Preliminary analysis of yellowfin tuna catch, effort, size and tagging data using an integrated age-structured model

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Introduction

This paper presents a progress report on the application of a length-based age-structured model (Fournier et al. in press) to the integrated analysis of western and central Pacific yellowfin tuna catch, effort, size and tagging data. This project was developed by a small working group of the Western Pacific Yellowfin Research Group (WPYRG), and has been funded by the University of Hawaii Pelagic Fisheries Research Program. The results presented below are from the early stages of the development of the analysis and should not be interpreted for stock assessment purposes. Many more fits to the data will be required before the results can be used for this purpose. At this point, the intention is to describe the structure of the analysis, examine the overall consistency of the results, identify any problem areas, and suggest how the analysis can be improved.

Data structures

The geographical area referred to by the analysis is the WPYRG area, sub-divided into seven areas as shown in Figure 1. The time period covered by the analysis is 1970–1995. All data are aggregated by quarterly time periods. Sixteen fisheries are represented, each consisting of a particular gear type (or fishing method) operating in one of the seven areas. The fisheries are shown in Table 1. The data comprise 1,421 “fishing incidents”, each of which consists of a catch estimate, an effort estimates (if available) and a length frequency sample (if available). The time series structure of the data by fishery is shown in Figures 2 and 3. No effort data were available for fisheries 1–3 (the Philippines and Indonesian fisheries); effort estimates were available for all other fisheries over their entire history. Length data were available for only a limited period in the 1990s for fisheries 1–3, and after 1988 for the purse seine fisheries. Length data were available for each of the longline fisheries over the entire period of the analysis.

Yellowfin tagging data from the SPC Regional Tuna Tagging Project were aggregated in a similar fashion to the fishery data. Tag releases from 1989 to 1992 were aggregated into 26 release groups (quarter/area strata). Recaptures were classified by quarter and recapture fishery. Overall, 39,423 releases and 4,025 recaptures were included in the analysis.

Table 1. Definition of fisheries.

Fishery	WPYRG area	Gear type/fishing method
1	3	Philippines ringnet/purse seine
2	3	Philippines handline
3	3	Indonesia various
4	3	Purse seine associated sets
5	3	Purse seine unassociated sets
6	4	Purse seine associated sets
7	4	Purse seine unassociated sets
8	5	Purse seine associated sets
9	5	Purse seine unassociated sets
10	1	Longline
11	2	Longline
12	3	Longline
13	4	Longline
14	5	Longline
15	6	Longline
16	7	Longline

Model structure

The technical details of the model and fitting procedure are described in Fournier et al. (in press). The major additional features of the yellowfin application are the incorporation of tagging data and multiple recruitments per year. The tag releases are internally assigned to age classes on the basis of the distributions of age-at-length determined from the growth parameters of the model. This is done dynamically during each function evaluation. For each time period following release, the model then predicts the number of recaptures by fishery on the basis of the parameters of the age-structured model. While the model has the capacity to estimate tag-reporting rates, we provide Bayesian priors for fishery-specific reporting rates based on other information (Hampton 1997). A likelihood component for the tag data is computed using a somewhat robust normal approximation to the Poisson distribution.

Earlier attempts to fit the model to yellowfin data using a standard one-cohort-per-year formulation proved unsuccessful. The model could not find a significant growth signal in the size data and the von Bertalanffy parameter *K* typically converged to zero. While there are clear length modes in the size data and these can be followed in some cases for a year or more, the appearance of modes is somewhat erratic and is certainly not with a consistent annual spacing. This situation is to be expected given that yellowfin spawning does not follow a clear seasonal pattern in the tropics but occurs sporadically when food supplies are plentiful (Itano, pers. comm.). To solve this problem, we introduced additional structure into the model to allow multiple cohorts per year. The results presented in this report were derived using a four-cohort-per-year structure.

We allowed a total of 20 quarterly age classes in the model. The oldest age class is approximately five years of age. Natural mortality and movement (transfer coefficients) are estimated by the model and are allowed to be age-dependent. Catchability is assumed to have a random walk time series behaviour, with random walk steps taken every two years for each fishery. Selectivity coefficients for the same gear type/fishing methods occuring in different areas are assumed to be the same, i.e. all longline fisheries are assumed to have identical selectivity characteristics regardless of area of operation.

Results

Growth, selectivity and age structure

Using the four-cohort-per-year formulation, the model was able to detect a coherent growth signal in the size data. This was evidenced by the estimates of *K* (0.395 yr^{-1}) and L_{∞} (184 cm) being reasonably consistent with other independent data (Lehodey and Leroy 1998). The estimated growth curve is shown in Figure 4. Examples of fits to the size data are shown in Figure 5.

Estimated selectivity coefficients are generally consistent with expectation (Figure 6). The Philippines ringnet/purse seine fishery selects the smallest fish, but also with a tail of larger fish. Purse seine associated sets have bimodal selectivity, consistent with the capture of both small and large yellowfin associated with FADs and logs. Selectivities for purse seine unassociated sets are unimodal at about 2–3 years. Longline selectivities increase to full recruitment at about 3 years of age. The resulting age structure of the population is also consistent with expectation (Figure 7). Small fish dominate in areas 1, 3 and 4. Larger yellowfin tend to predominate in the northern (1 and 2) and southern (6 and 7) areas.

Catchability trends

Estimated catchability trends are shown in Figure 8. Constant catchability fits are also shown for comparison. The trends are fairly flat for the purse seine fisheries, although the effort deviations for purse seine unassociated sets in area 5 are suggestive of period *El Nino* influences. Strong catchability trends are estimated for most of the longline fisheries, with similar patterns of change occurring in all. Catchability tends to peak around 1980, decline through the 1980s, then increase in the 1990s. These patterns could be associated with changes in targeting practices, decadal-scale environmental variation or a combination of the two.

Natural mortality rates

Natural mortality is allowed to vary with age class. A typical U-shaped mortality curve is estimated, although the rates estimated for the youngest age classes are considerably lower than those estimated from tagging data alone (Figure 9). Natural mortality estimates tend to be sensitive to many model assumptions, therefore these estimates will be subject to change as the analysis is improved (in common with all the estimates reported in this paper!).

Exploitation rates

Exploitation rates averaged over age class for each area are shown in Figure 10. The exploitation rates in area 3 (Philippines/Indonesia) are high, in the region of 0.4–0.5 in recent years. In area 4, the average exploitation rates are approximately 0.2 in recent years. These estimates are reasonably consistent with previous estimates from tagging data alone.

Recruitment

The recruitment estimates display considerable low and high frequency variation (Figure 11). The low frequency variation might be correlated with decadal-scale environmental variation, although such an analysis would be premature at this stage. It is however interesting to note that the downturn in recruitment in the 1990s corresponds to the beginning of the series of El Nino episodes that have occurred since that time.

Biomass distribution

The relative biomass distribution is shown in Figure 12. The estimated distribution is the one aspect of the present analysis that on face value appears unreasonable. Approximately two-thirds of the total biomass is estimated to occur in regions 6 and 7, which comprise a zone at 20°–40°S latitude. This is a low catch zone compared to regions 3, 4 and 5. This aspect of the analysis requires further investigation. One possibility is that movement coefficients from areas 6 and 7 to areas 4 and 5 are badly estimated because of the lack of tag releases in these areas.

Conclusions

These preliminary results are encouraging, in that most of the estimates appear to be reasonable, with some being consistent with independent data. The ability of the model to detect a coherent growth signal in the length data is particularly noteworthy. The exception to this is the biomass distribution, which requires further investigation.

Future work on this analysis will include the following:

- The use of priors on the biomass distributions should be investigated. These priors could possibly be based on the relative habitat suitability of the seven areas determined on physiological grounds.

- The incorporation of environmental information generally should be investigated. This might be done by framing environmentally-based movement hypotheses.
- The use of "effective" effort for the longline fisheries may provide better information on changes in yellowfin abundance. Effective effort would account for changes in targeting (fishing depth) and changes in the environment (such as variation in thermal topography) that might impact catchability.
- Extension of the time window of the analysis back to 1962 or earlier may assist in deriving better estimates of initial population sizes. These are currently estimated as independent parameters, but this parameterization might be simplified if the first year of the analysis could be reasonably assumed to be close to pre-exploitation conditions.
- A range of additional model hypotheses should be investigated. Some possibilities include incorporating a stock-recruitment relationship, seasonally-oscillating recruitment, seasonal catchability and density-dependent effects.
- Finally, further model development to facilitate comparision of current and projected stock conditions with a range of reference points could be usefully undertaken.

References

Fournier, D.A., J. Hampton, and J.R. Sibert. MULTIFAN-CL: a length-based age-structured model for fisheries stock assessment, with application to South Pacific albacore (*Thunnus alalunga*). Can. J. Fish. Aquat. Sci. In press.

Hampton, J. 1997. Estimates of tag-reporting and tag-shedding rates in a large-scale tuna tagging experiment in the western tropical Pacific Ocean. Fish. Bull. U.S. 95:68–79.

Lehodey, P. and B. Leroy. 1998. Age and growth of yellowfin tuna (*Thunnus albacares*) from the western and central Pacific Ocean as indicated by daily growth increments and tagging data. WP 12, SCTB 11, Honolulu, Hawaii, 28 May–6 June 1998.

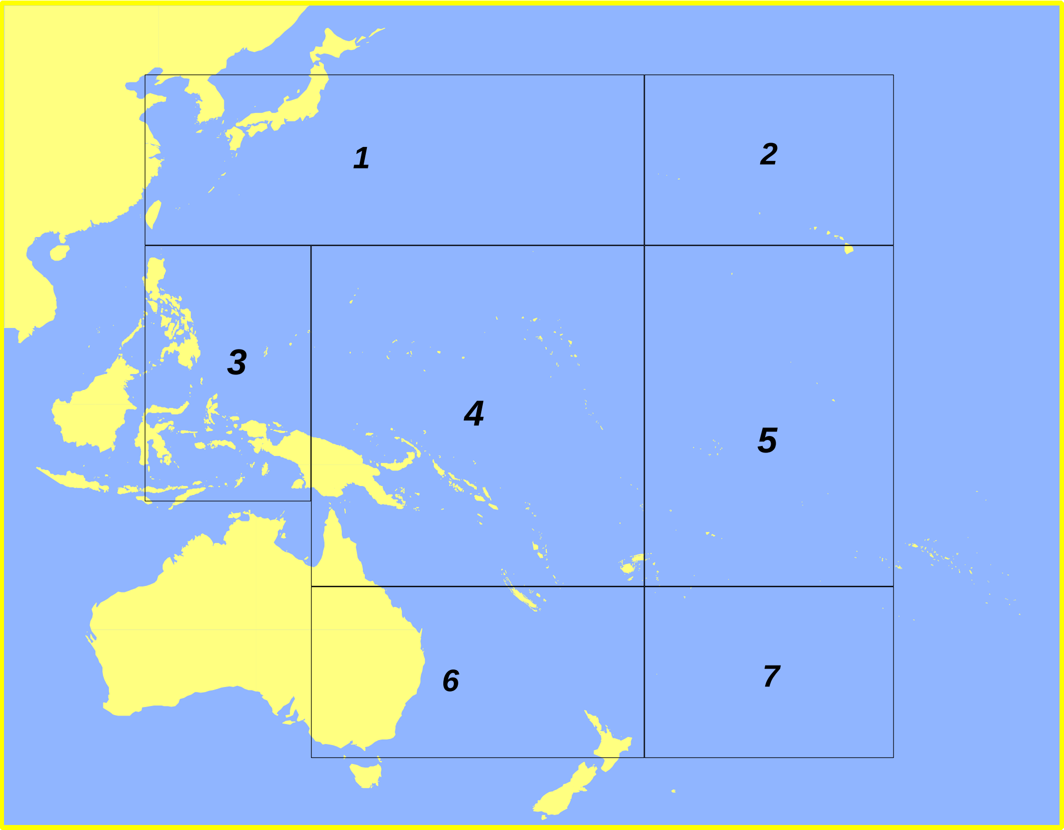


Figure 1. The Western Pacific Yellowfin Research Group area.

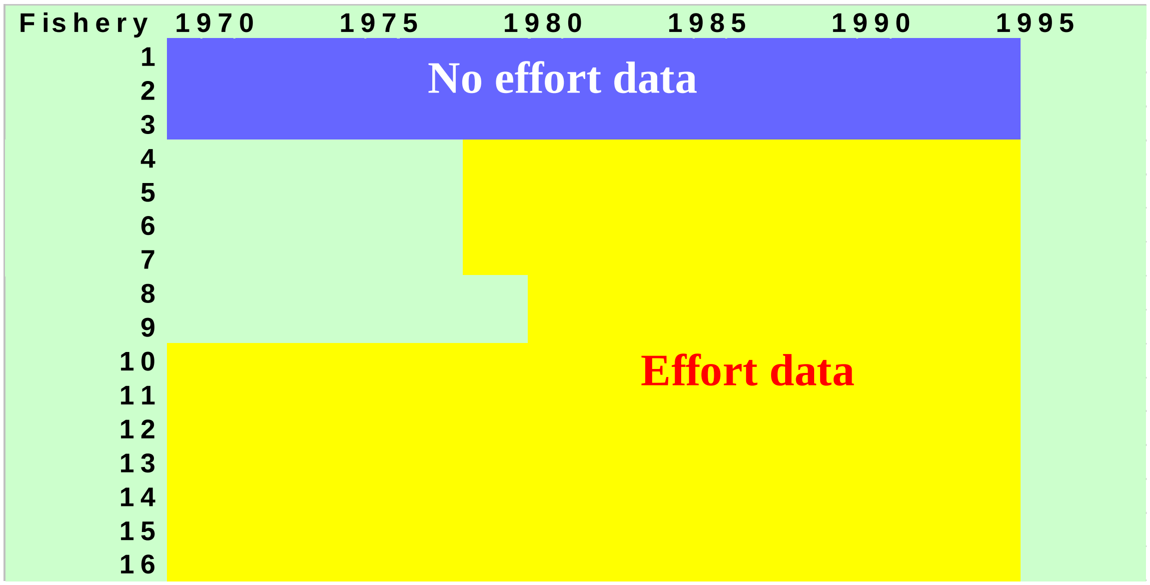


Figure 2. Structure of yellowfin effort data.

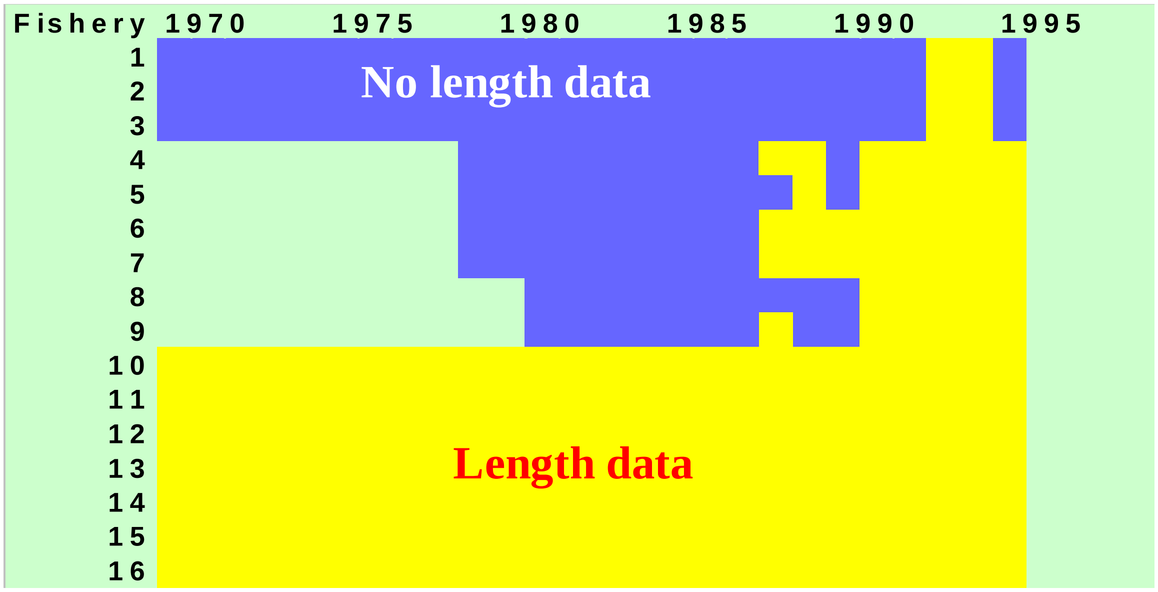


Figure 3. Structure of yellowfin length data.

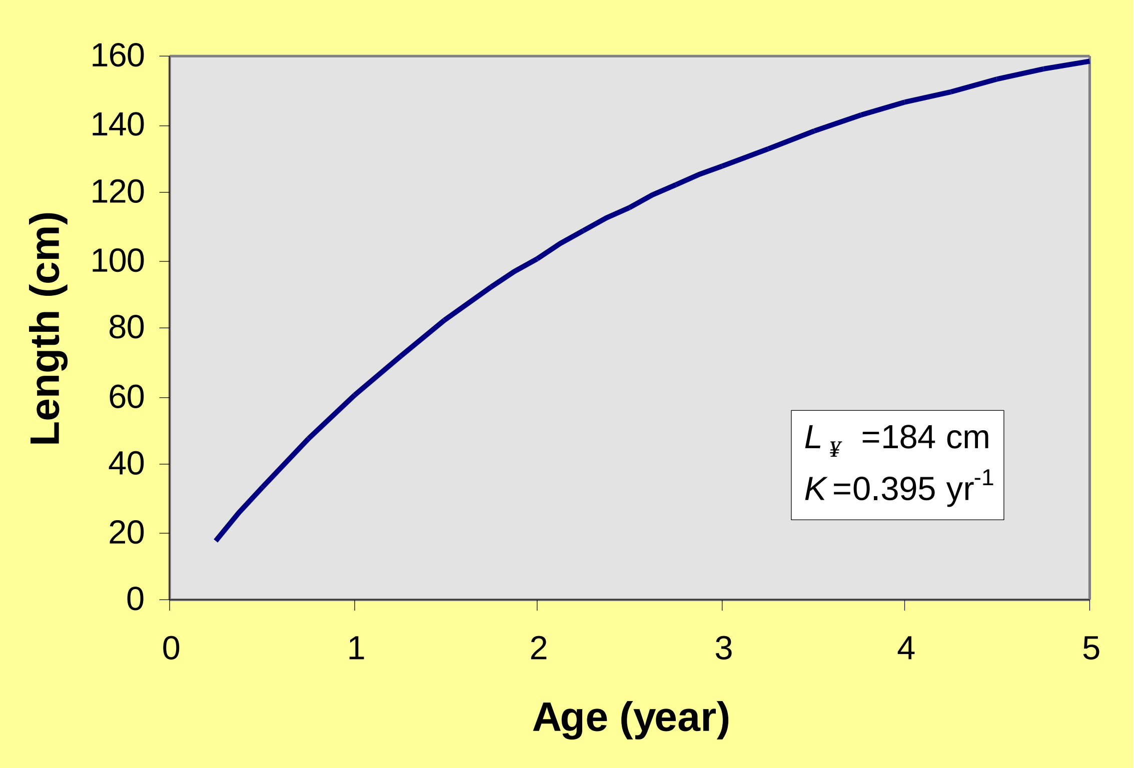


Figure 4. Estimated yellowfin growth curve.

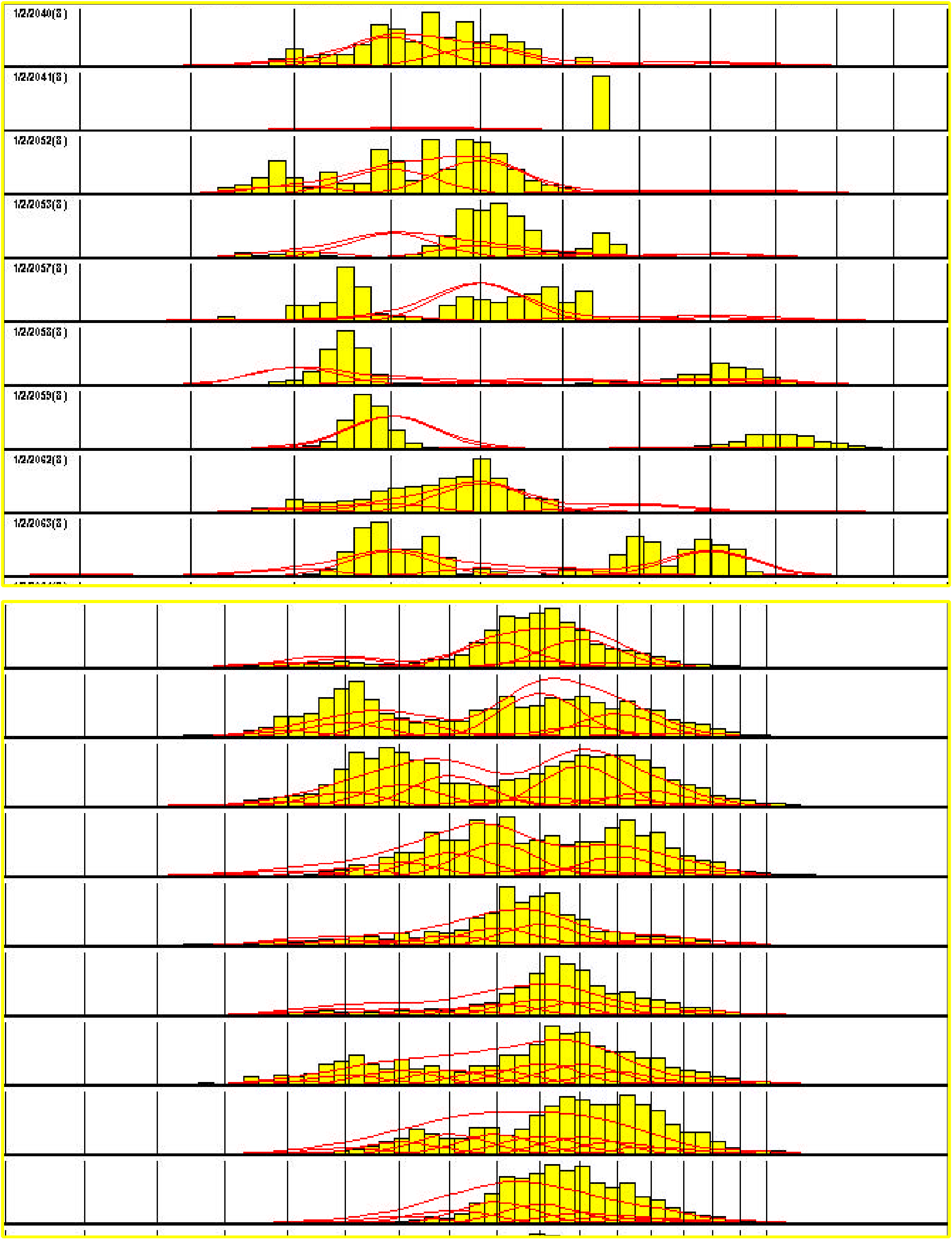


Figure 5. Examples of model fits to purse seine (upper) and longline (lower) length samples.

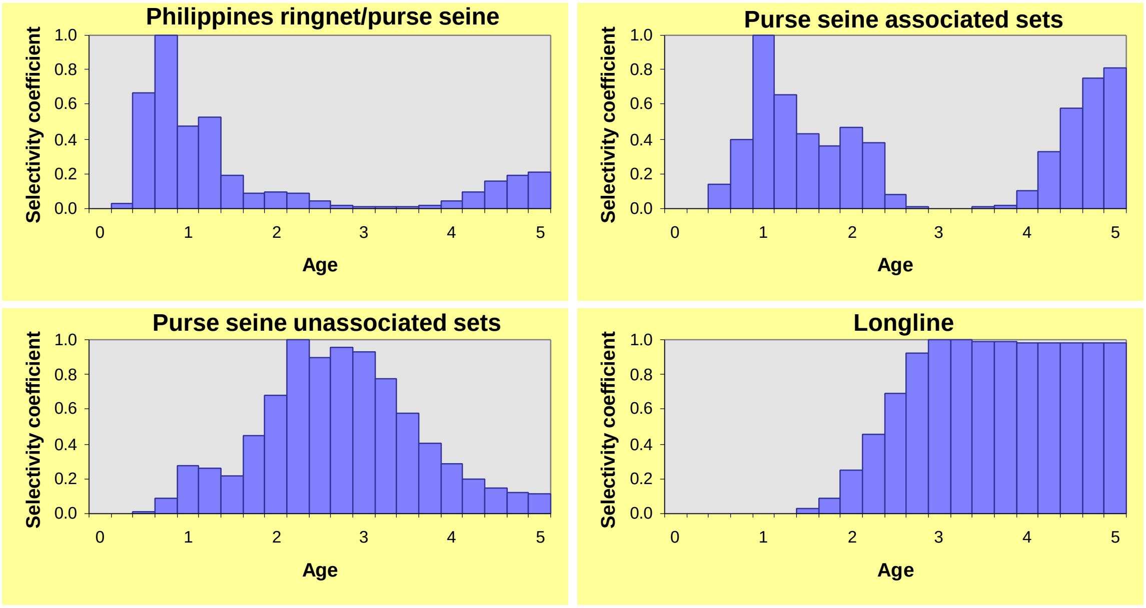


Figure 6. Estimated selectivity coefficients.

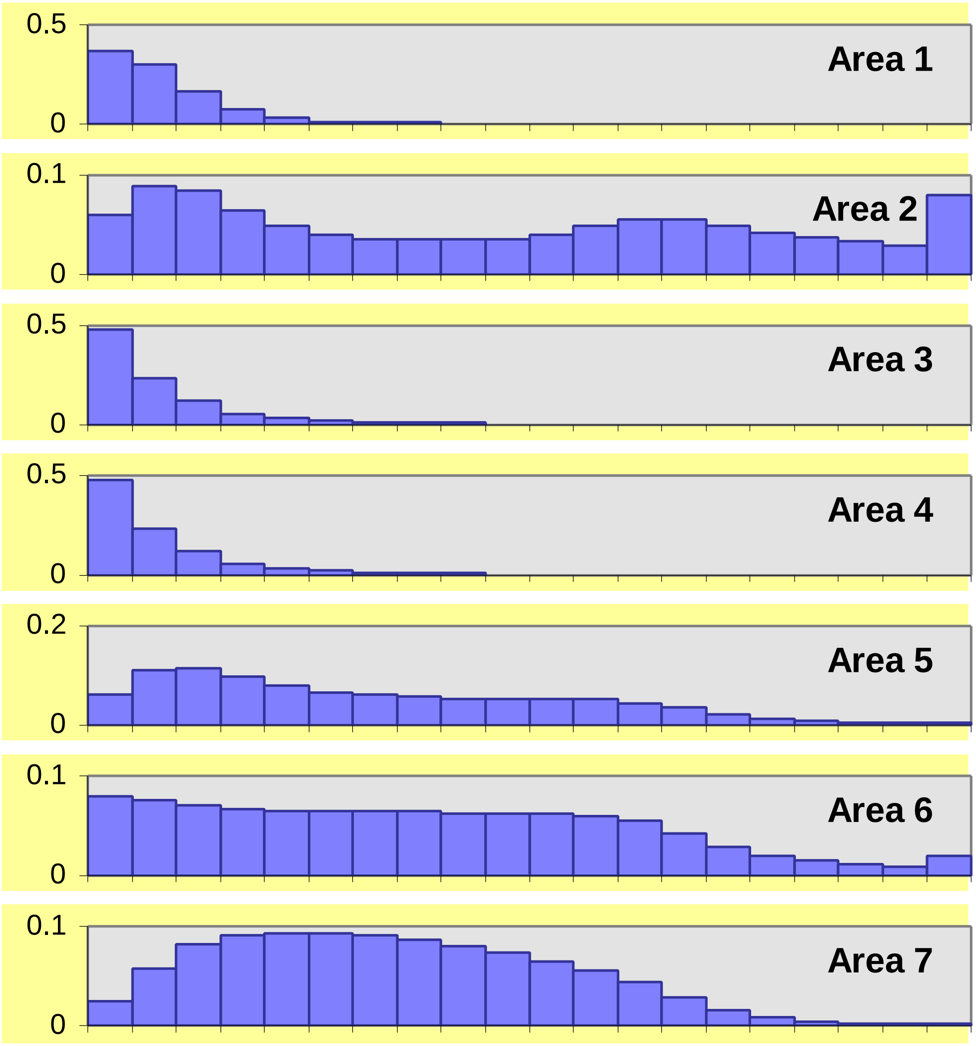
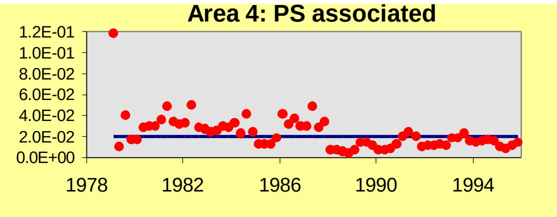
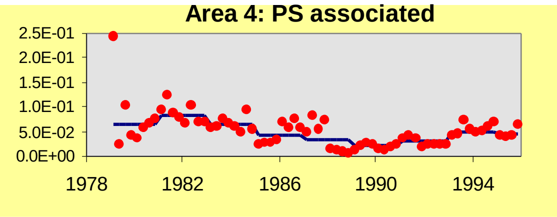


Figure 7. Estimated population age structure.


Area 4: PS associated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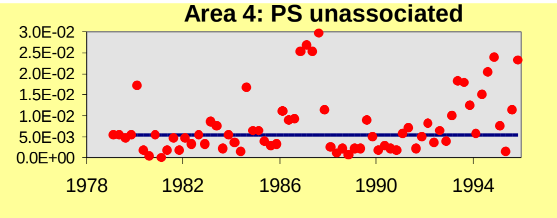
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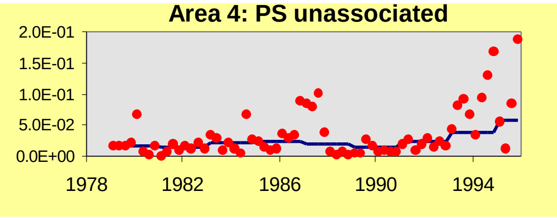
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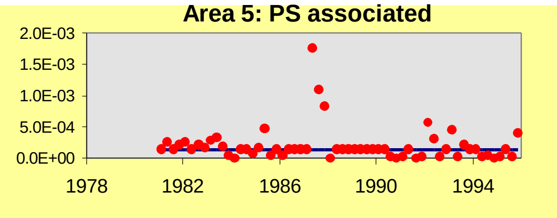
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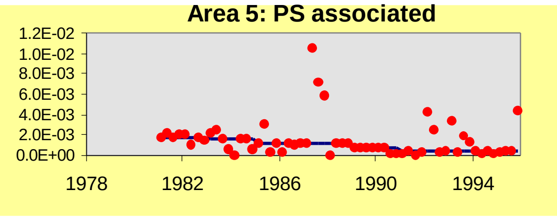
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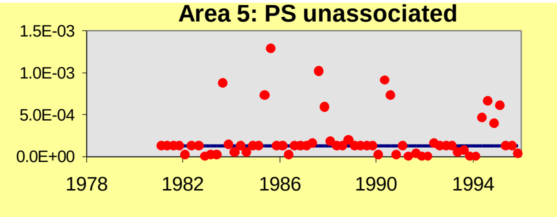
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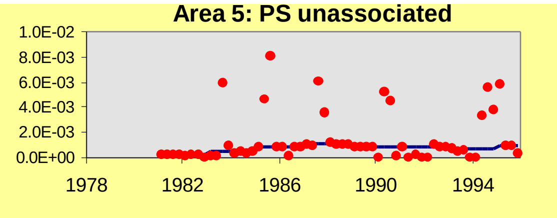
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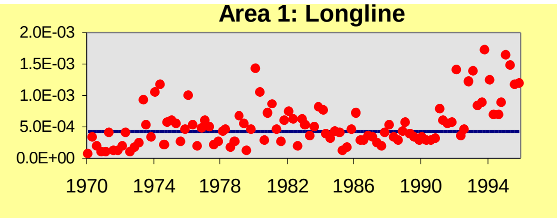
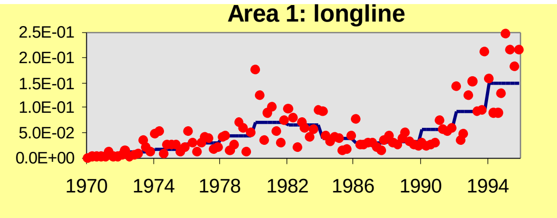
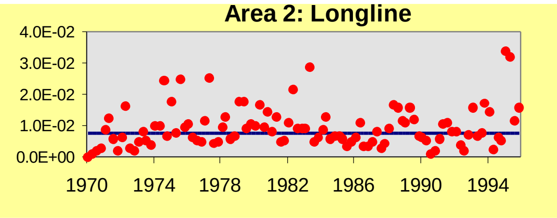
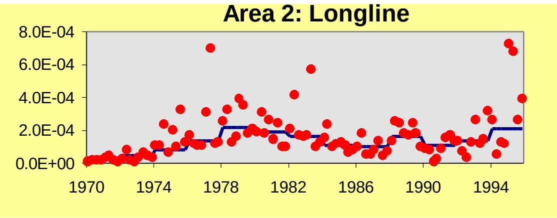

Area 1: Longline


Area 1: longline


Area 2: Longline


Area 2: Longline

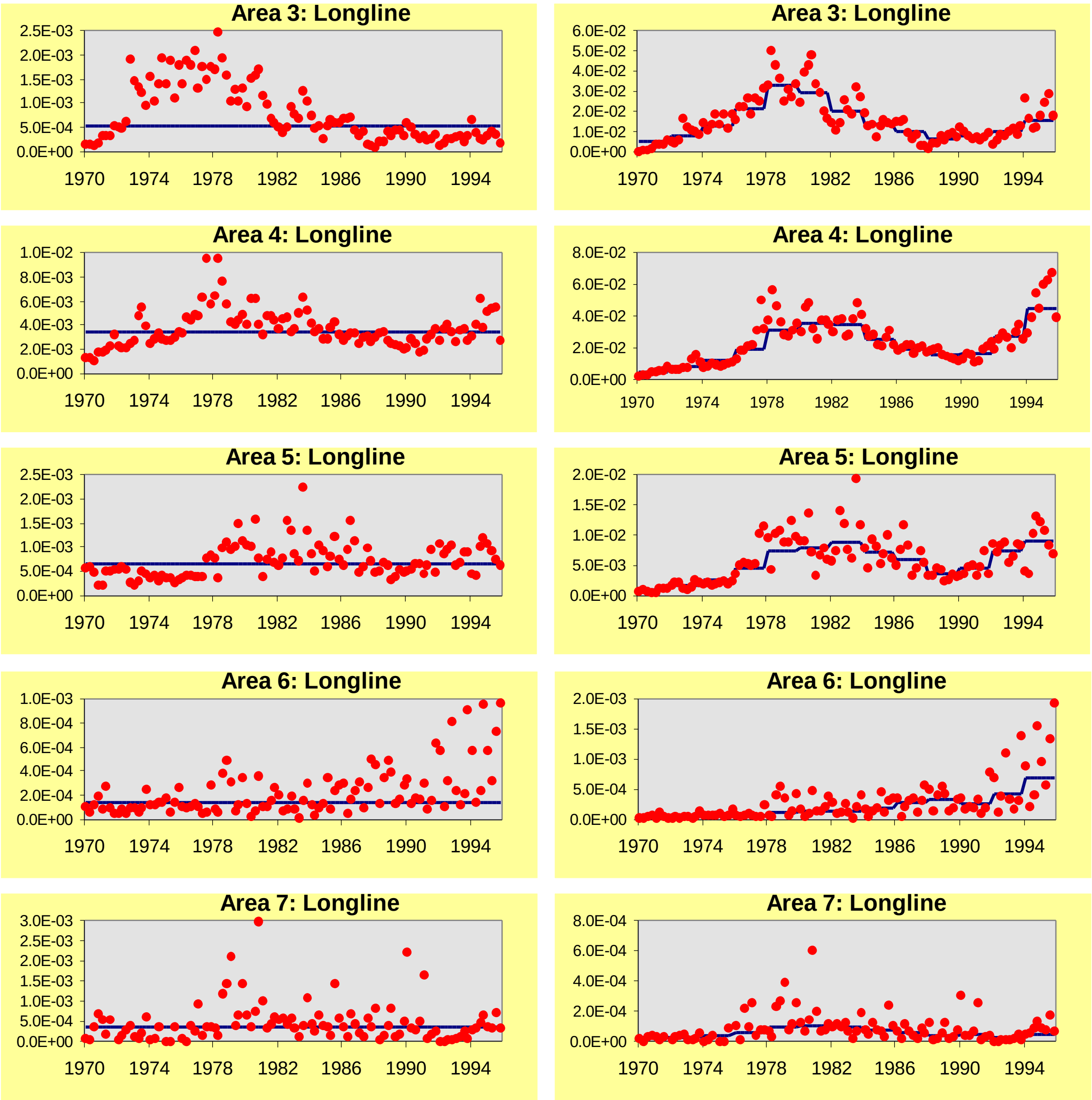


Figure 8. Estimated catchability coefficients and effort deviations. Constant catchability is assumed in the fits on the left.

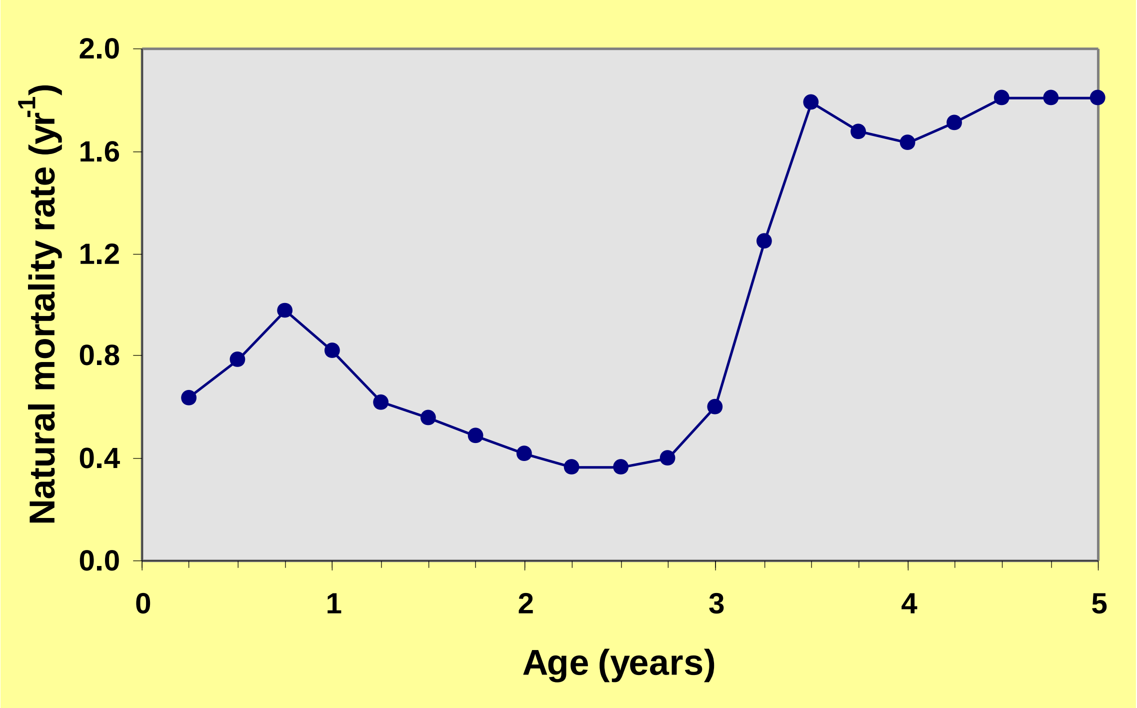


Figure 9. Estimated natural mortality rates.

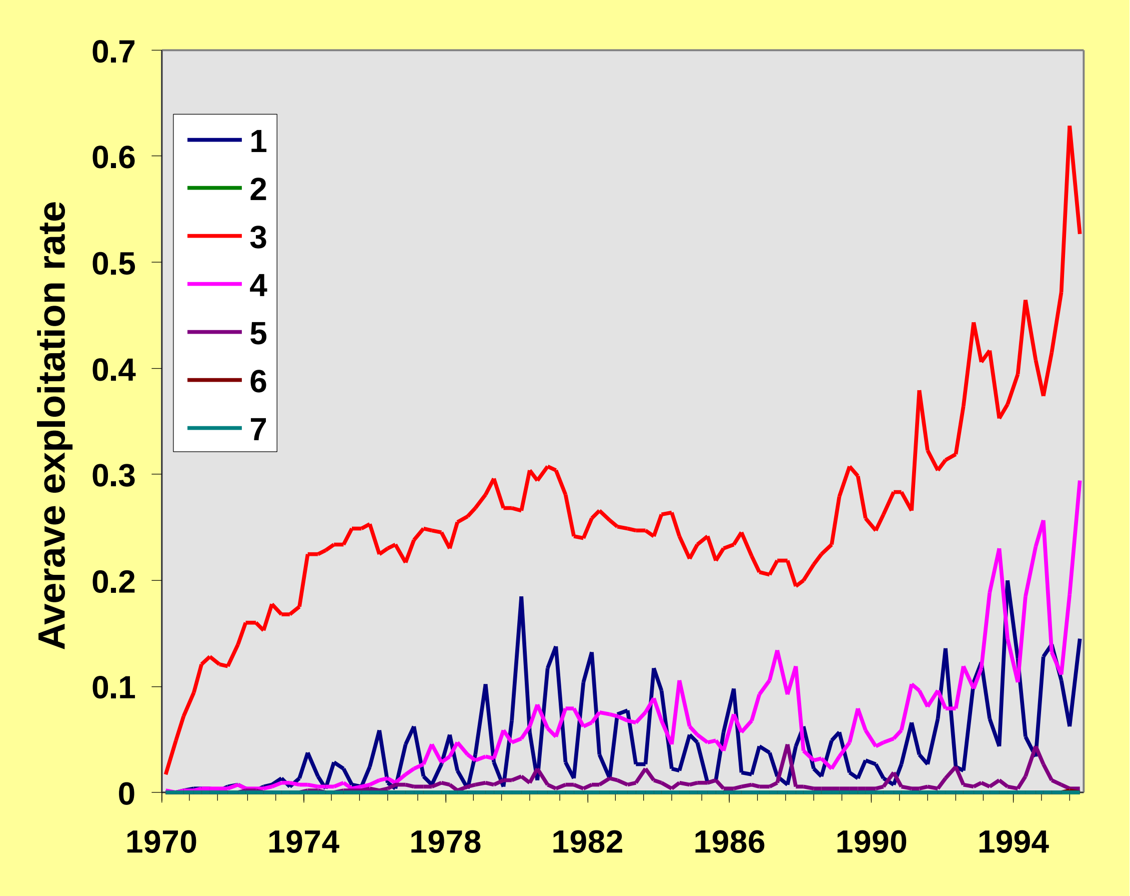


Figure 10. Estimated average exploitation rates, by area.

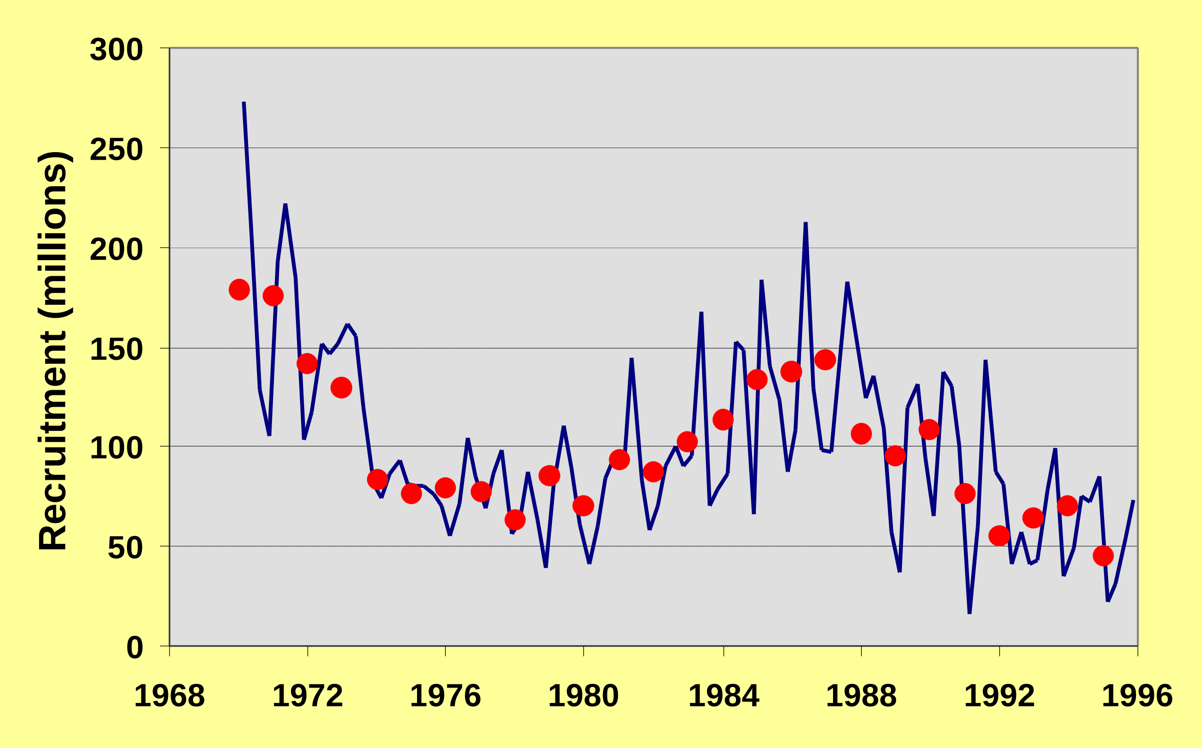


Figure 11. Estimated recruitment. The dots indicate the annual average.

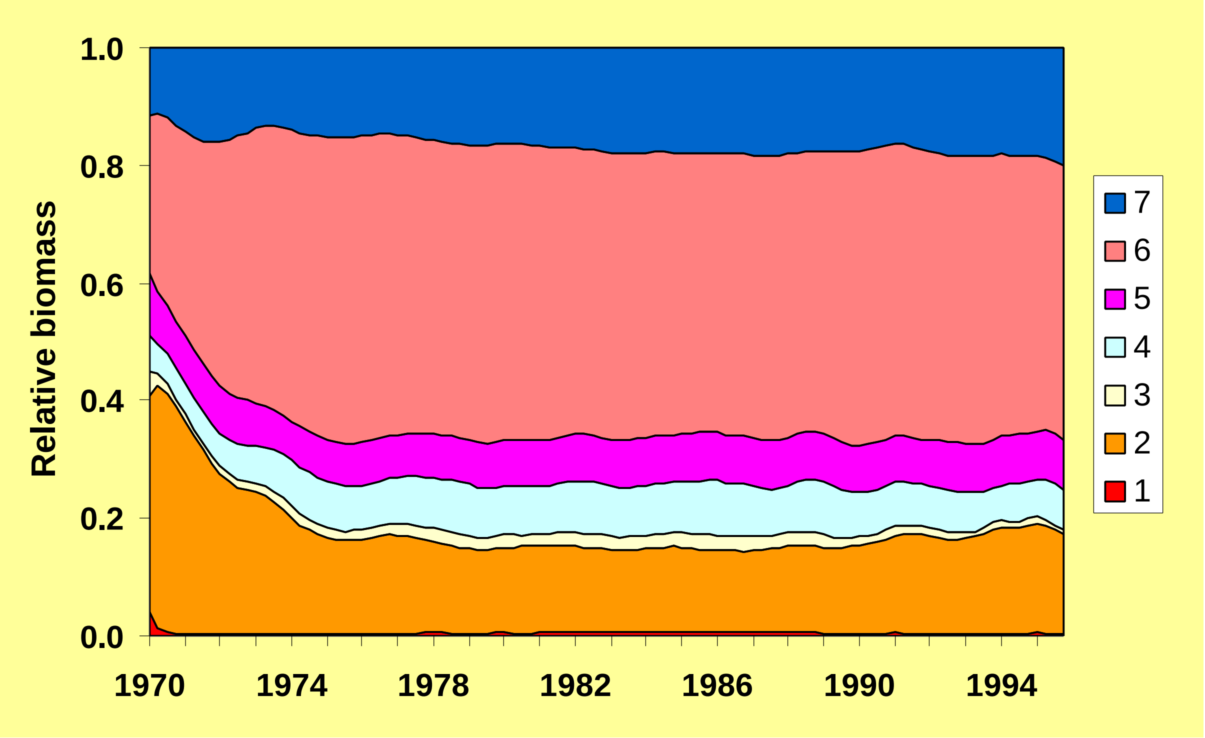


Figure 12. Estimated relative biomass distribution.