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AN EVALUATION OF SPATIAL STRUCTURE IN THE STOCK ASSESSMENT OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

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1. SUMMARY

Tagging studies indicate restricted movements and regional fidelity of bigeye tuna in the eastern Pacific Ocean (EPO). Such restricted movements, combined with the spatial heterogeneity of the fleet distribution and the catch, suggest that localized depletion patterns of bigeye sub-stocks may exist in the EPO. A preliminary evaluation of spatial structure in the stock assessment of bigeye in the EPO was made. The EPO was divided into four major geographical regions - inshore, central, northern and southern – with the assumption of no mixing of fish among regions. An independent stock assessment was conducted for each region. The preliminary analyses show differences in the depletion levels of bigeye among geographical regions in the EPO. These results indicate that smaller spatial scales are worthy of consideration. However, similar trends in recruitment indicate that recruitment of bigeye sub-stocks may be driven by a similar large-scale environmental effect and/or that bigeye sub-stocks may be connected through recruitment or similar recruitment processes.

2. BACKGROUND

Various approaches exist to deal with stock structure in stock assessment modeling. The simplest approach is to ignore spatial structure. This can be done if the rates of mixing of the population are high enough so that it is reasonable to assume a single stock that is randomly mixed. A variation of this approach may be necessary when some of the stock characteristics, such as age or size, vary spatially, regardless of high movement rates within the stock boundaries. In this case, a single stock may be considered but it may be appropriate to spatially define multiple fisheries that can have different catchabilities and selectivities.

In case there are substantial movement rates within the boundaries of a stock, but there are major spatial differences in the exploitation or other fishery or biological characteristics, then modeling interacting sub-stocks may be appropriate. Finally, if there is little or no mixing among regions, then modeling spatial regions as separate sub-stocks with no interactions (*e.g.*, separate assessments for each sub-stock) may be not only reasonable, but also convenient for management purposes.

The current IATTC bigeye tuna stock assessment (Aires-da-Silva and Maunder, 2010) assumes a single stock of bigeye in the eastern Pacific Ocean (EPO). Although this single-unit stock model is not spatially structured, the model accounts, to some extent, for spatial structure by assuming several fisheries that are defined in space and acting on the stock with different catchabilities and selectivities. The underlying assumption of this approach is that the bigeye stock is randomly mixed within the EPO, with no localized spatial structure.

Schaefer (2009) provides an overview of current knowledge about the stock structure of bigeye in the EPO. The results of tagging studies demonstrate the regional fidelity of the species (Figure 1), and indicate very low levels of mixing within the EPO and between the eastern and the western Pacific (Schaefer and Fuller, 2002; Schaefer, 2009). Such restricted movements and high “viscosity”, combined with the spatial heterogeneity of the fleet distribution and the catch, suggest that localized depletion patterns of bigeye sub-stocks may exist in the EPO, in which case it is important that spatial structural aspects be considered in the bigeye stock assessment.

This paper investigates the implications in the bigeye assessment from considering multiple sub-stocks within the EPO. Four individual sub-stocks (central, northern, southern and inshore; Figure 2) with no mixing, are considered and assessed separately. Time series of biomasses, recruitments, and management quantities are produced for each sub-stock, and localized depletion patterns are investigated.

3. METHODS

3.1. Definition of bigeye sub-stocks and fisheries in the EPO

In order to evaluate spatial structural aspects of the bigeye stock assessment, the EPO bigeye stock was divided into four sub-stocks: central, northern, southern and inshore (Figure 2). These stock structure assumptions correspond to the same spatial definitions of the floating-object fisheries taken in the current bigeye assessment (Aires-da-Silva and Maunder, 2010), which are based upon the IATTC sampling areas, and therefore provide great convenience for manipulation of the spatial data. Considering the apparent high degree of “viscosity” and low mixing rates of bigeye within the EPO, as shown from tagging data, these spatial definitions seem to represent a reasonable first approximation to the stock structure of bigeye in the EPO. Other stock structure assumptions could be evaluated in the future, such as those recently obtained from multivariate regression tree analyses on bigeye length frequency distributions and CPUE data (Lennert-Cody et al., 2010).

Each sub-stock is exploited by different fisheries (surface and longline fisheries) operating in the different regions (Table 1). The time series of annual bigeye catches for each sub-stock are shown in Figure 3.

3.2. Fishery data

Quarterly time series of purse-seine and longline catch, catch-per-unit-effort (CPUE), and length composition data were produced for each bigeye sub-stock. Longline CPUE indices are considered more reliable than purse-seine CPUE indices in the bigeye assessment. As in the formal bigeye assessment (Aires-da-Silva and Maunder, 2010), longline CPUE indices were obtained through CPUE standardization using a delta-lognormal approach.

3.3. Spatial stock assessments

An independent Stock Synthesis assessment model (Methot, 2005), was developed for each bigeye sub-stock in the EPO (central, northern, southern and inshore). Each stock assessment is fit to the purse seine and longline catch and CPUE, and bigeye length composition data are generated for each sub-stock. In general, the sub-stock assessments take the same model assumptions as those of the base case assessment (growth, reproduction, natural mortality, steepness of 1 for the stock recruitment relationship). The main difference between the base case and the sub-stock models is the treatment of growth and selectivity. While growth is estimated in the base case model (K is estimated) by fitting to otolith age-at-length and the length composition data, it is fixed for consistency purposes in the sub-stock models, since otolith readings are available only for the central sub-stock. With respect to selectivity, while the base case assumes one fishery only with logistic selectivity (southern longline fishery), the separate sub-stock models all assume logistic selectivity for their longline fishery (for stability purposes).

4. RESULTS AND DISCUSSION

4.1. CPUE trends

The quarterly time series of purse-seine and longline catch is plotted against the longline CPUE for each bigeye sub-stock in Figure 4. It is interesting to note the stronger decline observed in the longline CPUE in the central region following the expansion of the floating-object fishery in the mid 1990s. This suggests that the juvenile cohorts of the bigeye sub-stock exploited in the central region by purse seiners will subsequently become vulnerable to the longline fishery throughout their life-cycle. Similar declines in the longline CPUE are less apparent for other sub-stocks. However, these other sub-stocks were defined within much larger regions than the central sub-stock (Figure 2), and there may be a spatial mismatch between the spatial distribution of the purse-seine and longline fisheries within these larger areas. These results strongly suggest that localized depletion patterns of bigeye may exist within the EPO, and that spatial structure may be important to consider in the bigeye assessment.

4.2. Biomass and recruitment trends

The quarterly time series of the summary biomass (3+ quarter old fish) and spawning biomass obtained for each sub-stock are shown on Figures 5a and 5b. Estimated biomasses of bigeye are greater in the southern and northern regions, the two largest regions assumed in this spatial analysis (Figure 2). Although the absolute scale estimates of the biomasses vary among sub-stocks, the relative trends are very similar across space. The exception is the inshore sub-stock. However, the bigeye catches from the inshore region are very small and the longline CPUE data used in the model fit are highly variable due to smaller sample sizes. The stock assessment results for the inshore stock should be regarded with caution.

The regional estimates for the spawning biomass ratio (SBR, depletion with respect to virgin biomass) indicate localized depletion patterns of bigeye in the EPO (Figure 5c). It is interesting to note the sharper decline that occurred in central region following the expansion of the purse seine-fishery on floating objects beginning around the mid-1990s.

The quarterly time series of recruitment estimated for each bigeye sub-stock are shown in Figure 6. There are great similarities between the bigeye relative recruitment trends estimated for the different regions. For example, the high recruitments of 1985 and 1998 are seen in all regions. Less prominently, the time series of recruitment estimates for the current decade have also been very similar among regions, except for the inshore area. These results suggest that bigeye recruitment in different EPO regions may be driven by a similar large-scale environmental effect and/or that bigeye sub-stocks may be connected through recruitment or similar recruitment processes.

The time series of recruitments obtained for each EPO bigeye sub-stock were compared with the Pacific decadal oscillation index (Figure 7). The relationship tends to indicate that bigeye recruitment is increased by strong El Niño events and decreased by strong La Niña events. In fact, two of the periods of greatest recruitment (1982-1983 and 1997-1998) coincide with the two strongest El Niño events of the 20th century.

The estimates of total spawning biomass of bigeye in the EPO obtained by summing across the estimates derived from the four independent sub-stock assessments were compared with those derived from the single EPO stock base case model developed by Aires-da-Silva and Maunder (2010) (Figure 8). The biomasses summed across sub-stocks were higher than the estimates obtained from the base case model; however, the relative biomass trends are very similar. Total recruitments summed across sub-stocks are substantially greater than those estimated from the base case model (Figure 9a), particularly before the mid-1990s. Apparently, the spatial analysis helped to minimize the recruitment pattern observed in results from the base case model, which consists of a period of low recruitments (prior to the mid 1990s), followed by a period of greater recruitments as the floating object fishery expanded after the mid-1990s (Aires-da-Silva and Maunder, 2010) The relative trends of the total recruitment estimates obtained by the two methods are similar (Figure 9b).

4.3. Management quantities

The MSY-related management quantities obtained from the assessments for bigeye sub-stocks and those derived from the base case model (Aires-da-Silva and Maunder, 2010) are shown in Table 2. Again, the results from the spatial analyses suggest that localized depletion patterns of bigeye may exist within the EPO. The spatial stock assessment results indicate that while bigeye may be experiencing overfishing in some regions (*F* multiplier< 1 or *F* current>F msy; Central and Southern sub-stocks), overfishing may not be occurring in other regions (*F* multiplier>1; northern sub-stock).

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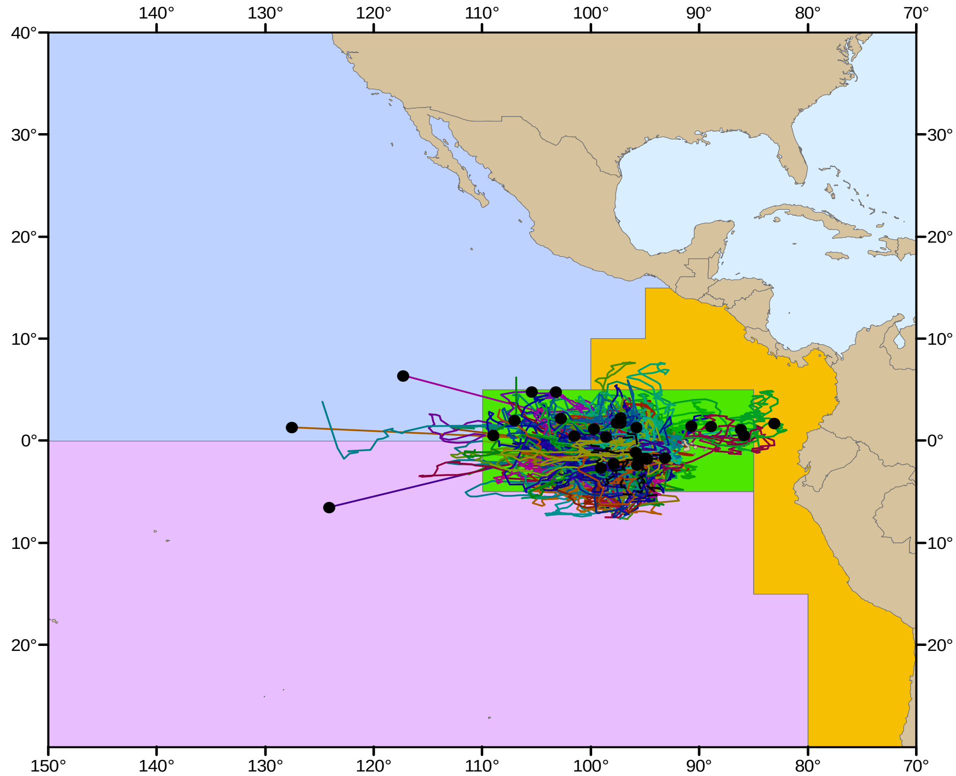

FIGURE 1. Movement paths inferred from archival tagging data for bigeye tuna at liberty for 30 days or longer in the EPO. The archival tag movement paths are based on data from 2000-2006 (Schaefer and Fuller, 2009).

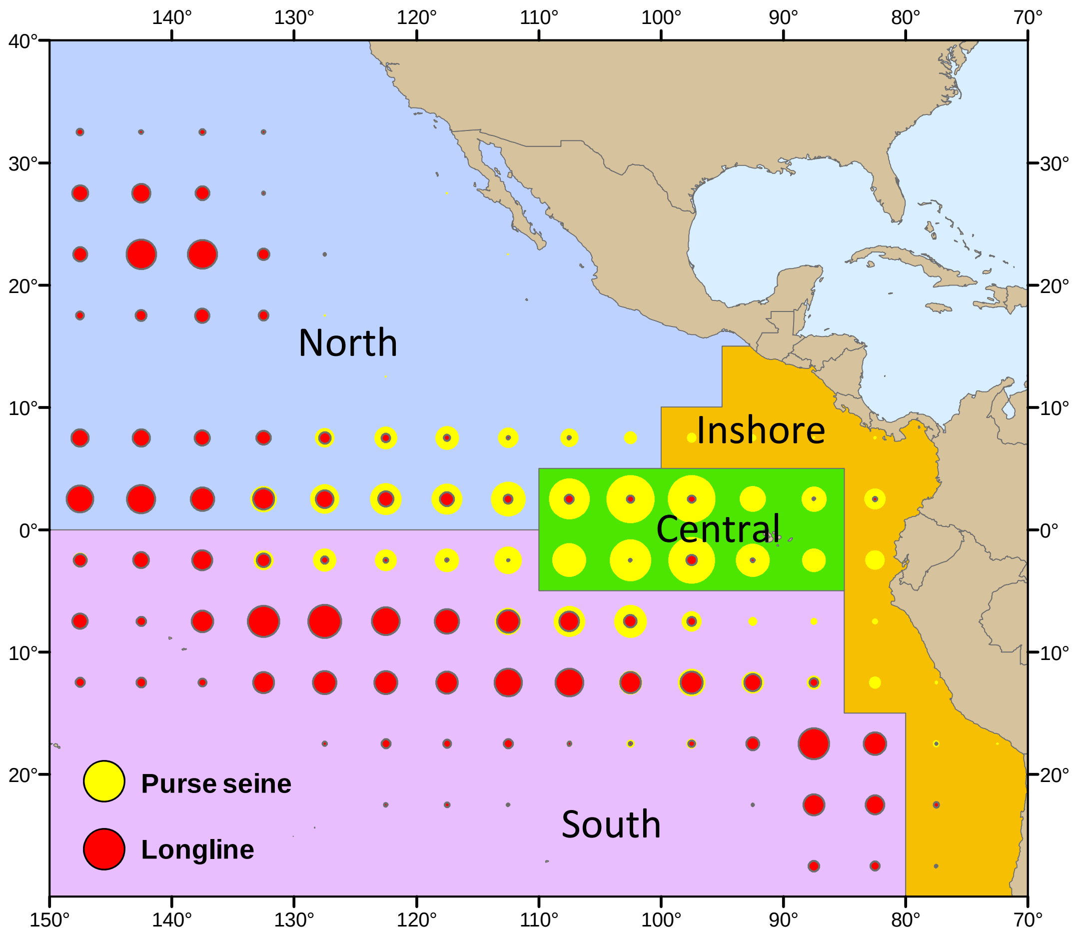

FIGURE 2. Four sub-stocks of bigeye assumed in the spatial stock assessment analysis (central, northern, southern and inshore). The spatial distribution of the longline (red circles) and purse-seine (yellow circles) catch is shown. The catch is the average over 2000-2006, and includes all data available in the IATTC databases.

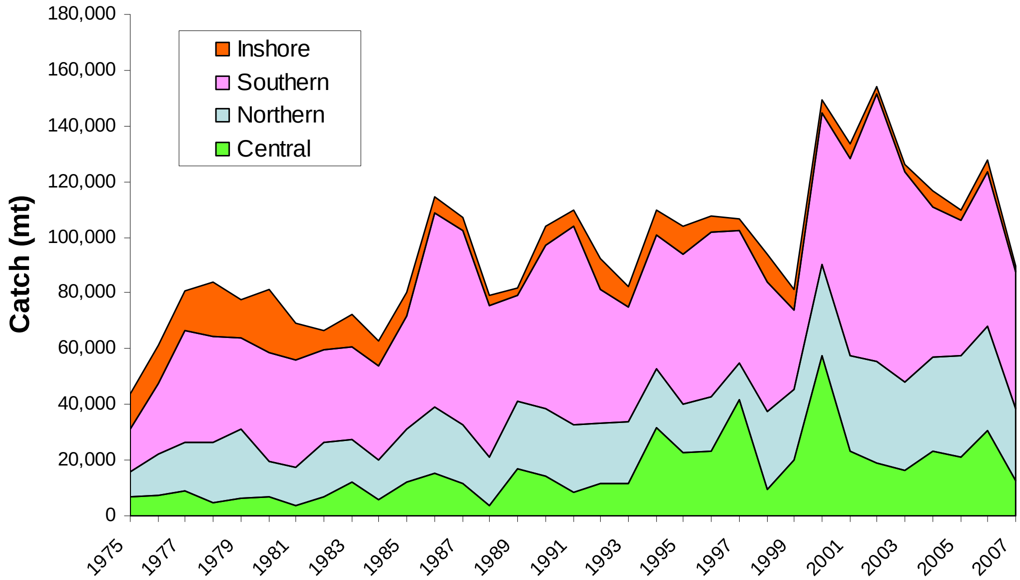

FIGURE 3. Annual catches (in tons) for each bigeye sub-stock.

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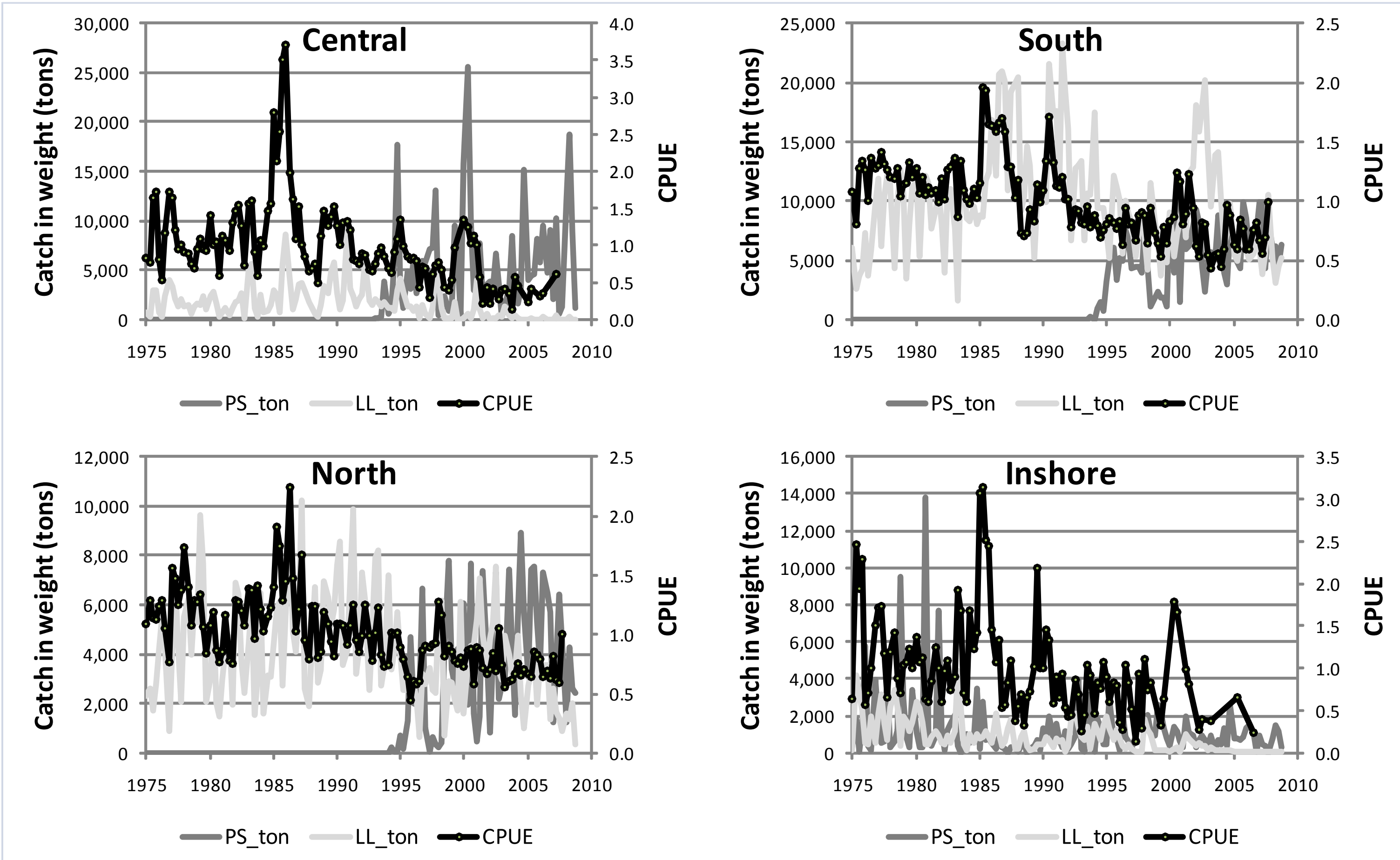


FIGURE 4. Quarterly time series of bigeye purse seine and longline catch (in tons), and longline standardized CPUE for each bigeye sub-stock in the EPO.

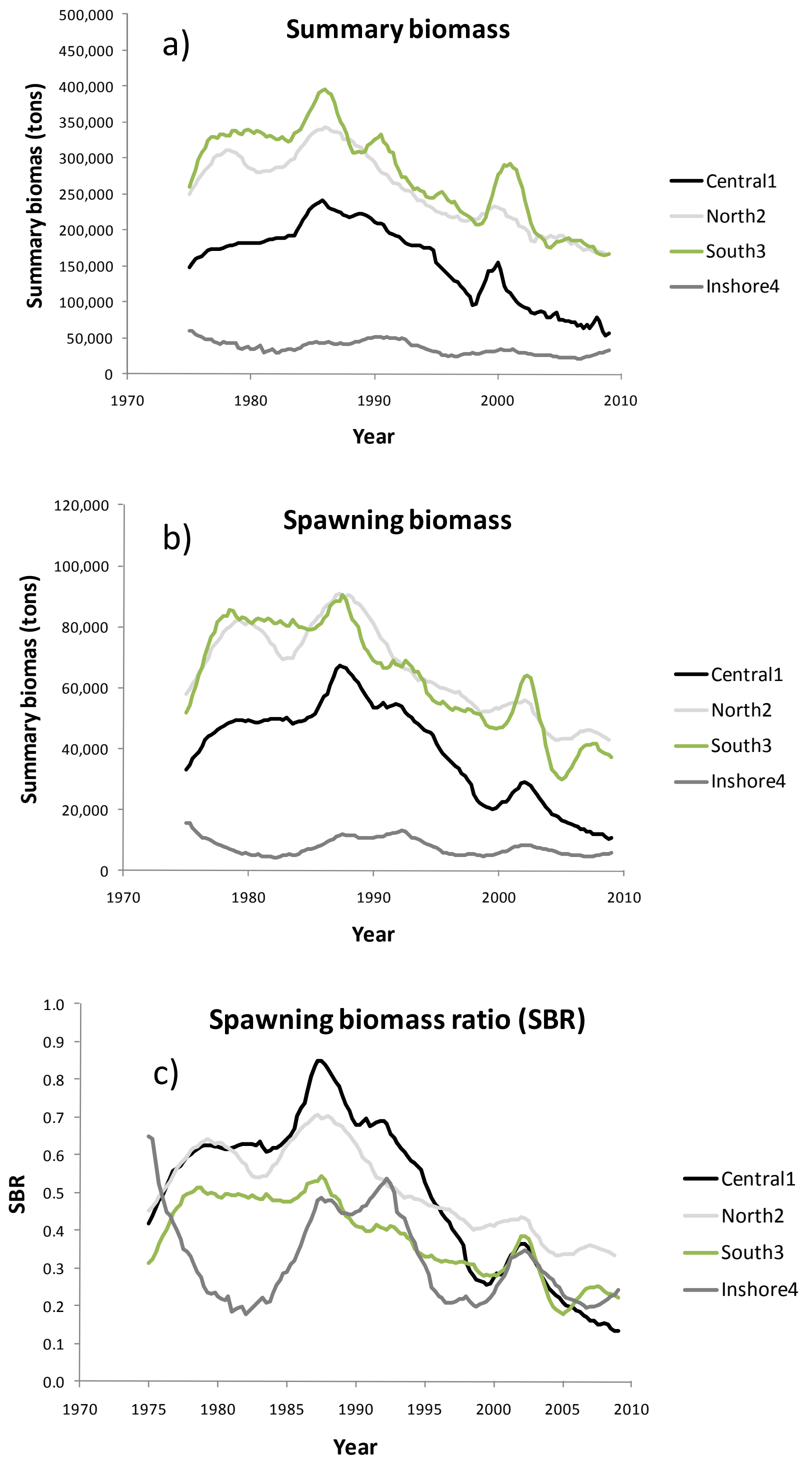
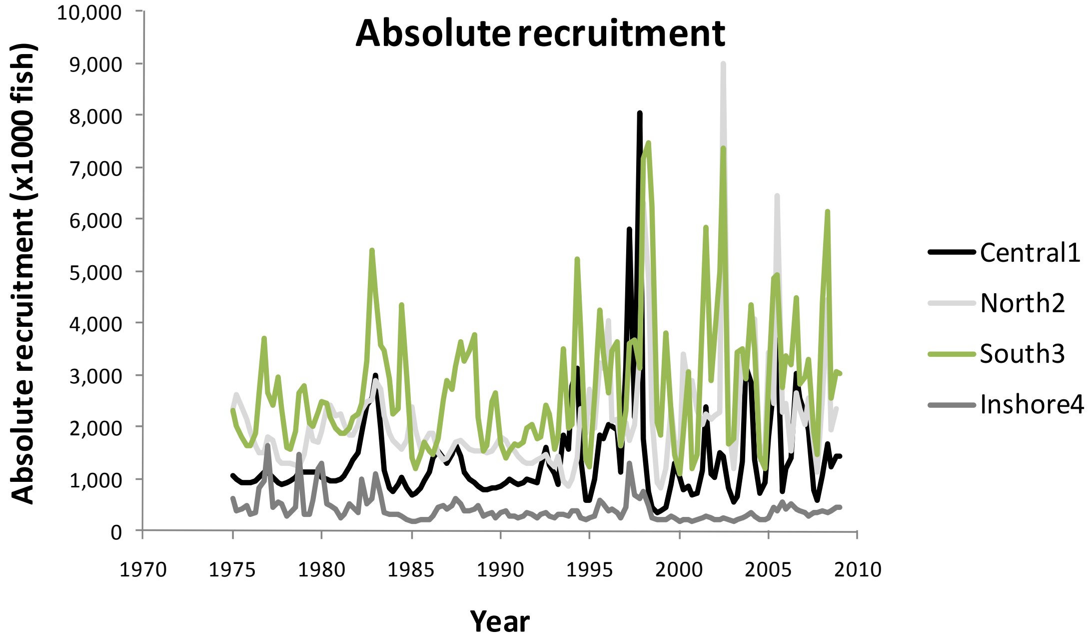


FIGURE 5. Quarterly time series of biomass (in tons) for each EPO bigeye sub-stock: a) summary biomass (3+ quarter old fish), b) spawning biomass and, c) the spawning biomass ratio (SBR, depletion level with respect to the virgin spawning biomass).



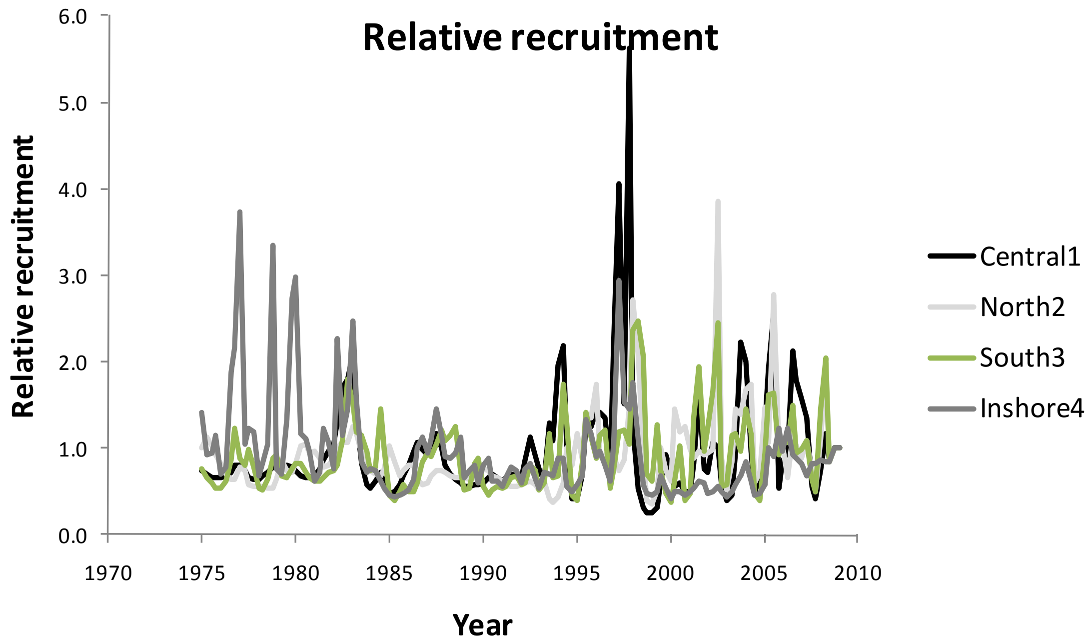


FIGURE 6. Quarterly time series of absolute (top) and relative recruitment (bottom) for each EPO bigeye sub-stock.

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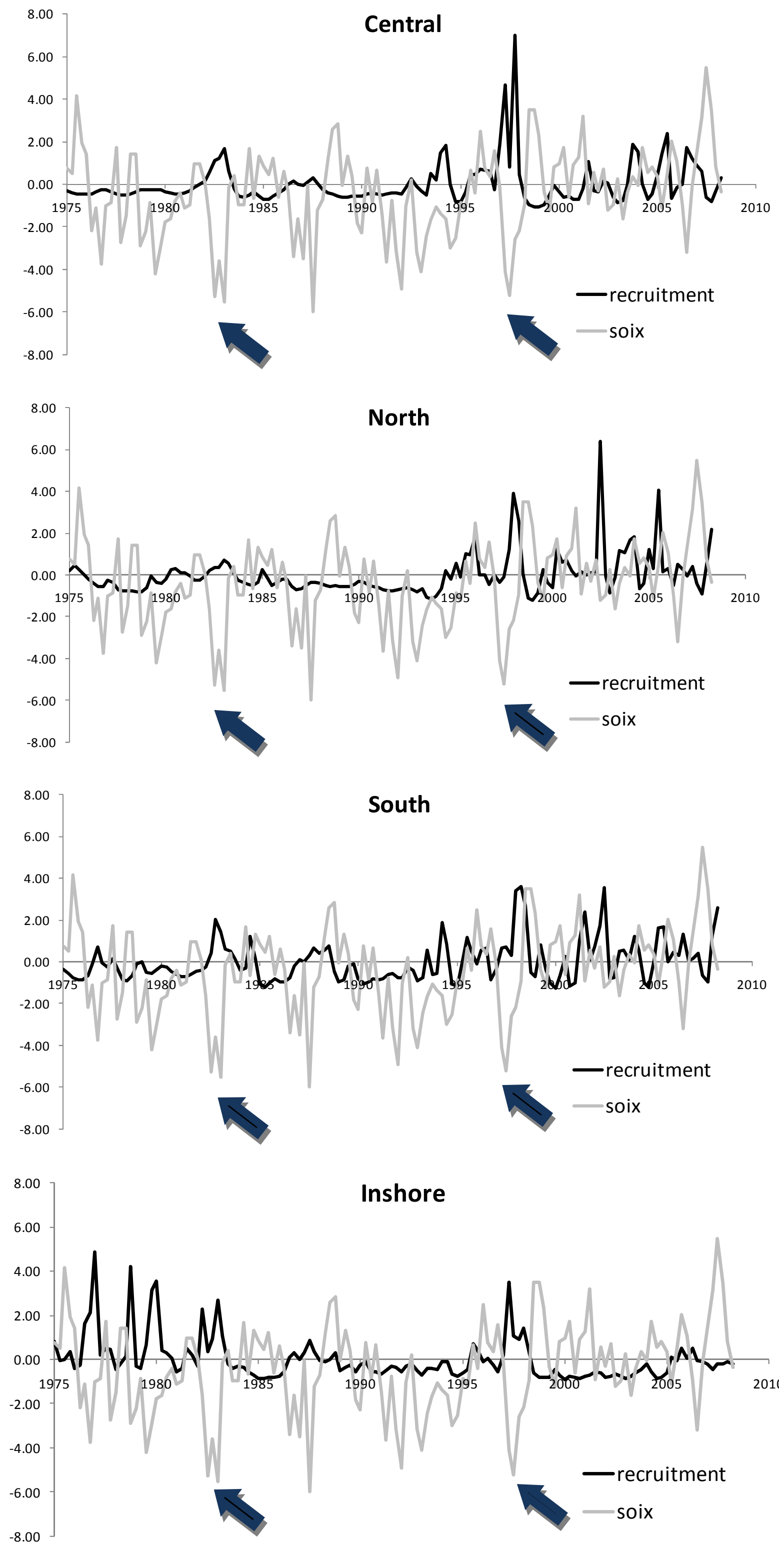

FIGURE 7. Quarterly time series of relative recruitment for each EPO bigeye sub-stock and the northern oscillation index (soi). The arrows indicate two of the strongest El Nino events of the 20th century.

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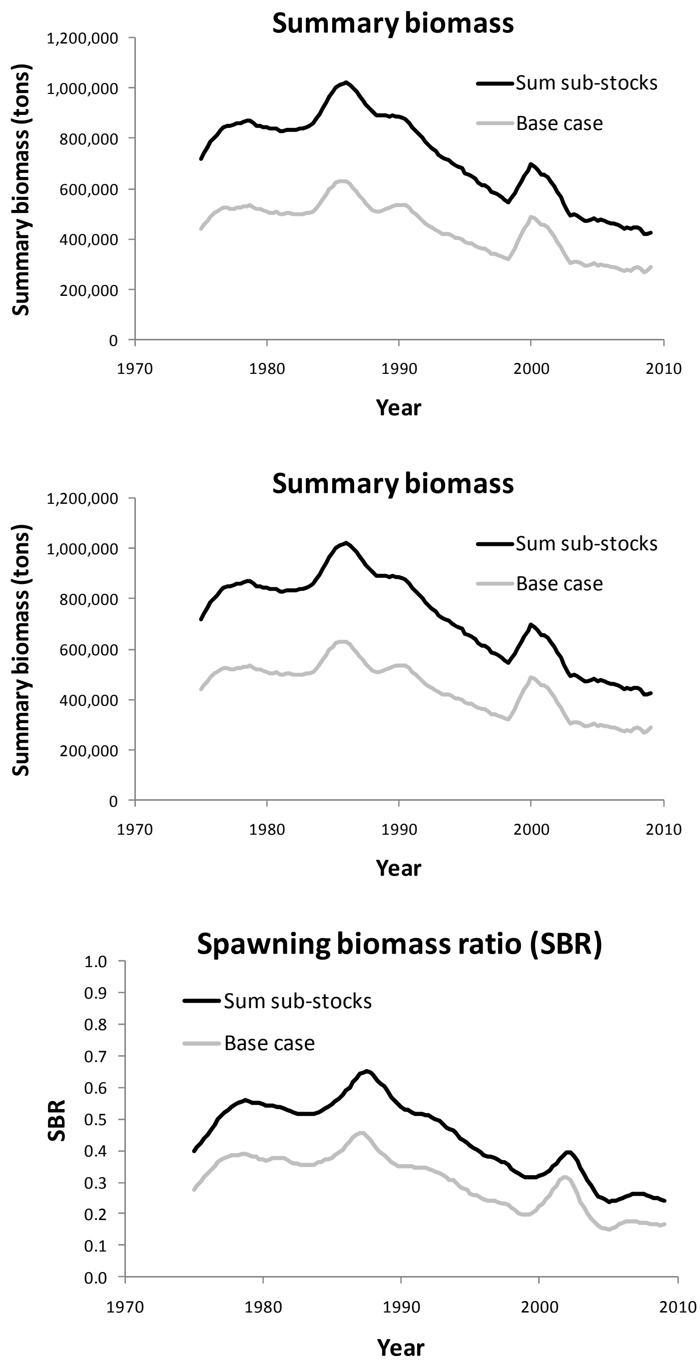

FIGURE 8. Time series of quarterly biomasses (summary, spawning, and the spawning biomass ratio) of bigeye in the EPO estimated from two methods: 1) summing across the results from individual EPO sub-stock models (central, northern, southern and inshore); 2) results from the single EPO stock base case assessment model (Aires-da-Silva and Maunder, 2010).

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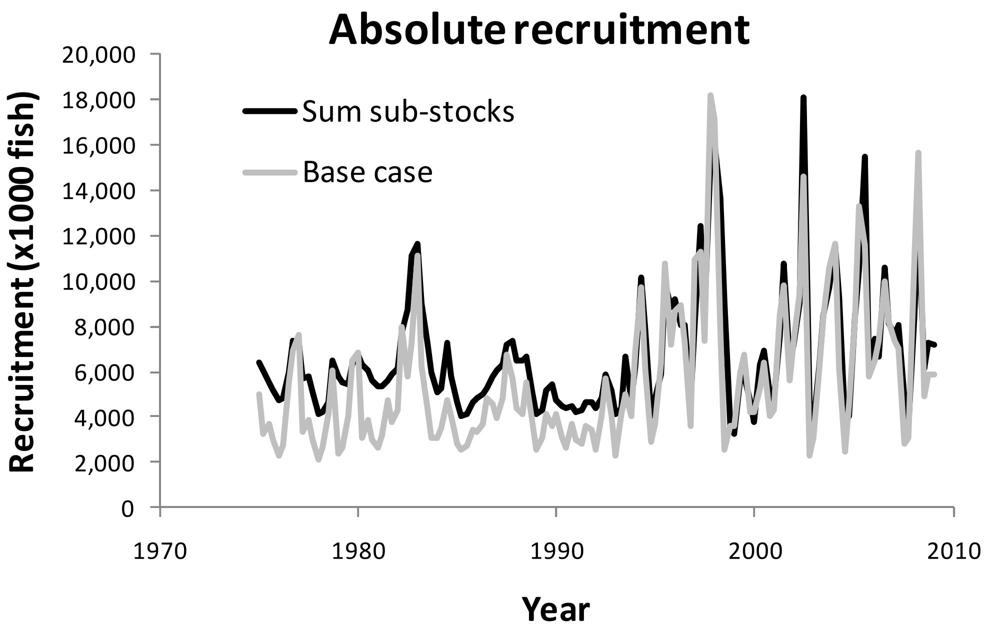

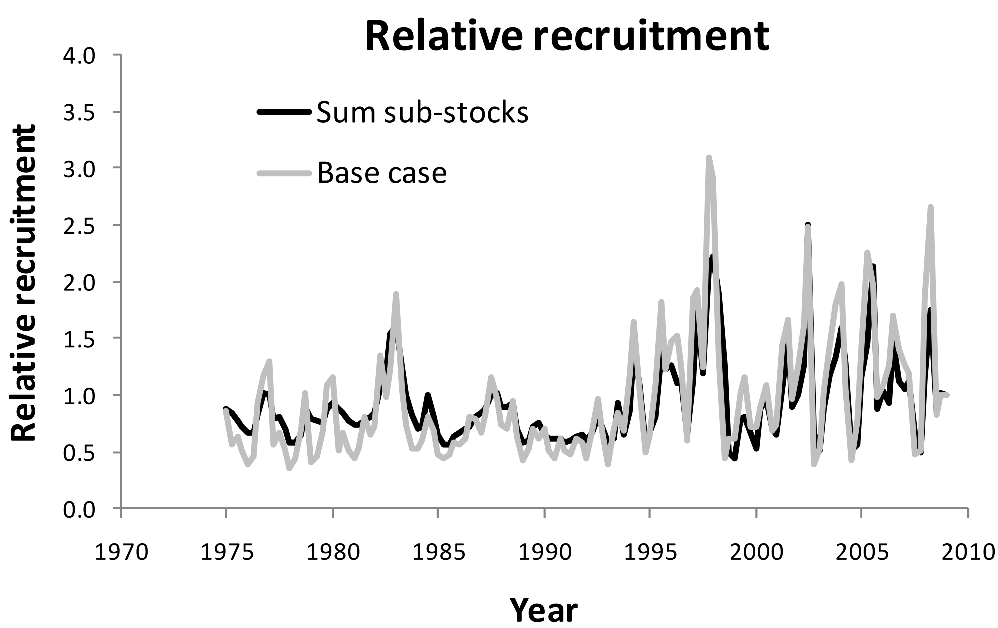

FIGURE 9. Time series of absolute and relative recruitment of bigeye in the EPO estimated from two methods: 1) summing across the results from individual EPO sub-stock assessments (central, northern, southern and inshore); 2) results from the single EPO stock base case model (Aires-da-Silva and Maunder, 2010).

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TABLE 1. List of fisheries defined in the regional stock assessments developed for each bigeye sub-stock (central, northern, southern and inshore), and those defined in the single EPO stock unit base case assessment (Aires-da-Silva and Maunder, 2010).

Central1	North2	South3	Inshore4	Base case (A&M, 2010)
F1-OBJ_C	F1-OBJ_N	F1-OBJ_S	F1-OBJearly_I	F1-OBJ_early
F2-OBJdisc_C	F2-OBJdisc_N	F2-OBJdisc_S	F2-OBJrecent_I	F2-OBJ_S
F3- LLn_C	F3-LLn_N	F3-LLn_S	F3-OBJdisc_I	F3-OBJ_C
F4- LLw_C	F4-LLw_N	F4-LLw_S	F4-NOA-DELearly_I	F4-OBJ_I
			F5-NOA-DELrecent_I	F5-OBJ_N
			F6-LLn_I	F6-NOA-DEL_early
			F7-LLw_I	F7-NOA-DEL_late
				F8-LL_N_num
				F9-LL_S_num
				F10-OBJ_S_disc
				F11-OBJ_C_disc
				F12-OBJ_I_disc
				F13-OBJ_N_disc
				F14-LL_N_w
				F15-LL_S_w

TABLE 2. MSY-related quantities derived from the single EPO stock unit base case assessment (Aires-da-Silva and Maunder, 2010), and the estimates from the regional stock assessments developed for each bigeye sub-stock (central, northern, southern and inshore).

Quantity	Base case	Central1	North2	South3	Inshore4	Sum
msy	83,605	20,371	23,521	42,682	7,056	93,630
Bmsy	289,409	59,102	99,977	151,448	21,768	332,295
Smsy	60,612	11,246	23,260	31,877	4,111	70,494
Bmsy/Bzero	0.25	0.20	0.21	0.25	0.24	
Smsy/Szero	0.19	0.14	0.18	0.19	0.17	
Crecent/msy	1.19	2.02	0.68	0.96	0.56	
Brecent/Bmsy	0.99	0.95	1.72	1.11	1.50	
Srecent/Smsy	0.89	0.94	1.84	1.16	1.44	
Fmultiplier	0.80	0.78	1.40	0.94	2.16	