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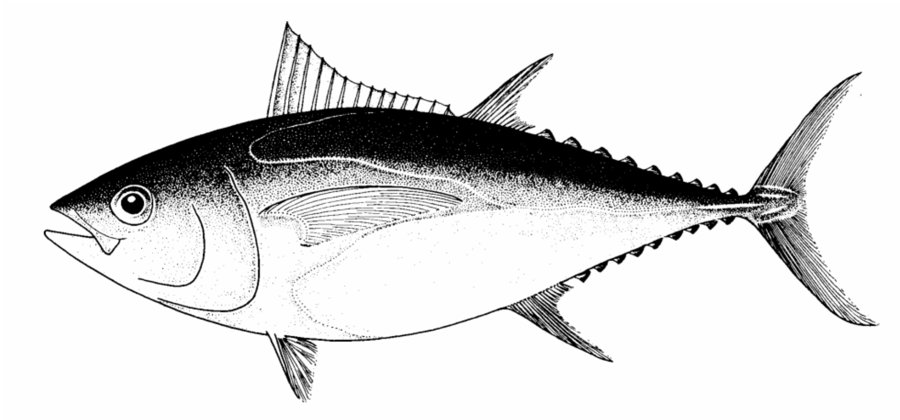
Comparison of Pacific-wide, western and central Pacific, and eastern Pacific assessments of bigeye tuna



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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. In 2003, a comparison of the results of the Pacific-wide model with the results of WCPO and EPO models was presented (Hampton et al. 2003, Appendix A). This comparison revealed consistent estimates of biomass and fishing mortality for comparable regions using the different models as well as consistent interpretations of the status of the stock.

In view of the various data and methodological updates to both the 2005 WCPO and EPO assessments, it was decided that another comparison of the results of these models with the Pacific-wide model should be undertaken. That comparison is reported in this paper.

2 Pacific-wide model for bigeye tuna

The Pacific-wide (PO) model for bigeye tuna incorporates similar structural assumptions and data as the WCPO model, with the following additions:

- The spatial coverage of the model is extended to include the EPO. Two EPO regions are defined, one north and one south of 20°N. The PO model therefore has an eight-region stratification, as shown in Figure 1.
- Longline fisheries for the two additional regions have been defined (LL ALL 7 and LL ALL 8). The catchability for these fisheries is assumed to be the same as the LL ALL 1–6 fisheries. Also, LL ALL 7 selectivity is grouped with LL ALL 1–2 and LL ALL 8 selectivity with LL ALL 3–6.
- Four purse seine fisheries occurring in region 8 have been defined. These fisheries have been defined according to their area of operation (nearshore, central and offshore areas) and set type (associated sets on floating objects and other set types). The PS OTH fishery includes a small amount of baitboat catch. These fisheries have independent catchability and selectivity parameterisations but have similar structural assumptions (catchability deviations, effort deviations and cubic spline selectivity) as the WCPO purse seine fisheries. The complete list of fisheries defined in the PO model is given in Table 1.
- The fishery data were the same as those used in the WCPO analysis, augmented by data for the additional fisheries. The PO model incorporates the same time window (1952–2004) and temporal structure (quarter) as the WCPO model.
- Some additional tagging data were used in the PO model, in particular 9,959 releases in region 8 in 2000, 2002 and 2003, and 2,714 subsequent recoveries of those tags.
- Because the EPO assessment used longline effort standardised using the statistical habitat based standardisation (SHBS) approach, we have also used the SHBS option for estimating longline effort for fisheries LL ALL 1–8 for the PO model.
- A fixed natural mortality-at-age was assumed in the PO model, as estimated for the 2005 EPO bigeye tuna assessment (Maunder and Hoyle 2005). The same *M*-at-age was used in the WCPO assessment.

3 PO–WCPO comparisons

3.1 Biomass, recruitment and fishing mortality

Comparisons of estimated total and adult biomass, recruitment and recent average fishing mortality-at-age estimated by the PO and WCPO models are given in Figure 2. Estimates of time series of average fishing mortality for three different age groups are compared in Figure 3. Each comparison is for the same region or group of regions in the WCPO. While the estimates are comparable, the PO model estimates slightly higher biomass and recruitment, and slightly lower fishing mortality compared to the WCPO model.

3.2 Stock assessment indicators

Comparisons of the yield curves for the two analysis are shown in Figure 4. MSY for the Pacific is estimated at around 150,000 t per year while for the WCPO, the MSY is around 65,000 t. The ratio of WCPO MSY to PO MSY (0.42) is slightly greater than the ratio of average biomass over the past ten years (0.37), probably because the yield-per-recruit in the WCPO is higher because of the higher contribution of longline fishing (larger fish) to the total catch. Recent fishing mortality is estimated to be close to the MSY level for the PO model and slightly above the MSY level for the WCPO.

The ratios of adult biomass to that resulting in MSY are plotted in Figure 5 for the two models. Spawning biomass ratios (SBR) are plotted in Figure 6. In both cases, adult biomass is estimated to have remained above MSY levels, although this has been approached in the WCPO in recent years. These indicators suggest a somewhat healthier stock condition for bigeye on a Pacific-wide basis than for the stock in the WCPO.

3.3 Discussion

The results for the WCPO portion of the PO model produce similar, but not identical results to the WCPO model. The PO model estimates a slightly more optimistic outlook for the stock, with higher estimates of recruitment and biomass, and lower estimates of fishing mortality. It is possible that these differences result from the influence of longline catch and effort data for the EPO regions. With these data included, average catchability for the main longline fisheries is considerably lower (0.015) than when only the WCPO fisheries are included (0.022). This would tend to lower the fishing mortality for older bigeye, and increase biomass estimates in the PO model. It is also possible that interaction between mortality and movement estimates plays a role in generating these differences. In the PO model, there is considerable movement from the WCPO into region 8, but such movement is absent from the WCPO model because the WCPO is assumed to be the limit of the stock. These issues should be investigated in future by (i) allowing independent catchability for the EPO longline fisheries and (ii) fixing WCPO–EPO movement at different levels in the PO model.

4 PO–EPO comparisons

Stock assessment of bigeye tuna in the eastern Pacific Ocean (EPO) is carried out annually by the staff of the Inter-American Tropical Tuna Commission (IATTC), using the A-SCALA stock assessment model (Maunder and Watters 2003). A-SCALA is based on MULTIFAN-CL (MFCL, Fournier et al. 1998; Hampton and Fournier 2001), but, due to data limitations and differences in the methodology, there are several differences between the two approaches. We describe the main differences in the methodology and results between the Pacific-wide MFCL assessment and the IATTC EPO assessment (the full IATTC assessment is presented by Maunder and Hoyle 2005).

4.1 Differences in methodology

The major difference between A-SCALA and MFCL is that A-SCALA does not have the ability to model multiple interacting sub-stocks or include tagging data. A-SCALA assumes a single population, and spatial differences can be represented only by differences in the selectivity and catchability of the fisheries that operate in the different areas. MFCL can explicitly model sub-populations and exchange between those sub-populations. The ability to fit to tag release and recapture data in the model provides information on the movement among the sub-stocks and other aspects of the population dynamics (Hampton and Fournier 2001). Previously analyses (Hampton et al. 2003) have been carried out to investigate the inclusion of spatial structure in the population dynamics of bigeye tuna assessments in the Pacific Ocean. These analyses indicated that the results were not sensitive to inclusion of spatial structure in the population dynamics, and that spatial structure in the fishery characteristics may be adequate to describe differences among areas. However, further analyses are needed. The Pacific-wide assessment also assumes that catchability for the major longline fisheries is invariant among the areas, which provides additional information on the relative abundance of fish in each of the areas.

Another major difference between the assessments is that the IATTC assessment starts at an exploited condition in 1975 and the Pacific-wide assessment starts at an (almost) unexploited condition in 1952. There was substantial expansion of the longline and purse-seine fisheries in the Pacific Ocean between 1952 and 1975. The purse-seine fisheries did not cover the majority of the EPO until about 1975, providing the rationale for beginning the IATTC assessment in that year.

There are several other differences between the two models, for example, the methods used to represent the selectivity and growth, the longline catch used in the assessments (Figure 7), and the aggregation of fisheries. One difference important for the discussions of the results below is the inclusion of age-length data in the IATTC assessment. Due to the sampling design, which selects a set number of fish to age within each set of size bins, age at length, rather than length at age, is modelled. Including age-at-length data into the model provides information about the mean length-at-age and the variation of length-at-age.

4.2 Comparison of results

The Pacific-wide assessment estimates a much greater spawning biomass than the IATTC assessment (Figure 8). The fishing mortality for the two analyses is similar between for the younger fish, but the IATTC assessment estimates greater fishing mortality rates for the older fish (Figure 9). These differences also translate into differences in the spawning biomass ratio (SBR, Figure 10).

There are several differences in the models that interact to cause these differences. However, we focus on differences in the growth-related quantities; the differences in the mean length at age and in variation of length at age. The IATTC assessment estimates somewhat larger lengths at age for individuals 3 years of age and older (Figure 11), and smaller standard deviations of the variation in length at age for all ages, with the differences increasing with age (Figure 12).

The IATTC assessment assumes that the L_∞ parameter of the Richards growth curve (a generalization of the von Bertalanffy growth curve), which represents the average asymptotic length, is equal to 186.5 cm. The Richards growth curve is then fit to the age-length data from Schaefer and Fuller (submitted) with this fixed L_∞ and the remaining parameters estimated. The Richards growth curve is then used as a very strong prior in the A-SCALA model. To test the sensitivity of the assessment to the assumed L_∞, we ran the assessment with the length at age fixed, using the Richards growth curve with different values for L_∞. For each value of L_∞, the remaining parameters are estimated outside the A-SCALA model by fitting to the age-length data from Schaefer and Fuller (submitted). For these analyses, we group the fisheries as in the Pacific-wide assessment, and do not include the discard fisheries. These changes had little effect on the results.

The results show that the estimates of the spawning biomass are very sensitive to the assumed value of L_∞. The estimated spawning biomass is greater for lower values of L_∞. The SBR is also greater for lower values of L_∞, in both 1975, at the start of the modelling period, and 2005, at the end of the modelling period (Figure 13, Table 2). The standard deviation of the variation of length at age is not sensitive to L_∞ (Figure 14); this is probably due to the inclusion of the age-length data in the model. The negative log-likelihood is optimized at an L_∞ around 170 cm (Figure 15), which is smaller than the L_∞ assumed for the IATTC assessment. However, for L_∞ = 170, the Richards growth curve does not fit the age-length data for the oldest fish in the data set (Figure 16).

A growth curve with the length at age estimated as free parameters for each age was also fit. This model gave similar estimates of growth for ages for which there are age-length data, but was very jagged for the older fish (Figure 17). The SBR estimates from this analysis were similar to those for which L_∞ = 170 cm (Table 2).

The IATTC assessment was also repeated with the mean length-at-age fixed at that estimated in the Pacific-wide assessment. The likelihood for this model was much worse than for the other mean length-at-age scenarios (Table 2). This is due to the poor fit to the age-length data that is a component of the combined likelihood function (Figure 18). The SBR estimates from this analysis were similar to those for which L_∞ = 170 cm and for which growth was estimated as free parameters (Table 2).

4.3 Discussion

There are substantial differences in estimated spawning biomass between the IATTC EPO assessment and the Pacific-wide assessment. These results have substantial implication for the status of the stock and consequential management action. The assumed L_∞ of the Richards growth curve has been identified as a major factor causing these differences. It is hypothesized that L_∞ influences the results through its interaction with the length-frequency data. If L_∞ is large, and few large individuals are represented in the length-frequency data, the model estimates that this is because the fishing mortality rate is high for older individuals and there are few individuals left of this size. This is particularly influential, since the model is started at an exploited state in 1975 and is not constrained by a historical catch-trajectory and the assumption of starting at an unexploited level. The standard deviation of the variation of length at age will also interact with L_∞ and the catch-at-length data. However, in the case of the IATTC assessment, this is not a factor because the standard deviation of variation of length at age is not sensitive to L_∞. Presumably, this is because of the inclusion of age-length data in the assessment.

Research should continue to determine the differences between the two assessments. Some aspects of the assessment could be resolvable (e.g. the longline catch data), but others may require the presentation of sensitivity analyses. The results highlight the need for research into the mean length and variation of length at age, particularly for the older individuals.

5 References

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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	Japan, Korea, Chinese Taipei	Longline	7
22	LL ALL 8	Japan, Korea, Chinese Taipei	Longline	8
23	PS ASS N	All	Purse seine, log/FAD sets, nearshore area	8
24	PS OTH	All	Purse seine, school, dolphin sets	8
25	PS ASS C	All	Purse seine, log/FAD sets, central area	8
26	PS ASS O	All	Purse seine, log/FAD sets, offshore area	8

Table 2. Results from the analyses investigating the influence of the growth parameters on the IATTC assessment. Lsd 1 = standard deviation in the variation of length at age 1 quarter. Lsd 40 = standard deviation in the variation of length at age 40 quarters.

L_∞	SBR 1975	SBR 2005	-ln(Like)	-ln(Like) – min[-ln(Like)]	Lsd 1	Lsd 40
Basecase	0.29	0.13			2.30	11.53
Free growth	0.64	0.32			2.14	16.43*
Pacific-wide growth	0.63	0.28	-350603	58.33	3.10	11.05
160	0.64	0.31	-350653	8.69	2.08	11.91
165	0.65	0.32	-350661	0.63	2.23	11.41
170	0.58	0.28	-350662	0.00	2.34	11.09
175	0.48	0.23	-350655	6.15	2.38	11.08
180	0.40	0.18	-350648	13.82	2.40	11.22
186.5	0.32	0.14	-350640	22.00	2.41	11.50
190	0.28	0.12	-350637	24.71	2.43	11.55
195	0.25	0.11	-350634	27.56	2.44	11.72

*The growth cure is not smooth for this analysis and the standard deviation in the variation of length at age is large for this age.

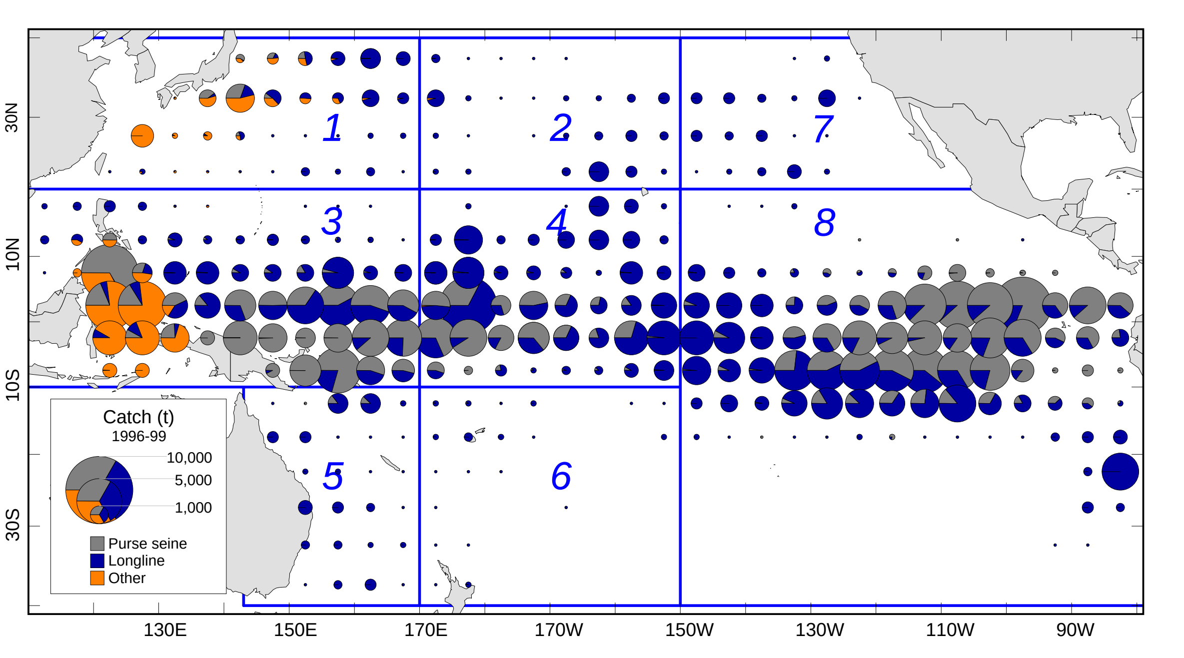

Figure 1. Pacific-wide bigeye tuna catch, 1996–1999. Regions 1–8 represent the spatial stratification adopted for the PO analysis. Regions 1–6 are those used for the WCPO assessment.

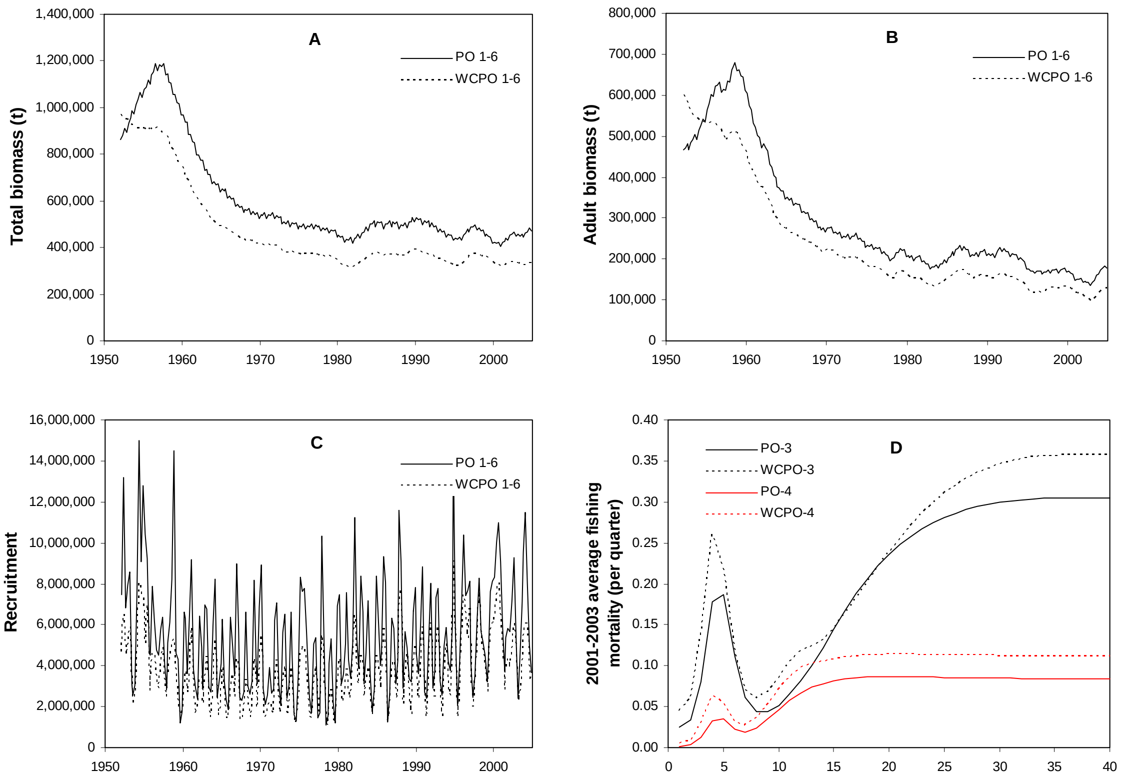

Figure 2. Comparisons of total biomass (A), adult biomass (B), recruitment (C) and average fishing mortality at age for 2001–2003 (D) for equivalent spatial regions of the PO and WCPO bigeye tuna models.

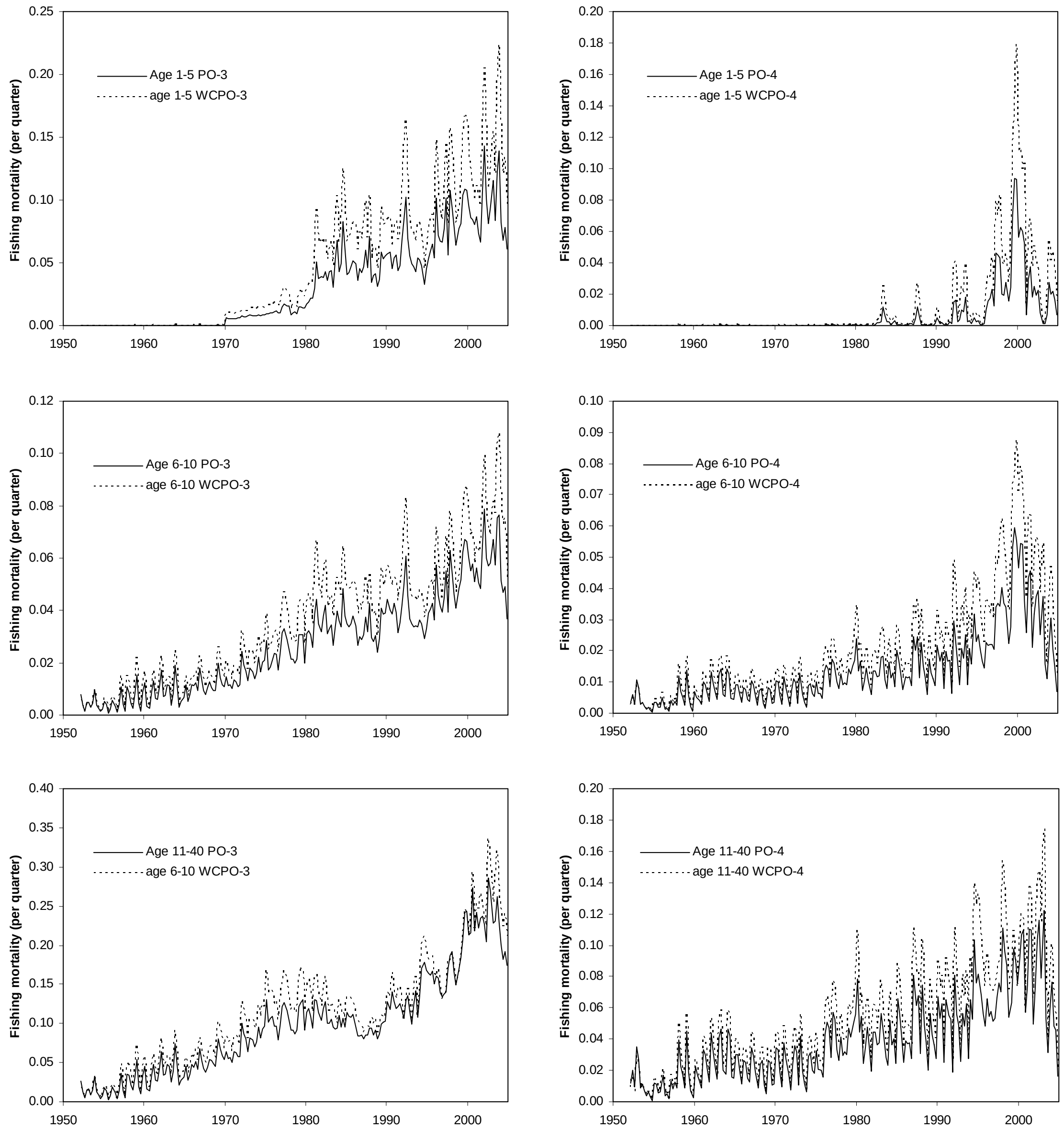

Figure 3. Estimates of average fishing mortality for age-classes 1–5 (top), 6–10 (middle) and 11–40 (bottom) for region 3 (left) and region 4(right) of the PO (solid lines) and WCPO (dashed lines) models.

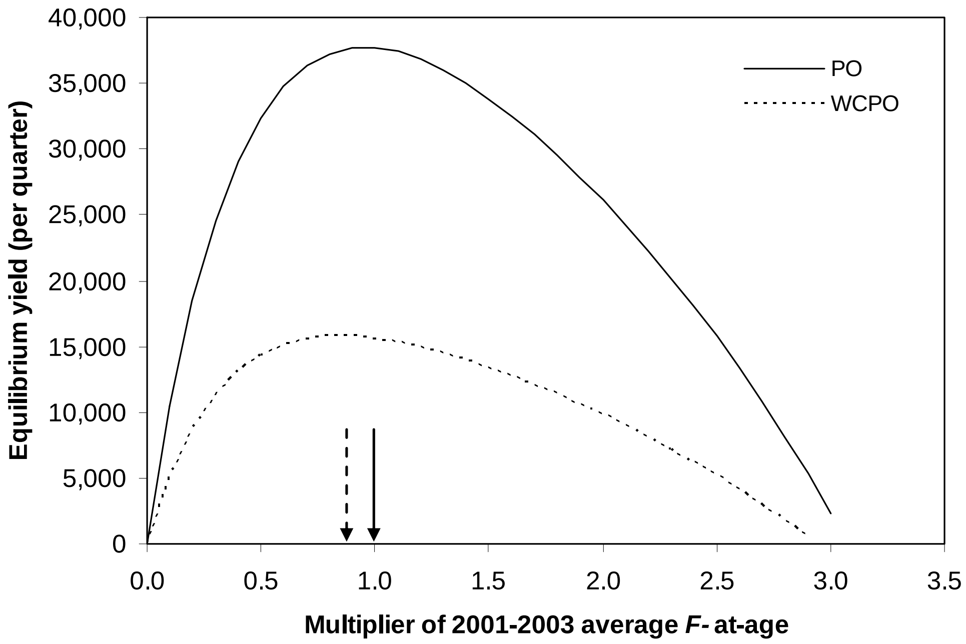

Figure 4. Estimates of equilibrium yield for the whole Pacific (PO) and western and central Pacific (WCPO) as a function of multiples of the 2001–2003 average fishing mortality-at-age. The arrows indicate the levels of relative fishing mortality that maximise equilibrium yield in the two analyses.

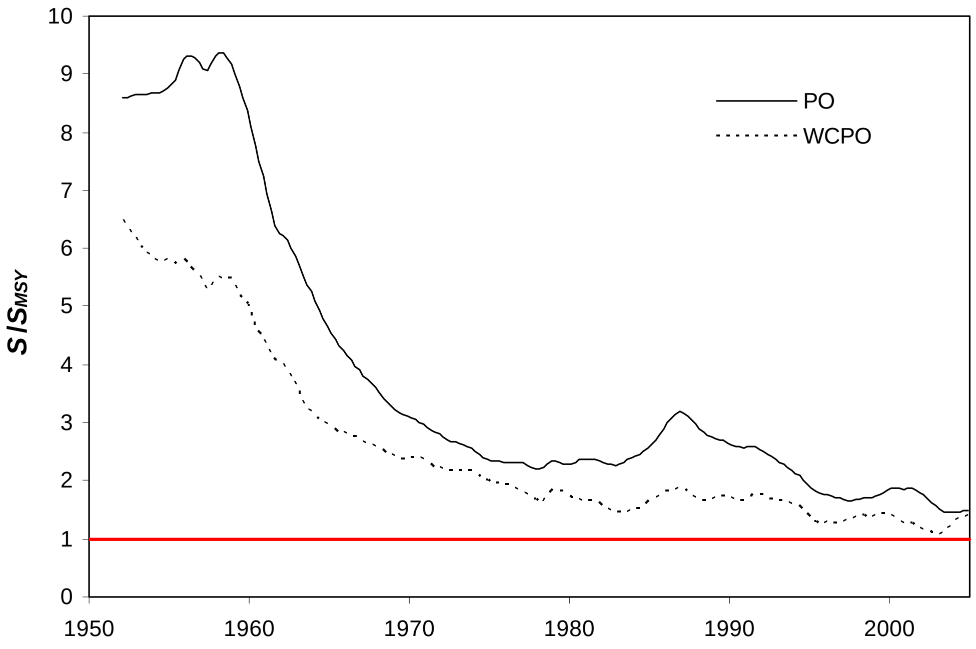

Figure 5. Estimates of the ratio of adult biomass (S) to adult biomass at MSY (S_{MSY}) for the Pacific (PO) and western and central Pacific Ocean (WCPO). The red line indicates the value $S/ S_{MSY} = 1$, which is often taken as a limit reference point for management purposes.

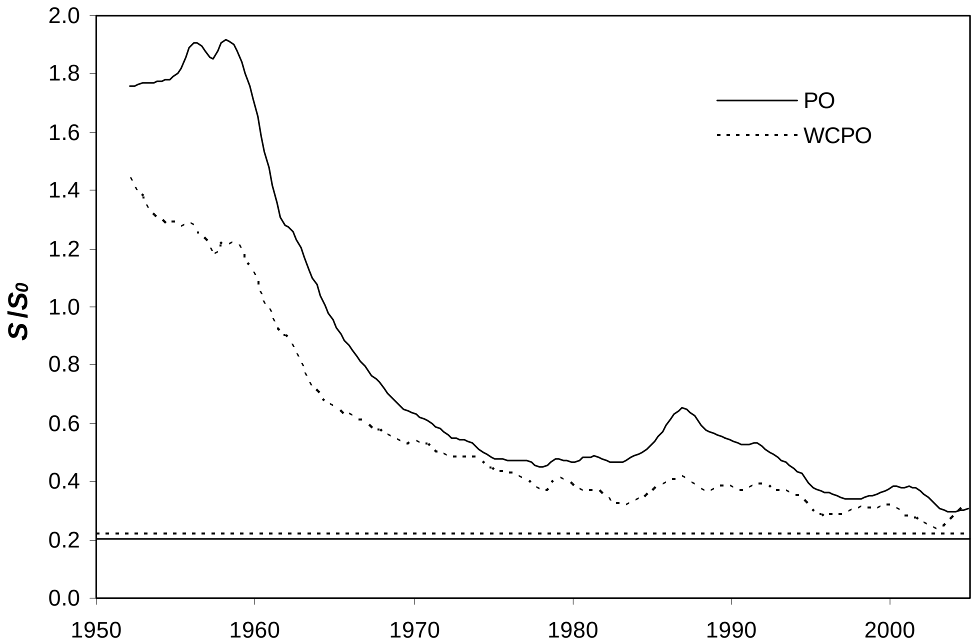

Figure 6. The ratio of adult biomass to the equilibrium unexploited adult biomass, or spawning biomass ratio (SBR). The horizontal lines indicate the ratios of spawning biomass at MSY to the equilibrium unexploited spawning biomass.

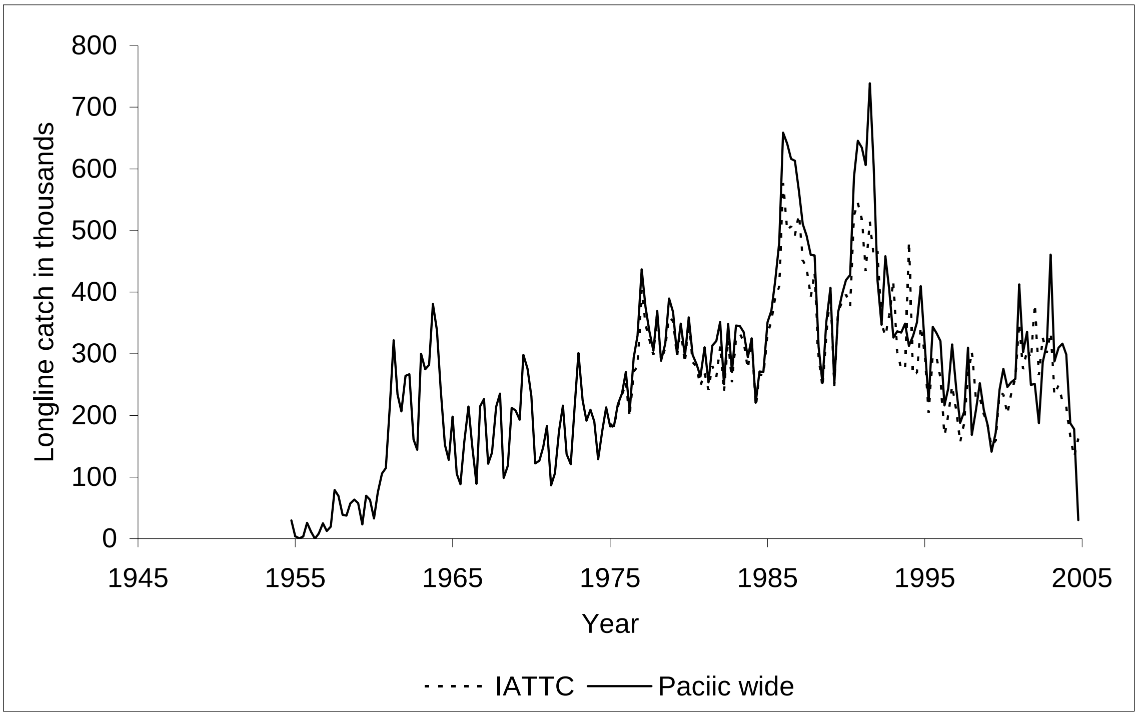

Figure 7. Comparison of longline catch data used in the IATTC EPO assessment and the EPO region from the Pacific-wide assessment.

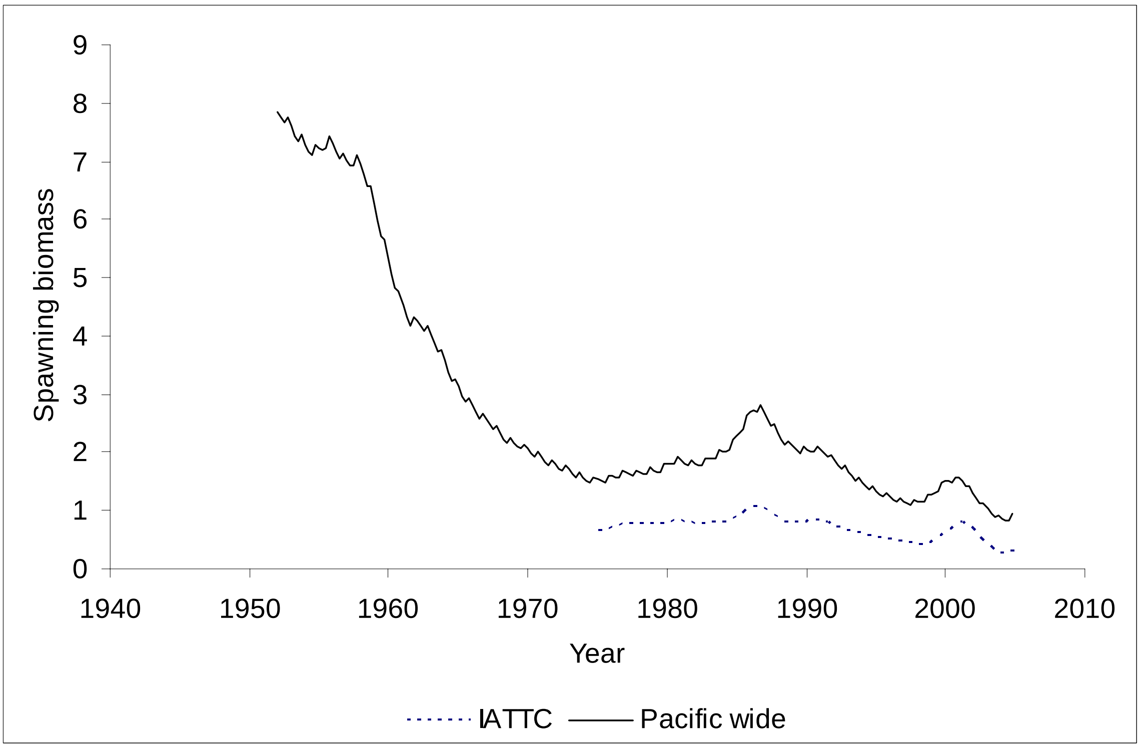

Figure 8. Comparison of spawning biomass (determined according to methods used in IATTC assessments) from the IATTC EPO assessment and the EPO region from the Pacific-wide assessment.

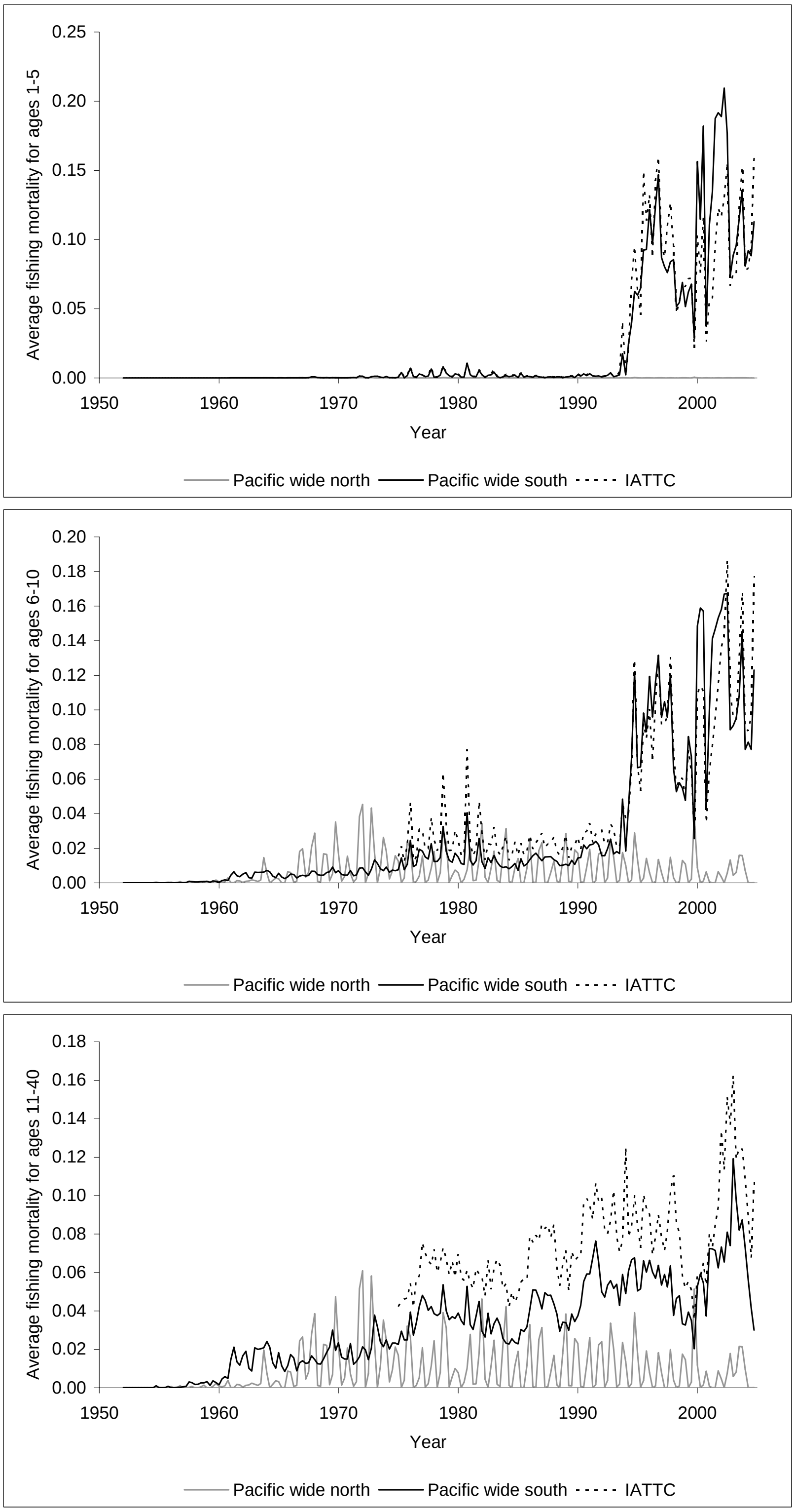

Figure 9. Comparison of average fishing mortality for three different age groups (in quarters) from the IATTC EPO assessment and the EPO region from the Pacific-wide assessment.

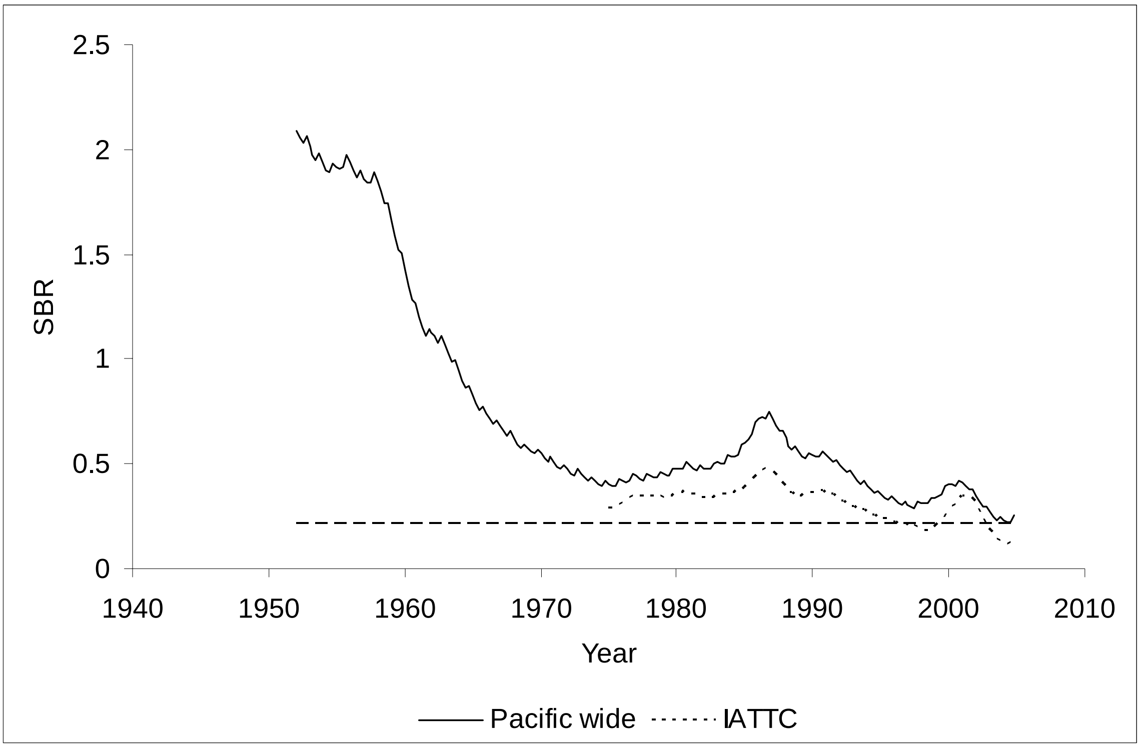

Figure 10. Comparison of spawning biomass ratio (SBR) from the IATTC EPO assessment and the EPO region from the Pacific-wide assessment. The horizontal dashed line is the SBR that supports MSY from the IATTC assessment.

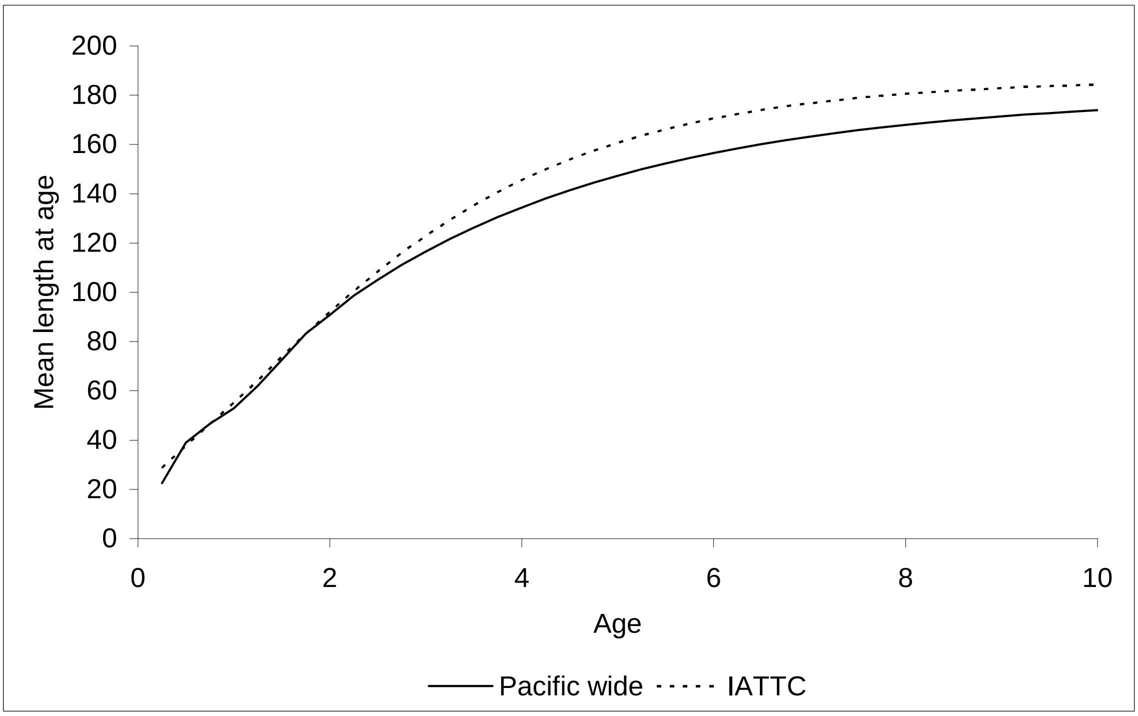

Figure 11. Comparison of the estimated mean length at age (in years) from the IATTC EPO assessment and the EPO region from the Pacific-wide assessment.

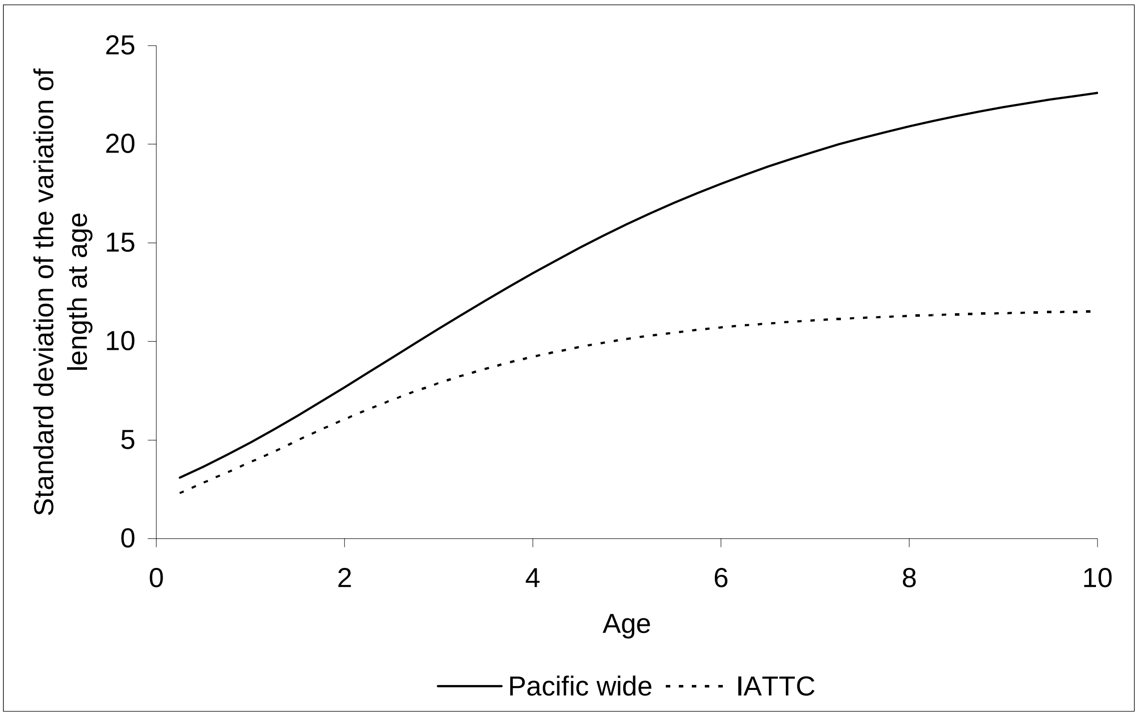

Figure 12. Comparison of the estimated standard deviation of variation of length at age (in years) from the IATTC EPO assessment and the EPO region from the Pacific-wide assessment.

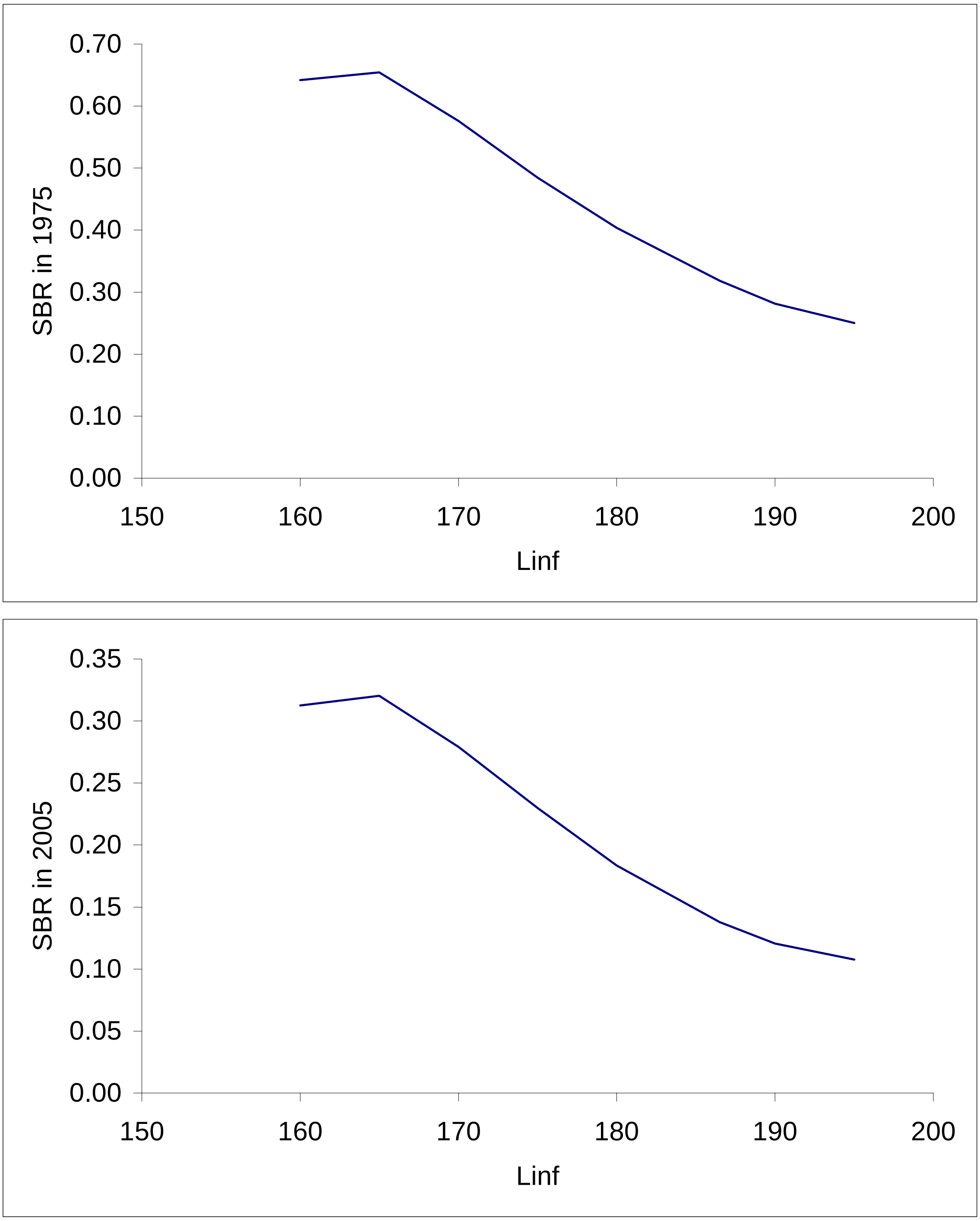

Figure 13. Comparison of the estimated SBR from the IATTC EPO assessment for different values of the L_∞ parameter of the Richards growth curve.

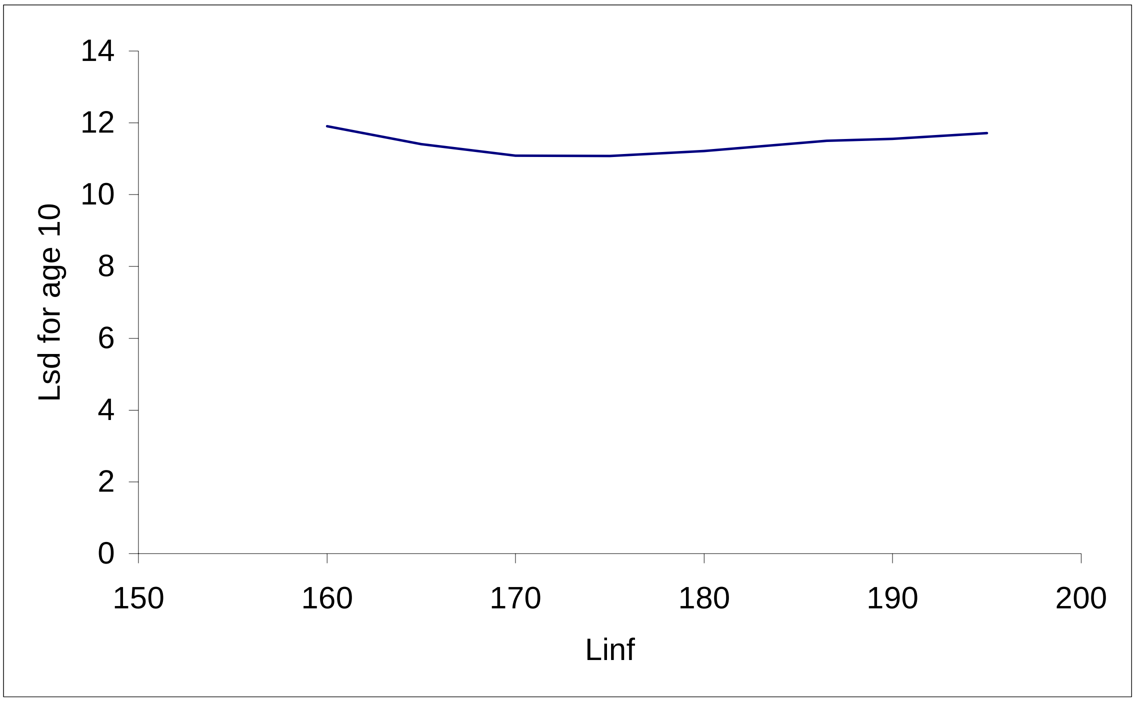

Figure 14. Comparison of the estimated standard deviation of the variation of length at age from the IATTC EPO assessment for different values of the L_∞ parameter of the Richards growth curve.

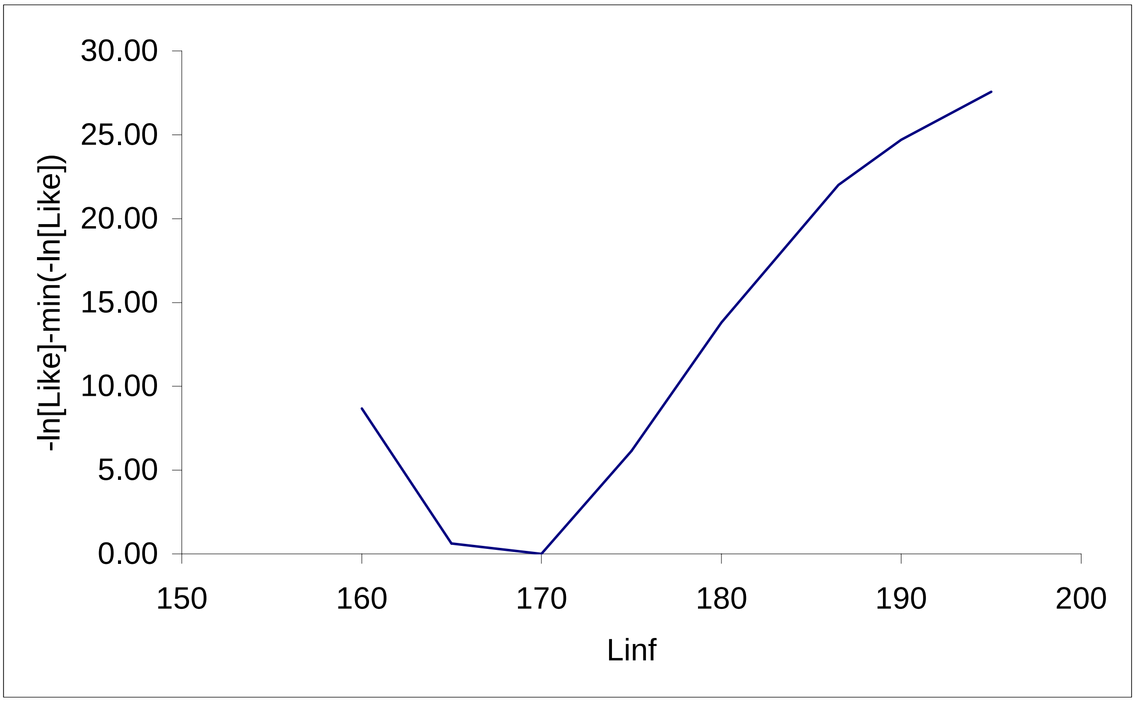

Figure 15. The negative log-likelihood minus the negative log-likelihood corresponding to the best estimate from the IATTC EPO assessment for different values of the L_∞ parameter of the Richards growth curve.

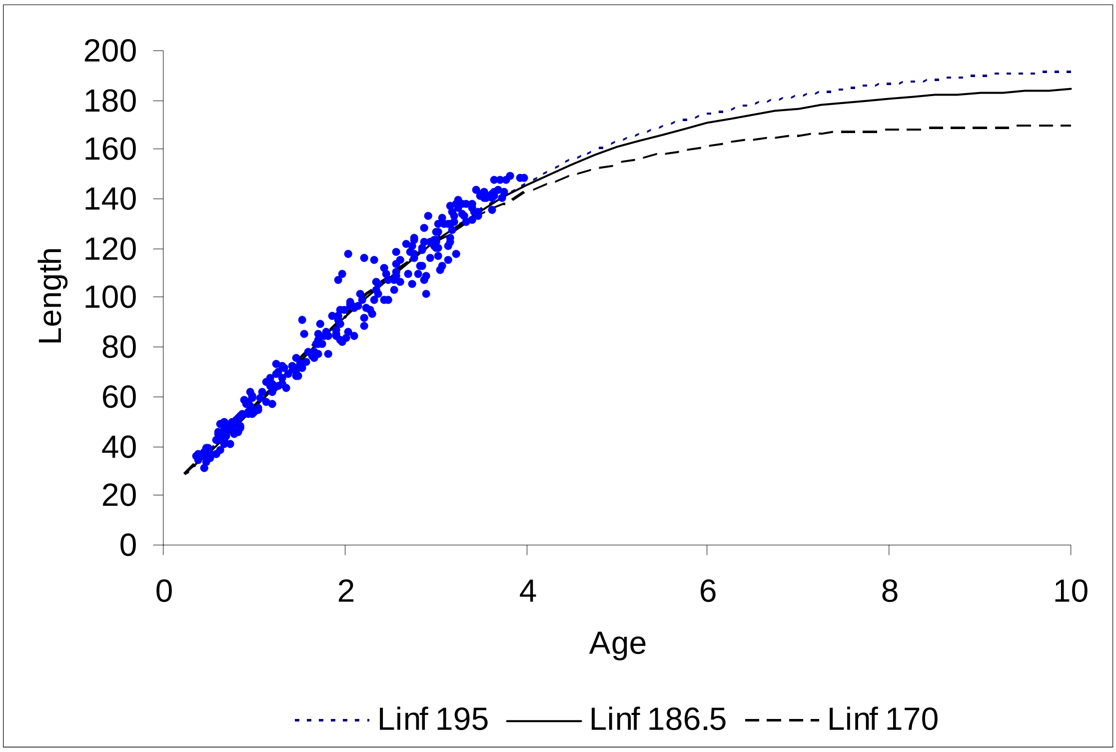

Figure 16. Fit to the age-length data from Schaefer and Fuller (submitted) (solid points) with different values of the L_{∞} parameter of the Richards growth curve.

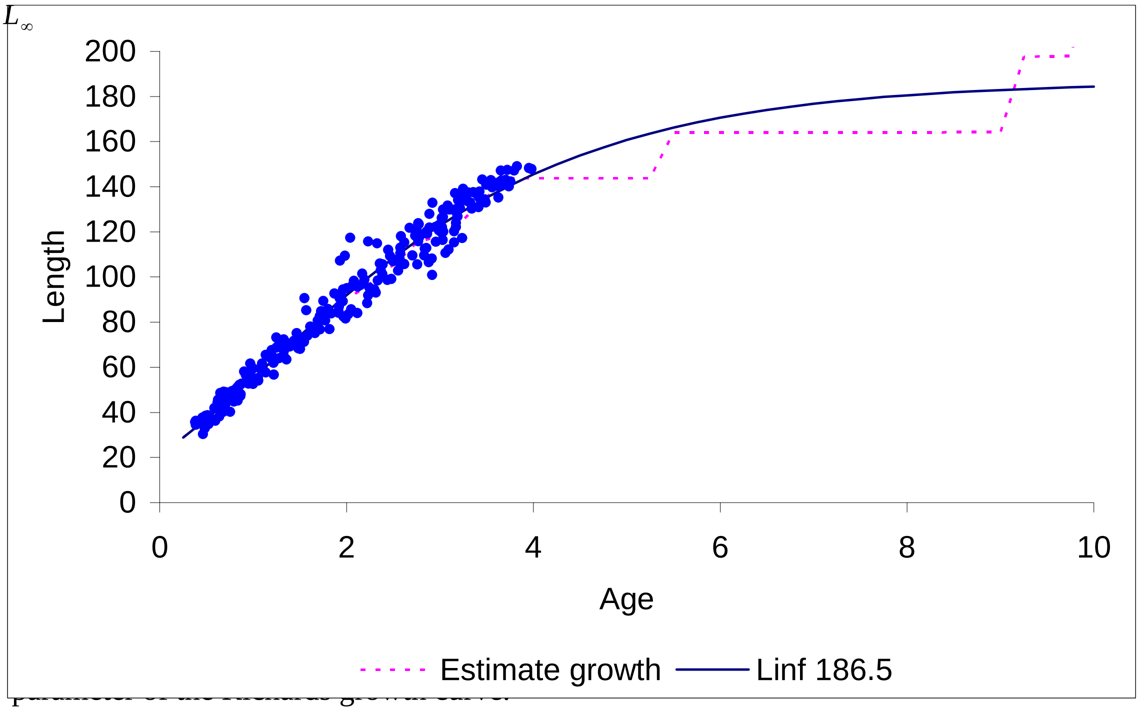

Figure 17. Fit to the age length data from Schaefer and Fuller (submitted) (solid points) with growth estimated as age-specific free parameters in the stock assessment model and with L_{∞} = 186.5 cm.

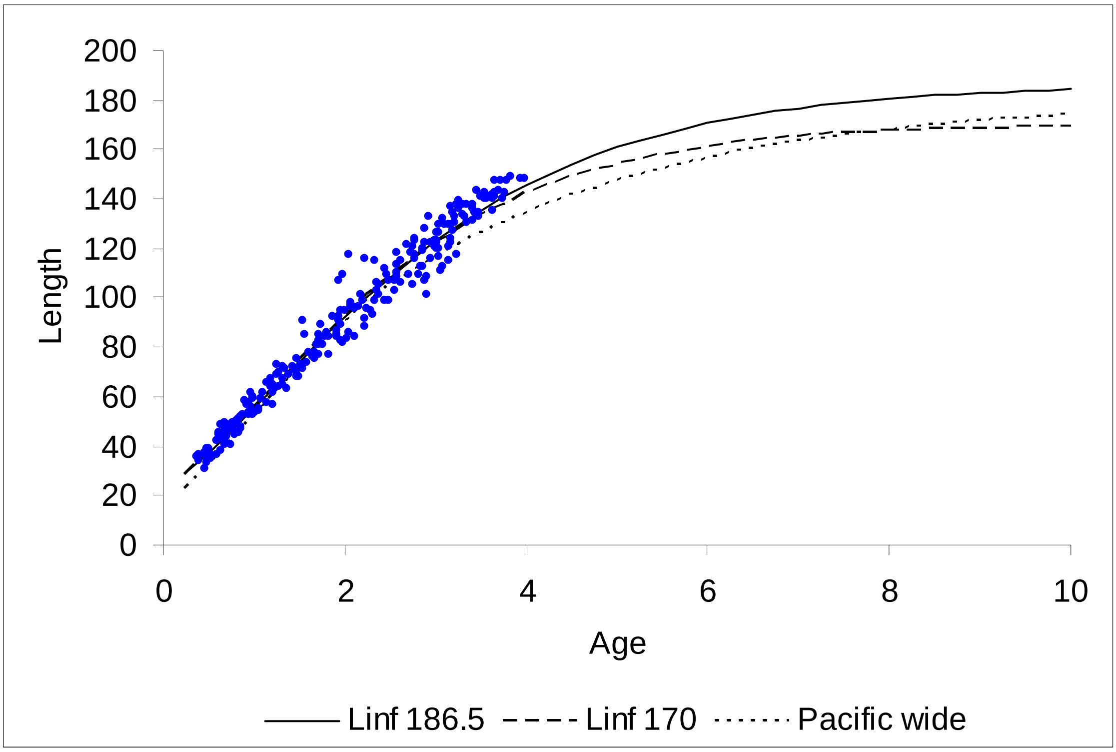

Figure 18. Fit to the age-length data from Schaefer and Fuller (submitted) (solid points) with different values of the L_∞ parameter of the Richards growth curve and the Pacific-wide growth curve.