SPAR6/WP.4

SIXTH SOUTH PACIFIC ALBACORE RESEARCH (SPAR) WORKSHOP

Rarotonga, Cook Islands, 5 - 7 March 1996

SOUTH PACIFIC STOCK ASSESSMENT USING THE REGIONALIZED SPARCLE MODEL

by

John Hampton
and
David Fournier

South Pacific Albacore Stock Assessment Using the Regionalized SPARCLE Model

John Hampton and David Fournier

Introduction

A preliminary analysis of South Pacific albacore length frequency, catch and effort data using the SPARCLE (South Pacific Albacore Research Catch at Length Estimator) model was presented in SPAR 5/WP.12. SPARCLE is an age-structured, likelihood-based catch-at-length model, which analyzes length frequency samples using an extension of the MULTIFAN concept (Fournier et al. 1990). The model differs fundamentally from catch-at-age models typically applied to tuna data (i.e. sequential cohort analysis) in several respects:

- A "separable" parameterization of fishing mortality into selectivity and catchability components enables the model to be fit to the data using a robust likelihood technique.
- The fitting procedure deals with the estimation of catch-at-age from the length frequency data and the various parameters of the catch-at-age model simultaneously, rather than sequentially.
- The model incorporates both persistent, random changes in catchability and transient, random deviations in the effort-fishing mortality relationship. Both effects can be estimated, allowing changes in catchability over time to be estimated.
- Confidence intervals on estimated relative recruitment and relative biomass time series (and other model parameters) can be estimated by virtue of the likelihood fitting procedure. Such confidence intervals incorporate the uncertainty in deriving age composition from length frequency samples.
- In principal, the likelihood-based approach allows the estimation of the natural mortality rate, which is impossible with sequential cohort analysis.

Since the analysis presented at SPAR 5 was carried out, several technical enhancements have been made to the model. Principal amongst these is the addition of one-dimensional spatial structure. This was necessary to deal with the recent expansion of Taiwanese longline effort in the southern region of the fishery and to acknowledge the apparent north-south size stratification of the albacore population in the South Pacific. This new feature is incorporated into the current analysis.

Two other significant additions to the model have also been made, but there has been insuffient time to incorporate this additional structure into the current analysis. The first of these additions involves density-dependent growth, whereby the growth rates of individual cohorts are influenced by their abundance. There are preliminary indications in the albacore data that large cohorts tend to grow more slowly and small cohorts more quickly than average. The second addition involves the incorporation of seasonal variation in catchability. There are strong indications from the CPUE time series of all fisheries that South Pacific albacore catchability varies seasonally. Both of these additions to the model are likely to result in a significant improvement in the fit, and are priorities for further development of the analysis.

Several additions and refinements to the SPAR database have also been made since SPAR 5. The previous analysis included data up to the end of 1991. Since that time, data from most of the fleets have been updated to at least the end of 1993. At the time of the previous analysis, historical length frequency data for the longline fishery for the most part did not have any spatial resolution and were aggregated by year. This was a major constraint on the previous analysis because it is well known that the size of albacore caught by longliners varies strongly with latitude and that fishing is highly seasonal. With the cooperation of the NMFS Honolulu Laboratory, length-frequency samples for Japanese, Korean and Taiwanese longliners unloading at Pago Pago dating back to 1962 are now available on a 5° square-month basis. In the present analysis, we were therefore able to stratify the longline fishery by three latitudinal bands with a quarterly time resolution.

This paper presents the most recent analysis of SPAR catch, effort and length frequency data, as outlined above. We do not present the full technical specifications of the model or the estimation procedure here. This is in the process of being documented in a separate paper for publication. That paper also contains extensive simulation testing of the model. A preliminary draft of the manuscript can be made available to interested SPAR participants on request.

Data Structure

The fundamental data structure of the model is based on the notion of a fishery, which is thought of as a collection of fishing units having similar catchability and selectivity characteristics. In the SPAR 5 analysis, we defined four fisheries, a New Zealand domestic troll fishery, a troll fishery operating in the sub-tropical convergence zone (STCZ) of the central Pacific, a driftnet fishery and a longline fishery. In the present analysis, we have maintained the previous definitions of the New Zealand troll, STCZ troll and driftnet fisheries. However, as foreshadowed earlier, the longline fishery has been further stratified. First, the distant-water fleets of Japan, Korea and Taiwan have been separated from the fleets of small-scale, domestic longliners, mostly using monofilament gear, that have developed in several Pacific Island countries in recent years. Second, the distant-water fleet activities have been stratified by three latitudinal bands: 0–10°S, 10°–30°S and south of 30°S. The age structure of the albacore stock in these regions appears to be different, resulting in different selectivity by longline gear. Also, targeting practices differ, resulting in differences in catchability. The definition of fisheries in the present analysis is therefore:

Fishery 1:	DWFN longline, 0–10°S
Fishery 2:	DWFN longline, 10–30°S
Fishery 3:	DWFN longline, south of 30°S
Fishery 4:	Domestic longline
Fishery 5:	New Zealand troll
Fishery 6:	STCZ troll
Fishery 7:	Driftnet

With the addition of spatial structure to the model, each fishery must be uniquely associated with a particular region. Denoting the three regions above as region A (0–10°S), region B (10–30°S) and region C (south of 30°S), we have the following association of fisheries and regions:

Fishery 1:	DWFN longline	Region A
Fishery 2:	DWFN longline	Region B
Fishery 3:	DWFN longline	Region C
Fishery 4:	Domestic longline	Region B
Fishery 5:	New Zealand troll	Region C
Fishery 6:	STCZ troll	Region C
Fishery 7:	Driftnet	Region C

Each occurrence of a fishery at a particular time is termed a fishing incident. In reality, fishing is more or less continuous, so the data for each fishery need to be aggregated over appropriate time intervals. For the longline fisheries (1–4), which occur continuously throughout the year, quarterly time periods are sufficient to capture the seasonal variation. The surface fisheries (5–7) tend to operate during the summer months only, therefore monthly time periods are used for these fisheries.

The history of effort and catch per unit effort (CPUE) for each fishery is shown in Figure 1.

Regionalized SPARCLE Model

While we are avoiding most of the technical details of the model in the paper, the addition of spatial structure requires some consideration as it involves a fundamental change in the interpretion of how the model works. The South Pacific is divided into three regions, denoted A, B and C, as described above. Fisheries are defined according to these regions. At the population level, instead of considering a spatially homogeneous population at age as we had with the previous model, we now attempt to keep track of numbers at age in each region. In order to do this, we need to make two assumptions:

1. Recruitment (i.e. the appearance of age 3 fish in the population) occurs only in region C. This is largely consistent with the capture of small albacore mainly in region C in coastal waters of New Zealand and in the STCZ. The assumption requires that pre-recruits move south from the spawning area (which is mainly in region B) into region C before age 3. It is possible that this assumption could be relaxed (i.e. estimate recruitment independently for each region), but it may not be possible to obtain a stable solution under these conditions.
2. Fish move among regions according to a one-dimensional diffusion-like process. Movement is parameterized in terms of three parameters, two of which determine the distribution of a cohort at equilibrium, while the third determines the speed at which this equilibrium distribution is approached. These parameters appear to be estimable (although they are probably poorly resolved) from the albacore fisheries data stratified by region. It is possible that tagging data could be used to refine the movement parameters. In any event, this simple representation of movement seems

to be sufficient to move the fish among regions in a way that is consistent with the estimated catch age structure in those regions.

The interpretation of some of the model results needs to be modified when spatial structure is incorporated. Fishery-related parameters such as selectivity need to be interpreted in relation to the region in which the fisheries occur. For example, we might expect higher selectivity coefficients than those obtained in the previous analysis for older fish in fisheries operating in region C, to compensate for the fact that the population resident in this region is biased towards younger fish. Previously, selectivity coefficients were based on the entire population, regardless of the location of the fishery.

Fitting Procedure

We have obtained some preliminary fits of the regionalized model to the SPAR data. The fitting procedure involved obtaining initial fits to the data with various parameters held fixed, after which these parameters were sequentially relaxed so that ultimately all parameters were estimated simultaneously. The sequence of parameter relaxation was as follows:

1. selectivity coefficients, initial cohort sizes, growth parameters (except *K*), average catchability coefficients, catchability deviations
2. movement parameters
3. catchability trends
4. von Bertalanffy growth parameter *K*
5. natural mortality rate

We assumed the presence of nine significant age classes in the data, which was the appropriate number of age classes estimated for the previous spatially aggregated analysis. According to the growth parameters estimated in the present analysis, these age classes correspond to ages 3 to 11+ years. Note that the catch equations of the model are structured so that the oldest age class is a cummulative age class, consisting of fish that age and older. Ultimately, we will need to fit the regionalized model with different numbers of assumed age classes and carry out statistical tests to determine the appropriate number of age classes for this model.

We used two different starting values for the natural mortality rate, M, 0.2 and 0.4 yr^{-1}. When M was eventually relaxed, both of the fits converged to the same solution. This encourages us to believe that the solution obtained is global, rather than local, at least with respect to M, which is a notoriously difficult parameter to estimate. Ultimately, we will need to use different starting values for other parameters, such as K and the movement parameters, to increase our confidence that an overall global solution has been found.

Results

Selectivity Coefficients

Selectivity coefficients (Figure 2) for the longline fisheries show an increasing trend with age. The differences among fisheries 1, 2 and 3 are in line with observations of increasing average size of longline-caught albacore from south to north. We originally tried fitting the model with the selectivities for fisheries 1, 2 and 3 constrained to be equal. However, a significantly improved fit was obtained when this assumption was relaxed. This suggests that differences in the size composition of longline catches in the three regions are not entirely due to the size structure of the albacore populations in those regions - other factors such as targeting may also have an effect.

The New Zealand troll fishery selectivities also increase with age, in order to accommodate occasional length frequency samples containing larger fish from that fishery. In the previous SPARCLE analysis, where selectivity coefficients were relative to the overall population rather than to the population in the region of the fishery, the New Zealand troll selectivities were more directed towards the younger age classes.

Catchability Coefficients

Estimated catchability time series are plotted with catchability deviations, by fishery, in Figure 3. Strong trends in catchability are evident in the longline fisheries. For the DWFN fisheries (fisheries 1-3), catchability is estimated to have declined substantially during the late 1960s and 1970s. At this stage, these longline fisheries are aggregated across the Japanese, Taiwanese and Korean fleets, which are known to have targeted albacore to different extents over time. It is possible, therefore, that the estimated trends in catchability to some extent reflect both the changing fleet composition in the three regions and changing targeting practices by those fleets over time. In recent years, catchability in fisheries 2 and 3 has increased somewhat. For fishery 4, which is assumed to operate in region B, catchability has shown a consistent increasing trend over time. For the troll and driftnet fisheries, no clear trends in catchability are evident.

Catchability deviations show a wide scatter about the estimated catchability trends. Much of this scatter is due to seasonal variation in catchability. We have made an attempt to estimate this seasonal variation in the previous spatially aggregated model, with some success. This feature will also be incorporated into the regionalized model in due course.

Exploitation Rates

Exploitation rates (the proportion of the population harvested per year) for two age groups, corresponding approximately to 4-7 years and 8-11+ years, have been estimated, along with their 95% confidence intervals (Figure 4). Overall, the exploitation rates are low, and are lower for the younger age group (primarily exploited by the surface fisheries) than for the older age group (primarily exploited by the longline fisheries). For the 4-7 year group, the exploitation rate surged in the late 1980s at the time of the driftnet fishery. Prior to the mid-1980s, exploitation of this group was inconsequential, as it was restricted to minor catches of these age classes by longliners. For the older age group, exploitation rate declined through the 1960s and 1970s from a high of around 0.15. Since the mid-1980s, exploitation rate has increased slightly, with the most recent estimate in the vicinity of 0.05. Note that these recent exploitation rates are consistent with the range of estimates obtained from albacore tagging data - a tag reporting rate of 0.2-0.3 (which is entirely conceivable) results in a tagging-based exploitation rate estimate of 0.05 (Bertignac et al. 1996).

Natural Mortality Rate

In the previous SPARCLE analysis, it was not possible to estimate biologically meaningful values of M from the available data. With the regionalized model, we have, for the first time, been able to obtain an estimate of M that is reasonably consistent with expectation, 0.53 yr^{-1}, with 95% confidence intervals of 0.49-0.58 yr^{-1}. As indicated above, this estimate was arrived at from two different starting values, 0.2 and 0.4 yr^{-1}. We believe that estimation of M has been enabled by the better resolution of historical longline length frequency data in combination with the various structural improvements to the model.

Growth Parameters and Catch Age Composition

The estimation of catch age composition from length composition assumes, amongst other things, that albacore grow according to a von Bertalanffy growth curve. We use a parameterization such that growth is specified by three parameters - the mean length of the first age class (47.7 cm), the mean length of the last age class (98.1 cm), and growth coefficient K (0.17 yr^{-1}). These parameters can be transformed to provide the usual von Bertalanffy growth parameter L_∞ (115.6 cm). These parameters imply a growth increment of about 10 cm after one year for a 50 cm albacore. This growth increment is somewhat less than that derived on the basis of tagging data (13.85 cm - Bertignac et al. 1996), but is probably within the bounds of uncertainty of that analysis.

In determining age composition from length composition, we also assume that the standard deviation (SD) of length at age is a linear function of age. The SD for the first age class is estimated to be 3.09 cm, while the ratio of the SDs of the first to the last age classes is 0.29. The fit of the model to the length data in terms of the correspondence of estimated mean lengths at age to obvious modes in the length frequency samples appears to be good for most of the fisheries (Figure 5).

Movement Parameters

The estimated movement parameters can be converted to annual exchange rates between regions for ease of interpretation. The annual rate of movement from region C (the recruitment region) to region B is 14.5%; from region B to region A and region C is 2.3%; and from region A to region B is 2.2%. These exchange rates result in a net "flow" of albacore from south to north.

Recruitment and Population Biomass

The time series of recruitment and population biomass are key outputs of the model from a stock assessment viewpoint. The time series can be looked at in terms of absolute or relative quantities. For the recruitment (Figure 6) and biomass (Figure 7) time series, we have plotted both of these measures, with the relative measures normalized to the average recruitment and biomass over the whole time series. As would be expected, the 95% confidence intervals for the relative measures are much tighter than for the absolute estimates.

The recruitment estimates (Figure 6) show an increasing trend through to the mid-1970s and a decreasing trend from the mid-1970s to about 1990. The 1992 recruitment is estimated to be close to the highest of the entire time series, whereas the 1993 level is the lowest. Note, however, that these later estimates of recruitment are associated with the highest uncertainty.

The interannual variability in estimated recruitment appears to be greater than previously estimated using the SPARCLE model, probably due to the greater spatial and seasonal resolution of the longline length frequency data available for this analysis. The low recruitments in 1985 and 1990 that were observed in the previous analysis are also present here. The 1980 recruitment also appears to be lower than average, while recruitment was higher than average during the period 1975-1979.

The biomass estimates (Figure 7) show a strongly increasing trend up to the late 1970s and a decreasing trend thereafter until about 1990. Biomass in the last two years increases, although the confidence limits about these estimates are relatively wide. Relative biomass shows similar trends in the three regions (Figure 8), although the post 1990 upturn is not evident in region A. Biomass is smallest in region A and largest in region C (the recruitment region).

Conclusions

The various structural enhancements to the model, particularly the incorporation of spatial structure, the addition of new data, and the acquisition of historical longline length frequency data of greater spatial and temporal resolution, have all resulted in a more informative assessment of the South Pacific albacore stock. At this stage, the results should be considered preliminary, as further questions concerning the analysis need to be explored. These include:

- testing different numbers of assumed age classes
- using different starting values of various model parameters
- incorporating additional model structure, as appropiate, e.g. seasonal catchability and density dependent growth

In the longer term, we might also investigate improvements that might result from further stratification of the DWFN longline fishery in each region by fleet (i.e. separating Japan, Korea and Taiwan), the incorporation of currently unavailable historical driftnet catch and effort data, the addition of an extra year of data to the analysis when 1994 longline data are available, and the weighting of effort data according to logbook coverage for the various fisheries. Pending the completion of this work, we can offer some observations on the basis of the results obtained to date:

- The estimated exploitation rates on both young and older age groups are relatively low, generally less than 10% per year.
- The trends in recruitment and population biomass are therefore unlikely to have been influenced significantly by the fisheries.
- The low exploitation rate of the younger age classes, even at the height of the driftnet fishery, implies that the surface fisheries are unlikely to have had an observable impact on the longline fishery.
- South Pacific albacore recruitment may be linked to *El Nino* events, with lower than average spawning success or larval survival during such episodes.

The model should be a useful tool for future management of the South Pacific albacore fishery. Two key uses come readily to mind, and would require only minimal adaptation of the existing computer software. First, it would be relatively straight forward to cast the results of the model in a form suitable for comparison with limit or target reference points, as envisaged by the recent UN agreement on straddling and highly migratory fish stocks. This could be done by calculating the probability that a particular reference point would be exceeded under a particular fishing regime. Second, it is possible that the model could be a useful forecasting tool for both the surface and longline fisheries. Given some reasonable model for future recruitment (perhaps random variation about the historical average recruitment, modified by environmental conditions such as *El Nino*), it would be possible to project the stock forward in time. Confidence intervals could also be determined for the projections to capture the uncertainty in future recruitment and the current population state. Such forecasting, if successful, would presumably assist both industry and management decision-making.

References

Bertignac, M., P. Lehodey and J. Hampton. 1996. An analysis of South Pacific albacore tagging data: estimation of movement patterns, growth and mortality rates. Sixth South Pacific Albacore Research Workshop, Working Paper 3. Rarotonga, Cook Islands, 5-7 March 1996.

Fournier, D.A., J.R. Sibert, J. Majkowski and J. Hampton. 1990. MULTIFAN: a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). Can. J. Fish. Aquat. Sci. 47:301-317.

Figure 1. Catch and catch per unit effort (CPUE) by fishery and year quarter.

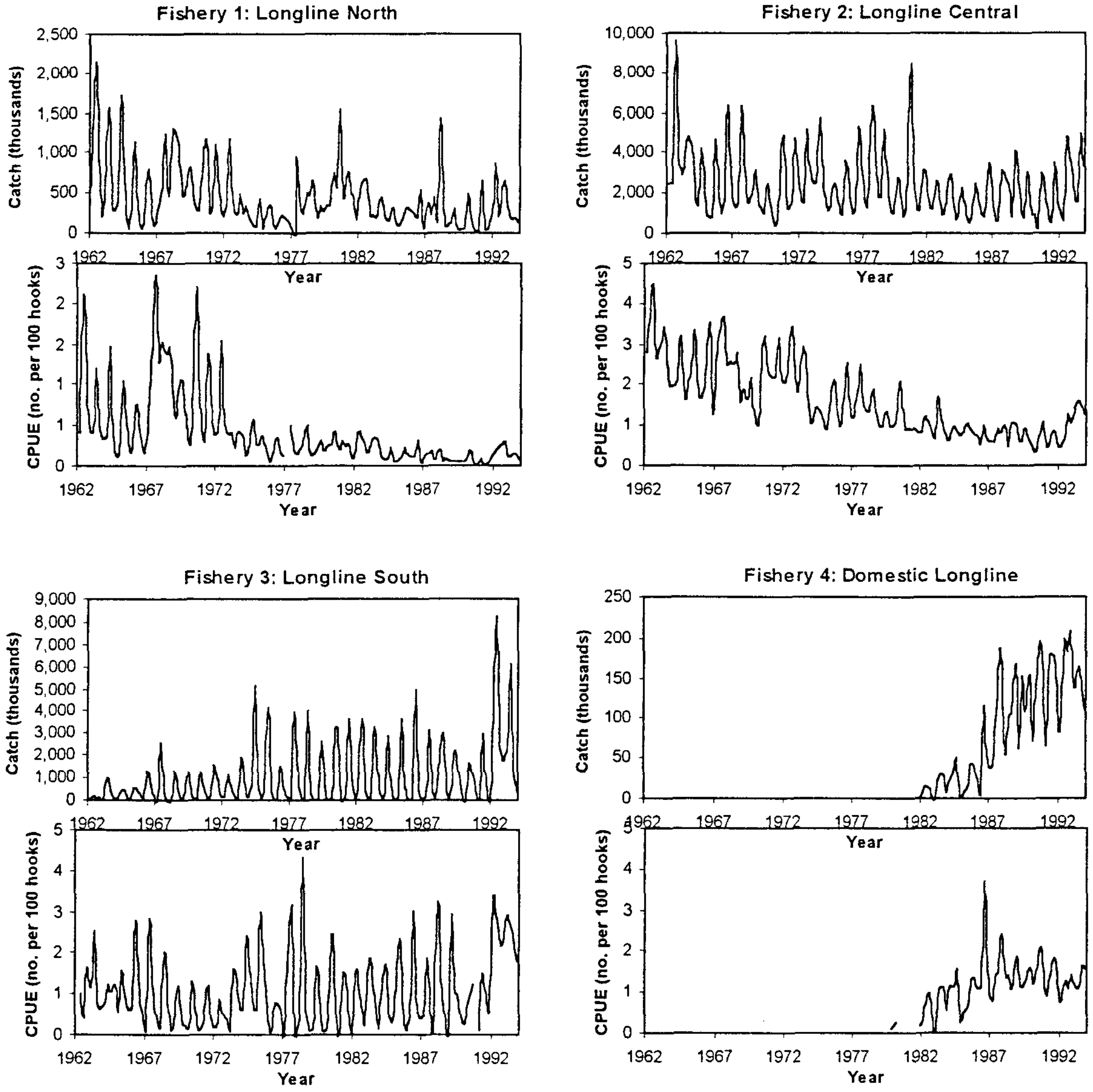
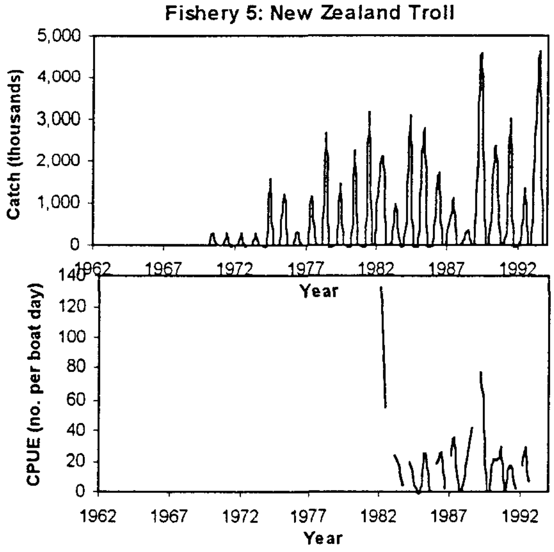
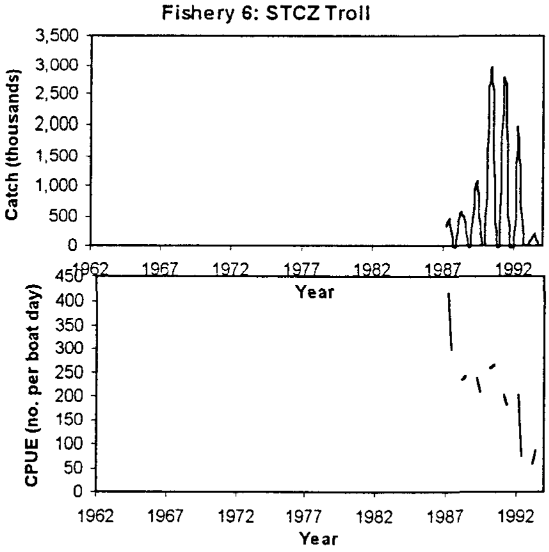


Figure 1. Continued.


Fishery 5: New Zealand Troll


Fishery 6: STCZ Troll

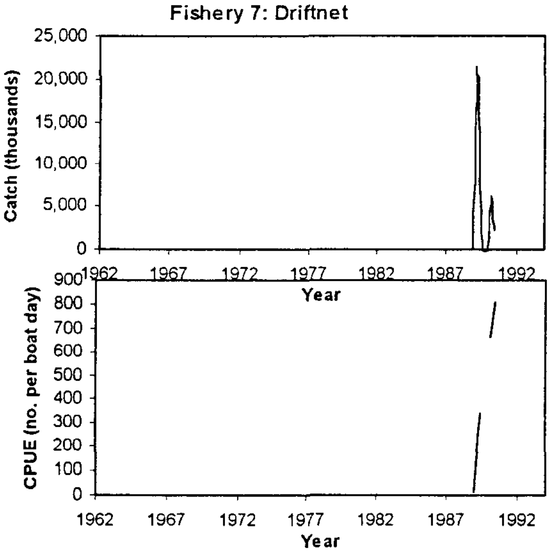

Fishery 7: Driftnet

Figure 2. Estimated selectivity coefficients for each fishery.

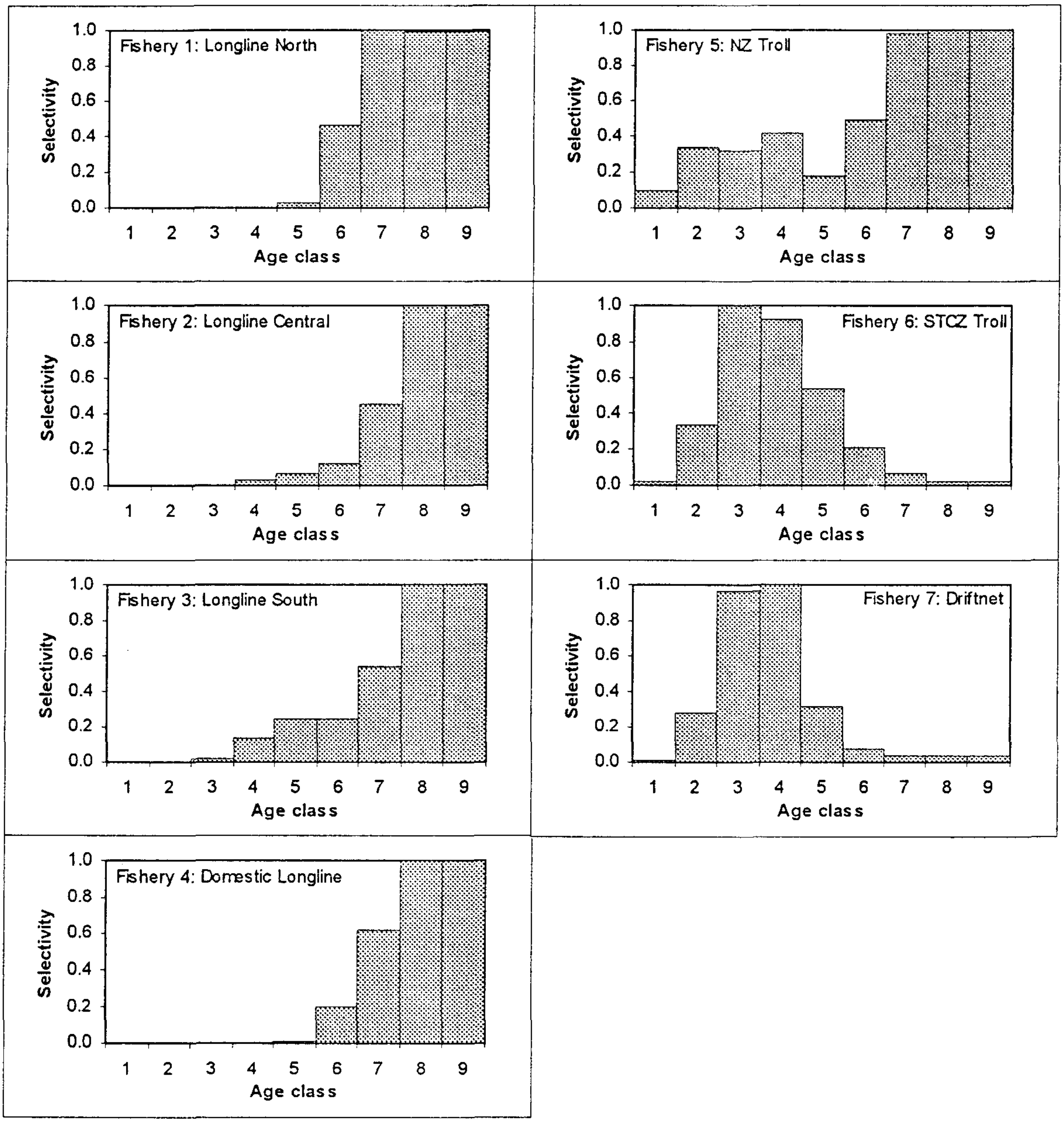


Figure 3. Estimated catchability (solid lines) and deviations from the effort-fishing mortality relationship (dots), by fishery. The "***" indicate deviations beyond the scale of the figures.

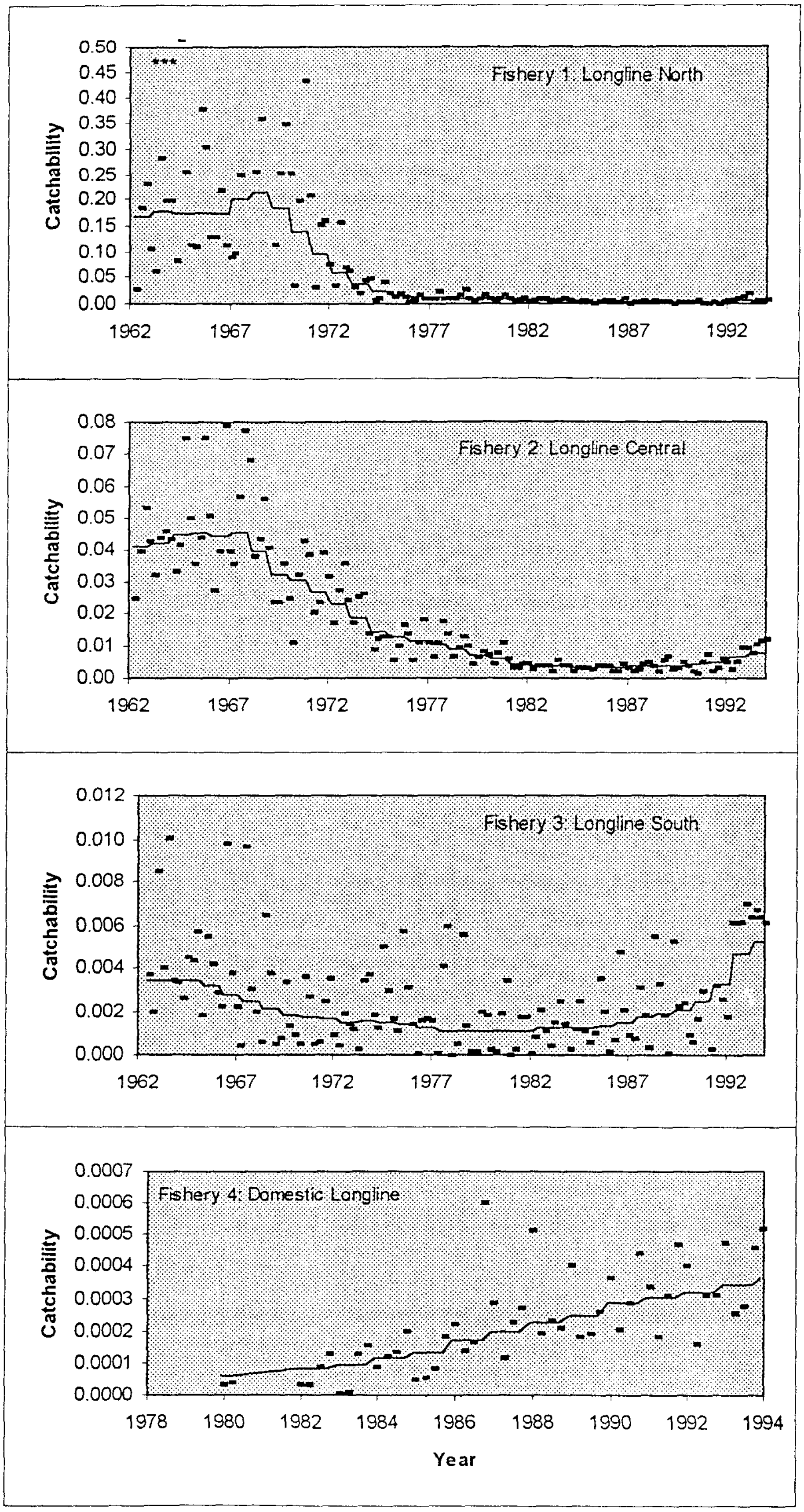


Figure 3. Continued.

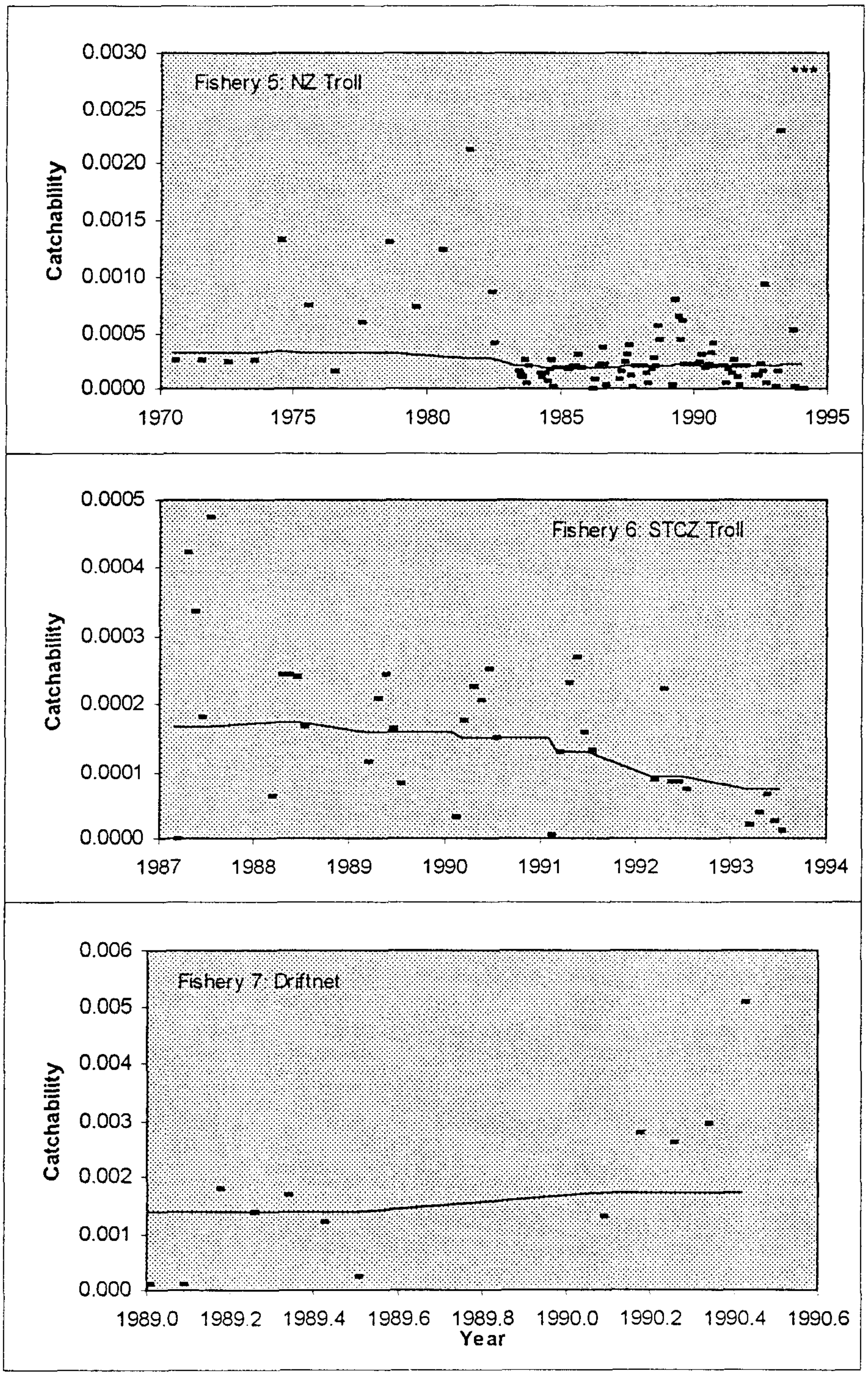


Figure 4. Estimated average annual exploitation rates (heavy lines) and their 95% confidence intervals (thin lines) of ages 4-7 and ages 8-11.

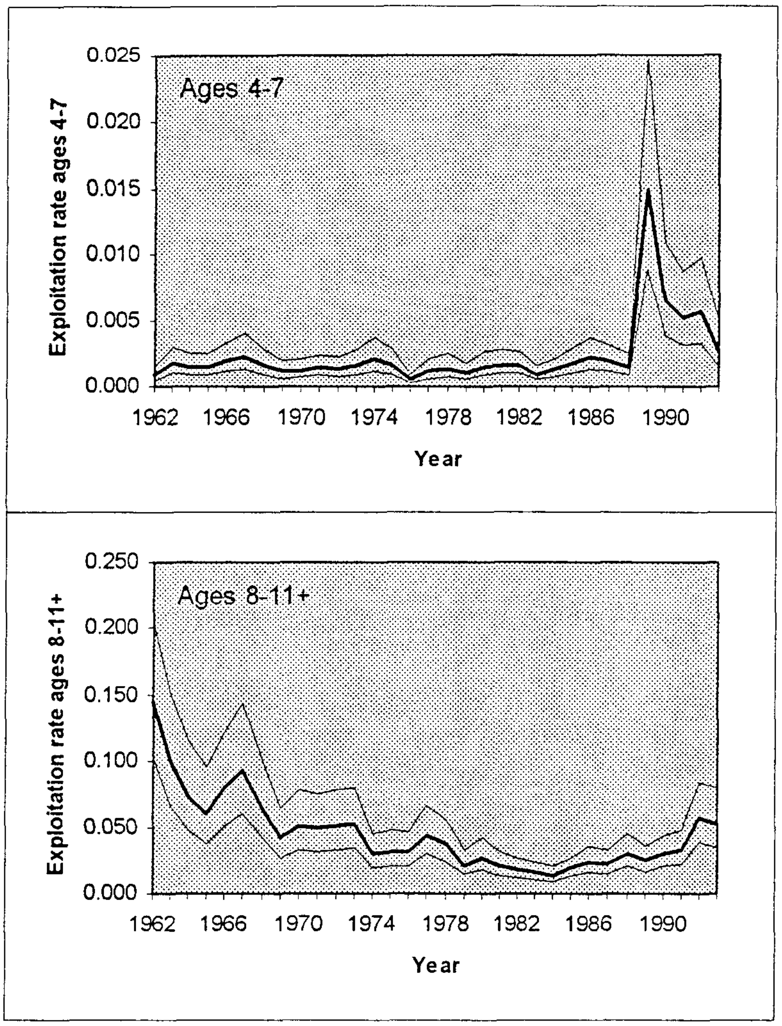


Figure 5. Examples of model fits to the length frequency samples.

Figure 6. Estimated relative (scaled to the average) and absolute recruitment, with 95% confidence intervals.

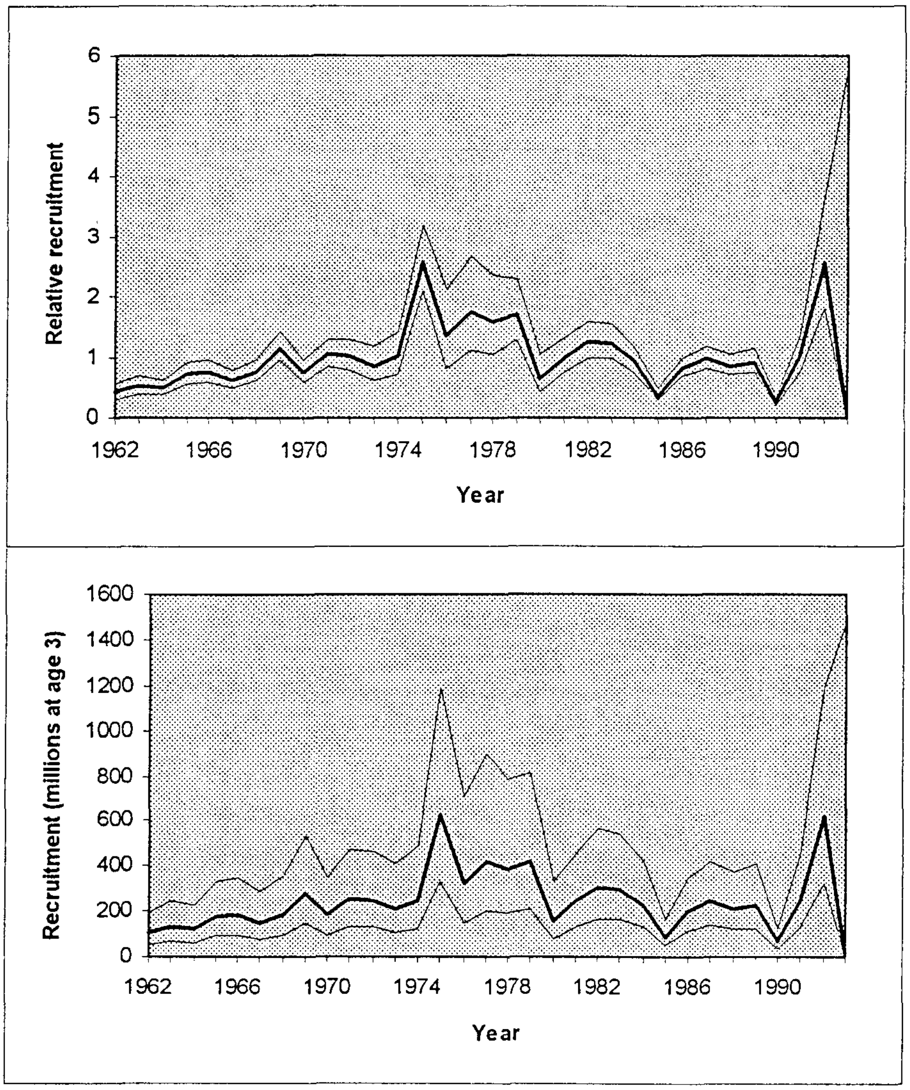


Figure7. Estimated relative (scaled to the average) and absolute biomass, with 95% confidence intervals.

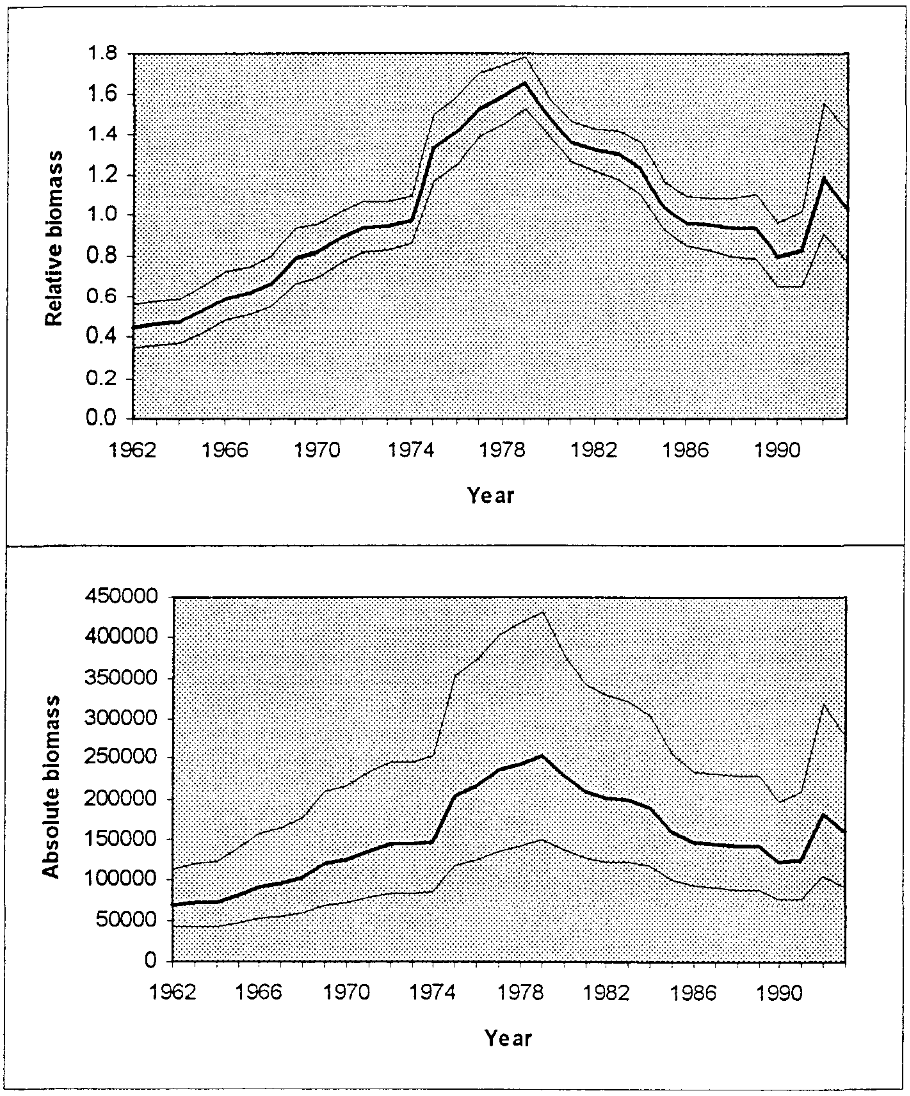


Figure 8. Estimated relative (scaled to the average) biomass by region, with 95% confidence intervals.