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INDICES OF RELATIVE ABUNDANCE OF YELLOWFIN TUNA DERIVED FROM PURSE-SEINE CATCH AND EFFORT DATA

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1. BACKGROUND

Indices of relative abundance are an essential component of contemporary fisheries stock assessments. Fishery-independent indices of abundance, which are preferred, are not available for tunas in the eastern Pacific Ocean (EPO). EPO tuna assessments therefore rely on indices of abundance derived from fishery catch and effort data. Catch-per-unit-of-effort (CPUE) data are usually standardized for a number of factors (*e.g*. month, area, fishing gear) to ensure that changes in these factors do not bias the index of abundance (*i.e*. to ensure that abundance is proportional to CPUE). Currently, only the longline fishery CPUE-based indices of abundance are standardized. Purse-seine fishery-based indices of abundance use nominal catch per day fished.

The purse-seine fishery for yellowfin tuna associated with dolphins captures a large proportion of the yellowfin caught in the EPO, while the longline fishery captures a lesser proportion and generally fishes at depths and in areas that may not be prime yellowfin habitat. Therefore, the dolphin-associated purse-seine fishery may provide a better index of abundance for yellowfin. The purse-seine fishery searches for schools of yellowfin using a variety of techniques, including bird radar and helicopters. Standardizing for these and other factors is desirable to minimize bias in the CPUE-based index of abundance. A delta-lognormal generalized additive model is used to standardize the catch-per-days-fished to accommodate the large number of zero-valued observations and provide a two dimensional smooth surface for the spatial effect.

2. DATA AND DATA PROCESSING

Data collected by IATTC observers aboard large (size-class 6; carrying capacity greater than 363 metric tons) purse-seine vessels were used in this analysis; these data are available for 1980 to date. The analysis was limited to data for vessels registered in Mexico and Venezuela because vessels of these countries have consistently produced a large fraction of the yellowfin catch over the last several decades (IATTC 2012, Table 3a). In order to achieve a more homogeneous data set with respect to vessel and gear characteristics and searching behavior, the data were further limited to those vessels that made a minimum of 5% of their sets each year on yellowfin associated with dolphins (hereafter referred to as "dolphin vessels"). In addition, to allow for sufficient data by vessel to model vessel-specific differences in mean CPUE, only data for vessels with a minimum of three years in the database were retained. As a result of these data restrictions, the time period covered in this analysis is 1986-2012. There were a total of 35 Mexican and 19 Venezuelan dolphin vessels in the final data set (Figure 1). Of the trips in this data set, 90% had at least 33% of their sets on tunas associated with dolphins.

Yellowfin CPUE, in metric tons per day fishing, was computed from catch and effort at a resolution of 1°

area by year-quarter by vessel trip. The catch and effort data were from the same sources as the nominal CPUE for the stock assessment model. A quarterly time interval was used because that is the time step used in the stock assessment model. Approximately 73% of the CPUE observations were zero-valued, and the frequency distribution of positive CPUE was somewhat skewed (Figure 2).

A number of variables describing vessel and gear characteristics were considered in this analysis to try to account for vessel and gear effects on CPUE. Vessel characteristics included in this analysis were the fish-carrying capacity and the year of construction of the vessel. Gear characteristics were presence/absence of bird radar, sonar, ring strippers, the number of speed boats, the length and depth of the purse-seine net, the length of the dolphin safety panel, and the diameter of the power block. These gear and vessel characteristics are recorded by observers for each trip. During 1986-2012, temporal trends can be observed in several of the gear variables (Figures 3-4). For example, bird radar was not used by all vessels in this data set until the early 1990s. Other characteristics such as presence/absence of a helicopter aboard the vessel and mesh size of the net and of the dolphin safety panel were not included in this analysis because these features were largely homogeneous among vessels.

3. METHODS FOR TREND ESTIMATION

Year-quarter effects were estimated using generalized additive models (GAM) (Wood 2006; mgcv library in R). Preliminary analysis of data for 1986-2011 suggested that all groups of variables (year-quarter effects, spatial variables, gear variables, vessel effects) were worth including in the model (based on reduction in the approximate AIC statistic). Stepwise selection of individual gear variables was not done in this analysis. Given the large percentage of zero-valued observations and the overall shape of the distribution of the positive observations (*i.e.*, 1° area - year-quarter - vessel trip data points with catch; Figure 2), two distributional models were initially considered for these data: delta-lognormal and delta-gamma. In the preliminary analysis, diagnostic plots of residuals indicated a better fit to the positive CPUE values with the lognormal model. Therefore, the following two delta-lognormal models were fitted to the data for 1986-2012:

i. logit(p) = overall constant + year-quarter effect + smooth(days fishing) + smooth(latitude, longitude)

   $\log(CPUE_+)$ = overall constant + year-quarter effect + smooth(latitude, longitude)

ii. logit(p) = overall constant + year-quarter effect + smooth(days fishing) + smooth(latitude, longitude) + gear + vessel effect

   $\log(CPUE_+)$ = overall constant + year-quarter effect + smooth(latitude, longitude) + gear + vessel effect

where:

smooth: smooth term or smooth surface (based on thin plate regression splines);

gear: either a gear effect for categorical variables (presence/absence of bird radar, presence/absence of sonar, presence/absence of ring stripper, number of speed boats) or a smooth term for continuous gear variables (vessel capacity, year of construction, power block diameter, net length, net depth and safety panel length);

p: probability of a positive observation; and

$CPUE_{+}$: CPUE for positive observations.

The amount of nonlinearity allowed for continuous gear variables was restricted by limiting the number of basis functions to 4 because it is believed that the effect of these variables on CPUE should be fairly smooth.

Standardized trends were estimated from the fitted GAM coefficients using the method of partial dependence (Hastie *et al*. 2009). The combined influence of gear variables and vessel effects on the standardized CPUE trend can be evaluated by comparing the standardized trends from the two models. Standardized trends were estimated separately for several of the purse-seine dolphin set stock assessment areas (Figure 5): Area 7 (Mexican dolphin vessels) and Area 8 (both Mexican and Venezuelan dolphin vessels). No trends were estimated for Area 9 due to temporal sparseness of the data. For Area 7, data south of 5°N were excluded in the analysis for Mexican dolphin vessels, and data north of 20°N were excluded in the analysis for Venezuelan dolphin vessels, in both cases due to data sparseness in both space and time.

4. RESULTS

Depending on the area and fleet, model (ii) explained 35-43% of the deviance in the logistic component and 14-17% of the deviance in the lognormal component. Gear and vessel variables provided the greatest improvement to the model fit for the lognormal component. Compared to model (i), model (ii) explained ~1% more of the deviance in the logistic component and ~3-4% more of the deviance in the lognormal component. Estimated year-effect coefficients from model (ii) fitted to the data for Mexican dolphin vessels in Areas 7-8 are shown in Figure 6. There is considerable variability about the estimated year-effect coefficients, particularly for the logistic component.

Standardized trends from both areas show similar patterns, with a general decline over the 1986-2012 period, except around 2001-2003 (Figure 7). Comparison of the trends from models (i)-(ii) indicates that the addition of gear variables and vessel effects in the GAM models resulted in greater values for the trends in the late 1980s through early 1990s. For comparison to stock assessment inputs, the mean-scaled nominal CPUE from the stock assessment and mean-scaled nominal and standardized CPUE for Mexican dolphin vessels for Areas 7-8 are shown in Figure 8.

5. DISCUSSION

The trend estimates presented in this document might be improved in several ways. First, particularly for the logistic component of the model, the year-quarter effect coefficients had large standard errors. This could be an artifact of gridding effort and catch to 1° areas. To explore this possibility, catch and effort data were aggregated to 5° area instead of 1° area, which decreased the percentage of zero-value observations by roughly 40%. However, neither the percent deviance explained by the models nor the magnitude of the standard errors was improved by fitting model (ii) to data aggregated to 5° area (in these models the spatial predictor was a categorical variable for 5° area); the trends of the year-quarter coefficients were similar to those shown in Figure 7. Another possibility is that some of the variability in CPUE might be an artifact of the manner in which effort is estimated. Currently, estimates of days fishing include all days at sea, less days assumed to be running to and from the fishing grounds at the beginning and end of the trip, and any days spent entirely in port during the trip. Estimates of effort might be improved by excluding periods during the trip when vessels were not explicitly searching, something that can be done with fine-scale (daily) observer data because observers record vessel activity (*e.g*., running, search, drifting) at several time points during each day. This would likely reduce the prevalence of zeros in the CPUE data, and might lead to better model fit. Second, other statistical distributions for these data could be explored, such as a Tweedie distribution.

Some of the gear characteristics have sharp simultaneous changes in all vessels (*e.g*. the use of bird radar), which provides no contrast to distinguish their effects from the year-quarter effect. It is likely that these gear changes will bias any year-quarter effect estimated by the model (*e.g*. see the change in the trend when gear characteristics were included in the GAM; Figure 7). Therefore, the index should be divided into two parts at the time of the change and each part fitted as separate abundance indices in the stock assessment model, each with its own catchability coefficient to be estimated. Given that most vessels changed to using bird radar by 1990 and that there are only a few years with data prior to 1990, the appropriate index of abundance to use in the stock assessment is one that starts in 1990.

The effect of the new proposed indices on the perception of the stock status of yellowfin in the EPO was assessed by including them in the current assessment model. Only the indices for 1990 to 2012 were used. Two model runs were performed, in each case replacing the whole nominal CPUE series (1975-2012) for fleets 7 (F7-DEL_N) and 8 (F8-DEL_I) with the Mexican dolphin standardized indices for areas 7 and 8, respectively: (i) all other assumptions for the base case model (Document SAC-04-04b) were maintained ("Fit 1"); and, (ii) the CV for the new indices was fixed at 0.2 and all other indices were excluded from the model run, namely longline south standardized index (F12-LL_S), nominal CPUE series for unassociated purse-seine sets in the north (F5-NOA_N) and south (F6-NOA_S) ("Fit 2").

In the case in which new indices are used while maintaining the southern longline fishery as the main index of abundance (Fit 1), the status of the stock is perceived to be slightly more pessimistic than estimated by the base case (Figures 9-10, Table 1) In the alternative case, in which the only indices used to fit the model are the new standardized indices (Fit 2), the status of the stock is perceived to be in a more optimistic situation, and the recent levels of fishing effort are estimated to be below the MSY level. The recruitment patterns for all models have minor differences (Figure 11).

ACKNOWLEDGEMENTS

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TABLE 1. MSY and related quantities for the base case and for the fits of the new standardized indices, based on average fishing mortality (*F*) for 2010-2012. Fits 1 and 2 were done by replacing the nominal CPUE series for fleets 7 (F7-DEL_N) and 8 (F8-DEL_I) by the Mexican dolphin standardized indices for areas 7 and 8, respectively. Fit 1 maintains all other assumptions for the base case, while Fit 2 excludes all other indices. B_{recent} and B_{MSY} are defined as the biomass, in metric tons, of fish 3+ quarters old at the start of the first quarter of 2013 and at MSY, respectively, and S_{recent} and S_{MSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch for 2012.

YFT	Base case	Fit 1: as base case	Fit 2: only with new indices
MSY	258,836	257,998	255,886
B_{MSY}	349,480	347,077	346,955
S_{MSY}	3,269	3,214	3,227
B_{MSY}/B_0	0.32	0.31	0.31
S_{MSY}/S_0	0.26	0.25	0.25
C_{recent}/MSY	0.75	0.75	0.76
$B_{\text{recent}}/B_{\text{MSY}}$	0.83	0.72	0.88
$S_{\text{recent}}/S_{\text{MSY}}$	0.85	0.72	0.91
F multiplier	1.01	0.97	1.21

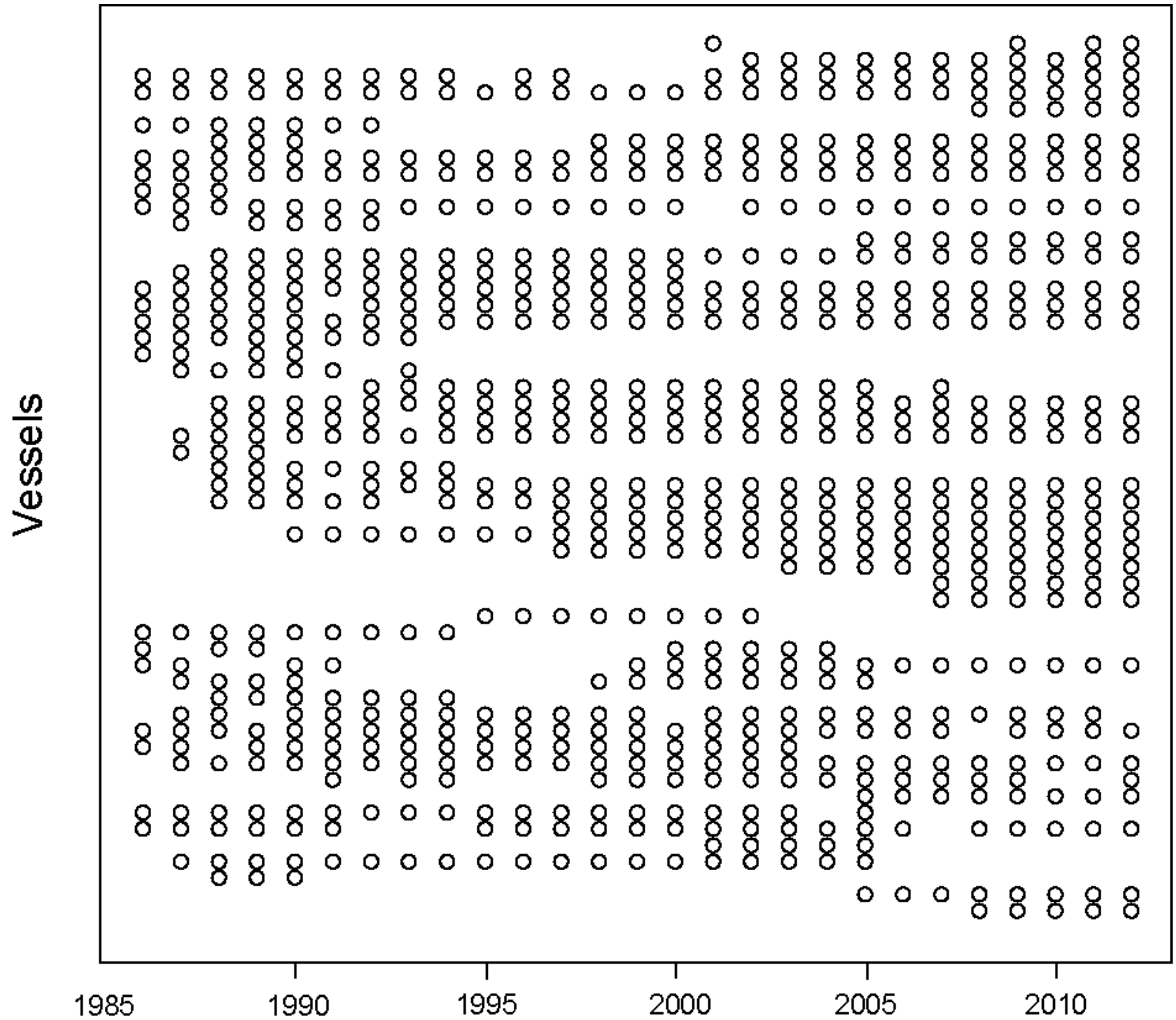

FIGURE 1. Time line of dolphin vessels. Each row in the figure corresponds to a unique vessel.

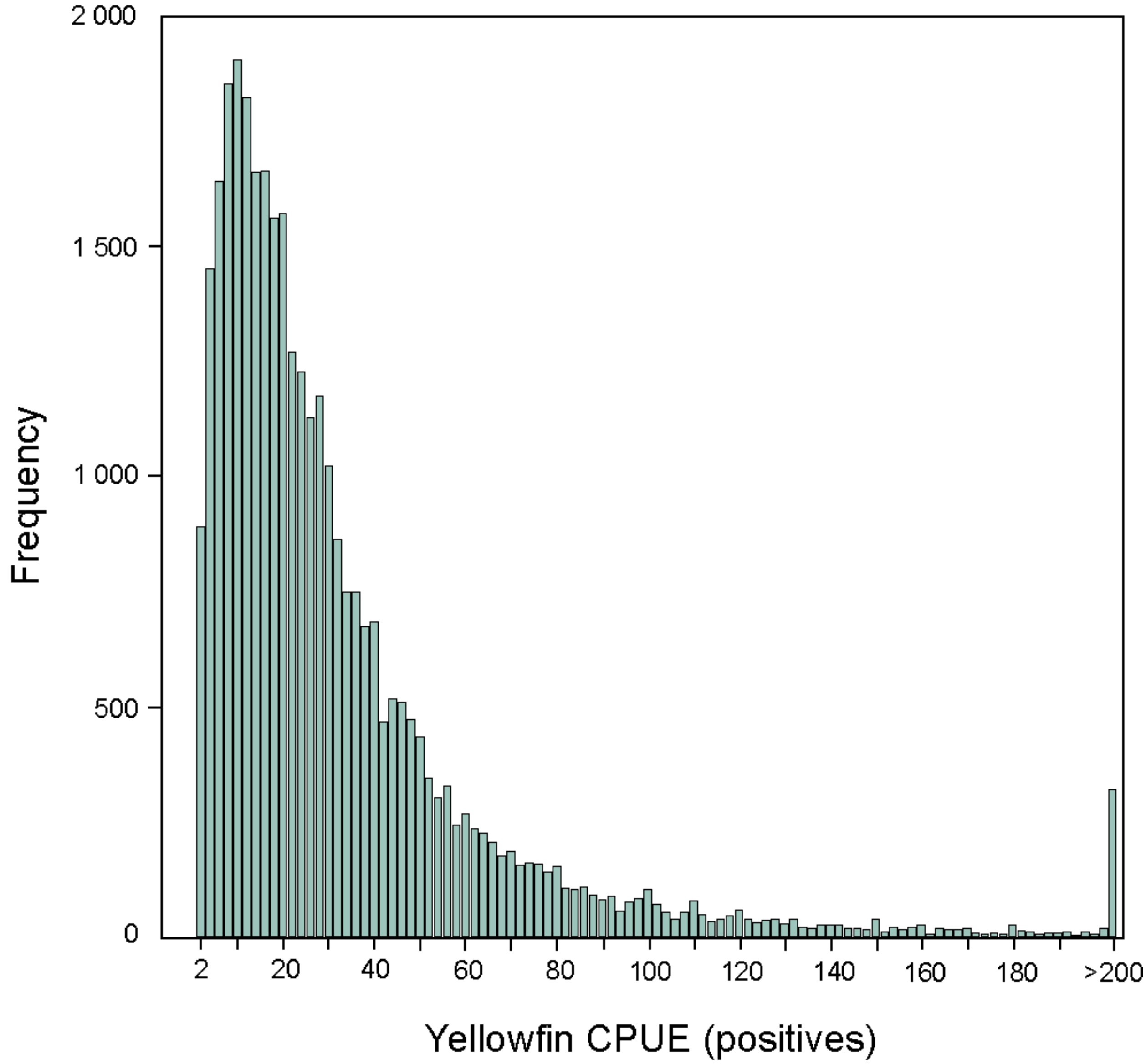

FIGURE 2. Frequency distribution of positive values of yellowfin tuna catch, in metric tons, per day fishing (CPUE) for dolphin vessels, 1986-2012. The data unit is 1° area x year-quarter x trip. Histogram interval labels correspond to the upper endpoints.

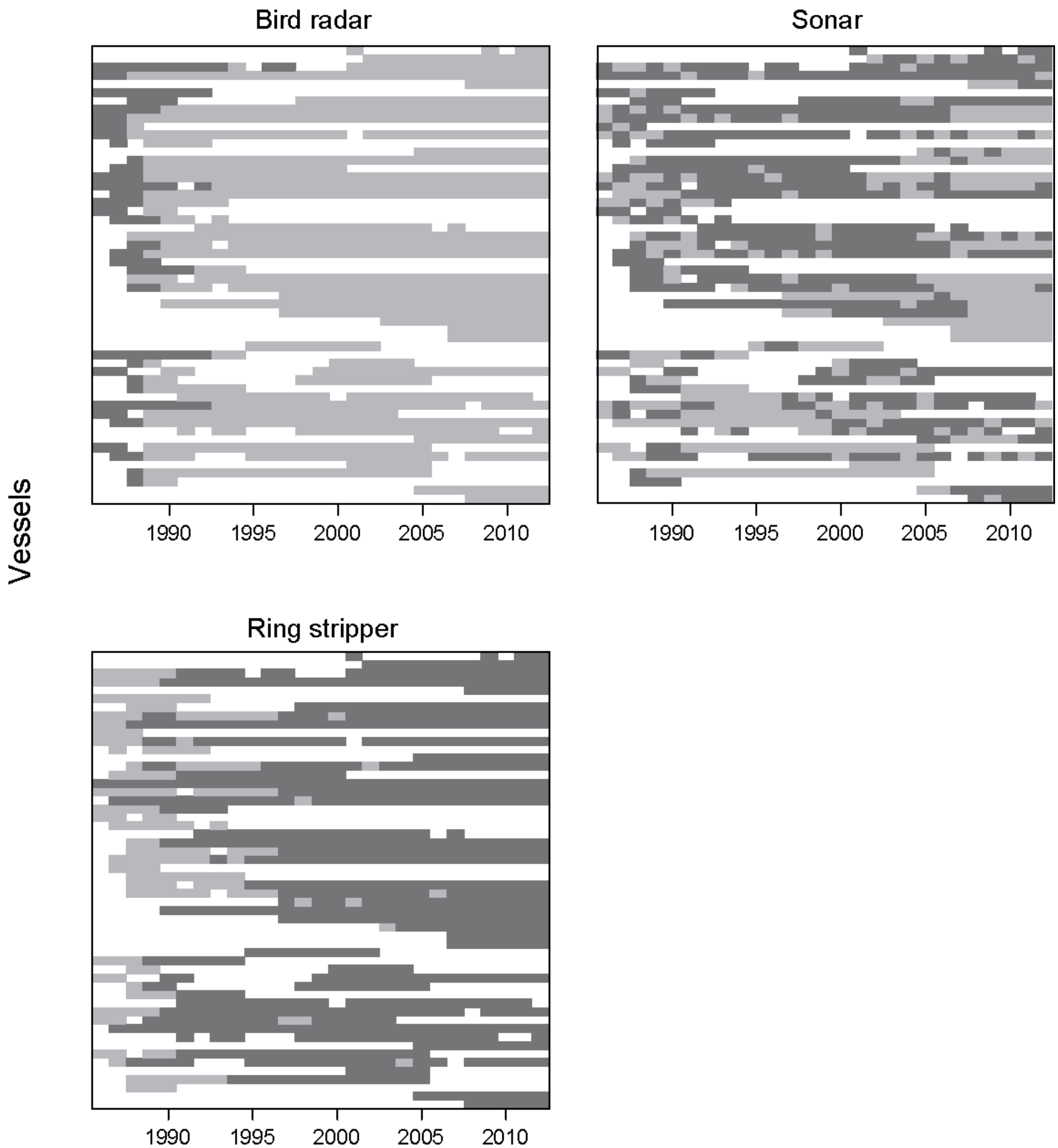

FIGURE 3. Time lines of gear characteristics for categorical variables included in the CPUE GAM standardization. Dark gray; absent or unknown; light gray: present. Presence/absence is by vessel, for each year; *i.e.*, if any trip by a vessel in a particular quarter had the gear type, that gear type is considered "present" (light gray) for that vessel for that quarter.

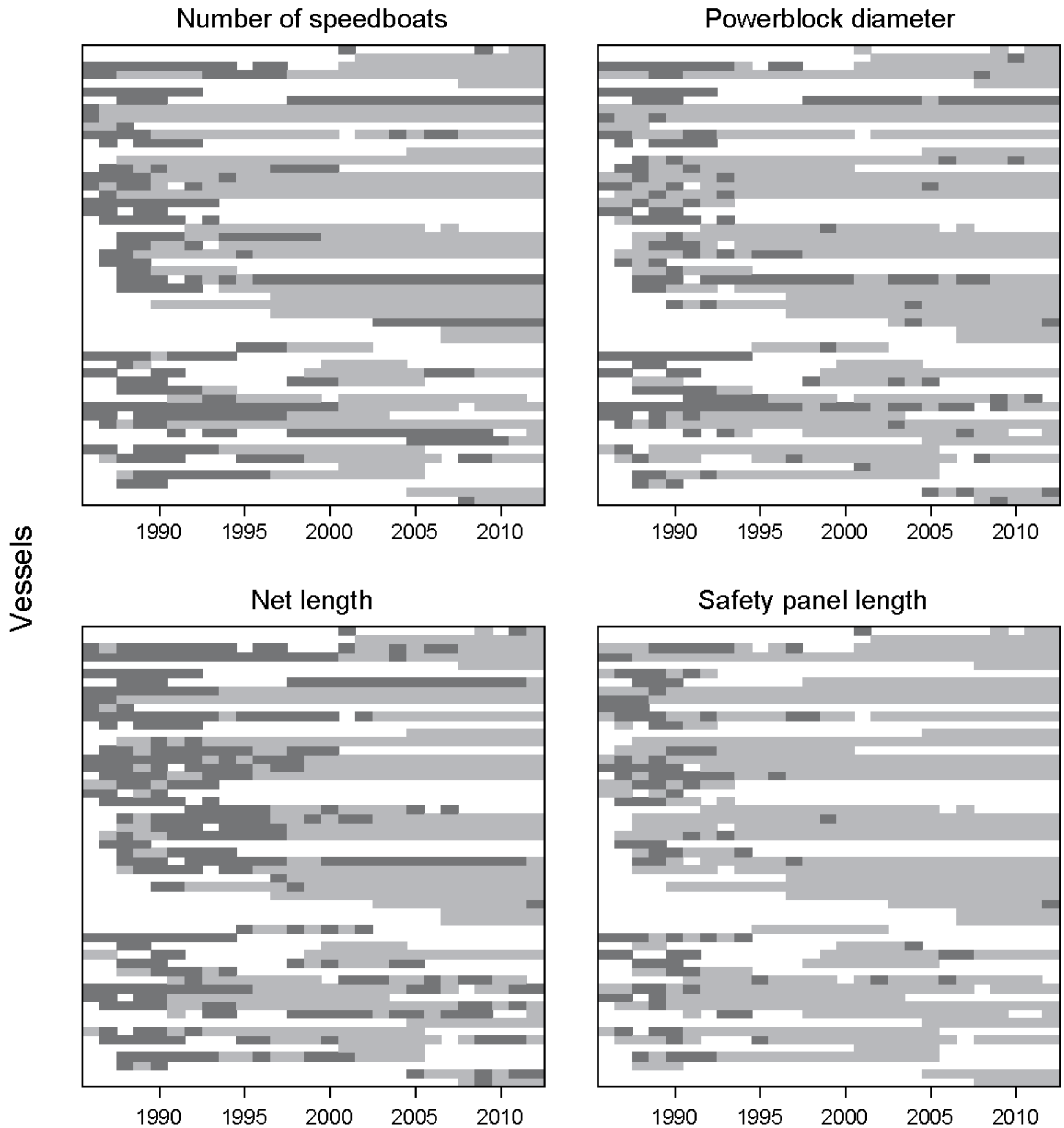

FIGURE 4. Time lines of gear characteristics for continuous variables included in the CPUE GAM standardization. Dark gray: at or below the mean/median; light gray: above the mean/median. The mean/median was taken over all unique values for the gear variable in the data set. Below/above the mean/(median) is by vessel, for each year-quarter; *i.e.*, if for any trip by a vessel in a particular year-quarter, the gear characteristic was above the mean/median, the value for that vessel for that quarter is shown as "above" (light gray).

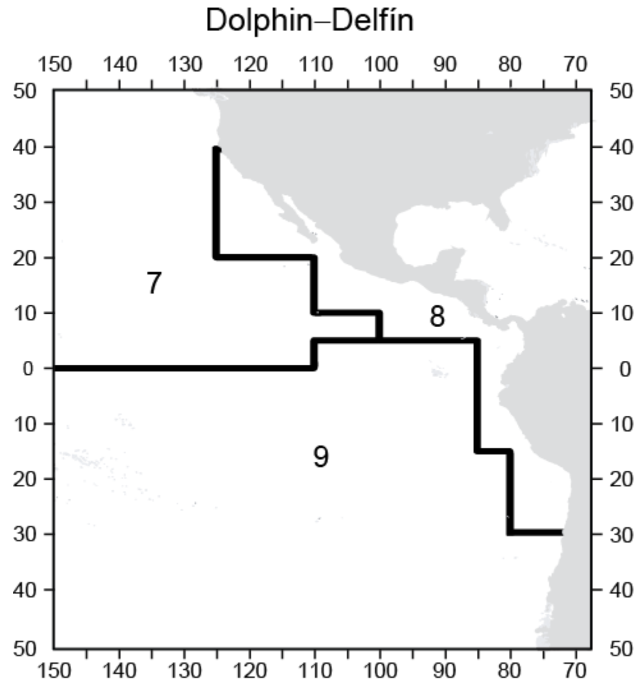

FIGURE 5. Yellowfin tuna stock assessment areas for purse-seine dolphin fisheries.

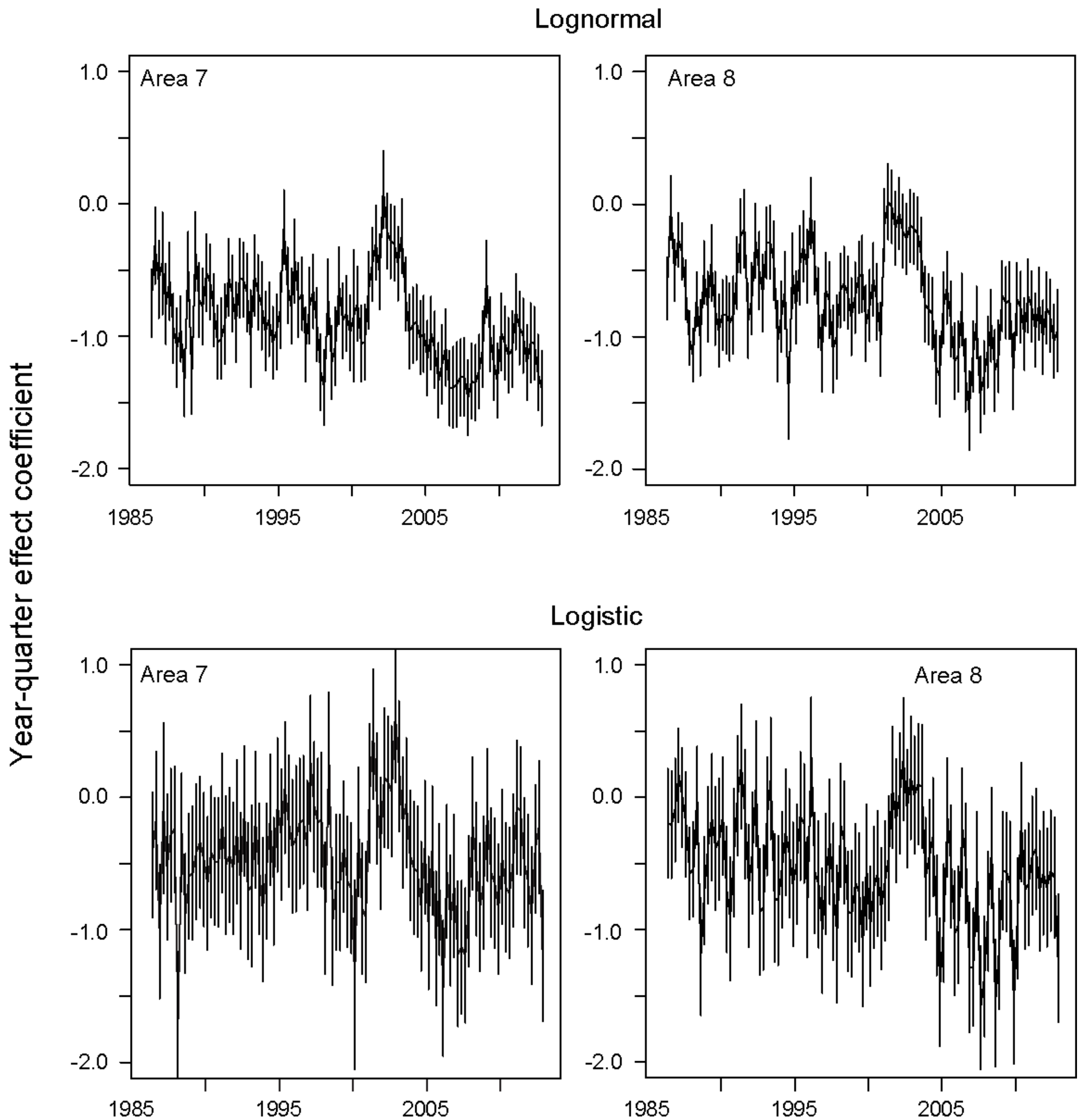

FIGURE 6. Estimated year-quarter effect coefficients (on the scale of the linear predictor) for Mexican dolphin vessels in stock assessment areas 7-8, plus/minus one standard error, for lognormal and logistic parts of the full delta-lognormal model (model (ii)).

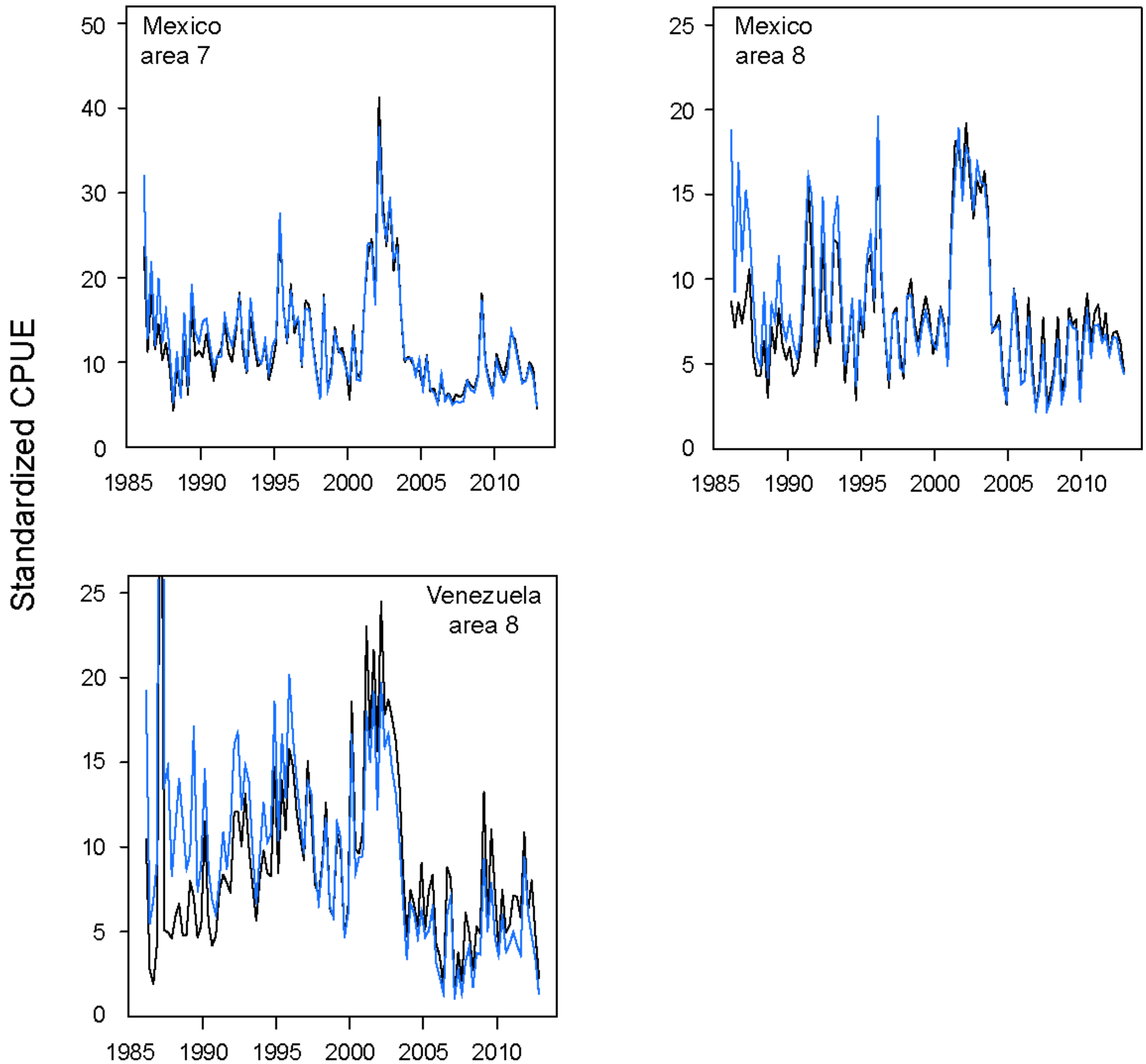

FIGURE 7. Standardized trends for Mexican dolphin vessels in stock assessment areas 7-8 and for Venezuelan dolphin vessels in stock assessment area 8. Black lines: GAM without gear and vessel predictors (model (i)); blue lines: GAM with gear and vessel predictors (model (ii)).

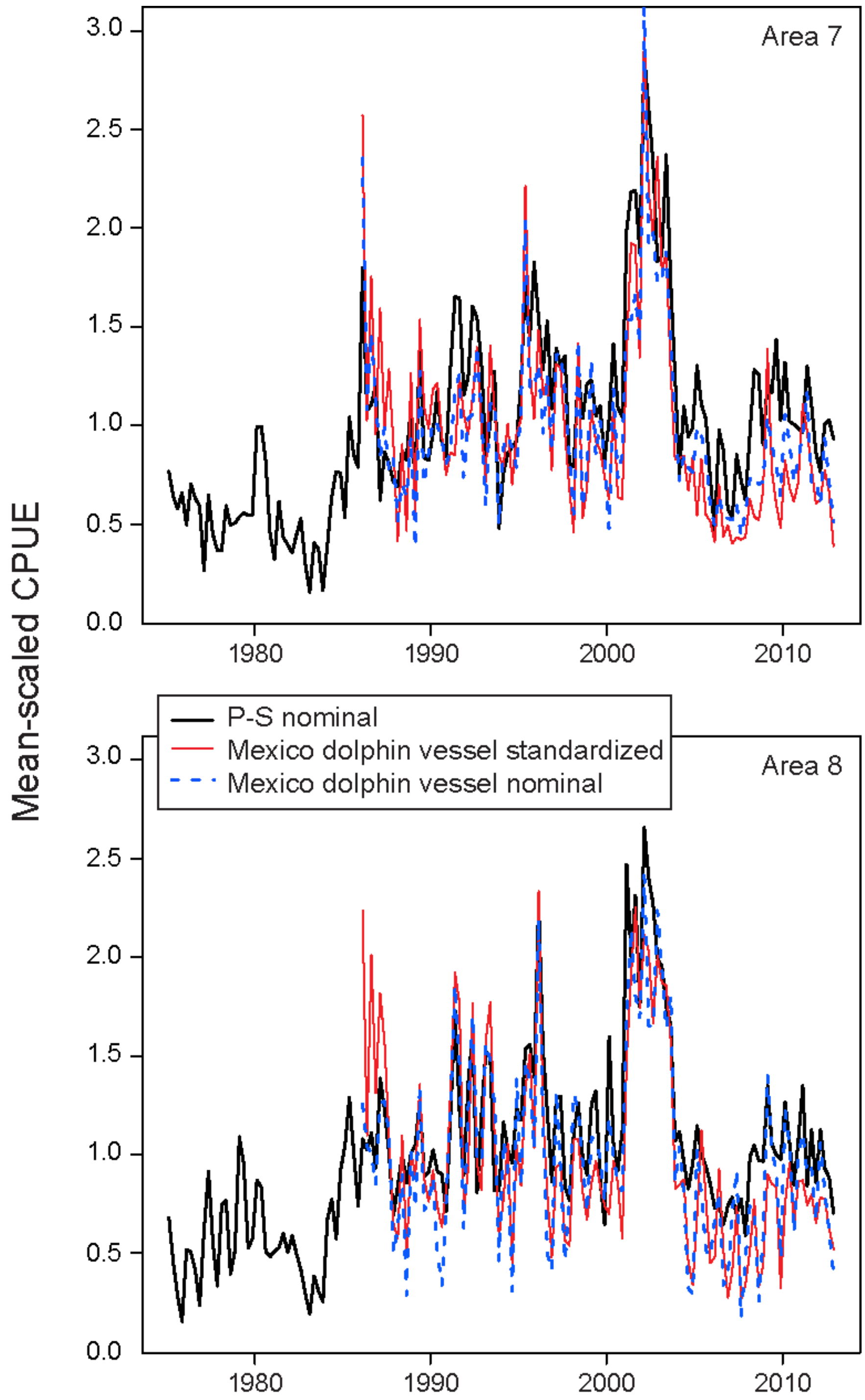

FIGURE 8. Mean-scaled CPUE in Areas 7-8. Black: purse-seine (P-S) nominal (from the stock assessment); blue: Mexican dolphin vessel nominal; red: Mexican dolphin vessel standardized.

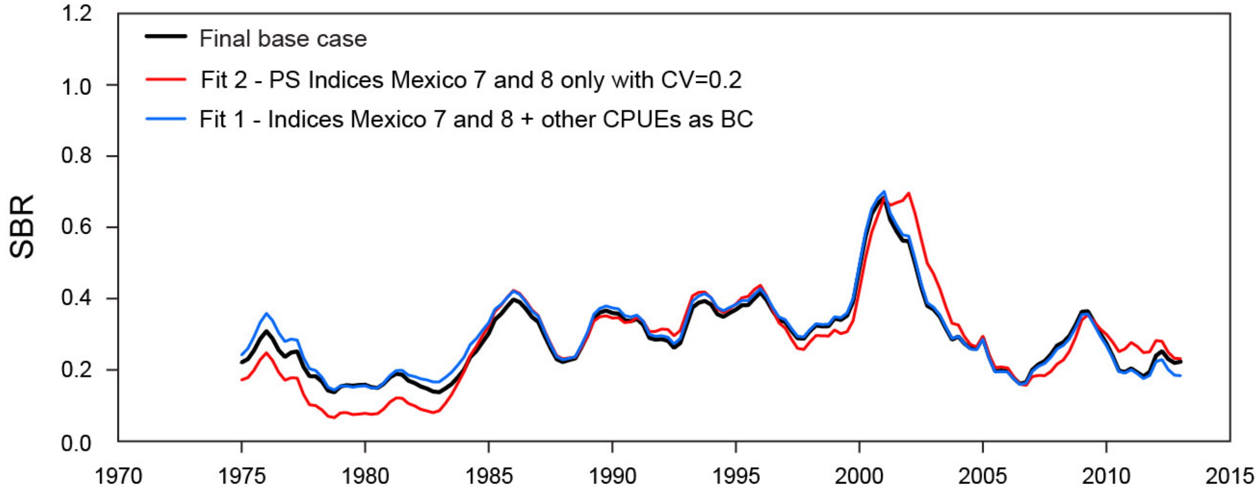

FIGURE 9. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case and from the two fits perfomed with the new standardized indices.

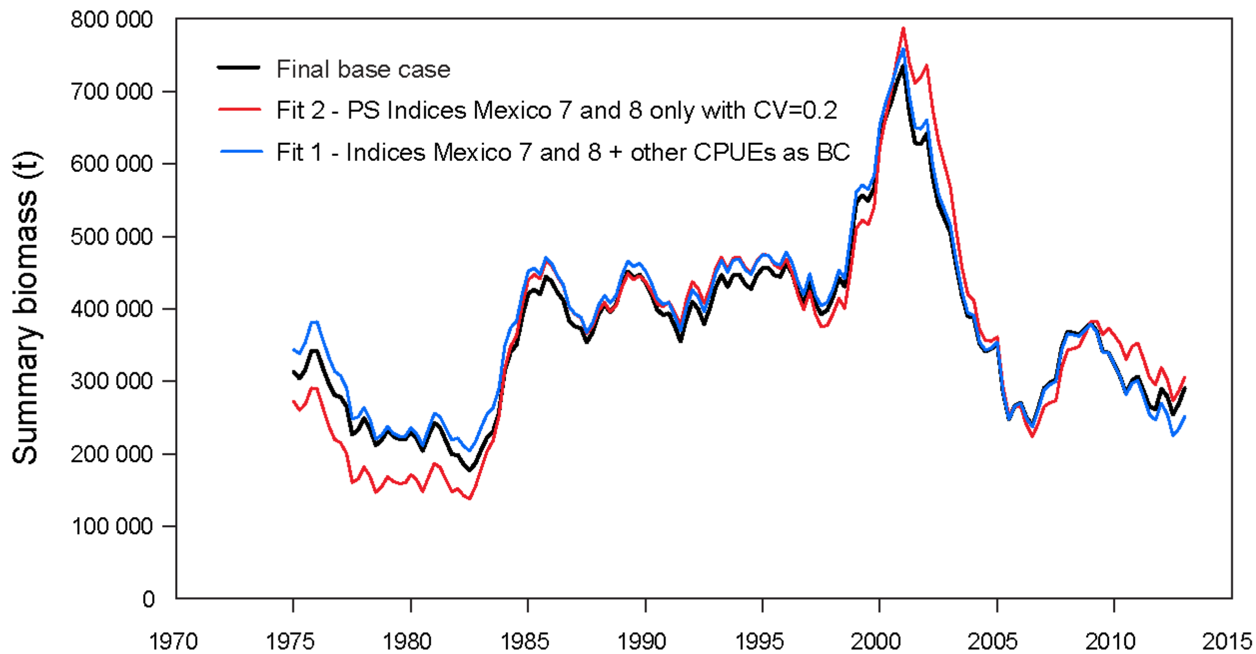

FIGURE 10. Comparisons of the estimates of biomass of yellowfin tuna from the base case model and from the analyses with the new standardized indices.

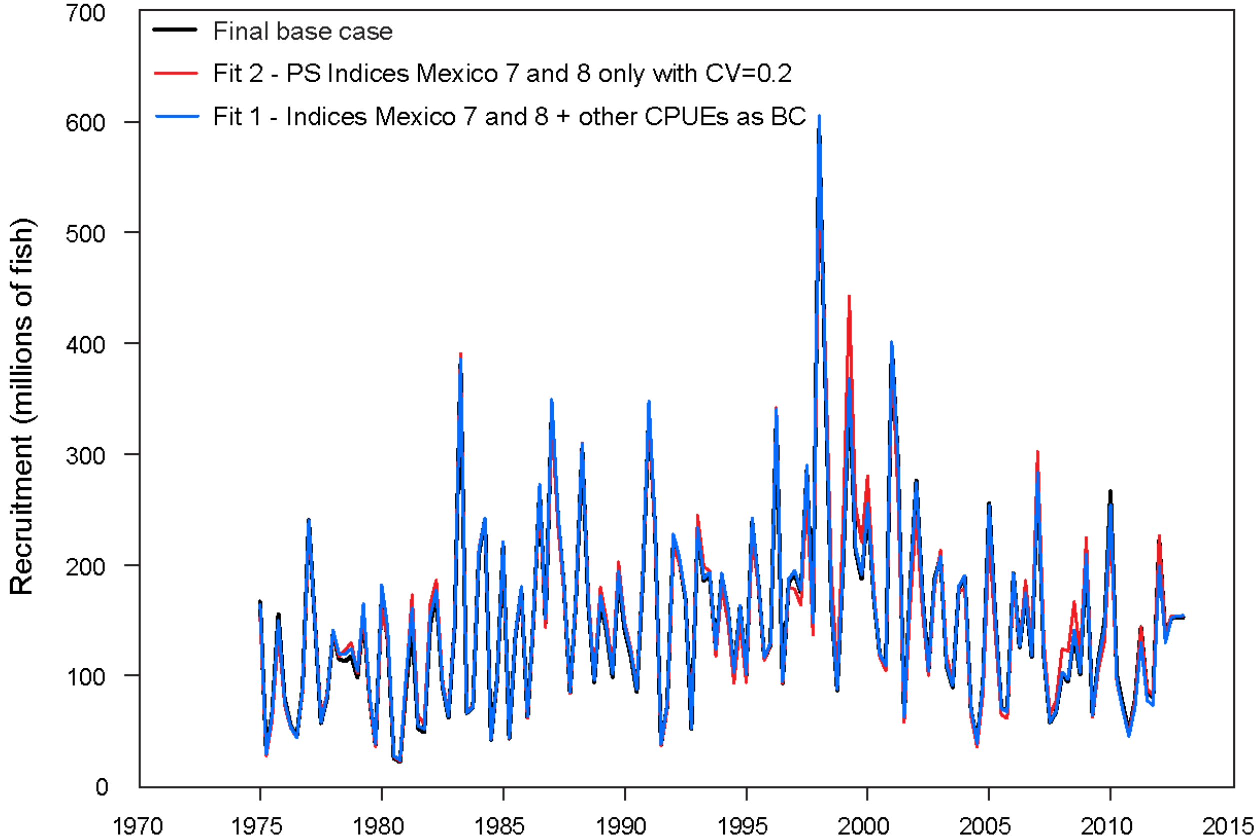

FIGURE 11. Comparisons of the estimates of recruitment of yellowfin tuna from the base case model and from the analyses with the new standardized indices.