SCIENTIFIC COMMITTEE
SECOND REGULAR SESSION

7-18 August 2006
Manila, Philippines

AN UPDATE OF PACIFIC-WIDE ASSESSMENT OF BIGEYE TUNA WITH COMPARISONS WITH EASTERN PACIFIC ASSESSMENT RESULTS

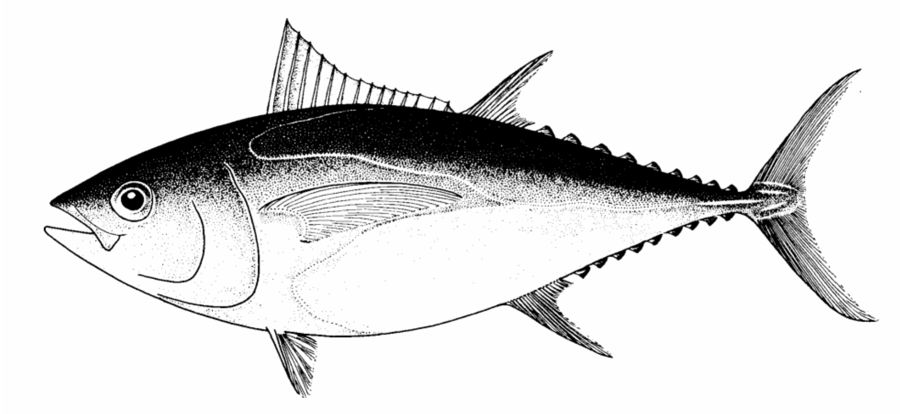
WCPFC-SC2-2006/SA IP-1

Paper prepared by

John Hampton[1] and Mark Maunder[2]

[1]Oceanic Fisheries Program, Secretariat of the Pacific Community, Noumea, New Caledonia
[2]Inter-American Tropical Tuna Commission, La Jolla, California, U.S.A

An update of Pacific-wide assessment of bigeye tuna with comparisons with eastern Pacific assessment results



John Hampton[1] and Mark Maunder[2]

[1]Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea, New Caledonia
[2]Inter-American Tropical Tuna Commission, La Jolla, California, U.S.A.

May 2006

1 Introduction

Assessments of bigeye tuna are routinely undertaken by the SPC for the western and central Pacific Ocean (WCPO) (e.g., Hampton et al. 2005) and by the IATTC for the eastern Pacific Ocean (EPO) (e.g., Maunder and Hoyle 2005). WCPO assessments are undertaken using MULTIFAN-CL (Kleiber et al. 2003), while EPO assessments are undertaken using A-SCALA (Maunder and Watters 2003). A-SCALA is very similar to MULTIFAN-CL, with some exceptions that are discussed below.

In view of uncertainties regarding the extent of basin-scale mixing of bigeye tuna on generational time scales, a Pacific-wide model has been developed collaboratively by SPC and IATTC, with cooperation and support of national fisheries agencies and the University of Hawaii. Comparisons of the results of the Pacific-wide model with regional assessments have been made on several occasions (Hampton et al. 2003, Appendix A; Hampton and Maunder 2005). These comparisons have revealed generally consistent trends in biomass and consistent interpretations of stock status, although absolute biomass has been lower and fishing mortality (particularly for older age classes) higher in the EPO assessment compared to the Pacific-wide model results for the EPO. These latter differences were found to largely attributable to different growth estimates used in the respective models.

In this paper, we update the Pacific-wide (PO) bigeye assessment model and compare the results for the EPO regions in that model with the most recent EPO assessment results. In addition, we explore the sensitivity of the Pacific-wide model results to various hypotheses regarding population mixing across the Pacific and assumptions about growth.

2 Model description

The configuration of the PO model, in terms of structural assumptions, parameterisation and specification of priors, was made to be as consistent as possible with the configuration used for the last WCPO bigeye assessment (Hampton et al. 2005). The most important aspects of the model structure, highlighting key differences with the EPO assessment model, are as follows:

- The PO model has a nine-region spatial structure, including 2 regions comprising the EPO (Figure 1). Movement parameters for adjacent regions are estimated. The EPO bigeye assessment does not have spatially structured population dynamics.
- 28 fisheries are defined in the model, including 4 purse seine and 2 longline fisheries in the EPO (Table 1). The fisheries are differentiated by fishing method, nationality, and region.
- The time period referenced by the PO model is 1952–2004 (with quarterly stratification), thus covering the period of significant post-war fishing. The EPO bigeye assessment begins in 1975.
- CPUE and effort for the main (primarily Japanese) longline fisheries operating in the region are standardised using a GLM approach (Langley 2005). The procedure incorporates the estimation of regional scaling factors that incorporates relative differences in density and the effective size of each region. The scaled CPUEs therefore provide an index of relative abundance for each region (Figure 2).
- Tagging data are included in the PO model, but not in the EPO model.
- The PO model incorporates weight-frequency as well as length-frequency data for the longline fisheries. The EPO model utilises only length-frequency data.
- Catchability of the main (primarily Japanese) longline fishery in each region (for which effort has been standardised using a GLM) is assumed to be constant over time, with the exception of seasonal variation. Catchability for these fisheries is also scaled to be the same so that longline CPUE is assumed to index relative abundance among regions.

- Selectivity of all longline fisheries is assumed to be monotonically increasing with age. Variability among age-classes is constrained with a cubic spline with 5 nodes. Selectivity for the main longline fisheries in the northern regions (1, 2 and 8) is assumed to be the same, as is the selectivity for the main longline fisheries in the equatorial and southern regions (3, 4, 5, 6, 7 and 9).
- In the PO model we have use the same (fixed) natural mortality at age (40 quarterly age classes) as for the EPO assessment. We have also used the same female maturity at age schedule such that the units of spawning biomass computed are the same for both models.

3 Pacific-wide model results, with comparisons to EPO results

3.1 Growth estimates

In the PO model, we have routinely estimated growth parameters determining both the mean length and standard deviation of length-at-age. The mean lengths are highly constrained in the EPO assessment based on a Richards growth curve fit to length-at-age observations from otolith data (Schaefer and Fuller 2006) and a fixed L_∞ based on the maximum length observed in length samples. The age-at-length data from otoliths (Schaefer and Fuller 2006) are included in the EPO assessment to provide information on the standard deviation of length-at-age. In the results presented below, we show the PO model estimates of the various population variables obtained with estimated growth and fixed growth equivalent to that used in the EPO assessments. The use of the EPO fixed growth parameters resulted in a large degradation in the fit of the PO model to all data and penalty components (Table 2).

Growth estimates based on the PO model and analyses of length-at-age data from the EPO are shown in Figure 3. Estimates of length-at-age are similar up to about 12 quarters of age, after which the EPO estimates predict larger length-at-age. The EPO curve is consistent with EPO length-at-age data (to which a growth curve fitted externally to the assessment model is used as a strong prior), although the length-at-age data are more linear than predicted by the EPO growth model. Length-at-age data from the WCPO (which are not included in the PO model) show positive residuals with respect to both growth curves for fish <100 cm, and are consistent with the EPO growth curve and EPO length-at-age data at larger sizes.

The models show a substantial discrepancy in estimates of SD of length-at-age. This is related to the smaller mean length-at-age estimated for the PO model, with the larger SD’s required to fit the size data. Weight-at-age estimates are divergent for age-classes older than about 10 quarters, reflecting the differences in mean length-at-age.

3.2 Recruitment

Recruitment estimates for the PO model are shown in Figure 4. Recruitment is estimated to be above average in the 1950s in several regions and in the 1990s in some of the tropical regions. These patterns are required to explain some of the longline CPUE trends that differ substantially among some regions. In particular, the model is forced to explain the declining trend in longline CPUE in the 1950s in regions 2 and 9 by declining recruitment because longline catchability is assumed to be constant and the catches during this early period were too small for the declines to be attributed to fishing mortality.

The comparison between PO and EPO model estimates of recruitment for the EPO is shown in Figure 5. There is good agreement between the estimates in both absolute and relative terms. When the IATTC growth estimates are used in the PO model, recruitment is slightly lower, particularly in the early period.

3.3 Biomass

Estimates of total biomass and population fecundity are shown in Figure 6 and Figure 7, respectively. Both series show similar trends. The trends are downwards in all regions except region 7 (Indonesia-Philippines), which shows an abrupt upwards shift around 1990. This is consistent with longline CPUE observations for this region (Figure 2).

The EPO biomass estimates from the PO model with estimated growth are slightly higher than the equivalent estimates obtained in the EPO assessment (Figure 8). However, when the IATTC fixed growth parameters are used in the PO model, the biomass estimates are very similar. For the population fecundity estimates, the estimates from the EPO assessment are substantially lower than those from either version of the PO model (Figure 9).

3.4 Fishery impact and fishing mortality

The impact of the fishery on the total biomass and total population fecundity is shown by the difference between the exploited and unexploited trajectories in Figure 6 and Figure 7, respectively. Impacts are initially small, except in region 1 (near Japan) where a significant longline fishery existed at the beginning of the time series. Impacts in recent years are high in the tropical regions (3, 4, 7, 9) and moderate in sub-tropical regions. Overall, the proportional reduction in Pacific-wide total biomass and population fecundity due to fishing is estimated to be 66% and 78%, respectively.

Estimates of average fishing mortality by quarter for aggregated age-classes and by age-class for aggregated time periods for the EPO portion of the PO model, and equivalent estimates from the EPO assessment, are shown in Figure 10. Estimates from the EPO assessment are slightly higher than those from the PO model with estimated growth, but are very similar to the estimates from the PO model with IATTC fixed growth. When plotted by age-class, it is evident that the PO model estimates are considerably smoother than the EPO estimates. This is due to the use of cubic spline selectivity smoothing in the PO model compared to penalized smoothing in the EPO model. The pattern of selectivity produced by both models is similar, although the peaks in fishing mortality are not perfectly aligned (see bottom right panel of Figure 10).

3.5 Stock assessment indicators

The Pacific-wide yield curve, estimated using the average fishery selectivity for 2001–2003, is shown in Figure 11. Pacific-wide MSY is estimated to be approximately 164,000 t per year and the *F*-multiplier (relative to 2001–2003 average *F*-at-age) corresponding to MSY is approximately 0.85 for the PO model with estimated growth. On this basis, it could be concluded that overfishing of bigeye tuna is occurring on a Pacific-wide basis. An even more pessimistic result is obtained for the PO model with IATTC growth – MSY is smaller (152,000 t per year) and the *F*-multiplier corresponding to MSY is 0.75.

The ratios of total population fecundity to equilibrium unexploited population fecundity are shown in Figure 12. For the PO model with estimated growth, recent population fecundity ratios are slightly above the MSY levels. Again, a more pessimistic result is obtained for the IATTC fixed growth run – the population fecundity ratio falls beneath the MSY level in the most recent years.

A comparison of population fecundity ratios for the EPO obtained from the PO model and from the EPO assessment is shown in Figure 13. The ratios obtained from the EPO assessment are very similar to the PO model with IATTC fixed growth, but those estimated from the PO model with estimated growth are somewhat more optimistic.

4 Pacific-wide stock structure of bigeye tuna

Part of the motivation of developing a Pacific-wide model of bigeye tuna was to investigate questions of stock structure. In the PO model, the parameters that define stock structure are the distribution of recruitment over time and the estimated movement rates. Information on relative recruitment among regions comes from the size composition data and the relative CPUE of fisheries in different regions, particularly those fisheries for which catchability is assumed to be constant among regions (main longline fisheries). Information on movement comes from the limited tagging data, relative trends in CPUE over time, and differences in size composition among regions. Currently, the model does not “remember” the region of origin of recruits, so phenomena such as the return of fish to natal areas for spawning, if they exist, cannot be modeled. However, it is possible to use the model parameters to conduct simulations to investigate 1) the changes in spatial distribution of fish over time of recruits originating in each of the model regions; and 2) the average composition of the sub-population of fish in each region in terms of region of origin. Such simulations will at least give some insight into how the model is interpreting the data in terms of spatial structuring of the stock.

The dispersal of simulated cohorts over time from their regions of origin is depicted in Figure 14. The predominant movement characteristic appears to be west to east movement among the tropical regions (3, 4, 7, 9). In fact, fish originating in all regions gradually move to region 9 in the EPO such that most of the older fish of the simulated cohorts occur in this region.

The simulated composition of sub-population biomass in each region is shown in Figure 15. With the exception of region 5, all regions are composed of a mixture of fish originating locally and in other regions. For the EPO regions (8 and 9), more than half of the biomass is estimated to originate in the EPO, with the remainder originating from regions in the WCPO.

These movement simulations indicate that population mixing on a generational time scale is estimated by the model to be substantial. We also fitted a model with no spatial structure in the population dynamics (not including the tagging data). The fit statistics for this model (Table 3) showed highly significant degradation of fit to all likelihood components. Also, the model showed clear trends in effort deviations for several of the main longline fisheries for which catchability was assumed to be constant over time (although both catchability and selectivity for these fisheries were allowed to be independently estimated in this model). This essentially means that a spatially-aggregated model that implicitly assumed instantaneous mixing of all age classes across the entire model domain could not reconcile the different trends in CPUE observed in the longline fisheries in different regions (Figure 2).

5 Discussion

The latest iteration of the Pacific-wide bigeye tuna model indicates that, considered on a basin-scale, current levels of fishing mortality of bigeye tuna constitute overfishing. On the other hand, average stock levels over the 2001-2003 period have remained above MSY-based reference points (due to above-average recruitment in recent years), although trends in biomass continue to be downwards. These status indicators are broadly similar to those obtained in recent WCPO and EPO assessments.

Comparisons between the EPO portion of the PO model and the latest EPO assessment conducted by IATTC have shown a high level of consistency in trends over time. Discrepancies in absolute biomass estimates were caused mainly by differences in growth estimates. When the growth estimates used in the EPO assessment are used in the PO model, the absolute estimates also converge to a large extent.

The inclusion of spatial structure in the PO model is required to adequately model the differences in longline CPUE trends among regions. The existence of such differential trends is strong evidence of restricted mixing of the bigeye tuna population on the basin scale. The predominantly west to east estimated movement means that the EPO acts as a population “sink” and suggests that the potential for interaction would largely be restricted to the west impacting the east. However, the tagging data has limited spatial coverage and much of the information about movement comes from differences in length-frequency data among regions (i.e. larger lengths in the EPO). More complete spatial coverage of the tagging data is needed to provide confidence in the estimates of movement.

Further research is required to determine if the apparent differences in estimated growth between the EPO and WCPO (the PO model estimates of growth are very similar to the WCPO estimates) are a biological phenomenon. It has long been observed that the average size of longline-caught bigeye tuna increases from west to east. The PO model accounts for this by differential age structure resulting from a net movement of fish from west to east. However, if the difference is in fact due to differential growth (possibly related to the higher productivity resulting from the equatorial upwelling in the central-eastern Pacific) and this structure could be included in the model, then different movement estimates and possibly stock structure interpretations could result. It would be useful to undertake a detailed comparison of age-at-length data from otoliths from the two regions to clarify this issue. If significant differences in growth are confirmed, re-structuring of the PO model to allow region-specific growth would be required. This would probably require re-structuring the model from age- to size-structured and the use of region-specific size transition matrices to model growth.

6 References

Hampton, J., Kleiber, P., Takeuchi, Y., Kurota, H., and Maunder, M.N. 2003. Stock assessment of bigeye tuna in the western and central Pacific Ocean, with comparisons to the entire Pacific Ocean. Working Paper BET-1, SCTB 16, Mooloolaba, Australia, 9–16 July, 2003.

Hampton, J., P. Kleiber, A. Langley, Y. Takeuchi, and M. Ichinokawa. 2005. Stock assessment of bigeye tuna in the western and central Pacific Ocean. WCPFC-SC1, SA WP-2. http://www.spc.int/OceanFish/Html/WCPFC/SC1/pdf/SC1_SA_WP_2.pdf.

Kleiber, P., Hampton, J., and Fournier, D.A. 2003. MULTIFAN-CL Users' Guide. http://www.multifan-cl.org/userguide.pdf.

Langley, A., Bigelow, K., Maunder, M., and Miyabe, N. 2005. Longline CPUE indices for bigeye and yellowfin in the Pacific Ocean using GLM and statistical habitat standardisation methods. WCPFC-SC1, SA WP-8. http://www.wcpfc.org/sc1/pdf/SC1_SA_WP_8.pdf.

Maunder, M .N. and Hoyle S. D. 2005. Status of bigeye tuna in the eastern Pacific Ocean. Document SAR-6-07, Inter-American Tropical Tuna Commission, Working Group on Stock Assessment, 6th Meeting, 2–6 May 2005, La Jolla, California.

Maunder, M. N., and Watters, G. M. 2003. A-SCALA: An age-structured statistical catch-at-length analysis for assessing tuna stocks in the eastern Pacific Ocean. *IATTC Bul.* **22**: 433–582.

Schaefer, K.M. and D.W. Fuller. 2006. Estimates of age and growth of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean, based on otolith increments and tagging data. Inter-Amer. Trop. Tuna Comm., Bull. 23: 33-76.

Table 1. Definition of fisheries for the MULTIFAN-CL analysis of Pacific-wide bigeye tuna.

Fishery Number	Reference Code	Nationality	Gear	Region
1	LL ALL 1	Japan, Korea, Chinese Taipei	Longline	1
2	LL ALL 2	Japan, Korea, Chinese Taipei	Longline	2
3	LL HW 2	United States (Hawaii)	Longline	2
4	LL ALL 3	All excl. Chinese Taipei & China	Longline	3
5	LL TW-CH 3	Chinese Taipei and China	Longline	3
6	LL PG 3	Papua New Guinea	Longline	4
7	LL ALL 4	Japan, Korea	Longline	4
8	LL TW-CH 4	Chinese Taipei and China	Longline	4
9	LL HW 4	United States (Hawaii)	Longline	4
10	LL ALL 5	All excl. Australia	Longline	5
11	LL AU 5	Australia	Longline	5
12	LL ALL6	Japan, Korea, Chinese Taipei	Longline	6
13	LL PI 6	Pacific Island Countries/Territories	Longline	6
14	PS ASS 3	All	Purse seine, log/FAD sets	3
15	PS UNS 3	All	Purse seine, school sets	3
16	PS ASS 4	All	Purse seine, log/FAD sets	4
17	PS UNS 4	All	Purse seine, school sets	4
18	PHID MISC 3	Philippines, Indonesia	Miscellaneous (small fish)	3
19	PH HL 3	Philippines, Indonesia	Handline (large fish)	3
20	HL HW 4	United States (Hawaii)	Handline	4
21	LL ALL 7	All excl. Chinese Taipei & China	Longline	7
22	LL TW-CH 7	Chinese Taipei and China	Longline	7
23	LL ALL 8	Japan, Korea, Chinese Taipei	Longline	8
24	LL ALL 9	Japan, Korea, Chinese Taipei	Longline	9
25	PS ASS N	All	Purse seine, log/FAD sets, nearshore area	9
26	PS OTH	All	Purse seine, school, dolphin sets	9
27	PS ASS C	All	Purse seine, log/FAD sets, central area	9
28	PS ASS O	All	Purse seine, log/FAD sets, offshore area	9

Table 2. Log-likelihood components of the PO model with growth estimated and with growth fixed using the IATTC parameters.

Likelihood component	Estimated growth	IATTC fixed growth
Total catches	787.64	802.73
Length frequency	-497,948.10	-497,705.77
Weight frequency	-728,036.41	-727,950.57
Tagging	3,237.05	3,334.64
Penalties	7,911.64	7,996.93
Total	-1,214,048.18	-1,213,522.04

Table 3. Log-likelihood components of a PO model with growth estimated and assuming no spatial structure.

Likelihood component	Log-likelihood
Total catches	934.86
Length frequency	-495,336.30
Weight frequency	-725,739.09
Tagging	
Penalties	8,998.31
Total	-1,211,142.22

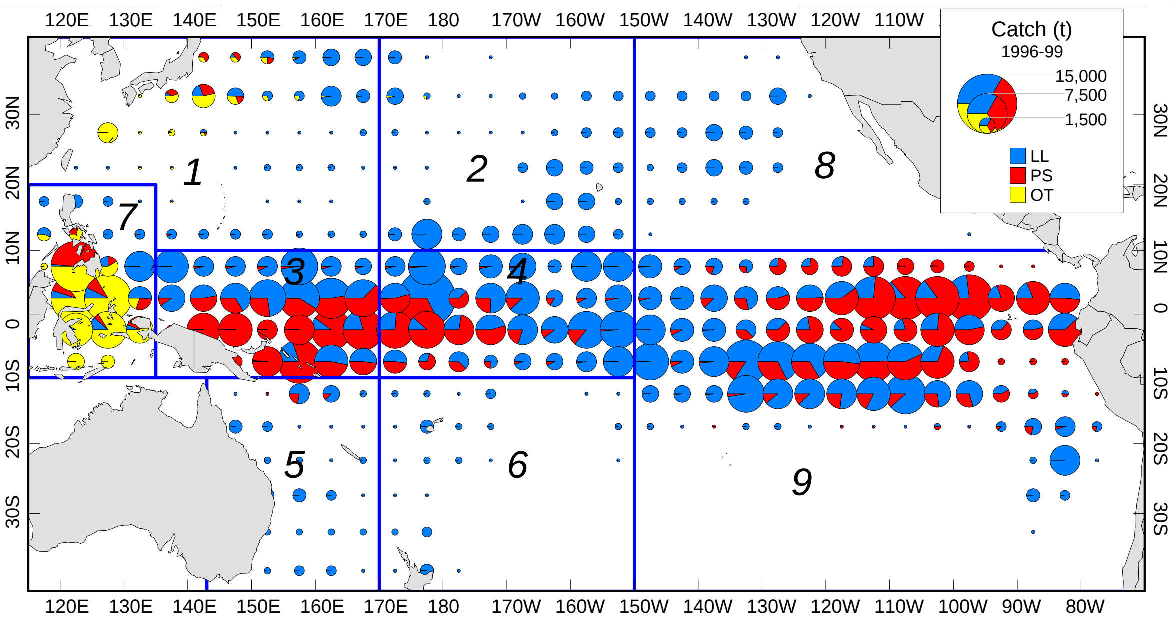


Figure 1. The nine-region spatial structure adopted for the PO model, with total catch by gear type for 1996–1999.

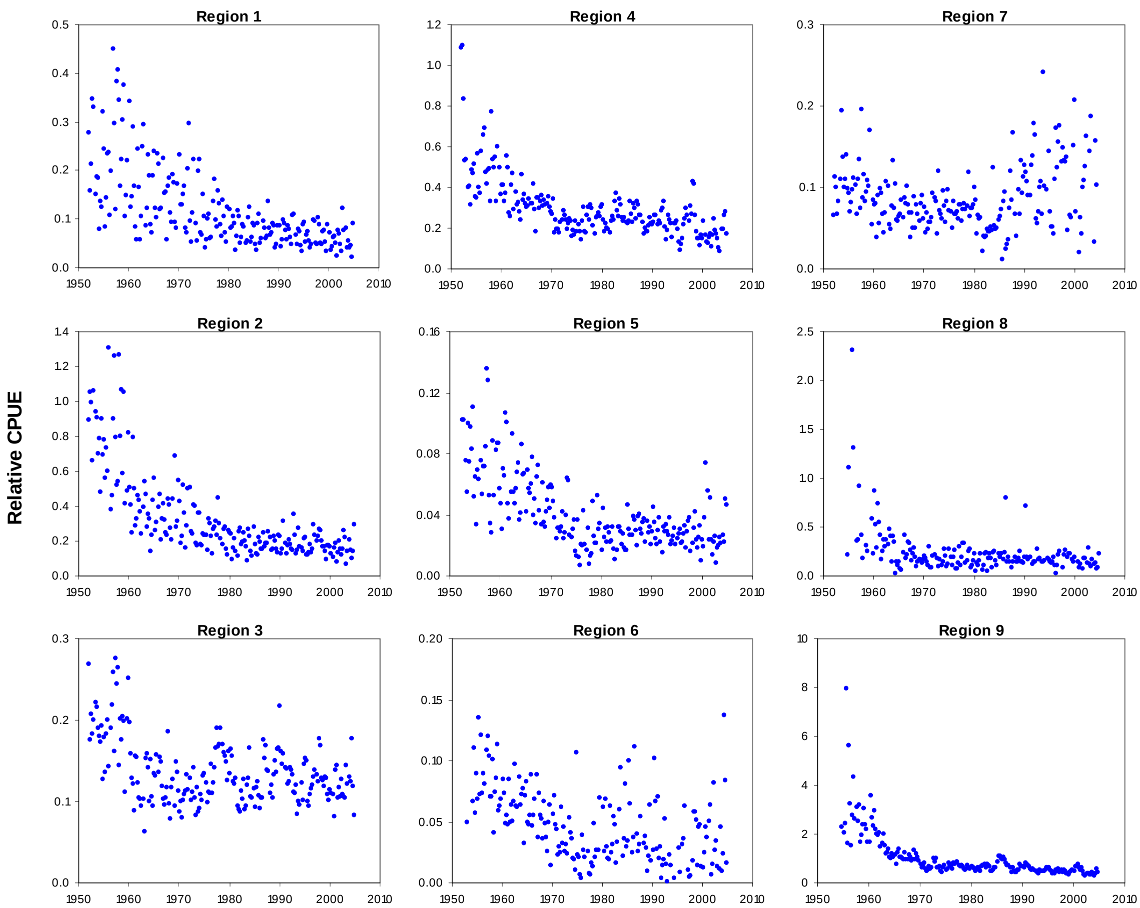


Figure 2. Quarterly standardised CPUE for the main longline fisheries in each model region. The estimates are scaled so as to represent the relative abundance of bigeye in each region.

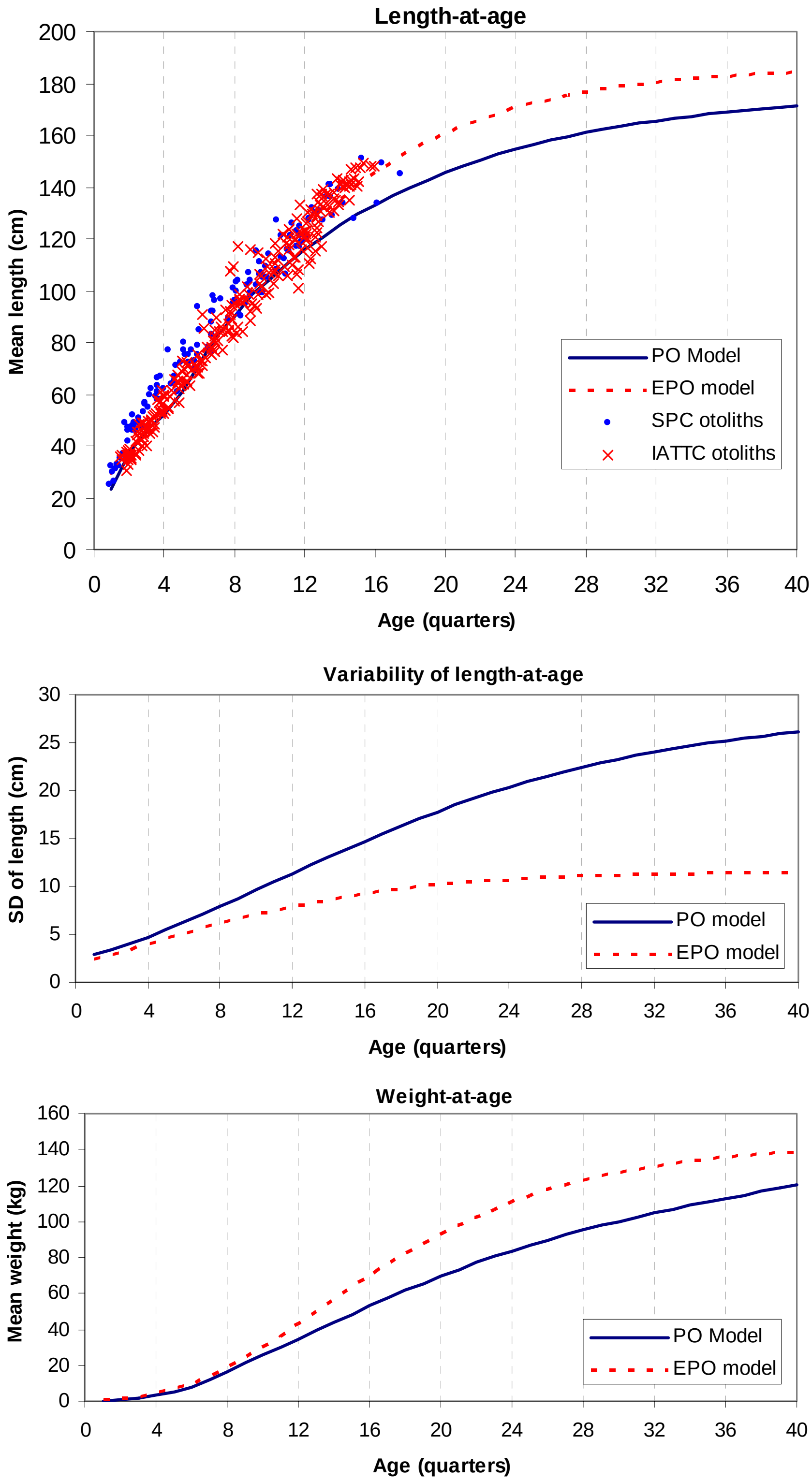


Figure 3. Estimates of length-at-age, SD of length-at-age and weight at age from the PO model and the EPO model.

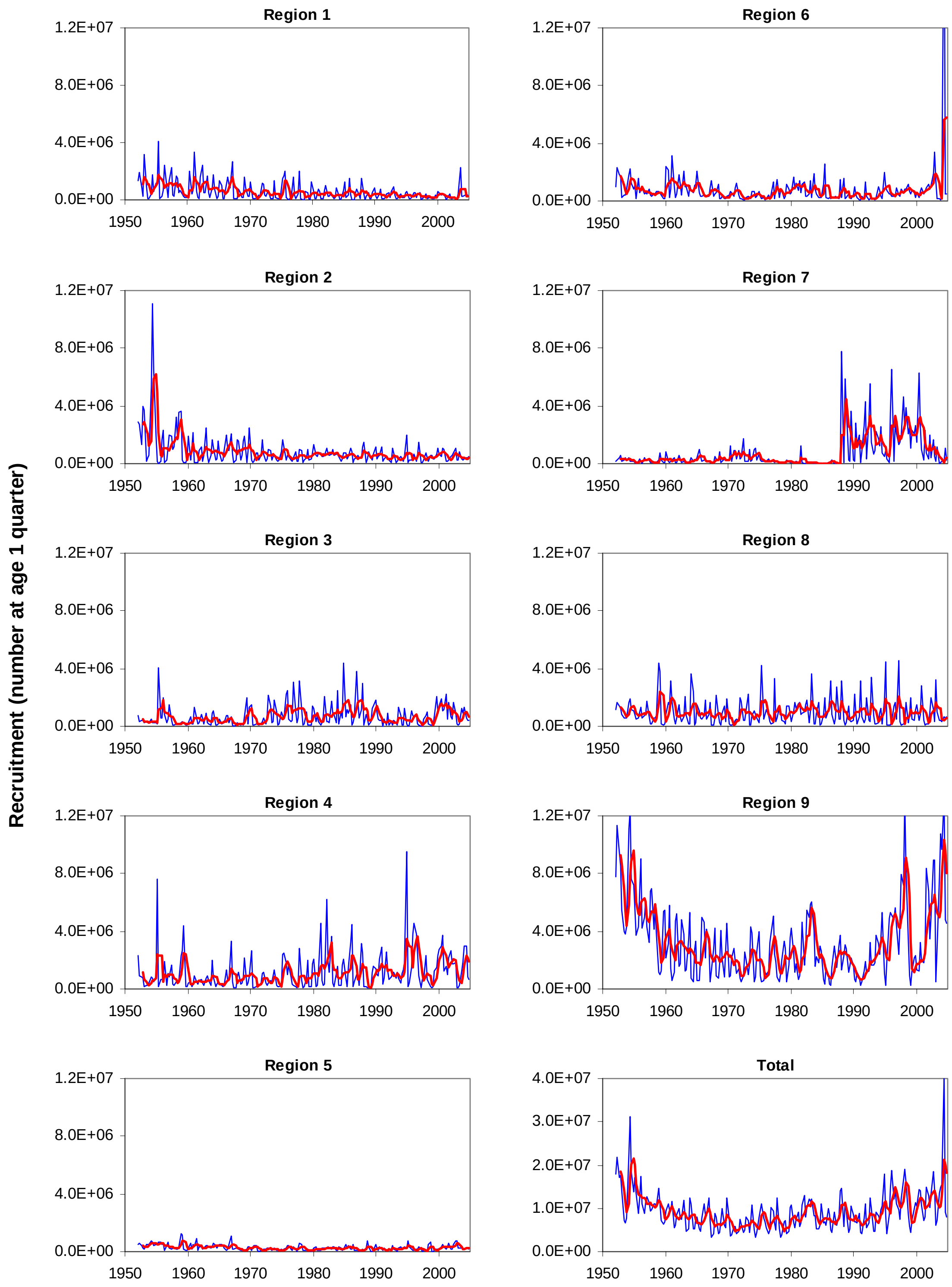


Figure 4. Estimates of quarterly recruitment (blue line) by region from the PO model. The red line is a 4-quarter moving average.

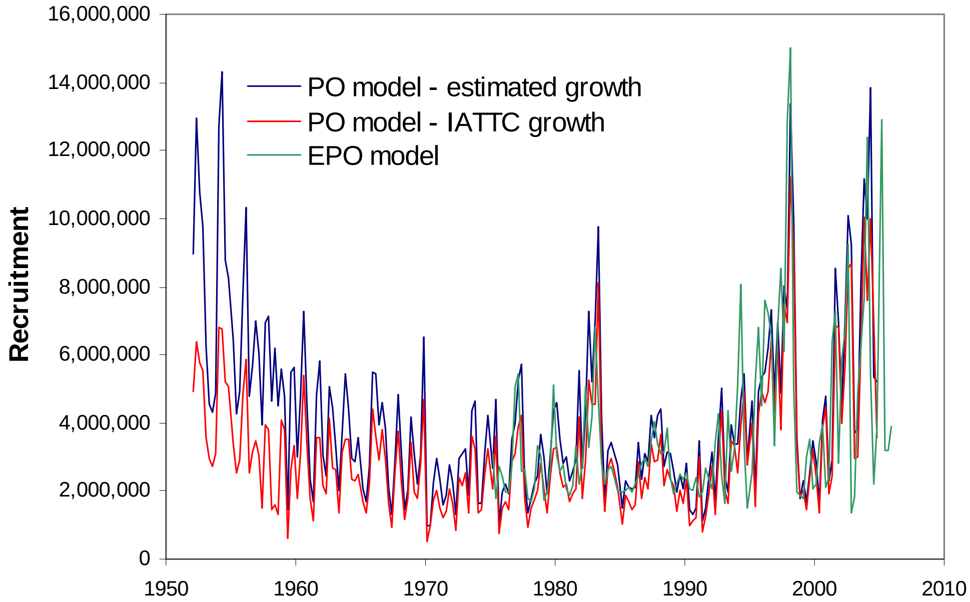


Figure 5. Estimates of recruitment for the EPO portion of the PO model (regions 8 and 9 combined) and equivalent estimates for the EPO model.

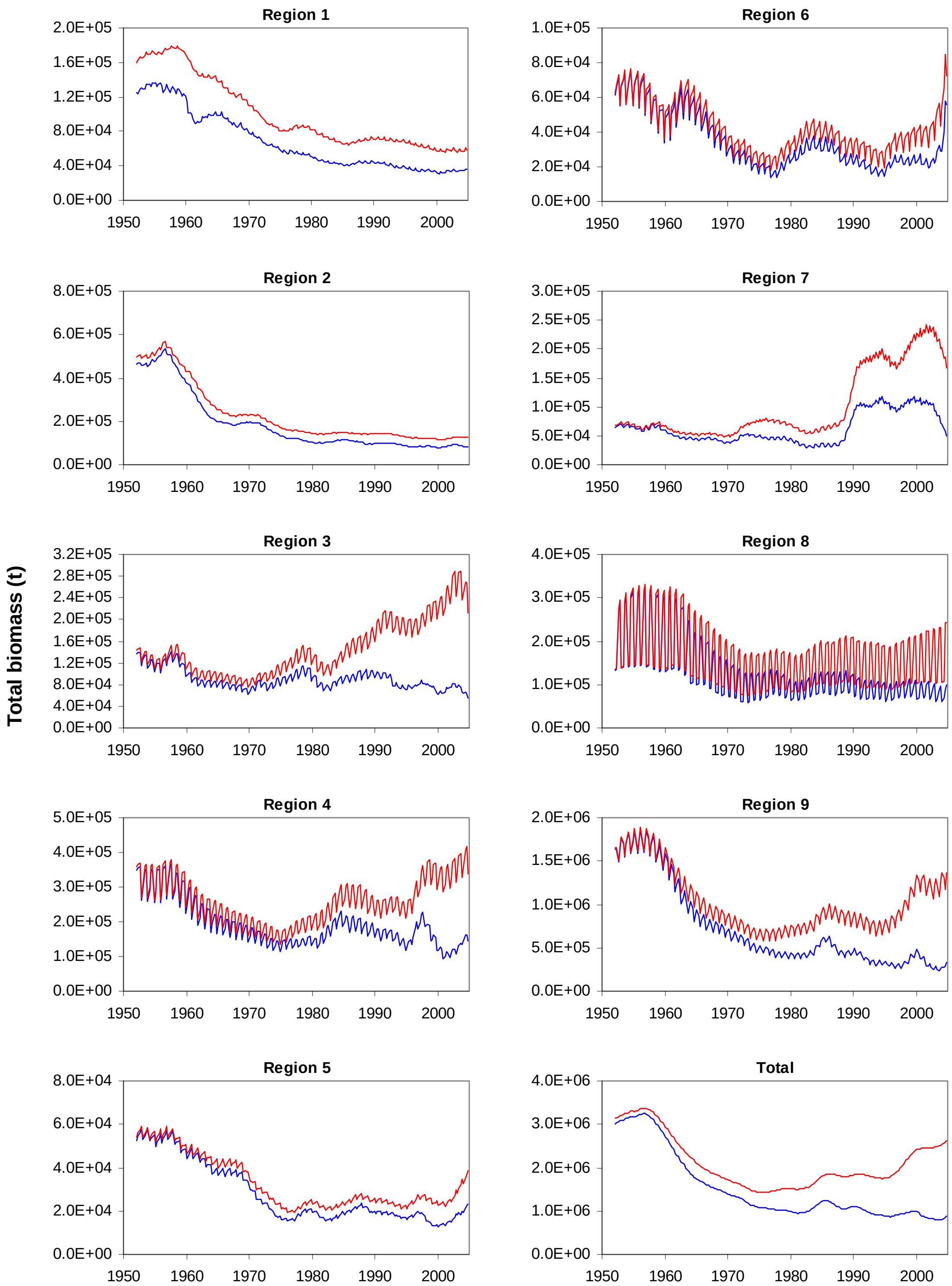


Figure 6. Estimates of total biomass by region from the PO model with (blue) and without (red) exploitation.

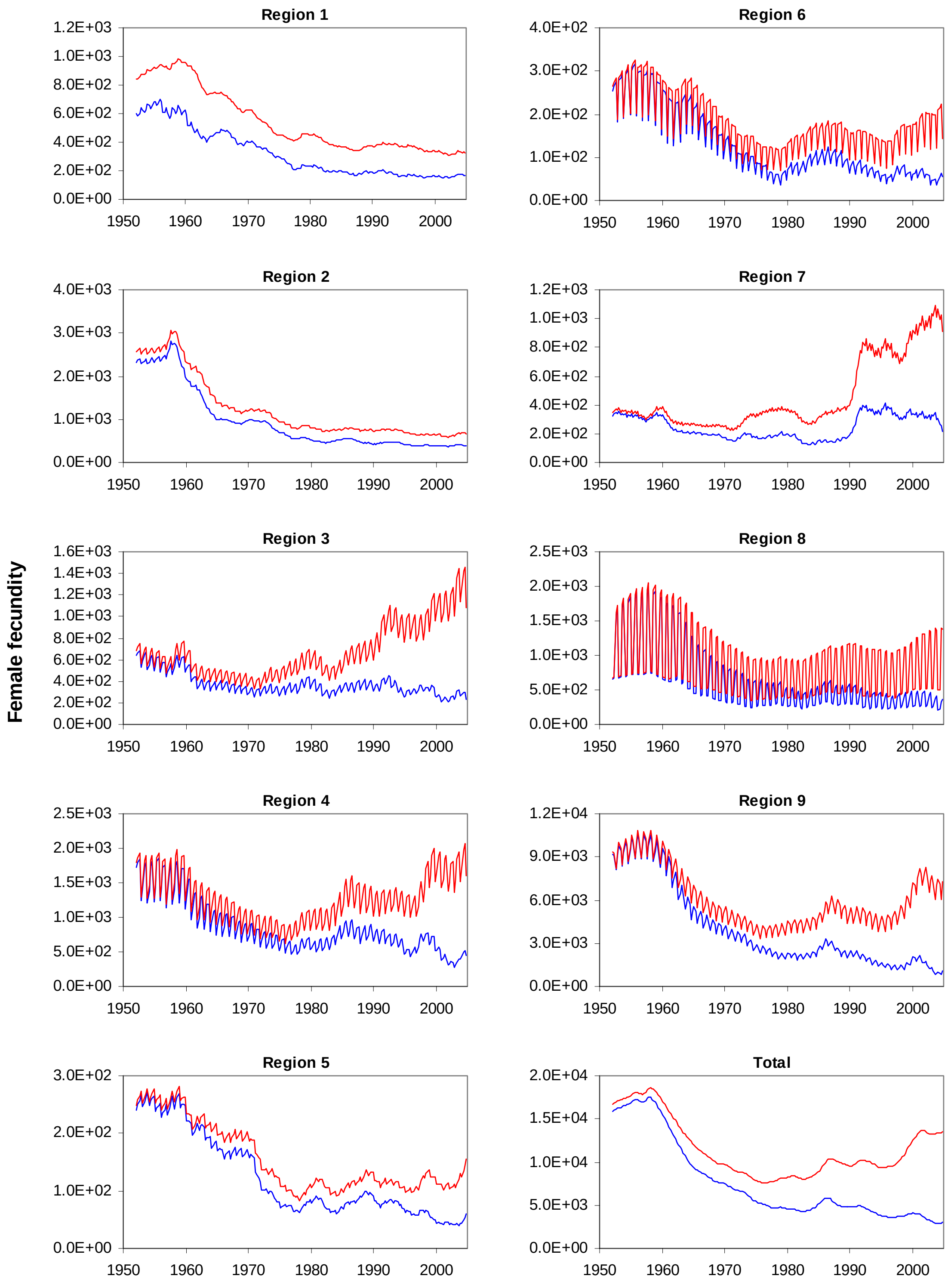


Figure 7. Estimates of relative population fecundity by region from the PO model with (blue) and without (red) exploitation.

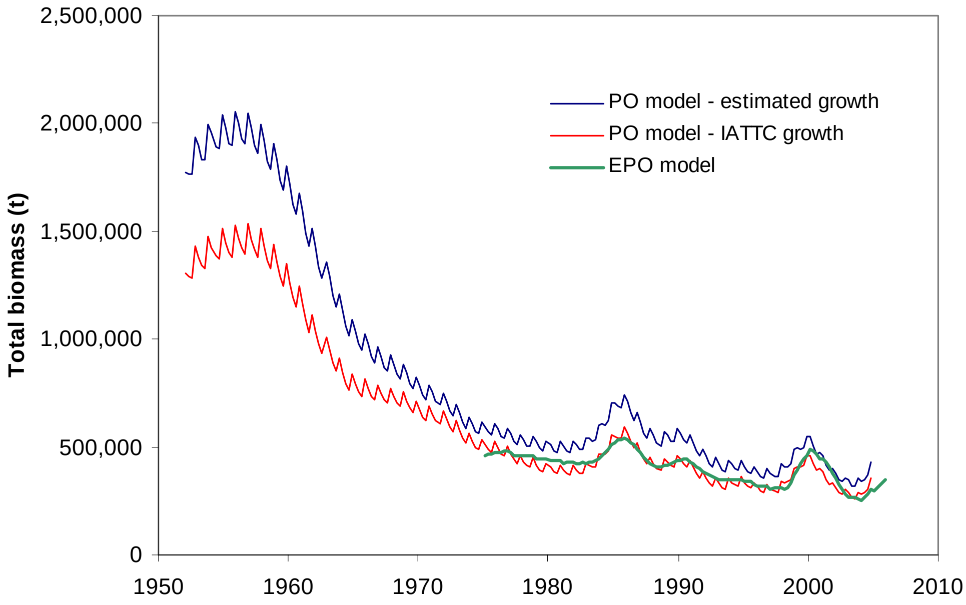


Figure 8. Estimates of total biomass for the EPO portion of the PO model (regions 8 and 9 combined) and equivalent estimates for the EPO model.

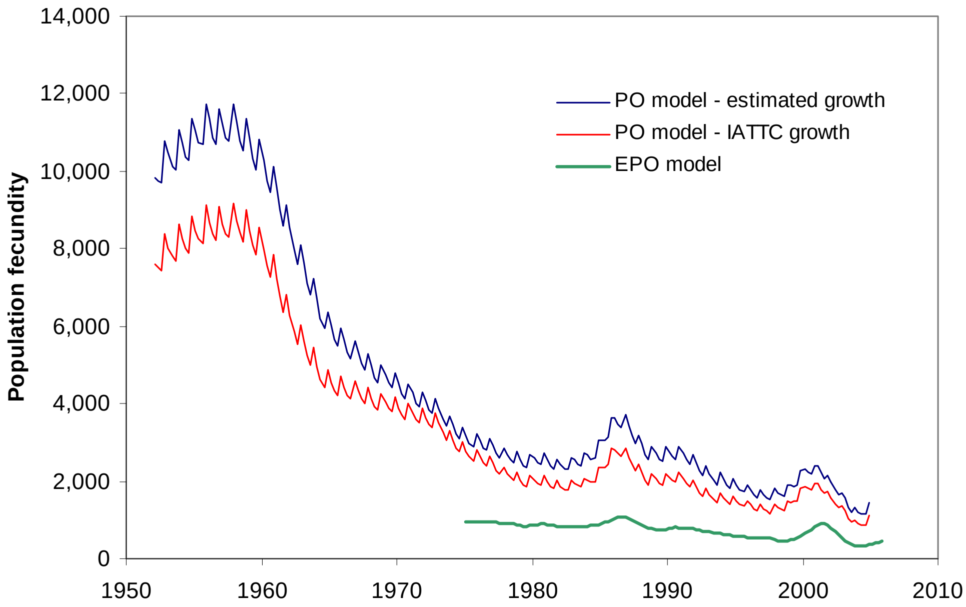


Figure 9. Estimates of total population fecundity for the EPO portion of the PO model (regions 8 and 9 combined) and equivalent estimates for the EPO model.

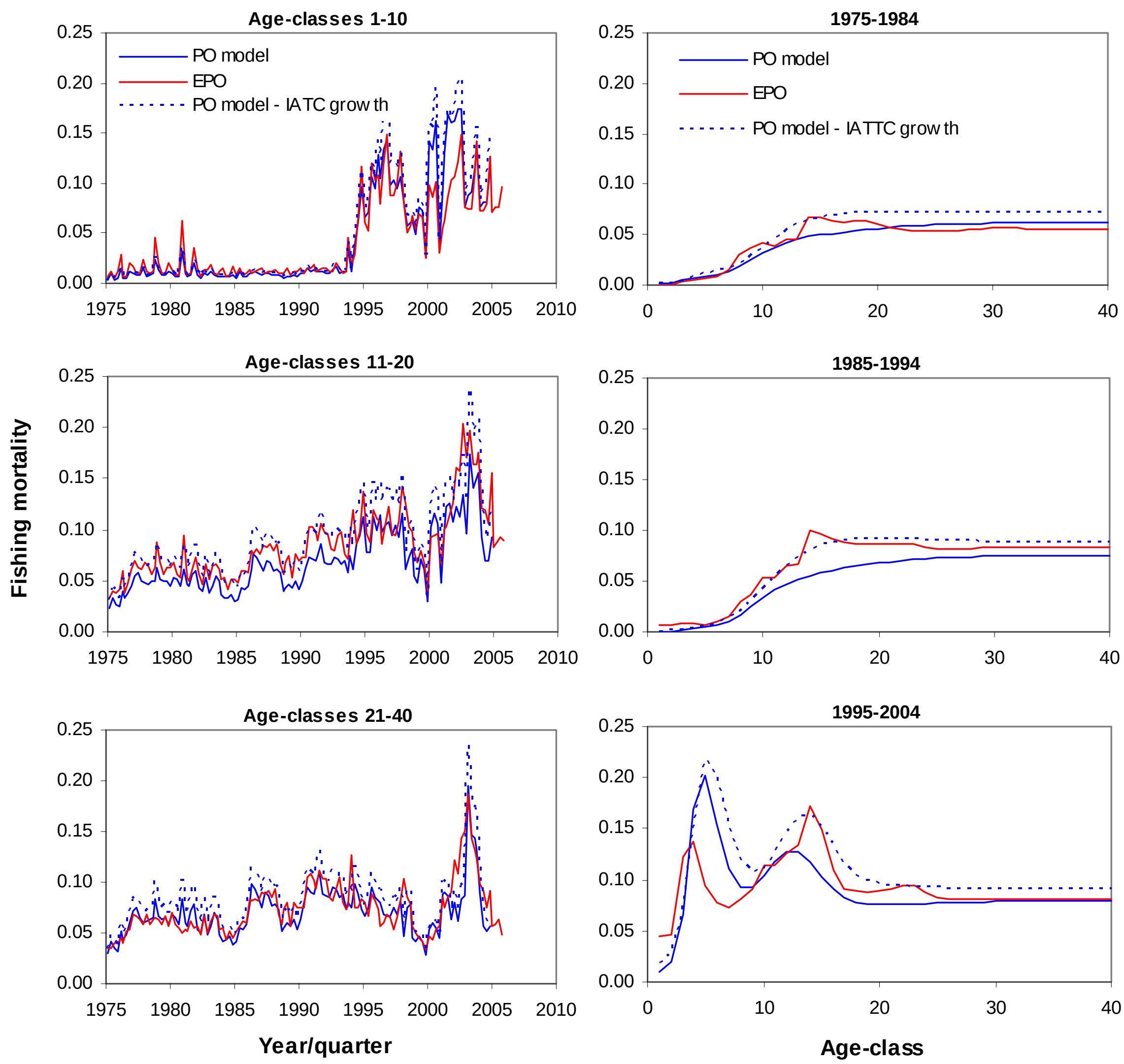


Figure 10. Estimates of fishing mortality for the EPO portion of the PO model (regions 8 and 9 combined) and equivalent estimates for the EPO model.

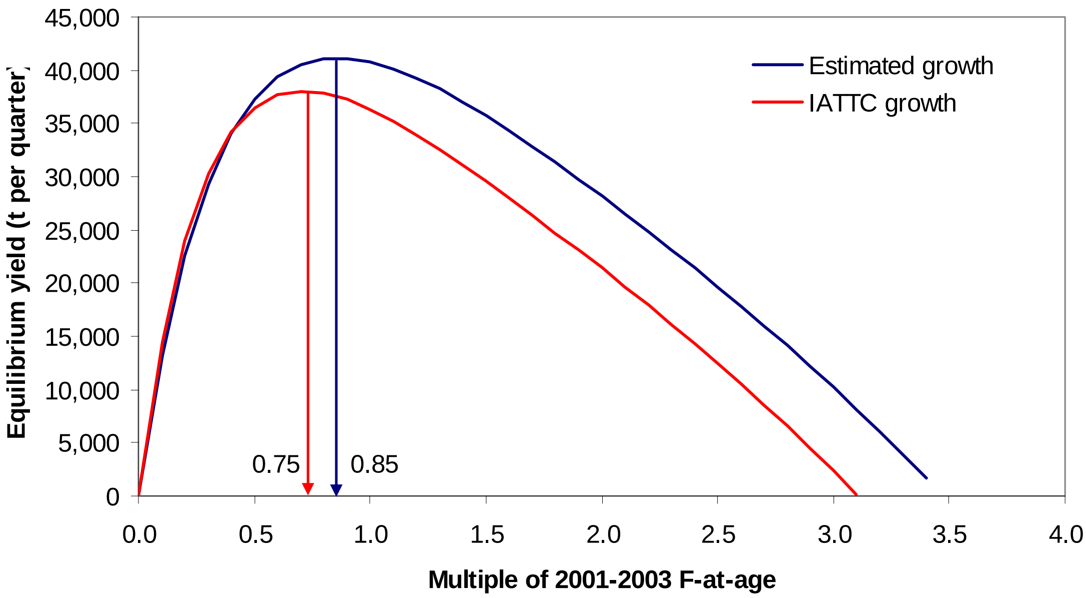


Figure 11. Equilibrium Pacific-wide yield curve based on the average 2001-2003 fishery selectivity.

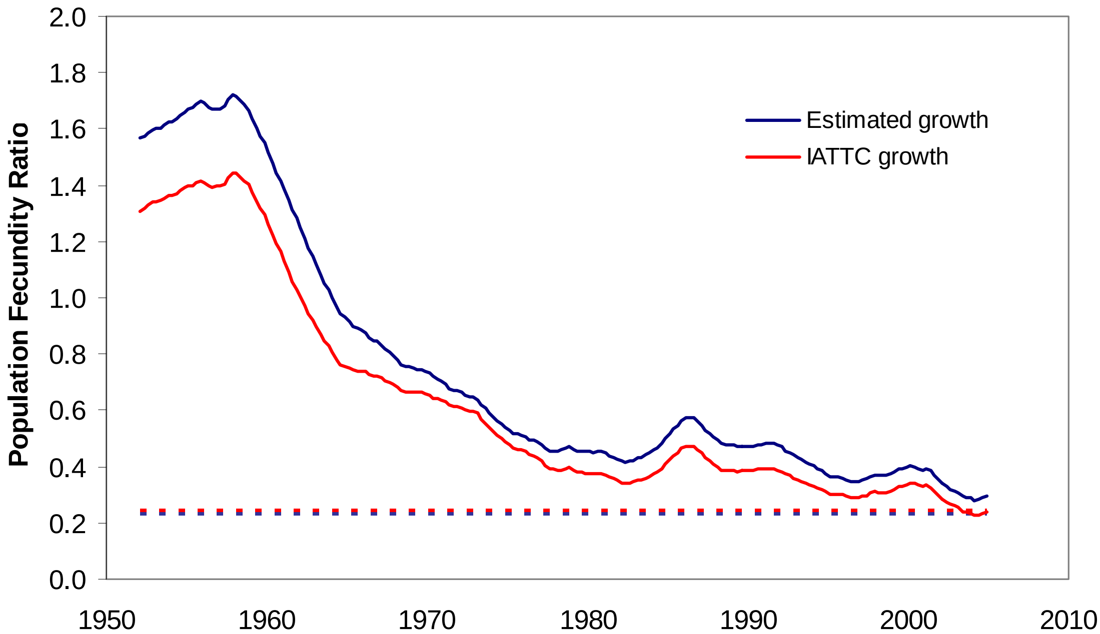


Figure 12. Estimated Pacific-wide population fecundity ratio with estimated (blue) and fixed (red) growth. The red and blue dashed lines (almost superimposed) indicate the population fecundity at MSY.

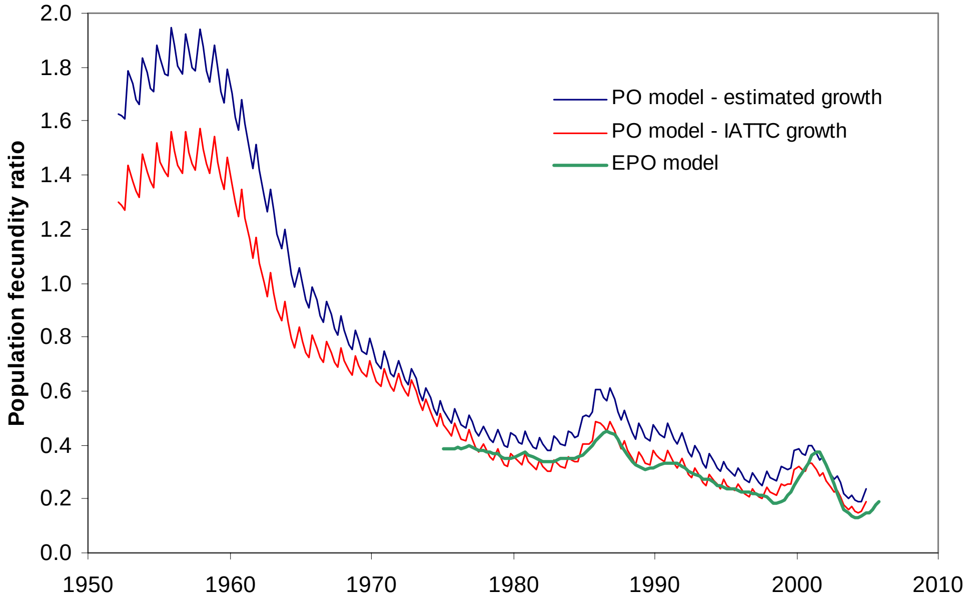


Figure 13. Estimates of total population fecundity ratio for the EPO portion of the PO model (regions 8 and 9 combined) and equivalent estimates for the EPO model.

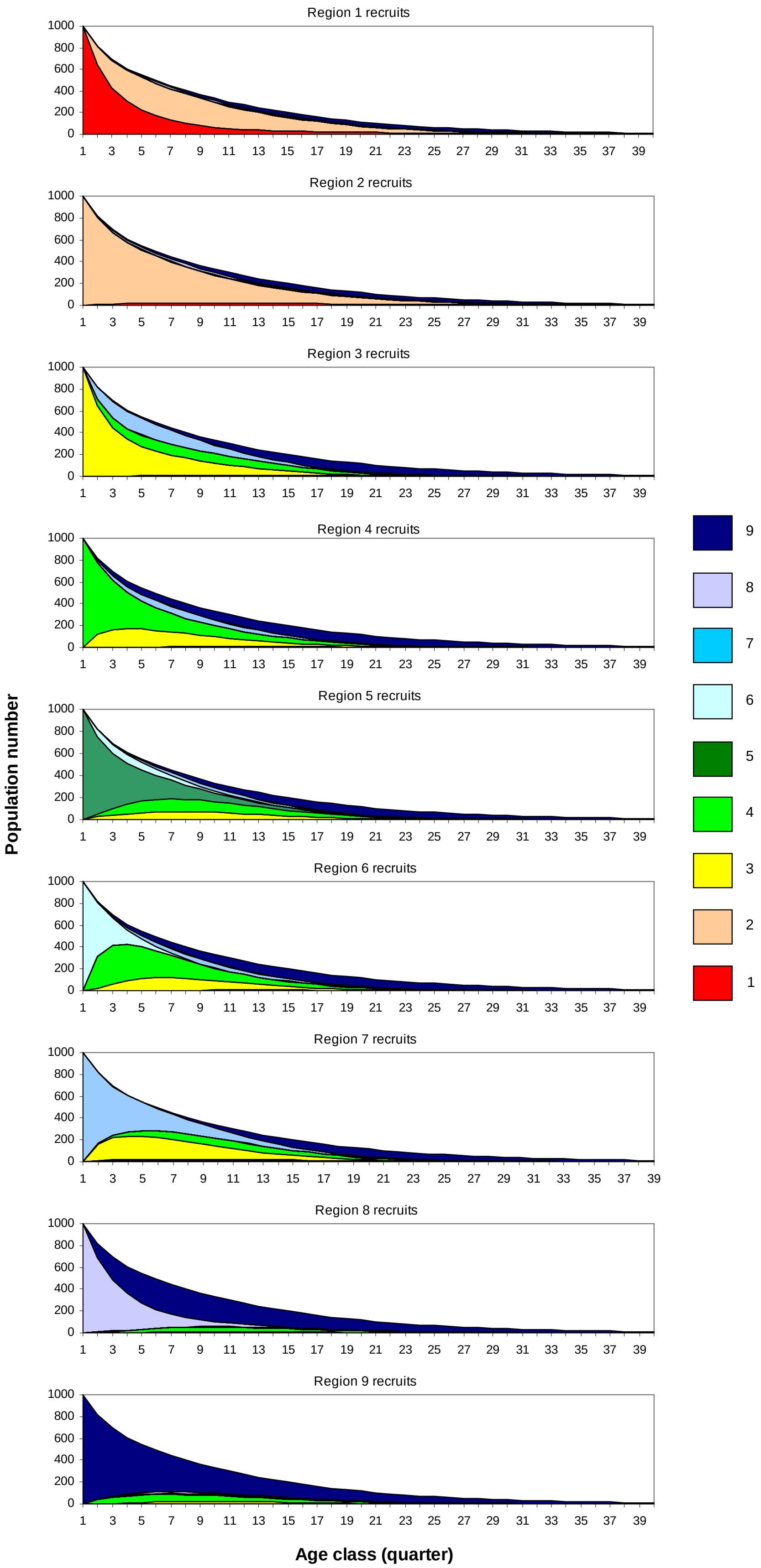


Figure 14. Distributions of simulated cohorts over time among regions.

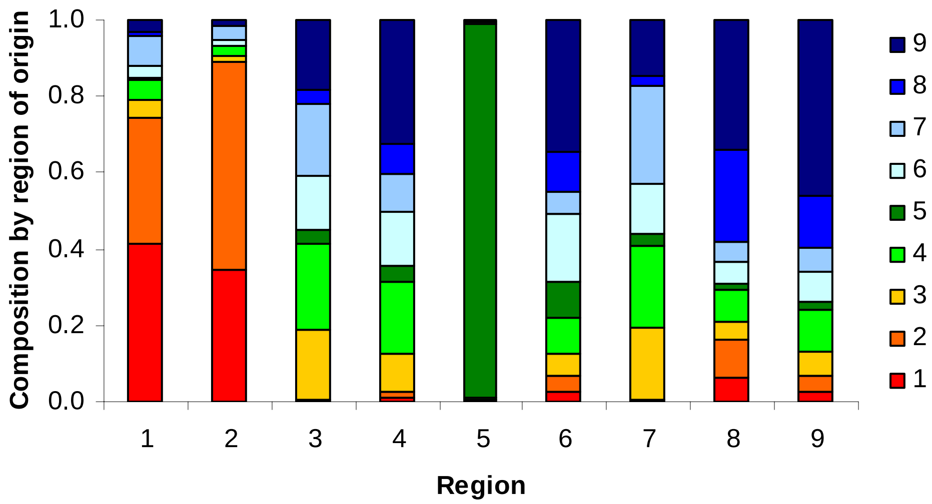


Figure 15. Composition of simulated unexploited population biomass by region of origin (recruitment). Recruitment in each region was assumed constant at average levels.