (mainly swordfish or yellowfin), at least during some periods of recent years. With changes in targeting, changes in selectivity of gears and therefore the size distribution of longline-captured albacore are also likely, reducing any correlations between effort and albacore size. Analysis of effort and size data on finer temporal scales is required to further assess correlations between changes in effort and changes in albacore size within an EEZ, allowing the influence of season and potential fishing impacts to be assessed.

The effect of the development and level of fishing effort on the size of albacore in catches is further supported by trends in fishery development and fish size displayed in the EEZs of Fiji and Tonga. The longline fleet operating in the Fiji of EEZ expanded in the mid to late 1990s with effort and catches peaking in 2002 and 2003 (Table 1). However, management changes reduced the levels of effort (reduced the number of vessels) and albacore catches in subsequent years. In response to changes in effort, the median size of albacore and the proportion of large fish from the Fiji EEZ declined until 2003, after which the median size stabilised (Figure 19) and the proportion of albacore greater than 100 cm FL increased (Figure 22). In the Tonga EEZ, the domestic fishery expanded rapidly during the late 1990s before declining since 2003 (Table 1). This resulted in increases in median albacore size (Figure 18, Figure 19) and the proportion of large albacore (Figure 21, Figure 22) in catches since 2003/04. These effects are more obvious when annualised data are examined (Appendix 1).

The effects of domestic fishery development in the sub-equatorial WCPO appear to include initially high CPUEs and subsequent reductions, reductions in median size and reductions in the abundance of larger fish in catches. These fishing effects are expected, as naturally rarer, larger (older) fish are removed with increasing levels of fishing (mortality), resulting in a reduced proportion of fish attaining larger sizes (older age classes). Changes in targeting of albacore by domestic fleets, including improvements in targeting, may also occur during the development of domestic fisheries. This may also influence the size of fish in catches as a result of change in selectivity of albacore by age-class.

Recruitment effects

Changes in recruitment strength can also influence the size (and catch rates) of fish in catches. For example, relatively strong recruitment can increase the proportion of fish in younger age classes (smaller fish), reducing the median size (and weight) of fish in future longline catches.

The most recent stock assessment for albacore (Langley and Hampton 2005) estimated long-term variability in albacore recruitment in the South Pacific Ocean (Figure 26). Recruitment has been estimated to have been relatively low in the 1960s, relatively high during the late 1980s and early 1990s before declining to lower levels in more recent times, similar to levels estimated in the late 1960s. However, a high degree of inter-annual recruitment variability is also estimated. In addition, the confidence limits on the annual estimates of recruitment are relatively wide.

There appears to be little correlation between the annual median size of fish in sub-regions 1 and 2 and the estimated recruitment (Figure 27, Figure 28). This may be expected as the sizes of older age classes merge, potentially blurring the relationship between recruitment and changes in size of older and larger albacore. However, a small increase in median size in these two sub-regions was observed approximately eight years after the peak estimated recruitment in the model. This is a similar lag period identified by Lu et al. (2003) between spawning and recruitment of albacore to longline fisheries of the southern Pacific Ocean, operating between 10–30°S. If related, the results suggest that the influence of recruitment on median size is relatively small in sub-regions 1 and 2. This may be related to the natural mortality of albacore (M~0.343, Langley and Hampton 2005), resulting in very few fish reaching the larger sizes, reducing the effects of very high recruitment. Coupled with the recent increases in fishing mortality of the longline-vulnerable proportion of albacore in sub-equatorial sub-regions (approaching 30%, Langley and Hampton 2005), the influence of strong recruitment on albacore size may be mitigated in sub-equatorial longline fisheries.

However, the proportion of large fish in the albacore catches by the Taiwanese fleet in sub-regions 3 and 4 have increased late in the time series (Figure 23), similar to a finding by Langley and Hampton (2005). This is consistent with the effects of reduced recruitment (i.e. increasing proportions of larger fish in catches). Given the time lag between recruitment and vulnerability to the longline fisheries, the increasing fish size by the Taiwanese fleet in the southern regions may be a result of a relatively strong period of recruitment, supporting the influence of recruitment on albacore size in the southern sub-regions of the model.

Oceanographic effects

The distribution of fish and their availability to fisheries are known to be influenced by oceanographic conditions (e.g. Lehodey et al. 1997). The influence of oceanography on fish availability to fisheries may be through direct effects (e.g. temperature exceeding a preferred range for a species and thus the species moving out of an area) and indirectly (e.g. oceanographic conditions influence good or bad periods of recruitment). Albacore catch rates and size may also be influenced by direct and/or indirect effects of variable oceanographic conditions in the southern Pacific Ocean.

Langley (2006) suggested that the recent period of neutral oceanographic conditions in the south Pacific Ocean may have resulted in the reduction of movement of water masses and subsequently reduced the movement of albacore through sub-equatorial areas of the WCPO (sub-regions 1 and 2). Langley (2006) identified the extension and contractions of the warm pool (as indexed by sea surface temperatures, SSTs) has changed in recent years (since 2002/03), with warm water (greater than 28˚C) remaining over the central areas of the WCPO for much of each year. Albacore prefer water temperatures less than approximately 25˚C, with catch rates responding to changes in SSTs in sub-equatorial EEZs (Figure 29, Figure 30). With water from the warm pool (greater than 28°C) remaining over many areas of the central WCPO, the movement of albacore through sub-equatorial EEZs in sub-regions 1 and 2 may have been reduced in recent years (2002–2005), reducing the replenishment of albacore into EEZs and the availability of albacore to longline fisheries. This is supported by declines in catch rates (i.e. local depletion) by domestic fisheries in sub-regions 1 and 2 during this period, with most fisheries reporting lower catch rates between 2002 and 2004 (Figure 8). This effect is further supported by declines in median size in most fisheries since 2002 (Figure 18 and Figure 19).

Differences in the timing of declines in catch rates and median size of albacore among fisheries operating in sub-regions 1 and 2 may be due to differences in the axis of movement of isotherms of sea surface temperature. In the south-western WCPO (sub-region 1), the seasonal movement of isotherms of SST is in a north–south direction, due to the presence of the warm pool in the western WCPO (i.e. to the north of sub-equatorial EEZs in this region of the albacore model). The influence of the warm pool declines in an eastward direction due to the interaction with the cold-tongue. In areas of the eastern WCPO, like the French Polynesia EEZ, the direction of movement of isotherms is along a north-west–south-east axis.

Further support for the reduced northward extension of albacore due to high water temperatures is provided by the in size data for the Taiwanese fleet operating sub-regions 3 and 4. For example, the Taiwanese fleet in sub-regions 3 and 4 has reported increased proportions of fish greater than 95 cm FL and 100 cm FL since 2002 (Figure 23). This may be a result of large albacore not moving as far north as in previous years, with large fish being more available in areas where the Taiwanese fleet operates in sub-regions 3 and 4 (i.e. south of 30°S). The median size of fish captured by the Taiwanese fleet in sub-region 3 has also increased since 2001 (Figure 18). However, the median size of fish by this fleet in sub-region 4 has declined since the late 1990s, which may be an effect of the relatively large recruitment about eight years previous (Figure 27, Figure 28). Still, size data for this fleet are limited, with no observer data available for this significant fleet. In addition, this fleet has changed its areas of operations since 2001, likely in response to changes in albacore distribution (Langley 2006).

The influence of water temperatures (SSTs) and albacore distribution is also potentially indexed by the southern oscillation index (SOI, Figure 31). For example, Lu et al. (1998) identified a significant positive correlation between quarterly average longline CPUE of albacore between 10˚S and 30˚S and the southern oscillation index (SOI), with a lag of approximately 8 years (32 quarters). Lu et al. (1998) concluded that negative SOI values (indicative of *El Niño* events) resulted in lower albacore recruitment due to lower ocean productivity. This is supported by the declining trend in albacore recruitment since the mid to late 1990s (Figure 21), coinciding with generally negative or neutral conditions of SOI.

Recruitment levels and movement, modulated by oceanographic conditions as indexed by the SOI, may influence the size of albacore and albacore catch rates in the longline fisheries in sub-regions 1 and 2. Coupled with the likely expansion of at least some domestic longline fleets in sub-equatorial EEZs of sub-region 1 and 2 leading to increasing levels of fishing mortality on the longline vulnerable proportion of the albacore stock, it is likely that median albacore size may continue to decline. Langley (2006) also warns that the lower levels of recent recruitment are likely to impact on the albacore fishery through reduced catch rates as smaller than average cohort sizes ‘move’ through the stock.

French Polynesia

Median albacore size data from the French Polynesian EEZ has generally being higher than the median size of albacore captured by other fleets in sub-region 2 of the model, despite large fluctuations in effort. There are several reasons why relatively large albacore are more likely to be captured by the domestic fishery of French Polynesia;

- The large size of the EEZ: large EEZs may simply contain a higher abundance (number) of large albacore;
- The distribution of fishing effort within the EEZ: most longline effort has been focussed in areas around Papeete and in a relatively small area north of Tahiti, resulting in many areas within the EEZ being lightly fished. Thus larger fish may move into the fishing grounds from less exploited areas of the EEZ;
- In addition, the fishery has expanded eastwards in recent years, moving into lightly exploited areas where larger albacore may be more common;
- The EEZ borders extensive areas of international waters to the south and east. These areas receive relatively low levels of effort compared to effort levels within many sub-equatorial EEZs. Thus, albacore in high seas areas may be expected to be relatively lightly fished, therefore containing higher abundances of older and larger albacore.

There also appears to be a higher abundance of larger fish in the southern areas of sub-region 2 (approximately 15–30ºS). For example, relatively high proportions of larger albacore are recorded from the domestic fisheries of French Polynesia, Tonga and the Cook Islands-South (Figure 21 and Figure 22). It may be that there are more favourable oceanographic conditions for larger albacore in the eastern areas of the WCPO, with a general increase in fish size from west to east in the sub-equatorial WCPO (e.g. Figure 19). As the French Polynesia EEZ is located at the extreme east of the WCPO, albacore from this area are expected to be among the largest in the WCPO.

The theory of larger fish in more easterly areas of the WCPO, especially within the southern areas of sub-region 2 may be tested in the future as the longline fishery in the Niue EEZ develops. It is expected that after initial high catch rates and relatively large median sizes and high proportions of large fish, catch rates will stabilise at (low) levels, similar to those recorded in Tonga, Cook Islands-South and French Polynesia EEZs. However, the proportion of large albacore form the Niue EEZ is expected to remain relatively high.

Conclusions

Declines in median size of albacore have been reported in many domestic longline fisheries within the albacore model region of the southern WCPO. Changes in size and the proportion of large albacore in catches of domestic fleets of sub-equatorial EEZs and the Taiwanese distant water fleet can be potentially explained by three hypotheses – impacts of longline fishing on the longline vulnerable component of the stock; changes in recruitment strength; and oceanographic influences on distribution and movement of large albacore in the WCPO.

It is likely that all three hypotheses interact to impact on the availability and size of albacore on domestic fleets in the model region. However, significant reductions in total longline effort of two fleets operating in sub-equatorial EEZs of the WCPO (Fiji and Tonga) and subsequent stabilisation or increases in the median size of albacore and the proportion of large fish in the catches suggests that the impacts of fishing by domestic fleets may be the most important factor on a local scale. Local effects may be strongest when oceanographic conditions are less variable, such as indexed by the period of neutral SOI values reported since 2002. With less variable oceanographic conditions, there is likely to be less water movement and subsequently a reduced movement of albacore throughout the WCPO and EEZs.

This suggests, firstly, that larger albacore exhibit longer-term residency and/or shorter movements than currently suspected, and that local populations that support domestic sub-equatorial fisheries can be impacted, as proposed by Langley (2006) (i.e. localised depletion).

However, not only can catch rates be reduced but the median size of albacore in domestic catches can also be reduced. Periods of residency of the order of 3–6 months have been estimated for yellowfin and skipjack in the WCPO (Sibert and Hampton 2003). Thus it may be possible that large albacore may also display similar periods of residency in sub-equatorial EEZs. Tagging studies of albacore are needed to further elucidate movement and periods of residency of adult albacore in the sub-equatorial WCPO, and the likely impacts of localised effort on the scale of EEZs. Such programmes are currently being planned.

Median size data also suggests that fisheries within an area of the scale of an individual EEZ can influence the catches of albacore and the proportion of larger (older) albacore in domestic catches. It is also likely that levels of effort within an EEZ also impact on the CPUE of albacore in domestic fisheries (Langley 2006). Management of domestic longline fishery development and effort levels the scale of individual EEZs (i.e. at the level of national fisheries management agencies) may be beneficial to domestic albacore fisheries. In addition, it may be possible to assess the impact of local effort by examining size-data collected by observers and port-samples within an individual EEZ, if such data are collected.

Nonetheless, similar trends in the size data and catch rate data from all EEZs within the two sub-equatorial sub-regions suggests that effects at the scale of sub-regions also impact domestic fisheries. Thus management with consideration of all (domestic) fisheries within each sub-region is also likely to benefit albacore sizes and catch rates of domestic fleets. In addition, the similar trends in median size of albacore of many fleets within each sub-region suggests that impacts of (domestic) longline fisheries are reaching levels that significantly impact (reduce) the longline-vulnerable component of the albacore stock (estimated at 30%, Langley and Hampton 2005). With increases in fishing mortality (effort), the likelihood of individual albacore reaching old ages (and larger sizes) will be further reduced.

While a reduction in median size may be an inevitable impact of longline fishing, the removal of a significant proportion of the longline-vulnerable component of the albacore stock would not necessarily impact negatively on stock status of albacore in the southern WCPO, due to the life history of albacore (i.e. a high proportion of albacore reach maturity and breed before becoming vulnerable to sub-equatorial longline fisheries). However, increased effort by domestic longline fisheries may result in lower catch rates (Langley 2006).

Finally, this paper highlights the importance of length-frequency data in the WCPO, not only as vital inputs in stock assessments models, but to assist the interpretation of local fishery impacts. Length-frequency data are only collected from observer programmes and port sampling programmes in the WCPO. The continuation and expansion of these two programmes will continue to yield information critical to better assess and manage tuna fisheries of the WCPO at both regional and national levels.

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Tables

Table 1. Summary albacore catch, effort, median size (cm) and fleet size (number of vessels) for sub-equatorial countries of the WCPO in sub-regions 1 and 2 of the albacore assessment model, 1997–2005. Source, raised estimates of catch and effort data by EEZ held by SPC, length-frequency data held by SPC and National Reports presented at Scientific Committee 1 (SC-1, 2005) and 2 (SC-2, 2006) (www.wcpfc.org). Catches, albacore catches in metric tonnes; Hooks, total annual effort in millions of hooks; hhooks/km^2, average annual number of hooks per square-kilometre of EEZ; Median FL, median annual fork length (cm); > 95 cm FL, proportion of albacore in catches greater than 95 cm FL; CPUE, kg/$hhooks^{-1}$; Vessels, number of longline vessels. NA, data not available. # No effort data were available for Samoa in 1997. Estimates of catch and effort for the Cooks Islands were based on information presented in the National Tuna Fisheries Status Report (2006). Estimates of catch and effort for Tonga were based on information presented in the National Tuna Fisheries Status Report (2007).

EEZ		1997	1998	1999	2000	2001	2002	2003	2004	2005
PNG	Catch (mt)	134	104	128	159	124	142	854	1,900	2,086
	Hooks	0.912	2.351	2.725	3.891	5.900	5.991	6.677	9.377	7.659
	hhooks/km^2	2.92	7.54	8.73	12.47	18.91	19.20	21.40	30.05	24.55
	Median FL	NA	NA	NA	98	96	97	94	90	93
	> 95 cm FL	NA	NA	NA	0.821	0.601	0.631	0.439	0.332	0.346
	CPUE	14.7	4.4	4.7	4.1	2.1	2.4	12.8	20.3	27.2
Solomon Islands	Catch (mt)	750	1,334	953	1,371	686	1,391	2,199	4,248	4,731
	Hooks	11.971	7.914	20.225	11.579	9.336	13.766	33.025	26.351	19.827
	hhooks/km^2	89.34	59.06	150.93	86.41	69.67	102.73	246.46	196.65	147.97
	Median FL	92	92	90	92	93	91	91	93	91
	> 95 cm FL	0.354	0.341	0.311	0.26	0.384	0.339	0.327	0.425	0.319
	CPUE	6.3	16.9	4.7	11.8	7.3	10.1	6.7	16.1	23.9
New Caledonia	Catch (mt)	186	818	689	892	1,029	1,165	1,088	1,381	1,576
	Hooks	0.732	3.319	3.631	4.682	5.321	4.412	6.255	6.119	5.083
	hhooks/km^2	6.66	30.17	33.01	42.56	48.38	40.11	56.87	55.63	46.20
	Median FL	98	95	93	88	98	98	97	97	95
	> 95 cm FL	0.756	0.542	0.545	0.097	0.708	0.703	0.605	0.642	0.527
	CPUE	25.4	24.6	19.0	19.1	19.3	26.4	17.4	22.6	31.0
Vanuatu										
	Catch (mt)	2,789	2,857	5,756	6,634	5,316	4,084	5,408	5,895	6,810
	Hooks	6.655	8.161	11.170	15.895	19.814	17.072	29.979	25.289	25.910
	hhooks/km^2	97.87	120.01	164.26	233.75	291.39	251.05	440.87	371.89	381.03
	Median FL	NA	NA	NA	97	96	97	95	95	93
	> 95 cm FL	NA	NA	NA	0.636	0.653	0.644	0.567	0.528	0.404
	CPUE	41.9	35.0	51.5	41.7	26.8	23.9	18.0	23.3	26.3
Fiji										
	Catch (mt)	4,380	3,229	2,752	5,260	7,356	6,447	4,298	5,866	3,979
	Hooks	15.182	10.042	10.453	18.184	26.242	26.901	25.578	28.177	15.274
	hhooks/km^2	117.69	77.85	81.03	140.96	203.43	208.53	198.28	218.42	118.40
	Median FL	95	98	96	NA	NA	95	94	94	93
	> 95 cm FL	0.525	0.765	0.57			0.528	0.487	0.45	0.424
	CPUE	28.8	32.2	26.3	28.9	28.0	24.0	16.8	20.8	26.1
Tonga										
	Catch (mt)	968	1,073	1,241	1,313	1,849	1,423	520	260	451
	Hooks	2.271	4.444	5.787	6.090	6.891	7.579	6.782	3.020	5.564
	hhooks/km^2	18.04	71.39	59.82	58.50	57.29	70.43	100.23	32.16	46.73
	Median FL	92	94	96	95	98	96	94	94	96
	> 95 cm FL	0.341	0.455	0.611	0.532	0.762	0.613	0.454	0.481	0.585
	CPUE	39.3	37.7	24.8	21.6	26.9	19.2	10.5	8.8	8.2

Samoa										
	Catch (mt)	4,108	2,882	2,740	2,254	4,723	3,695	1,473	1,136	1,151
	Hooks	#	6.331	7.852	8.491	5.320	6.255	5.064	5.237	3.633
	Hhooks/km^2	#	527.61	654.32	707.61	443.30	521.28	422.00	436.45	302.74
	Median FL	NA	95	93	98	96	95	91	95	92
	> 95 cm FL	NA	0.667	0.434	0.775	0.624	0.556	0.28	0.585	0.365
	CPUE	Na	45.5	34.9	26.5	88.8	59.1	29.1	21.7	31.7
American Samoa	Catch (mt)	307	825	1,053	1,816	3,292	5,554	3,390	1,988	2,674
	Hooks	0.615	1.917	3.473	4.628	6.175	13.924	13.552	10.236	18.295
	hhooks/km^2	15.78	49.16	89.05	118.68	158.34	357.01	347.49	262.47	469.09
	Median FL	NA	94	93	98	98	96	93	96	93
	> 95 cm FL	NA	0.468	0.434	0.77	0.724	0.668	0.405	0.598	0.41
	CPUE	49.9	43.0	30.3	39.2	53.3	39.9	25.0	19.4	14.6
Cook Islands-North	Catch (mt)	0	578	230	0	59	1,273	1,331	1,792	2,148
	Hooks	0.00	1.32	0.99	0.00	0.19	2.33	4.23	6.50	5.37
	hhooks/km^2	0.00	0.013	0.010	0.000	0.002	0.023	0.041	0.063	0.052
	Median FL	NA	NA	NA	NA	99	97	96	93	94
	CPUE	NA	NA	NA	NA	0.713	0.641	0.439	0.389	0.489
Cook Islands-South	Catch (mt)	0	3	19	0	2	216	591	182	165
	Hooks	0.00	0.01	0.16	0.00	0.03	0.76	3.32	2.48	2.00
	hhooks/km^2	NA	0.000	0.002	0.000	0.000	0.008	0.035	0.026	0.021
	Median FL	NA	NA	NA	NA	95	101	101	98	96
	CPUE	NA	NA	NA	NA	0.561	0.816	0.847	0.690	0.727
French Polynesia	Catch (mt)	2,543	3,336	2,576	3,473	4,227	4,198	3,637	2,148	2,030
	Hooks	8.804	11.044	16.013	16.883	13.083	13.200	17.611	23.122	18.692
	hhooks/km^2	17.97	22.54	32.68	34.46	26.70	26.94	35.94	47.19	38.15
	Median FL	99	104	NA	NA	94	100	98	98	95
	> 95 cm FL	0.835	1.00	NA	NA	0.483	0.766	0.801	0.778	0.507
	CPUE	28.9	30.2	16.1	20.6	32.3	31.8	20.7	9.3	10.9

Figures

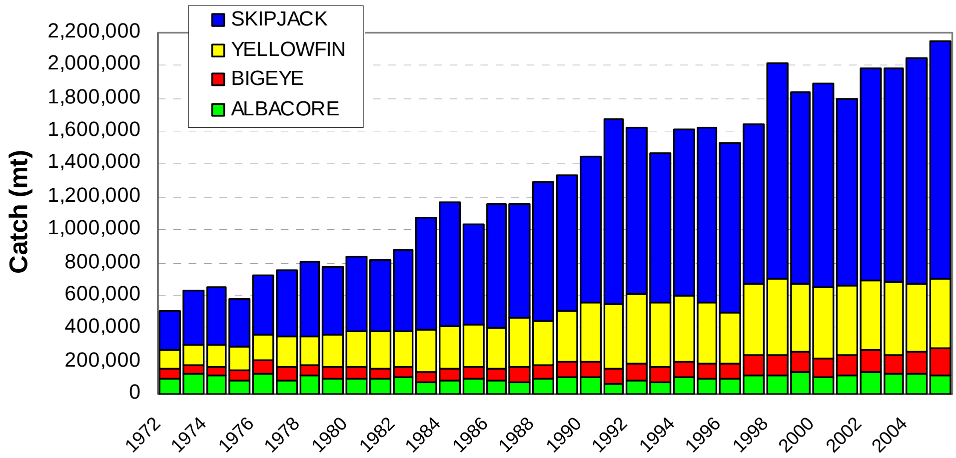


Figure 1. Catch (mt) of albacore, bigeye, skipjack and yellowfin in the WCP–CA. Source: Williams and Reid (2006).

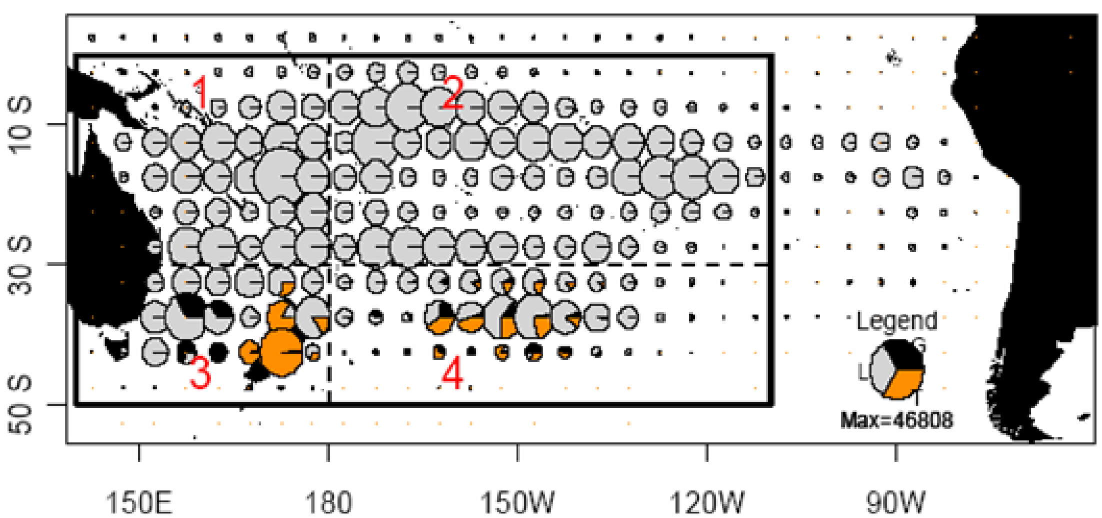


Figure 2. Distribution of albacore tuna catches, 1960–2003. The solid black line defines the model region while the black dashed lines define the four sub-regions used in the albacore MULTIFAN-CL model. Source: Langley and Hampton (2005). Legend codes: L, longline (grey); T, troll (orange); G, gillnet (black). No gill net fishing has been reported from the model regions since the early 1990s.

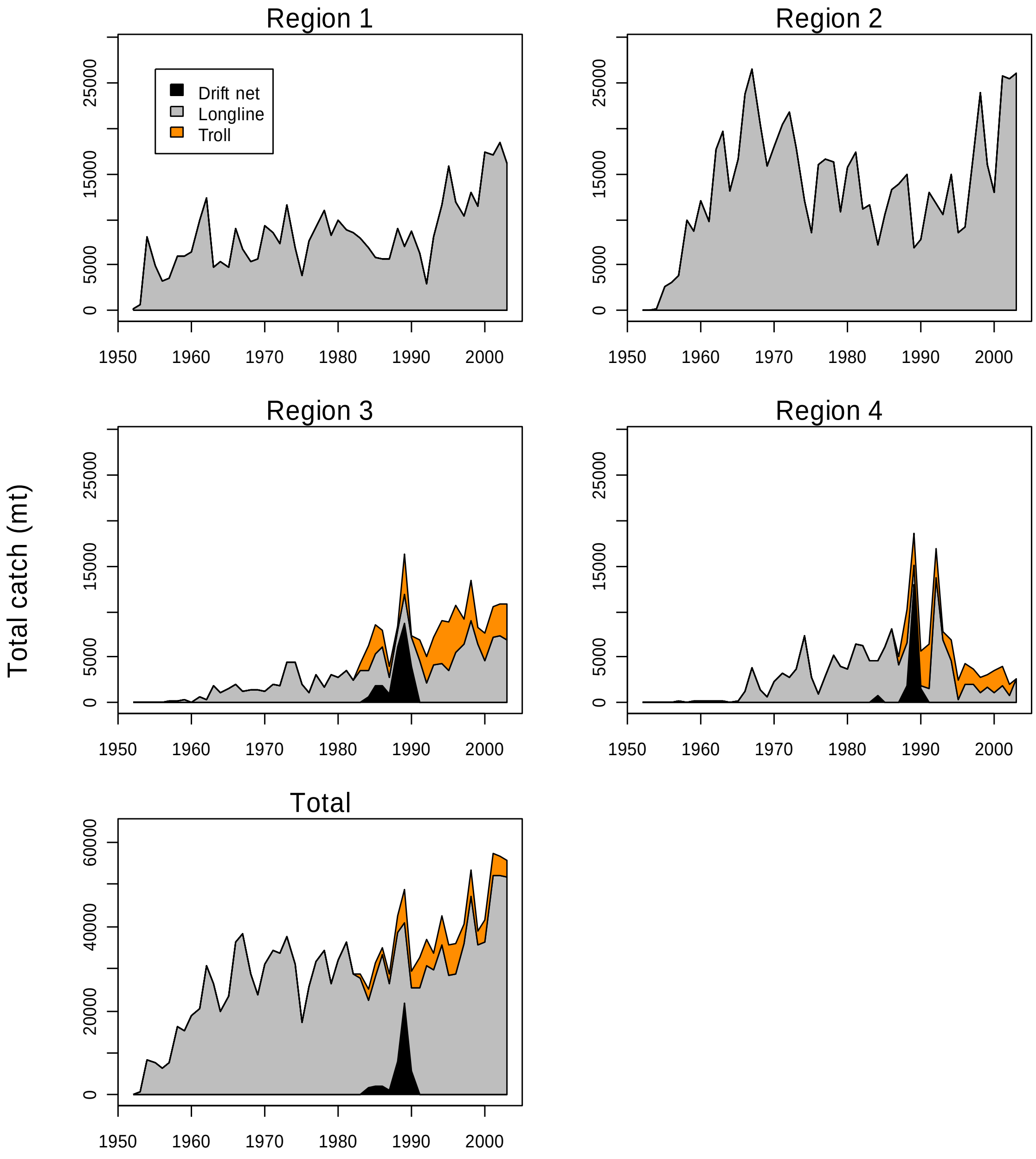


Figure 3. Annual catch (mt) of south Pacific albacore by fishing method and sub-region, and total combined annual catch for 1952 to 2003. Source: Langley and Hampton (2005).

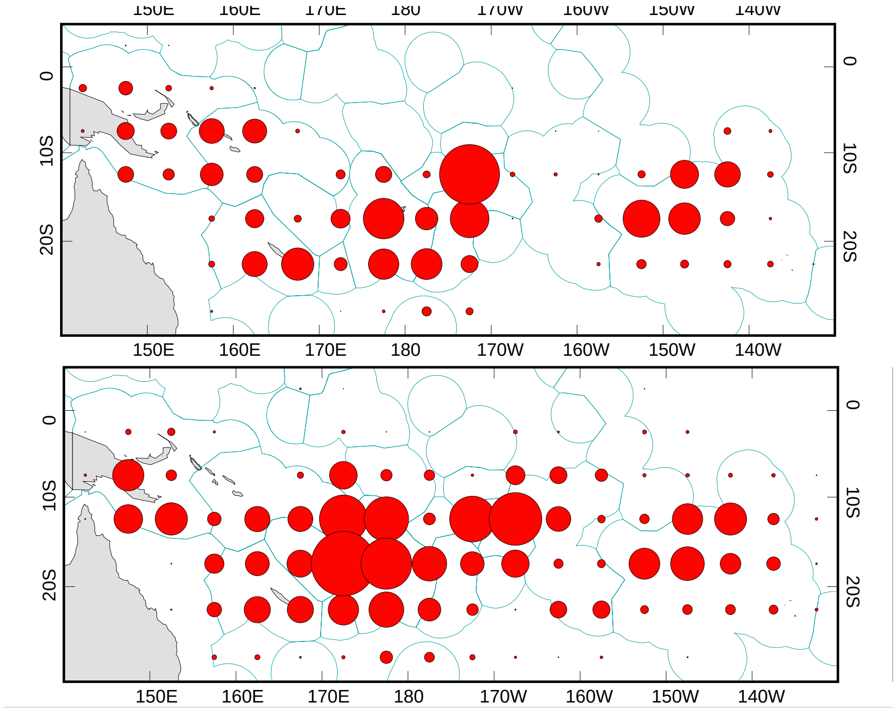


Figure 4. Distribution of Pacific-Islands domestic longline effort for 1999 (top) and 2004 (bottom). Source: Williams and Reid (2006). The size of each circle is proportional to longline effort.

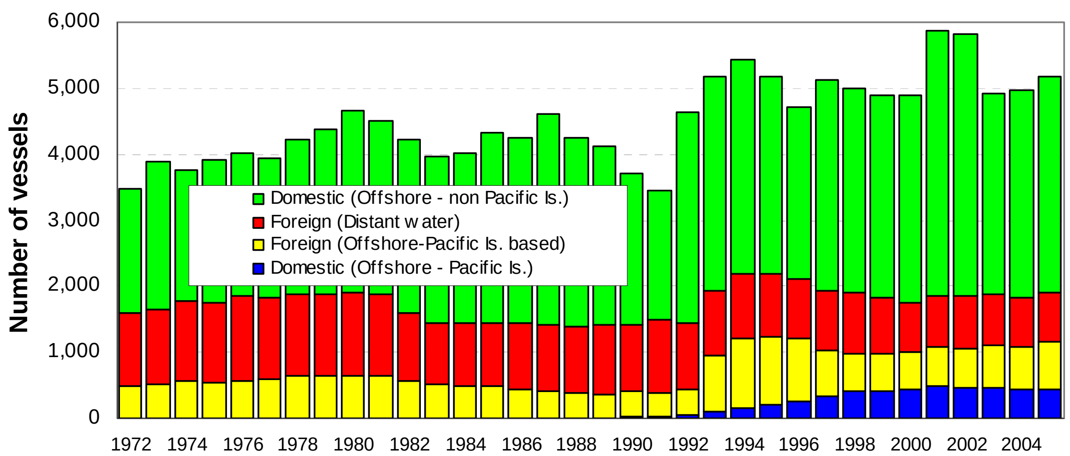


Figure 5. Number of longline vessels operating in the WCP–CA. Source: Williams and Reid (2006).

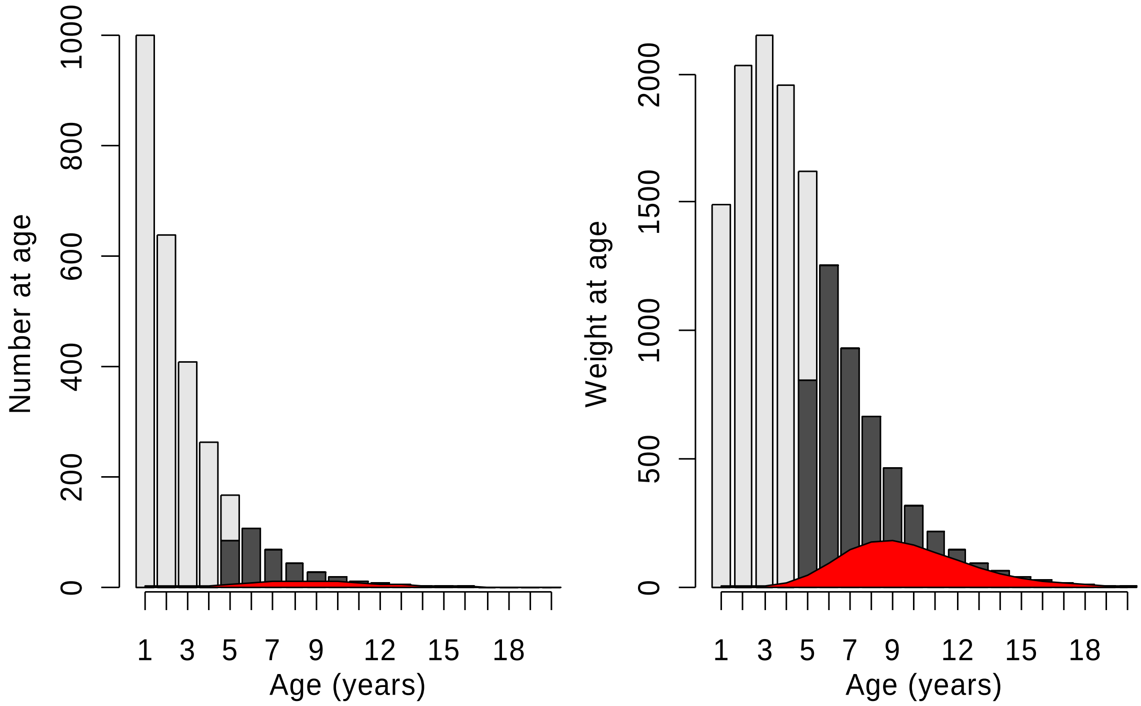


Figure 6. The composition of a theoretical cohort (numbers at age and weight at age) of albacore; immature (light grey), mature (dark grey) and vulnerable to sub-equatorial longline fisheries of the WCP-CA (red). Source: Langley and Hampton (2005).

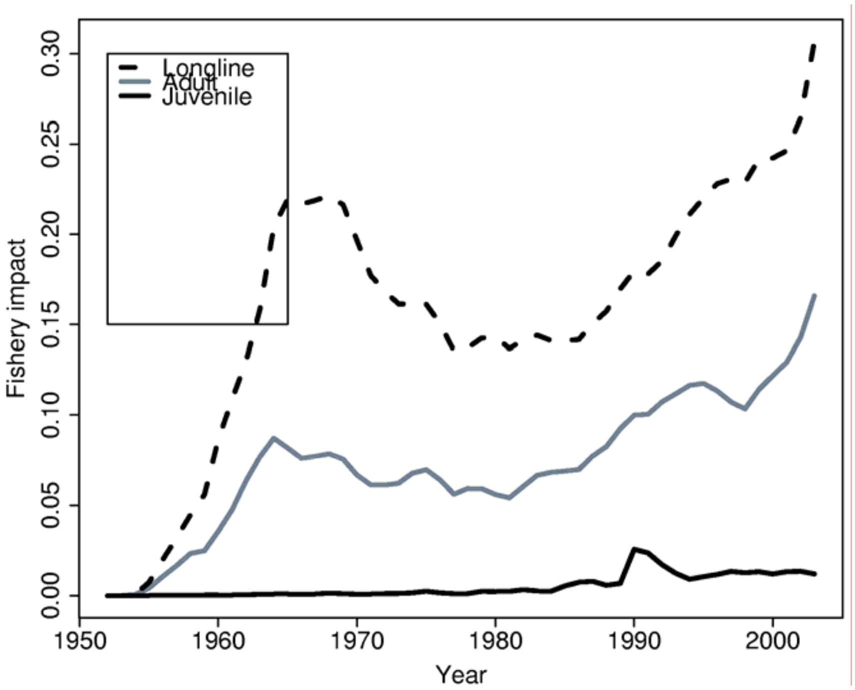


Figure 7. The estimated fishery impacts (proportional reduction in biomass attributable to fishing) on juvenile, adult and longline exploitable biomass from the one region model of the most recent albacore stock assessment. Source: Langley and Hampton (2005).

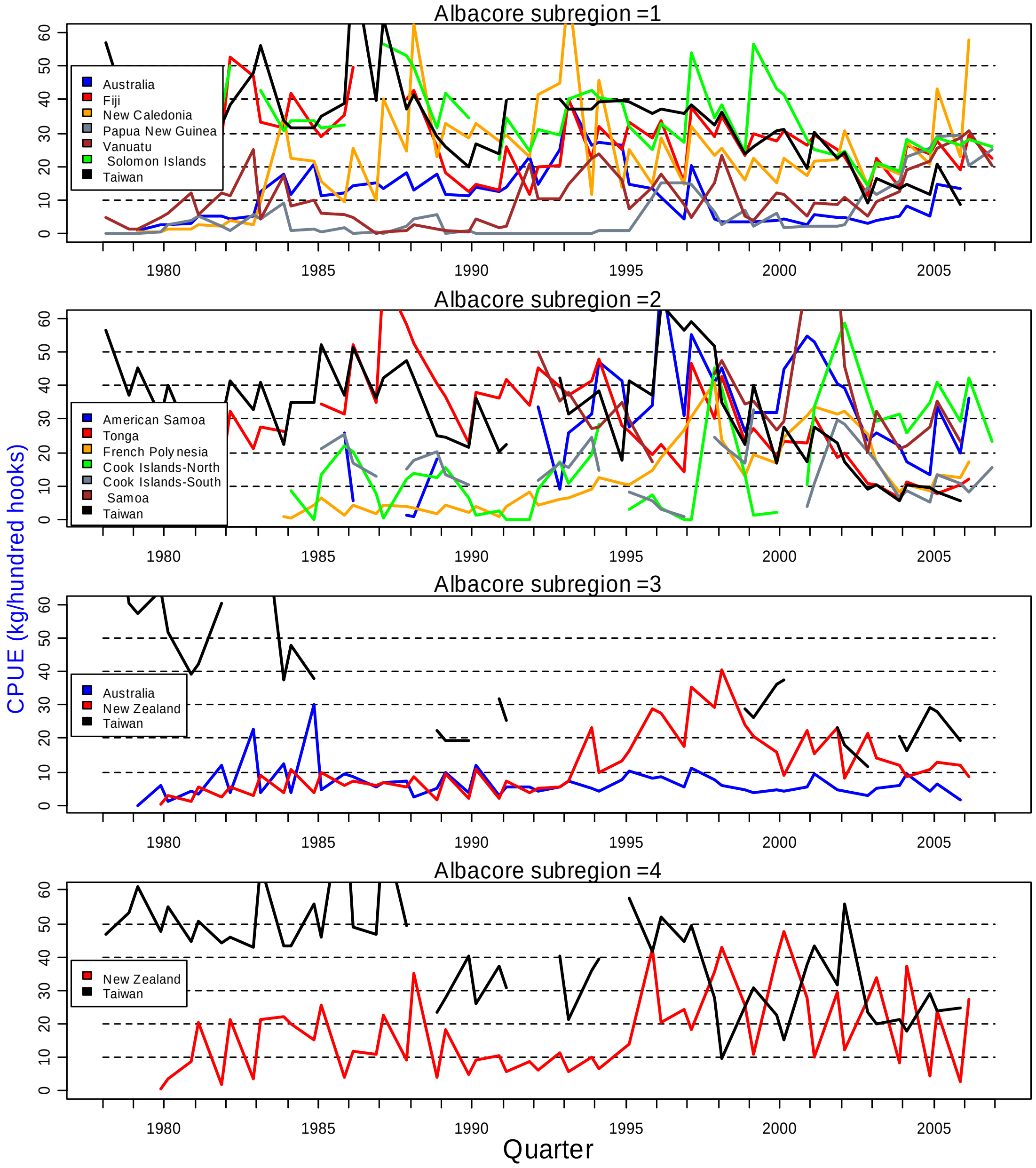


Figure 8. Nominal albacore catch rates (CPUE, kg.hhooks^{-1}) by EEZ within each sub-region in the albacore model, 1978–2006. Source: operational level logsheet data held by SPC.

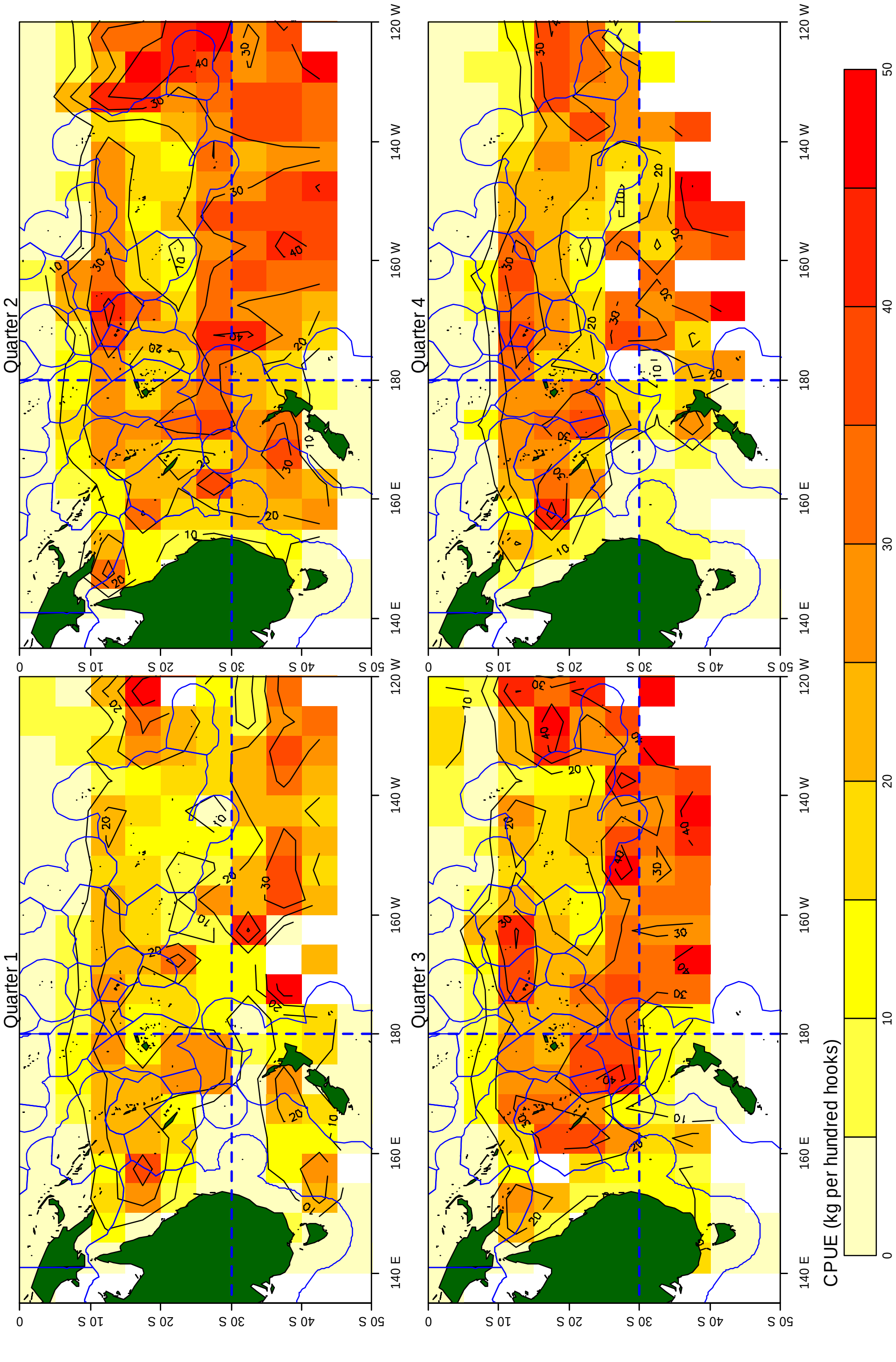


Figure 9. Quarterly albacore CPUE (kg. hhooks^{-1}) within each 5° x 5° cell of the assessment region for the south Pacific Stock, 1978–2003. Source: operational level logsheet data held by SPC. Dotted lines represent the boundaries of each sub-region within the model.

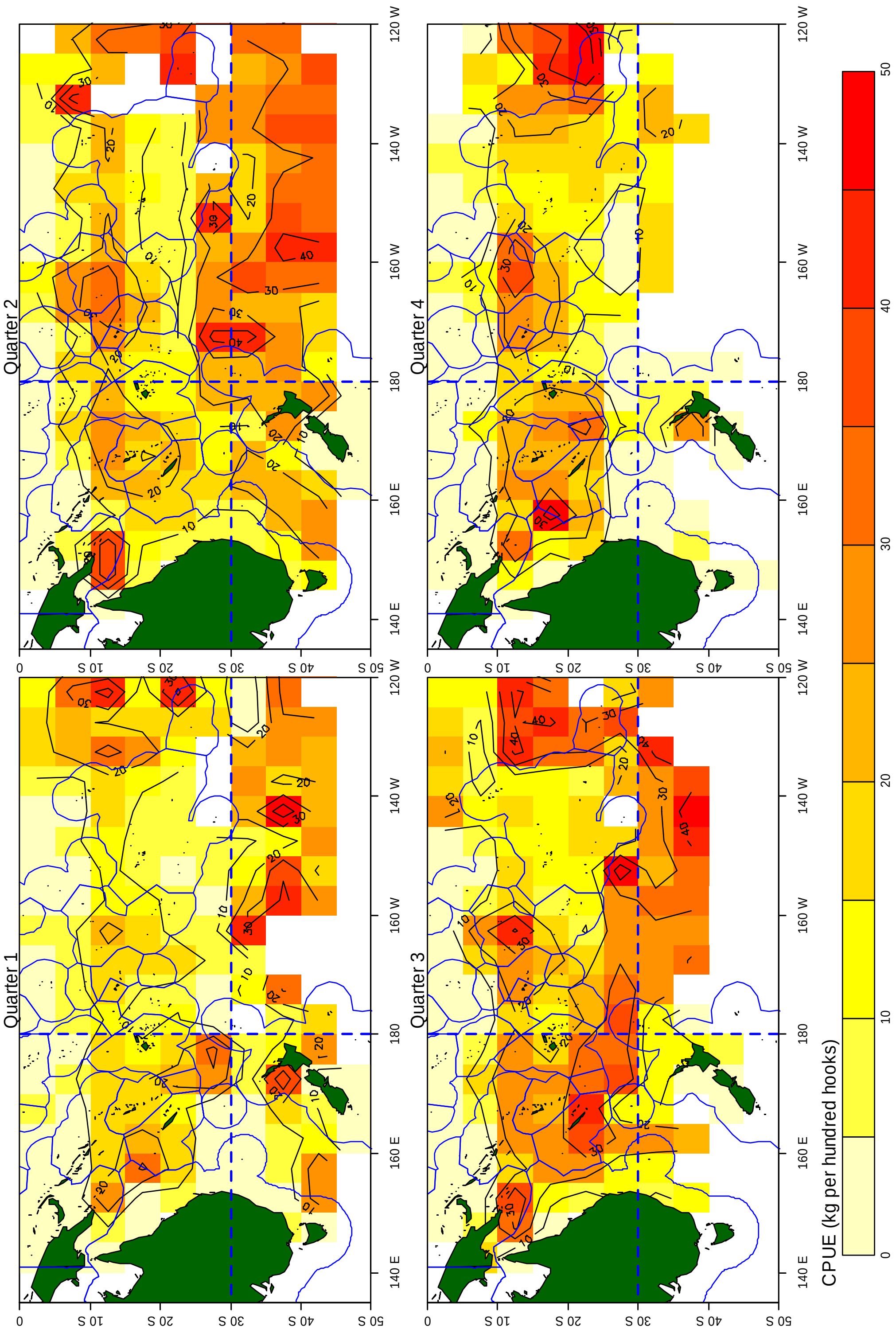


Figure 10. Quarterly albacore CPUE (kg. hhooks^{-1}) within each 5º x 5º cell of the assessment region for the south Pacific Stock, 2003–2006. Source: operational level logsheet data held by SPC. Dotted lines represent the boundaries of each sub-region within the model.

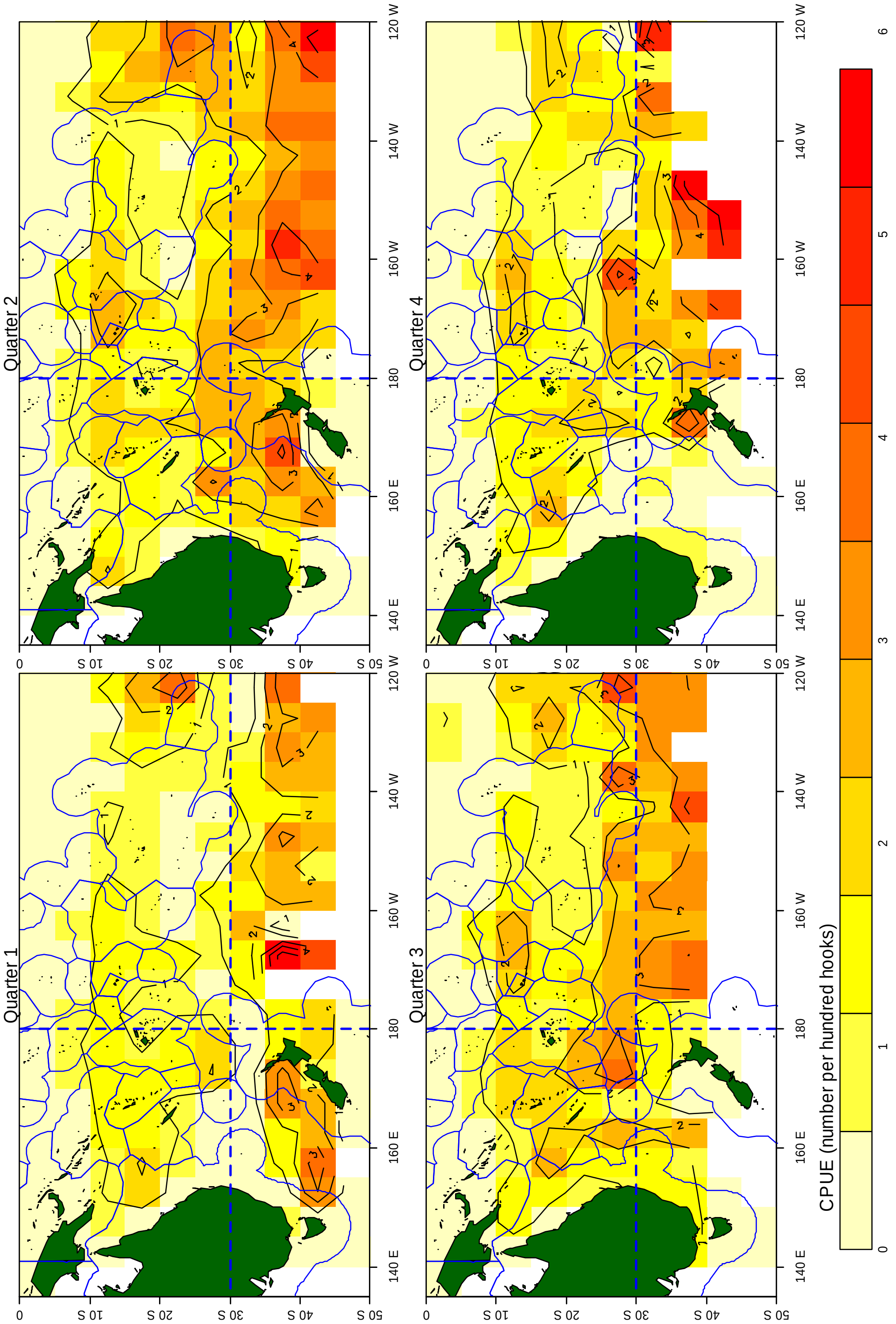


Figure 11. Quarterly albacore CPUE (number.hhooks^{-1}) within each 5º x 5º cell of the assessment region for the south Pacific Stock, 1978–2003. Source: operational level logsheet data held by SPC. Dotted lines represent the boundaries of each sub-region within the model.

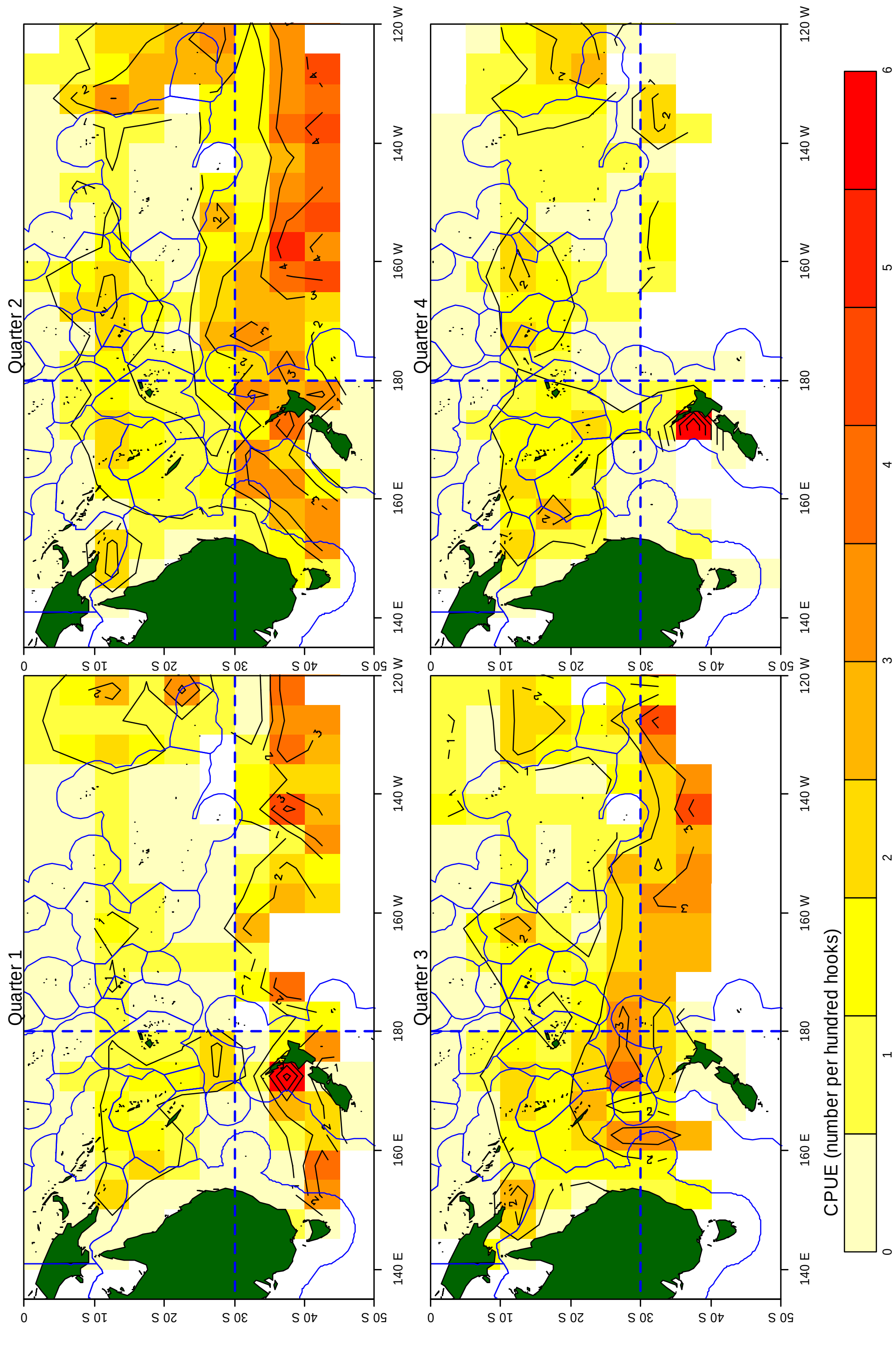


Figure 12. Quarterly albacore CPUE (number.hhooks^{-1}) within each 5° x 5° cell of the assessment region for the south Pacific Stock, 2003–2006 Source: operational level logsheet data held by SPC. Dotted lines represent the boundaries of each sub-region within the model.

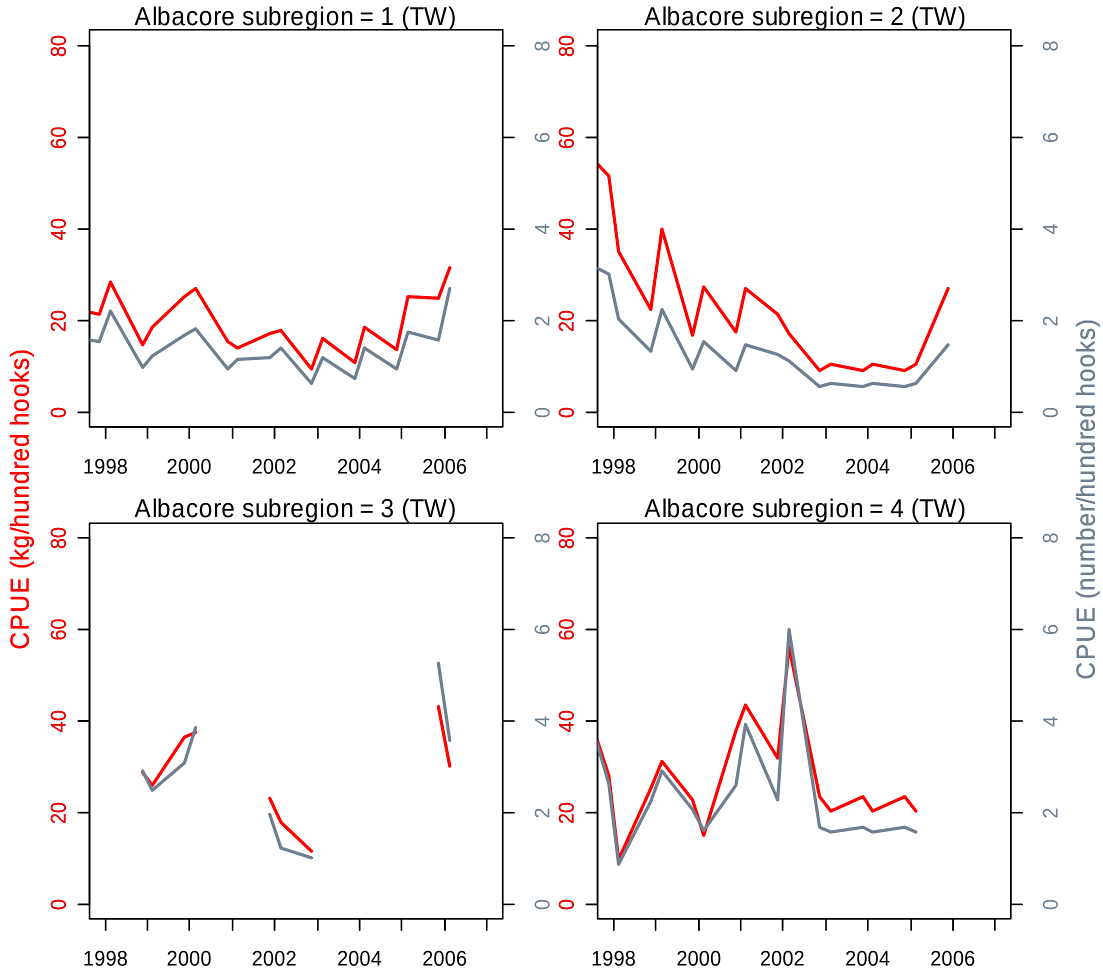


Figure 13. Nominal catch rates (CPUE, kg.hhooks^{-1}, number. hhooks^{-1}) for the Taiwanese distant water fleet operating within each sub-region of the albacore model, 1998–2006. Source: logsheet database held by SPC.

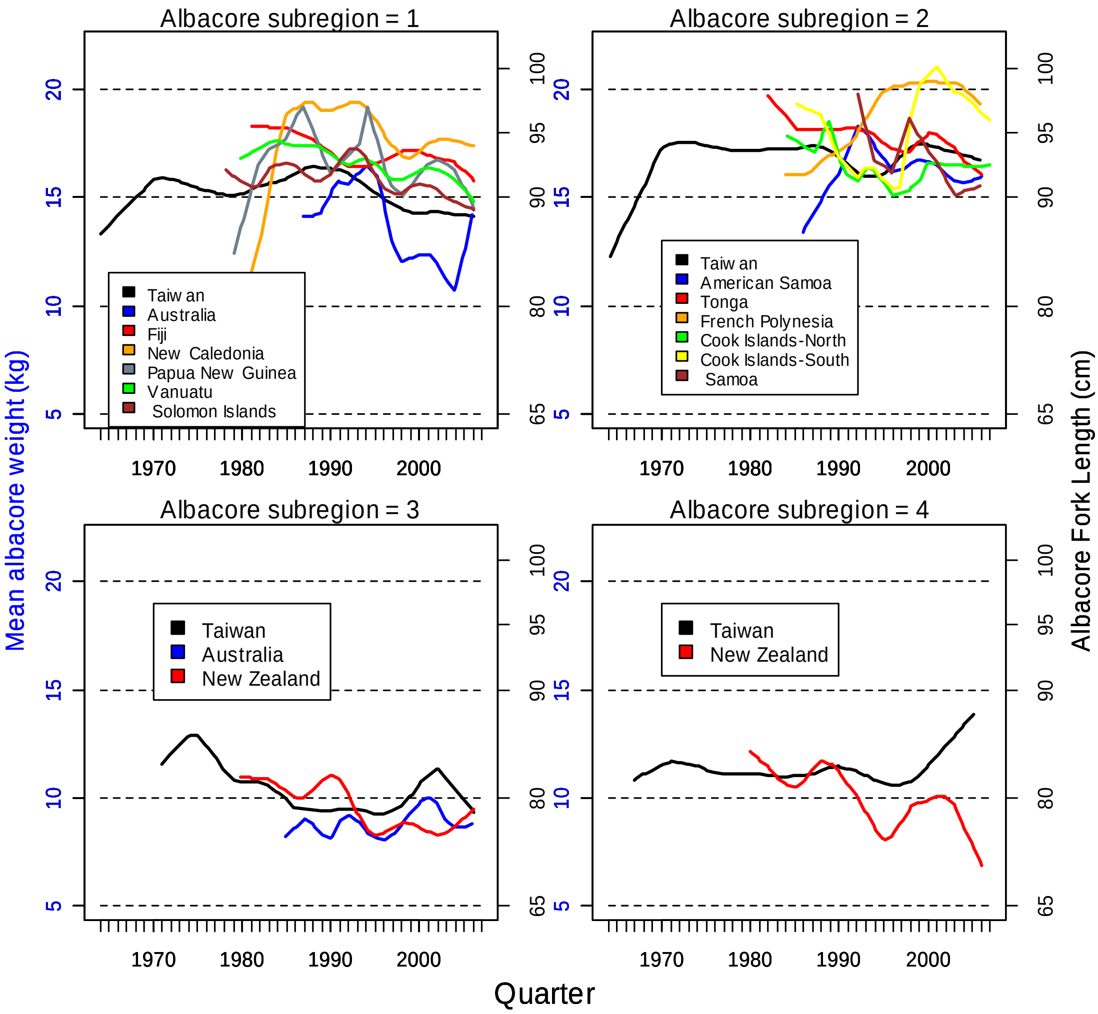


Figure 14. Nominal mean albacore weight (kg) by fleet in each sub-region of the albacore assessment model, 1965–2006. Source: logsheet data held by SPC. Each line represents a lowess fit to nominal size data for each fleet within each sub-region.

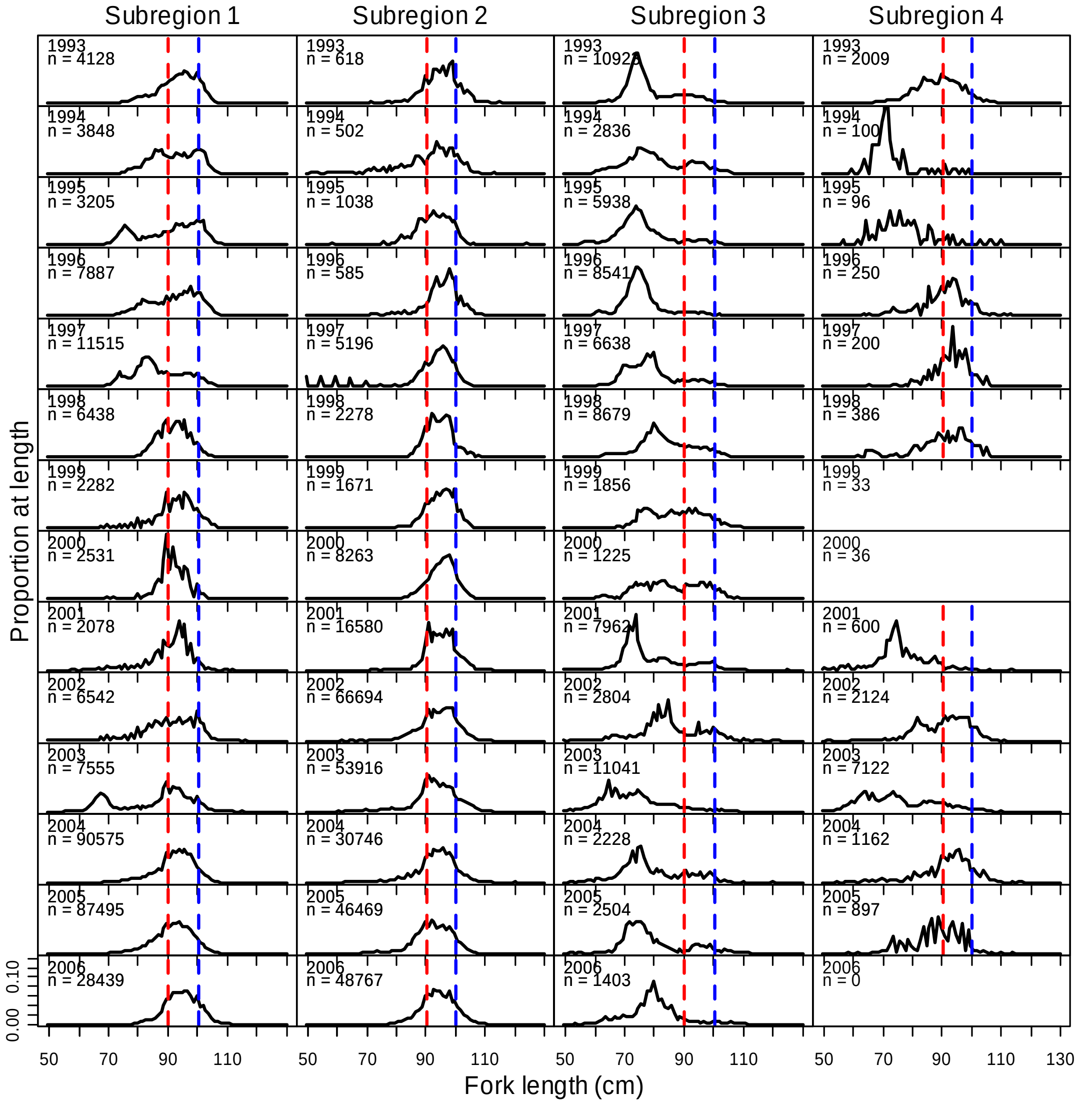


Figure 15. Annual length-frequency distributions of albacore pooled by sub-region, 1993–2006. Source: length-frequency database held by SPC. Vertical lines provide a comparison among years and sub-regions at 90 cm FL (red line) and 100 cm FL (blue line). n = the total number of albacore measured within each year and sub-region.

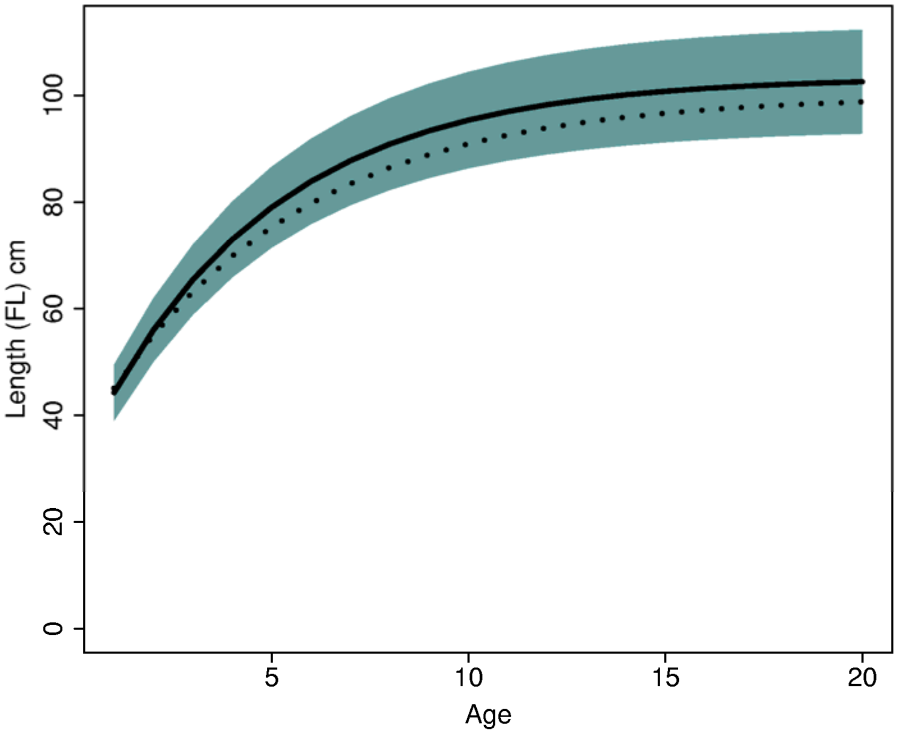


Figure 16. The estimated length (fork length) at age (years) (solid line) and the 95% confidence interval. The dashed line represents the initial values included in the model from the von Bertalanffy growth parameters. Source: Langley and Hampton (2005).

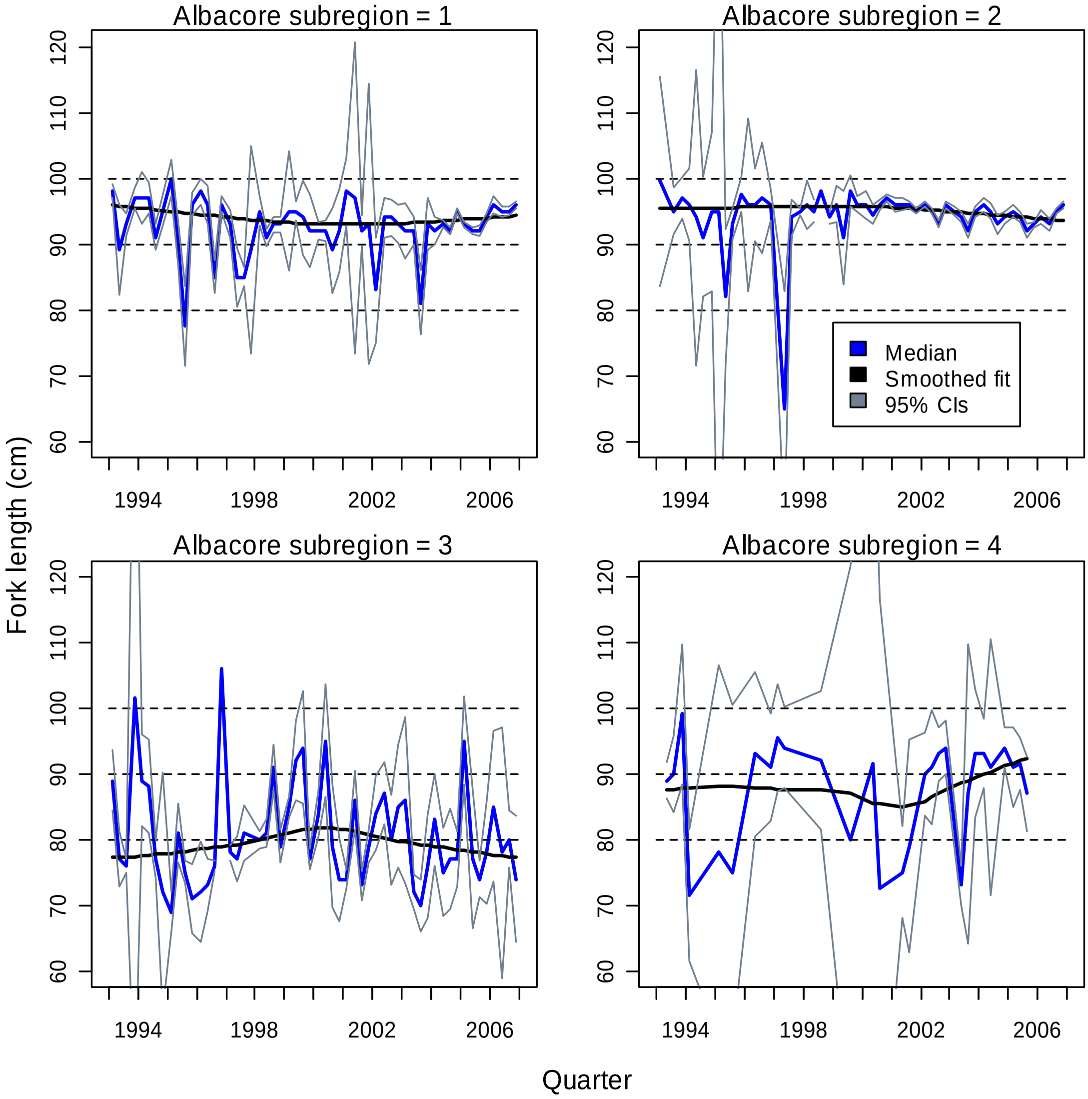


Figure 17. Quarterly trends in median fork length (cm, blue lines) of longline-captured albacore pooled within each sub-region of the assessment model, 1993–2006. Source: length-frequency database held by SPC. Grey lines represent 95% confidence intervals of median length. Black lines represent a lowess fit to each data series. Total sample size per region; region 1, n=264,587; region 2 n= 283,480; region 3 n=74,680; region 4 n= 15,076.

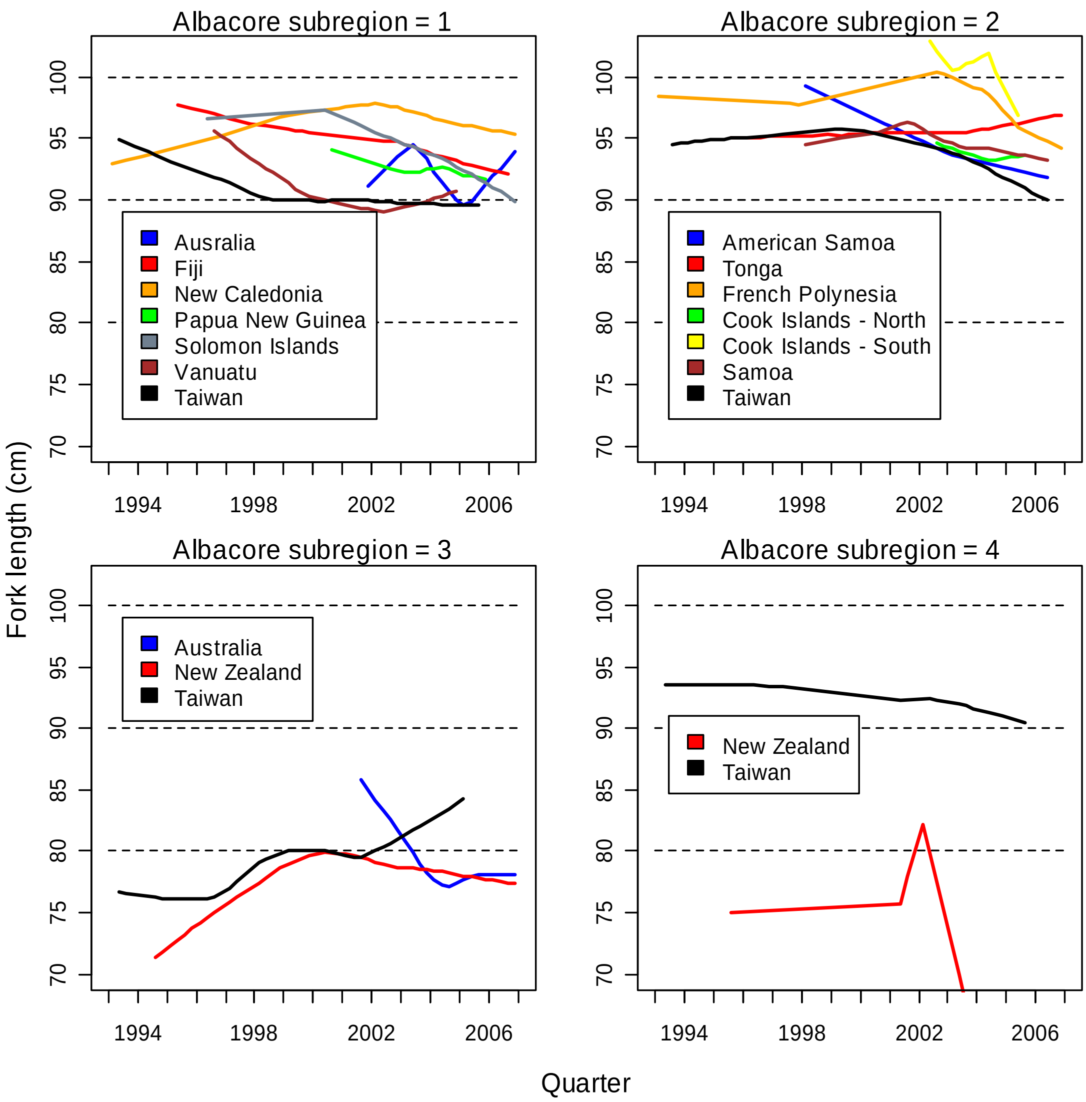


Figure 18. Trends in quarterly median albacore fork length (cm) for longline fisheries by flag in each sub-region of the albacore assessment model, 1993–2006. Source: length-frequency database held by SPC.

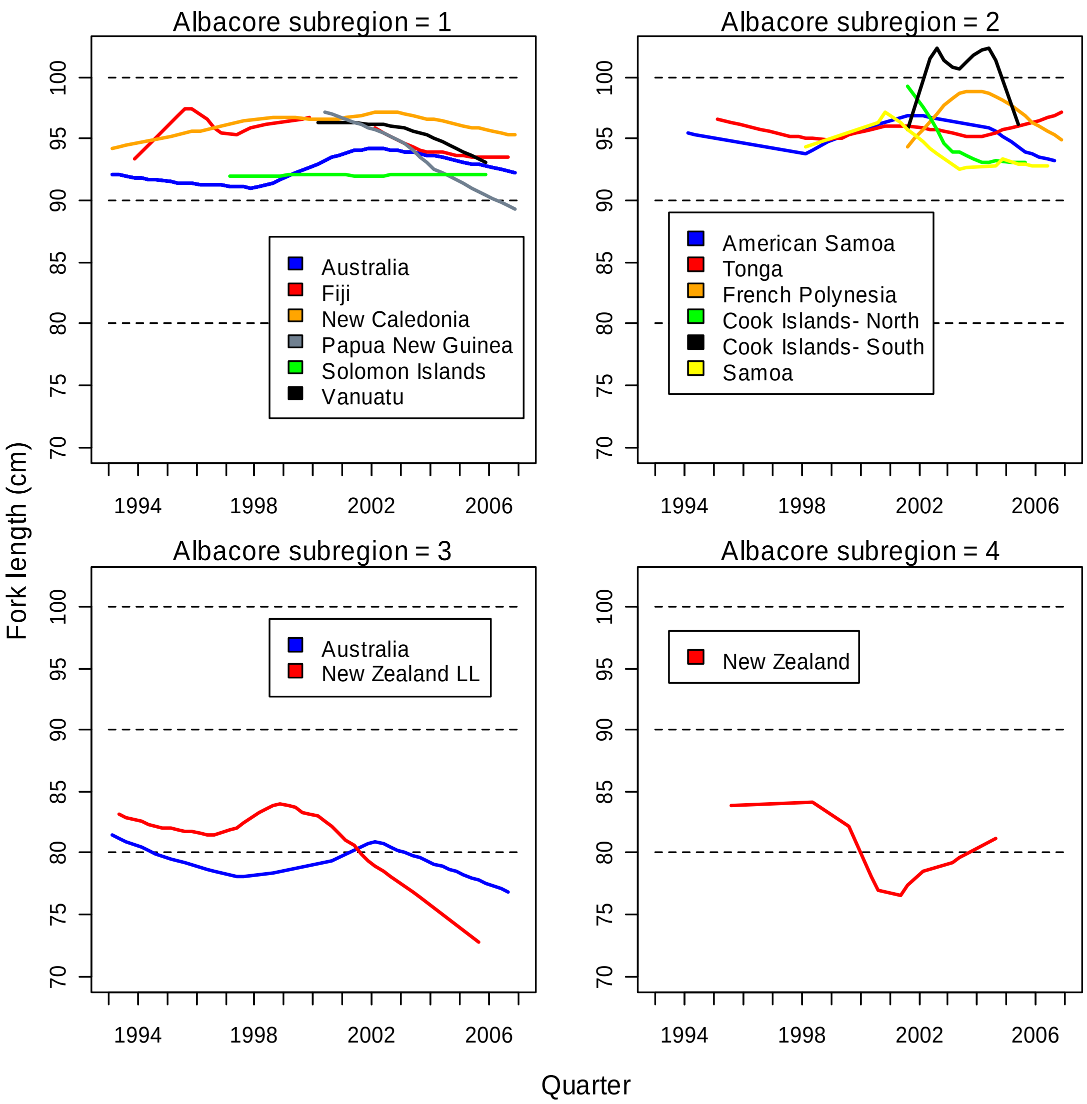


Figure 19. Trends in quarterly median albacore fork length (cm) for longline fisheries by EEZ in each sub-region of the albacore assessment model, 1993–2006. Source: length-frequency database held by SPC.

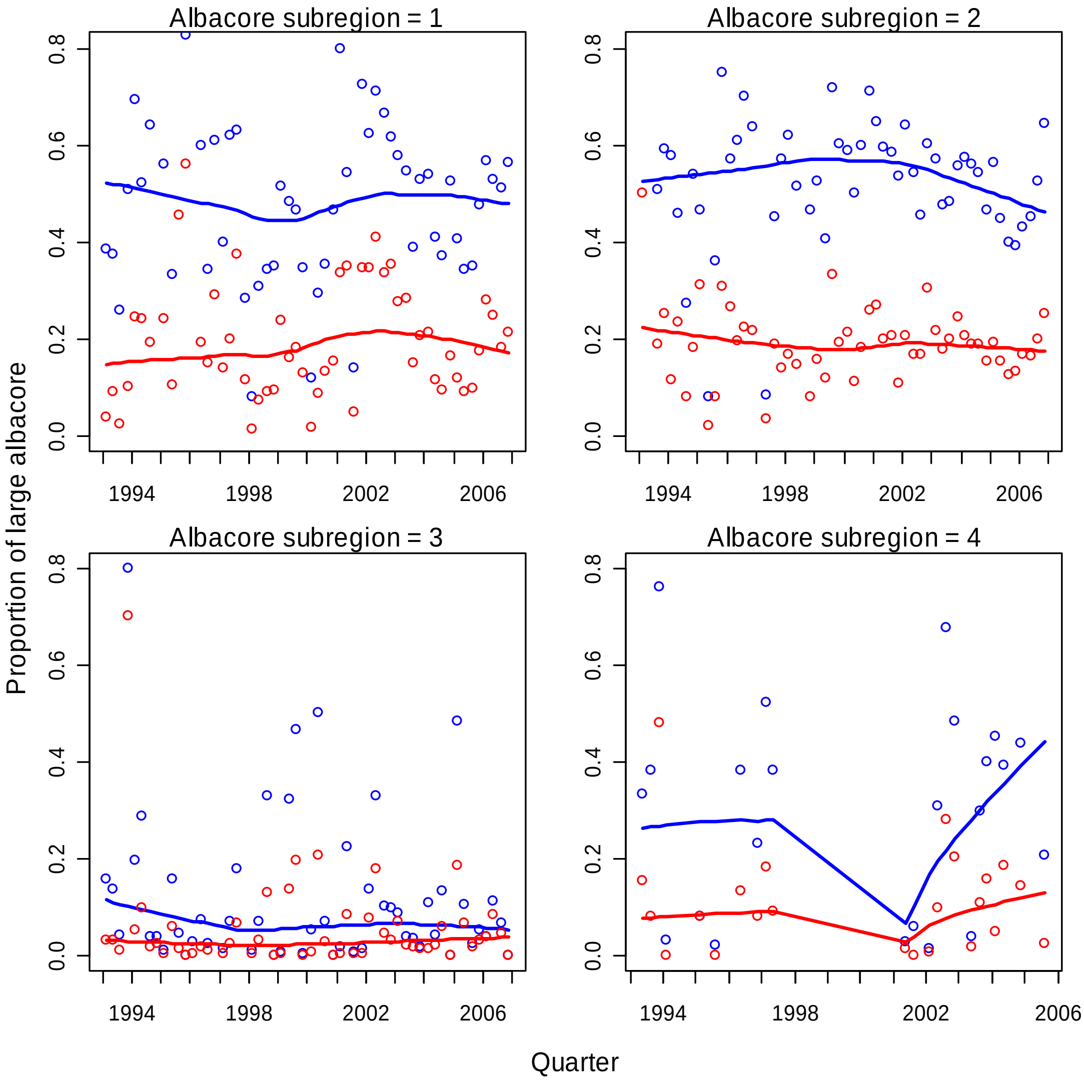


Figure 20. Proportion of albacore greater than 95 cm FL (blue points) and 100 cm FL (red points) in longline catches pooled within each model sub-region of the albacore assessment, 1993–2006. Source: length-frequency database held at SPC. Lines represent lowess fits to each data series.

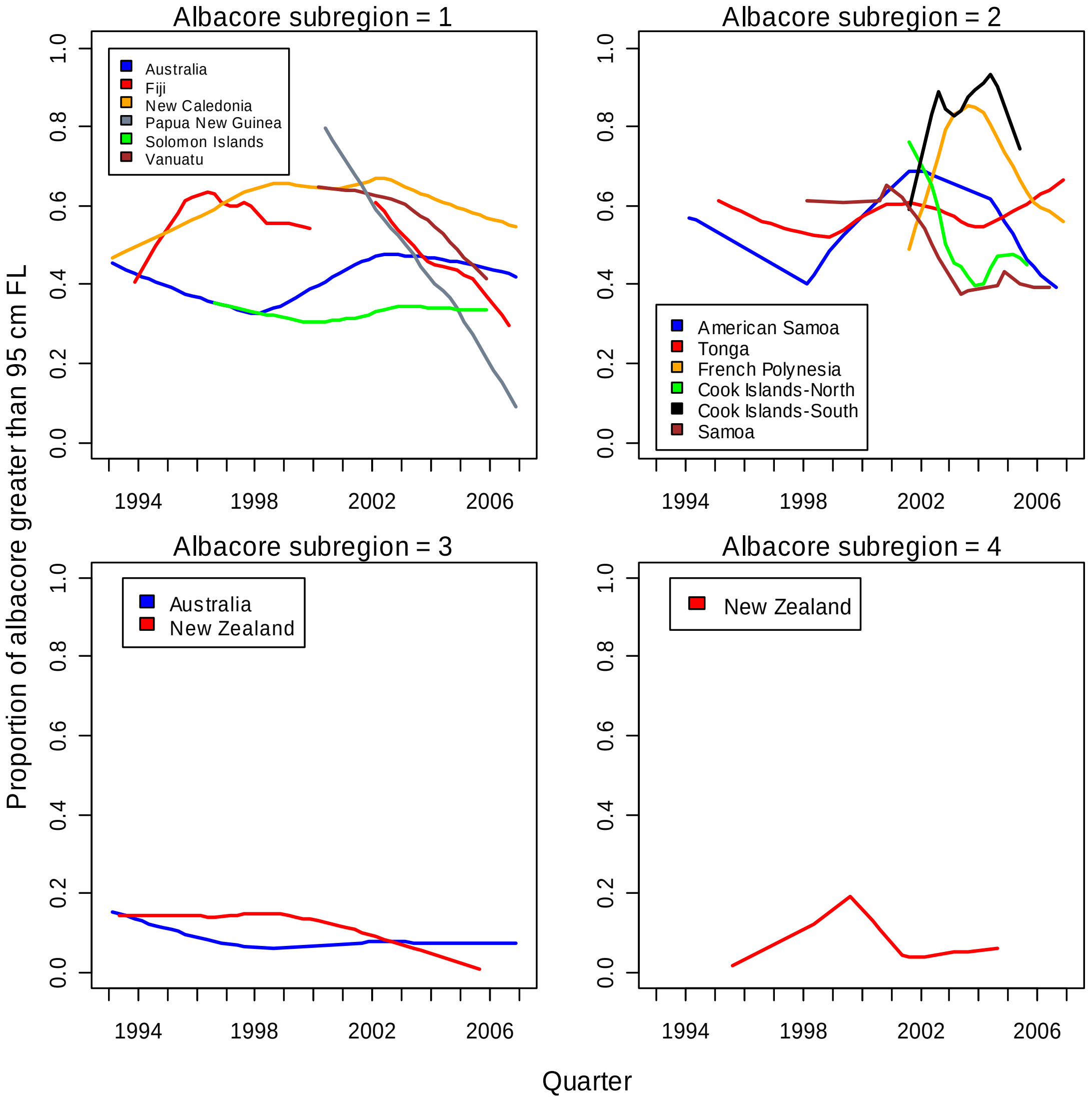


Figure 21. Lowess fit of the proportion of albacore greater than 95 cm FL within longline catches of each EEZ of each model sub-region of the albacore assessment, 1993–2006. Source: length-frequency database held at SPC.

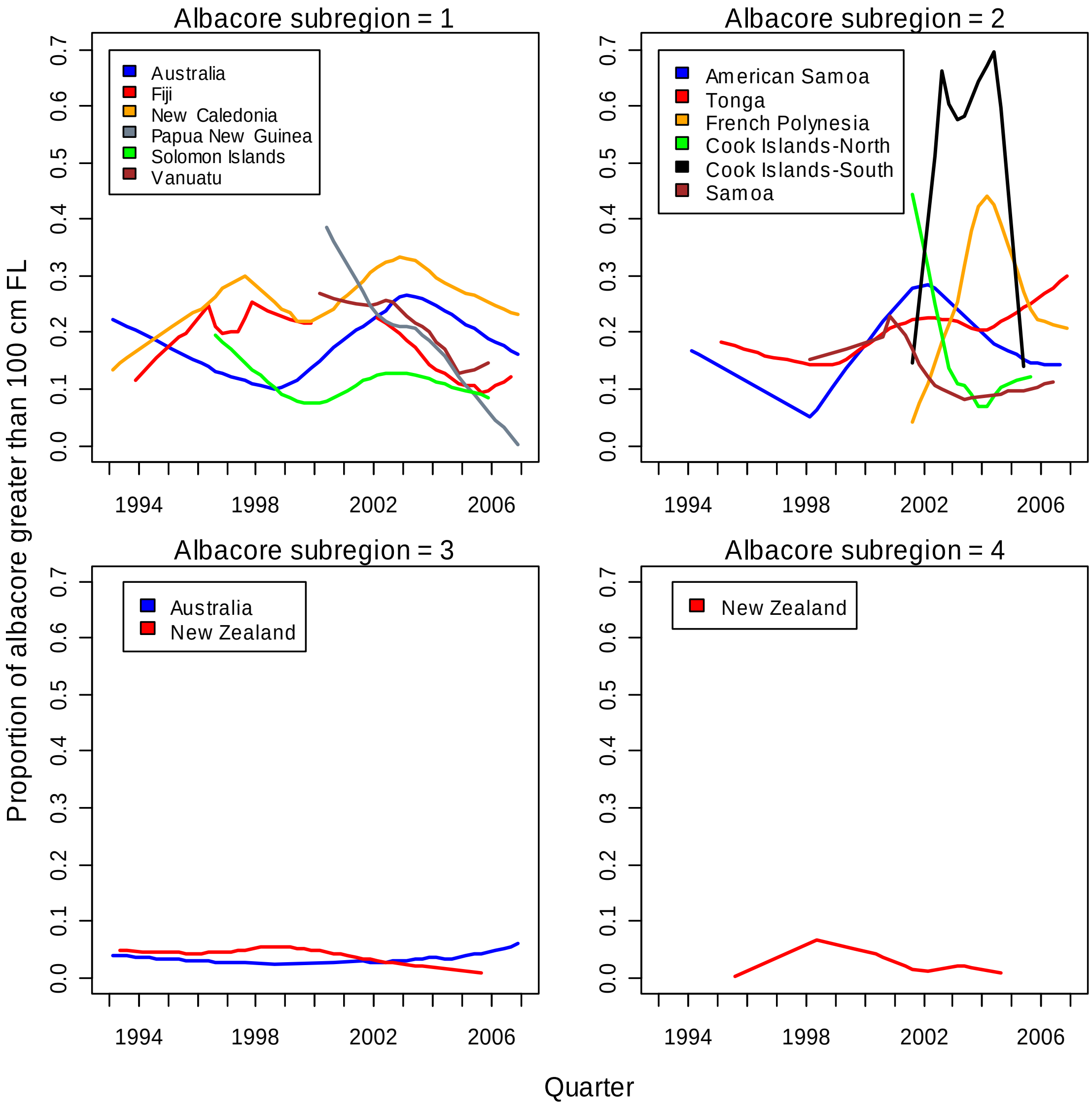


Figure 22. Lowess fits of the proportion of albacore greater than 100 cm FL within longline catches of each EEZ of each model sub-region of the albacore assessment, 1993–2006. Source: length-frequency database held at SPC.

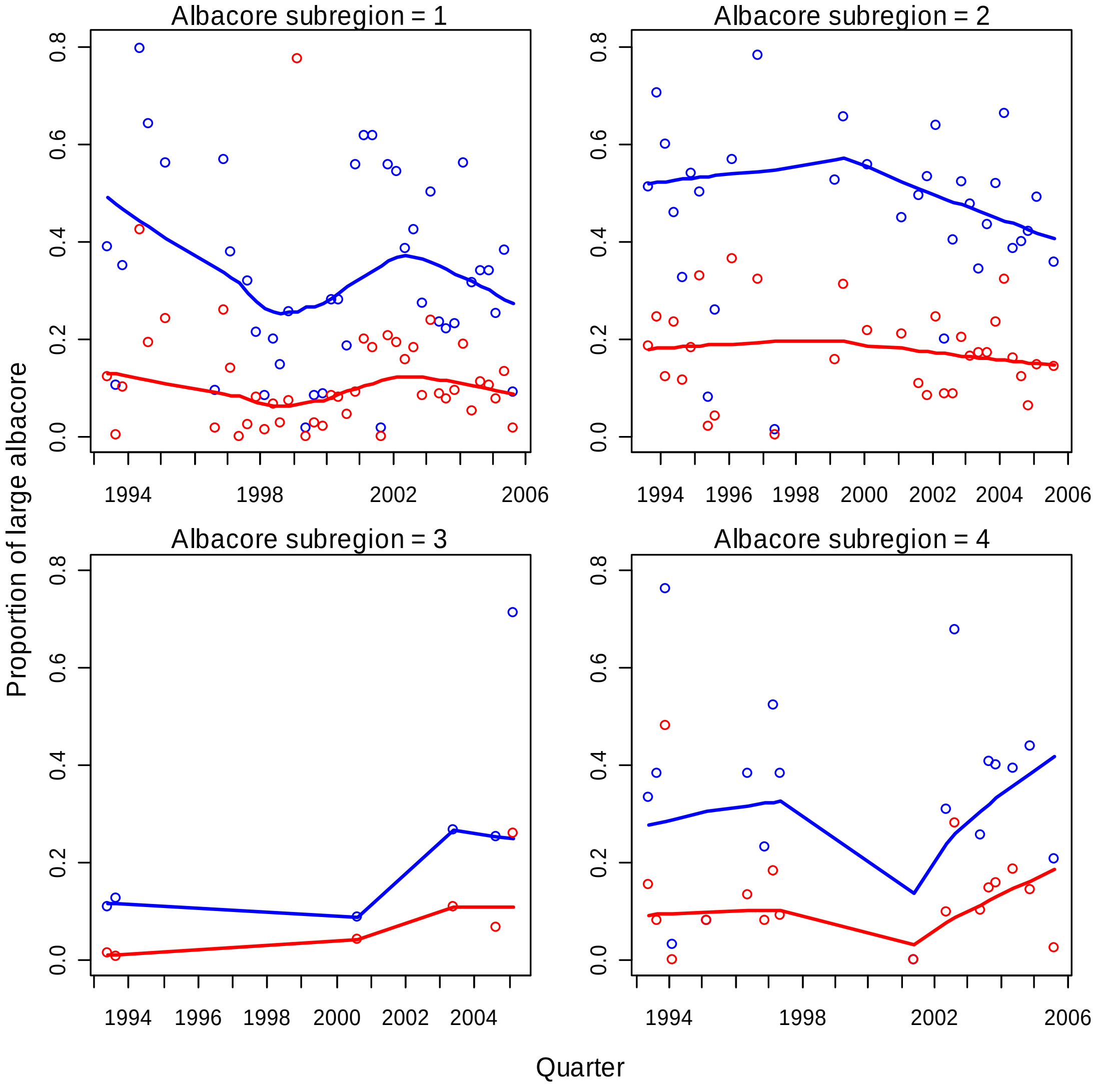
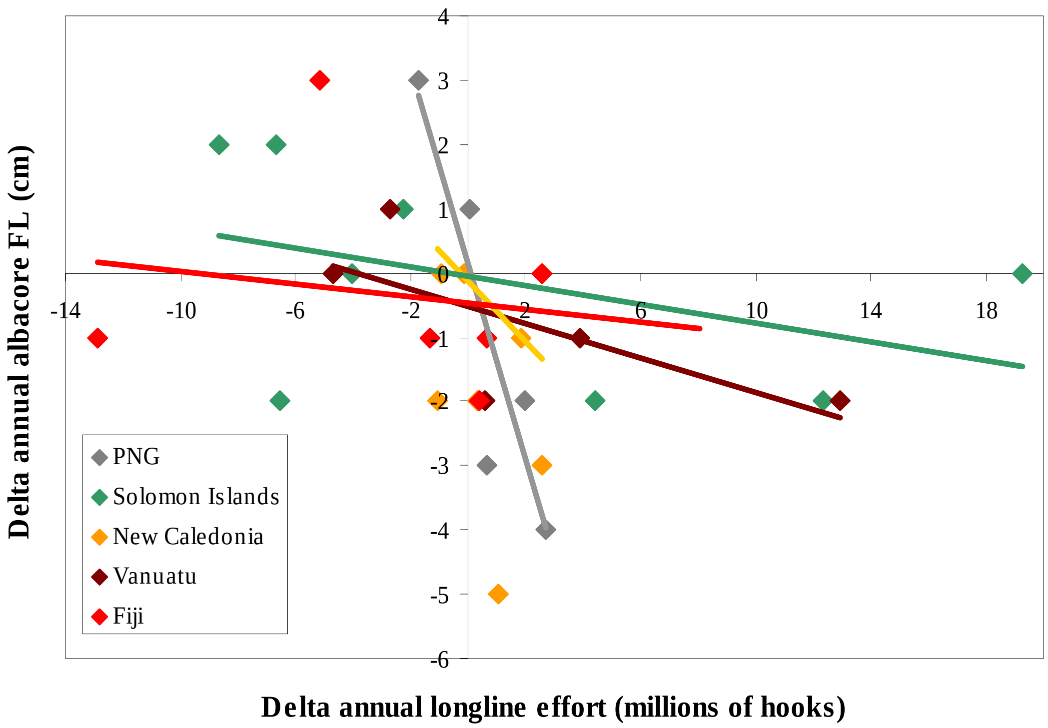


Figure 23. Proportion of albacore greater than 95 cm FL (blue points) and 100 cm FL (red points) in longline catches by the Taiwanese longline fleet operating within each model sub-region of the albacore assessment, 1993–2006. Source: length-frequency database held at SPC. Lines represent lowess fits to each data series.



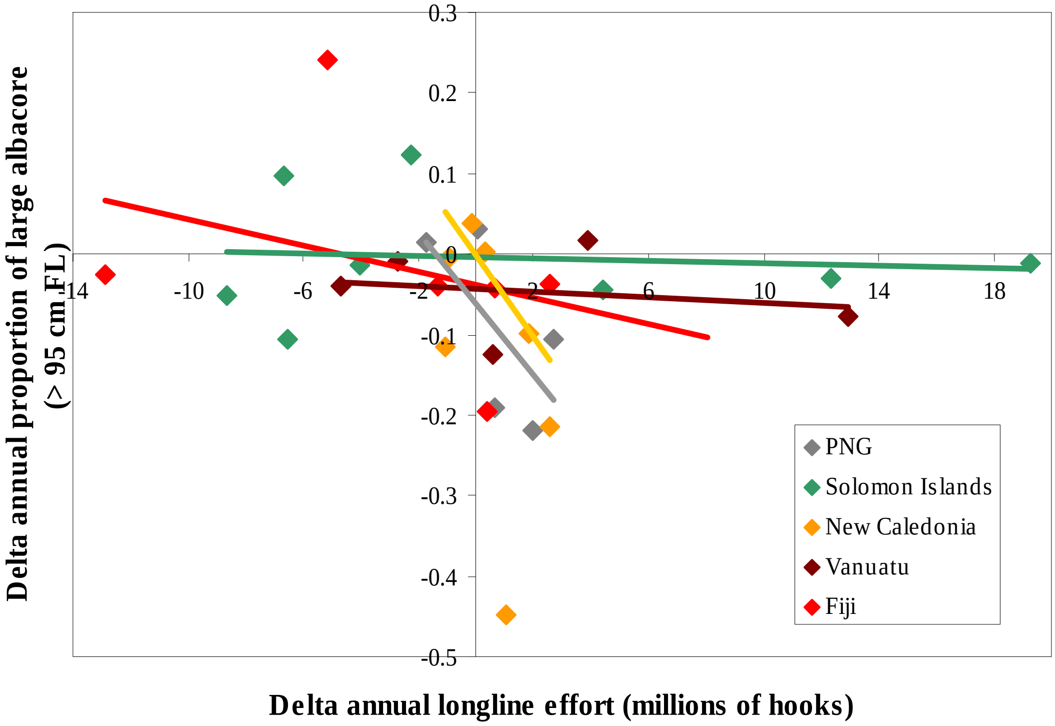
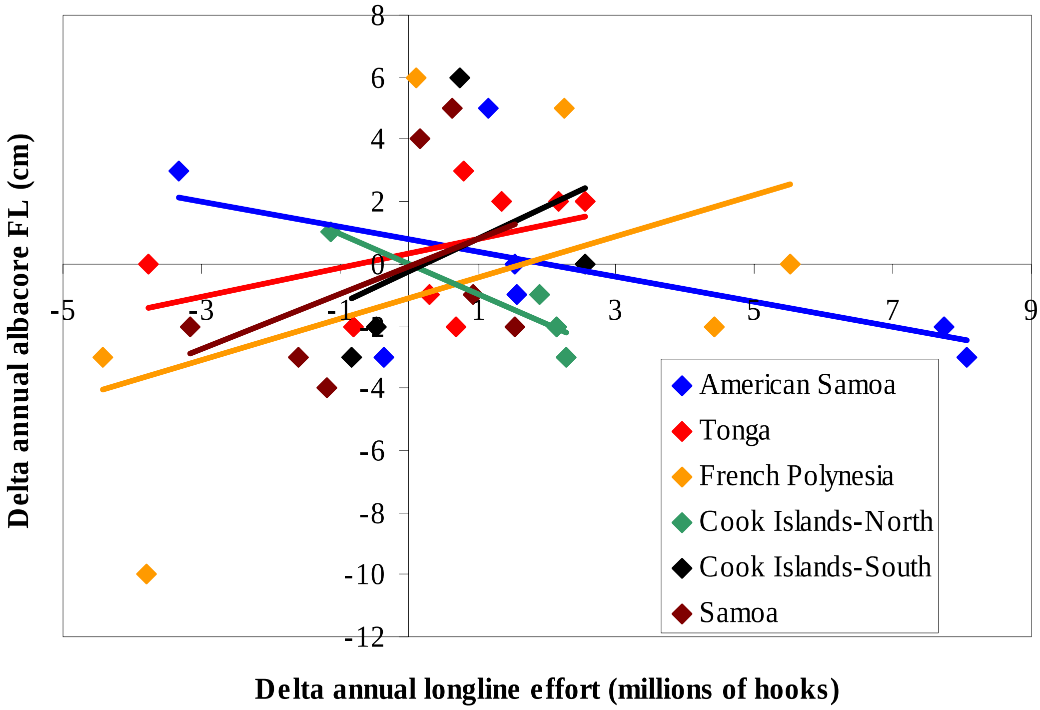


Figure 24. Correlations between changes in median annual albacore FL (y-axis, delta annual albacore FL (cm)) (upper figure) and change in the proportion of albacore greater than 95 cm FL (y-axis, delta annual proportion of large albacore (> 95 cm FL)) (lower figure) and changes in annual effort (x-axis, delta annual longline effort (millions of hooks)) in sub-region 1 of the albacore assessment model, 1997–2005. Each point represents the change in annual effort and FL between consecutive years for each EEZ. Sources: raised logsheet data and length-frequency data held at SPC.



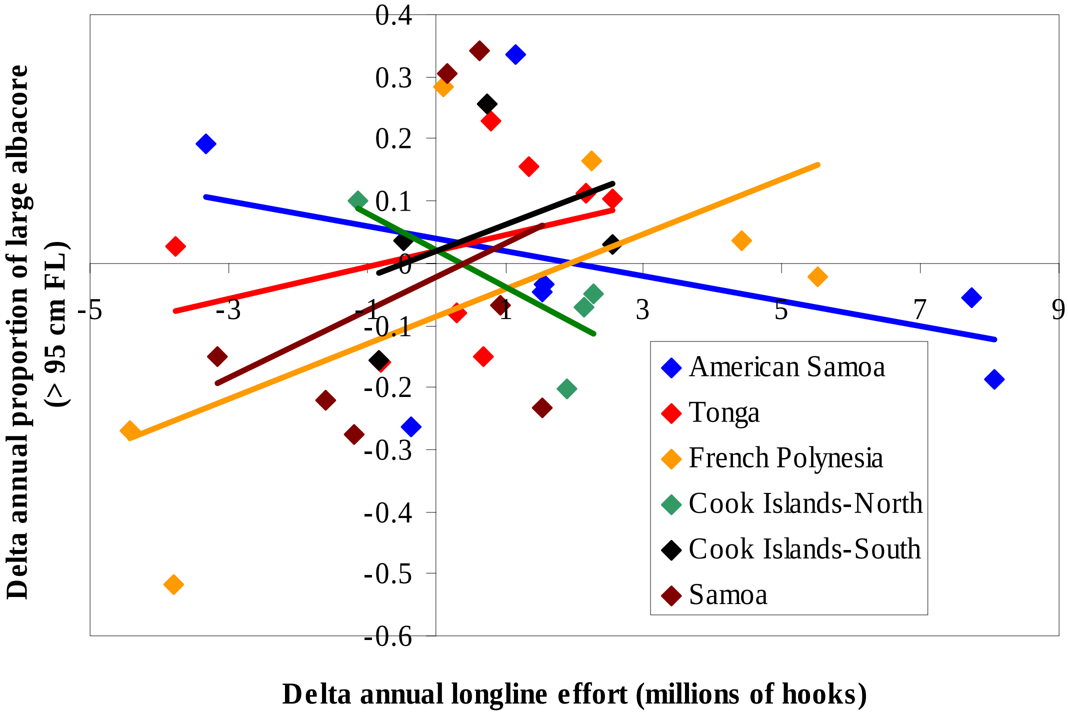


Figure 25. Correlations between changes in median annual albacore FL (y-axis, delta annual albacore FL (cm)) (upper figure) and change in the proportion of albacore greater than 95 cm FL (y-axis, delta annual proportion of large albacore (> 95 cm FL)) (lower figure) and changes in annual effort (x-axis, delta annual longline effort (millions of hooks)) in sub-region 2 of the albacore assessment model, 1997–2005. Each point represents the change in annual effort and FL between consecutive years for each EEZ. Sources: raised logsheet data and length-frequency data held at SPC.

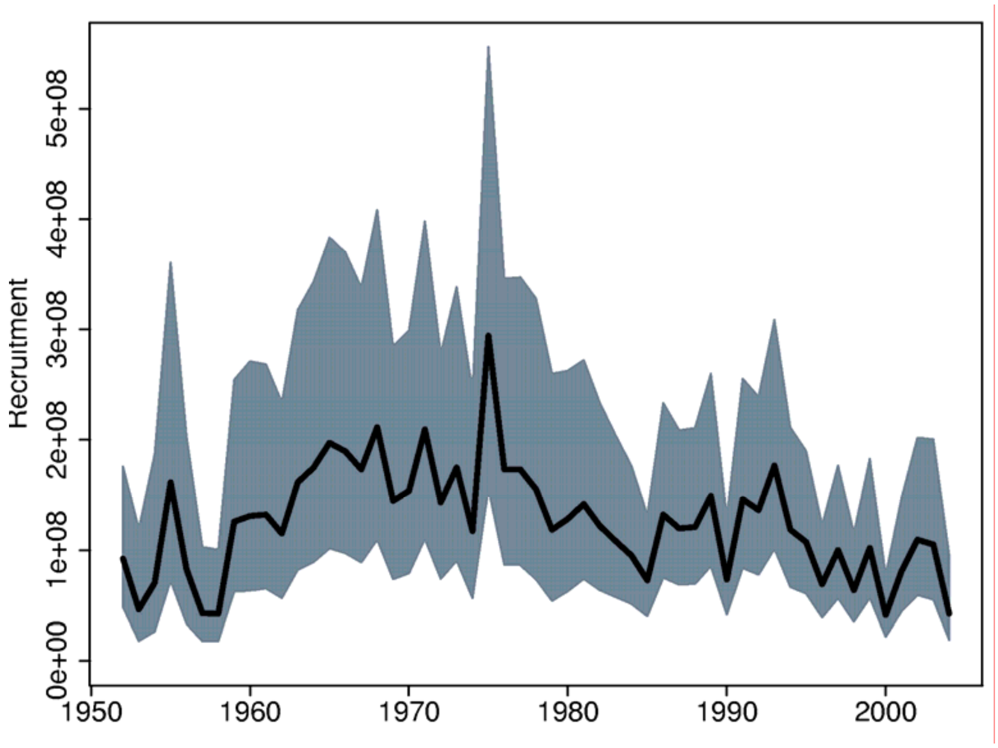


Figure 26. Annual recruitment (number of fish) estimated from the one region model of the most recent albacore stock assessment. The shaded area indicates the approximate 95% confidence intervals. Source: Langley and Hampton (2005).

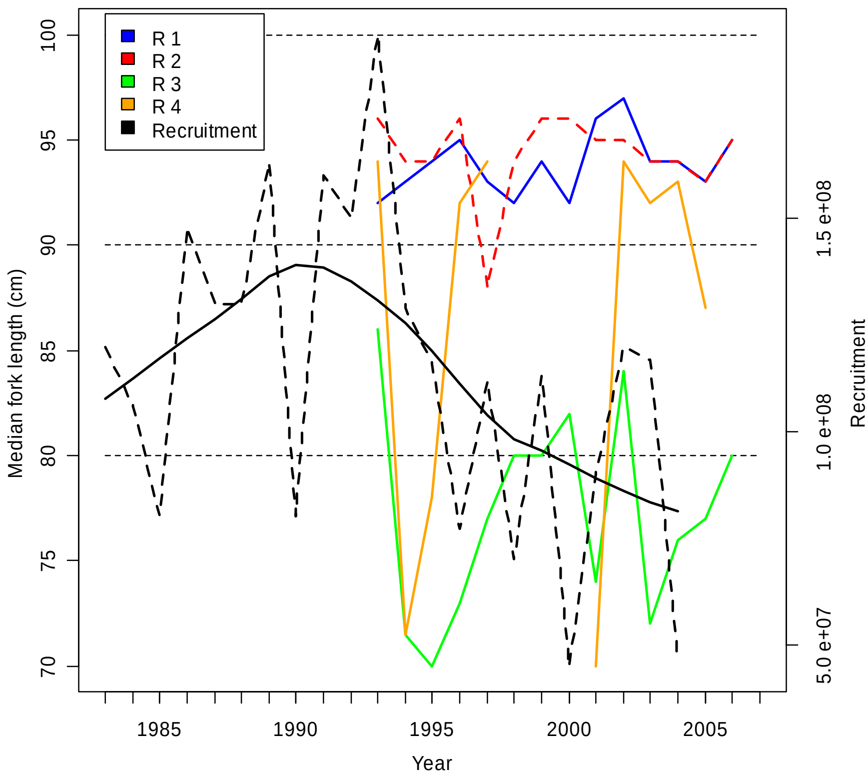


Figure 27. Annual median fork length of albacore for each sub-region of the albacore assessment model and estimated recruitment of albacore from the most recent stock assessment model, 1984–2006. The median size of region 2 is dotted as the trends for both region 1 and 2 lie across each other from mid-2003. The solid black line represents a lowess fit to the recruitment

estimated from the MFCL model. Sources: Langley and Hampton (2005) and length-frequency data held by SPC.

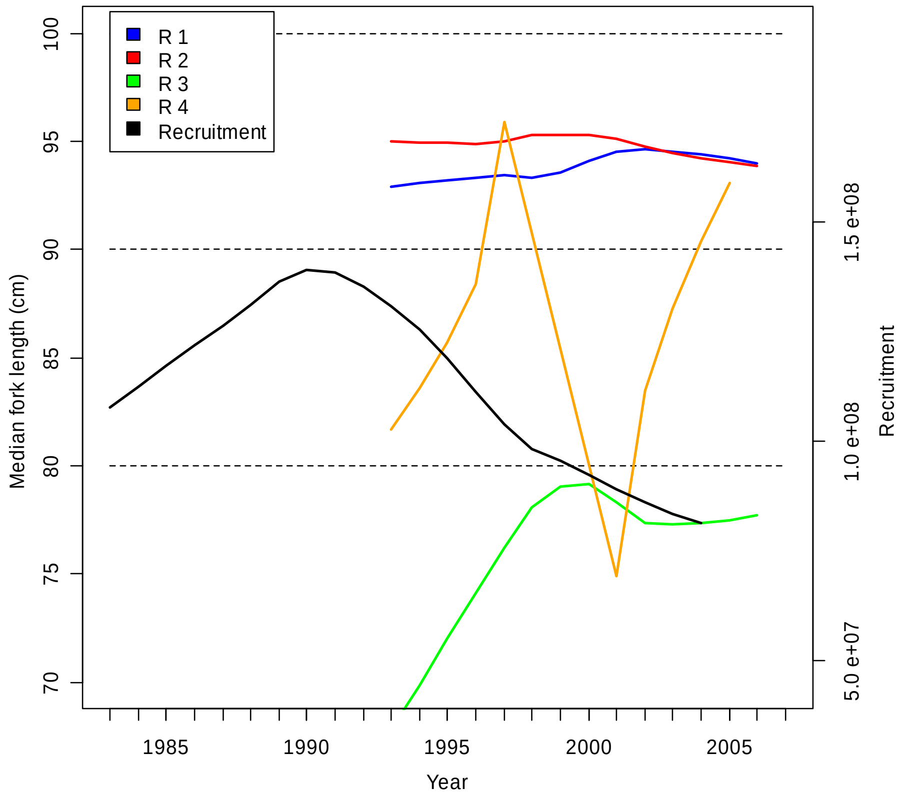


Figure 28. Lowess smoothed fits to annual median fork length of albacore for each sub-region of the albacore assessment model and estimated recruitment of albacore from the most recent stock assessment model, 1984–2006. Sources: Langley and Hampton (2005) and length-frequency data held by SPC.

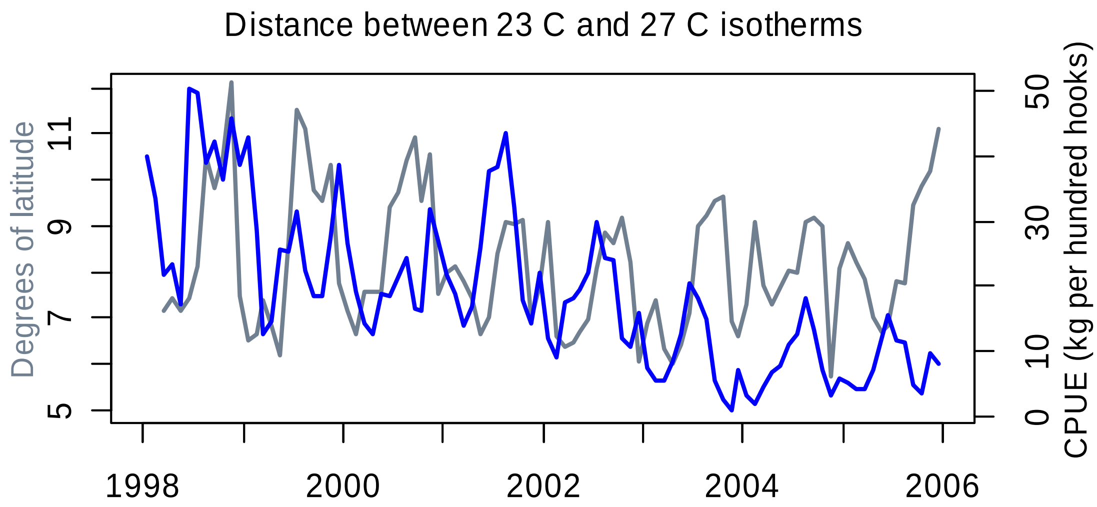


Figure 29. Monthly distance between the latitudes of the 23ºC and 27ºC isotherms (grey line) and nominal albacore catch rates (kg.hhooks^{-1}, blue line) in the Tonga EEZ, 1998–2006. Sources: NCEP data and logsheet data held by SPC.

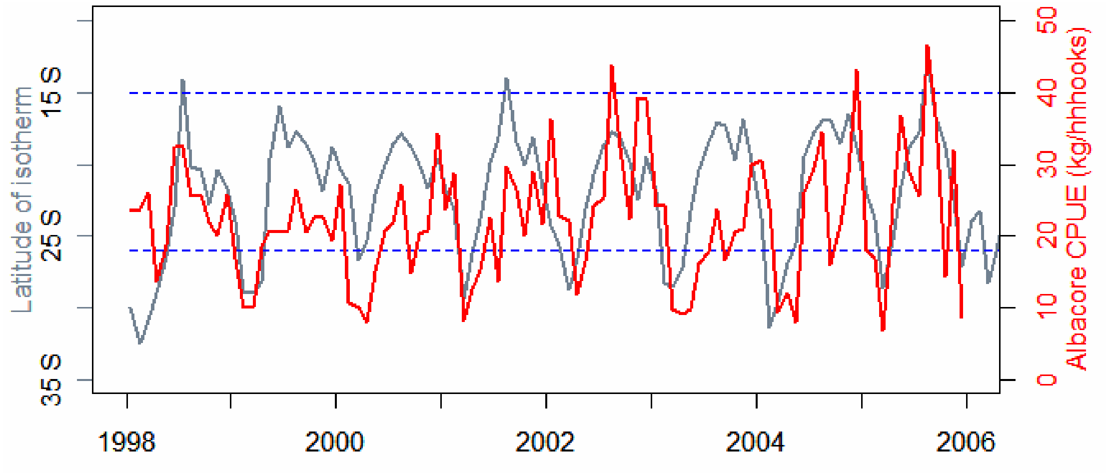


Figure 30. Relationship between the monthly latitudinal position of the 25°C isotherm of SST (grey line) and nominal albacore catch rates (red line) in the vicinity of the New Caledonia EEZ, 1998–2005. Sources: NCEP data and logsheet data held by SPC.

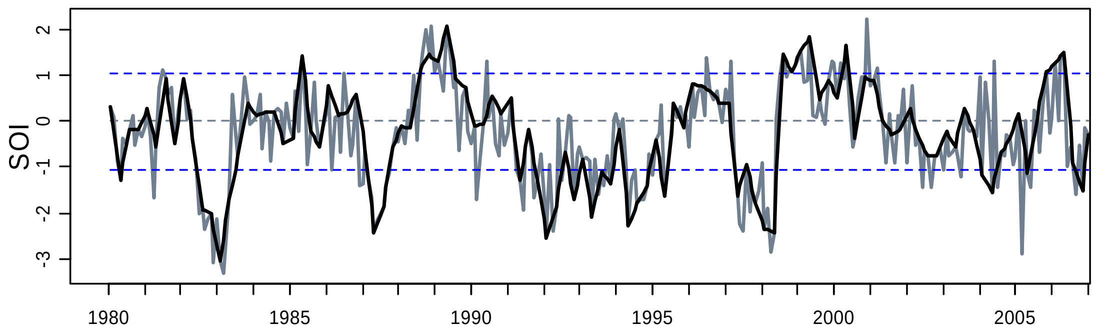


Figure 31. Monthly values of the southern oscillation index (SOI) (grey line) and quarterly smoothed fit (black line), 1980–2006. Source, Bureau of Meteorology, Australia (www.bom.gov.au/climate/enso/index.shtml). The SOI is calculated from the monthly difference in surface air pressure between Darwin and Tahiti. Negative SOI values indicate *El Niño* or warm event periods; positive SOI values indicate *La Niña* events. The horizontal grey dotted line indicates the average value of the series (0). Blue dotted lines represent +/- one standard deviation from the mean (0).

Appendix 1. Annualised series of selected data.

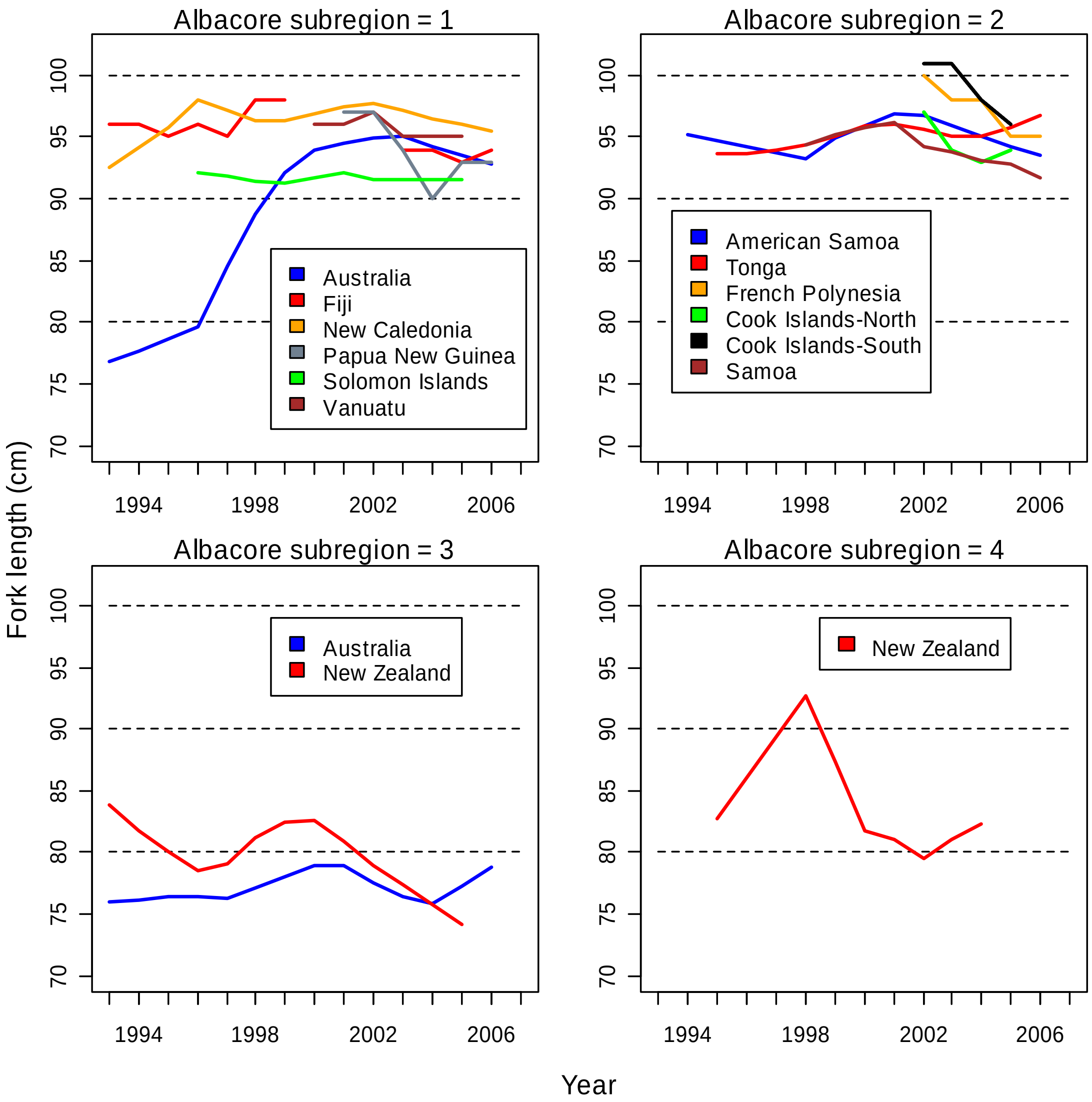


Figure A.1. Trends in annual median albacore fork length (cm) for longline fisheries by EEZ in each sub-region of the albacore assessment model, 1993–2006. Source: length-frequency database held by SPC.

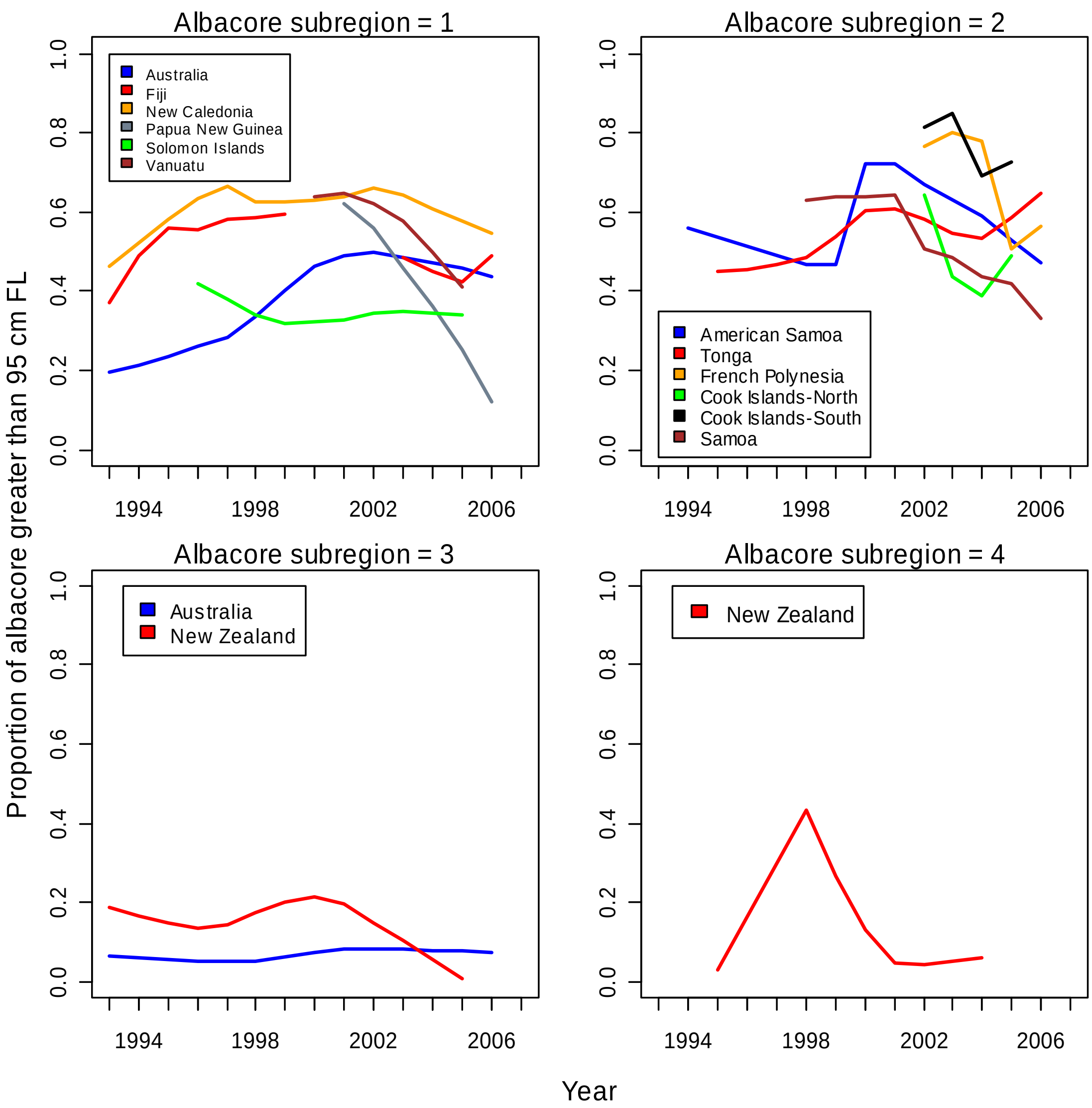


Figure A.2. Annualised lowess fits of the proportion of albacore greater than 95 cm FL within each EEZ of each model sub-region of the albacore assessment, 1993–2006. Source: length-frequency database held at SPC.

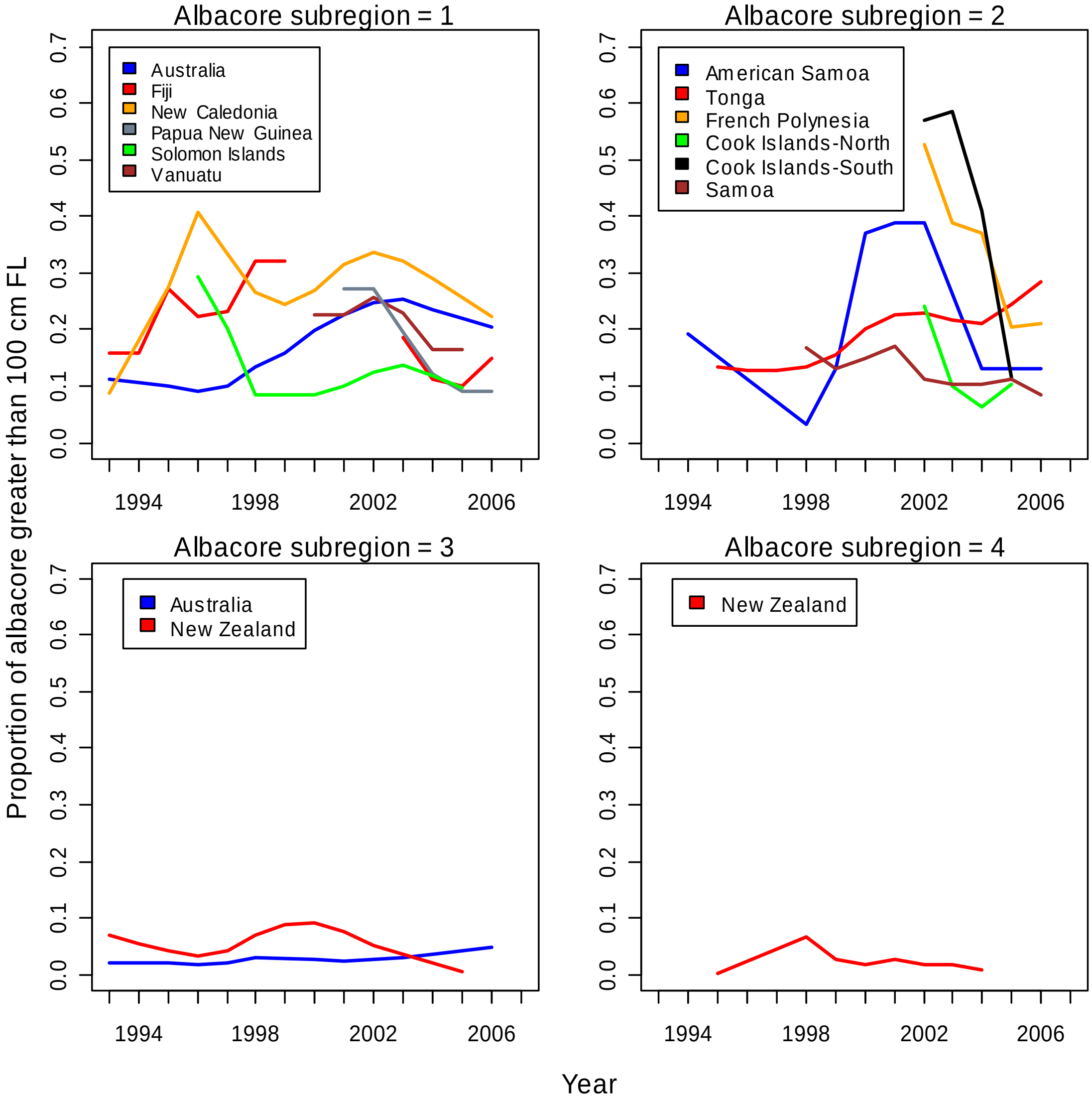


Figure A.3. Annualised lowess fits of the proportion of albacore greater than 100 cm FL within each EEZ of each model sub-region of the albacore assessment, 1993–2006. Source: length-frequency database held at SPC.