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CHANGES IN LONGLINE SIZE-FREQUENCY DATA AND THEIR EFFECTS ON THE STOCK ASSESSMENT MODELS FOR YELLOWFIN AND BIGEYE TUNAS

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ABSTRACT

Integrated statistical age-structured stock assessment models are used to assess the stocks of yellowfin and bigeye tuna in the eastern Pacific Ocean (EPO). Of the many pieces of information that the models require, length-frequency data for the longline fleets are among the most essential. For both species, the main indices of abundance are the standardized CPUE of the longline fleets. The length-frequency data indicate the sizes selected by the longline fisheries. Since there are no age-frequency data, the length-frequencies, via a growth curve, inform the model about the ages that comprise the relative abundance indices. In addition, for bigeye tuna, the longline fisheries were the main fisheries until the mid-1990s, when the purse-seine fisheries on fish-aggregating devices (FADs) commenced. In recent years, about a third of the bigeye tuna catches is taken by longliners. The IATTC has traditionally used the length-frequency data for the Japanese fleet to represent the longline fleets in the models. A pattern was evident in the length-frequency data, mainly for bigeye tuna, which consisted of smaller fish being caught prior to 1990 and larger fish thereafter. This pattern resulted in positive residuals for smaller fish before 1990 and negative residuals afterwards. Japan and the IATTC staff collaborated to investigate the possible causes of this pattern. The conclusion was that it appeared to be caused by a combination of converting the raw gilled-and-gutted weight data to fork length and complementing the length-frequency data for the commercial fleets with observations taken from training vessels[1]. Subsequently, Japan submitted the unconverted data by vessel type (commercial and training) to the IATTC. The data are available now as originally measured, *i.e.* as fork length or gilled-and-gutted weight. In this paper we explore the best way to incorporate the new size-frequency data into the stock assessment models for

[1] Vessels belonging to the Japanese prefectures that are used for teaching fisheries and training vessel crews (Okamoto 2014).

yellowfin and bigeye in the EPO. The analysis does not include the most recent data or a reevaluation of the composition data weighting. Therefore, the results should not be used for management advice.

1. INTRODUCTION

The stock assessments of yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna in the eastern Pacific Ocean (EPO) are undertaken using integrated statistical age-structured stock assessment models (Stock Synthesis Version 3.23b (SS3); Methot and Wetzel 2013). The models aggregate in a unified framework a substantial amount of information, including data on retained catches, discards, indices of abundance, and the size compositions of the catches of the various fisheries. In addition, the models require assumptions about processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure. Both models use longline catches per unit of effort (CPUEs) as the main indices of abundance. One of the key pieces of information used in both models is the size-frequency data of the longline fleets. These data inform the model about the sizes that are selected by the longline fleet, and therefore the ages of tuna to which the CPUE indices relate. The size-frequency also informs recruitment variability. In addition, the longline fisheries have historically been the main fisheries for bigeye, and currently still account for one-third of the total removals from the stock.

The IATTC has traditionally used the size-frequency data for the Japanese fleet to represent the longline fleets in the models. Usually, Japan provides the size data as length-frequencies. A pattern was evident in these data, mainly for bigeye but to some extent for yellowfin, which consisted of smaller fish being caught prior to 1990 and larger fish after (Aires-da-Silva and Maunder 2011). This pattern resulted in positive residuals (larger frequencies than were expected by the model) for smaller fish prior to 1990 and negative thereafter (smaller frequencies than expected by the model, Figure 1, Aires-da-Silva *et al.* 2010). As the premise for the stock assessment model is that the data are correct, the model was changed to accommodate this pattern. In the bigeye assessment model, where the pattern was more evident, two selectivity blocks were established for the longline fisheries, with the split around 1990. In consequence, the standardized CPUE indices for the longline fleets were also split, forming an early and a late series, with different catchabilities. Asymptotic selectivities were assumed for two fisheries: late longline Central (1993-2014) and late longline South (1993-2014). For the rest of the longline fisheries a more flexible selectivity function was assumed, which can take forms that range from domed to asymptotic. However, concern over the residual pattern in the longline composition data remained, and without a clear understanding of the cause. A shift of the estimated recruitment pattern around 1990 was also evident in the model, indicating that there was some form of misspecification in the modelling of the length-frequency data. The length-frequency data for all fisheries were substantially downweighted in the bigeye assessment, which mitigated the recruitment shift pattern and the residual pattern.

Japan and the IATTC staff collaborated to investigate the possible causes of this pattern. The conclusion of the study was that differences in size composition between the periods pre- and post-1990 are unlikely to be real, but may be an artifact of the predominant methodology for size sampling and reporting (Satoh *et al.* 2016). In years prior to 1990, the main raw size data for bigeye, and to a lesser extent for yellowfin, obtained from the Japanese commercial fleet was gilled-and-gutted weight, but after 1990 it was fork length. The gilled-and-gutted weight data were converted to fork length before being submitted to the IATTC. For most years, length data were also obtained from training vessels, which might have a different selectivity than commercial vessels. In some years the sole data available were from training vessels. The data submitted to IATTC were a combination of those three data types.

Following the conclusions by Satoh *et al.* (2016), in February 2016 Japan submitted the raw data to the IATTC. All the size-frequency data from Japan for 1967 to 2014 were replaced in the IATTC database by the new dataset, which included information on vessel type (commercial or training) and measurement type (length or weight). The data for 2014 were added, but not used for this research, to allow comparisons of the results with the most recent base case models (Aires-da-Silva and Maunder 2015; Minte-Vera *et al.* 2015), when no length-frequency information for longliners in 2014 was available. In this document, we explore the best way to incorporate the new size-frequency data into the stock assessment models for yellowfin and bigeye in the EPO. The analysis does not include the most recent data nor a reevaluation of the weighting of the composition data, which is the essential next step. Therefore, the results should not be used for management advice.

2. METHODS

The base case models for yellowfin and bigeye from the 2015 stock assessments (Aires-da-Silva and Maunder 2015; Minte-Vera *et al.* 2015) were used for this investigation. Several runs were performed with different combinations of length-composition data and selectivity assumptions (Table 1). When the data were assumed to have a different selectivity than the commercial length-frequency data, they were entered in the models as a "survey", the term used in SS3 for a fishery with no catch associated with it, which allows flexibility in the modelling of these data. For bigeye, the assumption of time blocks for selectivity and catchability was explored, as in the base case. The new data were weighted by multiplying the sample sizes by the the same weighting factor used in the stock assessment models for 2015.

There are no conversion factors for gilled-and-gutted weight specific to the EPO at this time. We used the conversion factors developed by Langley *et al.* (2006) for the entire Pacific:

$$\text{Bigeye: } w = 1.3264 * GGw^{0.969} \text{ (Equation 1)}$$

$$\text{Yellowfin: } w = 1.2988 * GGw^{0.968} \text{ (Equation 2)}$$

where w is whole weight, in kilograms, and GGw is the weight of the gilled-and-gutted fish in the ultra-low-temperature (ULT) freezer vessels. Processing the fish prior to ULT freezing included removing the operculum and the tail, which were retained when the fish were merely chilled (Langley *et al.* 2006). Thus, different conversion factors are needed for chilled fish and fish frozen at ULT. ULT freezer vessels were introduced in the Japanese fleet in 1966, and by 1980 all Japanese distant-water vessels were UTL vessels (Langley *et al.* 2006). Since there is no information in the data about what processing was performed, and most of the data are from the period after 1980, we assumed the UTL conversion for the whole period[2]. Three datasets were used to derive those conversion factors, one of them from the tropical EPO, which included about 10% of the data. The fits are dominated by data from the Western Pacific obtained by Australian observers aboard Japanese vessels operating within the Australian Exclusive Economic Zone (EEZ).

In order to avoid "sawtooth" distributions (large peaks followed by troughs at regular size intervals) in the converted data, caused by applying the conversion to low-resolution data (Langley *et al.* 2006), we divided each 1-kg raw gilled-and-gutted weight class into 10 equally-spaced intervals. The conversion factor was then applied to each interval, and 10% of the frequency of the original weight class was added to the converted weight class.

In Run 1, the gilled-and-gutted weight was also transformed into length, using the conversion table described by Satoh *et al.* (2016).

In the SS3 models, a size-transition matrix is produced to compute the expected whole weight from the

[2] Other conversion factors available in the literature are based on Japanese research in the early 1970s and earlier (Morita 1973; Kimimura and Honma 1959; Kume and Shiohama 1964). In that period most of the vessels chilled the fish, therefore those conversion factors are not appropriate for use here.

length-at-age model and the variability of length-at-age and the length-weight relationship. The length-weight relationship used in the stock assessment model for bigeye (Aires-da-Silva and Maunder 2010) is from Nakamura and Uchiyama (1966):

$$w = 3.661 \text{ X } 10^{-5}\, l^{2.90182}$$

where w = whole weight in kilograms, and l = fork length in centimeters.

The length-weight relationship used in the stock assessment model for yellowfin (Aires-da-Silva and Maunder 2012) is from Wild (1986):

$$w = 1.387 \text{ X } 10^{-5}\, l^{3.086}$$

The weight frequencies are included in the SS3 models as "generalized size data". Uneven intervals were used to meet the assumption of the SS3 models that no data size interval in the generalized size frequencies consist of more than one population size interval. In both the yellowfin and bigeye stock assessment models, the population size intervals are defined as 2-cm fork length. For larger fish the weight intervals need to be greater than 1 kg to include only one population length interval in SS3. The largest size class was assumed to be to be an accumulator size class (which includes all fish larger than or equal to that size).

Both length and weight information are aggregated into quarters. The sizes were not corrected for any growth that may happen within this time interval.

3. RESULTS AND DISCUSSION

For most years of the assessment period (1975-2014), the newly-submitted Japanese size data incorporated into the IATTC database simply replaced existing data, but with the addition of information on vessel and mesurement types; the exception was the 2000-2006 period, when additional data for both yellowfin and bigeye were included (Figure 2). Most of the data for both the assessment period and area (EPO) are now available at a finer resolution (5^{o} latitude by 10^{o} longitude) than in in the past (Figure 3). The longest series are those from training vessels: they include samples for both species for the whole period, but tend to dominate in the first 10 years and are more numerous for bigeye. Weight - frequency data are available for 1975-1999, but they tend to dominate in the 1980s. In 1986 fork length measurements started to be collected on commercial vessels, and these data dominate from the early 1990s to the present. The fishermen have been asked to measure fish on board since the mid-1970s; initially weight data were requested, but by the mid-1990s the requirement changed to measuring length (Okamoto 2014). For bigeye, all length measurements available for the EPO from commercial vessels were taken aboard the vessels, using calipers, while the weight data were obtained either on board or by port sampling (Okamoto 2014). There is no information in the IATTC database to indicate whether the weight data came from on-board or port sampling; however, Okamoto (2014) reported that since 1987, when information on sampling location was first recorded, the length data for bigeye obtained aboard commercial vessels predominate in the EPO, while most of the size data available for the Western and Central Pacific Ocean consist of weights measured in port. Also, there is substantial weight-frequency information available for the Western and Central Pacific Ocean, going back to the 1960s. Mainly for these two reasons, preference is given to the use of weight-frequency data in the stock assessments of yellowfin and bigeye for the Western and Central Pacific Fisheries Commission (WCPFC) (Sam McKechnie pers. comm.; Harley *et al.* 2014; McKechnie 2014).

Runs 1 (GGw converted to whole weight) and 2 (GGw converted to length) were designed to mimic the base case stock assessment models used in 2015 ("SAC6 base case"), in which all available new information was included in the fit, assuming the same selectivitity regardless of the type of size data. For both species, transforming the gilled-and-gutted weight to length or to whole weight made no difference to the estimates of relative biomass or management quantities (Figure 4, Table 2). For yellowfin, the biomass trajectory for Runs 1 and 2 was the same as in the SAC6 base case; for bigeye, the relative biomass was larger and the management quantities were more optimistic than in the SAC6 base case (Figure 4, Table 2). The length-frequency data (mainly for the late longline South fishery) have been shown in the past to have a large impact on the abundance estimate for bigeye (Aires-da-Silva and Maunder 2014), and adequate weighting needs to applied to these data (Francis 2011). We applied the weighting used in the SAC6 base case, but this may not be appropriate because, by fitting to all the new data types as separate series, the amount of data has increased relative to the SAC6 base case, where the data were combined in one series. The differences between the two species in the impact of the new data on the estimates of relative biomass trajectories may be due to two reasons: (i) the longline fisheries account for about one-third of the total removals of bigeye, but only about 1% of yellowfin; and (ii) the length-composition data for bigeye were greatly downweighted due to concerns about the reliability of the data indicated by the residual pattern.

For yellowfin, the model fits to the size-composition data indicate that not all data types are consistent with each other for the main (Southern) longline fishery, but they are for the Northern longline fishery. For runs 1 and 2 (Figure 5), the training-vessel length frequencies and the commercial length frequencies for the Northern fishery have similar distributions; both include large fish, and in general the model fits them well. The model is also able to fit well the gilled-and-gutted weight frequencies converted into either whole weight or length for the Northern fishery. For the Southern longline fishery, the length-frequencies for the training vessels are on average lower than predicted by the model, while the length-frequencies for the commercial vessels are slightly higher than predicted by the model. The gilled-and-gutted weight data, converted to either whole weight (Run 1) or fork length (Run 2), have lower frequencies of larger fish, and higher frequencies of smaller fish, than expected, indicating that either the gilled-and-gutted weight data or the conversion factor used are not consistent with the length data. The Southern longline fishery is the main fishery for longline removals of yellowfin; it is also a key component of the assessment, since the standardized CPUE from this fishery is assumed to be the main index of abundance. The selectivity for this fishery is asymptotic, while for the Northern fishery it is dome-shaped. Spatial differences in the length-weight relationship, as well as the different selectivity assumption, may contribute to the differences in the fits. When different selectivity functions are assumed for each data and vessel type (Run 3, Figure 5b), the fits improve for the weight-frequency data and training-vessel length-frequency data, as expected, but degrade for the commercial-vessel length-frequency data.

The results are similar for Runs 1 and 2 for bigeye: the length frequencies from training vessels and commercial vessels are in general smaller and larger, respectively, than those predicted by the model, and the weight and length data do not seem to be consistent with each other. Figure 6a shows the total observed size-frequency data and model predictions for the Southern longline fishery; similar results were obtained for the Central longline fishery (Figure 6b)). In addition, changes in the size distributions within data types between the early (1975-1992) and late (1993-2014) periods were also observed, but not all were in the same direction (Figures 6a and b). The gilled-and-gutted weight converted into either fork length or weight shows higher frequencies for larger sizes in the early period than in the late one, while the commercial length-frequency data show the opposite: larger sizes dominate in the later period. For training vessels, the length-frequencies show a different pattern between early and late periods, with a marked dominance of small fish in the later period. When different selectivity functions were assumed for each type of data (Run 3), the expected improvement in fit happened for the weight-frequency data and the training vessel length-frequency data (Figure 6c), but there was also a considerable improvement in fit for the length-frequency data of the commercial vessels, which are now less influenced by the other size-frequency data.

For both bigeye and yellowfin, there are clear residual patterns that depend on the data type (Figure 7a and b). The fits from Run 4, in which all size-frequency data were assumed to represent the commercial longline fleet well, showed a tendency for the commercial-vessel length frequencies to have positive residuals over time for the larger length classes. For the weight frequencies the tendency is the opposite: the positive residuals are in the smaller weight classes. The residual pattern for the training-vessel data depends on the species: for bigeye, but not for yellowfin, the positive residuals tend to be concentrated in the smaller length classes.

For yellowfin, the management quantities were more optimistic when the weight-frequency data were excluded or when their effect was minimized by assuming a different selectivity function for them (Runs 3, 5-7, Table 2). The biomass trajectories are very similar for all runs (Figure 8). The largest difference was observed for the historical period (from 1975 to about 2000) for Runs 3 and 5-7, which either excluded the weight-frequency data or minimized their effects.

For bigeye, the largest difference in management quantities was obtained when the assumption of two time periods for each longline series was replaced by assuming one series for the whole time period with the same catchability and selectivity (Runs 3-7, Figure 8). This new assumption is justified by the fact that the residual pattern that motivated the inclusion of the time blocks was likely an artifact of the mixture of incompatible data types used to compose the longline length frequencies that were used in the stock assessment model.

4. CONCLUSIONS AND RECOMMENDATIONS

The provision of raw size-frequency data for the Japanese longline fleets, with information on the type of vessel of origin, represents a great advance towards improving the stock assessments of yellowfin and bigeye in the EPO. The striking residual patterns for bigeye in the former stock assessment models, which consisted of positive residuals for small length classes in the early years and for larger classes in the later years, are very likely to have resulted from the mixture of data types and how the proportion of each type changed over time.

The gilled-and-gutted weight data require converting in order to be used in the stock assessment, but any conversion is likely to introduce further bias and uncertainty. For the EPO in particular, the converted weight-frequency data do not seem compatible with the length-frequency data for the same fisheries and species. The average weight from the weight-frequency data tends to be lower than expected by the models that also incorporate length-frequency data and assume the same selectivity for both data types. We recommend that the weight-frequency data be excluded from the base case models for both bigeye and yellowfin. A sensitivity analysis can be done with these data included. Preferably, a conversion factor specific for the EPO should be developed.

The training vessel length-frequency data do not represent the commercial fleet well, and should not be used for that purpose. However, they may contain information that could be of interest. Since the training-vessel length frequencies are on average smaller those from commercial vessels, it may have information that can be used for estimating temporal variation in recruitment, for example. We recommend that the training-vessel length-frequency data be included in the base-case models; the data will be included in the model as coming from a “survey” (in SS3 terminology), in order to have flexibility in modeling its selectivity as a separate function from the selectivities of other fisheries in the model. The selectivity function for these data should be one that can assume shapes from domed to asymptotic. By assuming that the data comes from a survey, no catches will be associated with it. The weighting of the training vessel length-frequency data should also be evaluated to avoid imbalance of excess length-frequency data in relation to CPUE data.

For bigeye, we recommend that the time blocks for the longline fleets be removed and the CPUE series be treated as one continuous series from 1975 to the present, as the temporal residual pattern that motivated the inclusion of the blocks is likely artificial. Now that the most likely cause of the residual pattern in the longline length-frequency data has been identified, the weighting of these data in the bigeye assessment should be reevaluated.

In conclusion, we recommend that the size-frequency data for the longline fleets be entered in the stock assessment models for bigeye and yellowfin as follows:

1. **Base-case model**: length-frequency of the commercial fleet, and length-frequency of the training vessel fleet treated as a survey with its own selectivity function; no time blocks on selectivity or catchability of the standardized CPUE longline series.
2. **Sensitivity model**: as for the base-case model, plus inclusion of the processed weight converted into whole weight using equations 1 or 2 . Preferably, a conversion factor specific for the EPO should be developed.
3. **Data weighting:** the weighting for the length- and weight-frequency data should be reevaluated before adopting a model to be used for management advice.

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TABLE 1. Model runs performed to assess the best way to incorporate the size-frequency data from the Japanese longline fleet into the stock assessments of bigeye and yellowfin tunas. LLc: commercial longline vessels, LLt: longline training vessels, GGw: gilled-and-gutted weight.
TABLA 1. Ejecuciones del modelo realizadas para evaluar la mejor forma de incorporar los datos de frecuencia de talla de la flota palangrera japonesa en las evaluaciones de las poblaciones de los atunes patudo y aleta amarilla. LLc: buques palangreros comerciales, LLt: buques palangreros de aprendizaje, GGw: peso desagallado y eviscerado.

Run **Ejecución**	**Description** **Descripción**	**Additional changes for bigeye** **Cambios adicionales para patudo**
SAC 6 BC	Base case model for the 2015 stock assessments presented at the 6th Scientific Advisory Committee meeting (SAC 6) Modelo de caso base para las evaluaciones de 2015 presentadas en la 6ª reunión del Comité Científico Asesor (SAC 6)	
1	LLc (length + GGw converted to whole weight) + LLt (length) selectivity shared by all size-frequency data types LLc (talla + GGw convertido en peso entero) + LLt (talla) selectividad compartida por todos los tipos de datos de frecuencia de tamaño	Time blocks for selectivity and catchability Bloques de tiempo para selectividad y capturabilidad
2	LLc (length + GGw converted to length) + LLt (length) selectivity shared by all size-frequency data types LLc (talla + GGw convertido en talla) + LLt (talla) selectividad compartida por todos los tipos de datos de frecuencia de tamaño	Time blocks for selectivity and catchability Bloques de tiempo para selectividad y capturabilidad
3	As Run 1, each size-frequency data type with its own selectivity Igual que 1, cada tipo de dato de frecuencia de talla con su propia selectividad	No time blocks Sin bloques de tiempo
4	= 1 = 1	No time blocks Sin bloques de tiempo
5	As Run 4, no LLc weight Igual que 4, sin pesos de LLc	
6	As Run 5, LLt length with its own selectivity Igual que 5, talla de LLt con su propia selectividad	
7	As Run 6, no LLt length Igual que 6, sin tallas de LLt	

TABLE 2. MSY and related quantities for the base case for SAC 6 and for model runs performed to assess the best way to incorporate the size-frequency data from the Japanese longline fleet in the stock assessments of yellowfin and bigeye tunas, based on the average fishing mortality (*F*) for 2012-2014. The models do not include the most recent data, nor a reevaluation the weighting of the size-composition data and should not be used for management advice. 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 2015 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 2014.

TABLA 2. RMS y cantidades relacionadas para el caso base de SAC 6 y para las ejecuciones (*runs*) del modelo realizadas para evaluar la mejor forma de incorporar los datos de frecuencia de talla de la flota palangrera japonesa en las evaluaciones de los atunes aleta amarilla y patudo, basados en la mortalidad por pesca (*F*) media de 2012-2014. Los modelos no incluyen los datos más recientes, ni tampoco una reevaluación de la ponderación de los datos de composición por tamaño, y no deben ser utilizados para asesoramiento de ordenación. Se definen B_{recent} y B_{RMS} como la biomasa, en toneladas, de peces de 3+ trimestres de edad al principio del primer trimestre de 2015 y en RMS, respectivamente, y S_{recent} y S_{RMS} como índices de biomasa reproductora (por lo tanto, no se expresan en toneladas). C_{recent} es la captura total estimada de 2014.

Bigeye Patudo	**SAC 6 BC**	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**
MSY-RMS	113,730	115,284	115,274	104,258	99,693	101,064	104,028	103,002
B_{MSY}- B_{RMS}	433,396	442,264	442,085	379,012	355,466	364,295	377,664	373,257
S_{MSY}- S_{RMS}	108,502	111,119	111,058	92,998	86,599	89,165	92,614	91,462
B_{MSY}/B_0- B_{RMS}/B_0	0.25	0.24	0.24	0.26	0.25	0.25	0.26	0.26
S_{MSY}/S_0- S_{RMS}/S_0	0.21	0.2	0.2	0.21	0.2	0.2	0.21	0.21
C_{recent}/MSY- C_{recent}/RMS	0.87	0.85	0.85	0.95	0.99	0.98	0.95	0.96
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	1.03	1.13	1.13	0.88	0.85	0.89	0.87	0.86
S_{recent}/S_{MSY}- S_{recent}/S_{RMS}	1.06	1.15	1.15	0.9	0.85	0.9	0.89	0.88
F multiplier- Multiplicador de *F*	1.14	1.25	1.25	0.94	0.91	0.95	0.94	0.92
Yellowfin Aleta amarilla	**SAC 6 BC**	**Run 1 (= Run 4)**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**
MSY-RMS	275,258	274,909	274,728	284,147		279,161	282,820	281,444
B_{MSY}- B_{RMS}	368,336	368,824	368,627	381,732		374,174	380,219	376,924
S_{MSY}- S_{RMS}	3,469	3,478	3,492	3,553		3,495	3,550	3,523
B_{MSY}/B_0- B_{RMS}/B_0	0.32	0.32	0.32	0.31		0.31	0.31	0.32
S_{MSY}/S_0- S_{RMS}/S_0	0.27	0.27	0.27	0.26		0.26	0.26	0.26
C_{recent}/MSY- C_{recent}/RMS	0.86	0.86	0.86	0.84		0.85	0.84	0.85
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	1.12	1.10	1.10	1.17		1.14	1.16	1.16
S_{recent}/S_{MSY}- S_{recent}/S_{RMS}	0.99	0.98	0.97	1.09		1.04	1.07	1.06
F multiplier- Multiplicador de *F*	1.11	1.10	1.08	1.28		1.20	1.25	1.22

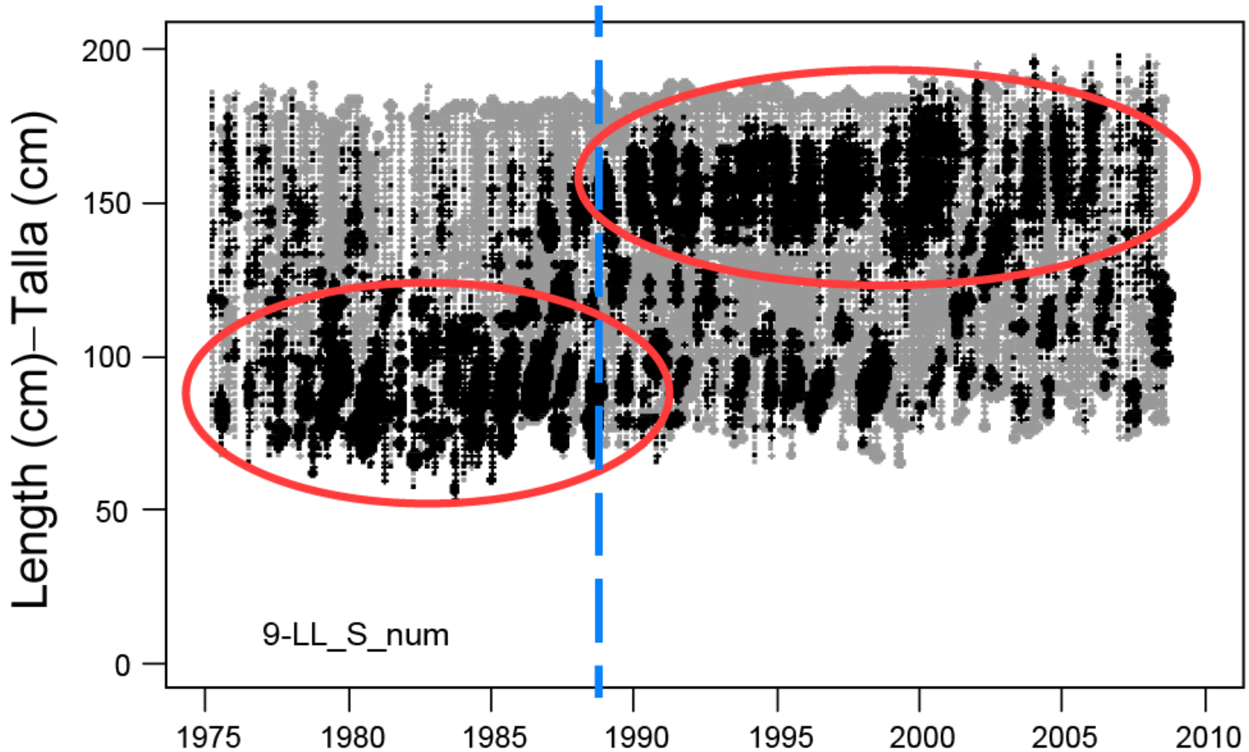

FIGURE 1. Pearson residual plots for the model fit to the length-composition data for the Southern longline fishery assumed in the base-case assessment in Aires-da-Silva and Maunder (2009). The gray and black circles represent observations that are lower and higher, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residual. The ovals identify clusters of prominent residual patterns. The dashed vertical line indicates where the residual pattern seems to change. From Aires-da-Silva *et al*. (2010).

FIGURA 1. Gráficas de los residuales del ajuste del modelo a los datos de composición por talla de la pesquería palangrera del sur supuestos en la evaluación de caso base en Aires-da-Silva y Maunder (2009). Los círculos grises y negros representan observaciones más bajas y más altas, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional a los valores absolutos de residual. Los óvalos identifican conglomerados de patrones prominentes de residuales. La línea de trazos vertical indica dónde el patrón de residuales parece cambiar. De Aires-da-Silva *et al*. (2010).

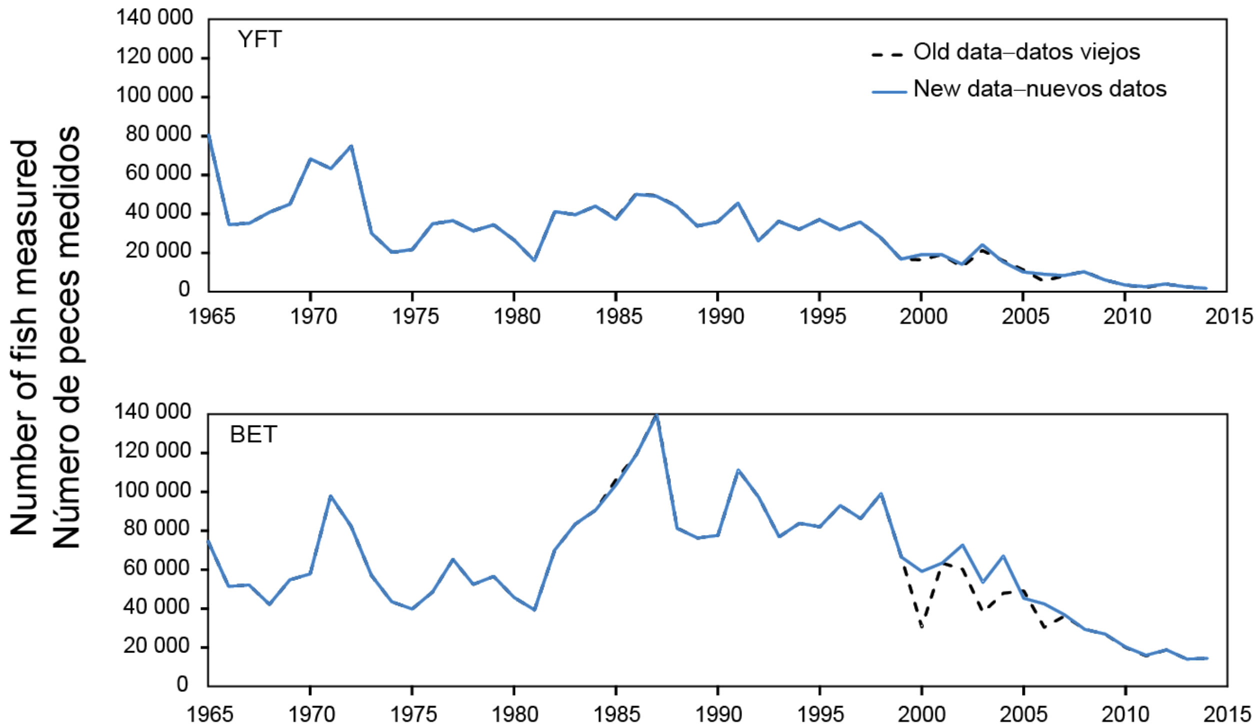

FIGURE 2. Number of size measurements for yellowfin (YFT, top panel) and bigeye (BET, bottom panel) tunas in the IATTC database before (old data) and after (new data) the submission of detailed data by Japan.

FIGURA 2. Número de mediciones de tamaño de aleta amarilla (YFT, panel superior) y patudo (BET, panel inferior) en la base de datos de la CIAT, antes (datos viejos) y después (datos nuevos) de la entrega de datos detallados por Japón.

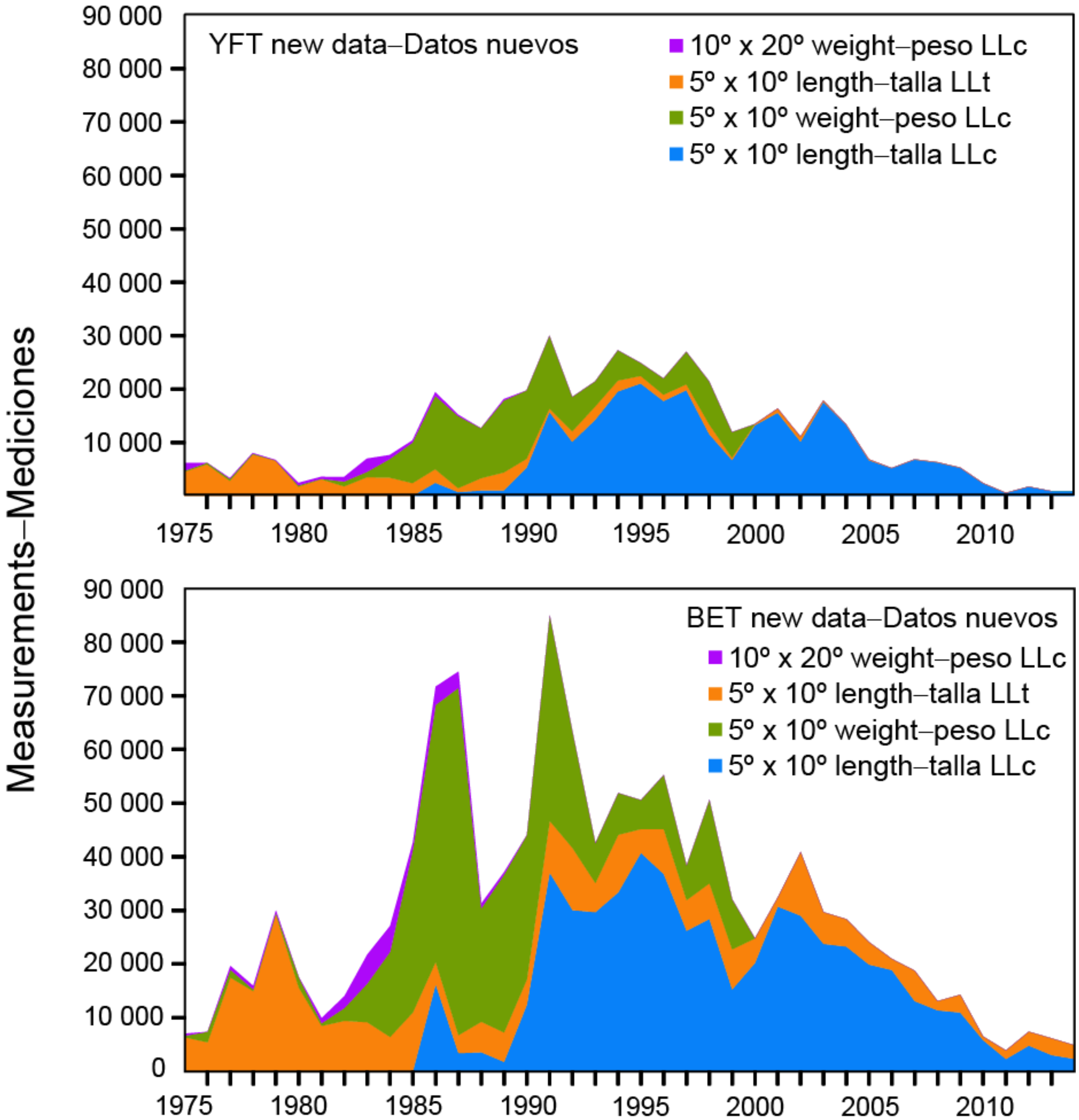

FIGURE 3. Number of size measurements of fish from the EPO during the stock assessment period (1975-2014), by species (yellowfin (YFT), top panel; bigeye (BET), bottom panel), type of vessel (LLc: commercial longline vessel; LLt: longline training vessel), spatial resolution (10° x 20° or 5° x 10°), and measurement type (weight: gilled-and-gutted weight; length: fork length).

FIGURA 3. Número de mediciones de tamaño de peces del OPO durante el periodo de la evaluación (1975-2014), por especie (aleta amarilla (YFT), panel superior; patudo (BET), panel inferior), tipo de buque (LLc: palangrero comercial; LLt: palangrero de aprendizaje), resolución espacial (10° x 20° o 5° x 10°), y tipo de medición (peso: peso desagallado y eviscerado; talla: talla furcal).

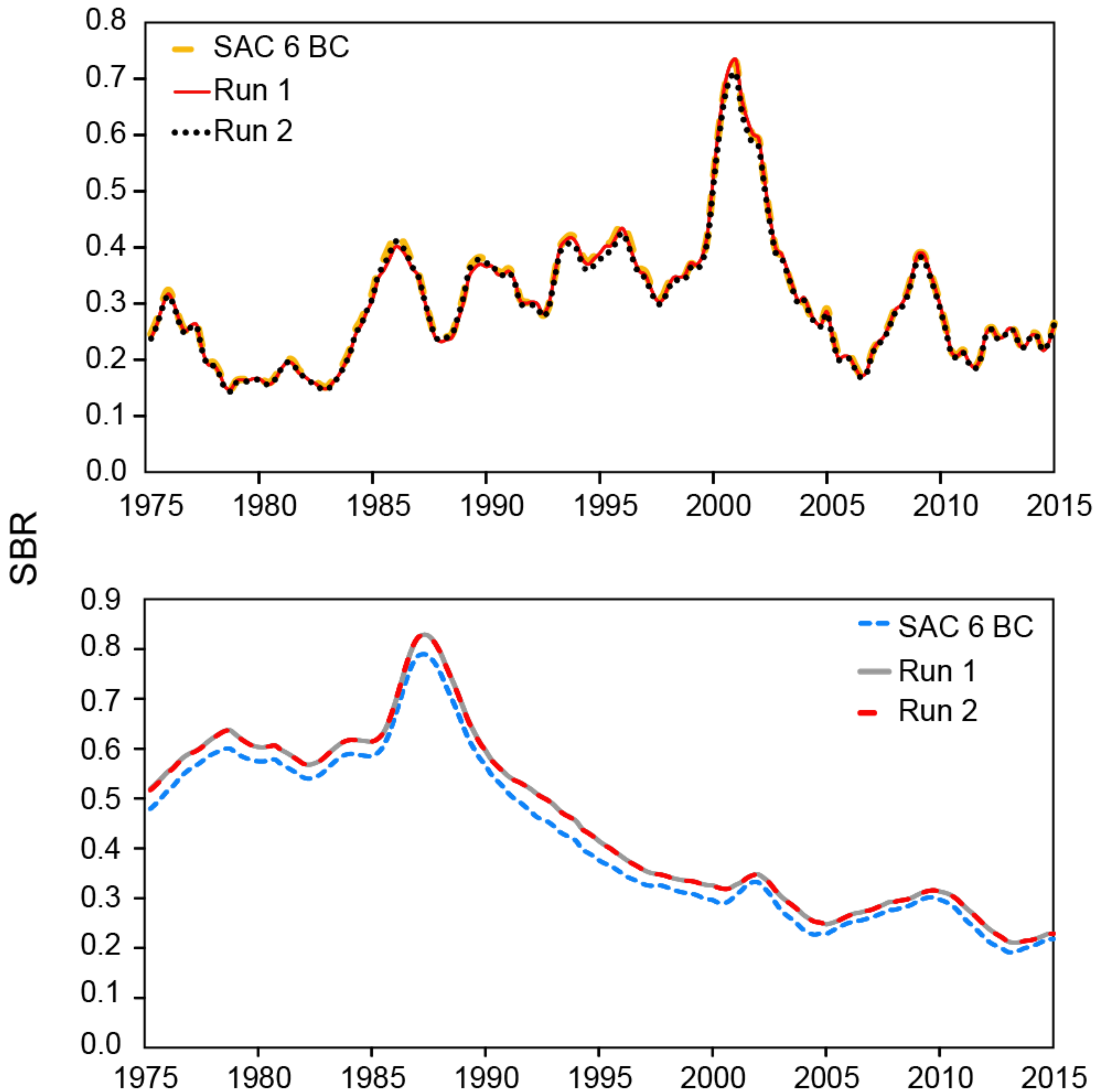

FIGURE 4. Spawning biomass ratio (SBR) from the base-case model for SAC 6 and from the two runs designed to mimic the base-case models but incorporating the new longline size-frequency data (Table 1), by species (yellowfin, top panel; bigeye, bottom panel).

FIGURA 4. Cocientes de biomasa reproductora (SBR) del modelo de caso base de SAC 6 y de las dos ejecuciones (*runs*) diseñadas para imitar los modelos de caso base reincorporando los nuevos datos de frecuencia de talla palangrera (Tabla 1), por especie (aleta amarilla, panel superior; patudo, panel inferior).

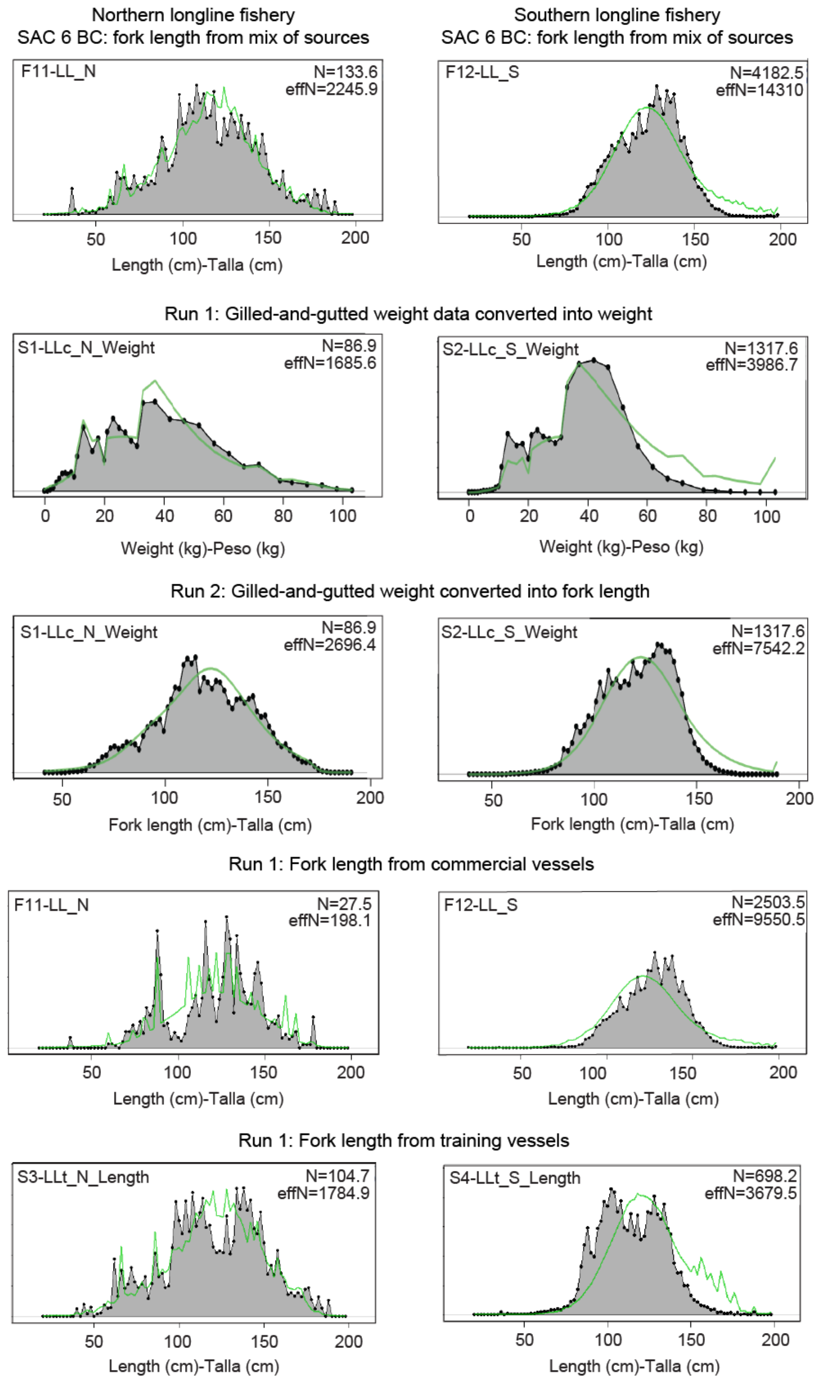

FIGURE 5a. Observed (grey area) and predicted (green lines) size frequencies of yellowfin, aggregated by fishery and data type, in the Northern and Southern longline fisheries, for the SAC 6 base case model and Runs 1 and 2 (Table 1). The four bottom plots for Run 2 (not shown) are similar to those for Run 1.

FIGURA 5a. Frecuencia de tamaño observada (área gris) y predicha (línea verde) de aleta amarilla, agrupado por pesquería y tipo de dato, en las pesquerías palangreras del norte y del sur, para el modelo del caso base de SAC 6 y las ejecuciones 1 y 2 (Tabla 1). Los gráficos de la ejecución 2 (no presentados) son similares a aquellos de la ejecución 1.

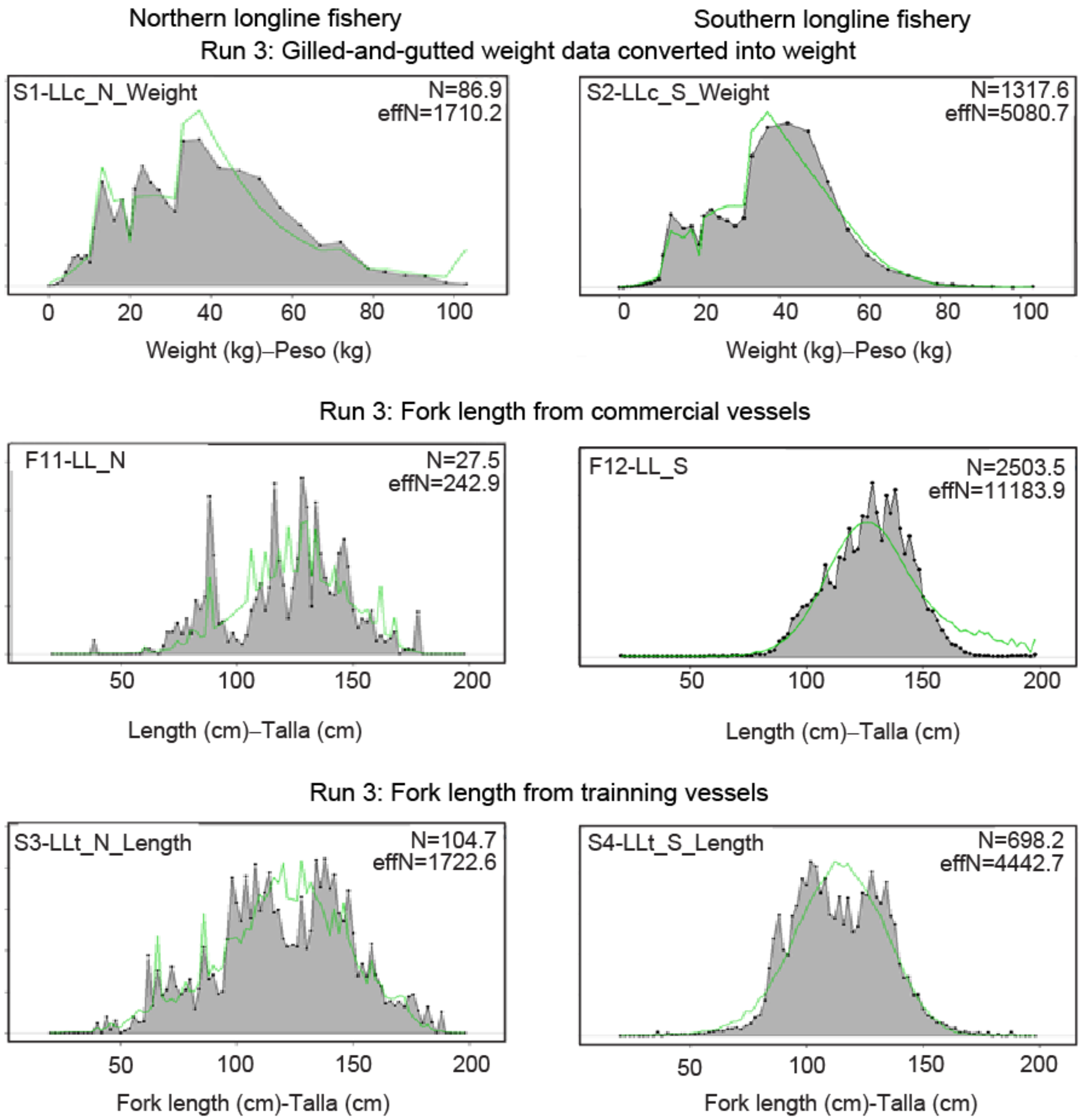

FIGURE 5b. Observed (grey area) and predicted (green lines) size frequencies of yellowfin, aggregated by fishery and data type, in the Northern and Southern longline fisheries used in Run 3 (Table 1) of the stock assessment model for yellowfin in the EPO.

FIGURA 5b. Frecuencias de tamaño observadas (área gris) y predichas (línea verde) de aleta amarilla, agrupadas por pesquería y tipo de dato, en las pesquerías palangreras del norte y del sur usadas en la ejecución 3 (Tabla 1) del modelo de evaluación de aleta amarilla en el OPO.

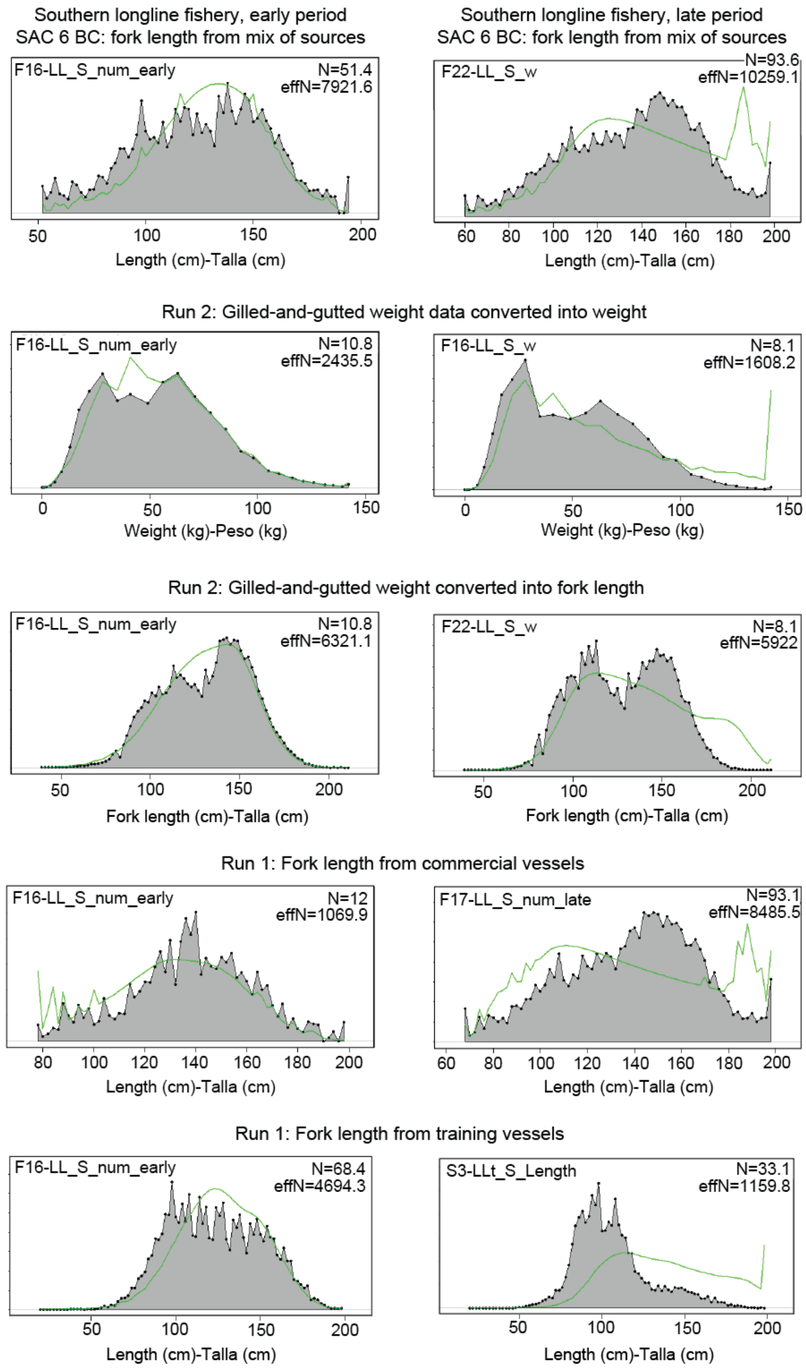

FIGURE 6a. Observed (grey area) and predicted (green lines) size frequencies of bigeye, aggregated by fishery and data type, for the Southern longline fishery (early and late period) used in the SAC 6 base case and Runs 1 and 2 (Table 1) of the stock assessment model for bigeye in the EPO. The four bottom plots for Run 2 (not shown) are similar to those for Run 1.

FIGURA 6a. Frecuencias de tamaño observadas (área gris) y predichas (línea verde) de patudo, agrupadas por pesquería y tipo de dato, de la pesquería palangrera del sur (periodos temprano y tardío)para el modelo del caso base de SAC 6 y las ejecuciones 1 y 2 (Tabla 1). Los gráficos de la ejecución 2 (no presentados) son similares a aquellos de la ejecución 1.

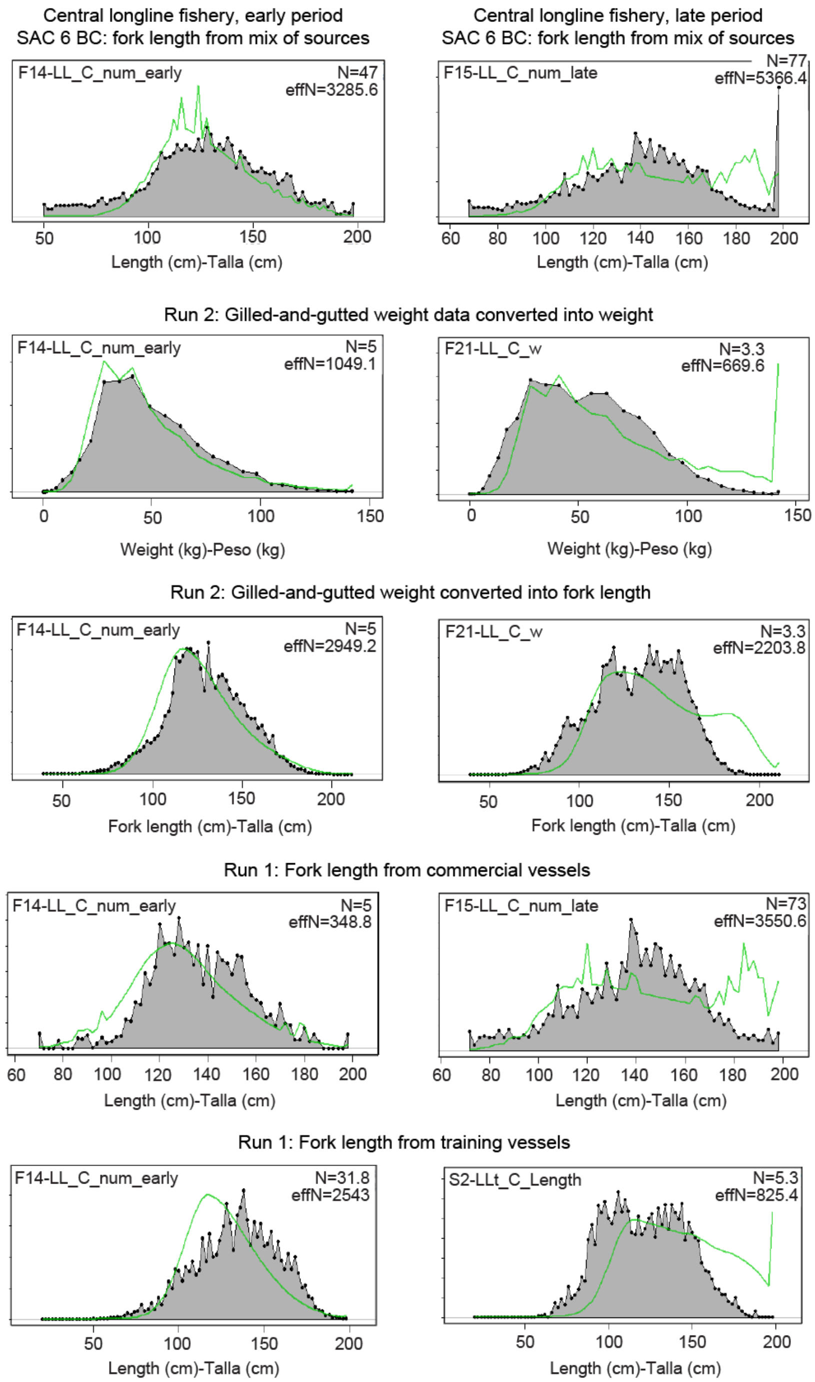

FIGURE 6b. Observed (grey area) and predicted (green lines) size frequencies of bigeye, aggregated by fishery and data type, for the Central longline fishery (early and late period) used in the SAC6 BC and Runs 1 and 2 (Table 1) of the stock assessment model for bigeye in the EPO. The four bottom plots for Run 2 (not shown) are similar to those for Run 1.

FIGURA 6b. Frecuencias de tamaño observadas (área gris) y predichas (línea verde) de patudo, agrupadas por pesquería y tipo de dato, de la la pesquería palangrera central (periodos temprano y tardío) usados en el caso base de SAC6 y las ejecuciones 1 y 2 (Tabla 1) del modelo de evaluación de patudo en el OPO. Los gráficos de la ejecución 2 (no presentados) son similares a aquellos de la ejecución 1.

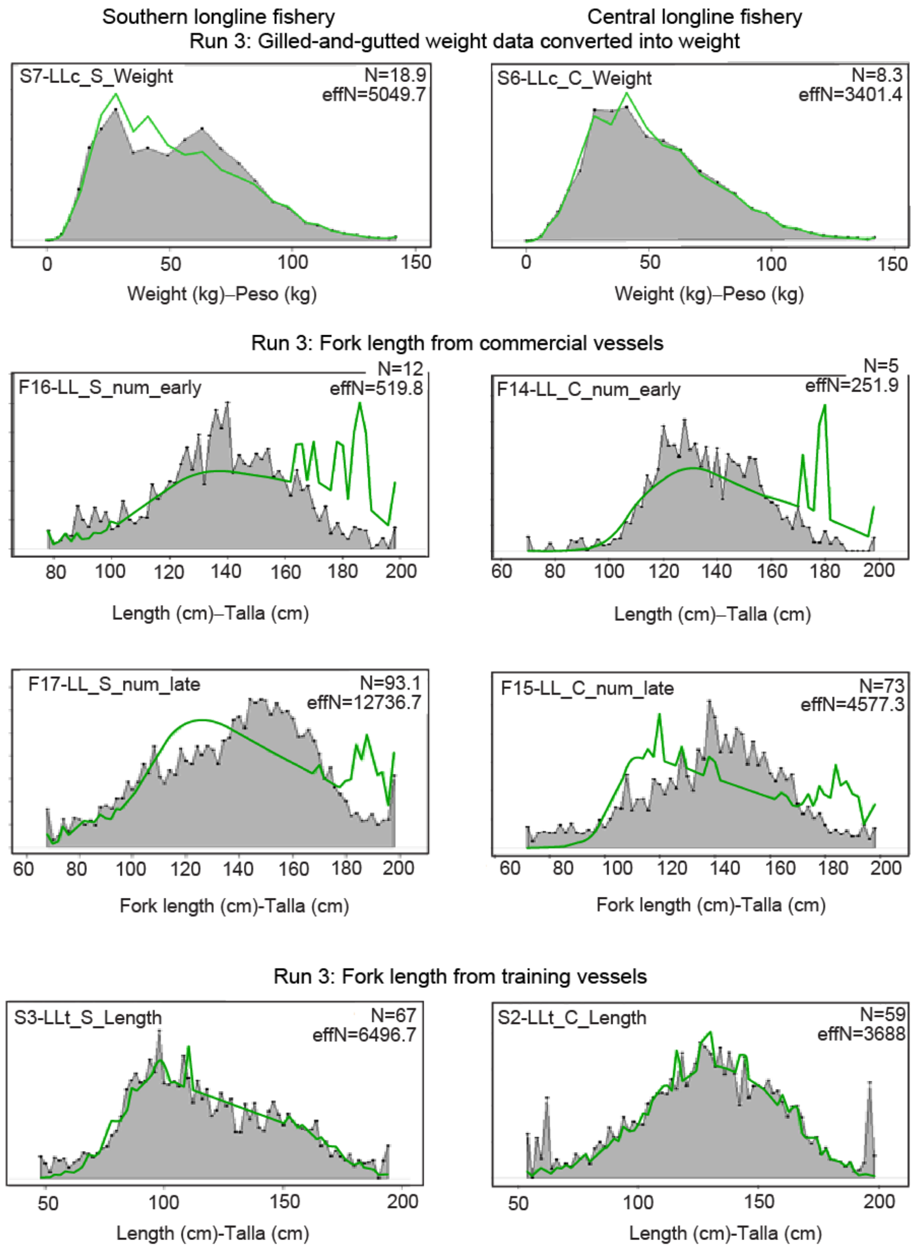

FIGURE 6c. Observed (grey area) and predicted (green lines) size frequencies of bigeye, aggregated by fishery and data type,for the Southern and Central longline fisheries for Run 3 of the bigeye stock assessment model in the EPO. The early and late periods are for the commercial vessels shown for comparison purposes to Run 1, as in Run 3 there are no time blocks of selectivity or catchability.

FIGURA 6b. Frecuencias de tamaño observadas (área gris) y predichas (línea verde) de patudo, agrupadas por pesquería y tipo de dato, de la ejecución 3 para las pesquerías palangreras del sur y central en el modelo de evaluación de patudo en el OPO. Se muestran periodos temprano y tardío para los buques comerciales para comparación con la ejecución 1, ya que la ejecución 3 no incluye bloques de tiempo para selectividad o capturabilidad.

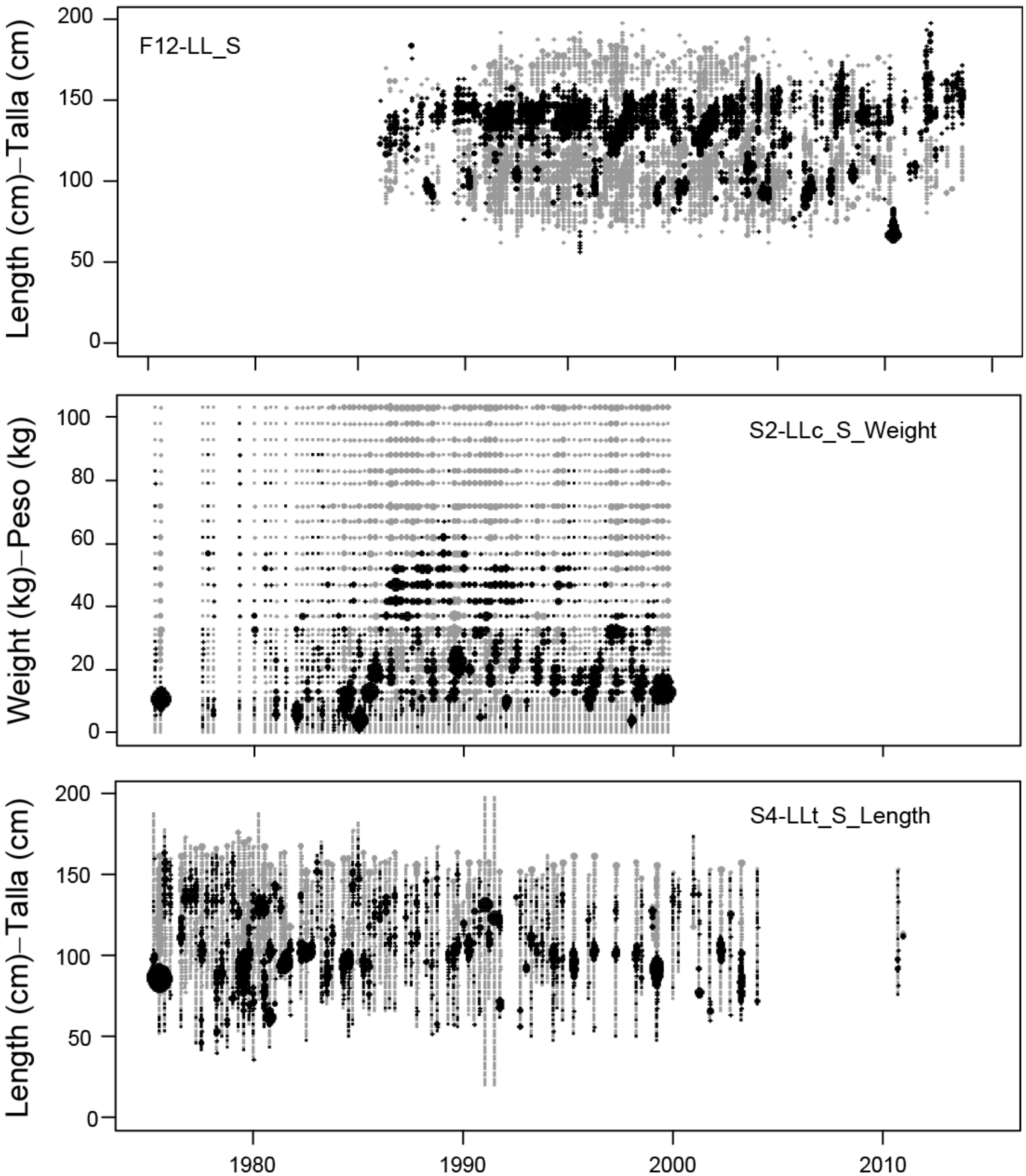

FIGURE 7a. Positive (black) and negative (gray) residuals for the size-frequency data of the Southern longline fishery for Run 1 of the model for yellowfin in the EPO. (LL and LLc: commercial longline vessel; LLt: longline training vessel).

FIGURA 7a. Residuales positivos (negro) y negativos (gris) de los datos de frecuencia de tamaño de la pesquería palangrera del sur para la ejecución 1 del modelo del aleta amarilla en el OPO. (LL y LLc: palangrero comercial; LLt: palangrero de aprendizaje).

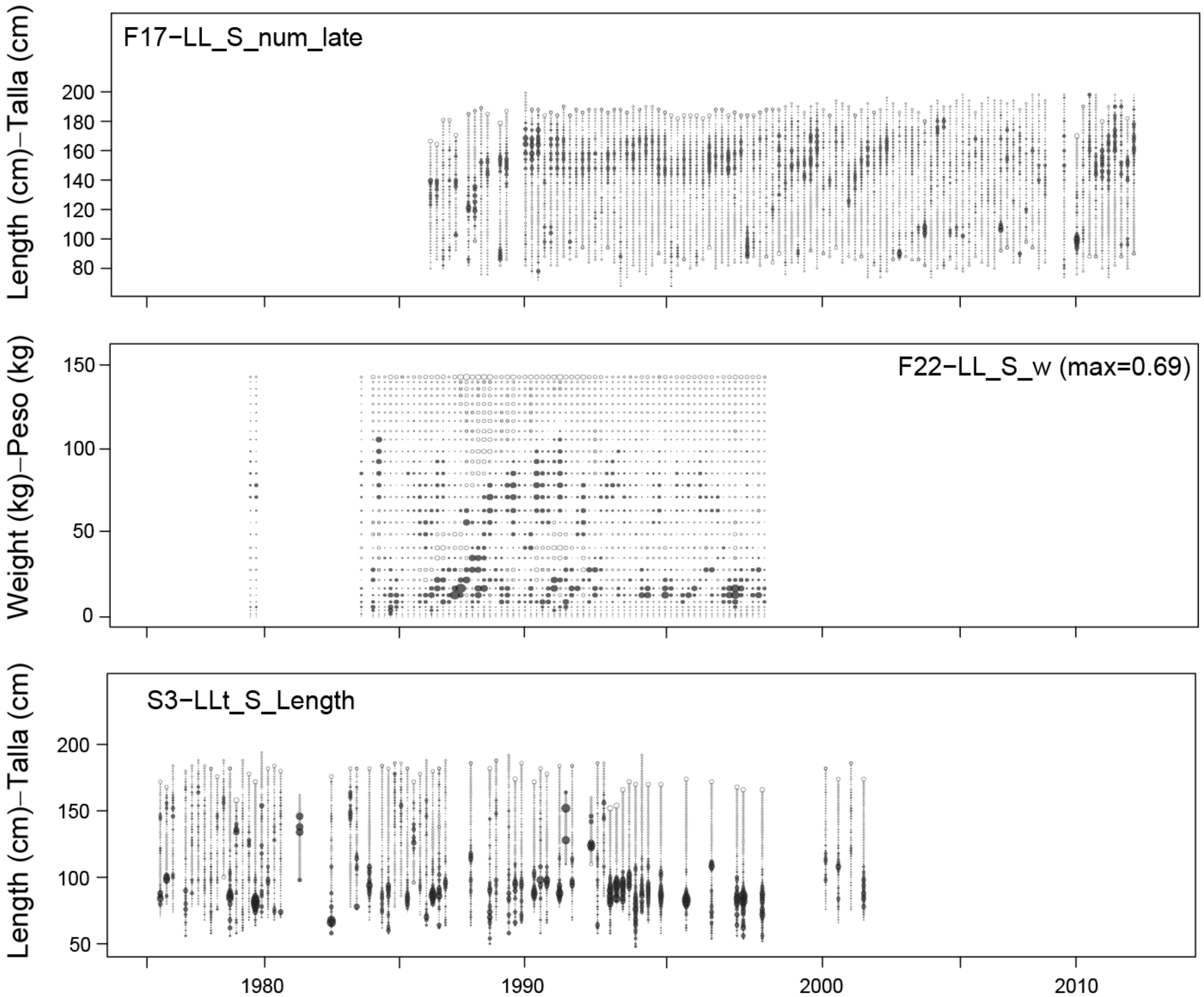

FIGURE 7b. Positive (dark gray) and negative (white) residuals for the size-frequency data of the Southern longline fishery EPO for Run 4 of the model for bigeye in the EPO. (LL: commercial longline vessel; LLt: longline training vessel; w: weight).

FIGURA 7a. Residuales positivos (gris oscuro) y negativos (blanco) de los datos de frecuencia de tamaño de la pesquería palangrera del sur para la ejecución 4 del modelo de patudo en el OPO. (LL: palangrero comercial; LLt: palangrero de aprendizaje; w: peso).

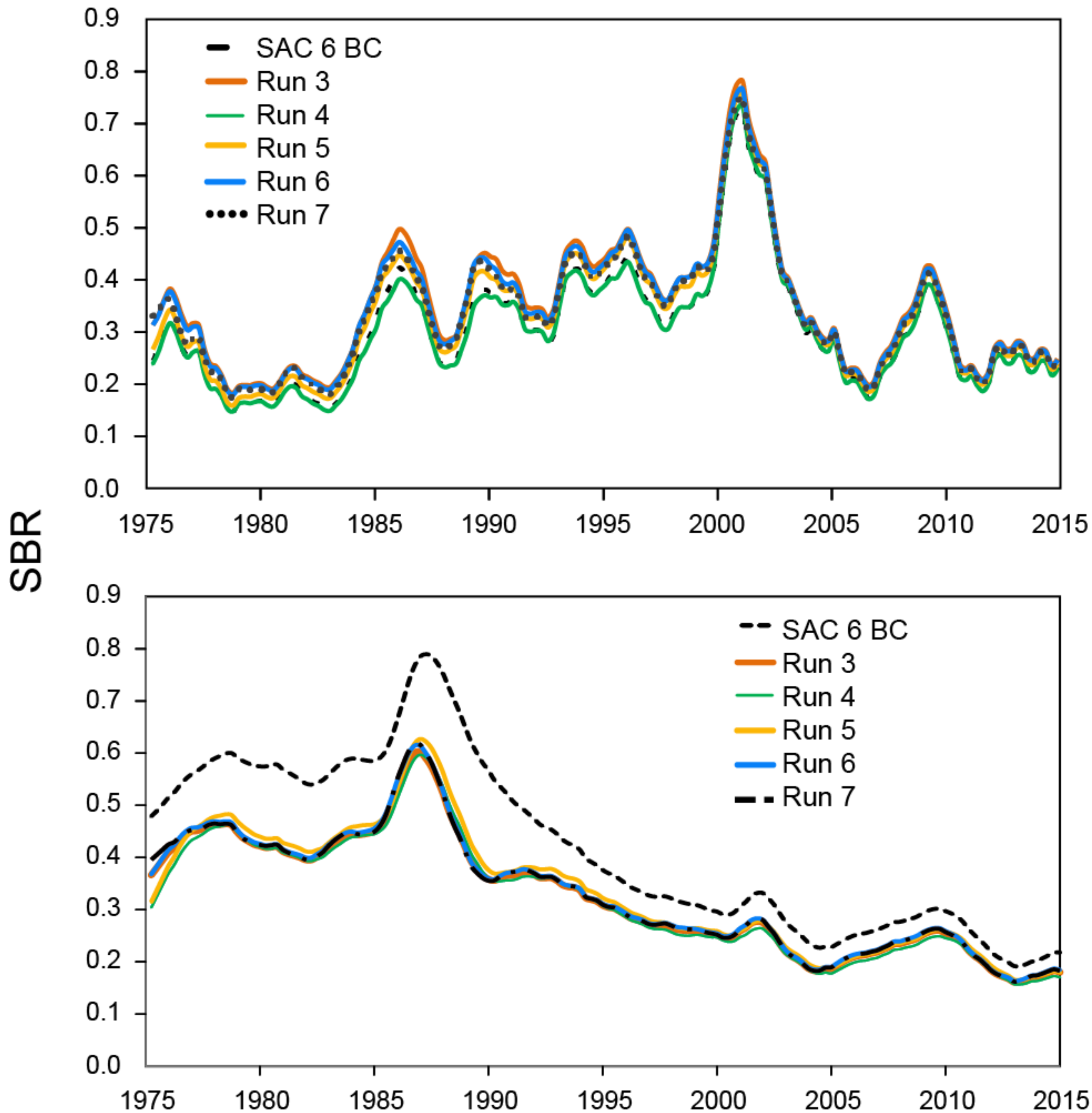

FIGURE 8. Spawning biomass ratios (SBR) from the base-case model for SAC 6 and from the runs designed to investigate the best way of incorporating the new longline size-frequency data into the assessment model (Table 1), by species (yellowfin (YFT), top panel; bigeye (BET), bottom panel).

FIGURA 4. Cocientes de biomasa reproductora (SBR) del modelo de caso base de SAC 6 y de las ejecuciones diseñadas para investigar la mejor forma de incorporar los nuevos datos de frecuencia de talla palangrera en el modelo de evaluación (Tabla 1), por especie (aleta amarilla, panel superior; patudo, panel inferior).