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A COLLABORATIVE ATTEMPT TO CONDUCT A STOCK ASSESSMENT FOR THE SILKY SHARK IN THE EASTERN PACIFIC OCEAN (1993-2010): UPDATE REPORT

SUMMARY

Since 2009, IATTC staff, national observer program staff, scientists of member countries, non-governmental organizations, and industry collaborators have worked together to accumulate, process, and analyze data for the silky shark (*Carcharhinus falciformis*) in the EPO. This collaborative effort has produced a great deal of fishery data and information on stock structure, biological parameters, and size selectivity of different fisheries catching silky sharks in the EPO, whether as a target or as bycatch.

A stock assessment covering the 1993-2010 period was attempted using Stock Synthesis. Unfortunately, the model was unable to fit the main index of abundance adequately, and therefore the results were not reliable since relative trends and absolute scale are compromised in the assessment. The poor performance of the model was probably due to incomplete information on the total catch in the EPO, particularly for the early period of the assessment (1990s and early 2000s). An alternative approach is therefore needed to provide management advice for silky sharks, and the staff recommends the use of indicators until adequate information becomes available to conduct a full assessment (Document SAC-05-11a). Catch, effort, and sex specific length-composition data should be collected for all fisheries capturing silky sharks in the EPO. In particular, implementation of a standardized longline survey, perhaps using commercial vessels, should be considered to improve the information available for creating indicators and a full stock assessment.

1. BIOLOGICAL AND FISHERY DATA COMPILATION

The collaborative assessment effort has produced a great deal of fishery data and information on stock structure and biological parameters (Report of 3rd Technical Meeting on Sharks, Appendix 1). This information has been archived in an IATTC data depository, and a joint publication (IATTC Bulletin) by IATTC staff and collaborators describing this large amount of new information is in preparation.

Among the valuable new information on the silky shark in the EPO is a first estimate of the magnitude of the catches taken by different fisheries north of the equator, where the majority of the catches are made. The catches of silky sharks in the south are much smaller (Figure 1).

It is estimated that only about 5% of the total catch of silky sharks in the EPO is taken by tuna purse-seine vessels, and 3% by tuna longline vessels. Ecuadorian artisanal fisheries account for a further 7%. The remaining 85% is taken by vessels operating from Mexico and Central America, in about equal proportions, using a variety of gears, mainly longlines. The Central American catch is about evenly divided between two components, a domestic fleet (coastal nations) and a foreign fleet (non-coastal nations), that land their catches in Central America.

There is great uncertainty about the catches by the non-coastal (foreign) fleet operating in Central America before 2004, when shark finning was not restricted in the region. With no catch and effort data available for this fleet, it is difficult to estimate the catches during the early period of the assessment. Nonetheless, an attempt was made using the main index of relative abundance (CPUE-OBJ: standardized catch-per-unit-effort in purse-seine sets on floating objects) to retrospectively scale the known catches since 2004, based on assumptions about historical effort (Figure 2).

2. BIOMASS DYNAMIC (SURPLUS PRODUCTION) MODEL

A Pella-Tomlinson (1969) biomass dynamic model was applied to the northern silky shark fishery data. Biomass dynamic models – also known as surplus production models – pool recruitment, growth, and mortality into a single "surplus production" term.

The data used in the surplus production model consisted of the historic northern silky shark catches (all fisheries aggregated) and an index of relative abundance. The standardized catch-per-unit-effort (CPUE) index for the purse seine fishery on floating objects (OBJ), considered to best represent stock trends, was used in the model fit (Figure 3). This CPUE-OBJ index was chosen because of its wider spatial coverage in the EPO, and because it includes all segments of the stock, although it is dominated by small sharks.

The main reason for using a surplus production model was to answer the following diagnostic question: given the assumed time series of catches, and using parameter estimates that are biologically reasonable for the silky shark, can a simple population dynamics model reasonably fit (explain) the index of abundance? This "surplus production diagnostic" is particularly useful for sharks. The intrinsic rate of population increase (r_{max}) of the Pella-Tomlinson model is directly comparable with the observed instantaneous rate of population increase (r_{obs}) derived from demographic studies. In fact, r_{obs} from a demographic analysis consists of a minimal estimate of r_{max} (Hoenig and Gruber, 1990).

Across a range of assumed values of r_{max}, which bracket the productivity of the stock, the surplus production model was unable to explain (fit) the early decline in CPUE (Figure 4). If r_{max} is estimated, the maximum likelihood estimate was 0.57, a value much higher than would be expected for silky sharks (at about 0.07, see section 4.1). This result indicates that trends observed in the CPUE-OBJ index are inconsistent with the productivity of silky sharks and the assumed levels of historic catches.

An attempt was made to estimate the missing early catch, using an effort deviate approach in the surplus production model. Catch was estimated to be higher in the early period, but the model still did not have enough flexibility to fit the early CPUE.

3. AGE-STRUCTURED MODEL

3.1. Stock Synthesis

An age-structured population dynamics model was built for the northern silky shark stock using Stock Synthesis (version 3.24f), an age-structured, integrated (fitted to many different types of data), statistical stock assessment model (Methot, 2005; Methot, 2009; Methot and Wetzel, 2013). SS has commonly been used for stock assessments of groundfish, as well as tuna and other pelagic fish species, in many regions of the world. The underlying integrated analysis approach of SS is the same as that of other commonly-used statistical age-structured models such as Multifan-CL (Fournier *et al.*, 1998) and CASAL (Bull *et al.*, 2005). However, Stock Synthesis is currently the only model offering a stock-recruitment relationship specifically designed for low-fecundity species (Taylor *et al.*, 2013). This is an advantage for sharks, in particular, and the main reason for choosing SS for the silky shark assessment.

In the silky shark surplus production model, catch was pooled by summing across fisheries and assumed to be taken from a lumped biomass quantity with no explicit assumptions being made about age structure (for both the stock and catches). For the silky shark in particular, the reality is much more complex, with strong spatial segregation patterns by age/length and sex known to occur across the EPO (Roman-Verdesoto and Orozco-Zoller, 2005; Watson *et al.*, 2009). Therefore, it is important to approximate this spatial structure in the stock assessment model. At this stage, however, it is not feasible to develop a spatially-structured model for the silky shark because this would require a large amount of tagging data to inform about movement, and no such data are currently available. Therefore, an attempt was made to deal with spatial structure by spatially defining multiple fisheries with different selectivities (Maunder, 2008). This allows fisheries to take catch out of the correct age-classes through their own selectivity curves estimated from catch-composition data.

In SS the stock assessment model is fitted to the observed data (indices of relative abundance, size-class and length-composition data) by finding a set of population dynamics and fishing parameters that maximize a penalized likelihood, given the amount of catch taken by each fishery. A total of 14 fisheries that catch silky sharks, as either a bycatch or target species, were defined in the SS model (Table 1). The various datasets used to calibrate the model are provided in Table 1 (survey data, either CPUE treated as indices of abundance, or size-class and length-composition data). The temporal coverage of the various datasets is shown in Figure 5.

3.2. Length composition and selectivities

A significant amount of knowledge was obtained about the length composition of the silky shark catches taken by different fisheries. On average, the model fitted the length-composition data from different fisheries reasonable well (Figures 6-13). The exceptions were some fisheries with very low sample sizes (Chinese and Korean tuna longline fisheries, whose selectivities had to be shared with the Japanese longline tuna fishery, for which more complete data are available (Figures 8-9). The model fit to the length-composition data for some Mexican fisheries could also be improved (Figure 10). This misfit is related to the logistic selectivity assumption made for these fisheries, because they generally catch higher proportions of larger fish. The asymptotic selectivity assumption may have to be relaxed for these fisheries, but without an asymptotic assumption for at least one fishery, the abundance scale may become highly uncertain.

This knowledge, plus the estimated selectivity curves for different fisheries (Figure 14), provide useful information for management; for instance, if the objective is to protect pupping or nursery grounds or, alternatively, the mature stock.

3.3. Model “misfit” to the CPUE-OBJ index of abundance

A reasonable model fit to the indices of abundance that are considered reliable is critical for obtaining management quantities from a statistical age-structured model (Francis, 2011). Indices of relative abundance (usually standardized CPUE) are the best information available on population trends, and, if combined with total catch data, they also provide information on absolute abundance. Therefore, estimates of the total catch are essential for traditional stock assessments. Composition data also provide information on absolute abundance and trends in abundance, but they require adequate specification of selectivity and growth, which is often difficult, particularly in data-limited situations.

The CPUE-OBJ index of relative abundance is considered to best represent the population trends for silky sharks, mainly due to its wider spatial coverage in the EPO. Obtaining a reasonable model fit to this index of abundance is critical for obtaining reliable management quantities. Unfortunately, the SS model was unable to fit (explain) the sharp decline observed early in the index (1995-1998) and the slow increase since 2004 (Figure 15).

In addition to the main CPUE-OBJ index, other indices of abundance are included in the model, mainly for the other two purse-seine set types (on dolphins (DEL) and unassociated schools of tuna (NOA)) and for different size classes of silky sharks. In order not to interfere with the model fit to the CPUE-OBJ index of abundance, it was decided not to include these other indices in the total likelihood. Even without fitting to these indices, an evaluation can be made on how well the model predictions correspond with these indices. Their trends are consistent with the CPUE-OBJ index, so unsurprisingly, the model is unable to fit the trends in these time series (Figure 16).

Assuming that the CPUE-OBJ index of abundance is reliable and the early sharp declines are real, the model misfit suggests that the observed early decline is inconsistent with the catch history and the life-history parameters (productivity) assumed in the model for the silky shark.

Considering that the catch for the Central American foreign fleet in the early period was approximated based on assumptions, and is expected to be significant, a possible explanation for the model misfit to the early CPUE-OBJ data is missing catch at the start of the model. A sensitivity analysis assuming various scenarios of assumed catch for this fleet was conducted (Figure 17). Some of these scenarios (for example scenarios 3 and 4) are extreme, and were used only to investigate the effect of strong catch perturbations on model performance. The model is still unable to fit the early CPUE decline (1994-1996) across these wide range of assumptions for the early catch (Figure 18). Even for the extreme cases when early catch is increased nearly four times, the improvement in fit to the early CPUE is minimal.

The time series of estimated total biomass, recruitment, and the spawning biomass ratio (SBR) estimated for the base case and sensitivity analyses are shown in Figure 19. The stock is estimated to have been depleted to about 30-40% across runs with no major fluctuations across the assessment period. The estimates of virgin biomass (B_0) across the base case and sensitivity analyses, over 1.5 million tons, seem unrealistically high compared to estimates available from other shark stock assessments. Since the model was unable to adequately fit the relative index of abundance, any absolute scale information from this index is compromised. The model does not fit the composition data from the fisheries with asymptotic selectivity, so absolute scale information from the composition data is also compromised. Therefore, the IATTC staff has no confidence in the absolute scale estimated in the stock assessment.

One hypothesis is that the model misfit to the early CPUE is caused by conflicting information between this index of abundance and the size-class or length-composition data. However, an age-structured production model diagnostic in which the SS model fits only to the CPUE data with selectivity parameters fixed and no estimated recruitment deviates likewise shows no improvement (Figure 20a). Allowing for recruitment deviations while still not fitting to the size-composition data gives more flexibility to the model (Figure 20b), but this is still not enough to explain the decline. The recruitment variability assumptions currently made in the model (σ_R = 0.4) are already probably quite large for a shark species, therefore trying to improve the fit to the data by increasing σ_R does not seem reasonable. Other sensitivity analyses were conducted, with different configurations of the stock-recruitment relationship, but none of these helped to improve the model fit to the CPUE-OBJ index of abundance.

4. FISHERY-INDEPENDENT ANALYSIS

4.1. Life-history based demographic analysis

A fishery-independent demographic analysis was conducted for silky sharks, based on life-history information available for the species in the EPO (Figure 21). An age-structured matrix population model (Leslie matrix type), in which the vital rates are stochastic, was constructed, following Aires-da-Silva and Gallucci (2007).

The resulting median finite rate of population increase (λ) of 1.07 year-1 and median population doubling time (t_2) of about 9.1 years indicate that the productivity (rate of increase) of the species is moderate, which confirms results from other studies (Cortés, 2002; Cortés, 2007). However, unless the age at first entry into the fishery is high, exploitation is sustainable (λ = 1) only at very low levels (Figure 22).

4.2. Yield-per-recruit analysis

A yield per recruit (YPR) analysis was conducted using the life-history information available for silky sharks (Figure 23). The YPR will increase greatly if no fishing mortality is allowed on the early juvenile segment of the population (pups age 0 and ages 1 and 2, at least).

5. CONCLUSION

There are uncertainties in the life-history data, but the data available and assumptions made seem quite reasonable for such important biological aspects as growth, reproduction, and natural mortality. In contrast, the reconstructed time series of catches rely on several assumptions which are highly speculative because the fishery statistics datasets for most countries are of low quality. There may also be problems with the preferred index of relative abundance from purse-seine sets on floating objects (CPUE-OBJ) (Maunder *et al.*, 2006), but it is consistent with the indices from the other purse-seine set types, and with no alternative indices (*e.g.* longline) available for calibrating the model, this index is the best available scientific information.

With no other index available, and without better catch estimates, the IATTC staff concludes that the reconstructed time series of historic catches of silky sharks is inconsistent with the observed trends in the CPUE-OBJ index and the life-history information for the species. It is also conclude that absolute scale is compromised in the assessment, due most likely to the inability of the model to fit the index of abundance. Additional information is needed for management advice on silky sharks in the EPO (see document SAC-05-11a). Catch, effort, and length-composition data should be collected for all fisheries capturing silky sharks in the EPO. In particular, implementation of a standardized longline survey, perhaps using commercial vessels, should be considered for improving the information available as a basis for creating indicators and a full stock assessment.

ACKNOWLEDGEMENTS

The IATTC staff would like to thank the scientists of member countries, non-governmental organizations, and industry collaborators whe have worked together to accumulate, process, and analyze data for the silky shark in the EPO. A list of collaborators in this project is available.

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TABLE 1. Catch per unit of effort (CPUE) and length-frequency (LF) data included in the silky shark Stock Synthesis model. PS: purse seine; LL: longline; TBS: tuna-billfish-shark.

FISHERY/SURVEY	CPUE	LF	SELECTIVITY	DESCRIPTION
FISHERY				
PURSE SEINE				
F1-OBJ-CL6		x*	Dome, gender	Floating-object sets, class 6
F2-NOA-CL6		x*	Dome, gender	Unassociated sets, class 6
F3-DEL-CL6		x*	Dome, gender	Dolphin sets, class 6
F4-OBJ-CL1-5			Mirror F1	Floating-object sets, class 1-5
F5-NOA-CL1-5			Mirror F2	Unassociated sets, class 1-5
F6-DEL-CL1-5			Mirror F3	Dolphin sets, class 1-5
F7-PS-night			Mirror F1	Handline; small longline; PS night sets, all capacity classes
LONGLINE				
F8-LL-tun			Dome, fit S33, gender	Tuna-billfish longline sets
F9-MEX-NC			Dome, fit S11, S12, S13	Mexico, Northern-Central region
F10-MEX-S			Dome, fit S14, S15, S16	Mexico, Southern region
F11-CA-Dom			Dome, fit S23, gender	Central America, coastal TBS fisheries
F12-CA-For			Mirror F11	Central America, non-coastal TBS fisheries
F13-ECU-LL		x	Dome, gender	Ecuador, artisanal longline
F14-ECU-GN		x	Dome, gender	Ecuador, artisanal gillnet
SURVEY				
S1-OBJ-CL6-ALL_F15	x		Mirror F1	PS CPUE, class 6, floating-object sets, all sharks
S2-OBJ-CL6-LRG_F16	x		Mirror F1	PS CPUE, class 6, floating-object sets, large sharks
S3-OBJ-CL6-MED_F17	x		Mirror F1	PS CPUE, class 6, floating-object sets, medium sharks
S4-OBJ-CL6-SML_F18	x		Mirror F1	PS CPUE, class 6, floating-object sets, small sharks
S5-NOA-CL6-ALL_F19	x		Mirror F2	PS CPUE, class 6, unassociated, all sharks
S6-NOA-CL6-LRG_F20	x		Mirror F2	PS CPUE, class 6, unassociated, large sharks
S7-DEL-CL6-ALL_F21	x		Mirror F3	PS CPUE, class 6, dolphin sets, all sharks
S8-DEL-CL6-LRG_F22	x		Mirror F3	PS CPUE, class 6, dolphin sets, large sharks
S17-LL-CHI_F31	x	x	Mirror F8	China, high-seas tuna LL LF
S18-LL-KOR_F32	x	x	Mirror F8	Korea, high-seas tuna LL LF
S19-LL-JPN_F33	x	x	Mirror F8	Japan, high-seas tuna LL LF
S9-LL-MEX-A_F23				Mexico, high-seas (A) LL CPUE
S10-LL-MEX-MA_F24	x		Mirror F9	Mexico, intermediate (MA) LL CPUE
S11-MEX-SinMA-NC_F25		x	Mirror F9	Mexico North-Central, Sinaloa intermediate (MA) LL, LF
S12-MEX-ColMA-NC_F26		x	Mirror F9	Mexico North-Central, Colima intermediate (MA) LL, LF
S13-MEX-ColA-NC_F27		x	Mirror F9	Mexico North-Central, Colima high-seas LL, LF
S14-MEX-ChiArt-S_F28		x	Mirror F10	Mexico South, Chiapas artisanal, LF
S15-MEX-GueArt-S_F29		x	Mirror F10	Mexico South, Guerrero artisanal, LF
S16-MEX-OaxArt-S_F30		x	Mirror F10	Mexico South, Oaxaca artisanal, LF
S20-CA-OSPESCA_F34		x	Mirror F11	Central America artisanal, OSPESCA, LF
S21-WWF_C15-C16_F35		x	Mirror F11	Central America artisanal, WWF, C-hooks 15-16, LF
S22-WWF_C18_F36		x	Mirror F11	Central America artisanal, WWF, C-hooks 18, LF
S23-WWF_J-J2-J3_F37		x	Mirror F11	Central America artisanal, WWF, J-hooks 18, LF
S24-ECU-LLanz1_F38	x		Mirror F13	Ecuador LL artisanal, hook 1 dorado, CPUE
S25-ECU-LLanz2_F39	x		Mirror F14	Ecuador LL artisanal, hook 1 dorado, CPUE

*: logistic

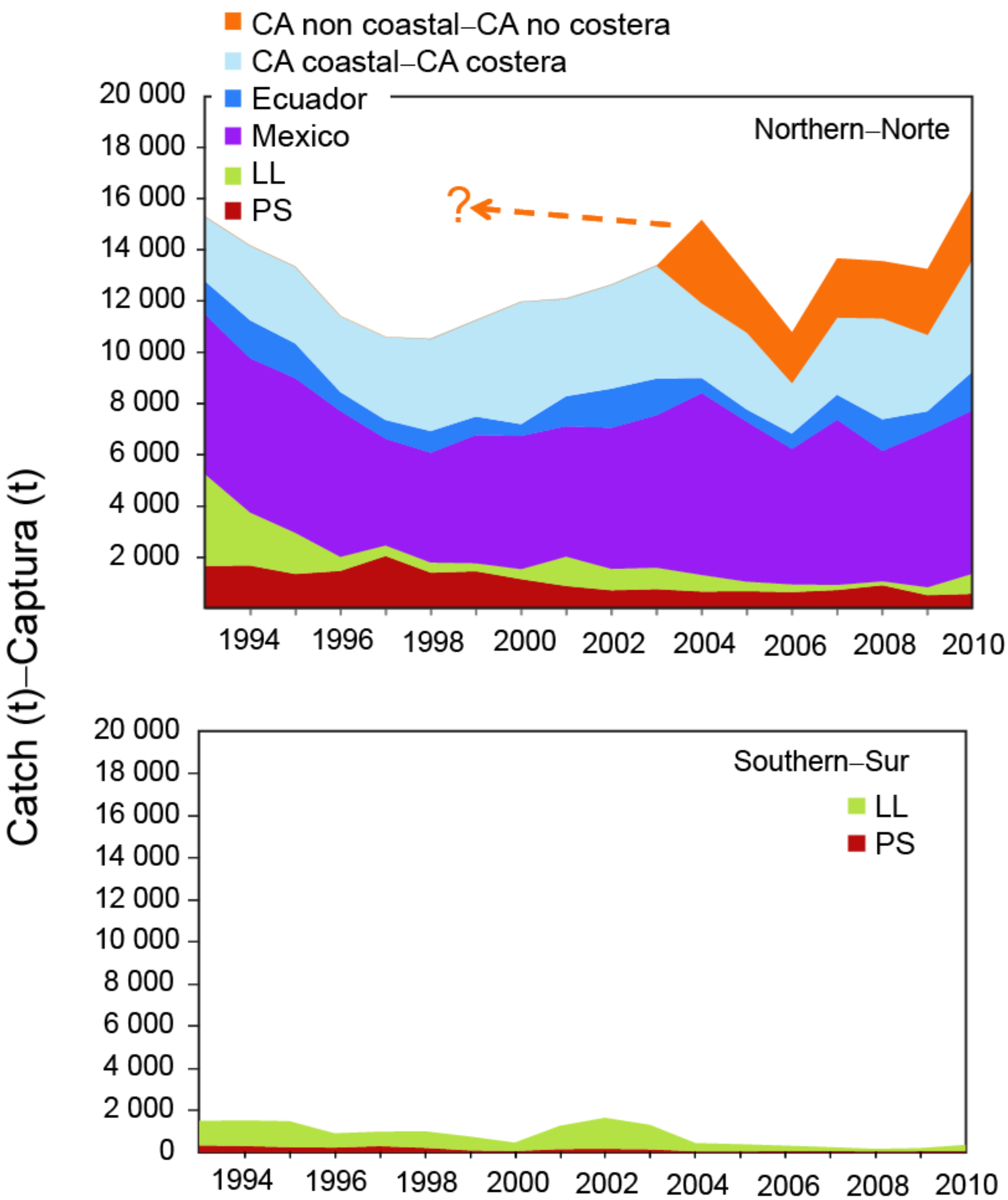

FIGURE 1. Reconstructed time series of silky shark catches, by fishery, in the northern and southern EPO. There are no estimates for the pre-2004 catches by the non-coastal (foreign) fleet operating in Central America (CA non-coastal). LL: longline; PS: purse seine.

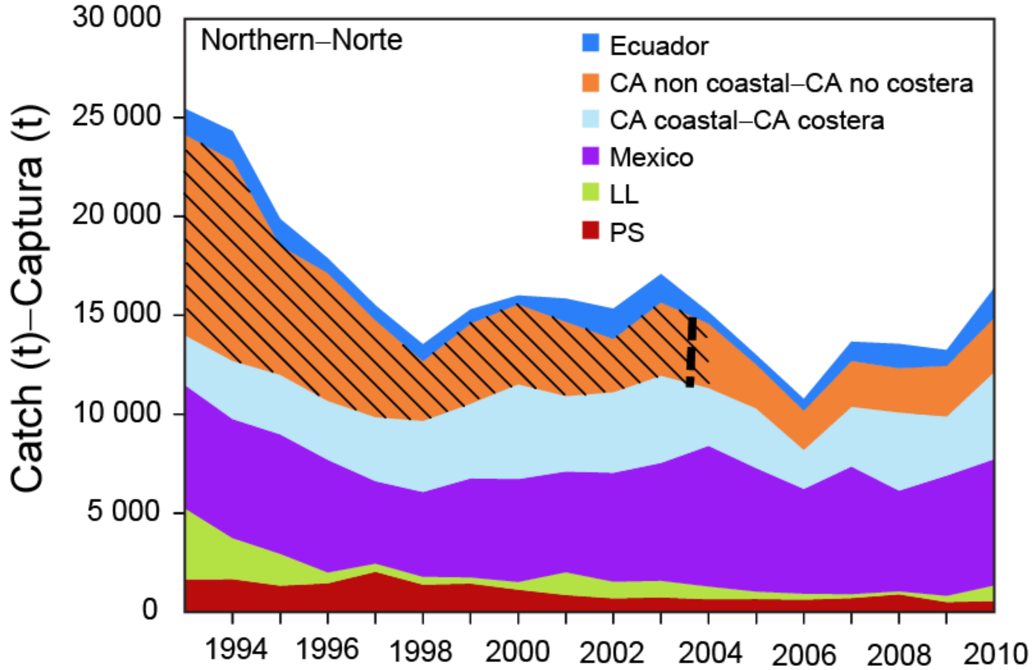

FIGURE 2. Reconstructed time series of silky shark catches, by fishery, in the northern EPO. The catches by the non-coastal (foreign) fleet operating in Central America (CA non-coastal) prior to 2004 (shaded) are based on assumptions; no data are available.

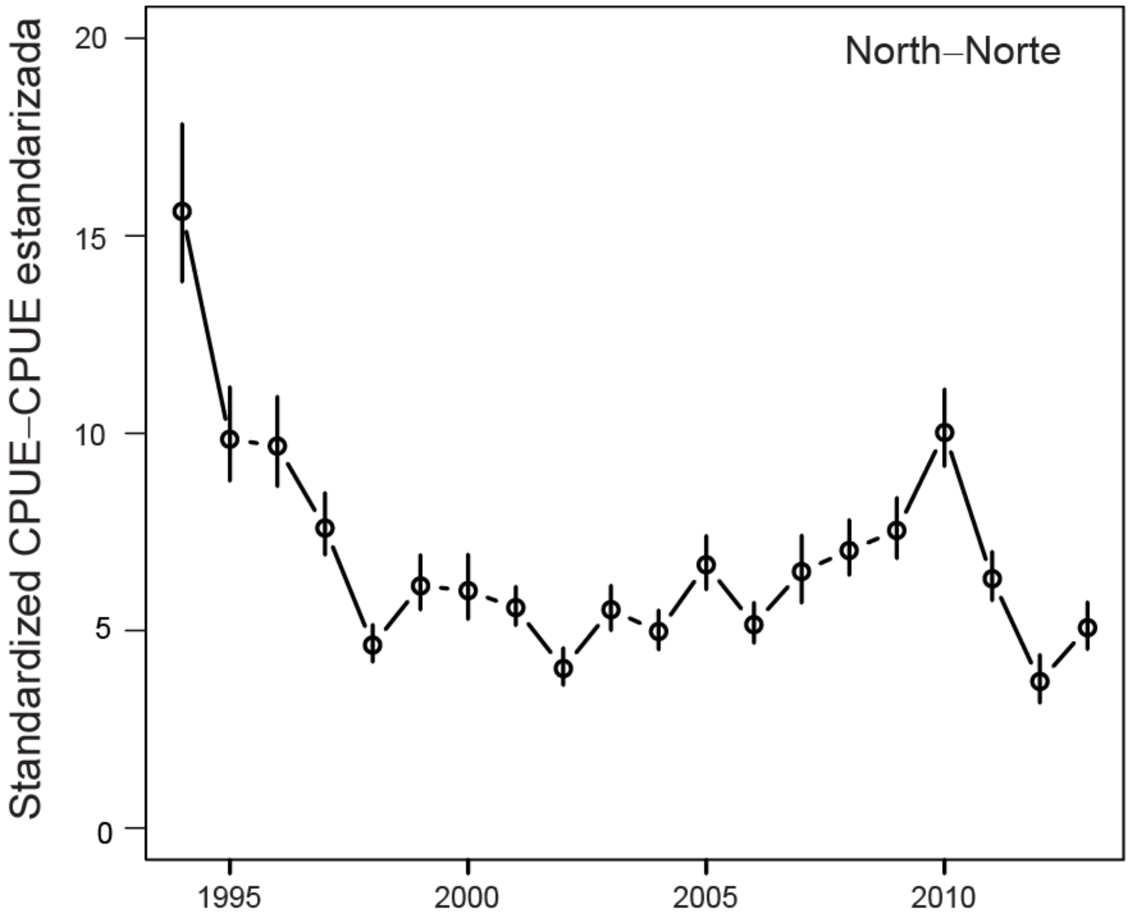

FIGURE 3. Standardized catch-per-unit-effort (CPUE) index from purse-seine sets on floating-objects (OBJ) for the northern silky shark stock.

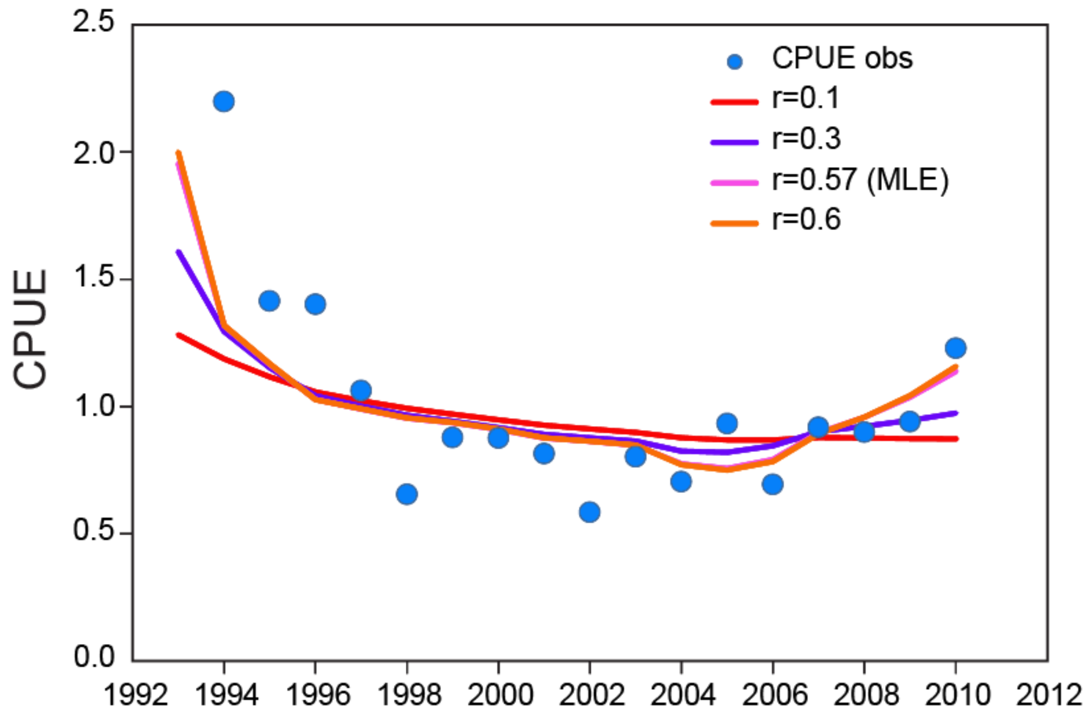

FIGURE 4. Surplus production (Pella-Tomlinson) model fit to the purse-seine floating-object (OBJ) standardized CPUE. The CPUE model fit obtained from the model run which provided the maximum likelihood estimate (MLE) (r_{max}=0.57) is shown, along with the fits for three other cases in which r_{max} is fixed (0.1, 0.3 and 0.6). The shape parameter of the Pella-Tomlinson model was fixed at 2.39 to produce an asymmetric surplus production curve with MSY at 60% of *K* (Cortés, 2007).

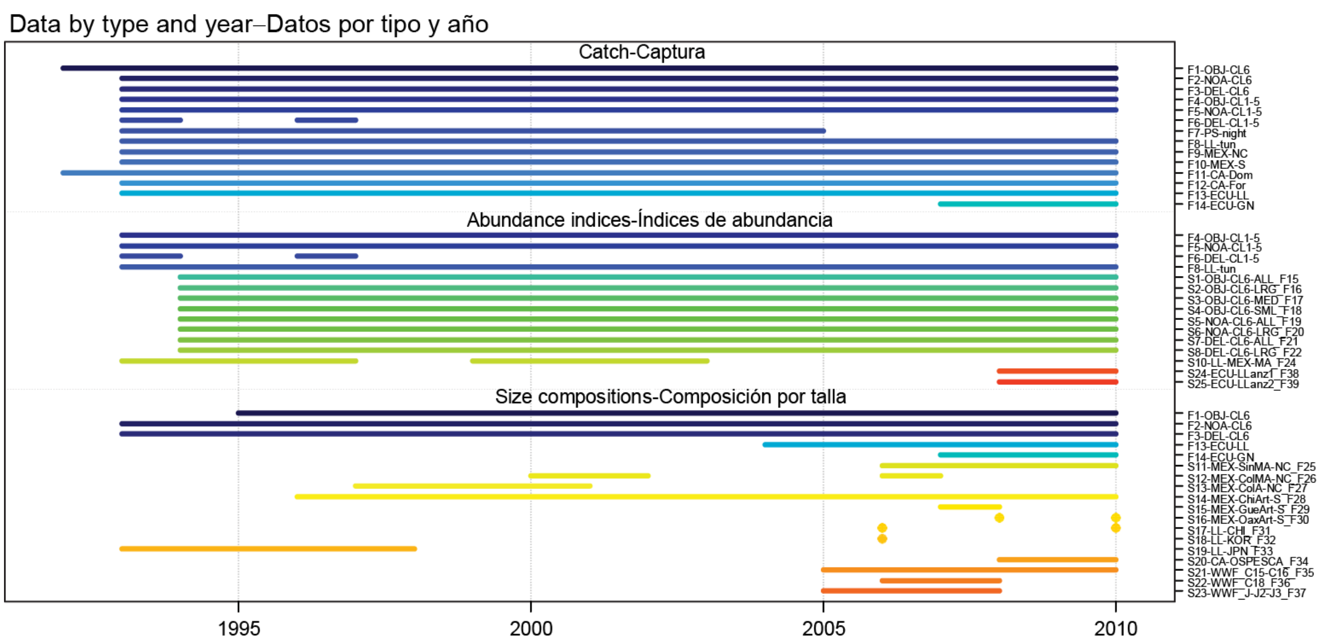

FIGURE 5. Temporal coverage of the silky shark data sets compiled in the collaborative work, by data type (catch, abundance indices, and size compositions).

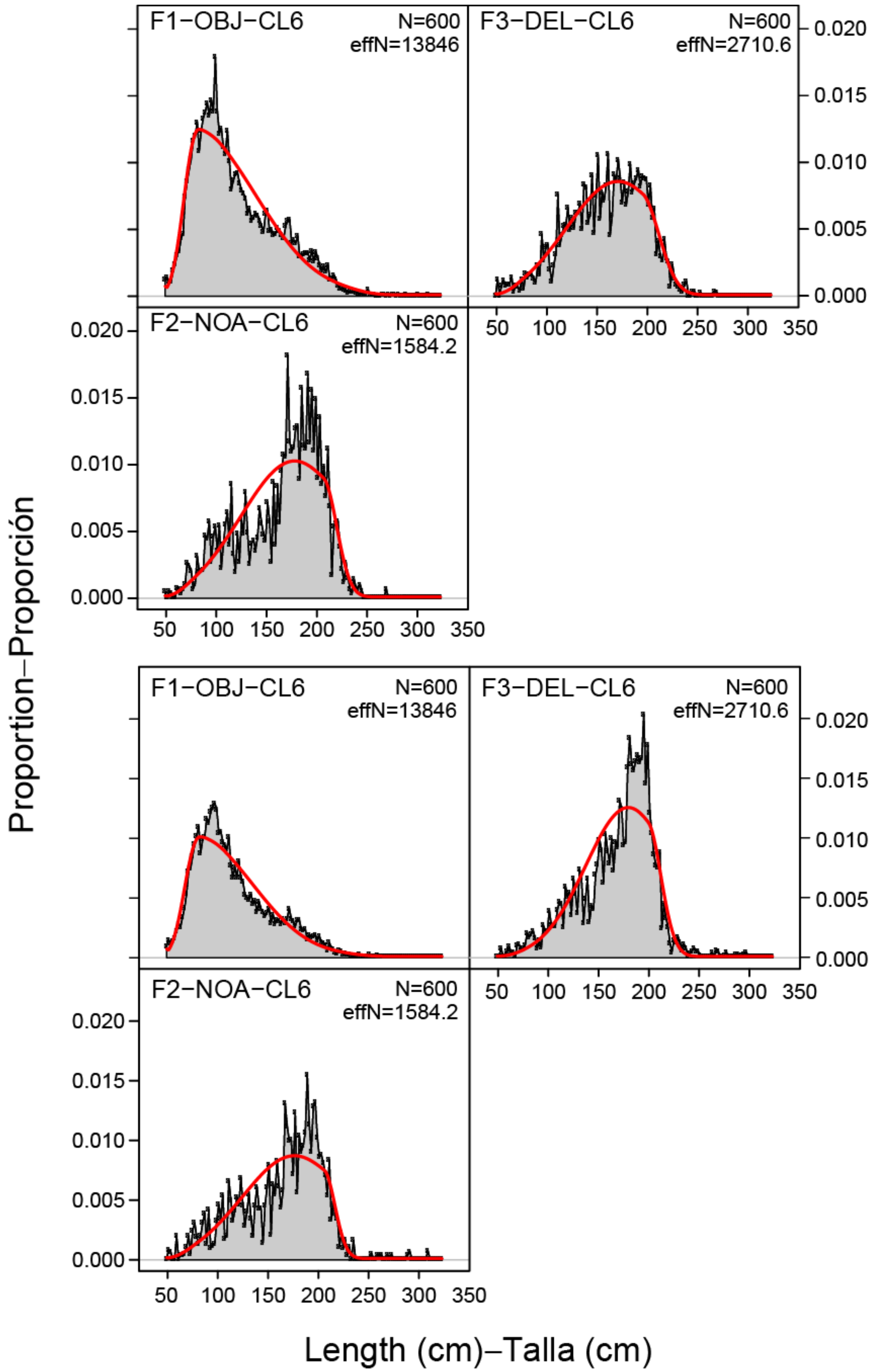

FIGURE 6. Average fit to the silky shark length-composition data for females (top) and males (bottom), for the purse-seine fisheries, by set type (OBJ, DEL, NOA). See Table 1 for descriptions of fisheries. IATTC observer data.

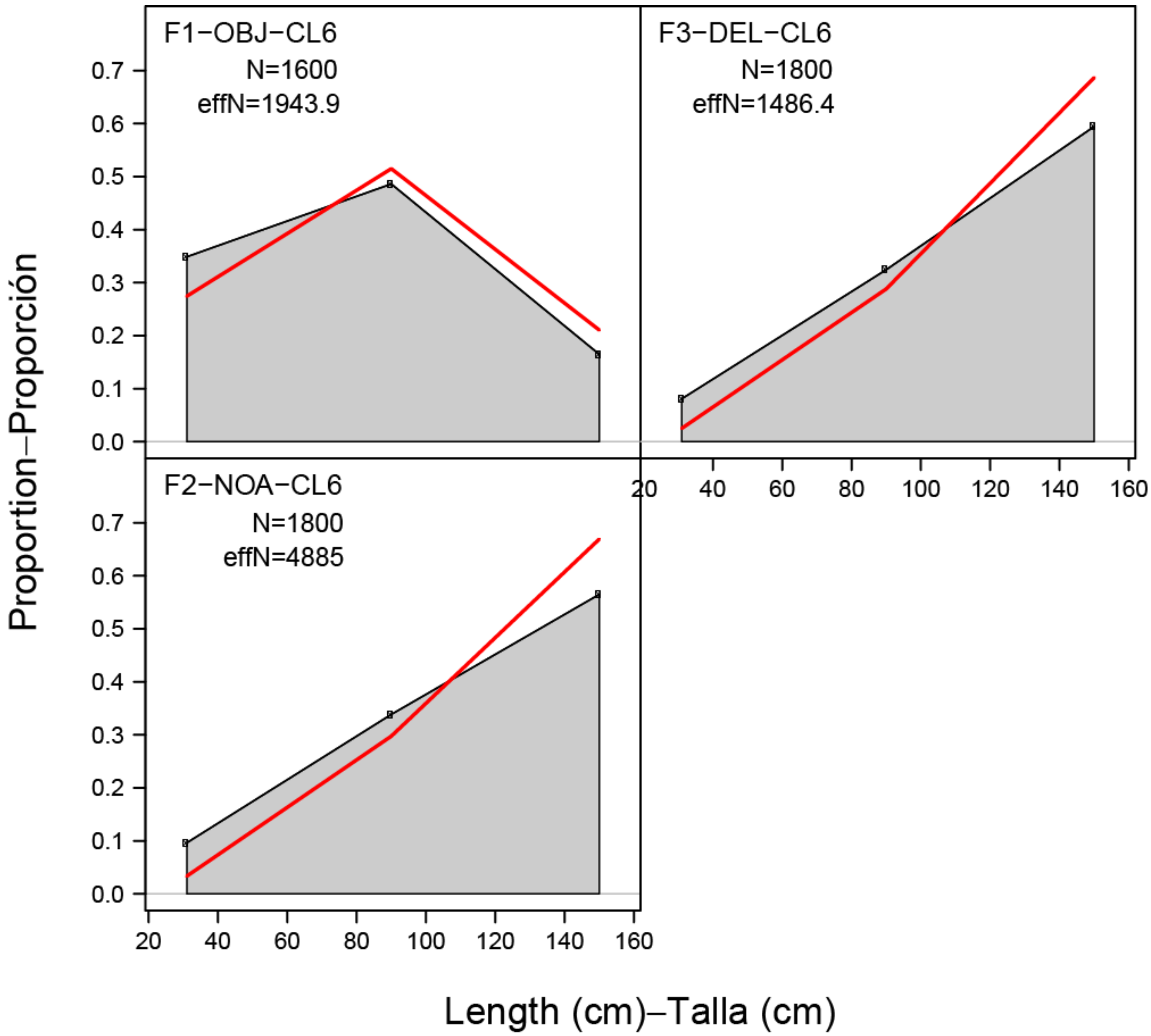

FIGURE 7. Average fit to the silky shark length-class composition data, both sexes combined, for the purseseine fisheries, by set type (OBJ, DEL and NOA). See Table 1 for descriptions of fisheries. IATTC observer data.

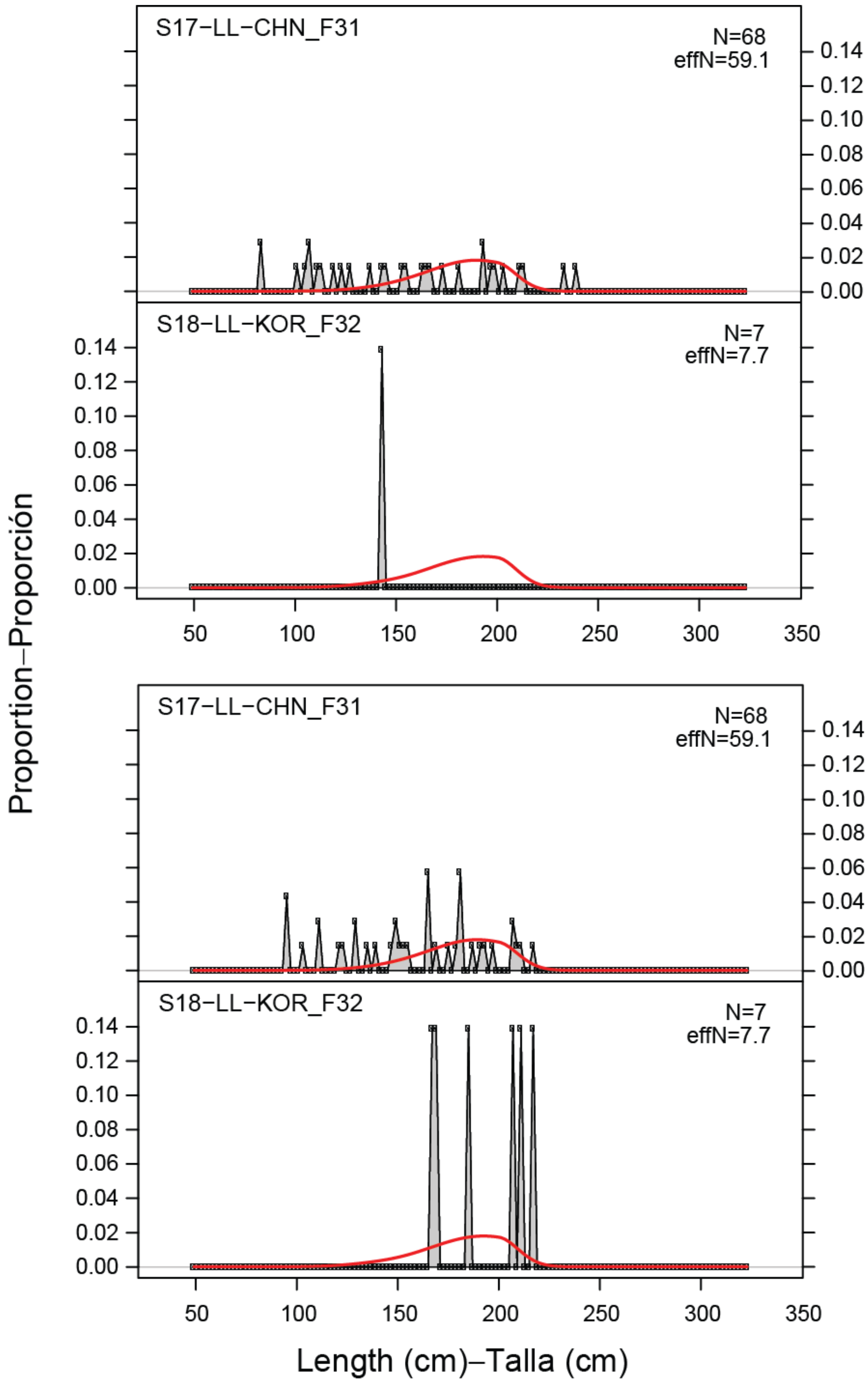

FIGURE 8. Average fit to the silky shark length-composition data for females (upper panel) and males (lower panel) for the Chinese and Korean high-seas tuna longline fisheries. See Table 1 for descriptions of fisheries.

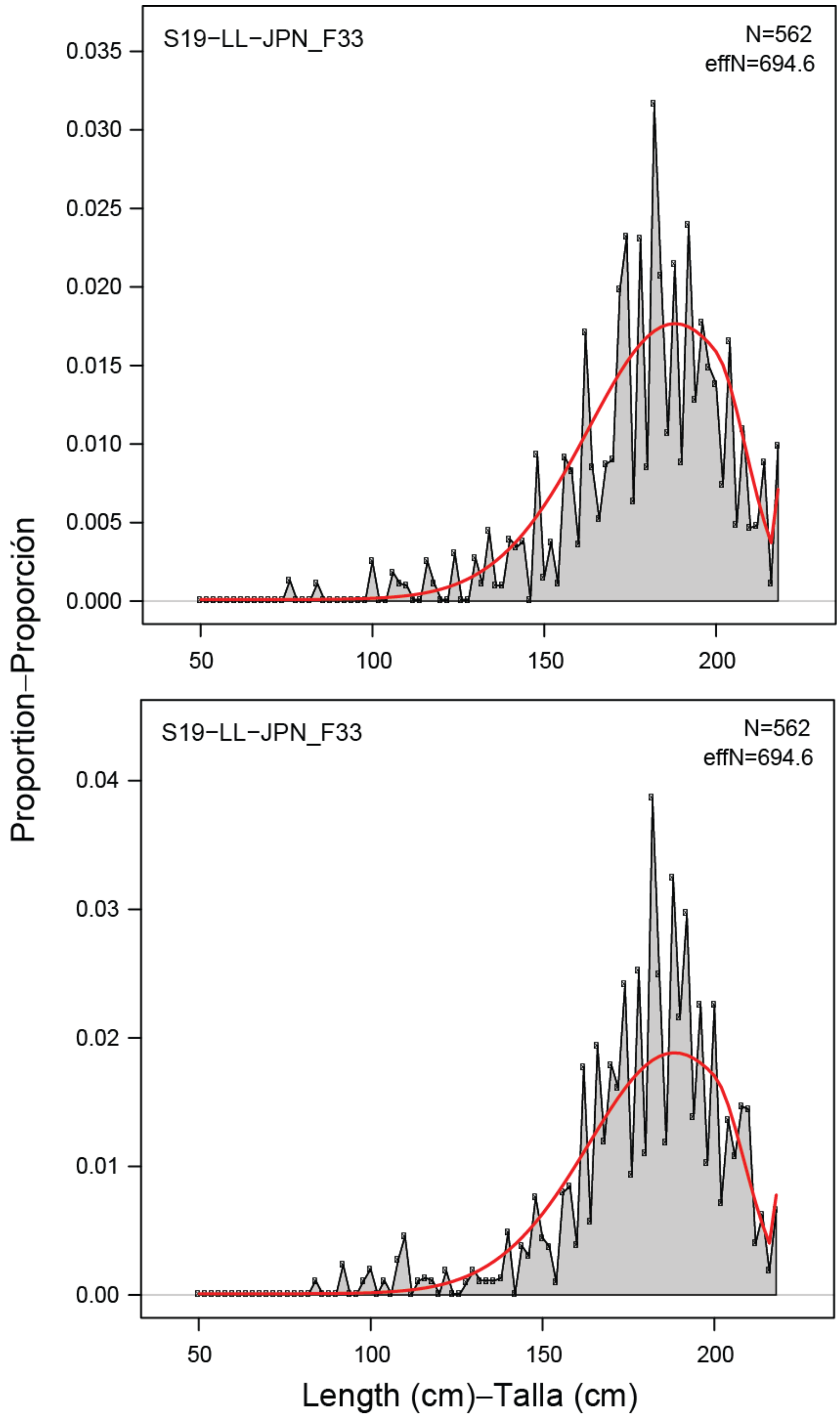

FIGURE 9. Average fit to the silky shark length-composition data for females (top) and males (bottom) for the Japanese high-seas tuna longline fisheries. See Table 1 for descriptions of fisheries.

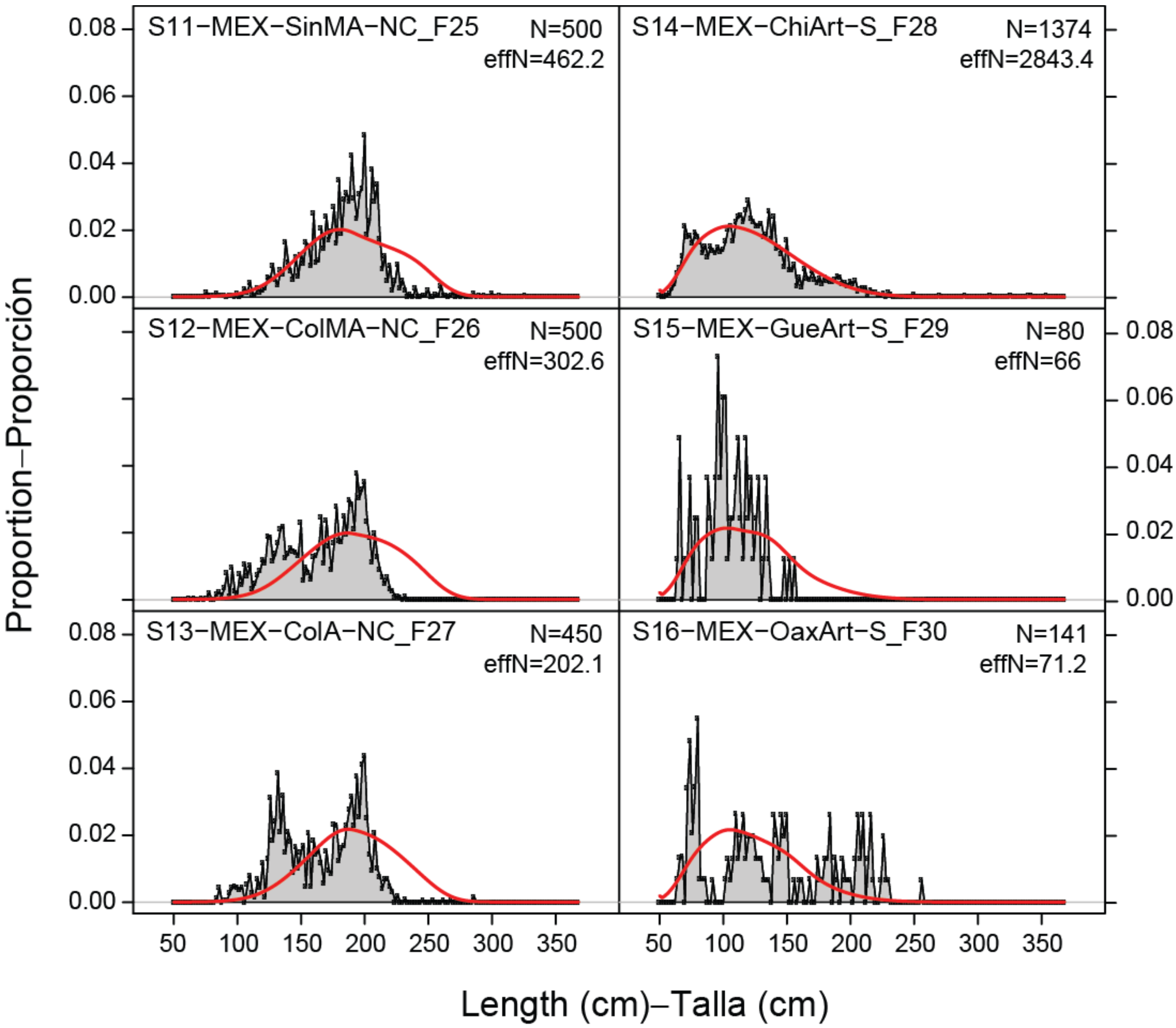

FIGURE 10. Average fit to the silky shark length-composition data, both sexes combined, for the Mexican fisheries. See Table 1 for descriptions of fisheries.

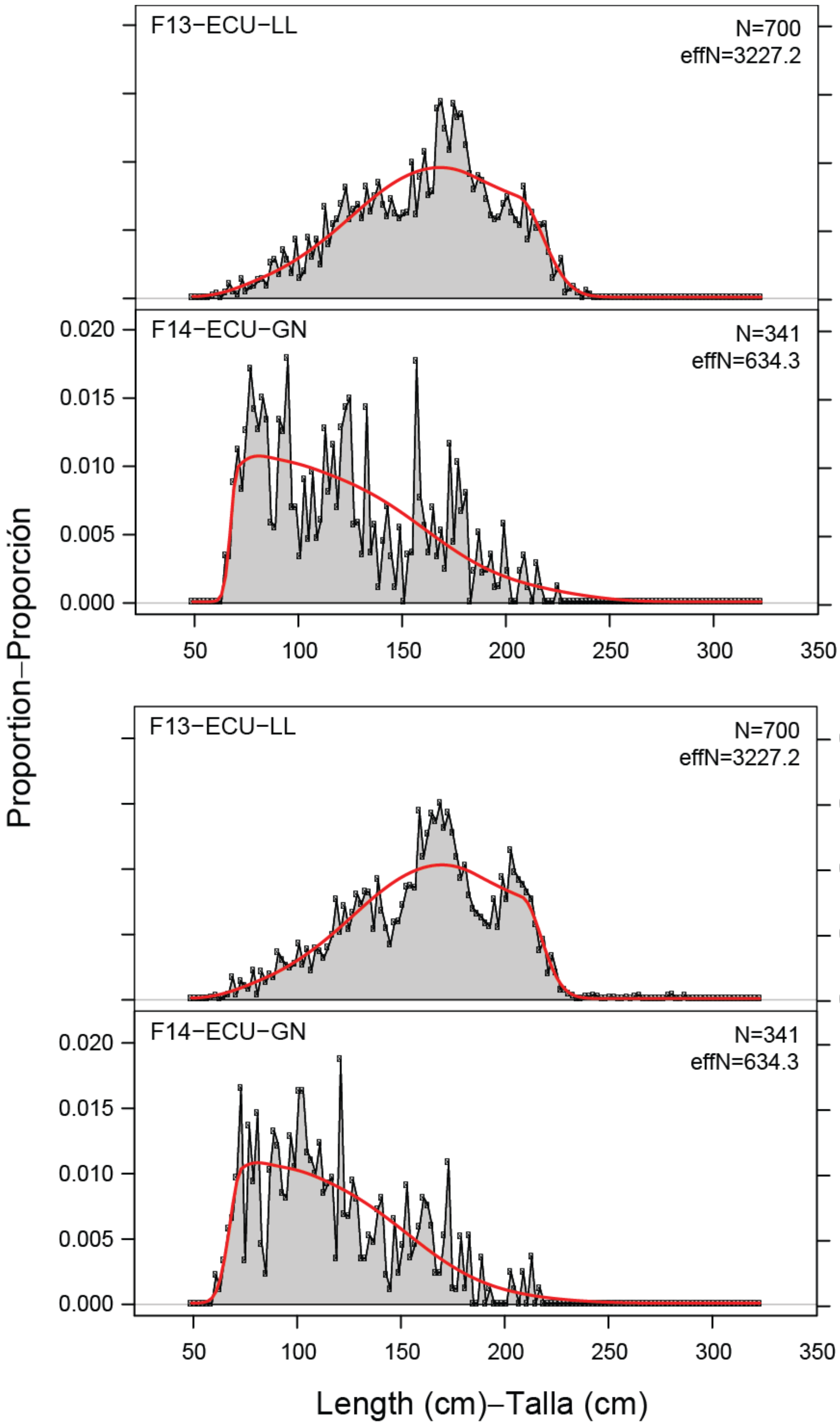

FIGURE 11. Average fit to the silky shark length-composition data for females (upper panel) and males (lower panel) for the Ecuadorian fisheries. See Table 1 for descriptions of fisheries.

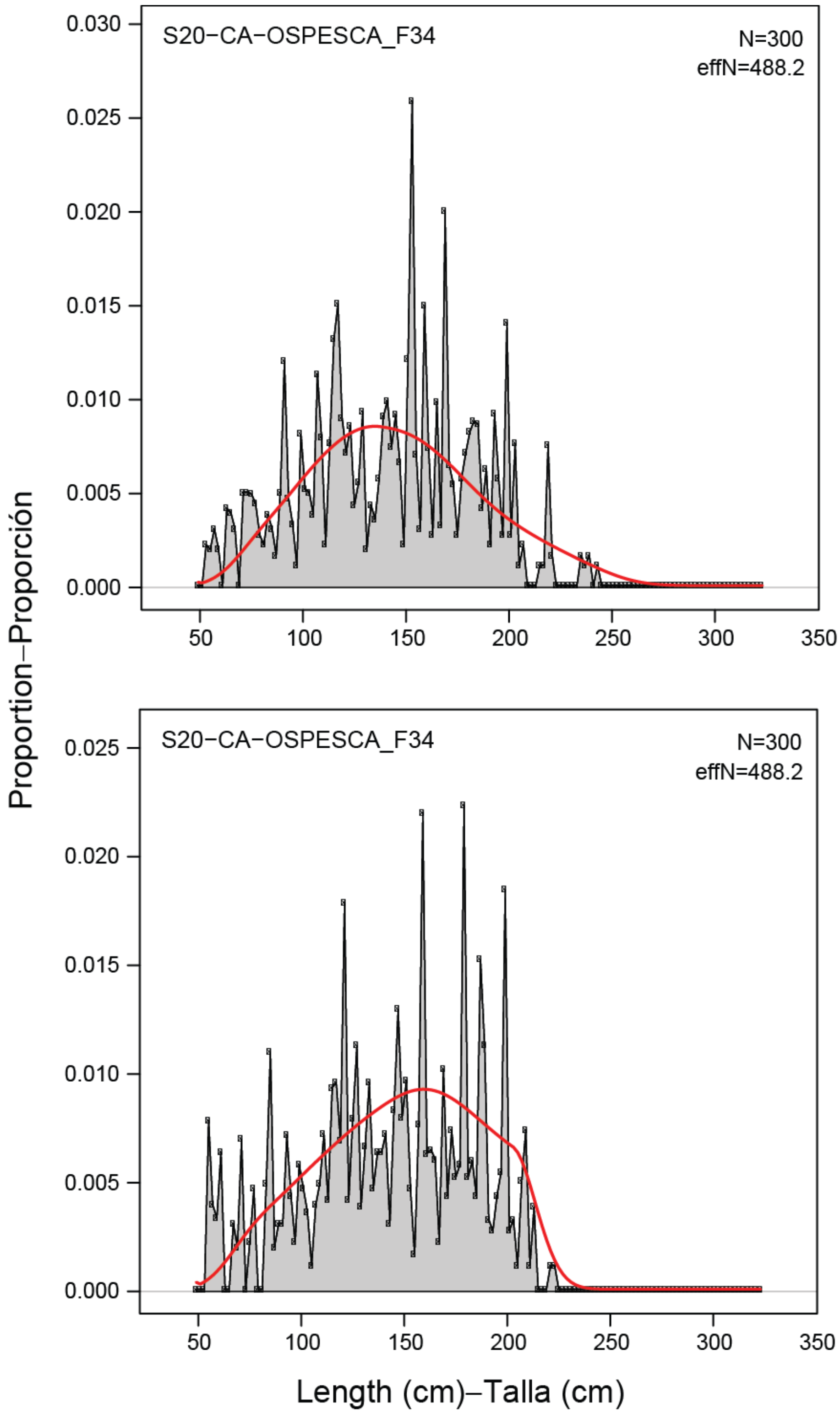

FIGURE 12. Average fit to the silky shark length-composition data for females (top) and males (bottom) for Central American artisanal fisheries. See Table 1 for descriptions of fisheries.

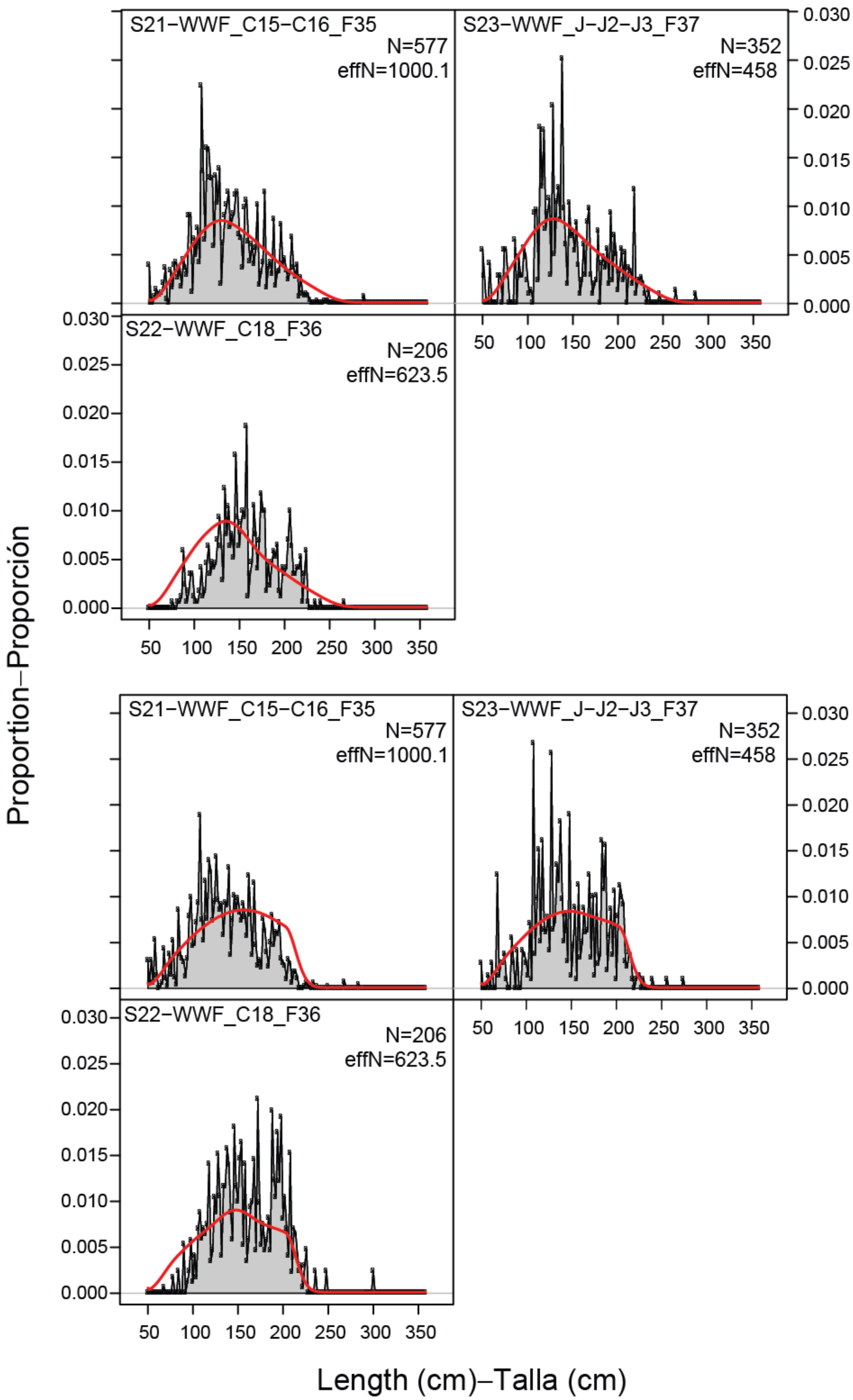

FIGURE 13. Average fit to the silky shark length-composition data, females and males combined, for Central American artisanal fisheries. See Table 1 for descriptions of fisheries.

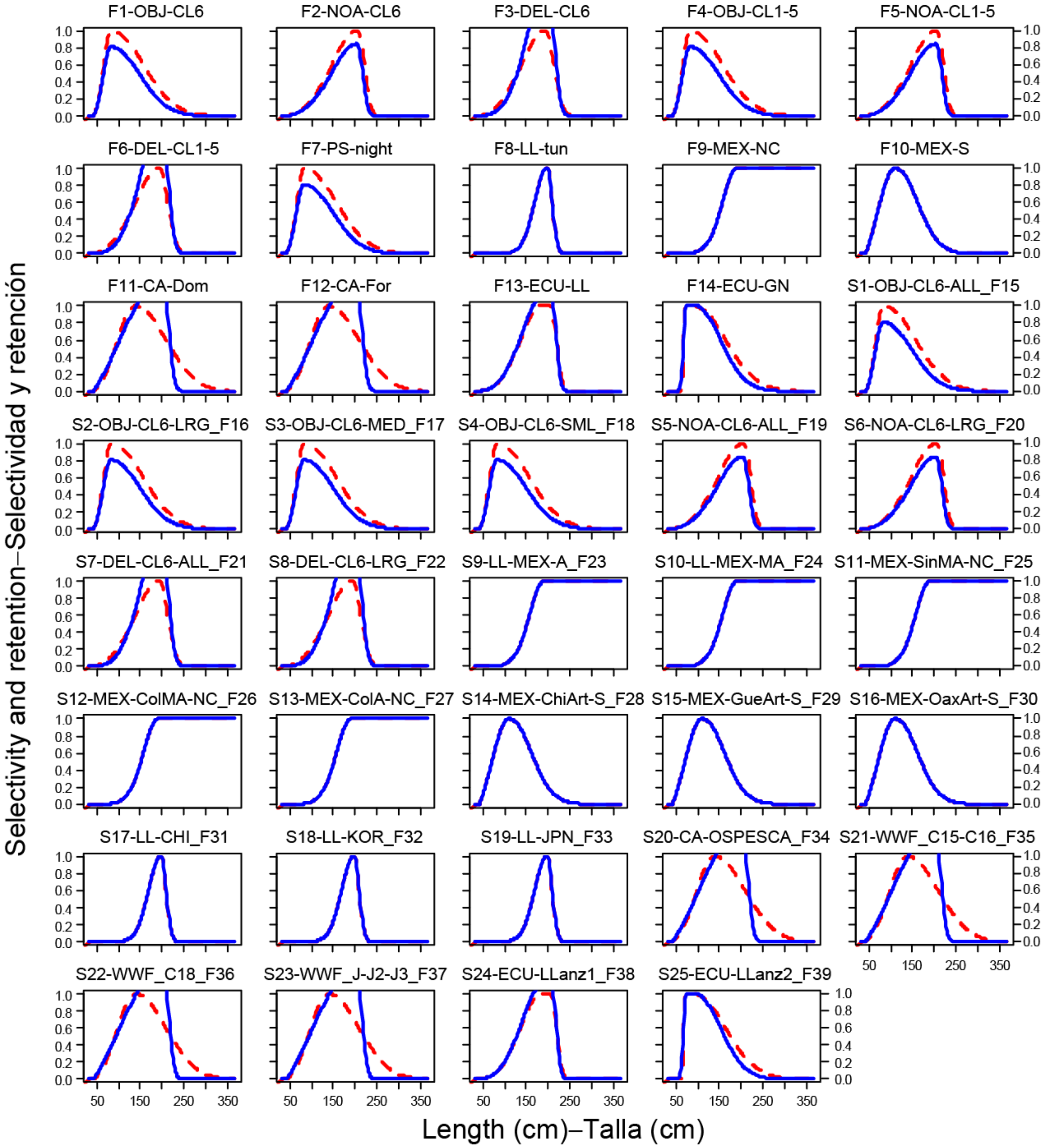

FIGURE 14. Estimated selectivity curves for different fisheries. Selectivities are estimated by sex when length-composition data are available for females (dashed lines) and males (solid lines) separately. See Table 1 for descriptions of fisheries.

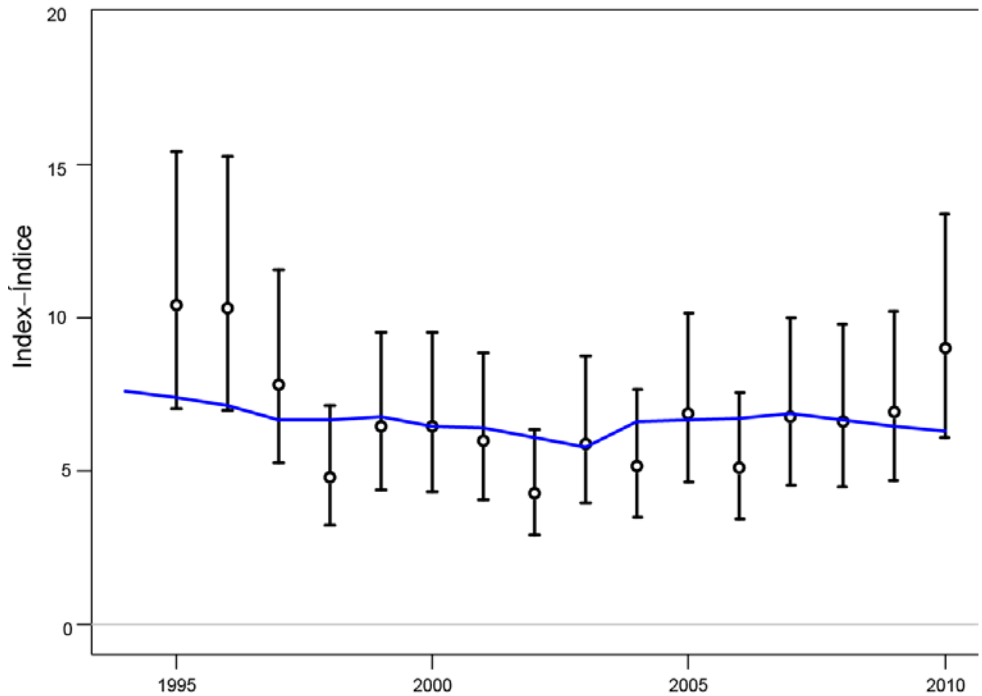

FIGURE 15. Base case model fit to the CPUE-OBJ index of abundance for the northern silky shark.

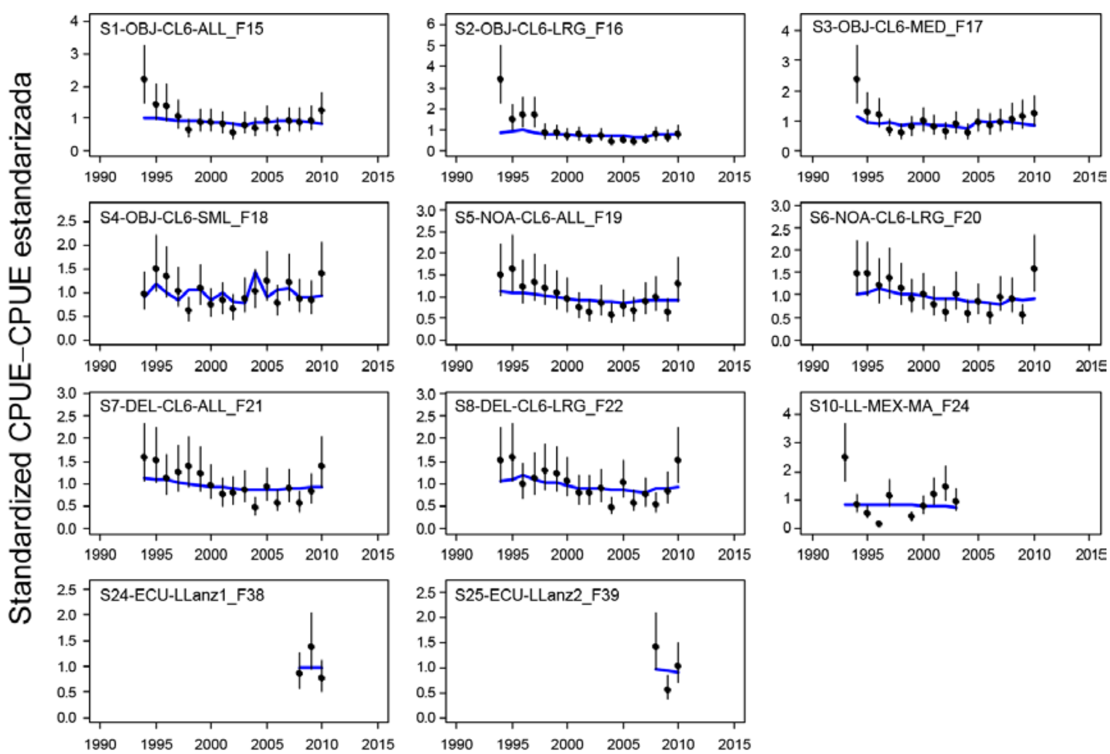

FIGURE 16. Model fit to other indices of abundance. Although the model fits only to the CPUE-OBJ index (S1), an evaluation can be made of how well the model predictions correspond with these other indices.

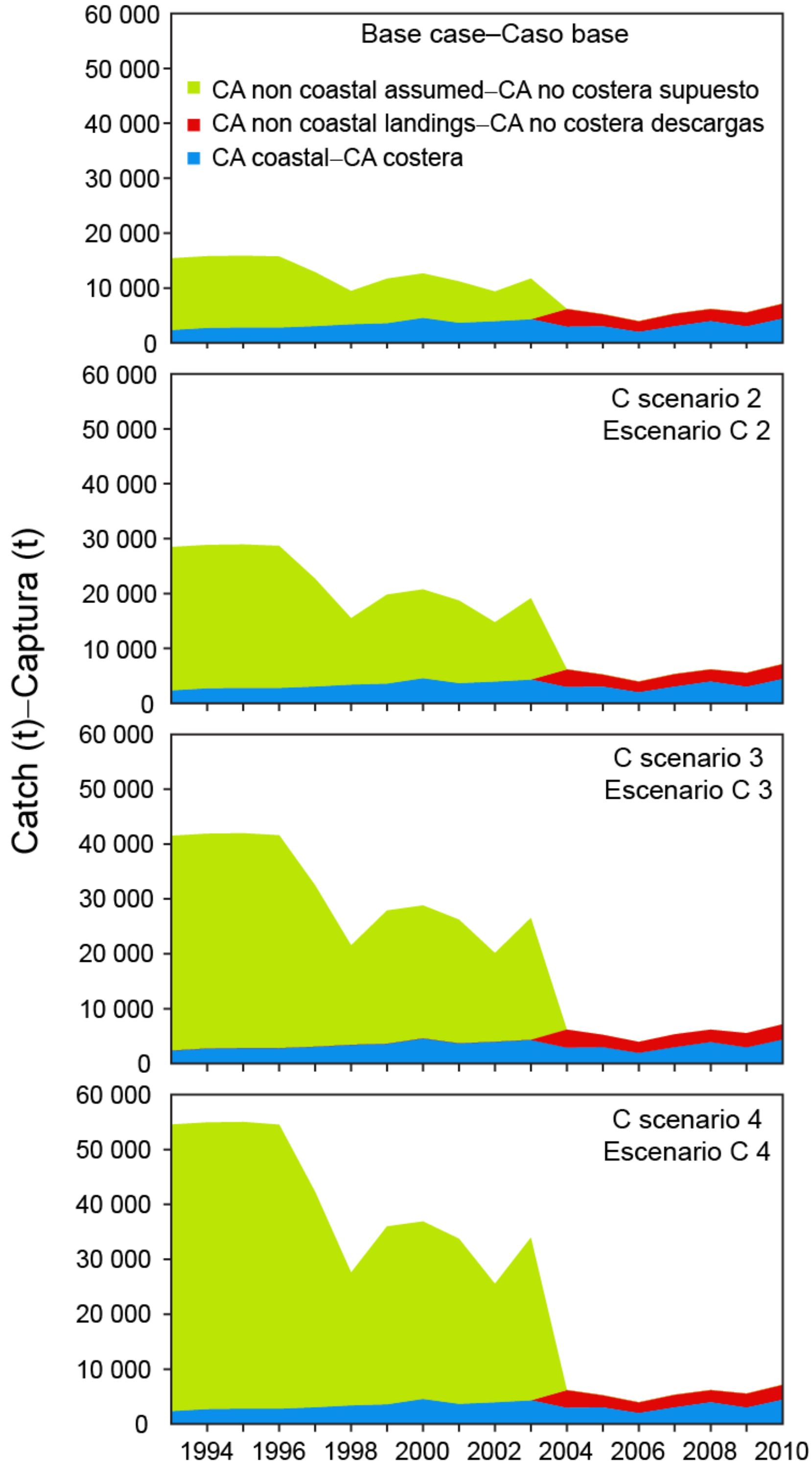

FIGURE 17. Hypothetical scenarios assuming different levels for the pre-2004 catch (C scenarios) by the Central American non-coastal fleet. Some of these scenarios (for example scenarios 3 and 4) are extreme, and were used only to investigate the effect of strong catch perturbations on model performance.

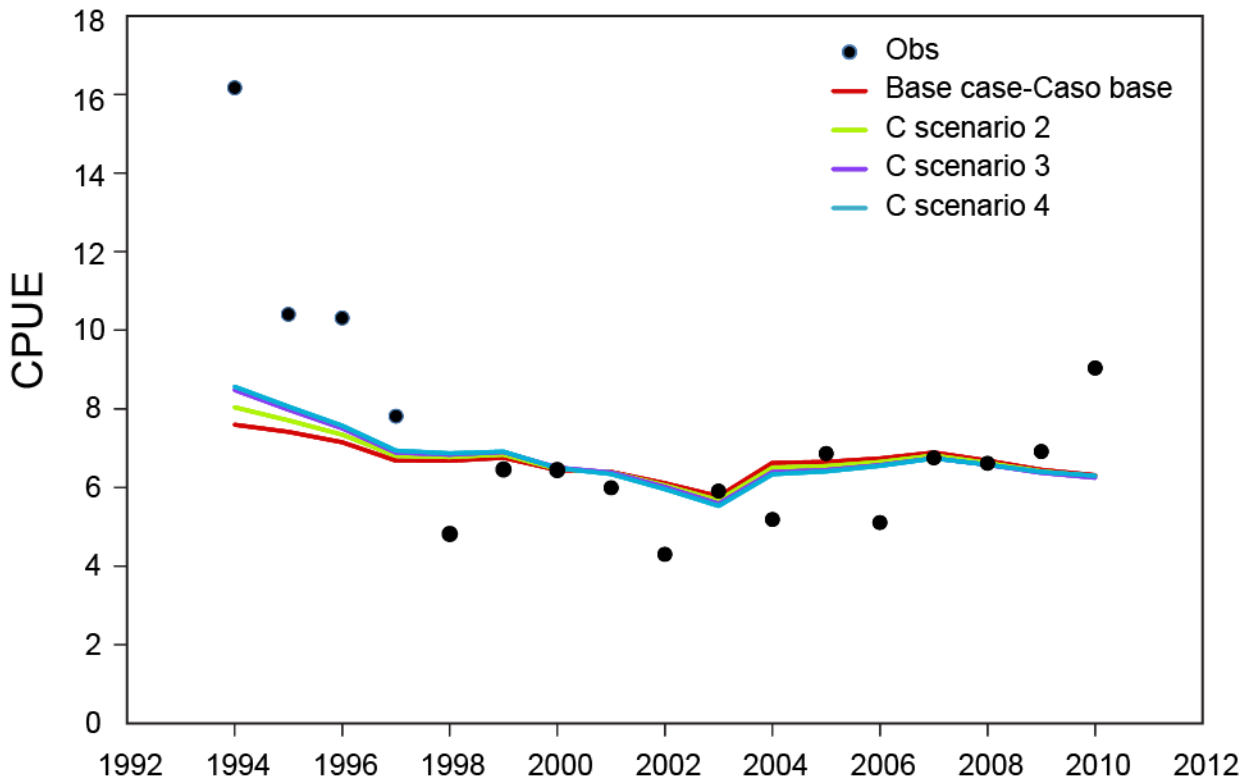

FIGURE 18. Model fits to the CPUE-OBJ index for the various scenarios, assuming different levels for the pre-2004 catches (C scenarios) by the Central American non-coastal fleet (Figure 17).

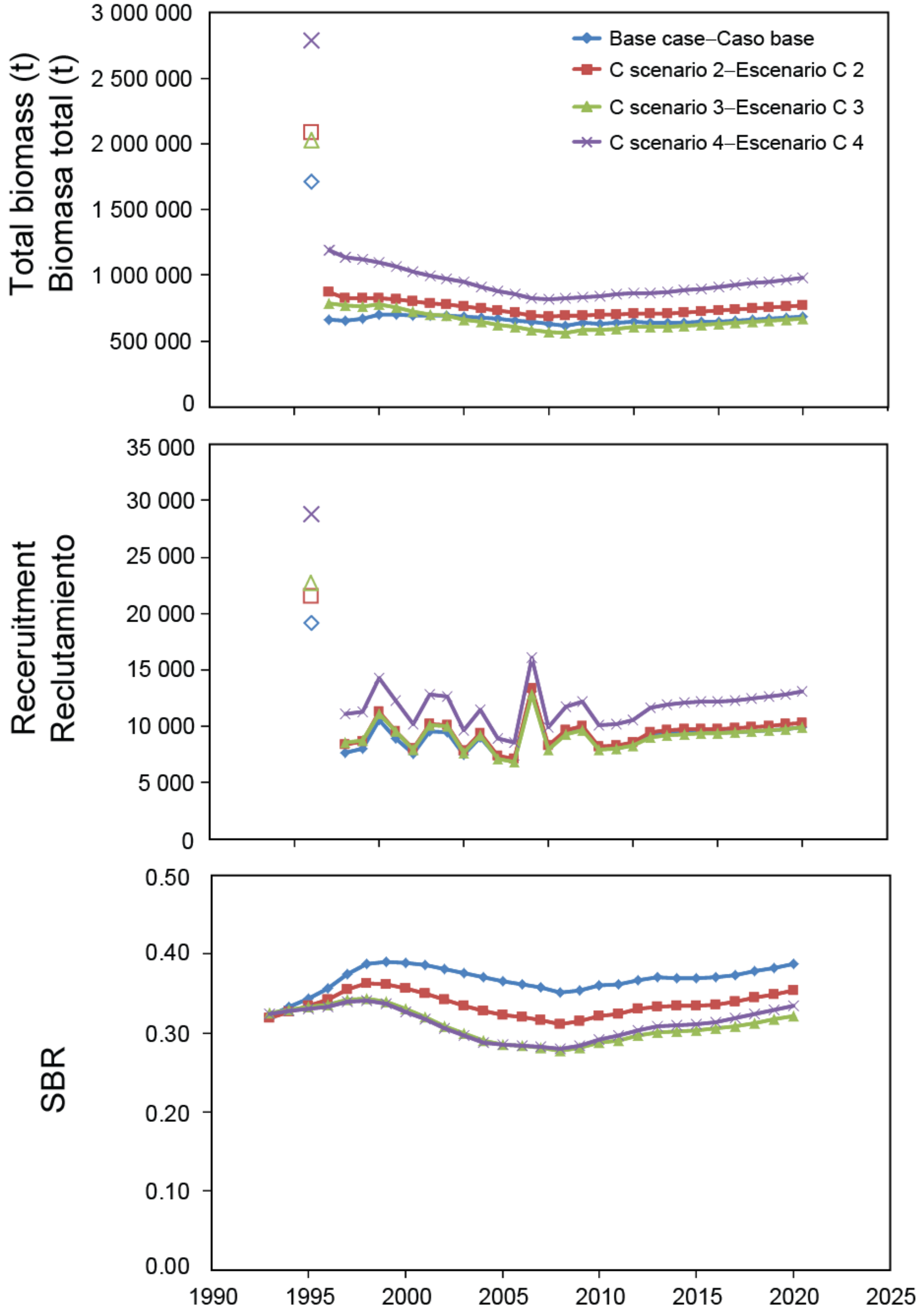

FIGURE 19. Time series of total biomass, recruitment and spawning biomass ratio for the base case and hypothetical scenarios assuming different levels for the pre-2004 catch (C scenarios) for the Central American non-coastal fleet (Figure 17). The time series include population projections over a 10-year period, assuming average fishing mortality of the most recent 3 years in the assessment (2008-2010).

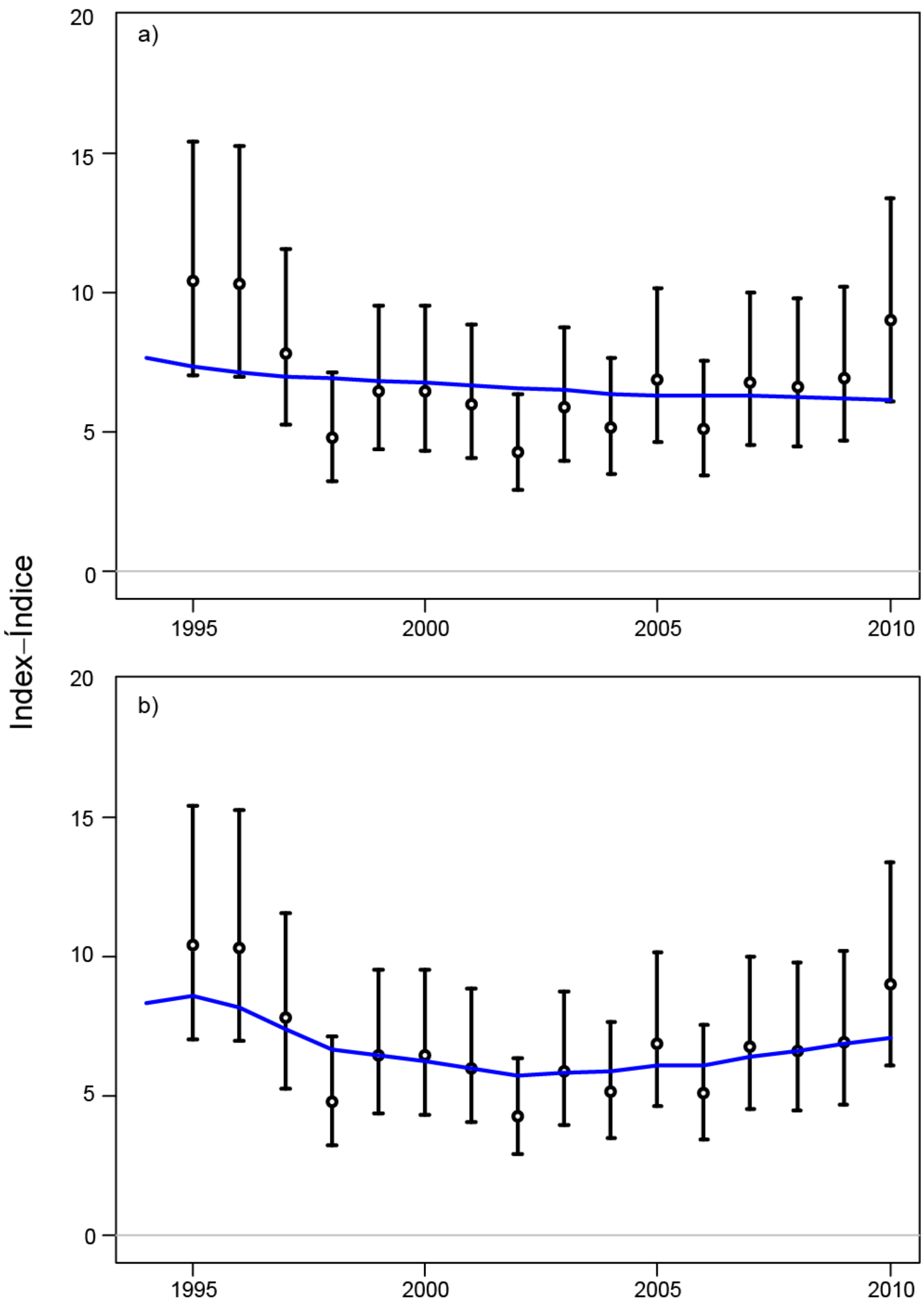

FIGURE 20. a) Age-structured production model (ASPM) diagnostic, b) ASPM runs allowing for recruitment deviations while still not fitting to the size-composition data.

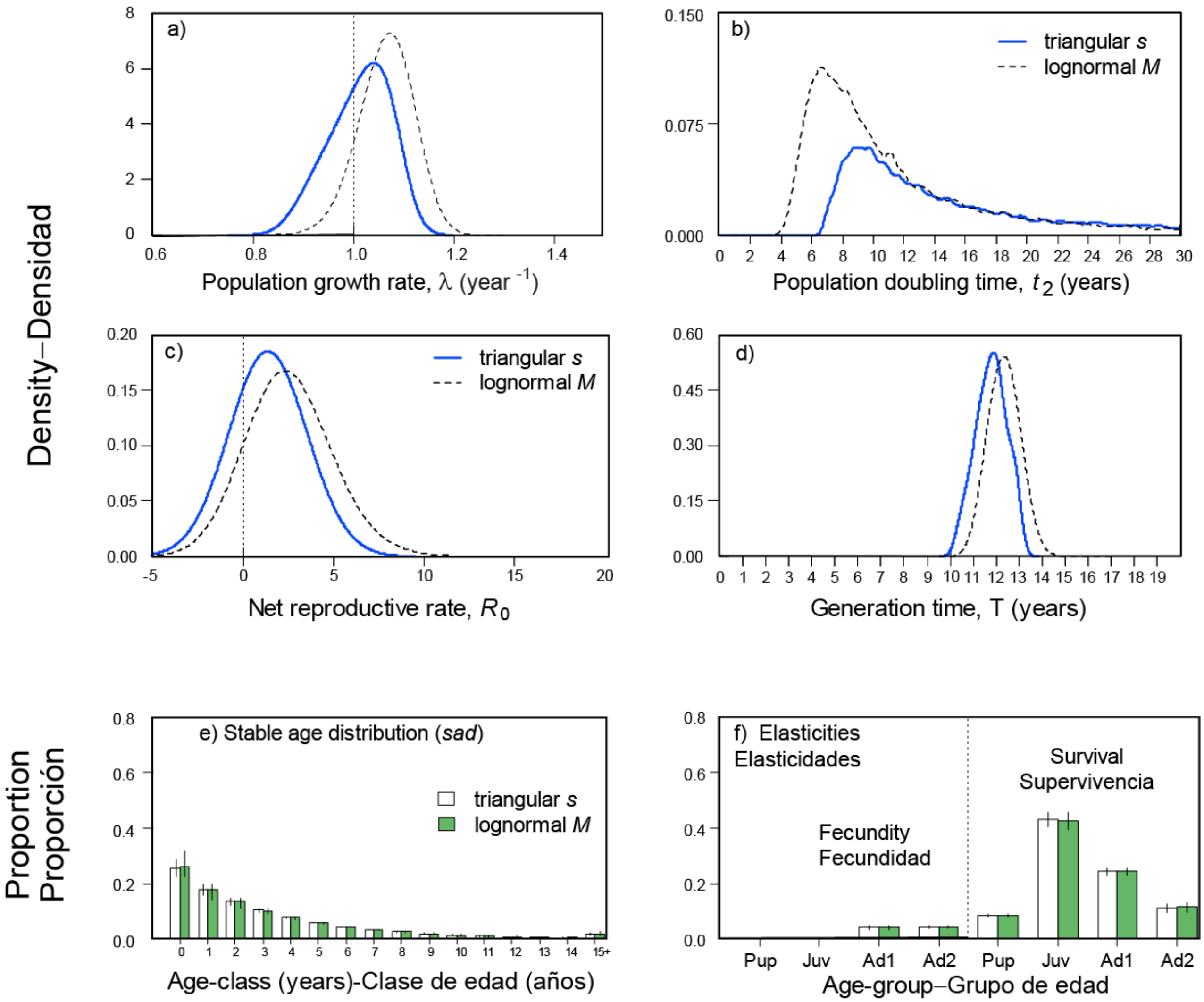

FIGURE 21. Statistical distributions of demographic parameters for an unfished silky shark population: (*a*) finite rate of population increase, λ; (*b*) doubling time, t_2; (*c*) net reproductive rate, R_0; and (*d*) mean generation time, *T*. (*e*) stable age distribution, *sad*; (*f*) elasticities (of fecundity and survival) for aggregated age-groups (pups – 0 years; Juv – juveniles, 1–5 years; Ad1 – small adults, 6–9 years; Ad2 – large adults, 10+ years). The statistical distributions are generated from Monte Carlo simulations assuming probability distribution functions (pdf) for silky shark life-history parameters (triangular pdf on survival and lognormal pdf on *M*).

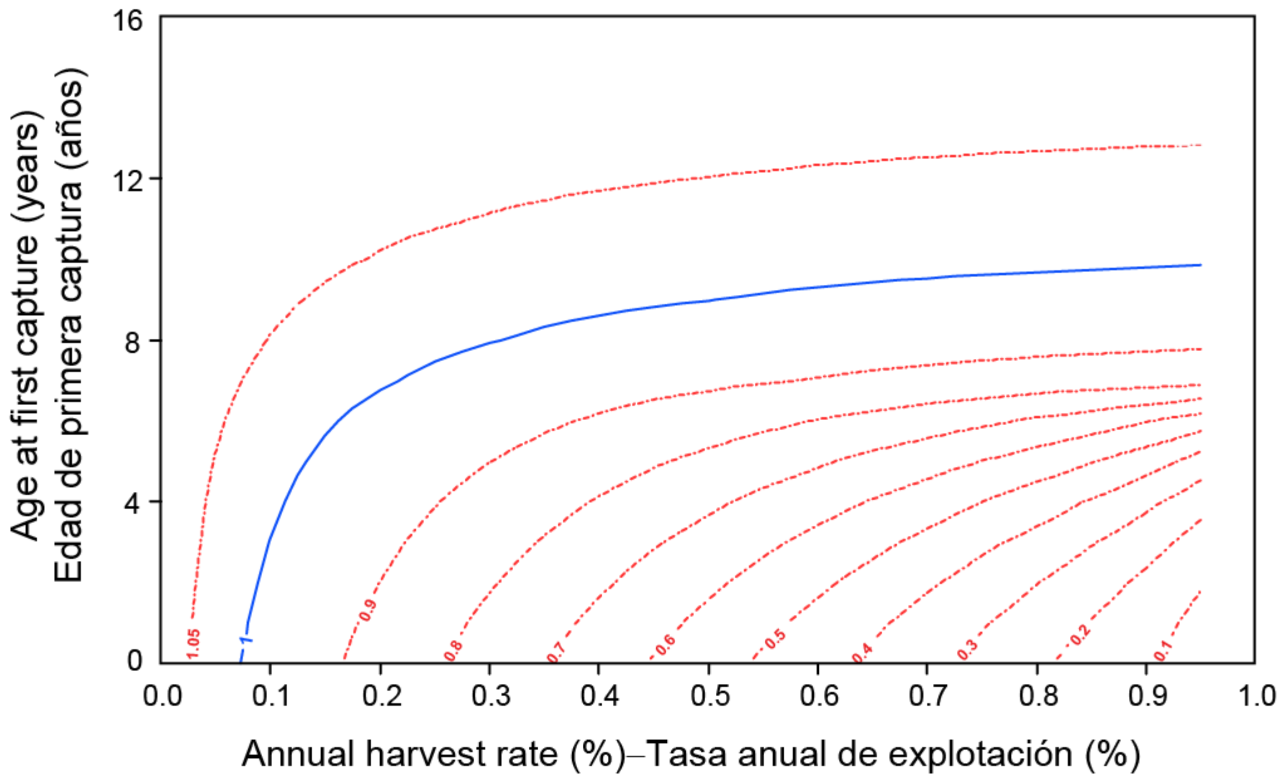

FIGURE 22. Isoclines for the average response in the silky shark population growth rate (λ) to different harvest rates (u) starting at different ages-at-first-capture (t_c).The solid line indicates a stable population (λ=1). Values above and below this line represent population growth (λ>1) and decline (λ<1), respectively.

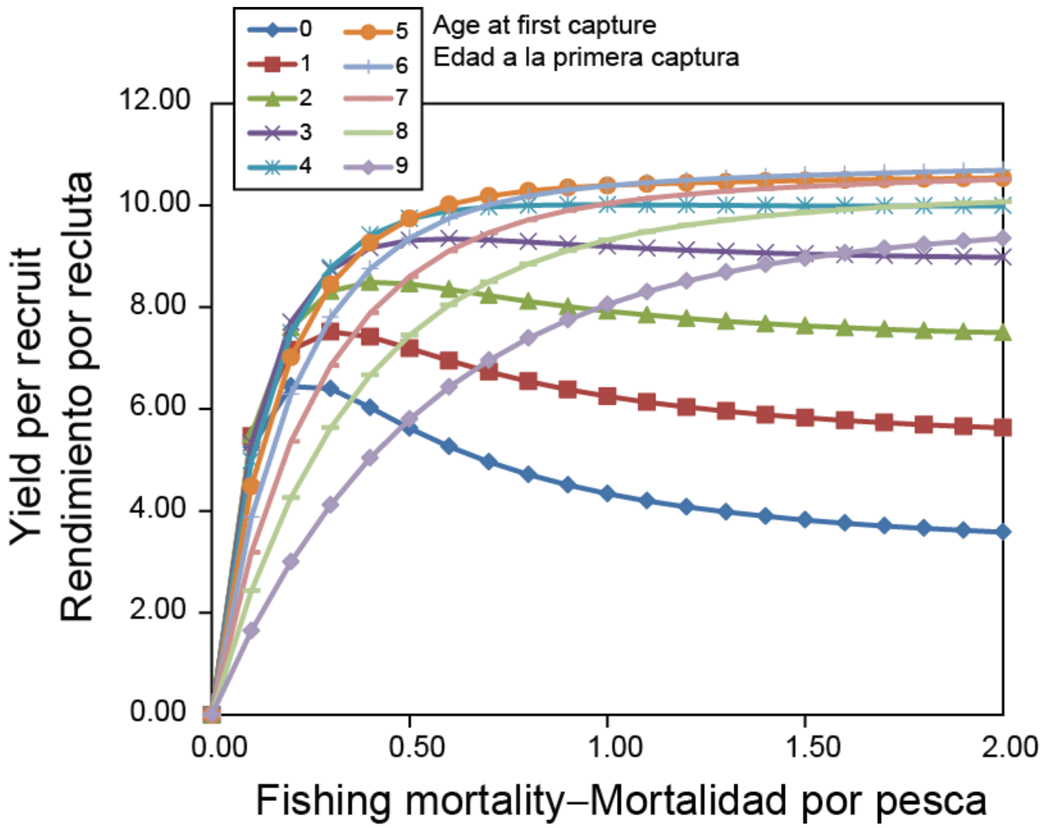

FIGURE 23. Yield-per-recruit analysis (YPR) for silky sharks in the EPO.