INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

SEVENTH MEETING

La Jolla, California (USA)
09-13 May 2016

DOCUMENT SAC-07-06a(i)

EXPLORATORY STOCK ASSESSMENT OF DORADO (*CORYPHAENA HIPPURUS*) IN THE SOUTHEASTERN PACIFIC OCEAN

Alexandre Aires-da-Silva, Juan L. Valero, Mark. N. Maunder, Carolina V. Minte-Vera, Cleridy Lennert-Cody, Marlon H. Román, Jimmy Martínez-Ortiz, Edgar J. Torrejón-Magallanes, and Miguel N. Carranza

CONTENTS

Summary 1
1. Introduction 2
2. Data 5
3. Assumptions and parameters 10
4. Model structure configurations 10
5. Results 12
6. Management quantities 15
7. Yield-per-recruit analysis 17
8. Future directions 17
References 19
Figures 24

SUMMARY

Dorado (*Coryphaena hippurus*) has a wide distribution throughout the tropical and subtropical waters of the world's oceans. It is one of the most important species caught in the artisanal fisheries of the coastal nations of the eastern Pacific Ocean (EPO), ranging from Chile in the south to Mexico in the north. Available fisheries statistics indicate that the EPO is the dominant region in global production of dorado. The species has been thought of as highly resilient to overfishing due to its high productivity in all the oceans of the world. However, stock assessments are needed to obtain a better picture of the stock status of the species and develop reference points for management. Coastal IATTC Member States have requested collaborative research and guidance from IATTC staff on regional research of dorado, in particular on stock assessments. Three IATTC Technical Meetings on Dorado have been conducted, in Ecuador, Peru, and Panama, in 2014, 2015, and 2016, respectively. A large and diverse amount of fishery and biological data for dorado available from IATTC Member States was identified and stock structure assumptions were discussed, as were the methodologies and stock status indicators to use. Available data were considered sufficient to attempt a conventional stock assessment of dorado in the southeastern Pacific Ocean (south of the equator; South EPO), where most of the recorded catches are taken. For dorado fisheries north of the equator (Colombia, Central America, or Mexico), the current data-limited situation handicaps conventional stock assessments. Improved data collection programs for dorado are needed for these fisheries.

This study presents an exploratory stock assessment for dorado in the southeastern Pacific Ocean. The geographical extent of the assessment is the "core" region of the dorado stock in the EPO, which is located off Peru and Ecuador. In this region, dorado are mainly subject to targeted artisanal longline fisheries from both States, but the species is also caught incidentally (as bycatch) by the tuna purse-seine fisheries. The assessment is implemented in the Stock Synthesis modelling platform, with a monthly time step, and covers the July 2007-June 2015 period. The catch data used were from Peru, Ecuador, and purse-seine bycatches. The model is fitted to (i) dorado catch per unit of effort (CPUE) data from Ecuadorian artisanal fisheries, (ii) length-composition data from Peruvian artisanal fisheries as well as purse-seine bycatches (sexes combined), and (iii) length-composition data from Ecuadorian artisanal fisheries (sexes separated). The monthly time step allows depletion caused by catch and measured by the CPUE to inform estimates of absolute abundance.

The assessment produces a good fit to Ecuadorian CPUE and length-composition data. Although the fit to the length-composition data is good, residual patterns for some months in the Ecuadorian fishery suggest that more work is needed to better capture processes (*e.g.* growth and/or selectivity) that could explain the lack of fit. Although the assessment results contribute to knowledge about the population dynamics of dorado and its history of exploitation in the EPO, the IATTC staff is unable to draw conclusions about stock status, because no reference points, target or limit, have been defined for dorado in the EPO. Nonetheless, some management quantities are presented and discussed for consideration. Recent catches are near the estimates of maximum sustainable yield (MSY) from the stock assessment. However, yield-per-recruit (YPR) analyses show that the yield curve is very flat, and the fishing mortality required to achieve the MSY is poorly defined. A complementary study presents an exploratory management strategy evaluation (MSE) for dorado in the southern EPO. Overall, this study shows that Stock Synthesis is a promising tool for conducting stock assessments of this species in the EPO. More research is needed to refine the model and the data used, and to prioritize collection of new data for assessing dorado. Analyses expanding the spatial extent of the assessment and including data from more fisheries (*e.g.* Central America, Mexico, and Chile) could be considered in the future.

This report includes a series of recommendations for future research to improve stock assessment analyses of dorado in the EPO. A conventional stock assessment for dorado in the northern EPO (north of the equator) remains to be developed. Unfortunately, the dorado fishery data available from the northern coastal States are still very limited, total catch and potential indices of relative abundance (e.g. catch rates) are poorly known. A monthly depletion estimator approach could be applied in these data-limited situations if some minimum CPUE data are available.

1. INTRODUCTION

1.1. Background

Dorado (*Coryphaena hippurus*) Linnaeus, 1758, is an epipelagic and primarily oceanic species with a wide distribution throughout the tropical and subtropical waters of the world's oceans world (Palko *et al*., 1982). Also known as *mahi mahi*, *dolphinfish, doradilla*, *lampuga*, *palometa*, and *perico*, it is one of the most important species caught in the artisanal fisheries of the coastal nations of the eastern Pacific Ocean (EPO). The species is thought to be highly resilient to overfishing due to its high productivity in all the oceans of the world (Palko *et al*., 1982). In the EPO in particular, dorado show high rates of growth during a very short lifespan (about three years), early maturity (50% maturity at 0.5-1 years of age), high fecundity, and the capacity to spawn throughout the year in some areas (Martínez-Ortiz and Zúñiga-Flores, 2012).

In the EPO, dorado is exploited by the fleets of nearly all coastal nations, from Chile in the south to Mexico in the north, and even occasionally in the southwestern waters of the United States, at the northernmost distribution of the resource (Dapp *et al*., 2013; Lasso and Zapata, 1999; Martínez-Ortiz and Zúñiga-Flores, 2012; Norton, 1999; Solano-Sare *et al*., 2008). The available fisheries statistics indicate that the EPO is the dominant region in global production of dorado, with between 47 and 70% of the total world catches during 2001-2012 (Aires-da-Silva *et al*., 2014). It is estimated that the average total annual catch of dorado in the EPO was about 71,000 metric tons (t) during 2008-2012 (Figure 1).

1.2. The IATTC and dorado

Despite the importance of the fishery for dorado in the EPO, there is great uncertainty about the status of the stock (SFP, 2013). A stock assessment was attempted in 1991, applying a length-based virtual population analysis to Ecuadorian data (Patterson and Martínez, 1991), but the results of that work are outdated. The exploitation of dorado has evolved greatly since the 1990s, with new fisheries emerging and becoming dominant in terms of catch volume (*e.g.* artisanal fisheries in Peru, which took between 57 and 81% of the total estimated removals of dorado in the EPO during 2001-2012; Aires-da-Silva *et al.* 2014).

The high value of dorado exports has also resulted in a growing interest in product certification and ecolabeling for some fisheries. This added to the existing demand for a stock assessment of dorado, since most fishery certifications require comprehensive stock assessments and a functioning management system, including reference points (target and limit) and harvest control rules. These are difficult to determine without conventional stock assessments, or at least an understanding of the stock and fishery dynamics at the level needed to conduct a stock assessment.

The Antigua Convention establishes that one of the functions of the Inter-American Tropical Tuna Commission (IATTC) is to "adopt appropriate measures to avoid, reduce and minimize … impacts on associated or dependent species." Dorado is caught incidentally in the purse-seine fishery for tunas in the EPO (Martínez-Rincon *et al*., 2009)), although in very small quantities (<5%) compared to the total volume of commercial catches in the EPO (Aires-da-Silva *et al*., 2014). In this context, some coastal Member States of the IATTC have requested collaborative research and guidance from IATTC staff on regional dorado research, in particular on stock assessments (Aires-da-Silva *et al*., 2014). Following this request, three IATTC technical meetings on dorado were held. The first meeting, held in Manta, Ecuador, in 2014, helped to establish the collaborative research forum that is necessary to work on dorado at the large regional scale of the EPO (Anonymous, 2015). Also, a large and diverse amount of fishery and biological data for dorado available from IATTC member countries was identified. The second meeting, held in Lima, Peru, in 2015, led to significant progress on two important questions that need to be addressed for regional management of dorado in the EPO (Anonymous, 2016): 1) stock structure assumptions, and 2) which methodologies and indicators of stock status to use. A third meeting was held in Panama City, Panama, in 2016. This meeting focused on evaluating data needs and assessment methods for data-limited dorado fisheries in the EPO.

1.3. Conceptual life-history model for dorado in the EPO

One important outcome of the second meeting on dorado was the elaboration by regional experts of a hypothesized conceptual model (Figure 2a) of the population structure and dynamics of dorado in the EPO, based on analyses of complementary data sets such as observer data from large (IATTC Class 6; carrying capacity greater than 363 t) purse-seine vessels, artisanal longline CPUE data, and compilations of monthly catches from Central American countries. The genetic studies available are preliminary, but they indicate high genetic variability within the EPO, and most indicate the need for increased sample sizes and improved spatio-temporal sampling. At this point, there is no clear evidence that there is more than one population of dorado in the EPO, but some information suggests that there may be coastal and oceanic sub-stocks (Téllez and Caballero, 2017). If that is the case, the coastal (or "more resident") sub-stock would be more available during the whole year towards the coast slightly north of the equator, while the oceanic sub-stock would move seasonally towards the coastal areas of the EPO around October-November.

The dorado fishing season for the longline artisanal fleet starts around October-November, peaks around December, and ends around February-March (Martínez-Ortiz *et al.* 2015). This coincides with oceanographic changes in the oceanic waters off Peru and Ecuador, between 2°S and 10°S from 90°W to 105°W (Figure 2b), and particularly with the 23°C isotherm, with which dorado are mostly associated. When the dorado season begins, subtropical waters with moderate (20-25°C) sea-surface temperatures (SSTs) are located south of the Equatorial Front and west of the cold (16-20°C) water mass associated with upwelling and the Humboldt Current system off Peru. As these warmer waters approach the coast, the cool water mass shrinks, and dorado become vulnerable to artisanal longline gear. By February-March, when the dorado fishing season ends, the cooler water is confined to the area along the Peruvian coast, and there is little habitat below 25°C available in the equatorial and tropical Pacific.

The catches of dorado by purse-seine vessels, although they account for less than 5% of the total known catches of the species in the EPO, can be used to expand the approximate spatial distribution of dorado indicated by the artisanal fishery data. Purse-seine effort is widely distributed in the EPO, and dorado is present in almost all the areas of operation of the purse-seine fleet (Figure 2c); also, all trips by large vessels are covered by observers, who have been recording bycatches by species and length category (0-30 cm, 30-60 cm, and >60 cm) since 2005. The size at maturity for dorado is around 60 cm, so the first two size categories are indicative of juvenile fish, and the third of adults.

Purse-seine bycatches of dorado are most frequent in the floating-object (OBJ) fishery. The catch per set (in numbers of large fish) in that fishery is greatest closer to the coast in the first and fourth quarters of the year, *i.e.* from October to March (Figure 2d). In the fourth quarter, there is almost no purse-seine effort on floating objects, and thus almost no catch, in the coastal areas south of the equator, but this is offset by the large catches of the artisanal longline fishery (Figures 2b, 2d). The dolphin (DEL) and unassociated (NOA) fisheries, which have a more coastal and northern distribution, expand the view towards the north, and confirm those spatial patterns (Figure 2e). In those two fisheries, the catch per set in numbers is greater in the first and fourth quarters in the coastal areas, with large concentrations towards the extreme north, around Baja California, and in the south, off Ecuador and Peru, where the California and Humboldt currents have their greatest influence. In Central American waters, there is an apparent gap in distribution off southern Mexico and Guatemala, which maybe due to selectivity.

The proportion of floating-object sets with catches of small (≤ 60 cm) and large (> 60 cm) dorado in different areas of the EPO indicates an almost synchronous and markedly seasonal pattern (Figure 2f), except in coastal areas. From January to May, the proportion of sets with small fish (juveniles hatched during October-January) increases steadily. Around June, when the fish are about 6 months old, the proportion of sets with large fish increases markedly; then, from October to December, it decreases south of the equator (areas 6-9) and in area 2 (0°-10°N, 130°-150°W), while off Central America and Colombia (areas 4 and 5) it remains about the same, due most likely to movement towards coastal areas. From January to March there is a marked decrease in adults in all areas, as the cohort hatched one year previously is depleted.

Compiling the monthly catches from the EPO coastal countries helps elucidate the dynamics of dorado in the coastal areas in the northern hemisphere (DOR-02-Report: Table 1). In Panama and Costa Rica, the greatest catches of dorado are taken during October-January, peaking in December, but with a secondary peak around May. In Colombia, the largest catches of dorado are from December through March, with the peak in February. Further north, in Guatemala, dorado is caught throughout the year, with the peak in November, while in Baja California Sur, Mexico, where dorado is also caught throughout the year, catches are highest during September-November, with the peak in October.

In conclusion, the available information does not provide strong evidence that there is more than one stock of dorado in the EPO, although there are indications of some spatial structure (Figure 2a). Current information indicates that the "core" area of the dorado stock lies south of the equator, off Ecuador and Peru, where the adult fish move to spawn and feed. The fishery that operates in that area mainly exploits one annual cohort, aged between about 10 and 16 months. The distribution of catches throughout the year in different areas suggests that there may be two sub-stocks in the EPO, an oceanic sub-stock that migrates seasonally towards the coast, and a more resident sub-stock in the coastal region. Most of the catches and the available data are from the southern hemisphere, where a marked seasonality is evident, resulting from periodic encounters of tropical waters with the cold Humboldt Current. There are some indications of a similar seasonality in the northern hemisphere, under the influence of the California Current, but there are no data available for the areas off Mexico, north of 10ºN, that could be used to investigate this hypothesis. From about 5°N to 10°N, the dynamics of dorado seem to be different, with the coastal (or "more resident") sub-stock more available throughout the year.

1.4. Objectives of the assessment

This report presents an exploratory stock assessment of dorado in the EPO south of the Equator (South EPO), which builds on the discussions at the first two IATTC technical meetings and the resulting datasets and knowledge. During the second meeting, it was discussed that an exploratory stock assessment could start by focusing on the "core" region of the dorado stock in the EPO, for which the best fishery data are available, and where most of the recorded catches are taken. In this region, off Peru and Ecuador, dorado is exploited mainly by targeted artisanal longline fisheries from those two nations, but is also caught incidentally (as bycatch) in the tuna purse-seine fisheries (Figure 2b). Together, these three fisheries account for about 90% of the recorded total catch of dorado in the EPO (Aires-da-Silva *et al*., 2014). Furthermore, they are the only fisheries for which moderately long time series of fishery data (*e.g.* catch and effort, standardized CPUE, and catch composition) are available for stock assessment analysis. Fisheries of other EPO coastal nations also catch dorado, but as far as is known, in much lesser amounts. Some of these nations (Chile and Costa Rica, for instance) have recently begun data-collection programs for dorado; including these data and expanding the spatial extent of this assessment could be considered in the future (see Section 8.2).

The main objective of this assessment work is to explore the potential usefulness of the Stock Synthesis modelling platform (Methot and Wetzel 2013) for assessing dorado in the EPO. Although the assessment results contribute to the understanding of the population dynamics of dorado and its history of exploitation in the EPO, the IATTC staff is unable to draw conclusions about stock status, because no reference points, target or limit, have been defined for dorado in the EPO. Nonetheless, some management quantities are presented and discussed for consideration. Also, a complementary study presents an exploratory management strategy evaluation (MSE) for dorado in the EPO (Valero *et al.* 2016).

2. DATA

The fisheries exploiting dorado in the EPO, and the data from those fisheries used in the assessment, are described below. After considering the quality of the different data sources available, it was decided that the stock assessment should cover 2007-2015, since the data sources available for this period are considered quite reliable. To better define the population dynamics of dorado over time in the seasonal stock assessment model (see Section 4), it is advantageous to use a fishing year (FY), which in this case starts on 1 July and finishes on 30 June, rather than the calendar year (CY). Accordingly, the historic period of the assessment extends from month 1 of FY 2007 (July 2007) to month 12 of FY 2014 (June 2015).

The data used in the stock assessment model are shown in Figure 3 by type, fishery, and fishing years included in the model. Also presented below are data sources collected for the period prior to 2007. Although these early data were not used in the assessment, they are presented to illustrate the construction of available time series of data for dorado.

2.1. Definitions of the fisheries

In the South EPO, dorado are mainly subject to targeted artisanal longline fisheries by Peru and Ecuador, but the species is also caught incidentally (as bycatch) by the tuna purse-seine fisheries. The stock assessment model is not spatially-structured, in the sense that no fisheries based on spatial considerations are defined, except as implicit in the spatial distribution of the Ecuadorian and Peruvian fisheries. However, these three fisheries are defined separately in this assessment (Table 1), so that their catches are associated with separate size selectivity curves. The different data sets that describe the dorado catches taken by these fisheries are described below.

2.2. Catch

The time series of historic catches of dorado obtained for the stock assessment from Peruvian, Ecuadorian, and IATTC sources are described below. No information on dorado discards is available; therefore, in this report the term 'catch' refers to retained catch, and thus observed landings and unloadings.

2.2.1. Peru (Fishery F1)

Dorado is exploited by artisanal fisheries in coastal and oceanic waters off Peru (Fishery F1 in the assessment). Availability of the resource is highly seasonal, usually occurring from September to March, and is associated with warm SSTs (21-30˚C). During these months, dorado accounts for about 90% of the total volume of landings by the Peruvian artisanal fishery (Solano-Sare *et al*., 2008). The Instituto del Mar de Perú (IMARPE) has some landing records going back to the late 1980s, but the major expansion of the Peruvian fishery occurred in the early 2000s, following the increased availability of dorado in 1998 that coincided with the strong El Niño event of that year. Although Peru has the greatest catches of dorado in the EPO, it is second to Ecuador in terms of exports (filleted and fresh) to the United States (Aires-da-Silva *et al*., 2014). Information from various sources indicates that most of the Peruvian catch is consumed domestically.

For this assessment, IMARPE made available official catch landings data, collected by the Statistics Office of the Ministry of Production (PRODUCE), for dorado taken by the Peruvian artisanal fisheries during 2000-2015. Only annual statistics are available for the 2000-2005 period, but after that they are available by month. Using this combination of annual and monthly data, an attempt was made to construct a historical monthly time series of Peruvian dorado catches for the January 2000-December 2015 period (Figure 4a). Monthly estimates for 2000-2005 were obtained by applying to the annual data the average monthly proportions of the catches available for 2006-2015 (Figure 4f).

2.2.2. Ecuador (Fishery F2)

Dorado is exploited by Ecuadorian artisanal fisheries, mainly the multi-species longline fishery which shifts target among large pelagic fish species, including dorado, tuna, billfishes, and sharks. This fishery (Fishery F2 in the assessment) began gradually in the mid-1970s, but underwent a great expansion during the 1990s and 2000s. The traditional fishing areas, which were initially within 40 nautical miles (nm) of the coast, have expanded gradually over the years to as far as 1,400 nm from the mainland coast west of the Galapagos Islands, establishing what is now known as the "oceanic-artisanal fishery" in Ecuador. As in Peru, there is a great seasonality in these fisheries: the longline fishery targeting dorado operates mainly during October-February, with peak catches in December and January. Dorado accounts for more than 65% of the estimated landings of large pelagic fish species by artisanal fisheries in Ecuador, and 35 to 40%

of the exports of pelagic fish to the United States (Martínez-Ortiz and Zúñiga-Flores, 2012). The longline fishery for tuna-billfish-shark (TBS) species takes place all year round. However, catches of TBS species decline greatly during the dorado season because longline vessels change their gear in order to target dorado, using the smaller *doradero* hooks. Martínez-Ortiz *et al.* (2015) provide an extensive description of the Ecuadorian artisanal fishery for large pelagics, including species composition and spatio-temporal dynamics.

An attempt was made to construct a historical monthly time series of dorado catches taken by Ecuadorian fisheries during the January 1987-June 2015 period (Figure 4b). For the most recent years (2008-2015), catch statistics were extracted from the databases of Ecuador's landings monitoring system for artisanal fisheries (*Sistema de Control y Monitoreo*; SCM), operated by the Undersecretariat of Fisheries Resources (SRP) (Martínez-Ortiz *et al*., 2015). Catch estimates for the early period were obtained from fishery statistics published by the National Fisheries Institute (INP)[1].

2.2.3. Bycatch from tuna purse-seine fisheries (Fishery F3)

Dorado are caught as bycatch in the tuna purse-seine fisheries in the EPO (Fishery F3 in the assessment). There are three types of purse-seine sets for tuna (on tunas associated with dolphins, associated with floating objects, and unassociated tunas); dorado are caught predominantly in floating-object sets (97% of total catch in weight). IATTC observers on large purse-seine tuna vessels have collected data on bycatches of dorado (Figure 4c) since 1993, and the records available for the assessment cover the 1993-2015 period. Data on bycatches by smaller vessels (classes 1-5; carrying capacity less than 363 t) are not available, so they were estimated by applying the catch-per-set rates of large (Class-6) vessels to sets by the smaller vessels (23% of the total number of purse-seine sets).

2.2.4. Other fisheries

There are other sources of fishing mortality of dorado in the EPO that were discussed at the IATTC Technical Meetings on Dorado. In the South EPO, the Peruvian and Ecuadorian fisheries are clearly the predominant sources of the dorado removals, and these data are included in this assessment. However, there are some additional reliable dorado data from Chilean fisheries which could be added to the South EPO model in future improvements of this assessment (Anonymous, 2016). The distant-water longline fleets targeting tuna and billfishes also have bycatches of dorado. IATTC Resolution C-11-08 established a scientific observer program for longline vessels over 20 meters length overall, which would cover at least 5% of the fishing effort (defined as effective days fishing, excluding transit days) by such vessels, starting in 2013. Therefore, additional reliable data on dorado bycatches by these fleets may become available in the future.

2.2.5. Catches during the assessment period (FYs 2007-2014)

Total annual catches of dorado during the assessment period are shown in Figure 4d. Annual catches averaged about 61,000 t during the assessment period, with 82%, 16%, and 2% of the catches taken by Peru, Ecuador, and as bycatch in the tuna purse-seine fisheries, respectively. While total annual catches peaked in FY 2009 at about 76,000 t, the lowest catch was about 39,000 t during FY 2010. Monthly catches of dorado in the South EPO show a pronounced seasonal pattern, usually peaking in December (Figure 4e).

---

[1] Instituto Nacional de Pesca Ecuador (1999) Estadísticas de los Desembarques Pesqueros en el Ecuador 1985-1997. Departamento Procesamiento de Datos división de Biología y Evaluación de Recursos Pesqueros. Marín de López C, Ormaza-Gonzalez *F* y Arriaga-Ochoa L (eds). INP. 152 pp.

2.3. Indices of abundance

CPUE data from the Peruvian and Ecuadorian artisanal longline fisheries were used to produce a set of candidate indices of relative abundance. The real changes in dorado abundance assumed to be represented in CPUE data may be confounded with changes over time in fishing practices and/or spatio-temporal effects. “Catch-effort (or catch) standardization” is the procedure which accounts for (*i.e.* removes) the impact on catch rates of changes over time of factors other than abundance (Maunder and Punt, 2004). Generalized additive models (GAMs) were used for catch-effort standardization of the CPUE data for dorado; the results are summarized below, and presented in detail in Appendix A.

2.3.1. Peru

A GAM for the dorado CPUE in weight that assumes a gamma error distribution was used to standardize the Peruvian CPUE data. The explanatory variables included in the GAM were year, month, and fish-carrying capacity of the vessel. Information on geographical location (latitude and longitude) is not available in the Peruvian trip records at this stage. An attempt was made to account for spatial effects on the CPUE by producing separate indices of abundance for three main fishing regions, based on port of landing: North (Paita); Central (Chimbote-Pucusana); and South (Ilo). Since the CPUE data after FY 2010 may be of better quality than those for previous years, standardized CPUEs were computed separately for two time periods, FYs 2003-2010 and 2011-2014 (Figure A.1). Model diagnostics for the GAM produced for the different regions and time periods of the Peruvian fishery are shown in Figures A.2-A.7.

2.3.2. Ecuador

GAMs were used to develop a standardized CPUE index for the Ecuadorian longline fishery targeting dorado during FYs 2007-2014. Several different GAMs were explored for the catch data: a negative binomial (NB) GAM for counts of fish (taking effort into consideration) (Figure A.8), and two different GAMs for the CPUE in weight, one based on a gamma distribution with log link and the other based on a lognormal distribution (Figures A.9-A.10). The NB GAM fitted to the count data had the following form for the right side of the model equation:

= year-month effect + 2-D spatial smooth surface + linear term for log(effort)

where effort is in number of hooks and the spatial smooth surface is a function of the latitude and longitude of the fishing location. The two GAMs for CPUE in weight had the same form for the right side of the model equation:

= year-month effect + 2D spatial smooth surface.

For the CPUE models, a small constant (a value slightly lower than the lowest non-zero CPUE value) was added to the CPUE values before fitting the models, because only 1.6% of trips that used dorado hooks had no catch of dorado; delta-*F* or zero-inflated models were not considered at this point because the percentage of zero-value observations is so small. After reviewing the model diagnostics (Figures A.11-13), and assuming that the weight data are more accurate than the count data, the gamma model was selected. Judging by the generalized cross-validation score, the gamma distribution was a better fit to the CPUE data than the lognormal distribution, but not by percent deviance explained or adjusted R^2. However, diagnostic plots for the gamma model looked slightly better than for the lognormal model, and the gamma distribution has the advantage that it does not require a bias correction to obtain the back-transformed CPUE predictions. Nonetheless, all three models appeared to suffer from a similar problem: they overestimated at lower values and underestimated at the highest values. However, this is not surprising, given the variance formulations for all three distributions. In future research, other distributions could be explored, including a right-truncated distribution (which would de-emphasize the very largest catches) and mixture distributions to try to better capture the largest catches without affecting the fit to smaller catches. These data, both counts and CPUE (weight), are too overdispersed for the NB/gamma/lognormal distributions, given the available predictors. It is noted that the slope of the linear term for log(effort) in the NB model was different from 1.0 (estimated slope = 0.455, SE = 0.0338; a slope estimate of ≈ 1.0 would correspond to log(effort) as an offset). The standardized indices computed from these three models were a) data-weighted for the NB GAM; and b) area-weighted for the gamma and lognormal GAMs.

There are differences in the standardized indices obtained from different GAMs (Appendix A). As described above, the standardized CPUE derived from the gamma model was chosen as the best available index of relative abundance for calibrating the stock assessment model for dorado (Figure 5a). The CPUE mainly reflects the decay of a cohort of dorado over time (months) year after year.

2.4. Length-composition data

Length-composition data from the dorado catches were obtained from Peruvian, Ecuadorian, and IATTC sources. These data are typically considered to inform the stock assessment model about the selectivity of the different fisheries and cohort strength. The length-composition data from different fisheries are described below.

2.4.1. Peru

Dorado length-composition data, collected by IMARPE at the principal ports where Peruvian artisanal fisheries unload their catches, are available for FYs 2004-2014, but not separated by sex. Sampling was mainly opportunistic, since it depends on the availability of dorado and the logistics of access to the catches for sampling. Length frequencies of dorado were taken in fork length to the next-lowest centimeter. For this stock assessment, only the length-composition data for which monthly information is available are used (FY 2007-2014; Figure 6a). Although these data are very sparse over the years (Figure 6a), they can be informative about the size selectivity of dorado by the Peruvian fishery.

2.4.2. Ecuador

Dorado length-composition data from Ecuadorian artisanal fisheries were collected at the ports of Esmeraldas, San Pablo de Manta, and Anconcito, mainly by SRP samplers, who record fork length, total weight, and sex (Martínez-Ortiz and Zúñiga-Flores, 2012). Some size data collected by fishery observers are also available. For this assessment, only monthly length-composition data for FYs 2008-2014, by sex, from artisanal fisheries targeting dorado were used.

The Ecuadorian length-composition data show the clear dominance and progression of a single cohort of dorado over the months of each fishing year (Figure 6b). The smallest sizes of dorado (40-60 cm FL) are recruited to the fishery as early as June-July, and this new cohort is then targeted by the fishery until the end of the fishing season, around March-April. The mean length of the fish in the catches gradually increases as the fishing season progresses and the fishery targets an individual cohort growing in size (Figure 6b). There is a sharp drop in the mean size of the fish in the catches at the end of the fishing season, as the recruits of the following cohort enter the fishery.

2.4.3. Tuna purse-seine fishery

Since 1993, IATTC observers have estimated the size composition of the bycatches of dorado in the tuna purse-seine fishery by classifying the fish into three size categories (0-30 cm, 31-60 cm, >60 cm) (Figure 6c). Although there are concerns about the reliability of these estimates, they were included in the assessment model as an approximation of the selectivity of dorado by the tuna purse-seine fishery (FYs 2007-2014).

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological information

Defining the biological parameters is a first important step in the construction of any stock assessment model. The biological assumptions defined in the dorado stock assessment model are described below.

3.1.1. Growth

Goicochea *et al.* (2012) was adopted as the best available study for defining the age and growth parameters for dorado. According to this study, which used an age determination technique based on counts of microincrements in otoliths collected from dorado caught in northern Peruvian waters, growth of dorado is almost linear during the first year of life, reaching about 80 cm FL at 1 year of age. The asymptotic length parameter is estimated at 128 and 147 FL for females and males, respectively. The growth curves estimated in this study for females and males are assumed in the stock assessment model (Figure 7a).

Another important component of growth used in age-structured statistical catch-at-length models is the variation in length-at-age. Information on the variability of the length-at-age can be obtained from age-at-length data, which are available from Goicochea *et al.* (2012). Unfortunately, the dorado samples were not collected randomly, but rather to cover a range of sizes to provide information on mean length-at-age. Therefore, the otolith data are not the best basis for a reliable measurement of variation of length-at-age. The parameters that define the variation of the length-at-age were estimated from inspection of identifiable cohorts in the length-composition data. These estimates were fixed in the stock assessment model (Figure 7b).

The length-weight relationships determined by Zúñiga-Flores (2014) were used to convert lengths to weights in the current stock assessment (Figure 8). The study presents length-weight relationships obtained from fish of both sexes sampled at different ports in Ecuador. For this assessment, the relationships estimated for the ports of Santa Rosa and Anconcito were used. These ports are closer to the main southern fishing grounds exploited by the Ecuadorian fleet, but most importantly, closer to the areas exploited by Peruvian artisanal fisheries where the majority of the removals take place.

3.1.2. Natural mortality (*M*)

Estimates of *M* for dorado have been produced using indirect methods (Martínez-Ortiz and Zúñiga-Flores, 2012; Zúñiga-Flores, 2014). However, these estimates vary greatly (0.43-2.5 yr^{-1}) depending on the methodology used. An *M* value of 1 yr^{-1} is considered reasonable to use in the dorado stock assessment. For a virgin (F=0) or heavily exploited population (F=2), M=1 allows for some survivorship beyond 1 year of age (Figure 9).

3.1.3. Recruitment and reproduction

The dorado maturity ogive estimated by Zúñiga-Flores (2014) was used in the assessment. Recruitment is assumed to be independent of the spawning stock size because dorado is a highly fecund pelagic spawner. In the parameterization of the Beverton-Holt stock-recruitment relationship used in the stock assessment model (see Section 4), this assumption is defined by fixing the steepness parameter (h) at 1.

4. MODEL STRUCTURE CONFIGURATIONS

The Stock Synthesis model (SS - Version 3.24f; Methot and Wetzel 2013) was used to assess the status of dorado in the South EPO. It consists of a catch-at-length, age-structured, integrated (fitted to many different types of data) statistical stock assessment model. It is fitted to the observed data (indices of relative abundance and size compositions) by finding a set of population dynamics and fishing parameters that maximize a penalized likelihood, given the amount of catch taken by each fishery. The underlying concept of the model is that monthly declines in the CPUE are explained by the catch, and therefore provide information on absolute abundance, as assumed in standard depletion estimators (Maunder *et al.* 2015).

The principal assumptions and parameters for the current stock assessment of dorado in the South EPO are described in Section 3. The following parameters were assumed to be known:

1. Mean length-at-age, and variability of the length-at-age (Figure 7b);
2. Length-weight relationship (Figure 8);
3. Natural mortality rate (M = 1 yr^{-1} for both sexes);
4. Sex ratio of age-0 fish (post-larval) (0.5);
5. Length-specific maturity curve (Figure 10);
6. Steepness (h) of the stock-recruitment relationship (h = 1).
7. The CPUE time series of the Ecuadorian artisanal fishery was chosen as the most reliable index of abundance to calibrate the stock assessment model. For this reason, its coefficient of variation (CV) was fixed at 0.2.
8. Female selectivity curves for the Peruvian and Ecuadorian fisheries, which catch larger dorado, are assumed to be asymptotic. Males are allowed to have a lower selectivity than females and to have dome-shape selectivity. The selectivity of the purse-seine bycatch fishery was assumed to be asymptotic.

The following parameters were estimated:

1. **Recruitment** at age zero (post-larval) occurring during December-January of every year in the 2007-2014 period (includes estimation of virgin - or average - recruitment and monthly temporal recruitment anomalies).
2. **Catchability coefficients for the Ecuadorian CPUE time series** used as the main index of abundance. The availability of dorado may be strongly linked to environmental conditions, which are very dynamic off Ecuador and Peru, where most of the dorado catches are taken, and this may affect catchability of dorado by the fishing fleets on a yearly basis. Therefore, catchability (Q) is assumed to be time-varying, with one catchability parameter estimated for each fishing year (which mainly applies to a single cohort).
3. **Parameters defining the selectivity curves** for the three fisheries defined in the model. Since length-composition data for dorado caught by the Ecuadorian fisheries are available by sex, selectivity curves are estimated for both sexes separately. For Peru, sexes are pooled in the length-composition data, so there is no information on the sex composition of the catch; therefore, the selectivity of males is fixed at the offset between males and females as estimated for the Ecuadorian data from an exploratory run.
4. **Initial population size and age structure**. The starting conditions of the assessment cannot be considered as unfished because there is a history of catch prior to the period modelled in the assessment. Stock Synthesis allows an initial fishing mortality to be estimated, so that the model takes into account catches before the model starts. In this assessment, one initial fishing mortality parameter is estimated (for Peru, which dominates the catches). This is not intended to describe any particular process in the dynamics of the fishery, or mean that all the early catch is assigned to Peru, it just provides a way to start the model parsimoniously from a fished condition.

An important decision that needs to be made in integrated statistical stock assessment models is the relative weighting assigned to the different data components. Francis (2011) argues that abundance information should primarily come from the indices of abundance (CPUE) and not from composition data. Following this approach, the size compositions of the different fisheries were down-weighted so that the Ecuadorian CPUE is the main dataset driving the population dynamics and defining absolute scale (R_0) in the model. Multiplicative weighting factors (λ (lambda)) were applied to the likelihoods of the composition data, as follows: 0.05 for Peru, 0.5 for Ecuador, and 0.005 for the tuna purse-seine fishery. Thus, the highest weighting is given to the Ecuadorian sex-specific length-composition data, and the lowest to the IATTC length-composition data.

There is uncertainty in the results of the current stock assessment, because the observed data do not perfectly represent the population of dorado in the South EPO, and also in the model, which may not perfectly represent the dynamics of the dorado population or of the fisheries that operate in the EPO. Uncertainty is expressed as approximate confidence intervals and CVs, which were estimated under the assumption that the model does perfectly represent the dynamics of the system. Since it is unlikely that this assumption is satisfied, these values may underestimate the amount of uncertainty in the results of the current assessment. The model structure uncertainty is investigated in several sensitivity analyses.

The important aspects of the base case assessment (1) and the three sensitivity analyses (2-4) can be summarized as follows:

1. **Base case assessment**: steepness of the stock-recruitment relationship = 1 (no relationship between stock and recruitment); mean length-at-age, and the parameters that define the variability of the length-at-age, are fixed; fitted to CPUE time series for Ecuadorian artisanal fishery; asymptotic length-based selectivities for females caught by the Ecuadorian and Peruvian fisheries; down-weighted size composition data for all fisheries (λ = 0.05 for Peru, 0.5 for Ecuador, 0.005 for the tuna purse-seine fishery; see above).
2. **Sensitivity to alternative natural mortality (*M*) values**

   M values between 0.1 yr^{-1} and 1.6 yr^{-1} were used as alternatives to the *M* of 1 yr^{-1} assumed in the base case. This range of alternatives is partially based on the wide range of reported *M* values for dorado, from 0.43 yr^{-1} (Zúñiga, 2014) to 2.5 yr^{-1} (Hoening method applied to data from Zúñiga, 2009).
3. **Sensitivity to time-varying catchability**

   The base case model estimates time varying catchability (*Q*) for Ecuadorian CPUE. An alternative analysis was conducted with catchability estimated as a single parameter with no time-varying deviates (*Q*notv).
4. **Sensitivity to alternative selectivity curves**

   The base case assumes that the selectivity functional form is asymptotic. We allowed selectivity to be dome-shaped in the Peruvian fishery, where selectivity is allowed to be lower for larger fish.

5. RESULTS

5.1. Base case model

5.1.1. Model fit

The model produces a reasonably good fit to the Ecuadorian CPUE, which was chosen as the main index of abundance for calibrating the model (Figure 11a). For all years, the model is able to capture the CPUE decline, which mainly measures the monthly decay of a single cohort due to natural mortality and fishery exploitation. In general, the model captures the high CPUE values at the start of the fishing season (around September), and follows its rapid decline as the season progresses before it tapers off around April. However, the quality of the model fit varies among years, particularly at the start and end of the fishing season (Figure 11b). In some years (FYs 2011 and 2013, for instance), the model is unable to capture the high CPUE values at the start of the season. Likewise, it is unable to fit the lower CPUE values at the end of the season for most years. This may be caused by a model misspecification that needs to be resolved in the future. For example, rapid changes in availability as the dorado move in and out of the fishing grounds (Martínez-Ortiz *et al*., 2015) or different timing of recruitment from year to year. Such processes could be better specified in the model. Improvements could be made in the future by using the time-varying selectivity/seasonal recruitment options in Stock Synthesis.

Although, as explained above, the CPUE data from Peruvian fisheries were not considered reliable enough for inclusion in the stock assessment model at this stage, they were included in the model so that comparisons could be made between trends in these data and the model predictions of relative abundance obtained from fitting to the Ecuadorian CPUE data alone. It is remarkable that the CPUE trends observed in the three fishing regions exploited by the Peruvian fisheries in the late period (2011-2014) are reasonably consistent with the model fit to the Ecuadorian CPUE (Figure 11c), but this is not surprising considering that both fisheries exploit the same dorado stock and overlap in space, at least at some point during the fishing season. It also supports the belief that the quality of the data collected from Peruvian artisanal fisheries has improved since 2010. This improvement should continue, in particular by obtaining georeferenced data (latitude and longitude) for the catch and effort records from fishing trips. This will allow space to be dealt with explicitly in the CPUE standardization, rather than separating by principal port of landing, a proxy for geographic area of operation.

The model fit to the length-composition data of the Peruvian fishery aggregated for all years is good (Figure 12a). The model fits to the monthly length-composition data from the Peruvian and Ecuadorian artisanal fisheries for dorado, as well as the length-class composition data from the dorado bycatches of tuna purse-seiners, are shown in Appendix B. It also fits very well to the monthly length-composition data from Peru (Figure B.1). In general, the modal peaks for each cohort predicted by the model correspond very well to those observed in the data. This indicates consistency with the mean length-at-age predicted by the growth curve assumed in the model, which was derived from dorado caught by the Peruvian fishery (Goicochea *et al*., 2012). The variability of the length-at-age as predicted by the model is very consistent with that observed in the data, particularly for the larger fish that are caught later in the season. However, the variability of the length-at-age estimated by the model is not consistent with the proportions observed for smaller fish (*e.g.* July-October 2007; Figure B.1).

The model fit to the sex-specific length-composition data of the Ecuadorian fishery aggregated for all years is good for both sexes (Figure 12b). The fit to the monthly length-composition data for Ecuador is reasonably good for most months, particularly the months in which most of the catch is taken (September-February); however, in some years there are misfits to the main modes in the data. In addition, the model produces poor fits for other months, particularly between April and August (Figure B.3). This could be the result of several processes. First, the model does not estimate growth, which is fixed at the growth curves for dorado caught by the Peruvian fishery (Goicochea *et al.* 2012). Although there is information from Ecuador on length-at-age, it was not included in the assessment because the ages were estimated using a different method based on scale readings, and there was no rigorous cross-comparison study evaluating both age determination techniques (otoliths versus scales). Estimating growth inside the model could improve the model fits to the length-composition data for all fleets. Second, there could be intra-cohort differences in growth that are not accounted for in the model. Third, the poor fits at the beginning or end of the fishing season could be a result of changing availability or selectivity as the fish start to become available to the fishery or become dispersed at the end of the fishing season. There could be other processes, or a combination of processes, that are responsible for these misfits. However, the fact that fits are good when the data are aggregated for all years and both sexes (Figure 12b), and also good for the months in which most of the catch is taken indicates that the model is removing fish at sizes consistent with the data.

The estimated selectivity curves for dorado for different fisheries are shown in Figure 13.

5.1.2. Recruitment and biomass

The base case estimates of the annual recruitment of dorado in the South EPO during FYs 2007-2014 are shown in Figure 14. There is variability in the inter-annual recruitment. Although the parameter that defines recruitment variability (σ_{-R}) is fixed in the assessment (σ_{-R} = 0.6), the root mean square error (R_{mse}) of the estimated recruitment deviations is very similar (0.56). Recruitment deviates were unconstrained (*i.e.* no penalties on their deviation), suggesting that the assumed recruitment variability is similar to that supported by the data. Since catch and length-composition data for the FY 2015 are not available for the assessment, it is not possible to reliably estimate recruitment in 2014, which begins to occur at the end of the year (December and January, as defined in the model). For this reason, the 2014 recruitment is estimated at average conditions (virgin recruitment, R_0). Within the historic period of the assessment (FYs 2007-2014), the highest and lowest annual recruitments were estimated to have occurred in FYs 2008 and 2009, respectively. In the stock assessment model, larval recruitment (at age zero) is estimated to occur during December-January, half-way through the fishing year (July-June). Therefore, the annual cohorts are mainly recruited to, and progress through, the fishery during the following fishing year. Accordingly, the highest and lowest recruitments were each followed by the highest and lowest annual catches observed, in FY 2009 and 2010, respectively (Figure 4d).

There are pronounced seasonal (monthly) fluctuations in the biomass of dorado in the South EPO (Figure 15). On average, the annual summary biomass (the total biomass of fish over 1 month old) peaks late in the calendar year (September-December), and rapidly declines to its lowest values around May-June of the following year. This pattern generally represents the total weight of a cohort, which increases initially because growth rates are higher than total mortality, and then declines as the growth rates decrease and/or the mortality increases. According to the base case, and while measured at the start of the spawning season (November, as defined in the model), the summary biomass of dorado has remained quite stable during the historic period of the assessment, averaging about 90,000 t per year (Figure 15). Likewise, the spawning biomass, also measured at the start of the spawning season, has remained very stable over the historic period of the assessment, averaging about 18,000 t; Figure 16). The precision of the spawning biomass estimates is very high (average CV = 0.1).

5.1.3. Fishing mortality (*F*)

The base case estimates of the annual fishing mortality rate (*F*) varied from 0.53 to 0.85 during 2007-2014 (Figure 17a). The instantaneous monthly *F* by fishery is shown in Figure 17b; note that these values are on an annual scale.

5.1.4. Model diagnostics

5.1.4.a R_0 profile

Likelihood profiling of virgin recruitment, a method for diagnosing over-weighting of size-composition data, data conflicts, and model misspecification, was applied to the dorado assessment. Virgin recruitment (R_0; the equilibrium recruitment in the absence of fishing) is a common parameter in stock assessment that scales the population size. Information on population size comes from two main sources: 1) how catch changes indices of relative abundance; and 2) how the relative abundance changes in consecutive ages of age-composition data (or appropriately adjusted length-composition data). Francis (2011) argues that abundance information should primarily come from indices of abundance, and not from composition data. The diagnostic indicates over-weighting of composition data or model misspecification when the composition component of the likelihood profile for R_0 provides substantial information about R_0 and conflicts with information from the relative abundance index data. The model misspecification should be corrected (*e.g*. the selectivity curve for the fishery related to those composition data should be modified) or the weighting of the composition data reduced, so that they have little information on R_0.

A likelihood profile on the average recruitment (R_0) showed that data types diverge on their information about abundance levels (Figure 19). The CPUE data support a lower R_0 than the length-composition data, but both CPUE and length-composition data have very steep likelihood gradients at values not much lower than the R_0 estimated in the base case (Figure 19). The length-composition data support higher R_0 values, but there is not much information from length composition at large R_0 values, *i.e.*, the likelihood is very flat. The profile was very unstable, with convergence issues for a number of intermediate values. The divergence in support between CPUE and length-composition data suggests that some misspecification in the base model is likely, and more processes could be added to the modelling of CPUE and length data (*e.g.* estimating growth internally in the stock assessment model rather than fixing to an externally derived curve, alternative selectivity patterns). However, adding processes with estimable parameters may increase the convergence issues. Regardless of potential improvements which could be made in the future, in the base case model the maximum likelihood estimate of R_0 (lowest negative log-likelihood) is driven mainly by the CPUE data, not the composition data. Not letting the length-composition data dominate the CPUE data in the model fit was the main desired effect for the specific data weighting assigned to the different datasets (indices of abundance versus composition data).

5.1.4.b Age-structured production diagnostic

The age-structured production model (ASPM) diagnostic was proposed by Maunder and Piner (2015) as a way to: (i) further evaluate model misspecification, (ii) ascertain the influence of composition data on the estimates of absolute abundance and trends in abundance, and (iii) check whether catch alone can explain the trends in the indices of abundance. The diagnostic produces estimates of abundance similar to those of the full integrated analysis, suggesting that there is information in the indices of relative abundance about absolute abundance and how it is depleted by the catch (Figure 20). This is expected because the monthly CPUE usually includes a single cohort and is akin to a depletion-based estimator. The ASPM estimates lower and more variable abundance. Annual recruitment can be estimated in the diagnostic (ASPM-Rdev) because the depletion estimation is essentially applied to each cohort to estimate its initial strength. The estimates of biomass are lower, but the variation in biomass is about the same as in the full integrated model. These results suggest that the composition data are having some influence on the estimates of absolute abundance, but not as much as has been found in many other assessments of short-lived species that lack the strong signal of cohort depletion year after year observed in the dorado data and stock assessment model.

6. MANAGEMENT QUANTITIES

6.1. Base case model

At present, there are no reference points (target or limit) defined for dorado in the EPO. For tuna, the IATTC evaluates stock status on the basis of calculations based on spawning biomass and the maximum sustainable yield (MSY). In this exploratory stock assessment, some spawning biomass and MSY-related quantities are presented, and their potential applicability to managing dorado in the EPO is discussed.

The spawning biomass ratio (SBR; the ratio of the current spawning biomass to that of the unfished stock), described by Watters and Maunder (2001), has been used to define reference points in many fisheries. It has a lower bound of zero. If it is near zero, the population has been severely depleted, and is probably overexploited. If the SBR is 1, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than 1, it is possible that the stock has entered a regime of increased production.

This SBR definition of Watters and Maunder (2001) can be considered a *static* quantity, since it is related to equilibrium status of the unfished stock. Hereafter, to differentiate it from the *dynamic* SBR concept described below, this *static* SBR measure is referred to as *s*SBR. The *s*SBR for dorado was computed as the ratio of the spawning stock biomass (*S*) in a given year to that of the unfished stock, both measured at the start of the spawning season (November). The *s*SBR estimates produced by the base case model are quite stable over the assessment period, averaging about 0.20 (Figure 18). This value coincides with the base case model estimate for *s*SBR corresponding to the MSY ($sSBR_{MSY} = S_{MSY}/S_{F=0}$).

Various studies (*e.g.* Clark 1991, Francis 1993, Thompson 1993, Mace 1994) suggest that some fish populations are capable of producing the MSY when the *s*SBR is about 0.3 to 0.5, and others are not capable of producing the MSY if the spawning biomass during a period of exploitation is less than about 0.2. Unfortunately, the types of population dynamics that characterize tuna stocks and other very highly productive species such as dorado were generally not considered in those studies, and their conclusions are sensitive to assumptions about the relationship between adult biomass and recruitment, natural mortality, and growth rates. The effect of misspecifying the SBR that produces MSY and using MSY-based reference points for management could be evaluated by simulation work similar to that of Valero *et al.* (2016).

A *dynamic* concept of SBR (Wang *et al.* 2009), hereafter referred to as *d*SBR*,* can also be considered for dorado. Specifically, SBR can be computed as the ratio of the spawning biomass at the start of the spawning season with fishing to that without fishing. Using *d*SBR produces higher SBR estimates than those computed using *s*SBR (Figure 21).

Precautionary reference points, as described in the FAO Code of Conduct for Responsible Fisheries and the United Nations Fish Stocks Agreement, are being widely implemented as guides for fisheries management. The maximum sustainable yield (MSY) is defined as the largest long-term average catch or yield that can be taken from a stock or stock complex with the constant fishing mortality under prevailing ecological and environmental conditions while maintaining recruitment at average levels. The base case estimate for the MSY is 89,211 t, which is about 17% higher the maximum recorded total annual catch of about 76,000 t. However, because the yield curve is flat, the fishing mortality needed to obtain MSY is three times greater than the current fishing mortality (see Section 7).

6.1.1. Sensitivity to alternative model configurations

The results of an analysis of sensitivity to the configuration of the model were summarized in time series of quantities of interest (spawning biomass, SBR, recruitment; Figures 23-26, Table 2).

1. **Sensitivity to alternative natural mortality (*M*) values**

   The base case model assumes an *M* of 1 yr^{-1}, but the likelihood profile over *M* indicates that the CPUE and the length-composition data support lower values of *M*, around 0.6 yr^{-1} (Figure 22, top panel) for the length data and around 0.24 yr^{-1} for the CPUE. Although values as low as 0.43 yr^{-1} have been reported for dorado (Zúñiga-Flores 2014), the values supported by the likelihood profile over *M* are suspect for several reasons. On the one hand, *M* is notoriously difficult to estimate (Lee *et al.* 2011), even in cases with informative data types (such as age compositions) and exploitation histories (long history of exploitation with varying levels of exploitation), neither of which are the case with dorado. On the other hand, the *M* profile is conditional on the model being properly specified and, as discussed above, the R_0 profile indicates some level of model misspecification. Figure 22, bottom panel, shows the expected MSY at different levels of *M*.

2. **Sensitivity to time-varying catchability**

   Estimating catchability (*Q*) as a single parameter with no time-varying deviates results in slightly higher recruitment variability (Figure 23), but the time series of age-0 recruitment (Figure 24), spawning biomass (Figure 25), and SBR (Figure 26), are not markedly different from the base case.

3. **Sensitivity to alternative selectivity curves**

   Allowing the selectivity of the Peruvian fishery to be dome-shaped resulted in estimated dome-shape selectivities, but the results were very similar to the base case model (Figures 23-26).

7. YIELD-PER-RECRUIT ANALYSIS

A yield-per-recruit (YPR) analysis was carried out using the Stock Synthesis model, which makes the YPR analysis consistent with the stock assessment assumptions. The YPR analysis was used to investigate the impact of seasonal closures and minimum legal size (MLS) limits. To implement the YPR analysis, the Stock Synthesis model was first re-run using the fishing mortalities as parameters and checked to ensure that the results were the same as when using the hybrid approach (an efficient method of solving the catch equation) to implement fishing mortality. Using the fishing mortalities as parameters allows the fishing mortality rates to be fixed for the YPR analysis and manipulated to implement the MLS through a knife-edge retention curve. Likewise, the seasonal closures can be manipulated by changing the fishing mortality to zero for the closed months. We investigated MLS of 80, 90, 100, and 110 cm, with mortality rates (chosen arbitrarily for illustrative purposes only) of zero and 30% mortality rates for the fish discarded because they are under the MLS limit. We investigated both delaying the opening of the season and closing the season early. The YPR analysis is conducted using the absolute yield, which is equivalent to MSY because the stock assessment assumes that recruitment is independent of stock size, and all scenarios use the same average recruitment.

The yield curve resulting from the YPR analysis is very flat-topped, and the mortality rates that maximize YPR are about three times higher than the current fishing mortality rates (*F* multiplier ≈ 3) (Figure 27). However, a fishing strategy aimed at maximizing the yield per recruit is not recommended because the yield curve is flat-topped, and increasing fishing mortality by a factor of three would result in small gains in yield. Analyses based on projections with effort remaining at current levels or on implementing management retrospectively might be more useful (see Valero *et al.* 2016). The maximum equilibrium yield could be increased by a moderate amount if an MLS is implemented, even with a discard mortality rate of 30% (Table 3). The discard mortality has a moderate influence on the maximum equilibrium yield. An MLS causes only a small increase in the SBR measured at the time of spawning (November). Seasonal closures have less impact on maximum equilibrium yield, but a larger impact on SBR, than the MLS (Table 4). Delaying the start of the fishing season is more beneficial in terms of both maximum equilibrium yield and the corresponding SBR.

8. FUTURE DIRECTIONS

The following issues related to the stock assessment of dorado in the EPO, listed in no particular order, require further research:

8.1. Growth

Estimate growth inside the stock assessment model, using age and size data not only from Peru but also from Ecuador. This would necessitate a comparison of the different methodologies used in Peru (based on otoliths) and Ecuador (based on scales). Explore potential growth differences between cohorts (cohort-specific growth). A more flexible growth curve may be needed.

8.2. Spatial extent of assessment

Dorado is exploited by fleets of nearly all coastal nations in the EPO, ranging from Chile in the south to Mexico in the north. The current exploratory stock assessment is for the south EPO, as it uses data from Peru and Ecuador only. Further work should consider including data for other fleets from other coastal nations in the south EPO, in particular Chile, which also exploits the resource.

A conventional stock assessment for dorado in the northern EPO - the EPO north of the equator - remains to be developed. Unfortunately, the dorado fishery data available from the northern coastal nations are very limited; total catch and potential indices of abundance (*e.g.* CPUE) in particular are poorly known. A monthly depletion estimator approach (Maunder *et al*. 2015) could be applied and used for management in these data-limited situations if some minimum CPUE data are available.

The degree of connectivity between southern and northern EPO dorado stocks is still poorly known. Therefore, the geographical scale of dorado assessments in the EPO should evolve as knowledge about dorado stock structure in the EPO and beyond improves. As data series from northern EPO States become available, conventional stock assessments could be performed for a potential northern EPO stock or, eventually, an EPO-wide assessment of dorado.

8.3. Integration of stock assessment and alternative management strategies

The quantity, type, and quality of the data available vary greatly among the coastal nations that fish for dorado in the EPO (IATTC 2014). Although limited data may preclude, in some instances, conducting an integrated assessment of the kind presented here, emerging properties of the assessment (*e.g.* strong seasonal trends in CPUE, strong seasonal modal progression in sizes, *etc*.) may allow implementation of simple harvest control rules based on limited data, and management strategies based on available or easily obtainable data could be tested formally in an integrated way with available stock assessments, as in Valero *et al.* (2016).

8.4. Data collection

Improve both the process of collecting the data and the quality of the data collected. For example, georeferencing of catches in Peru may improve the standardization of CPUE. More basic information, such as monthly CPUE and length-composition data, would be very informative. Obtain more information on catch statistics, including removals by recreational fisheries, and estimates of likely unreported catches.

8.5. Tagging

Tagging programs would provide invaluable information, such as independent estimates of fishing mortality, natural mortality, and movements north and south of the Equator, and the data could be integrated with otolith and scale data to estimate growth rates, as in similar analyses done with tuna (Aires-da-Silva *et al*. 2016). Determining the movement, if any, of dorado north and south of the Equator is important for conceptualizing the life history of the species and its potential impact on stock structure in the EPO. Care should be taken in designing tagging programs intended describe long-term movement patterns in a period of rapidly-changing environmental conditions, such as the recent El Niño event, that could result in biased descriptions of dorado movement. For example, in recent years catches of dorado have been lower than usual in Ecuador and higher in Peru, although this assessment assumes all the fish in the area belong to the same stock. Catches have also been lower than in recent years throughout Central America, although it is not yet clear whether these fish form a different stock from those south of the Equator.

8.6. Movement in and out of the fishing area and timing of the movement

Significant questions remain about the process and timing of dorado entering and leaving the fishing area, which are confounded with fishing mortality. A better understanding of this dynamics would enable a better conceptual model of the processes at the start and end of the fishing season, and provide information on how to parameterize stock assessment processes (*e.g.* selectivity and catchability). An important assumption in this assessment is that the resource is fully available to the fishing gear during some part of the year (the dorado fishing season). Violations of this assumption may result in biased results. Tagging studies could be done to investigate such violations.

8.7. Sex ratio differences in the catch

The participants at the 2nd Technical Meeting on Dorado shared information on dorado sex ratios by area. A compilation of the available data was presented and discussed, with a focus on identifying the processes underlying apparent changes in the sex ratios of dorado. It is not clear whether the variability in sex ratios is due to biological (*e.g.* sex ratio at birth, differences in rates of natural mortality), fishery (availability or exploitation rates) or sampling (*e.g.* potential misidentification of immature males and females) processes. The impact of some of these alternatives was explored during the building of the model, and was eventually modelled as males being less selected than females and allowing dome-shaped selectivities for males. However, the underlying causes of the differences in sex ratios are unknown, and more research is needed to identify them.

8.8. Availability or recruitment

It is unclear whether inter-annual differences in CPUE are due mostly to changes in availability, changes in recruitment between years, or a combination of the two. Similarly, intra-annual changes in catchability may be due to movements in and out of the fishing area or temporal variation in the timing of recruitment or growth. More research is also needed on potential drivers of recruitment or changes in availability, such as the potential effects between SSTs and those processes.

REFERENCES

Aires-da-Silva, A., Lennert-Cody, C.E., Maunder, M.N., Román-Verdesoto, M., Minte-Vera, C., Vogel, N.W., Martínez-Ortiz, J., Carvajal, J.M., Guerrero, P.X., and Sondheimer, F. 2014. Preliminary results from IATTC collaborative research activities on dorado in the eastern Pacific Ocean and future research plan. Document SAC-05-11b. Inter-American Tropical Tuna Commission, Scientific Advisory Committee, Fifth Meeting: 1-27.

Aires-da Silva, A. M., Maunder, M. N., Schaefer, K. M., and Fuller, D. W. (2015). Improved growth estimates from integrated analysis of direct aging and tag-recapture data: An illustration with bigeye tuna (*Thunnus obesus*) of the eastern pacific ocean with implications for management. Fisheries Research, 163:119-126.

Dapp, D., Arauz, R., Spotila, J.R., and O'Connor, M.P. 2013. Impact of Costa Rican longline fishery on its bycatch of sharks, stingrays, bony fish and olive ridley turtles (*Lepidochelys olivacea*). Journal of Experimental Marine Biology and Ecology. 448: 228-239.

Francis, R. 2011. Data weighting in statistical fisheries stock assessment models. Can J Fish Aquat Sci. 68: 1124-1138.

Goicochea, C., Mostacero, J., and Moquillaza, P. 2012. Age and growth of *Coryphaena hippurus* (Linnaeus) in the northern Peruvian Sea, February 2010. Inf Inst Mar Perú. 39.

IATTC (2015). Report of the 1st Inter-American Tropical Tuna Commission Technical Meeting on Dorado. Manta, Ecuador, October 14–16, 2014.

Lasso, J., and Zapata, L. 1999. Fisheries and biology of *Coryphaena hippurus* (Pisces: Coryphaenidae) in the Pacific coast of Colombia and Panama. Scientia Marina. 63: 387-399.

Lee, H.H., Maunder, M.N., Piner, K.R. and Methot, R.D., 2011. Estimating natural mortality within a fisheries stock assessment model: an evaluation using simulation analysis based on twelve stock assessments. Fisheries Research, 109(1), pp.89-94.

Maunder, M.N., and Piner, K.R. 2015. Contemporary fisheries stock assessment: many issues still remain. ICES Journal of Marine Science (2015), 72(1), 7–18. doi:10.1093/icesjms/fsu015.

Maunder, M.N., Aires-da-Silva, A., Minte-Vera, C., Lennert-Cody, C., Valero, J.L., and Martínez-Ortiz, J. 2015. A step-by-step illustration of the basis for the monthly depletion estimator in a Stock Synthesis model for dorado. Inter-American Tropical Tuna Commission. 2nd Technical Meeting on Dorado, Lima, Peru, 27-29 October 2015.

Martínez-Ortiz, J., Aires-da-Silva, A.M., Lennert-Cody, C.E., and Maunder, M.N. 2015. The Ecuadorian artisanal fishery for large pelagics: species composition and spatio-temporal dynamics. Plos One. 10.

Martínez-Ortiz, J., and Zúñiga-Flores, *M*. 2012. Estado actual del conocimiento del recurso dorado (*Coryphaena hippurus*) Linnaeus, 1758 en aguas del Oceano Pacifico Suroriental (2008-2011). Informe Tecnico Final del proyeto titulado: "Dinámica de la población: la pesca y la biología del dorado en Ecuador". MAGAP-MSC-EPESPO 2012. 122 pp.

Martínez-Rincon, R.O., Ortega-Garcia, S., and Vaca-Rodriguez, J.G. 2009. Incidental catch of dolphinfish (*Coryphaena* spp.) report by the Mexican tuna purse seiners in the eastern Pacific Ocean. Fish Res. 96: 296-302.

Maunder, M.N., and Punt, A.E. 2004. Standardizing catch and effort data: a review of recent approaches. Fish Res. 70: 141-159.

Methot, R.D., and Wetzel, C.R. 2013. Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish Res. 142: 86-99.

Norton, J.G. 1999. Apparent habitat extensions of dolphinfish, *Coryphaena hippurus*, in response to climate transients in the California Current. Scientia Marina. 63: 239-260.

Palko, B.J.,Beardsley, G.L., and Richards, W.J. 1982. Synopsis of the biological data on dolphin-fishes, *Coryphaena hippurus* Linnaeus and *Coryphaena equiselis*, Linnaeus. NOAA Technical Report NMFS Circular 443. FAO Fisheries Synopsis No. 130.

Patterson, K.R., and Martínez, J. 1991. Exploitation of the dolphin fish *Coryphaena hippurus* L. off Ecuador: analysis by length-based virtual population analysis.

SFP. 2013. SFP Global Sustainability Overview of Pacific Ocean Fisheries that Supply Mahi mahi.

Solano A., A. Tresierra, V. García, C. Goicochea, V. Blaskovic', B. Buitrón & G. Chacón. (2015). Biología y pesquería del perico o dorado *Coryphaena hippurus* en febrero, 2010. Bol. Inst. Mar. Perú. 42(1): 1-46.

Solano-Sare, A., Tresierra-Aguilar, A., García-Nolasco, V., Dioses, T., Marín, W., Sánchez, C., and Wosnitza-Mendo, C. 2008. Biologia y pesqueria del Perico. Instituto del Mar del Perú. 23 pp..

Téllez, R.T. and Caballero, S. (2017). Seasonal variation of dolphinfish stocks (*Coryphaena hippurus*) in the Pacific coast of Colombia. Oceanography & Fisheries, 3(1), pp.1-11

Valero, J.L., Aires-da-Silva, A., Maunder, M.N., Minte-Vera, C.V. and Martínez-Ortiz, J. (2016). Exploratory management strategy evaluation (MSE) of Dorado (*Coryphaena hippurus*) in the South Eastern Pacific

Ocean. Inter-American Tropical Tuna Commission, Scientific Advisory Committee, Seventh Meeting.

Wang, S.P., Maunder, M.N., Aires-da-Silva, A. and Bayliff, W.H., 2009. Evaluating fishery impacts: application to bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean. Fisheries Research, 99(2), pp.106-111.

Zúñiga-Flores, M.S. 2014. Determinación e interpretación de los parámetros poblacionales, edad, crecimiento y reproducción del dorado (*Coryphaena hippurus*) capturado en aguas del Océano Pacifico Sur-Oriental durante 2008-2012. Reporte final de la consultoría para World Wildlife Fund/ ViceMinisterio de Acuacultura y Pesca (MAGAP), Ecuador. 73 pp.

TABLE 1. Fisheries defined for the stock assessment of dorado in the South EPO. LL = longline; PS = purse-seine. Survey: fishery defined in Stock Synthesis with no catch associated with it, but with other data sources available (CPUE in the case of the dorado model).

TABLA 1. Pesquerías definidas para la evaluación del dorado en el OPO sur. LL = palangre; PS = red de cerco. Estudio: pesquería definida en *Stock Synthesis* sin captura asociada, pero con otras fuentes de datos disponibles (CPUE en el caso del modelo de dorado).

	Name	Nombre	Gear / Arte	Fishing years / Años pesqueros
Fishery-Pesquería				
F1	Peru	Perú	LL	2007-2014
F2	Ecuador	Ecuador	LL	2007-2014
F3	PS-bycatch	PS-captura incidental	PS	2007-2014
Survey-Estudio				
S1	Peru_N-early	Perú_N-temprana	LL	2007-2010
S2	Peru_N-late	Perú_N-tardía	LL	2011-2014
S3	Peru_C-early	Perú_C- temprana	LL	2007-2010
S4	Peru_C-late	Perú_C- tardía	LL	2011-2014
S5	Peru_S-early	Perú_S- temprana	LL	2007-2010
S6	Peru_S-late	Perú_S- tardía	LL	2011-2014

TABLE 2. Model summaries for main analyses of sensitivity to different configurations of the base case (see Section 6.1.1). *M*: natural mortality; *Q*notv: catchability, no temporal variation; Dome: dome-shaped size selectivity curve for the Peruvian fishery. *S* is the spawning stock biomass, and *B* is the summary biomass (defined as the biomass of fish 1+ months old), in metric tons (t). MSY is the estimated maximum sustainable yield, in metric tons.

TABLA 2. Resúmenes del modelo de los principales análisis de sensibilidad a distintas configuraciones del caso base (ver sección 6.1.1). *M*: mortalidad natural; *Q*notv: capturabilidad, sin variabilidad temporal; Dome: curva de selectividad por tamaño en forma de domo para la pesquería peruana. *S* es la biomasa de la población reproductora, y *B* la biomasa sumaria (definida como la biomasa de peces de 1+ meses de edad), en toneladas (t). RMS es el rendimiento máximo sostenible estimado, en toneladas.

	Base case Caso base	Sensitivity analyses-Análisis de sensibilidad			
		1		2	3
		***M*_0.43**	***M*_1.6**	***Q*notv**	**Dome**
S_0 (t)	90,045	205,001	62,015	85,577	89,952
B_0 (t)	254,687	545,880	192,791	242,067	254,429
S_{MSY} (t)- S_{RMS} (t)	17,987	15,336	22,351	17,196	17,893
MSY (t)-RMS (t)	89,211	79,502	100,530	84,490	89,010
S_{2014}/S_0	0.22	0.08	0.38	0.23	0.22
S_{MSY}/S_0- S_{RMS}/S_0	0.20	0.07	0.36	0.20	0.20
S_{2014}/S_{MSY}- S_{2014}/S_{RMS}	1.10	1.00	1.07	1.16	1.11

TABLE 3. Results of the yield-per-recruit analysis with different minimum legal sizes (MLSs) and discard mortality rates.
TABLA 3. Resultados del análisis de rendimiento por recluta con diferentes tallas legales mínimas (TLM) y tasas de mortalidad de descartes.

MLS-TLM (cm)	Discard mortality rate Tasa de mortalidad de descartes	MSY RMS	% base MSY % de RMS base	SBR
None-Ninguna	0	89,770	100	0.18
80	0	105,791	118	0.19
80	0.3	99,241	111	0.18
90	0	115,300	128	0.20
90	0.3	101,948	114	0.19
100	0	116,348	130	0.21
100	0.3	98,942	110	0.19
110	0	108,835	121	0.21
110	0.3	94,924	106	0.19

TABLE 4. Results of the yield-per-recruit (YPR) analysis with different months of closure. (**NOTE**: these analyses were conducted using an early version of the base case assessment model, and therefore do not exactly match the results of the other YPR analyses).
TABLA 4. Resultados del análisis de rendimiento por recluta (RPR) con diferentes meses de veda. (**NOTA**: se realizaron estos análisis con una versión temprana del modelo de evaluación de caso base, y por lo tanto no concuerdan exactamente con los resultados de los otros análisis de RPR).

Closure	Veda	MSY	% base MSY	SBR
		RMS	% RMS base	
None	Ninguna	72,326	100	0.17
Jan-May	Ene-May	75,138	104	0.25
Jan-Jun	Ene-Jun	76,882	106	0.25
Jan-Jul	Ene-Jul	78,169	108	0.24
Jan-Aug	Ene-Ago	77,756	108	0.22
Jan-Sep	Ene-Sep	74,653	103	0.19
Aug-Dec	Ago-Dic	71,647	99	0.15
Sep-Dec	Sep-Dic	72,285	100	0.16
Oct-Dec	Oct-Dic	72,540	100	0.17

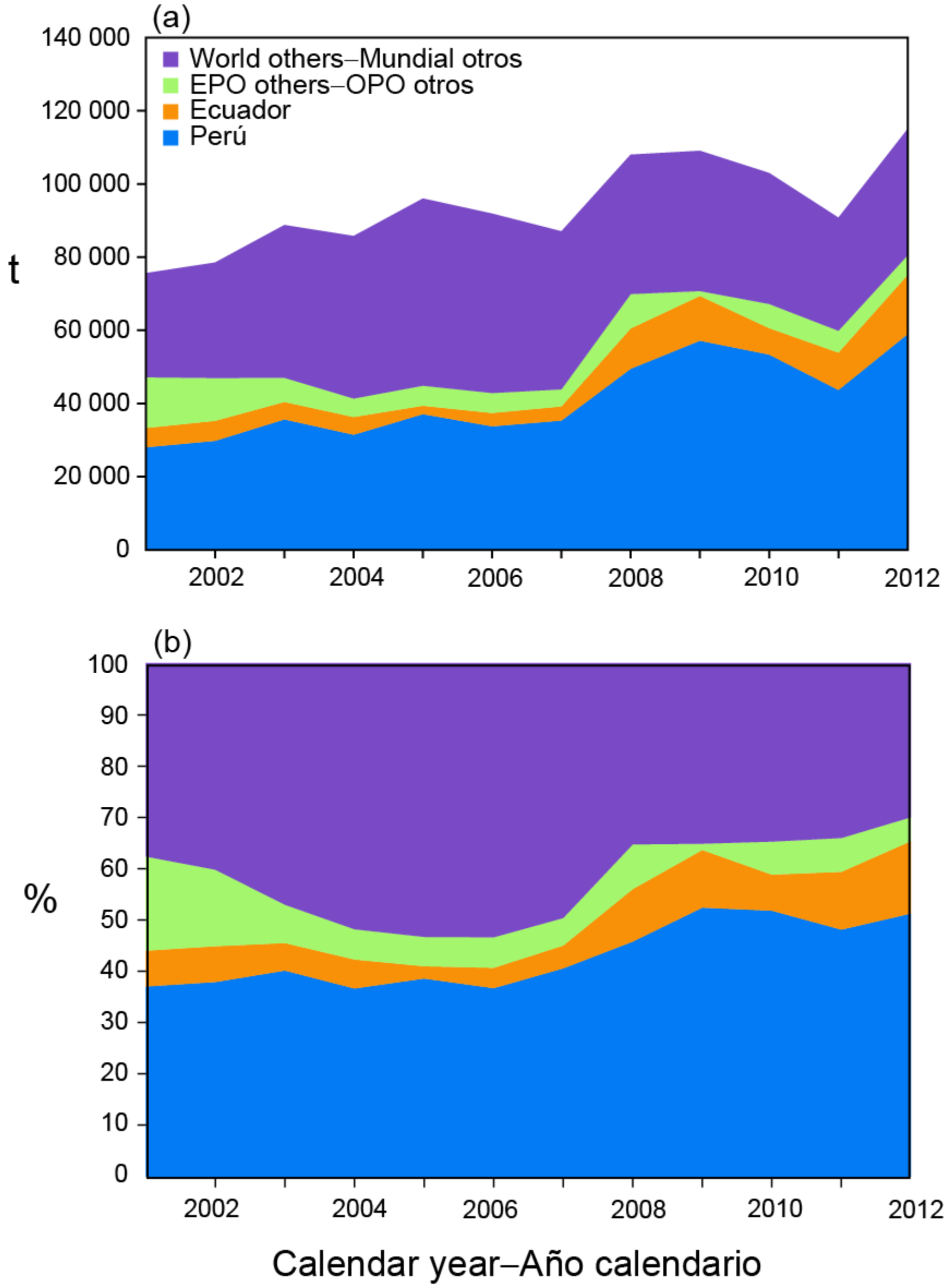

FIGURE 1. World catches of dorado, 2001-2012, by weight (a) and percentage (b). Source: Aires-da-Silva *et al.* (2014). Catch statistics were compiled from the following sources: 1) FAO FishStat database, 2) US import trade records (United States International Trade Commission, USITC), and 3) statistics reported by EPO coastal nations.

FIGURA 1. Capturas mundiales de dorado, 2001-2012, por peso (a) y porcentaje (b). Fuente: Aires-da-Silva *et al.* (2014). Las estadísticas de captura fueron compiladas de las siguientes fuentes: 1) base de datos FishStat de FAO, 2) registros de importaciones a EE.UU. (United States International Trade Commission, USITC), y 3) estadísticas reportadas por naciones costeras del OPO.

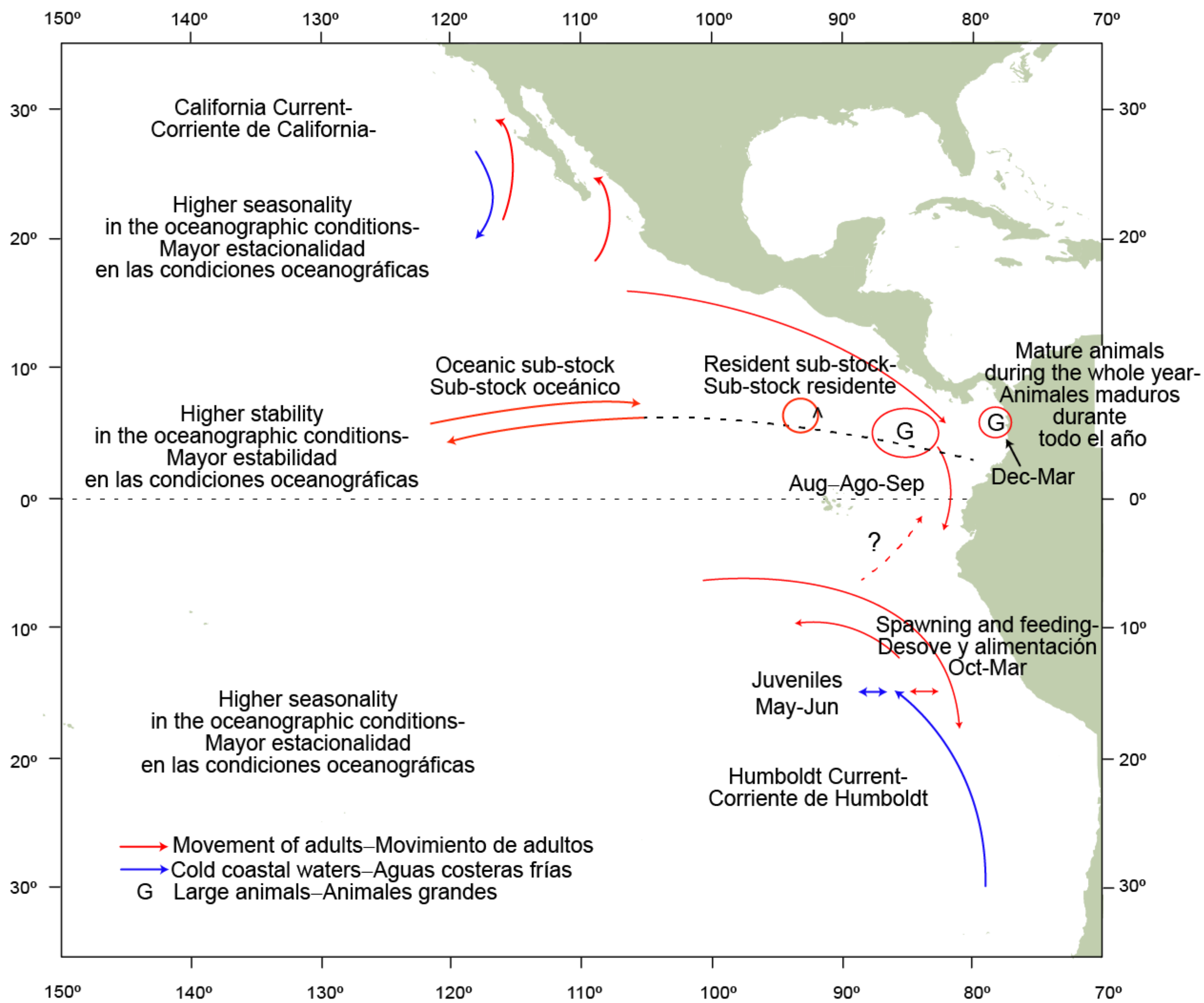

FIGURE 2a. Conceptual model of the movements and spatial distribution of dorado (2nd Technical Meeting on Dorado, 2015).

FIGURA 2a. Modelo conceptual de los desplazamientos y la distribución espacial del dorado (segunda Reunión Técnica sobre Dorado, 2015).

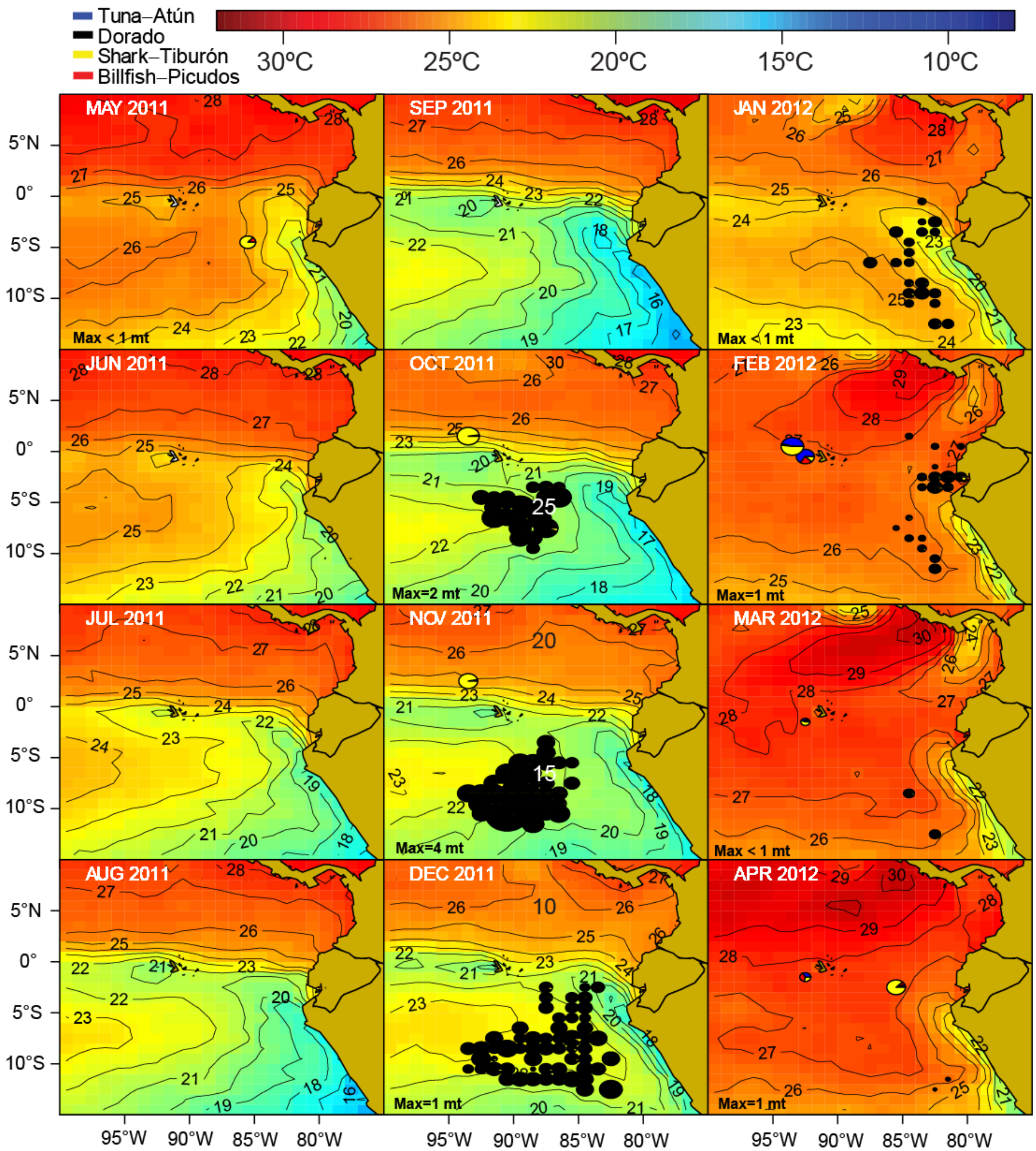

FIGURE 2b. Sea-surface temperatures and spatio-temporal distribution of the catches by the Ecuadorian artisanal longline fishery targeting dorado during the 2011 fishing year (from Martínez-Ortiz *et al.* 2015).
FIGURA 2b. Temperatura superficial del mar y distribución espaciotemporal de las capturas de la pesquería palangrera artesanal ecuatoriana dirigida al dorado durante el año pesquero 2011 (de Martínez-Ortiz *et al.* 2015).

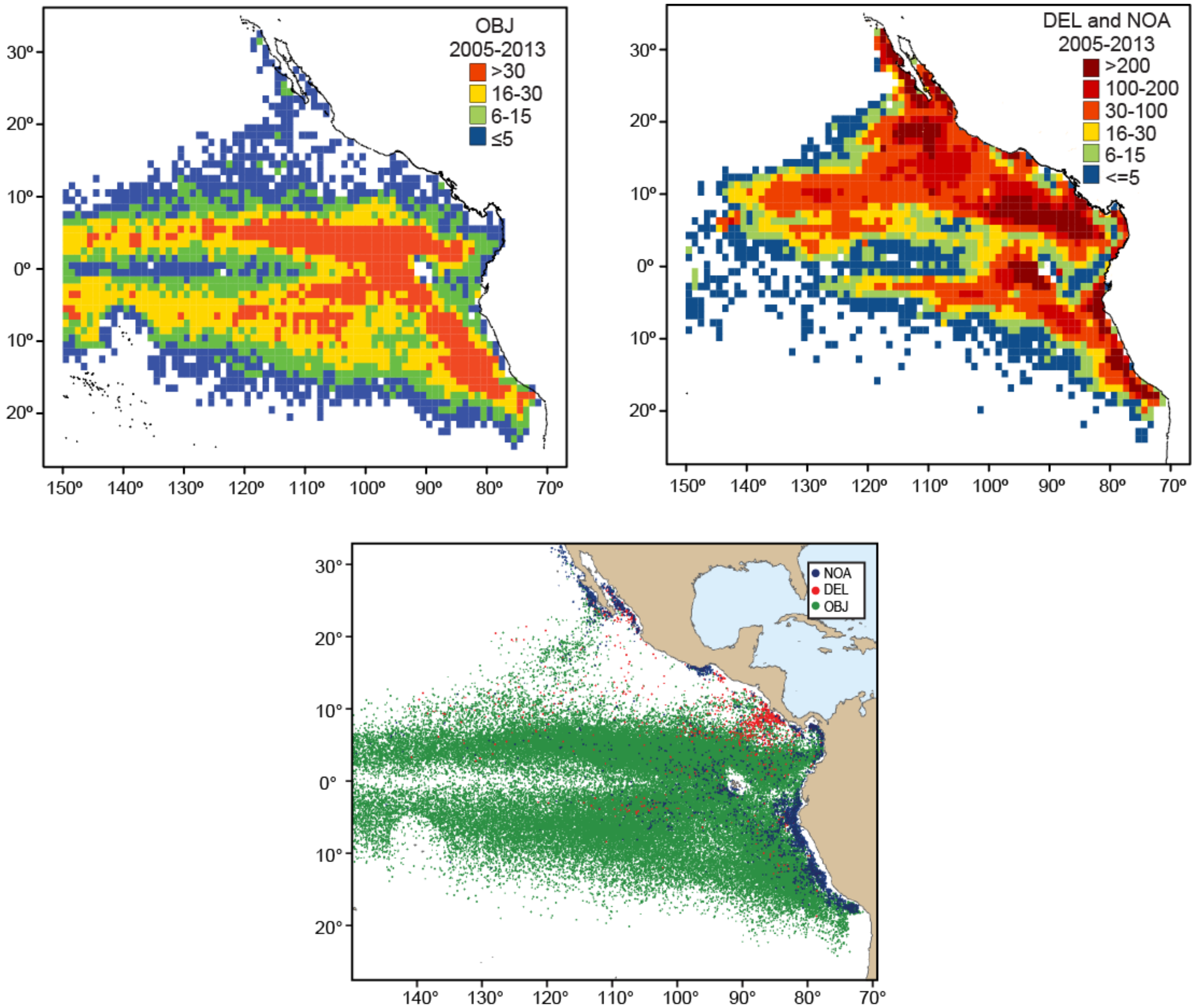

FIGURE 2c. Top: Number of floating-object (OBJ) sets (left panel) and dolphin (DEL) and unassociated (NOA) sets (right panel) by large purse-seine vessels, by 1° area, 2005-2013. Bottom: Spatial distribution of tuna purse-seine sets with capture of dorado, by set type, 1993-2013.

FIGURA 2c. Arriba: Numero de lances sobre objetos flotantes (OBJ; panel izquierdo) y sobre delfines (DEL) y no asociados (NOA) (panel derecho), por área de 1°, 2005-2013. Abajo: Distribución espacial de lances atuneros de cerco con captura de dorado, por tipo de lance, 1993-2013.

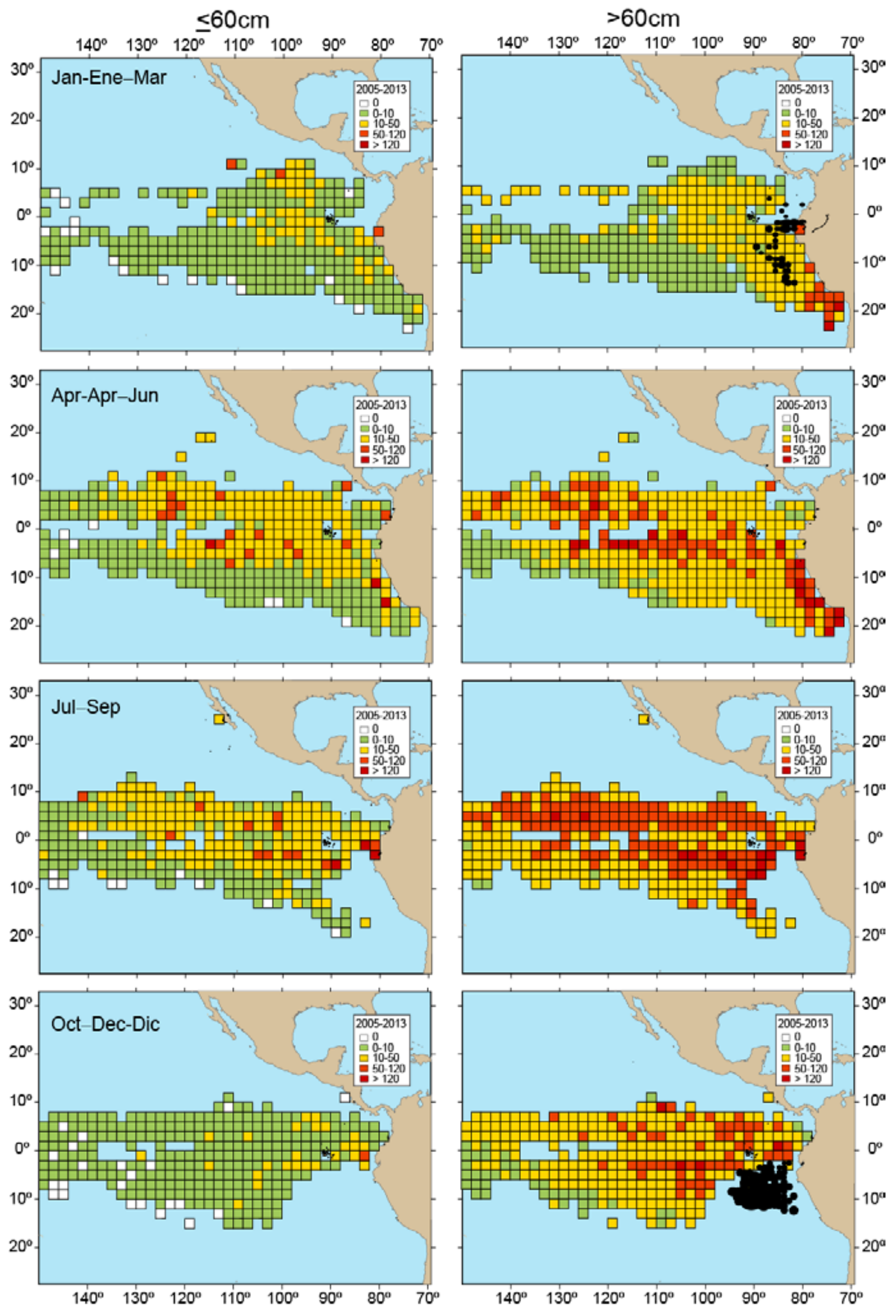

FIGURE 2d. Distribution, by 2°x2° area and quarter, of the average catch per set, in numbers of fish, of small (≤ 60 cm, left panels) and large (> 60 cm, right panels) dorado in the purse-seine fishery on floating objects (OBJ) during 2006-2013 (IATTC observer data base). The black dots represent the catches by the Ecuadorian artisanal longline fishery targeting dorado during the 2011 fishing year (from Martínez-Ortiz *et al.* 2015).

FIGURA 2d. Distribucion, por área de 2°x2° y trimestre, de la captura promedio por lance, en número de peces, de dorado pequeño (≤ 60 cm, paneles izquierdos) y grande (> 60 cm, paneles derechos) en la pesquería de cerco sobre objetos flotantes (OBJ) durante 2006-2013 (base de datos de observadores de la CIAT). Los puntos negros representan las capturas de la pesquería palangrera artesanal ecuatoriana dirigida al dorado durante el año pesquero de 2011 (de Martínez-Ortiz *et al.* 2015).

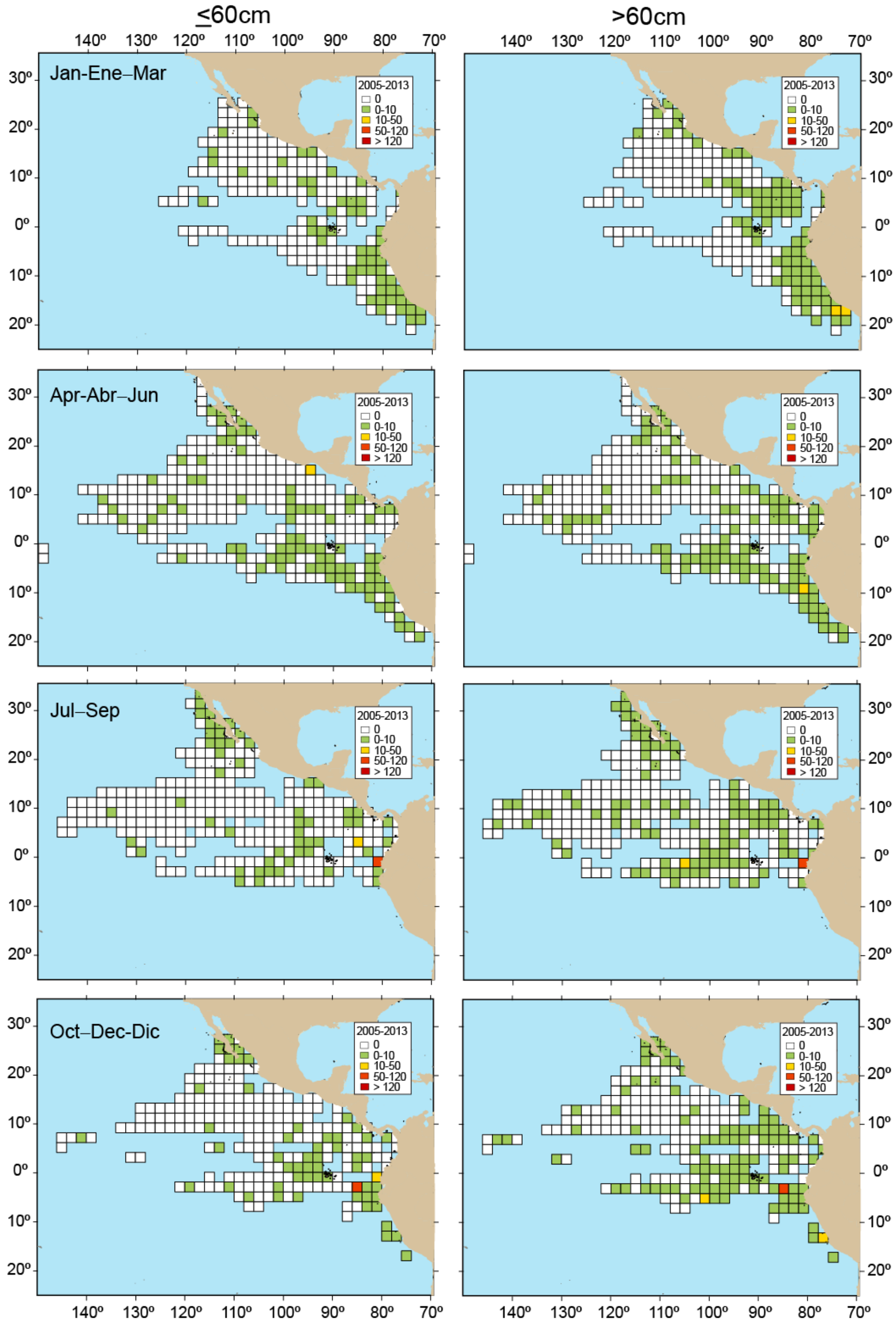

FIGURE 2e. Distribution, by 2°x2° area and quarter, of the average catch per set, in numbers of fish, of small (≤ 60 cm, left panels) and large (> 60 cm, right panels) dorado in the purse-seine fishery on unassociated schools (NOA) and dolphins (DEL) during 2006-2013 (IATTC observer data base).

FIGURA 2d. Distribucion, por área de 2°x2° y trimestre, de la captura promedio por lance, en número de peces, de dorado pequeño (≤ 60 cm, paneles izquierdos) y grande (> 60 cm, paneles derechos) en las pesquerías de cerco sobre delfines (DEL) y no asociada (NOA) durante 2006-2013 (base de datos de observadores de la CIAT.

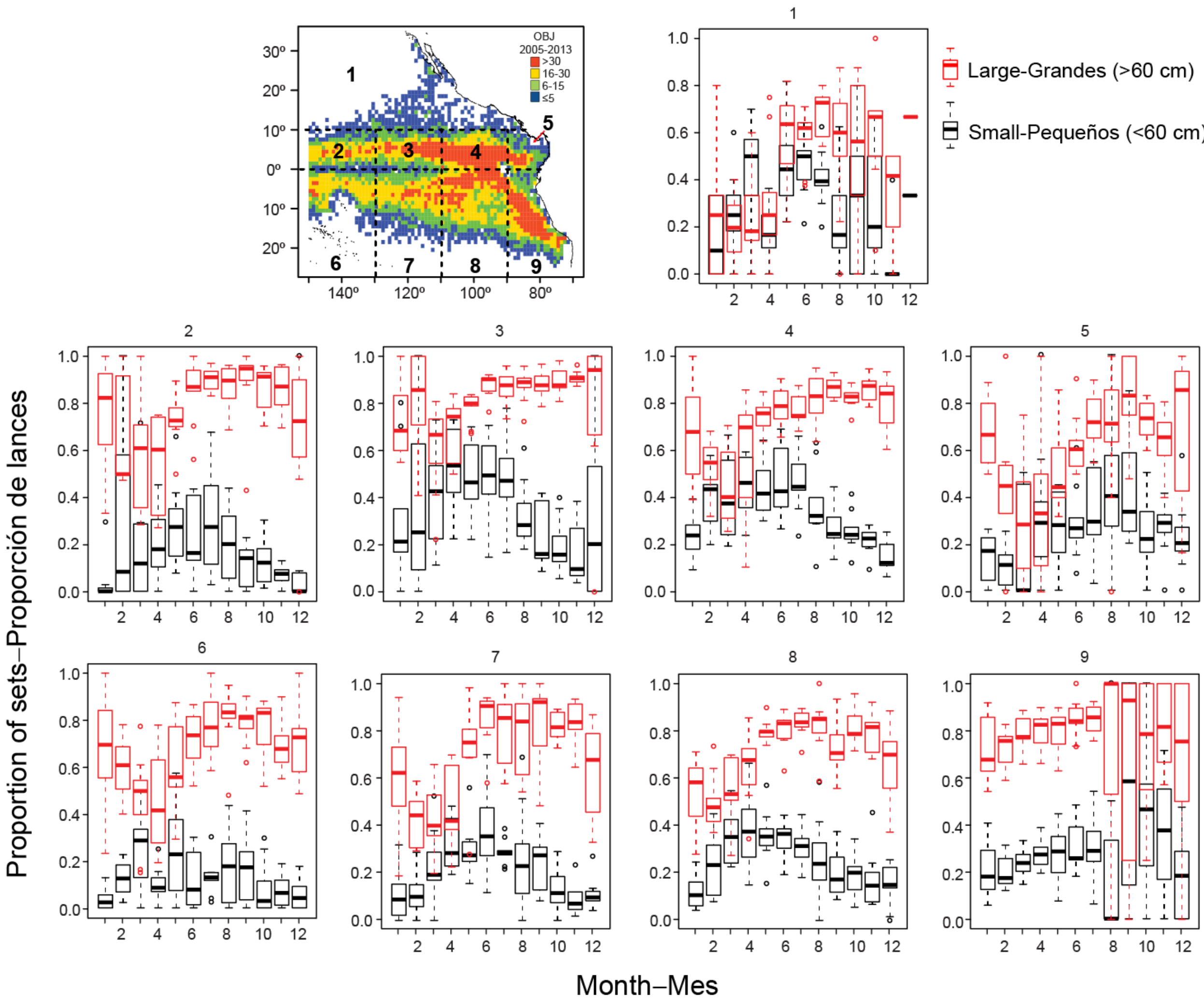

FIGURE 2f. Spatio-temporal distribution of the proportion of sets with catches of small (≤ 60 cm) or large (> 60 cm) dorado in the purse-seine fishery on floating objects (OBJ) (IATTC observer data base). The boxplots correspond to the nine areas shown in the map.

FIGURA 2f. Distribucion espaciotemporal de la proporción de lances con capturas de dorado pequeño (≤ 60 cm) o grande (> 60 cm) en la pesquería de cerco sobre objetos flotantes (OBJ) (Base de datos de observadores de la CIAT). Las gráficas de caja corresponden a las nueve áreas indicadas en el mapa.

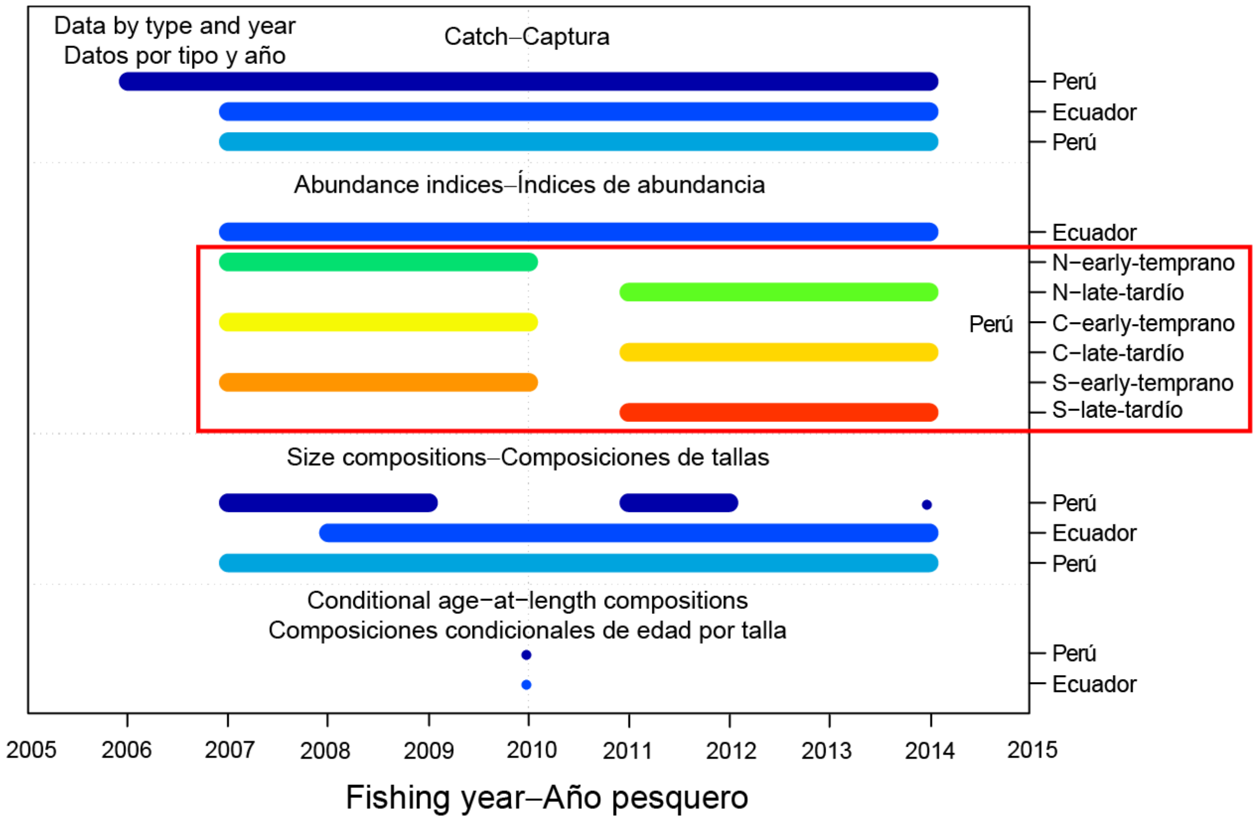

FIGURE 3. Types of data, by fishery and year, available for the assessment of dorado in the South EPO. The abundance indices inside the red square are not used in the model; they are included for comparative purposes only. The historic period of the assessment covers the 2007-2014 fishing years (July 2007-June 2015).

FIGURA 3. Tipos de datos, por pesquería y año, disponibles para la evaluación del dorado en el OPO sur. No se usaron en el modelo los índices de abundancia dentro del cuadro rojo; se incluyen para fines comparativos solamente. El periodo histórico de la evaluación cubre los años pesqueros de 2007 a 2014 (julio 2007-junio 2015).

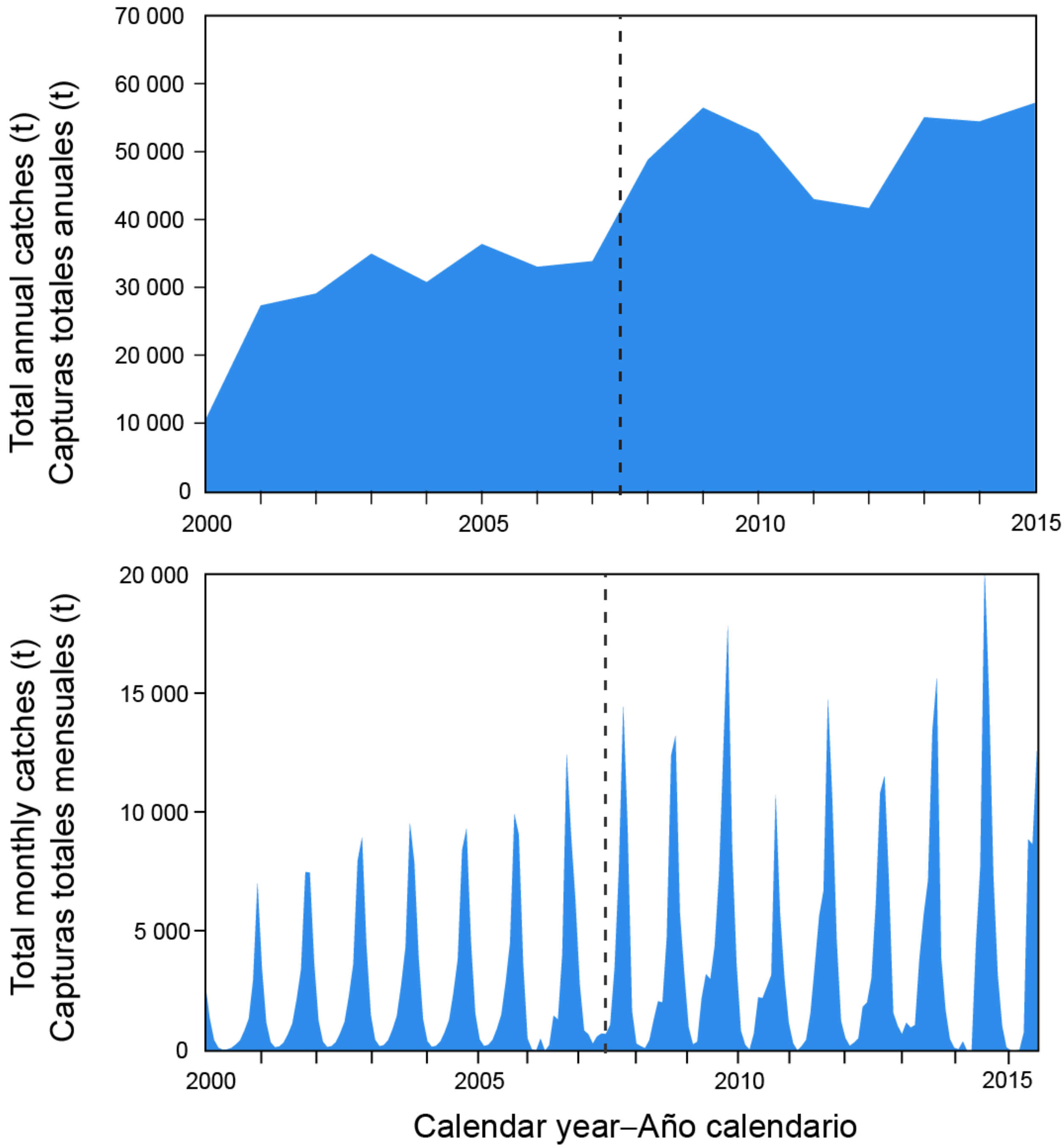

FIGURE 4a. Total annual (top) and monthly (bottom) catches of dorado by Peruvian artisanal fisheries, January 2000-December 2015, in tons. Monthly catch data for 2000-2005 are not available: they were estimated by applying the average monthly proportions of the available catches to the annual data (see Figure 4f).

FIGURA 4a. Capturas totales anuales (arriba) y mensuales (abajo) de dorado por las pesquerías artesanales peruanas, enero 2000-diciembre 2015, en toneladas. No se dispone de datos de capturas mensuales de 2000-2005: fueron estimadas mediante la aplicación de proporciones mensuales medias de las capturas disponibles a los datos anuales (ver Figura 4f).

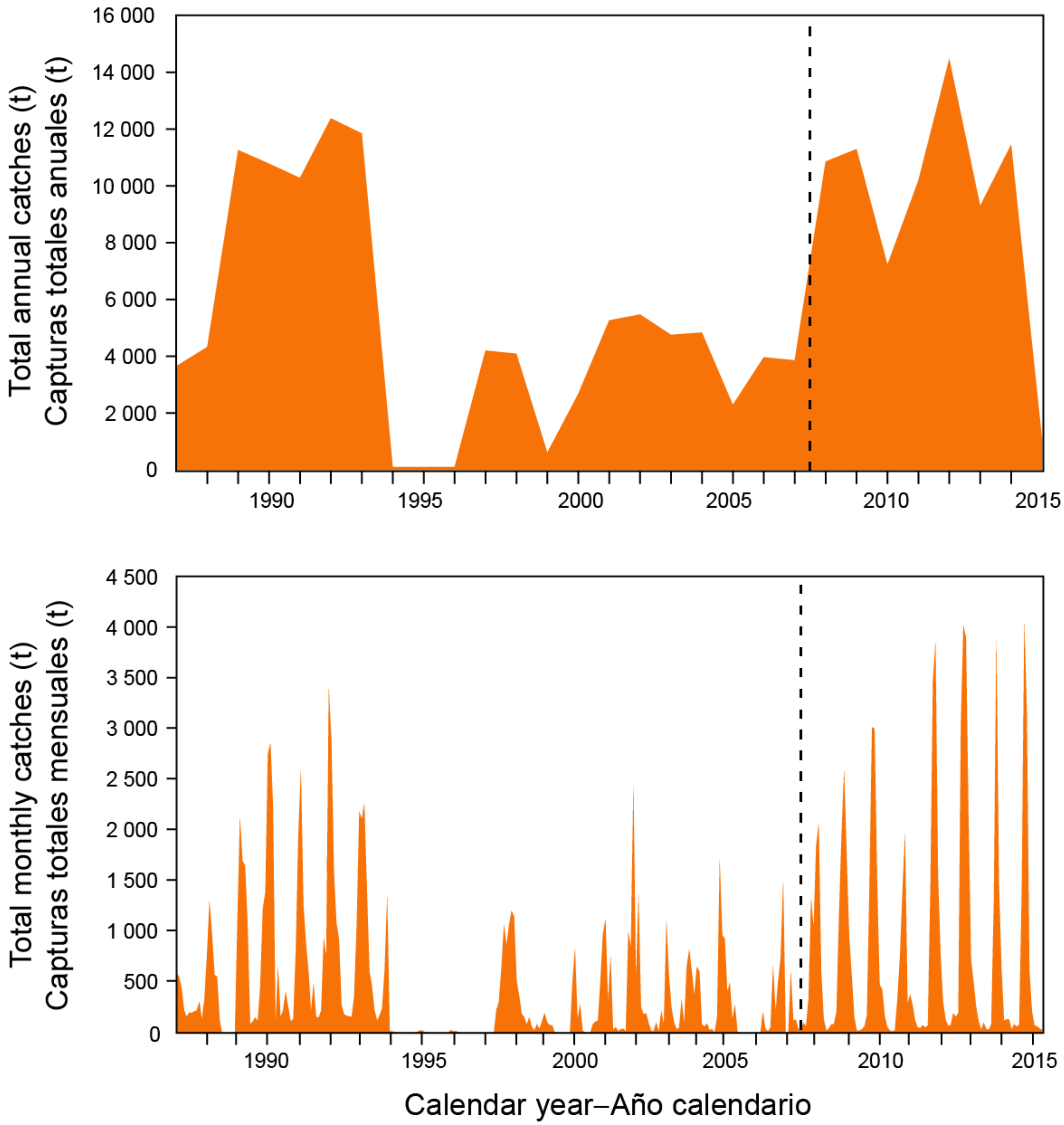

FIGURE 4b. Total annual (top) and monthly (bottom) catches of dorado by Ecuadorian artisanal fisheries, January 1987-June 2015, in tons.

FIGURA 4b. Capturas totales anuales (arriba) y mensuales (abajo) de dorado por las pesquerías artesanales ecuatorianas, enero 1987-junio 2015, en toneladas.

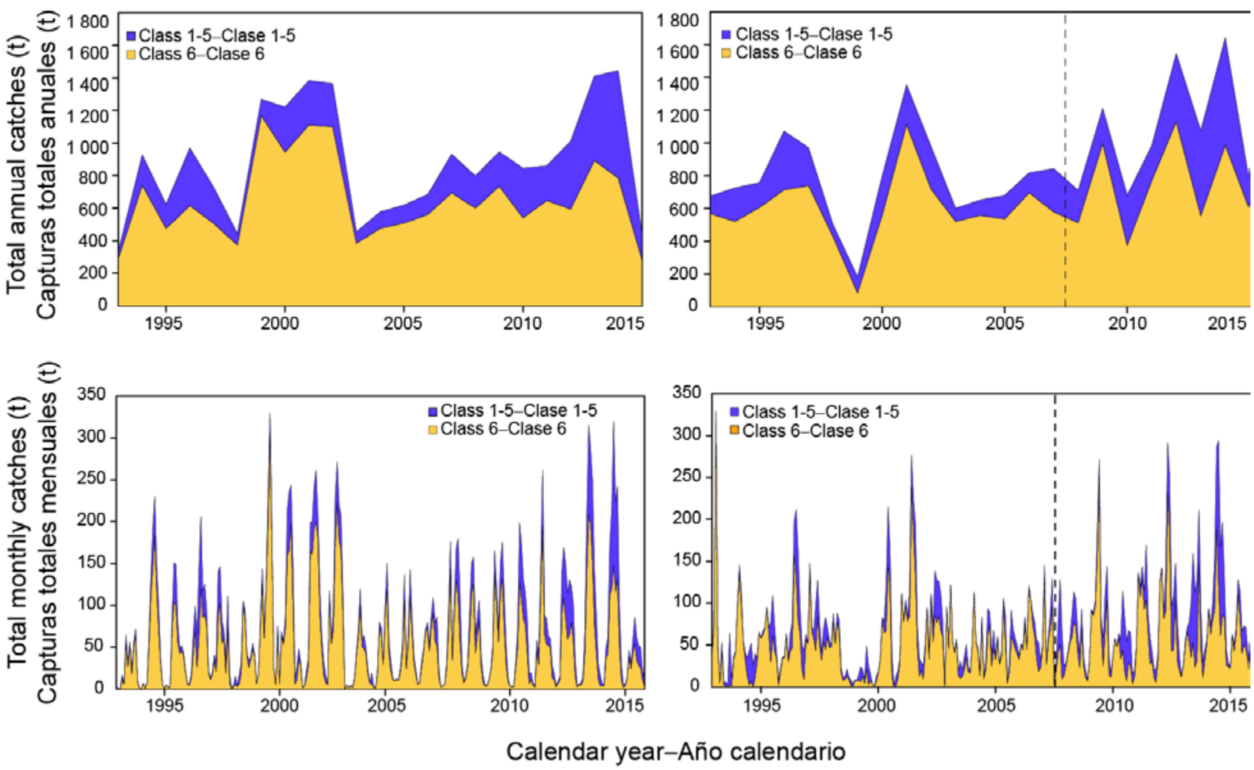

FIGURE 4c. Total annual (top) and monthly (bottom) bycatches of dorado by tuna purse-seine fisheries, north (left) and south (right) of the Equator, by vessel size class, January 1993-December 2015 (see section 2.2.3). IATTC vessel size classes: 1-5: carrying capacity <363 t; 6: carrying capacity >363 t.

FIGURA 4c. Capturas incidentales totales anuales (arriba) y mensuales (abajo) de dorado en las pesquerías atuneras de cerco, al norte (izquierda) y sur (derecha) de la línea ecuatorial, por clase de capacidad del buque, enero 1993-diciembre 2015 (ver sección 2.2.3). Clases de capacidad de la CIAT: 1-5: capacidad de acarreo <363 t; 6: capacidad de acarreo >363 t.

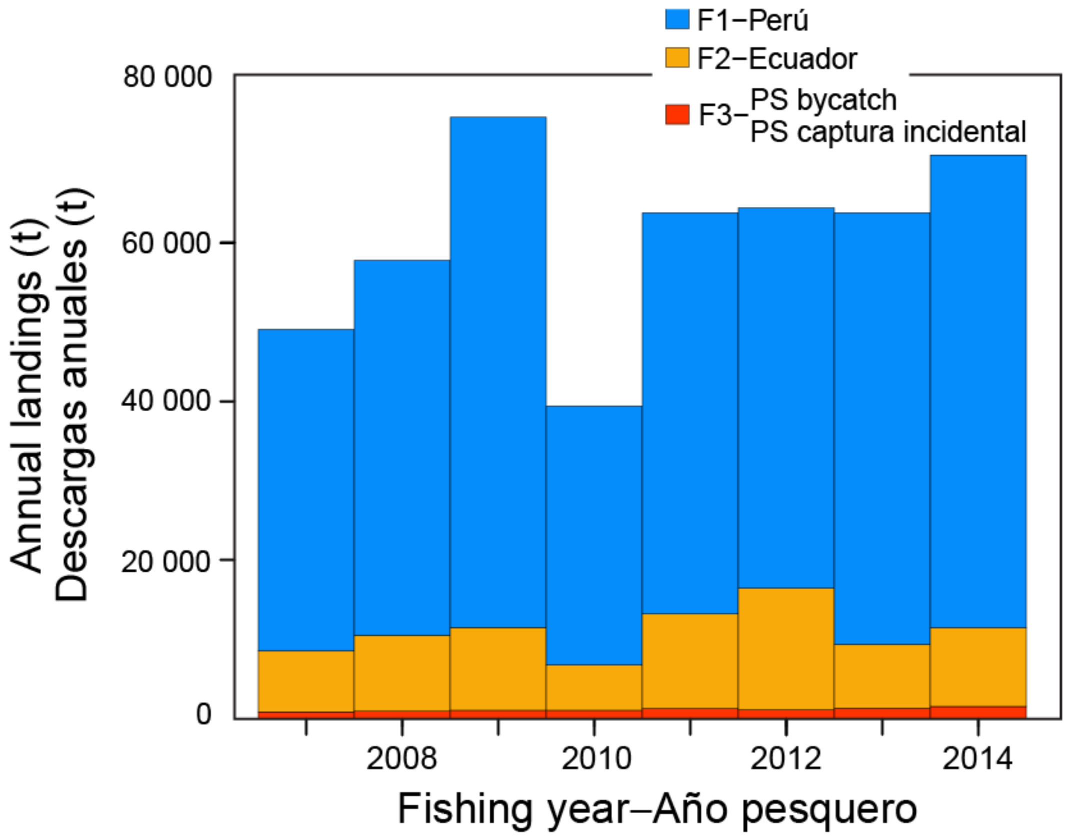

FIGURE 4d. Total annual landings of dorado in the South EPO, by fishery, fishing years 2007-2014 (July 2007-June 2015).

FIGURA 4d. Descargas anuales totales de dorado en el OPO sur, por pesquería, años pesqueros 2007-2014 (julio 2007-junio 2015).

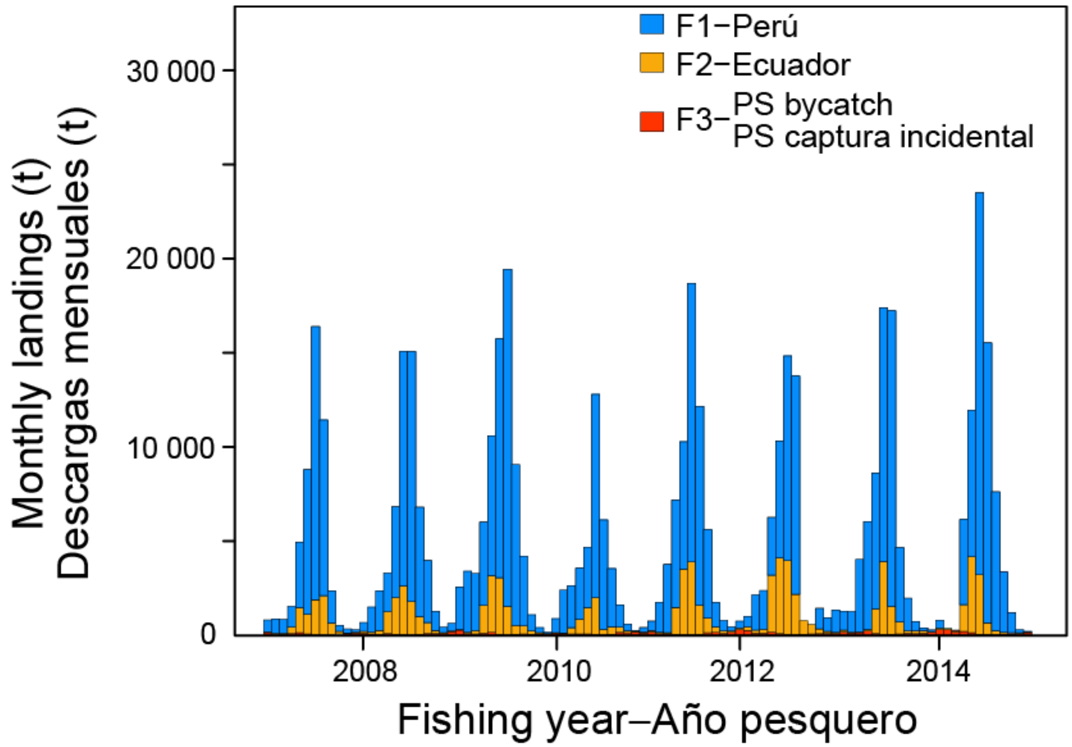

FIGURE 4e. Total monthly landings of dorado in the South EPO, by fishery, fishing years 2007-2014 (July 2007-June 2015).

FIGURA 4e. Descargas mensuales totales de dorado en el OPO sur, por pesquería, años pesqueros 2007-2014 (julio 2007-junio 2015).

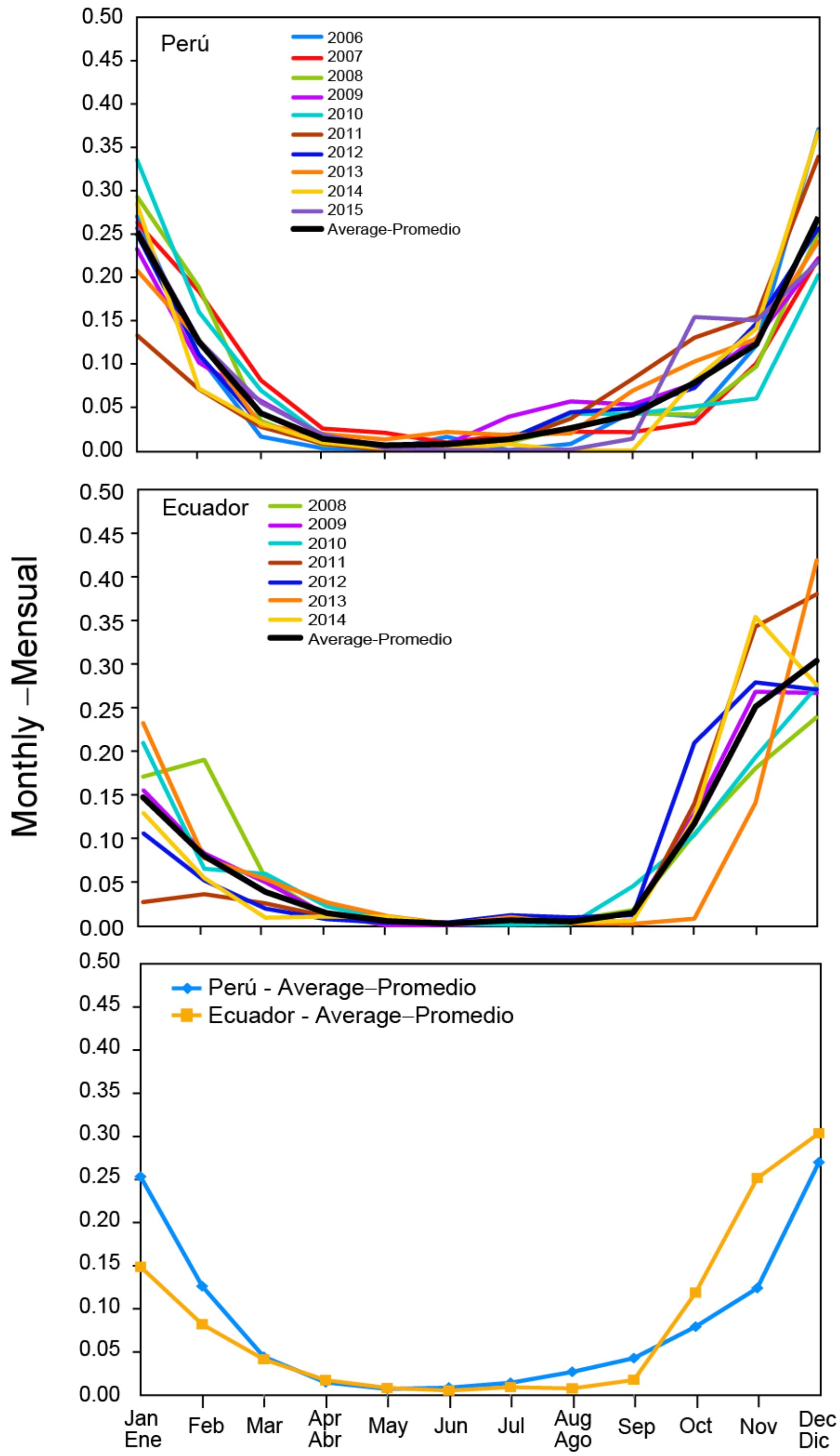

FIGURE 4f. Monthly proportions of dorado in the catches of the artisanal fisheries of Peru (2006-2015) and Ecuador (2000-2014).

FIGURA 4f. Proporciones mensuales de dorado en las capturas de las pesquerías artesanales de Perú (2006-2015) y Ecuador (2000-2014).

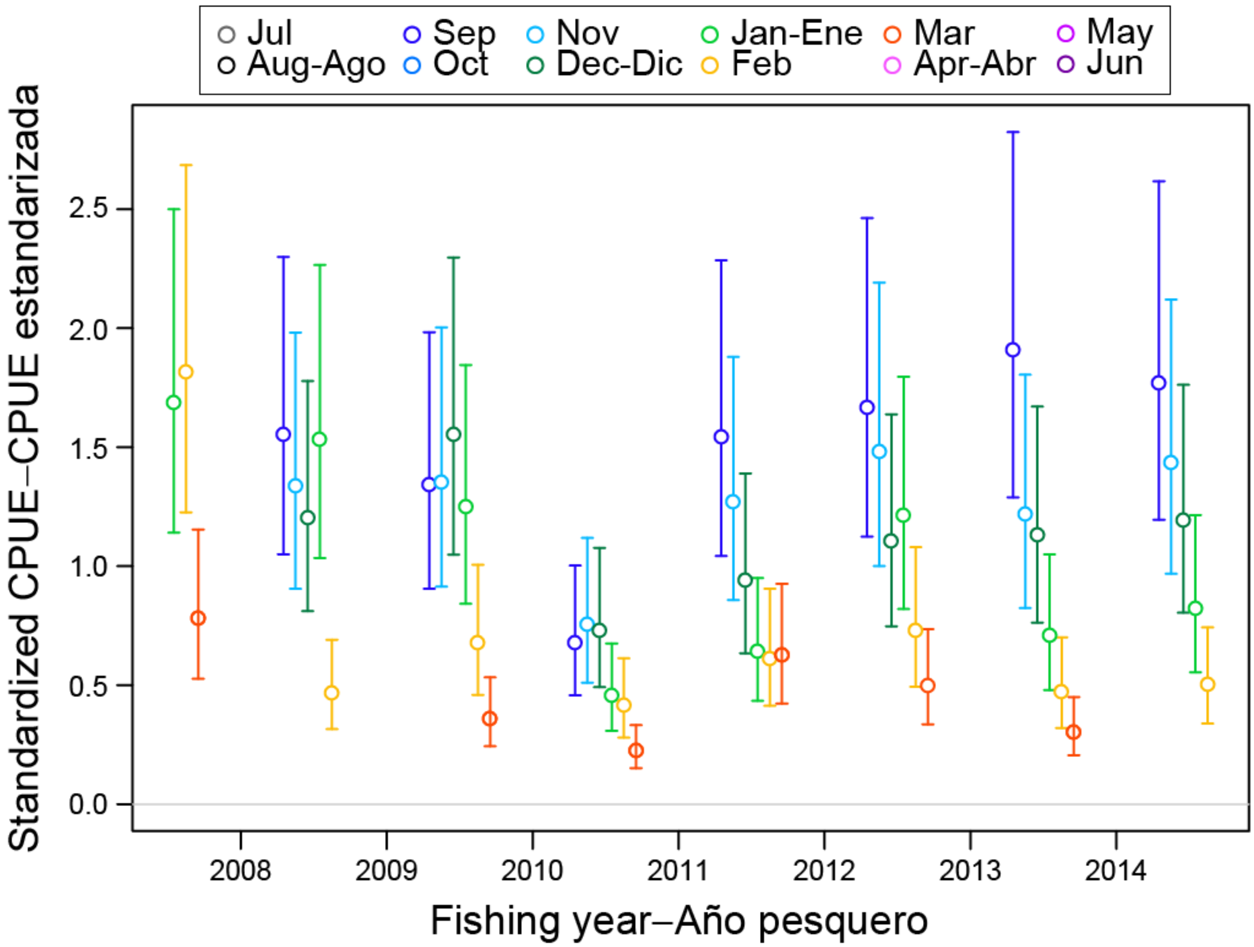

FIGURE 5a. Standardized CPUE of dorado from Ecuadorian artisanal fisheries, fishing years 2007-2014. The vertical lines represent the fixed confidence intervals (±2 standard deviations) around the CPUE values.

FIGURA 5a. CPUE estandarizada de dorado de las pesquerías artesanales ecuatorianas, años pesqueros 2007-2014. Las líneas verticales representan los intervalos de confianza fijos (±2 desviaciones estándar) alrededor de los valores de la CPUE.

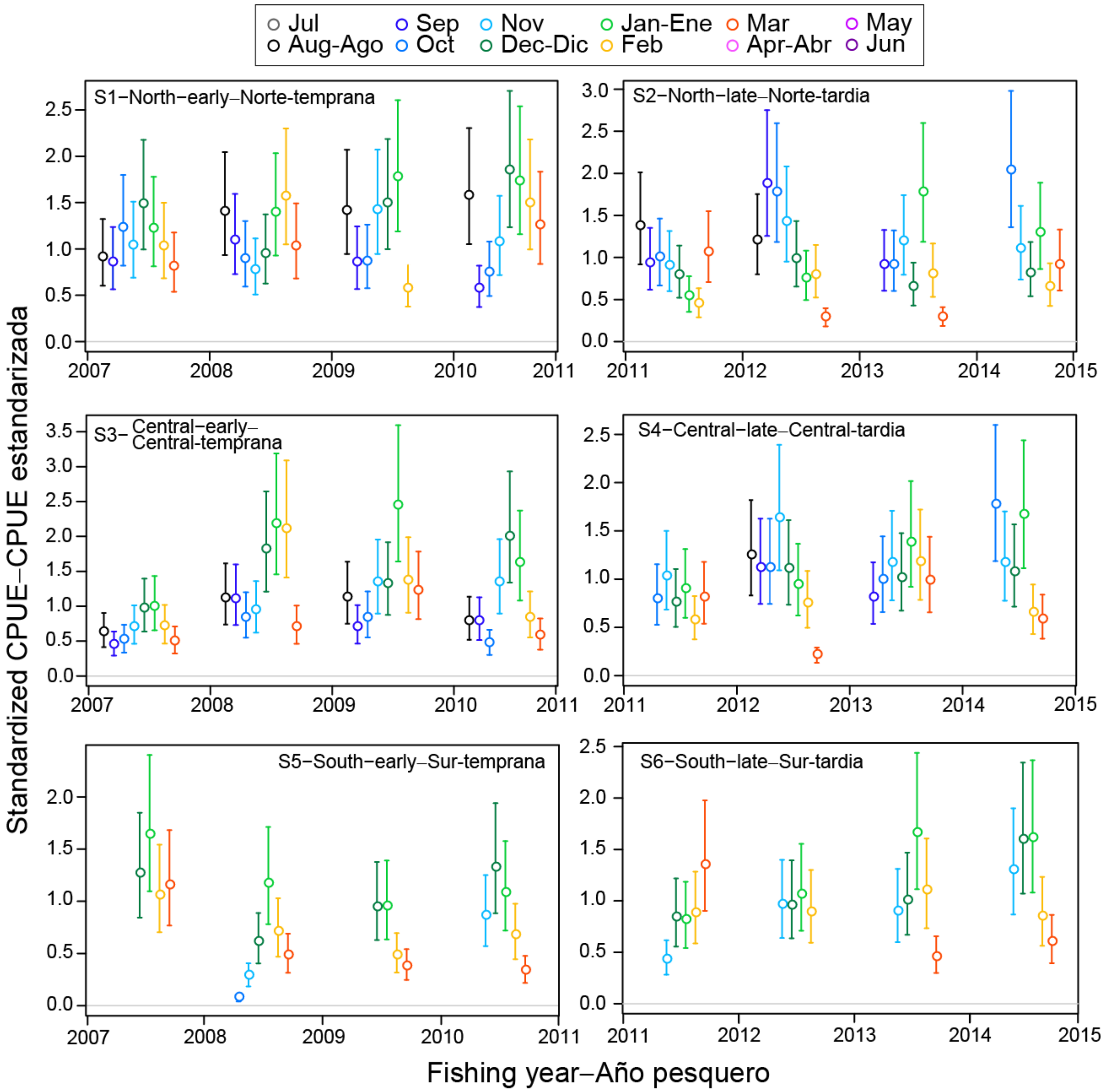

FIGURE 5b. Standardized CPUE of dorado from Peruvian artisanal fisheries, fishing years 2007-2014. The vertical lines represent the fixed confidence intervals (± 2 standard deviations) around the CPUE values.
FIGURA 5b. CPUE estandarizada de dorado de las pesquerías artesanales peruanas, años pesqueros 2007-2014. Las líneas verticales representan los intervalos de confianza fijos (±2 desviaciones estándar) alrededor de los valores de la CPUE.

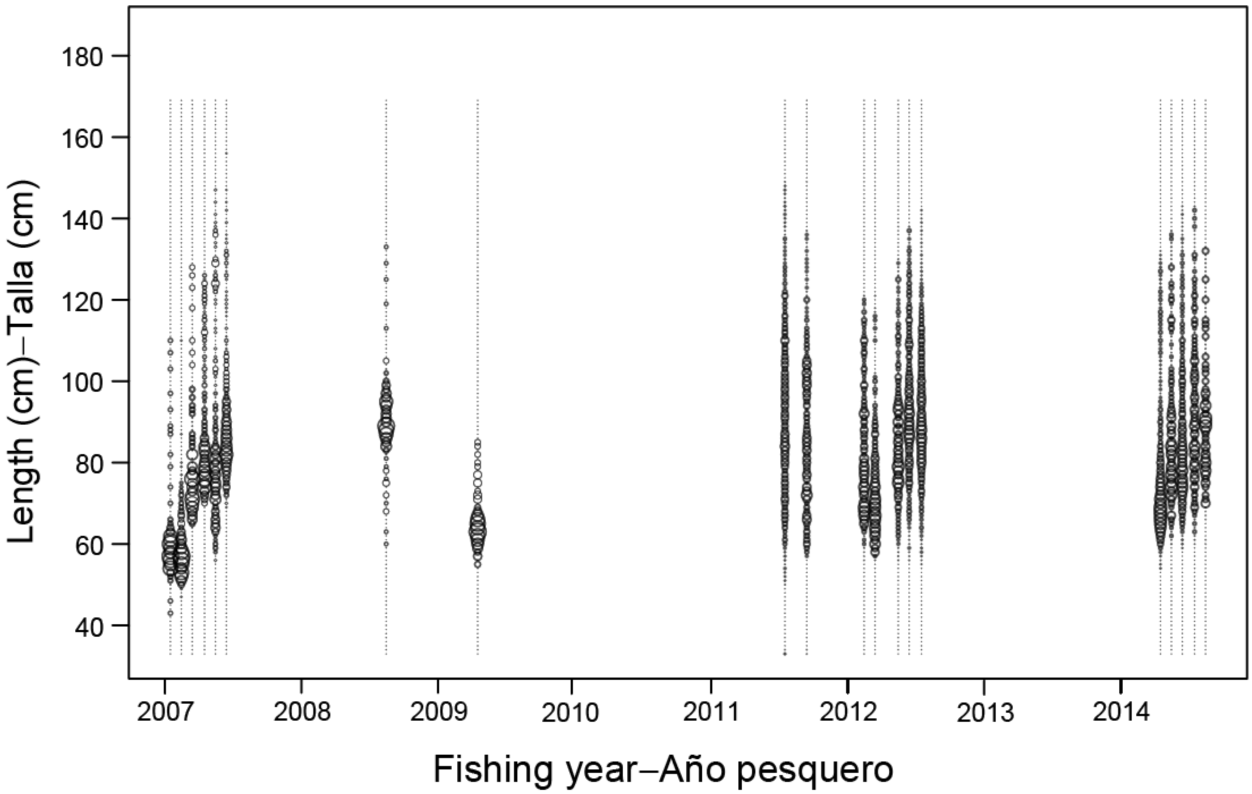

FIGURE 6a. Size compositions of dorado catches by Peruvian fisheries, by month, fishing years 2007-2014, sexes combined. The areas of the circles are proportional to the catches.
FIGURA 6a. Composiciones por talla de las capturas de dorado por las pesquerías peruanas, por mes, años pesqueros 2007-2014, sexos combinados. El área de los círculos es proporcional a las capturas.

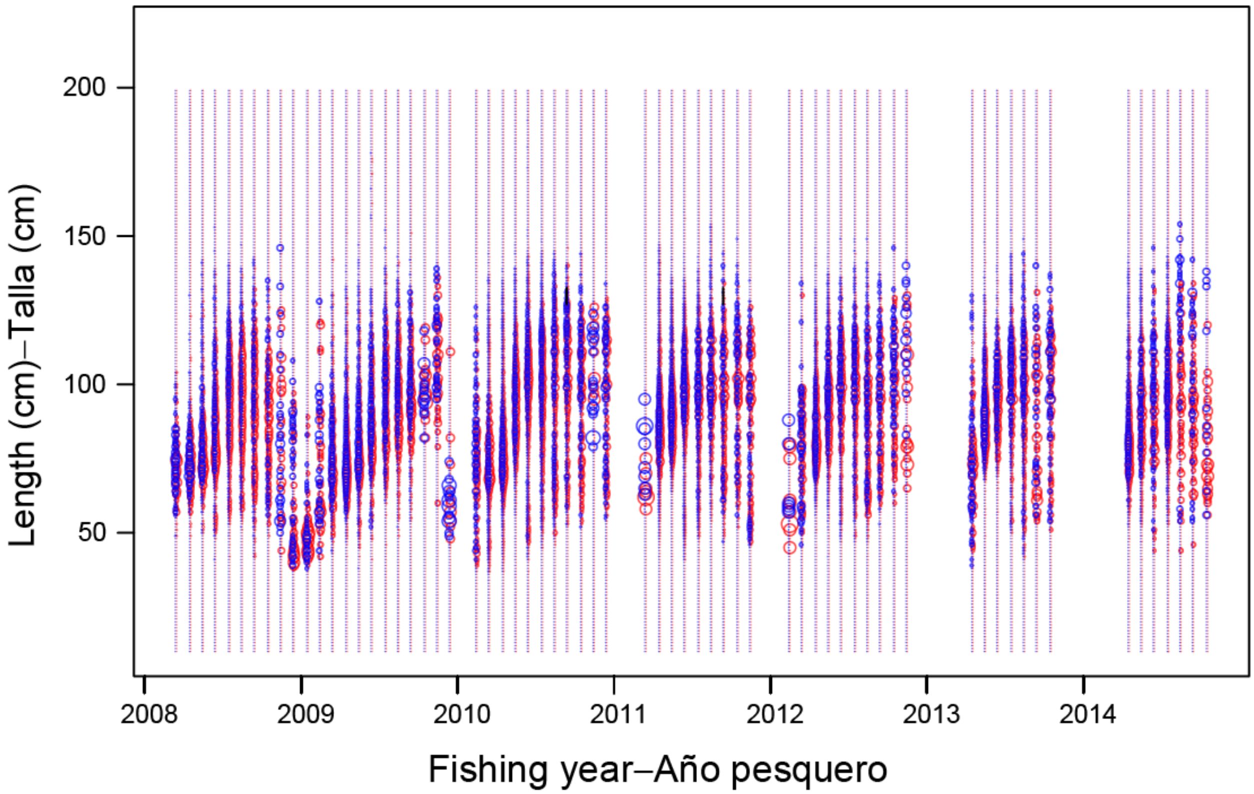

FIGURE 6b. Size compositions of dorado catches by Ecuadorian fisheries, by month, fishing years 2008-2014. Red and blue circles represent females and males, respectively. The areas of the circles are proportional to the catches.

FIGURA 6b. Composiciones por talla de las capturas de dorado por pesquerías ecuatorianas, por mes, años pesqueros 2007-2014. Los círculos rojos y azules representan hembras y machos, respectivamente. El área de los círculos es proporcional a las capturas.

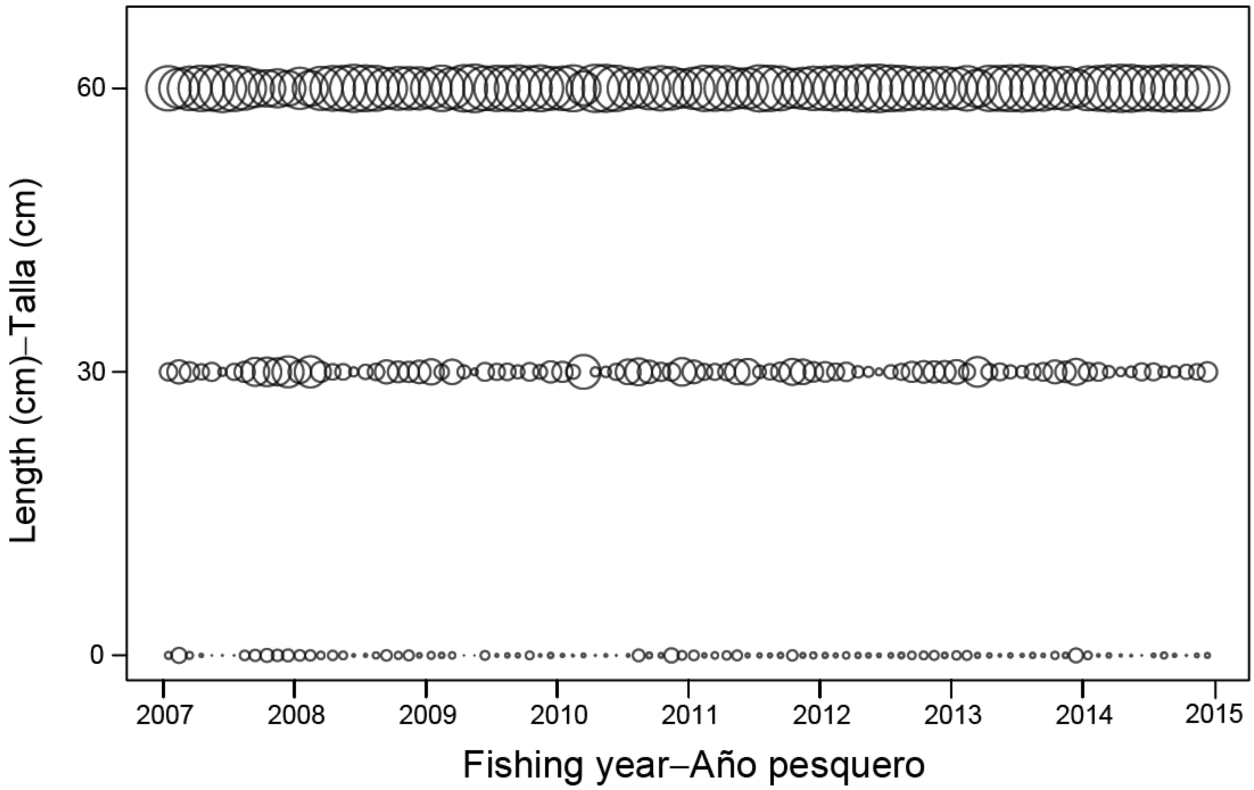

FIGURE 6c. Size compositions of dorado bycatches in the tuna purse-seine fisheries, fishing years 2007-2014, sexes combined. Fish are classified into three size categories (0-30 cm, 31-60 cm, > 60 cm FL). The areas of the circles are proportional to the catches.

FIGURA 6c. Composiciones por talla de las capturas incidentales de dorado en las pesquerías atuneras de cerco, años pesqueros 2007-2014, sexos combinados. Se clasifica el pescado en tres categorías de talla (0-30 cm, 31-60 cm, > 60 cm). El área de los círculos es proporcional a las capturas.

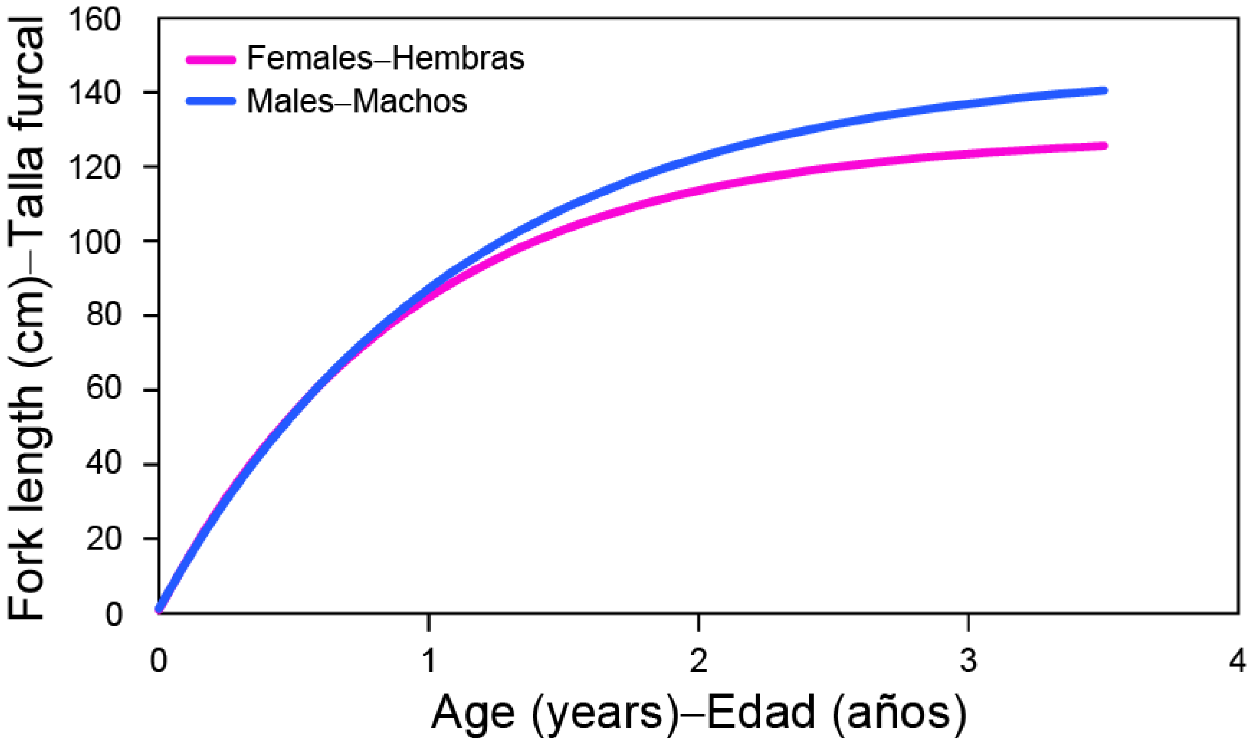

FIGURE 7a. von Bertalanffy growth curves for male and female dorado assumed in the stock assessment model (from Goicochea *et al.* 2012).
FIGURA 7a. Curvas de crecimiento de von Bertalanffy para machos y hembras de dorado supuestas en el modelo de evaluación (de Goicochea *et al.* 2012).

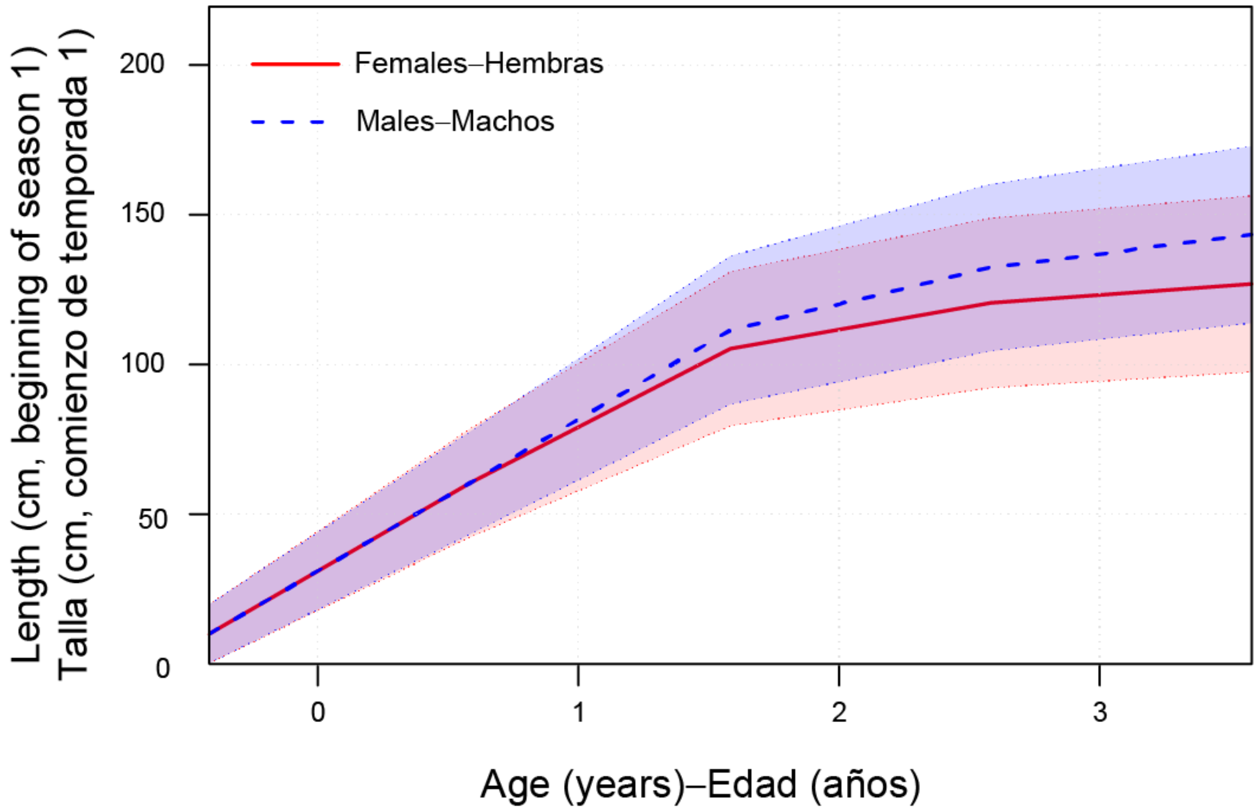

FIGURE 7b. Variability of the length-at-age assumptions in the stock assessment model for dorado. The shaded areas represent the variation of the length at age (±2 standard deviations) around the mean lengths-at-age (solid line: females; dashed line: males).

FIGURA 7b. Variabilidad de los supuestos de talla por edad en el modelo de evaluación de dorado. Las zonas sombreadas representan la variación de la talla por edad (±2 desviaciones estándar) alrededor de la talla media por edad (línea sólida: hembras; línea de trazos: machos).

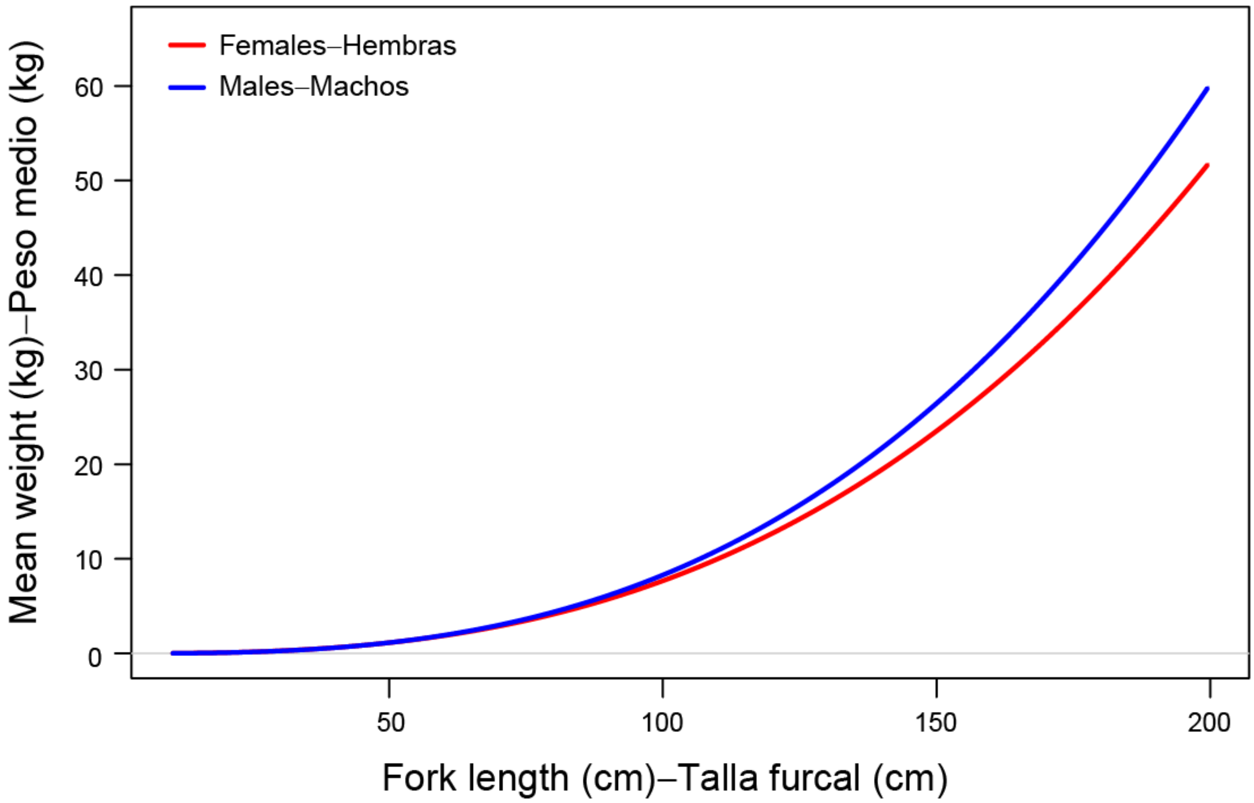

FIGURE 8. Length-weight relationship for dorado, by sex (from Zúñiga-Flores (2014)).
FIGURA 8. Relación talla-peso de dorado, por sexo (de Zúñiga-Flores (2014)).

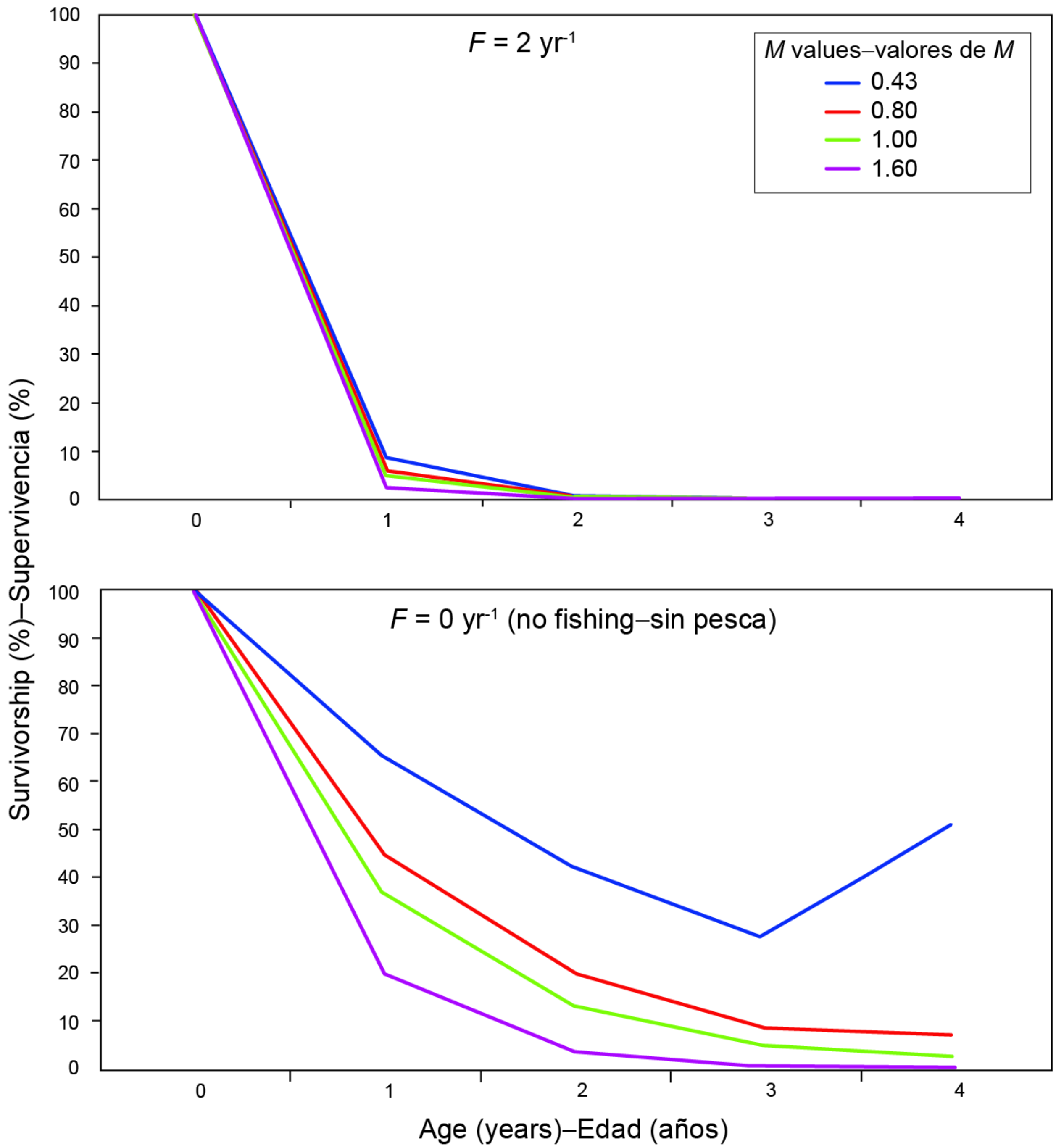

FIGURE 9. Percent survivorship of a cohort over time (in years) under different *M* values. Top: no fishing mortality (*F* = 0); bottom: under exploitation with *F* = 2 yr^{-1}.

FIGURA 9. Supervivencia porcentual de una cohorte a lo largo del tiempo (en años) con distintos valores de *M*. Arriba: sin mortalidad por pesca (*F* = 0); abajo: con explotación, *F* = 2 yr^{-1}.

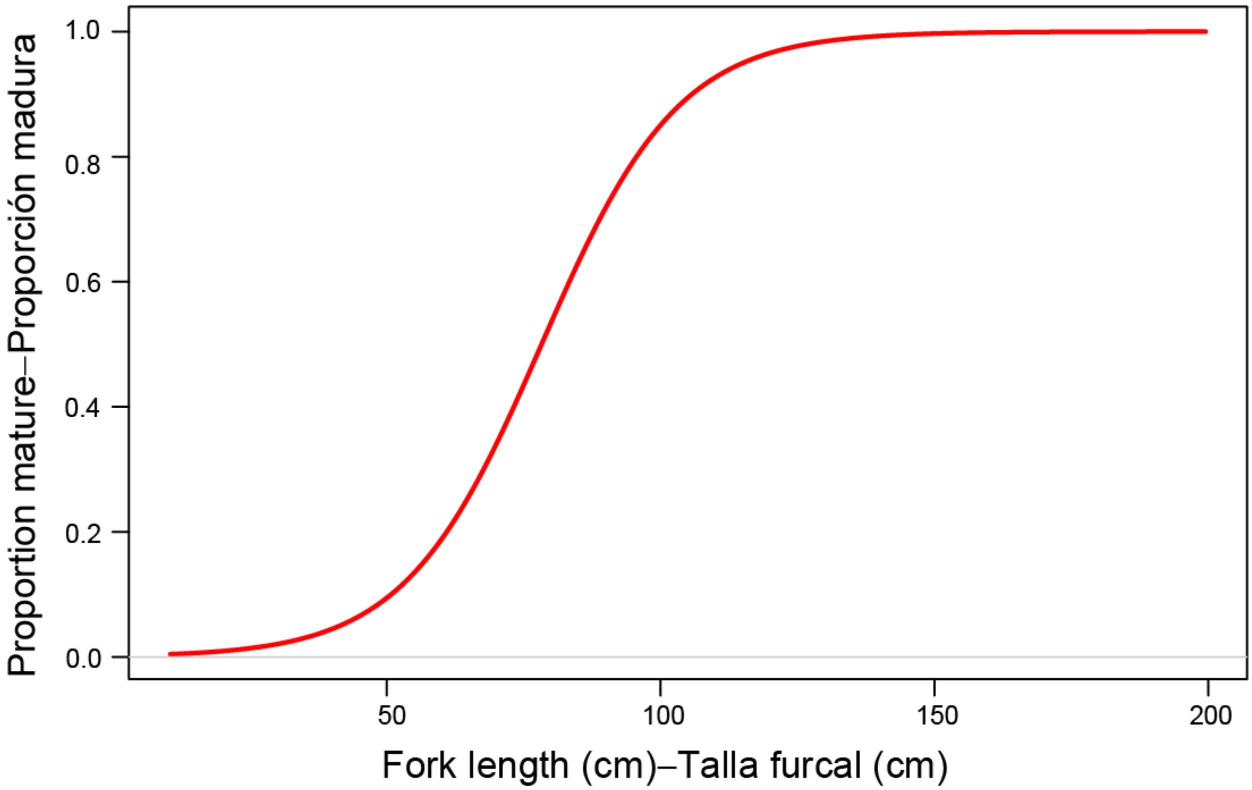

FIGURE 10. Length-maturity ogive for female dorado (from Zúñiga-Flores 2014).
FIGURA 10. Ojiva de talla-madurez para hembras de dorado (de Zúñiga-Flores 2014).

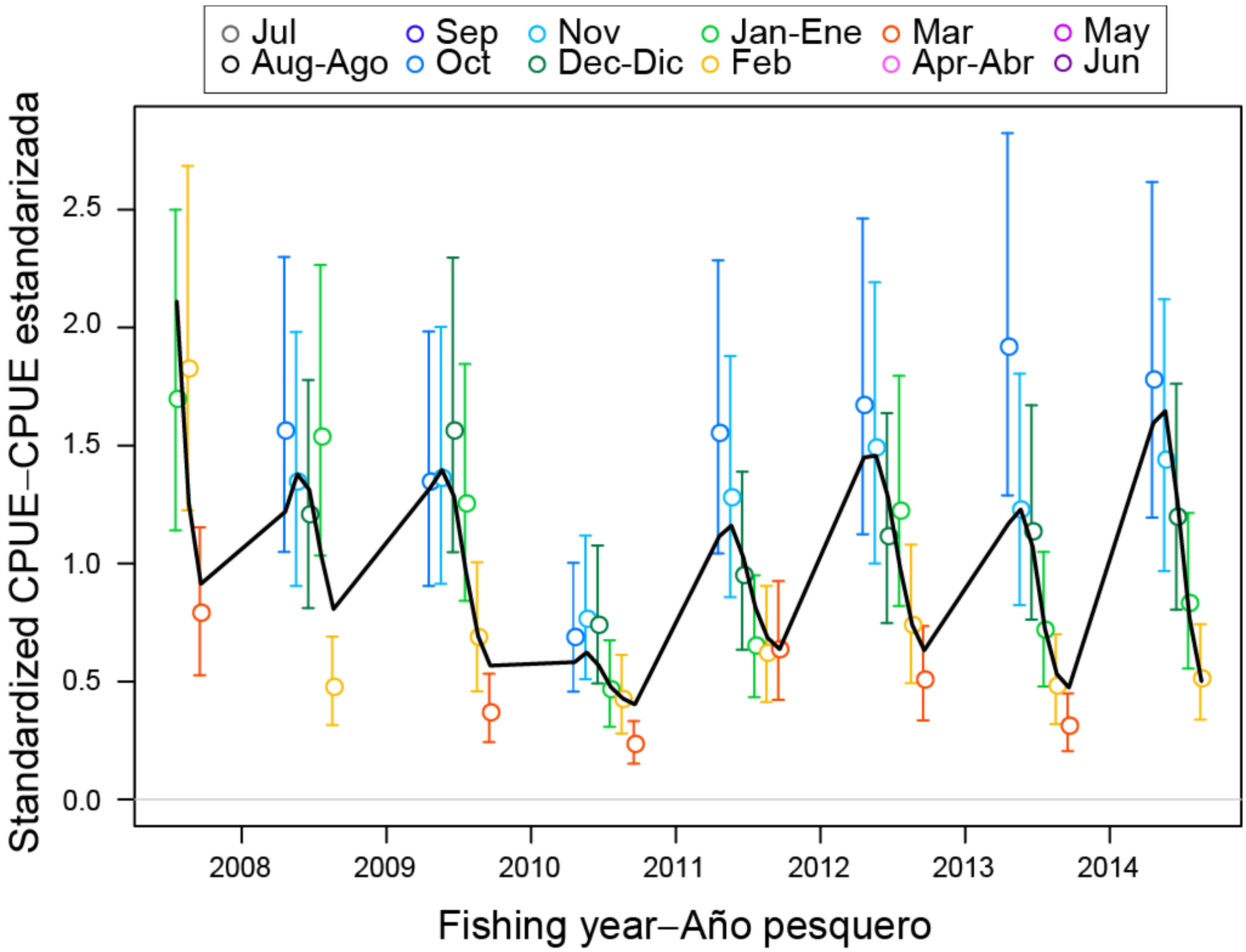

FIGURE 11a. Base-case model fit to the standardized CPUE data from the Ecuadorian artisanal fishery. The vertical lines represent the fixed confidence intervals (±2 standard deviations) around the CPUE values.

FIGURA 11a. Ajuste del modelo de caso base a los datos de CPUE estandarizada de la pesquería artesanal ecuatoriana. Las líneas verticales representan los intervalos de confianza fijos (±2 desviaciones estándar) alrededor de los valores de la CPUE.

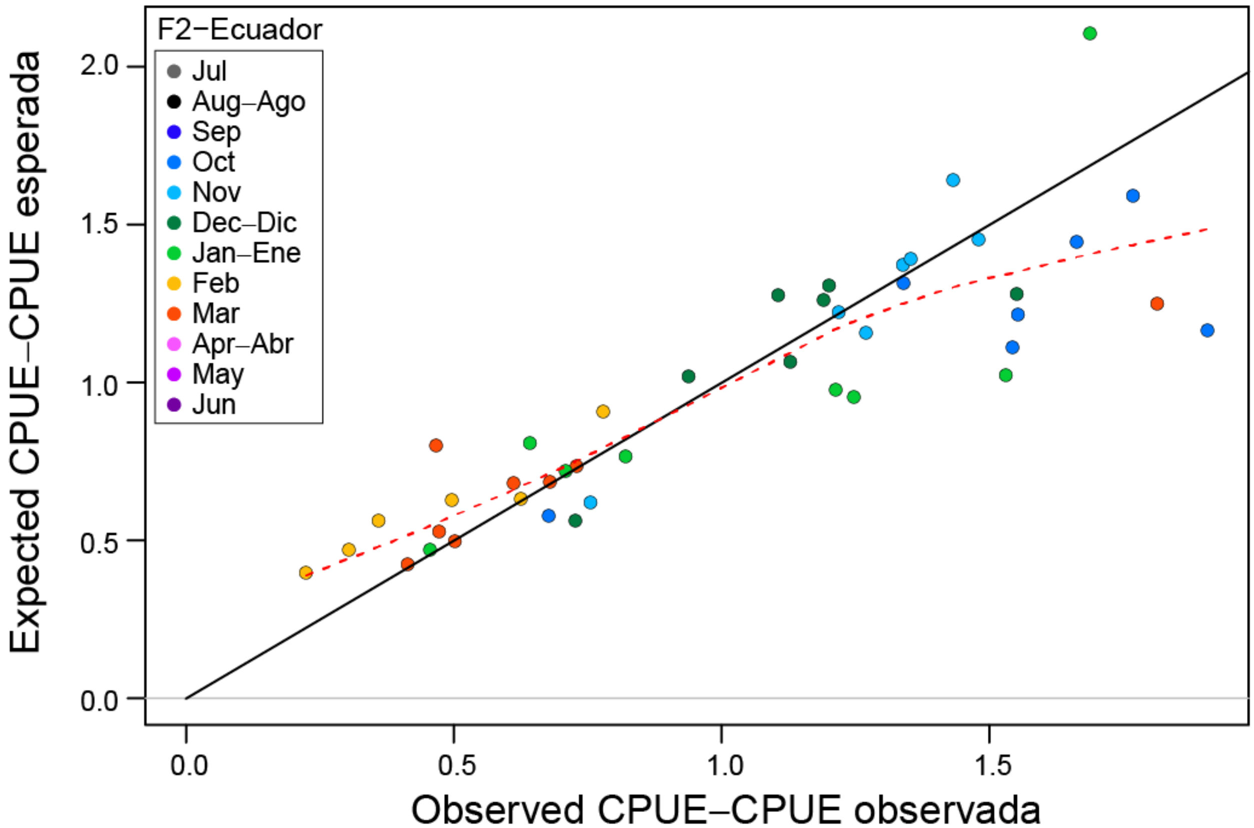

FIGURE 11b. Observed versus expected CPUE values for the Ecuadorian artisanal fishery. The solid black line represents a 1:1 relationship; the dashed red line is a smoother over the points.

FIGURA 11b. Valores observados y esperados de la CPUE de la pesquería artesanal ecuatoriana. La línea negra sólida representa una relación 1:1; la línea roja de trazos es un suavizador sobre los puntos.

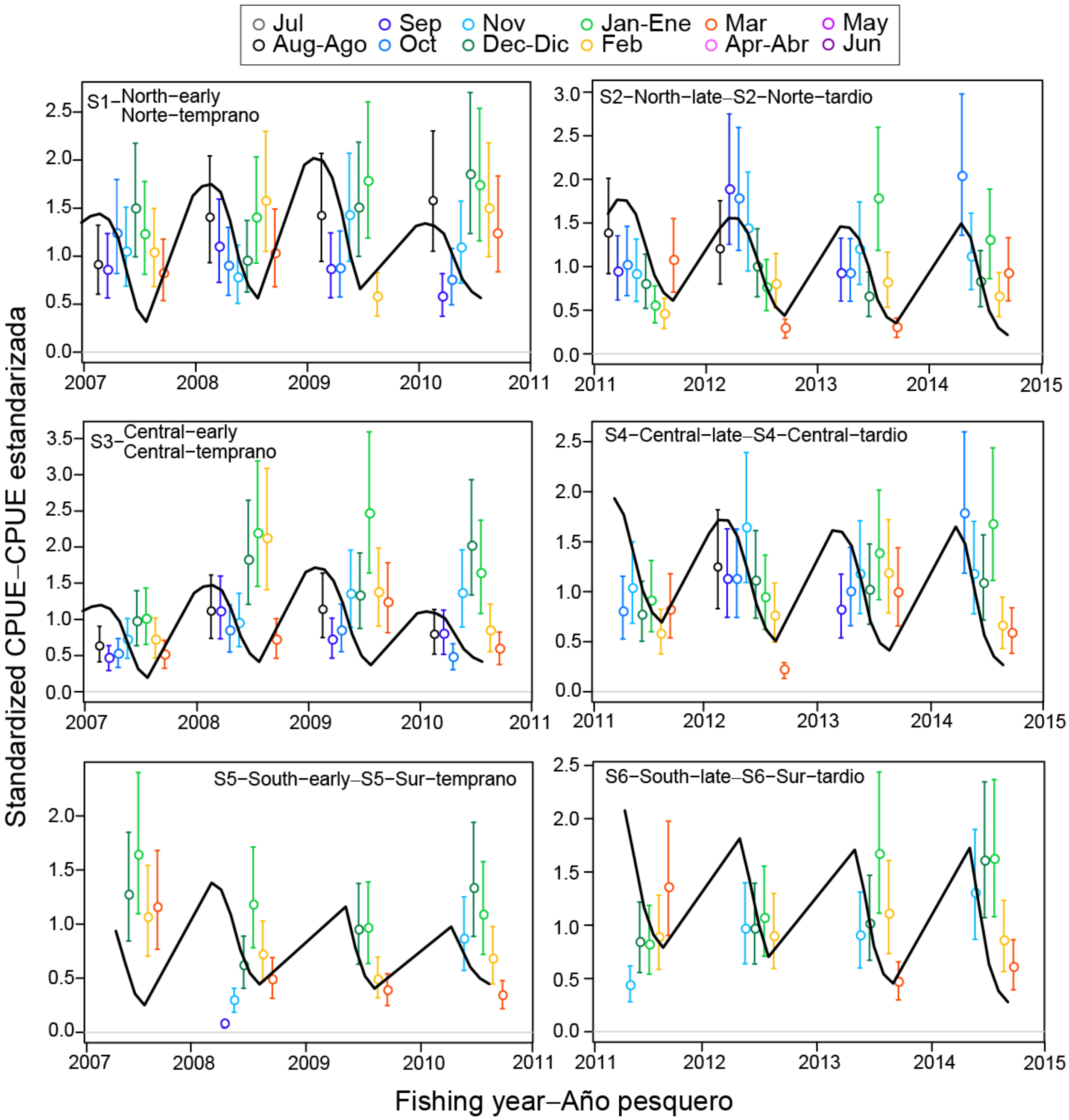

FIGURE 11c. Model fit to the standardized CPUE data from Peruvian artisanal fisheries operating in three regions: North (Paita), Central (Chimbote-Pucusana), and South (Ilo). The CPUE indices are separated at 2010 into early and late periods, corresponding to improvements in the quality of the data collected.

FIGURA 11c. Ajuste del modelo a los datos de CPUE estandarizada de las pesquerías artesanales peruanas que operan en tres regiones: Norte (Paita), Central (Chimbote-Pucusana), y Sur (Ilo). Se separan los índices de CPUE en dos periodos, temprano y tardío, correspondientes a mejoras en la calidad de los datos recolectados.

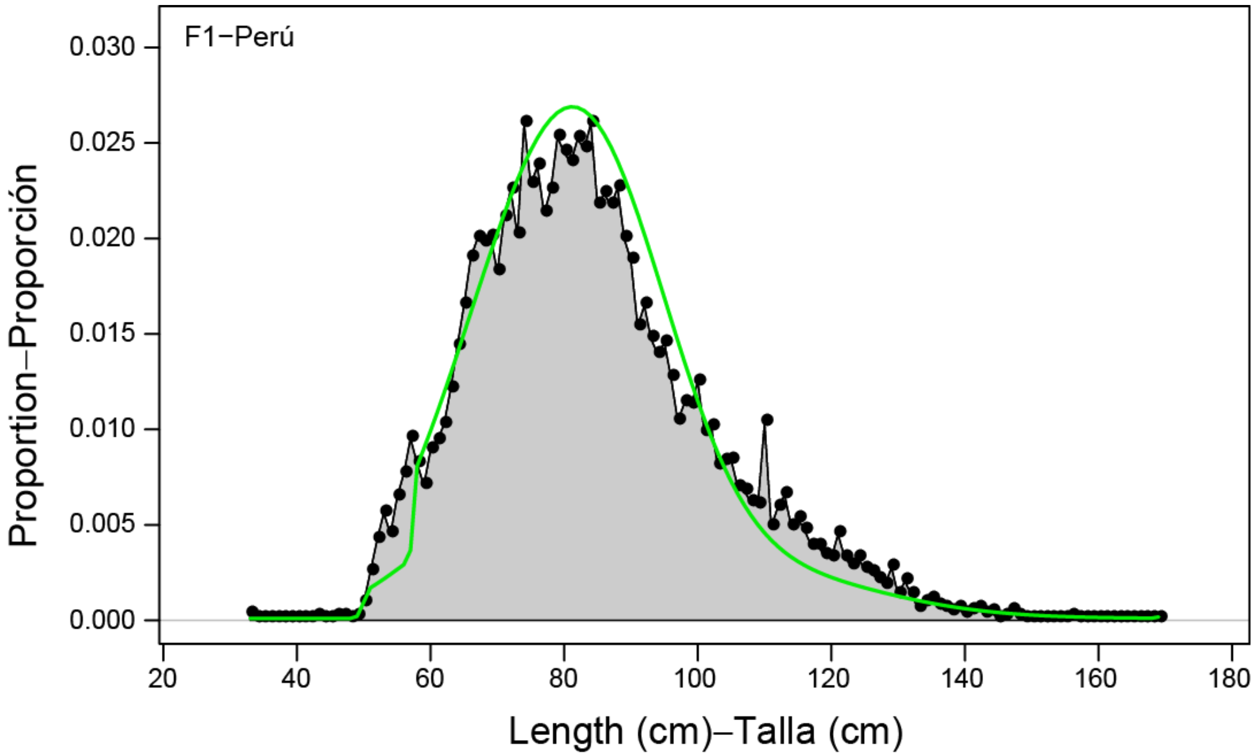

FIGURE 12a. Average observed (dots) and predicted (green line) length compositions of the catches taken by the Peruvian artisanal fishery (F1), both sexes combined.

FIGURA 12a. Composiciones por talla medias observadas (puntos) y predichas (línea verde) de las capturas de dorado de la pesquería artesanal peruana (F1), ambos sexos combinados.

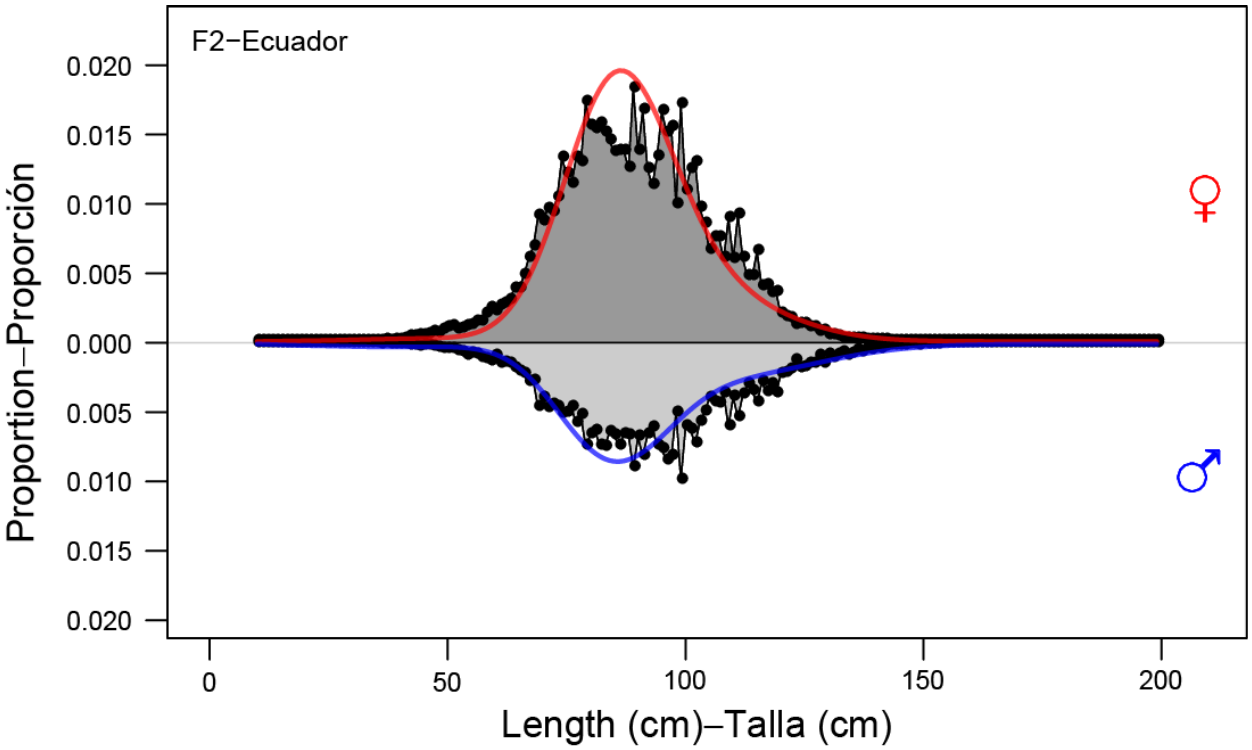

FIGURE 12b. Average observed (dots) and predicted (lines) length composition of the catches taken by the Ecuadorian artisanal fishery (F2), for females (red line) and males (blue line).
FIGURA 12b. Composiciones por talla medias observadas (puntos) y predichas (líneas) de las capturas de dorado de la pesquería artesanal ecuatoriana (F2), de hembras (línea roja) y machos (línea azul).

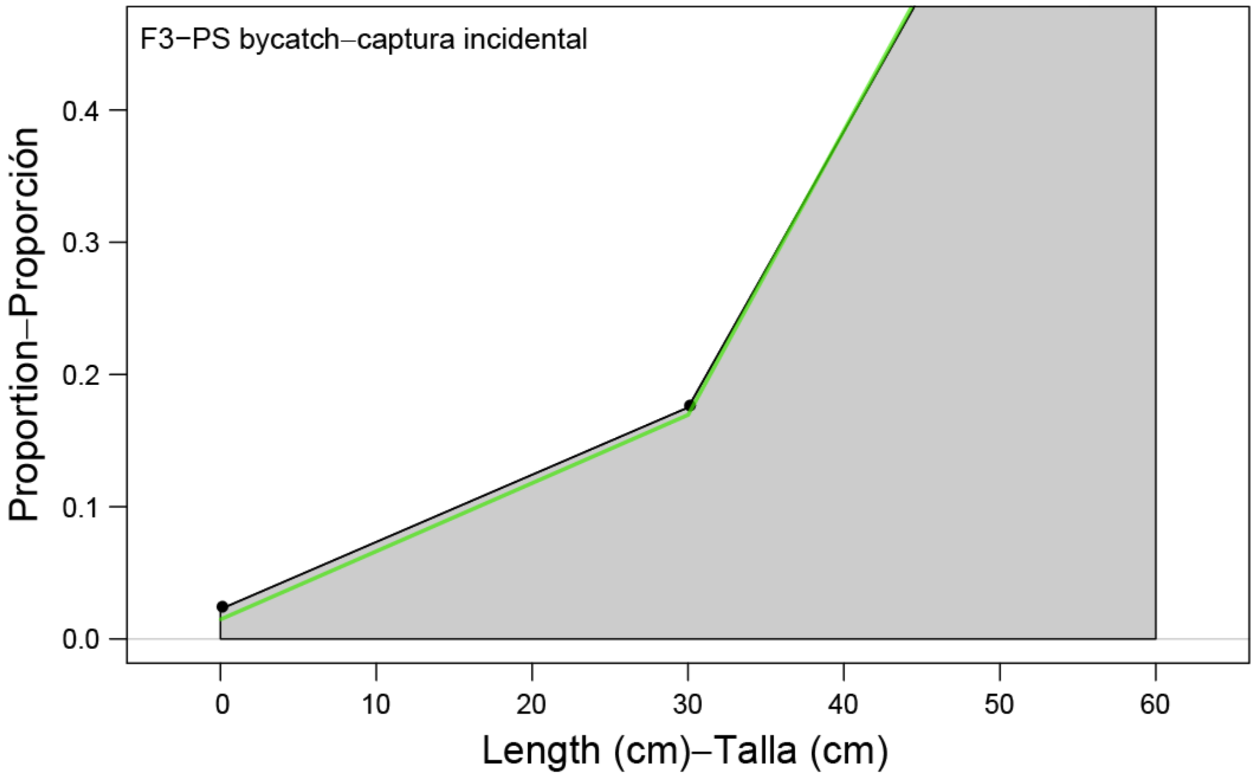

FIGURE 12c. Average observed (dots) and predicted (green line) length-class composition of the bycatches of dorado in the tuna purse-seine fishery (F3). Fish are classified into three size categories (0-30 cm, 31-60 cm, > 60 cm FL).

FIGURA 12c. Composiciones por talla medias observadas (puntos) y predichas (línea verde) de las capturas incidentales de dorado en la pesquería atunera de cerco (F3). Se clasifican los pescados en tres categorías de talla (0-30 cm, 31-60 cm, > 60 cm TF)

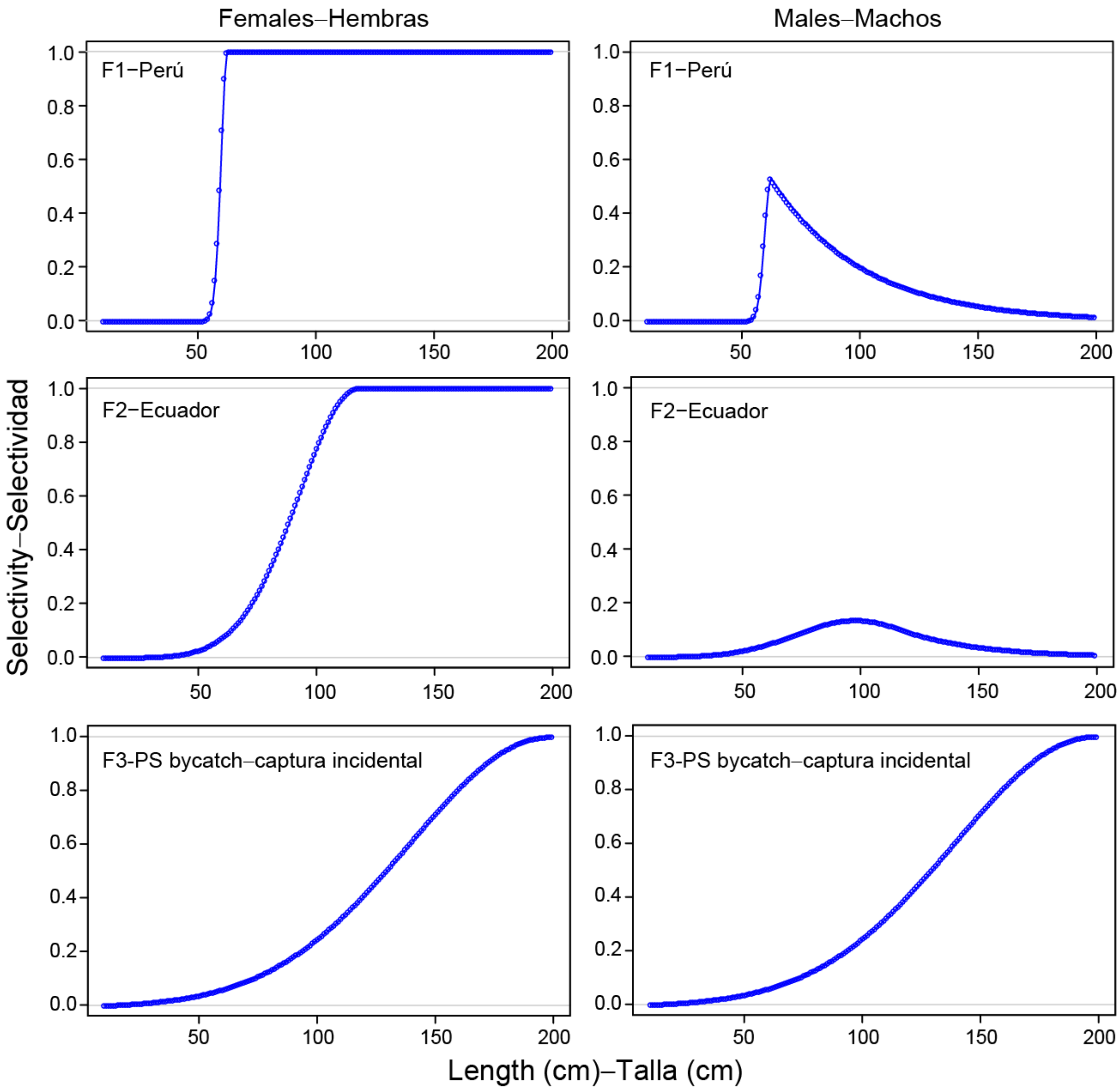

FIGURE 13. Size selectivity curves for the three dorado fisheries defined in the assessment. Left: females; right: males.
FIGURA 13. Curvas de selectividad por tamaño de las tres pesquerías de dorado definidas en la evaluación. Izquierda: hembras; derecha: machos.

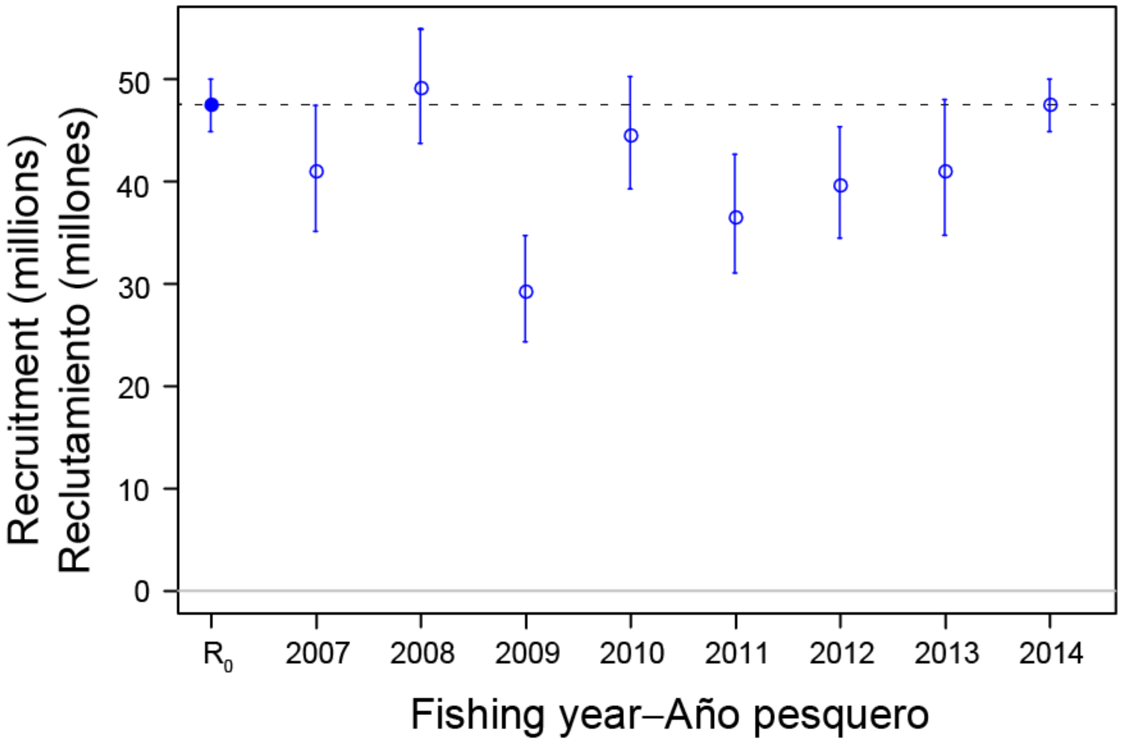

FIGURE 14. Estimates of the annual recruitment of dorado in the South EPO. The vertical lines represent the 95% confidence intervals around the recruitment estimates (open circles). The solid blue circle represents the estimate of virgin recruitment (R_0). In Stock Synthesis, age-0 recruitment is defined as post-larval fish.

FIGURA 14. Estimaciones del reclutamiento anual de dorado en el OPO sur. Las líneas verticales representan los intervalos de confianza de 95% alrededor de las estimaciones de reclutamiento (círculos abiertos). El círculo azul sólido representa la estimación del reclutamiento virgen (R_0). En *Stock Synthesis*, se define el reclutamiento a edad 0 como peces poslarvales.

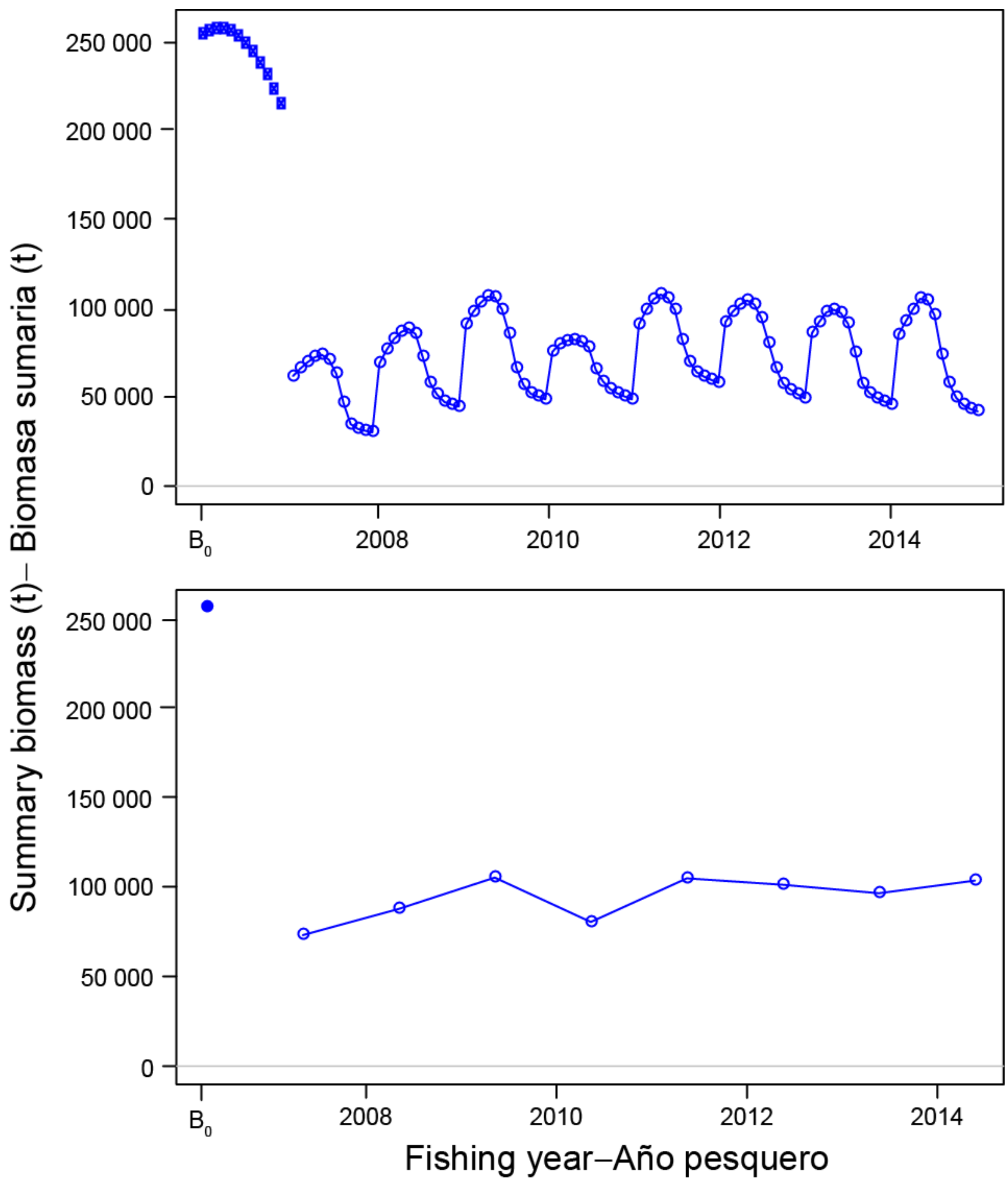

FIGURE 15. Estimates of the biomass of dorado 1+ months old (summary biomass) in the South EPO at the start of each month (top) and at the beginning of the spawning season (defined as the month of November in the assessment model; bottom). The blue dot represents the estimate of the virgin summary biomass (B_0) at the beginning of the spawning season.

FIGURA 15. Estimaciones de la biomasa de dorado de 1+ meses de edad (biomasa sumaria) en el OPO sur al principio de cada mes (arriba) y al principio de la temporada de desove (definido como el mes de noviembre en el modelo; abajo). El punto azul representa la estimación de la biomasa sumaria virgen (B_0) al principio de la temporada de desove.

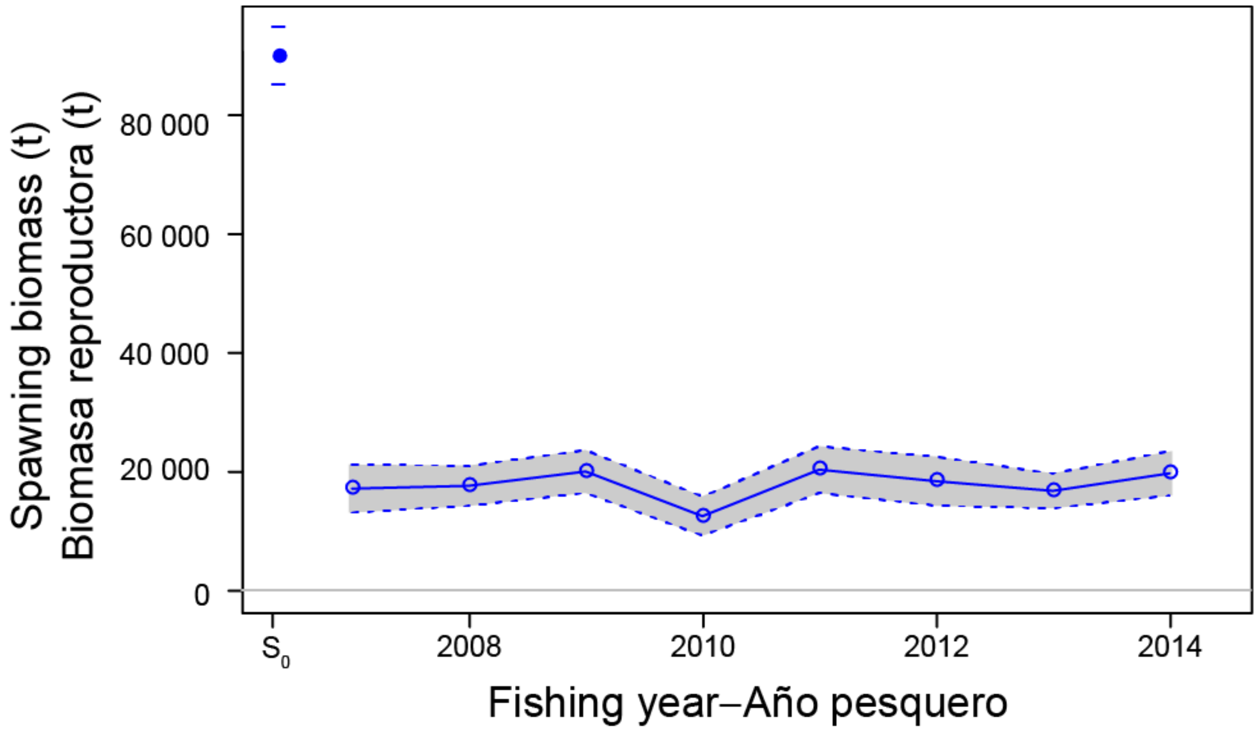

FIGURE 16. Estimated spawning biomass of dorado in the South EPO at the beginning of the spawning season in November. The solid blue line connects the maximum likelihood estimates (open circles), and the shaded area indicates the approximate 95% confidence intervals around these estimates. The blue dot represents the virgin spawning biomass.

FIGURA 16. Biomasa reproductora estimada de dorado en el OPO sur al principio de la temporada de desove en noviembre. La línea azul sólida conecta las estimaciones de verosimilitud máxima (círculos abiertos), y el área sombreada indica los intervalos de confianza de 95% alrededor de estas estimaciones. El punto azul representa la biomasa reproductora virgen.

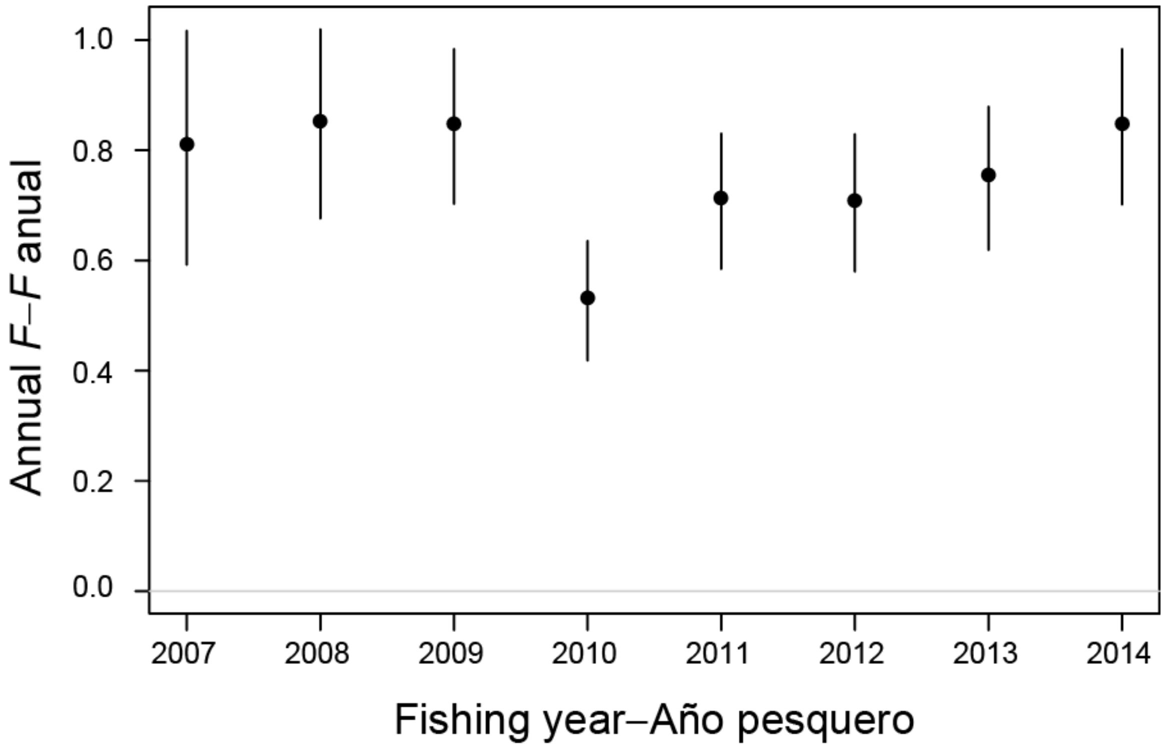

FIGURE 17a. Annual fishing mortality (*F*), for all fisheries, of dorado recruited to the fisheries of the South EPO.

FIGURA 17a. Mortalidad por pesca (*F*) anual, de todas las pesquerías, de dorado reclutado a las pesquerías del OPO sur.

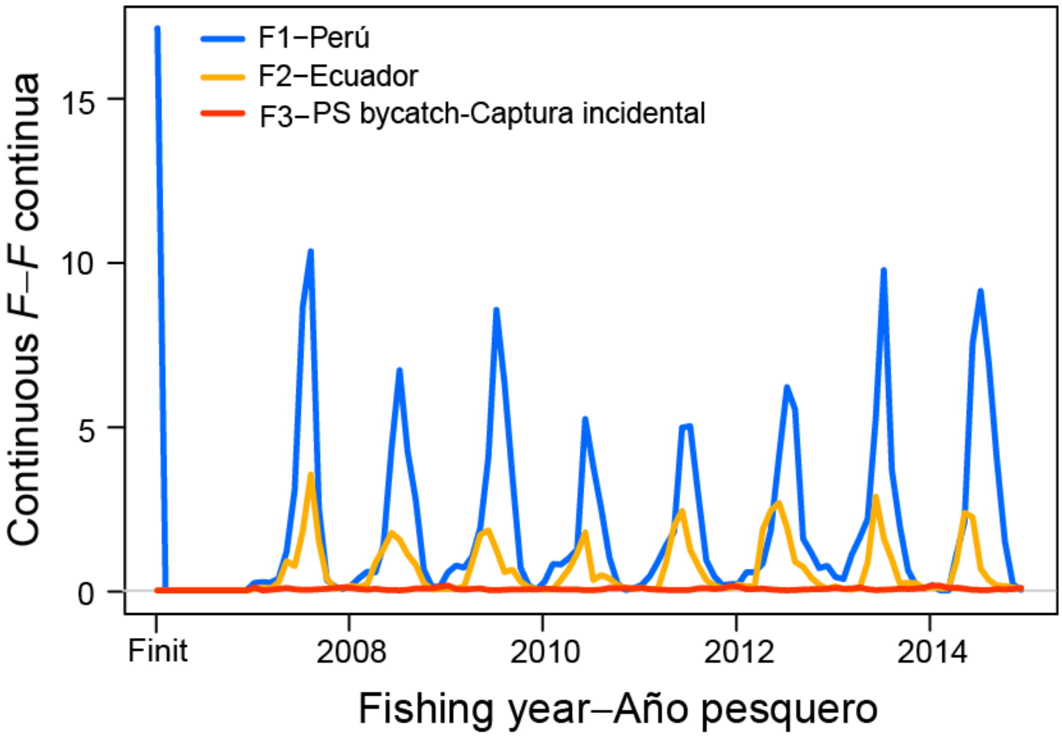

FIGURE 17b. Annualized monthly instantaneous fishing mortality (*F*), by fishery, for dorado recruited to the fisheries of the South EPO.

FIGURA 17b. Mortalidad por pesca instantánea mensual anualizada (*F*), por pesquería, de dorado reclutado a las pesquerías del OPO sur.

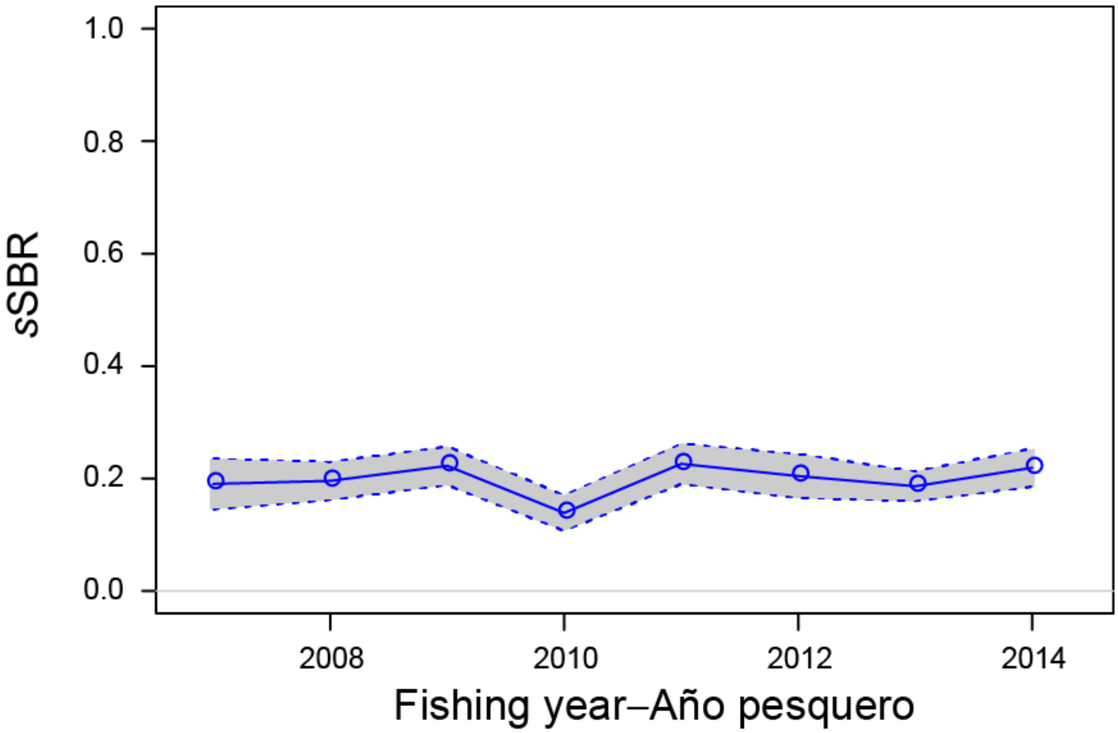

FIGURE 18. Estimated static spawning biomass ratios (sSBR) of dorado recruited to the fisheries of the South EPO. The solid blue line connects the maximum likelihood estimates (open circles), and the shaded area indicates the approximate 95% confidence intervals around these estimates.

FIGURA 18. Cocientes de biomasa reproductora estáticos (*s*SBR) estimados de dorado reclutado a las pesquerías del OPO sur. La línea azul conecta las estimaciones de verosimilitud máxima (círculos abiertos), y el área sombreada indica los intervalos de confianza de 95% alrededor de estas estimaciones.

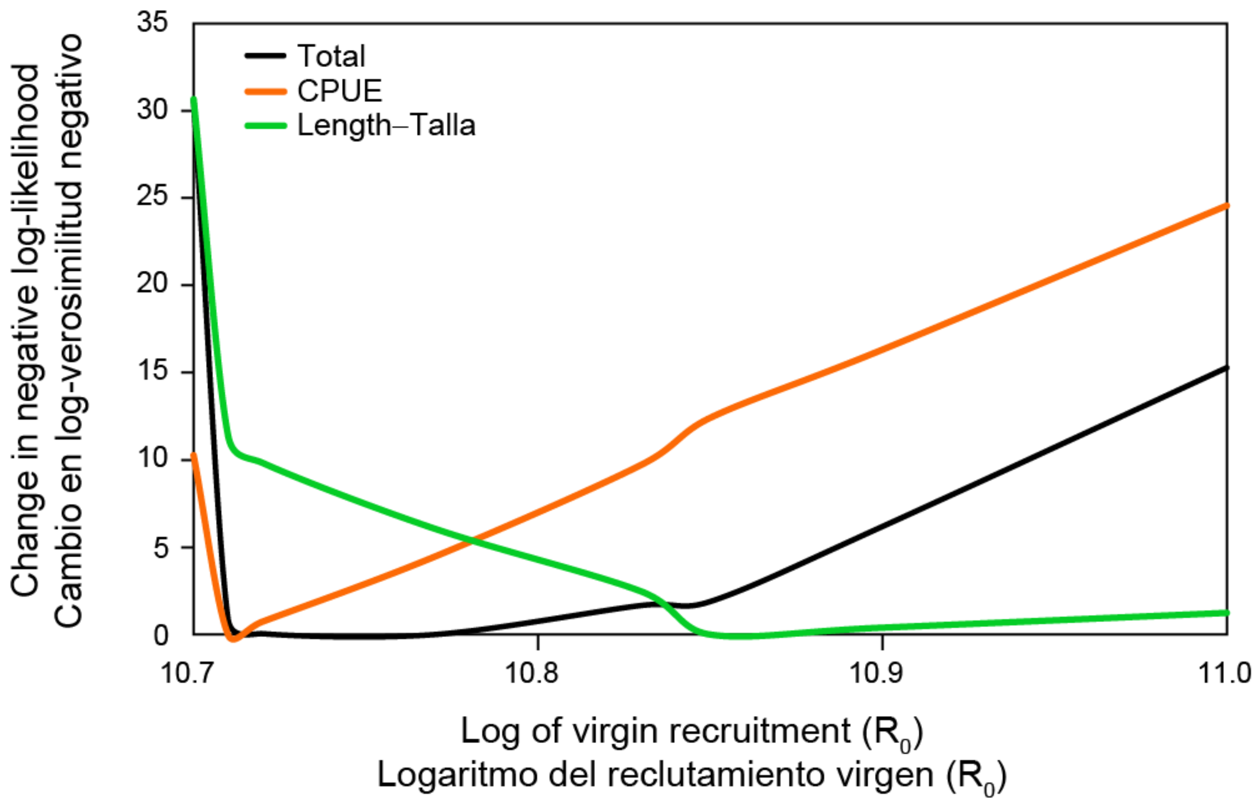

FIGURE 19. Likelihood profile for the virgin recruitment (R_0) parameter estimated under the previous base case model configuration (Aires-da-Silva and Maunder 2011), which assumed the original input sample sizes of the size composition data (λ = 1). The lines represent the profiles for each of the two data components included in the model fit and for the total likelihood.

FIGURA 19. Perfil de verosimilitud del parámetro de reclutamiento virgen (R_0) estimado con la configuración previa del modelo de caso base (Aires-da-Silva y Maunder 2011), que supuso el tamaño de muestra de entrada original de los datos de composición por talla (λ = 1). Las líneas representan el perfil de cada uno de los dos componentes de datos incluidos en el ajuste del modelo y de la verosimilitud total.

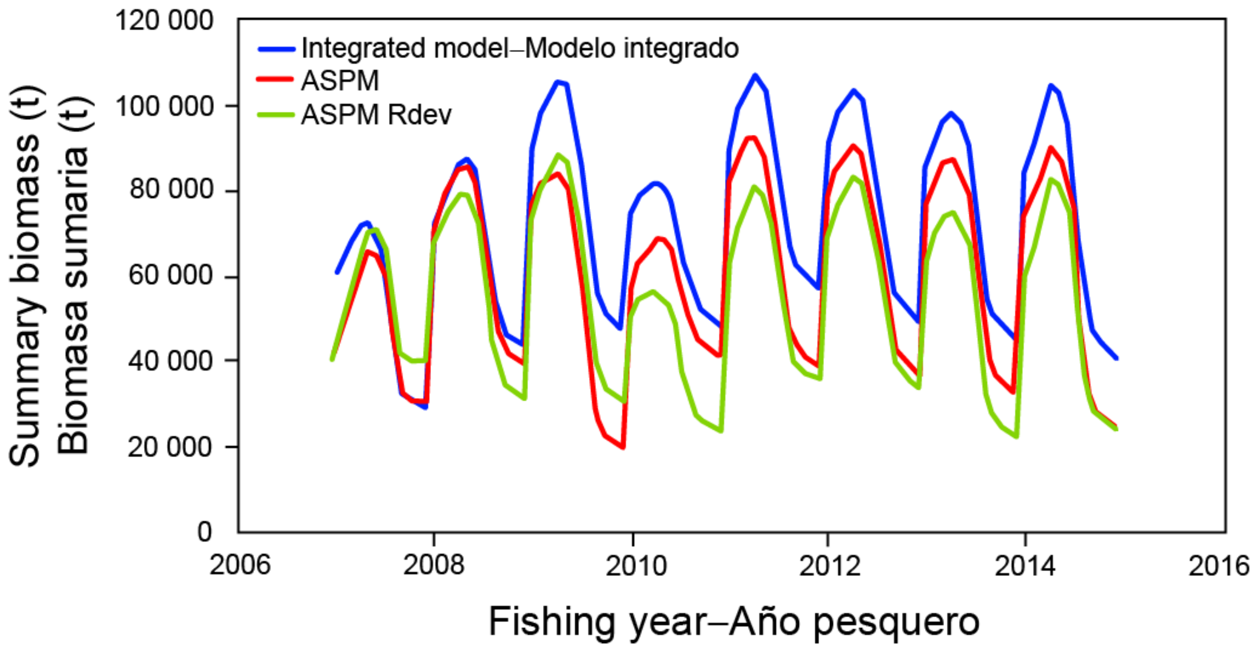

FIGURE 20. Age-structured production model (ASPM) diagnostic. The lines represent the estimates of the summary biomass from the integrated model (base case), the ASPM diagnostic, and the ASPM diagnostic with the recruitment deviations estimated (ASPM-Rdev). See section 5.1.4.b in text.

FIGURA 20. Diagnóstico de modelo de producción con estructura por edad (ASPM). Las líneas corresponden a las estimaciones de biomasa sumaria del modelo integrado (caso base), el diagnóstico ASPM, y el diagnóstico ASPM con las desviaciones del reclutamiento estimadas (ASPM-Rdev). Ver sección 5.1.4.b en el texto.

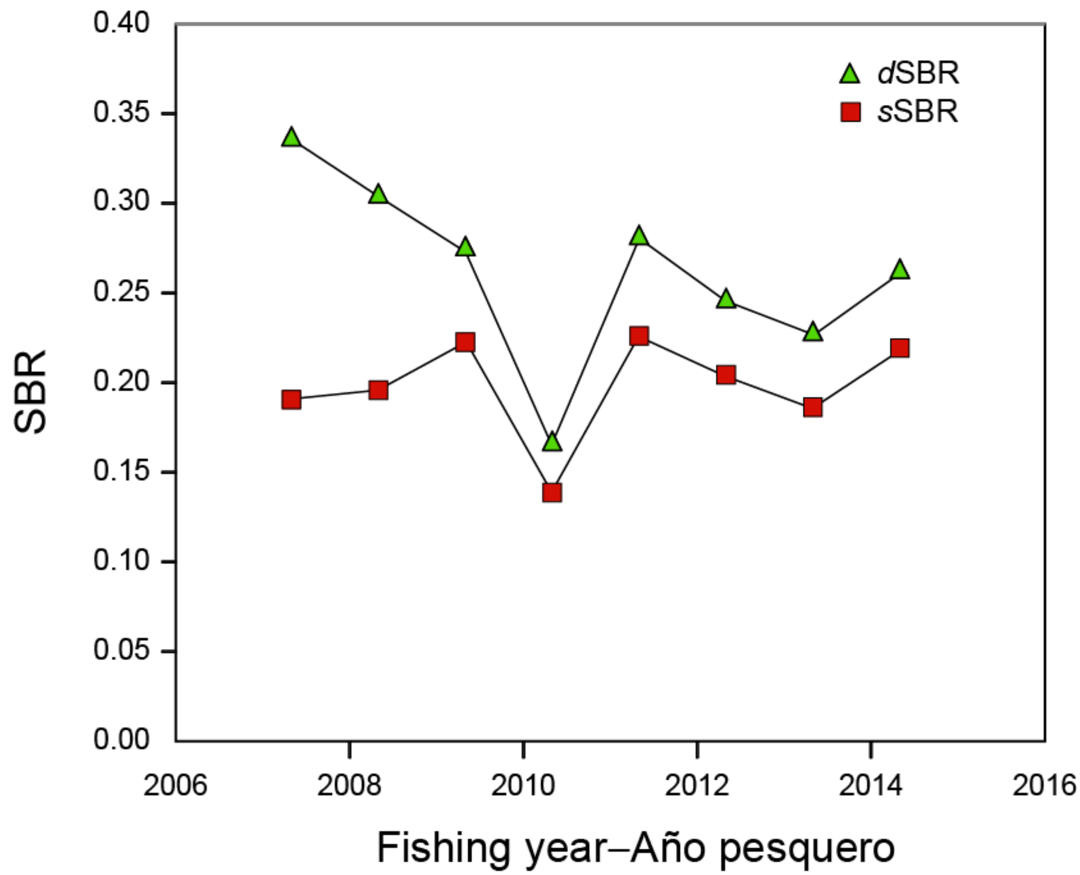

FIGURE 21. Estimates of the spawning biomass ratio (SBR) for the base case obtained using the static (sSBR) and dynamic (*d*SBR) methods. See section 6.1. in text.

FIGURA 21. Estimaciones del cociente de biomasa reproductora (SBR) del caso base obtenidas con el método estático (*s*SBR) y dinámico (*d*SBR). Ver sección 6.1 en el texto.

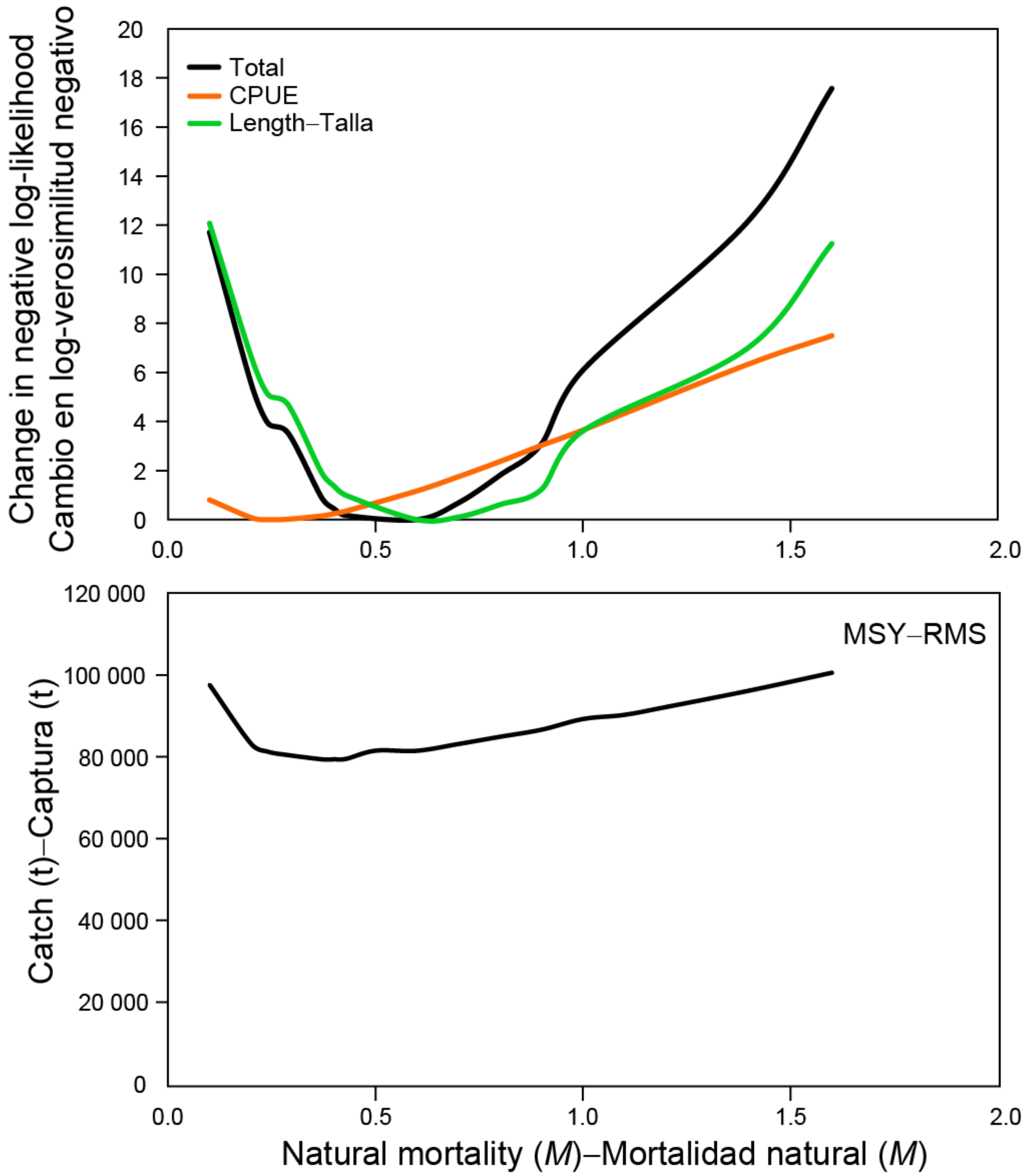

FIGURE 22. Top panel: Likelihood profile for the natural mortality (*M*) parameter estimated under the previous base case model configuration (Aires-da-Silva and Maunder 2011), which assumed the original input sample sizes of the size composition data (λ = 1). The lines represent the profiles for each of the two data components included in the model fit and for the total likelihood. Bottom panel: maximum sustainable yield (MSY), in metric tons.

FIGURA 22. Panel superior: Perfil de verosimilitud del parámetro de mortalidad natural (*M*) estimado con la configuración previa del modelo de caso base (Aires-da-Silva y Maunder 2011), que supuso el tamaño de muestra de entrada original de los datos de composición por talla (λ = 1). Las líneas representan el perfil de cada uno de los dos componentes de datos incluidos en el ajuste del modelo y de la verosimilitud total. Panel inferior: rendimiento máximo sostenible (RMS), en toneladas.

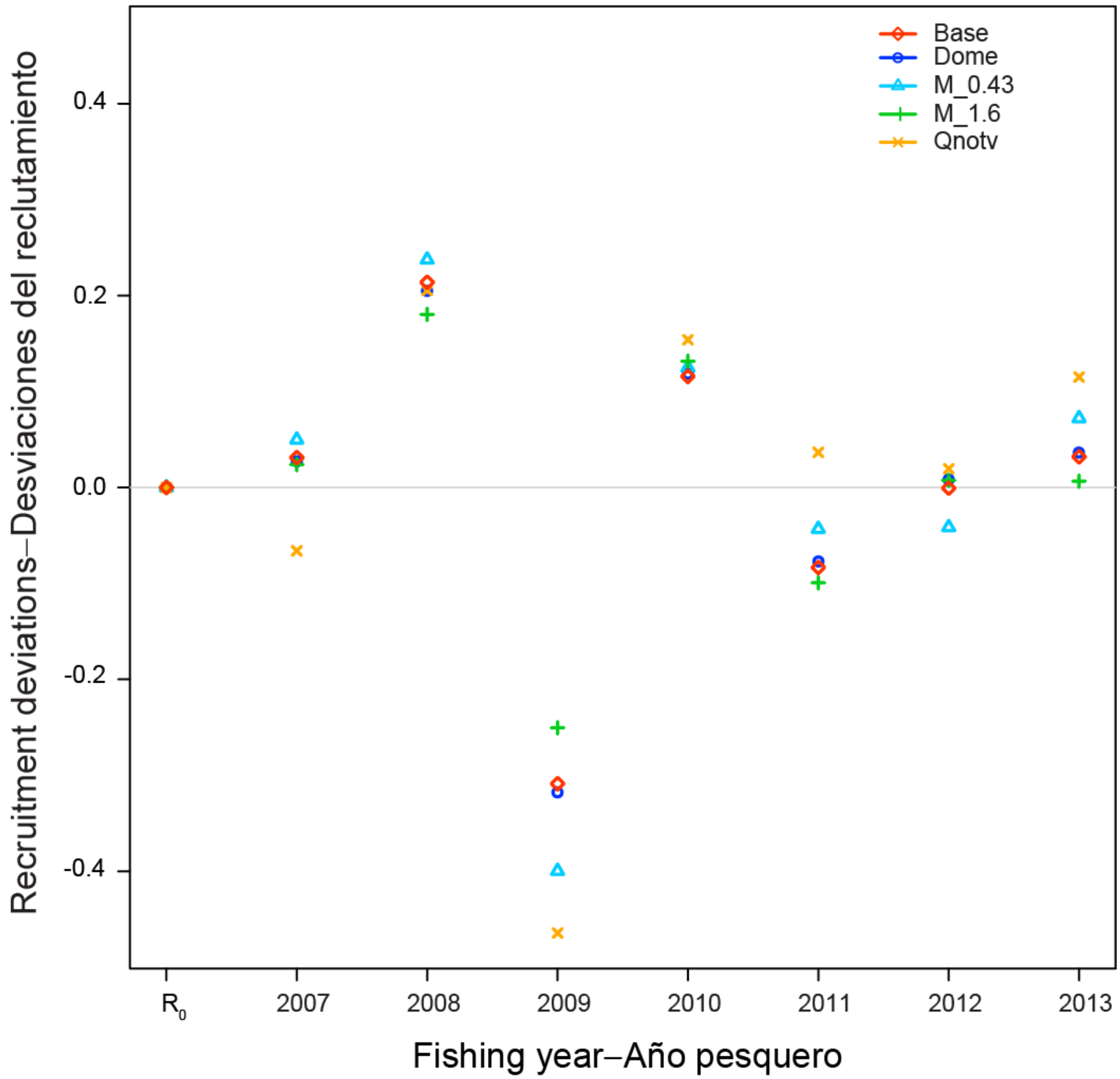

FIGURE 23. Recruitment deviations during 2007-2013, estimated in the base case (Base) and by the analyses of sensitivity to dome-shaped selectivity (Dome), natural mortalities of 0.43 and 1.6 (*M*_0.43 and *M*_1.6, respectively), and no time-varying selectivity (*Q*notv).

FIGURA 23. Desviaciones del reclutamiento durante 2007-2013, estimadas en el caso base (Base) y los análisis de sensibilidad a selectividad en forma de domo (Dome), mortalidad natural de 0.43 y 1.6 (*M*_0.43 y *M*_1.6, respectivamente), y selectividad sin variabilidad temporal (*Q*notv).

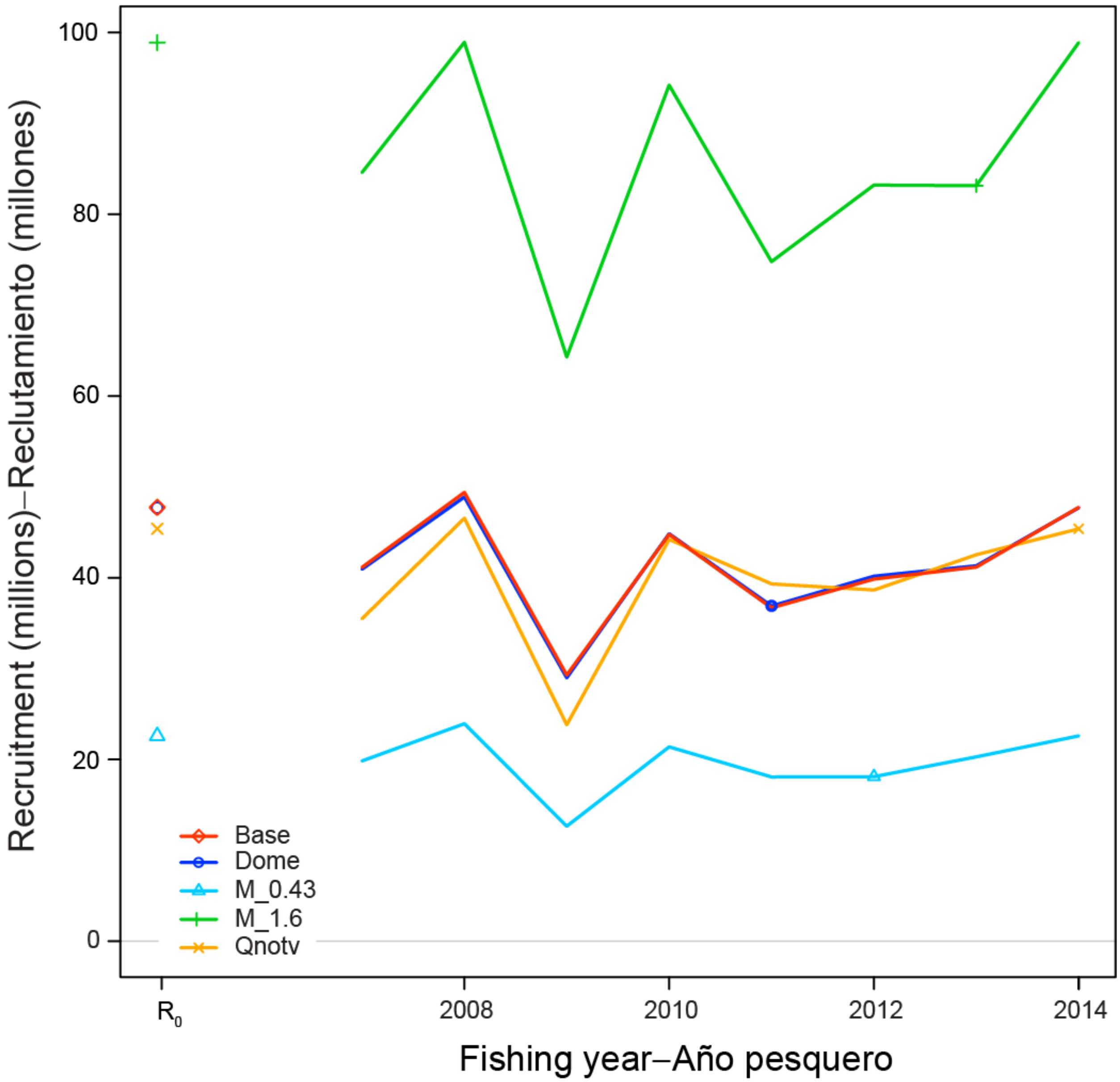

FIGURE 24. Recruitment of age-0 dorado during 2007-2014, estimated by the base case (Base) and by analyses of sensitivity to dome-shaped selectivity (Dome), natural mortalities of 0.43 and 1.6 (*M*_0.43 and *M*_1.6, respectively), and no time-varying selectivity (*Q*notv).

FIGURA 24. Reclutamiento de dorado de edad 0 durante 2007-2014, estimado por el caso base (Base) y por los análisis de sensibilidad a selectividad en forma de domo (Dome), mortalidad natural de 0.43 y 1.6 (*M*_0.43 y *M*_1.6, respectivamente), y selectividad sin variabilidad temporal (*Q*notv).

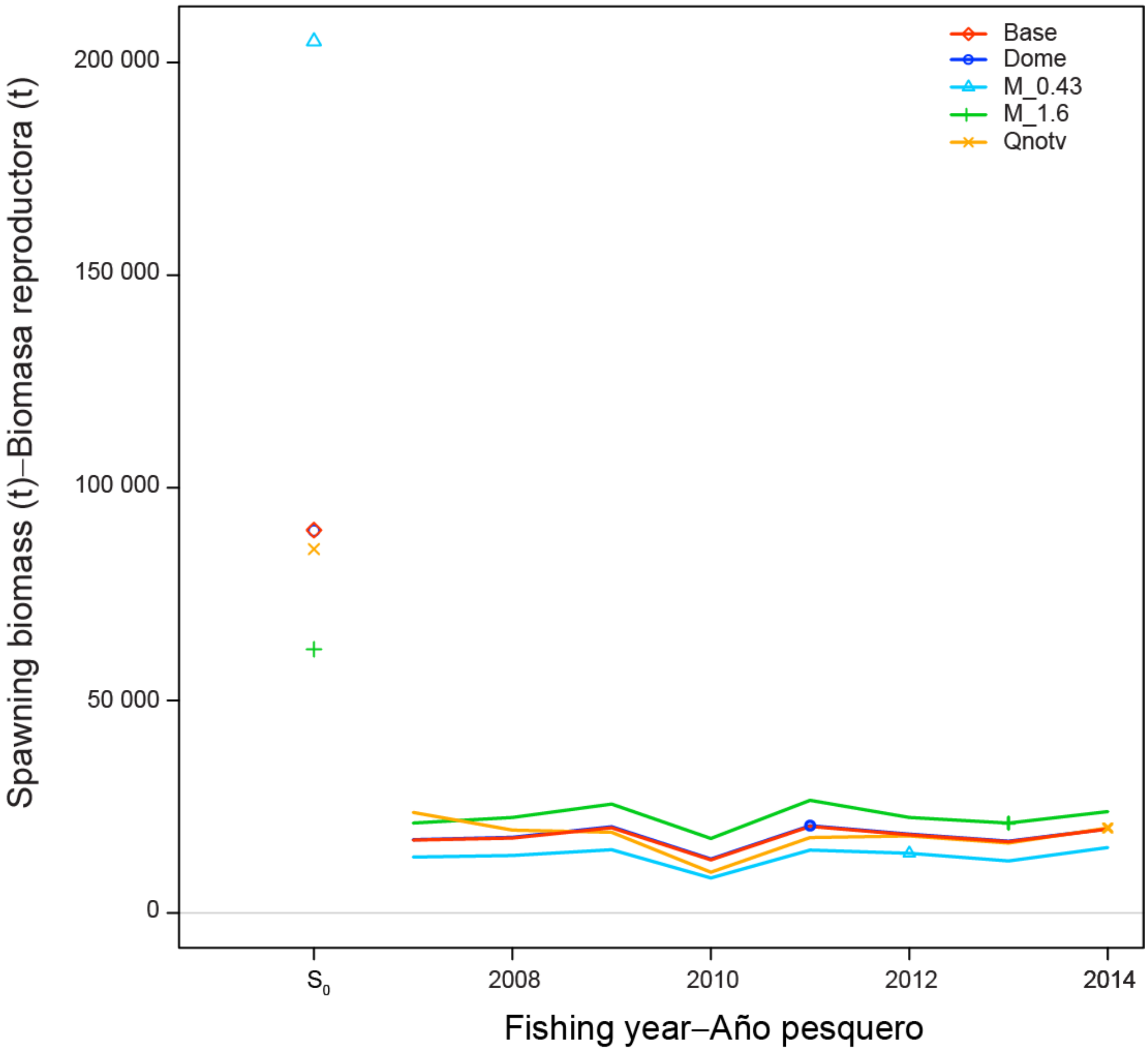

FIGURE 25. Spawning biomass (t) of dorado during 2007-2014, estimated by the base case (Base) and by analyses of sensitivity to dome-shaped selectivity (Dome), natural mortalities of 0.43 and 1.6 (*M*_0.43 and *M*_1.6, respectively), and no time-varying selectivity (*Q*notv).

FIGURA 25. Biomasa reproductora de dorado durante 2007-2014, estimada por el caso base (Base) y por los análisis de sensibilidad a selectividad en forma de domo (Dome), mortalidad natural de 0.43 y 1.6 (*M*_0.43 y *M*_1.6, respectivamente), y selectividad sin variabilidad temporal (*Q*notv).

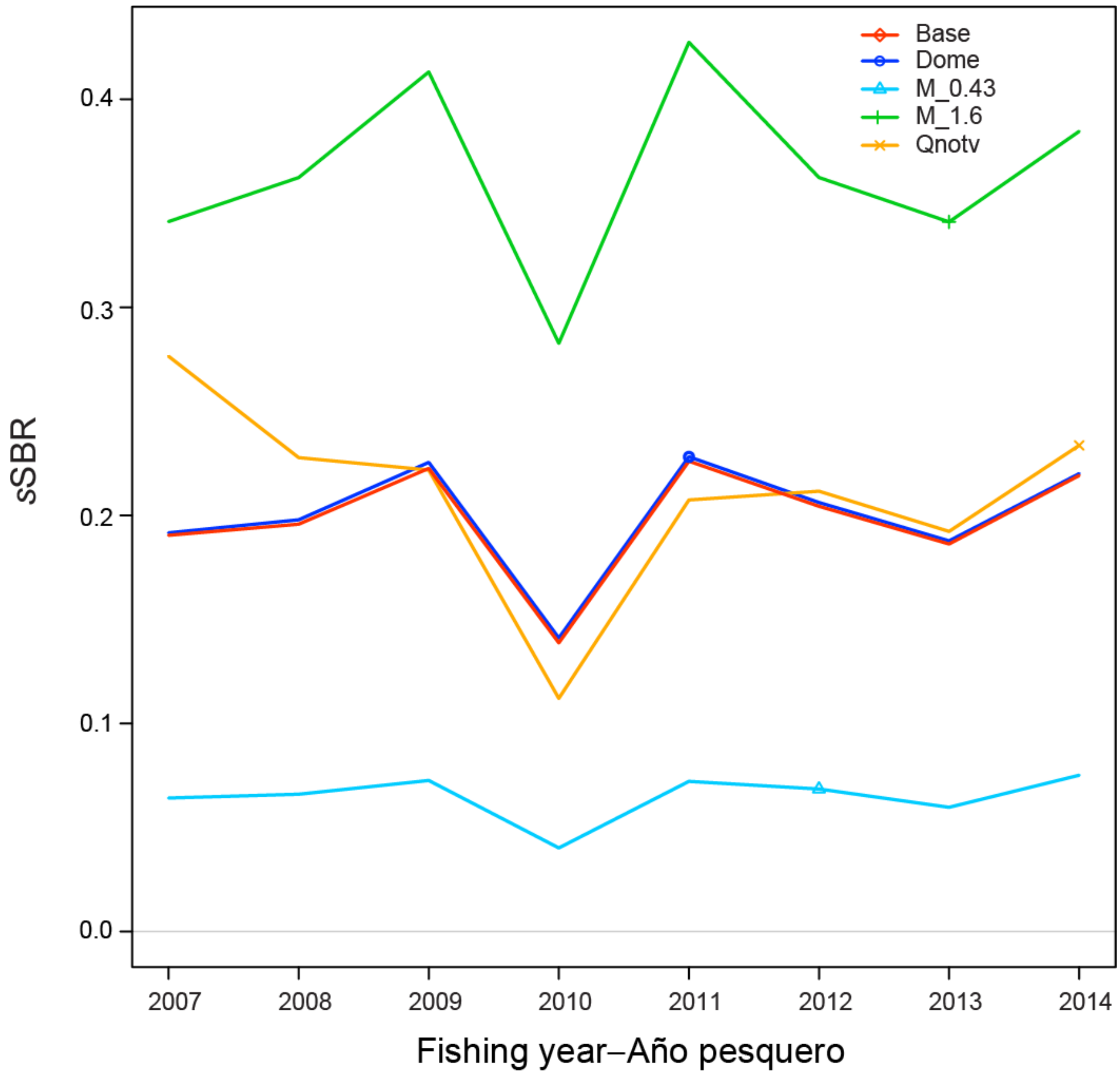

FIGURE 26. Static spawning biomass ratio (*s*SBR; see section 6.1) during 2007-2014, estimated by the base case (Base) and the analyses of sensitivity to dome-shaped selectivity (Dome), natural mortalities of 0.43 and 1.6 (*M*_0.43 and *M*_1.6, respectively), and no time-varying selectivity (*Q*notv).

FIGURA 26. Cocientes de biomasa reproductora estáticos (*s*SBR; ver sección 6.1) durante 2007-2014, estimados por el caso base (Base) y por los análisis de sensibilidad a selectividad en forma de domo (Dome), mortalidad natural de 0.43 y 1.6 (*M*_0.43 y *M*_1.6, respectivamente), y selectividad sin variabilidad temporal (*Q*notv).

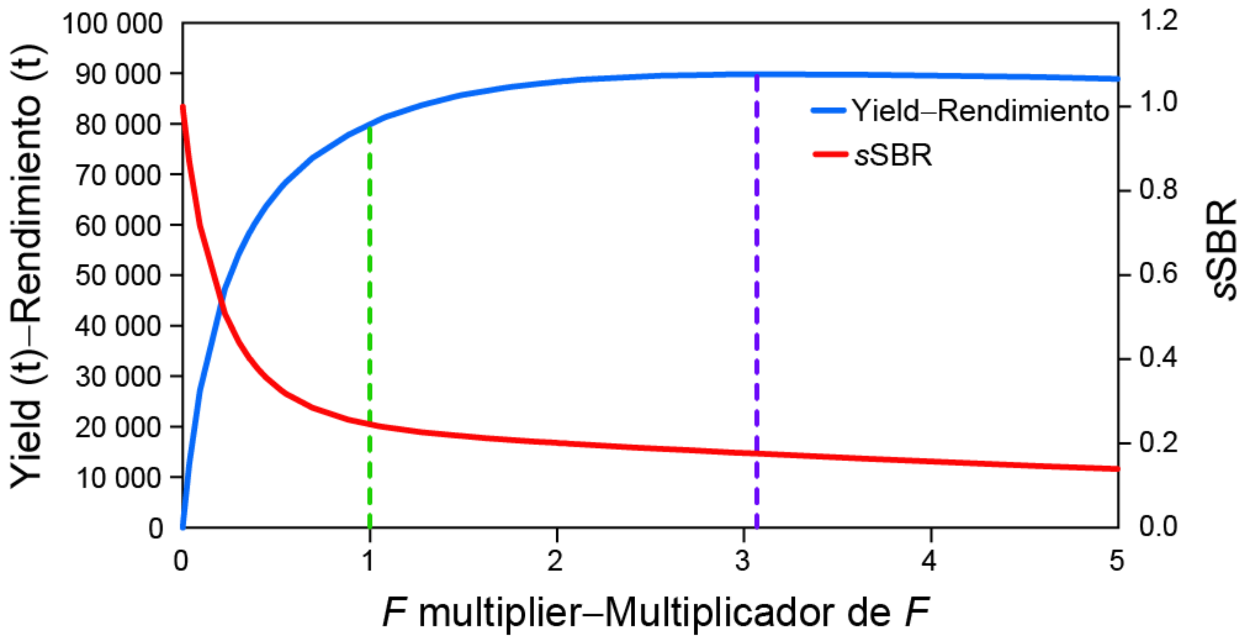

FIGURE 27. Equilibrium yield, in tons, and static spawning biomass ratio (*s*SBR; see section 6.1) versus the *F* multiplier (vertical blue dashed line), which indicates how many times effort would have to be effectively increased from the current level (vertical green dashed line) to achieve MSY.

FIGURA 27. Rendimiento de equilibrio, en toneladas, y cociente de biomasa reproductora estático (*s*SBR; ver sección 6.1) como funciones del multiplicador de F (línea de trazos vertical azul), que indica cuántas veces se ha de incrementar el esfuerzo del nivel actual (línea de trazos vertical verde) para lograr el RMS.

Appendix-Anexo A.

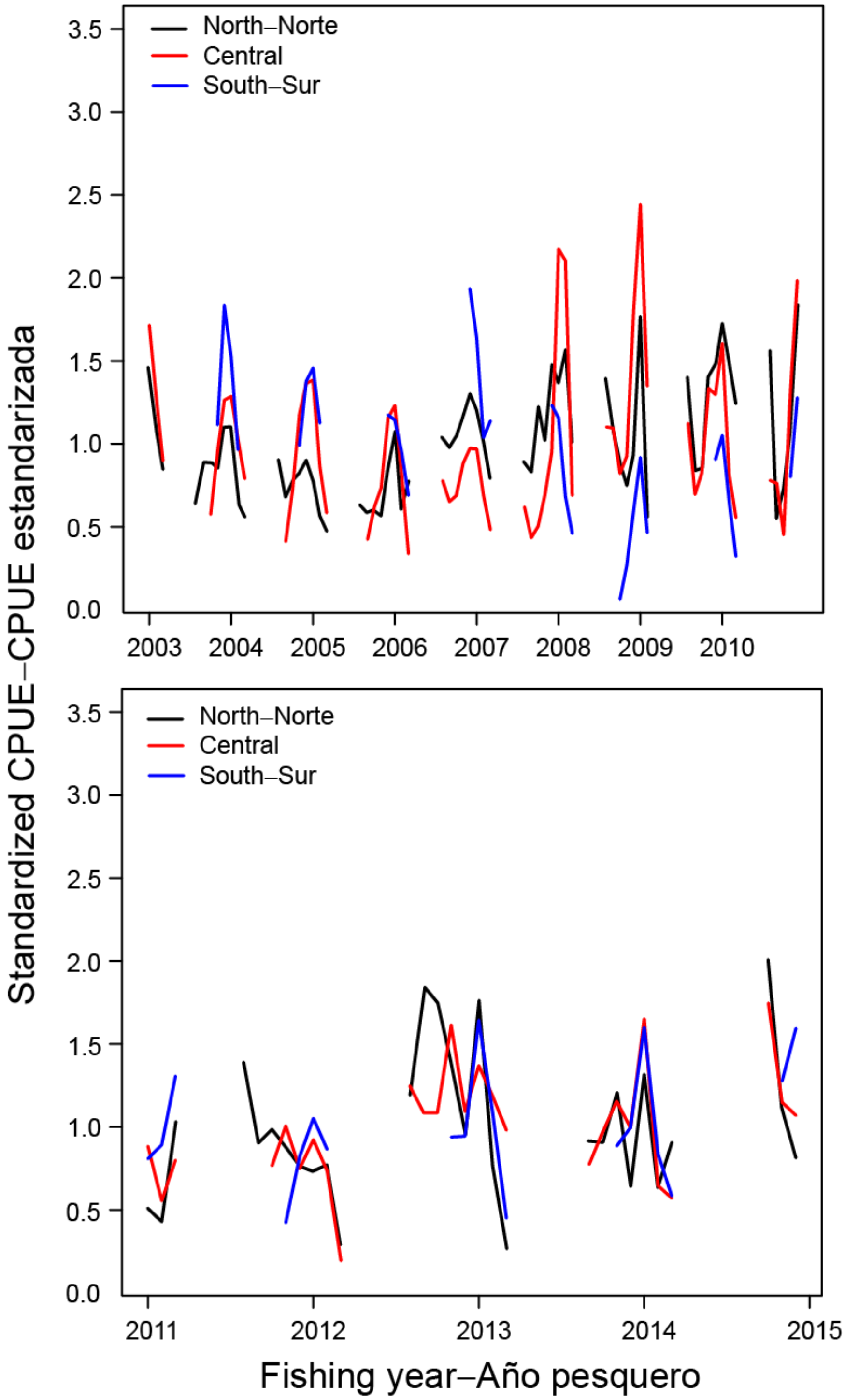

FIGURE A.1. Standardized CPUE from the gamma generalized additive models (GAMs) for CPUE in weight of dorado caught by Peruvian artisanal fisheries for three regions (North, Central, and South) during two periods (2003-2010 and 2011-2014).

FIGURA A.1. CPUE estandarizada de los modelos aditivos generalizados (MAG) gamma de CPUE en peso de dorado capturado por pesquerías artesanales peruanas en tres regiones (Norte, Central, y Sur) durante dos periodos (2003-2010 y 2011-2014).

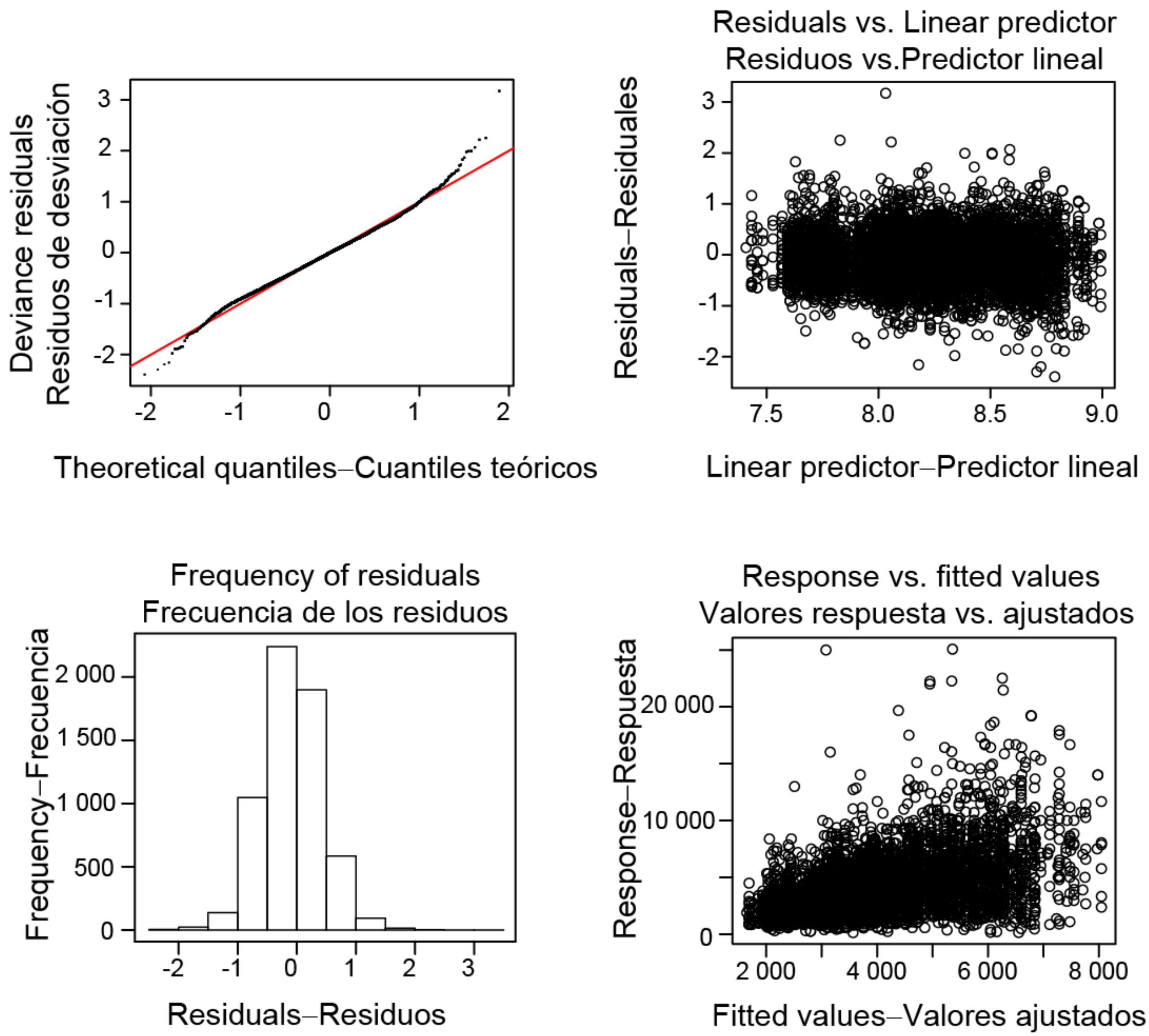

FIGURE A.2. Diagnostic plots for the GAM using CPUE in weight for the Peruvian artisanal fisheries operating in the Northern area during the early period (2003-2010). GAM assumed gamma distribution with log link.

FIGURA A.2. Graficos diagnósticos del MAG usando CPUE en peso de las pesquerías artesanales peruanas que operaron en el área Norte durante el periodo temprano (2003-2010). El MAG supuso una distribución gamma con función de enlace logarítmico.

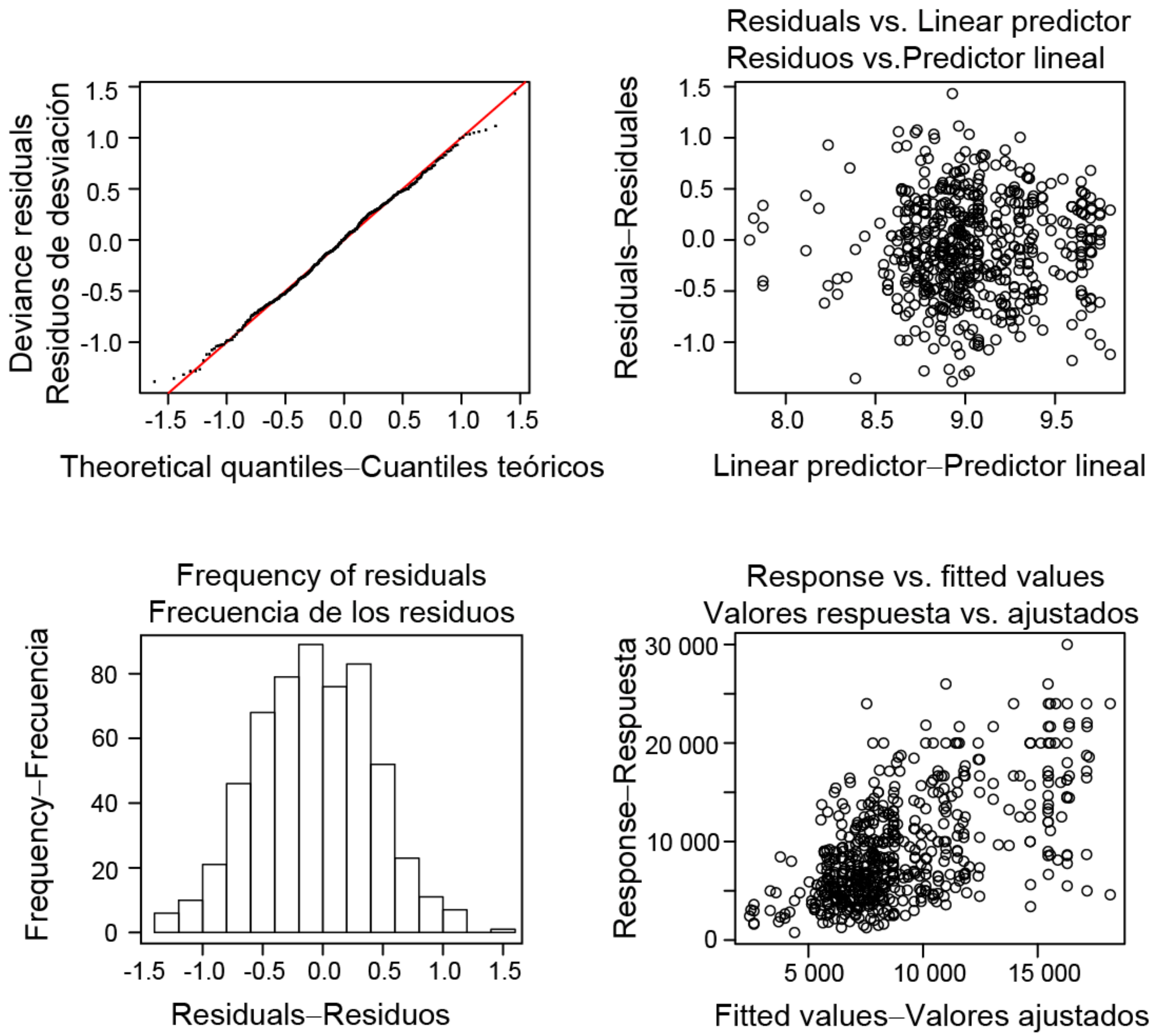

FIGURE A.3. Diagnostic plots for the GAM using CPUE in weight for the Peruvian artisanal fisheries operating in the Northern area during the later period (2011-2014). GAM assumed gamma distribution with log link.

FIGURA A.3. Graficos diagnósticos del MAG usando CPUE en peso de las pesquerías artesanales peruanas que operaron en el área Norte durante el periodo tardio (2011-2014). El MAG supuso una distribución gamma con función de enlace logarítmico.

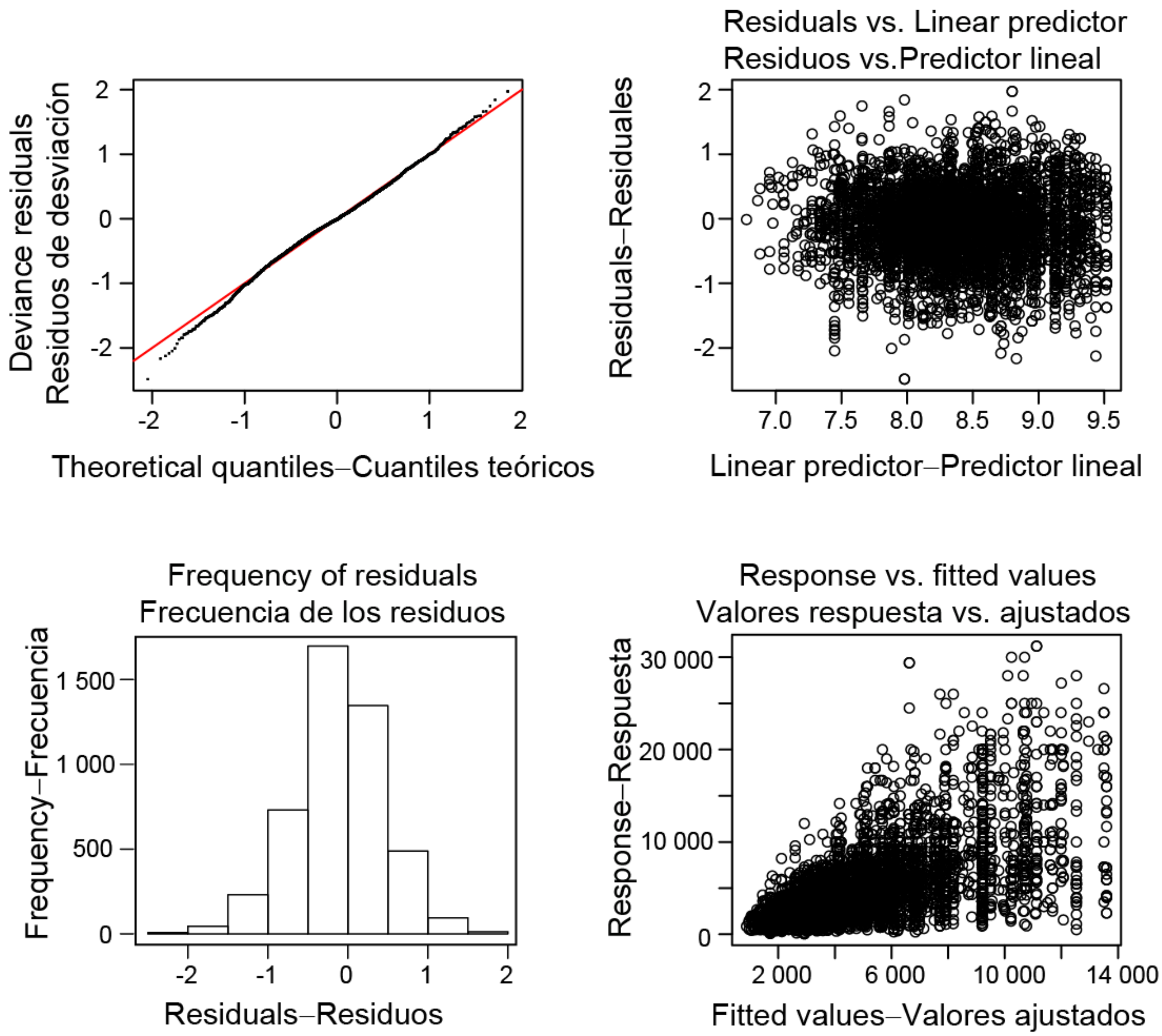

FIGURE A.4. Diagnostic plots for the GAM using CPUE in weight for the Peruvian artisanal fisheries operating in the Central area during the early period (2003-2010). GAM assumed gamma distribution with log link.

FIGURA A.4. Graficos diagnósticos del MAG usando CPUE en peso de las pesquerías artesanales peruanas que operaron en el área Central durante el periodo temprano (2003-2010). El MAG supuso una distribución gamma con función de enlace logarítmico.

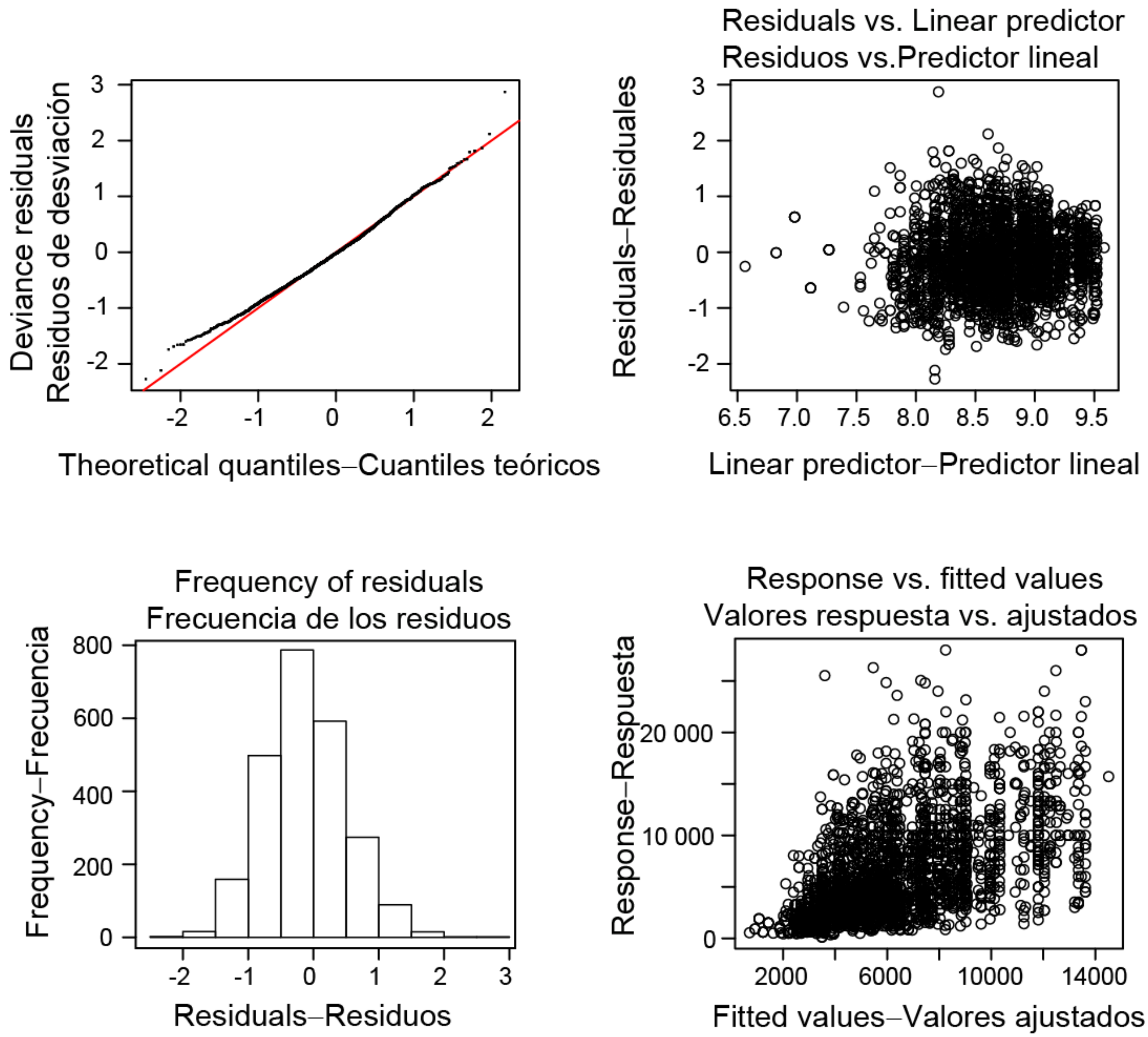

FIGURE A.5. Diagnostic plots for the GAM using CPUE in weight for the Peruvian artisanal fisheries operating in the Central area during the later period (2011-2014). GAM assumed gamma distribution with log link.

FIGURA A.5. Graficos diagnósticos del MAG usando CPUE en peso de las pesquerías artesanales peruanas que operaron en el área Central durante el periodo tardio (2011-2014). El MAG supuso una distribución gamma con función de enlace logarítmico.

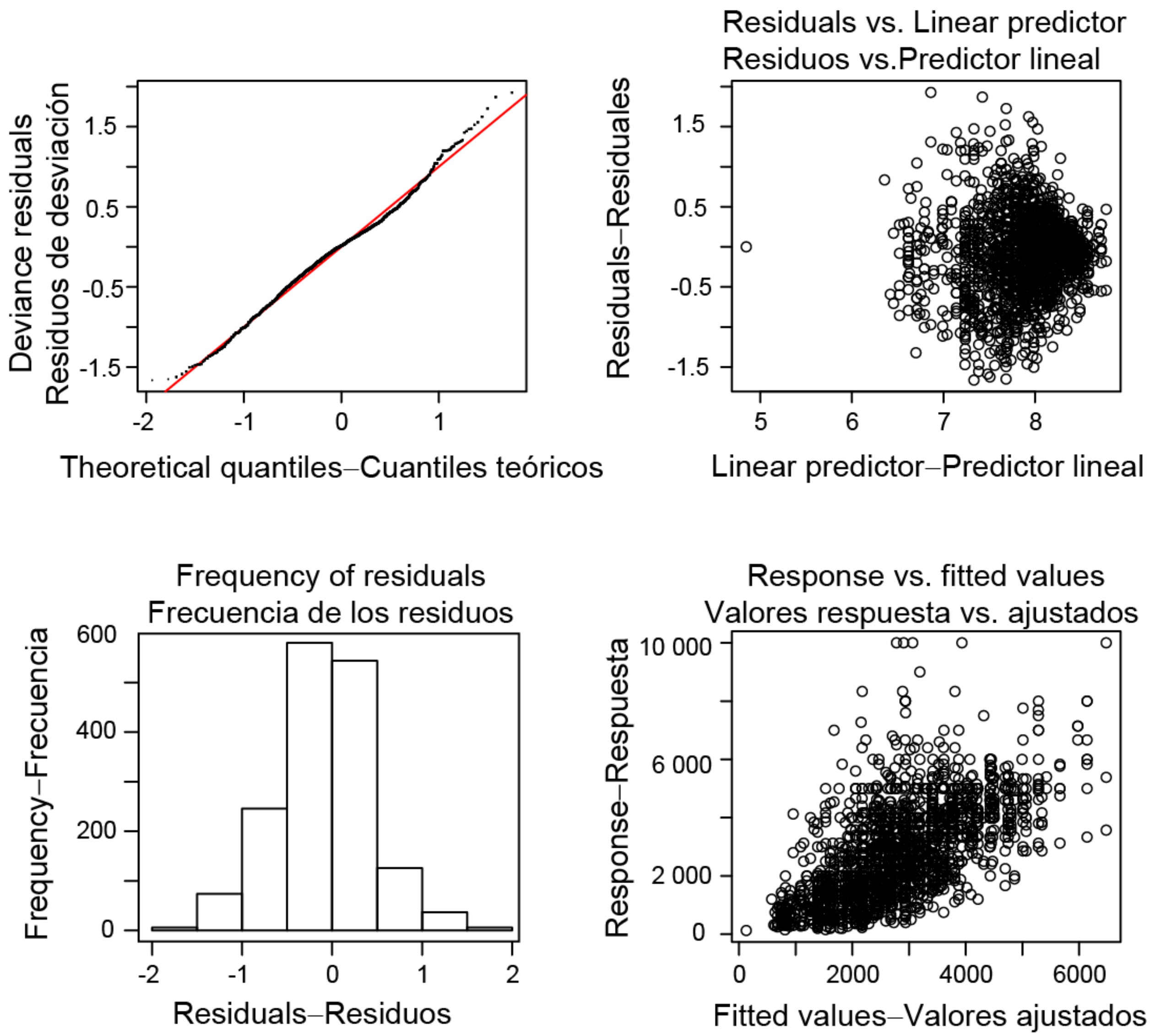

FIGURE A.6. Diagnostic plots for the GAM using CPUE in weight for the Peruvian artisanal fisheries operating in the Southern area during the early period (2003-2010). GAM assumed gamma distribution with log link.

FIGURA A.6. Graficos diagnósticos del MAG usando CPUE en peso de las pesquerías artesanales peruanas que operaron en el área Sur durante el periodo temprano (2003-2010). El MAG supuso una distribución gamma con función de enlace logarítmico.

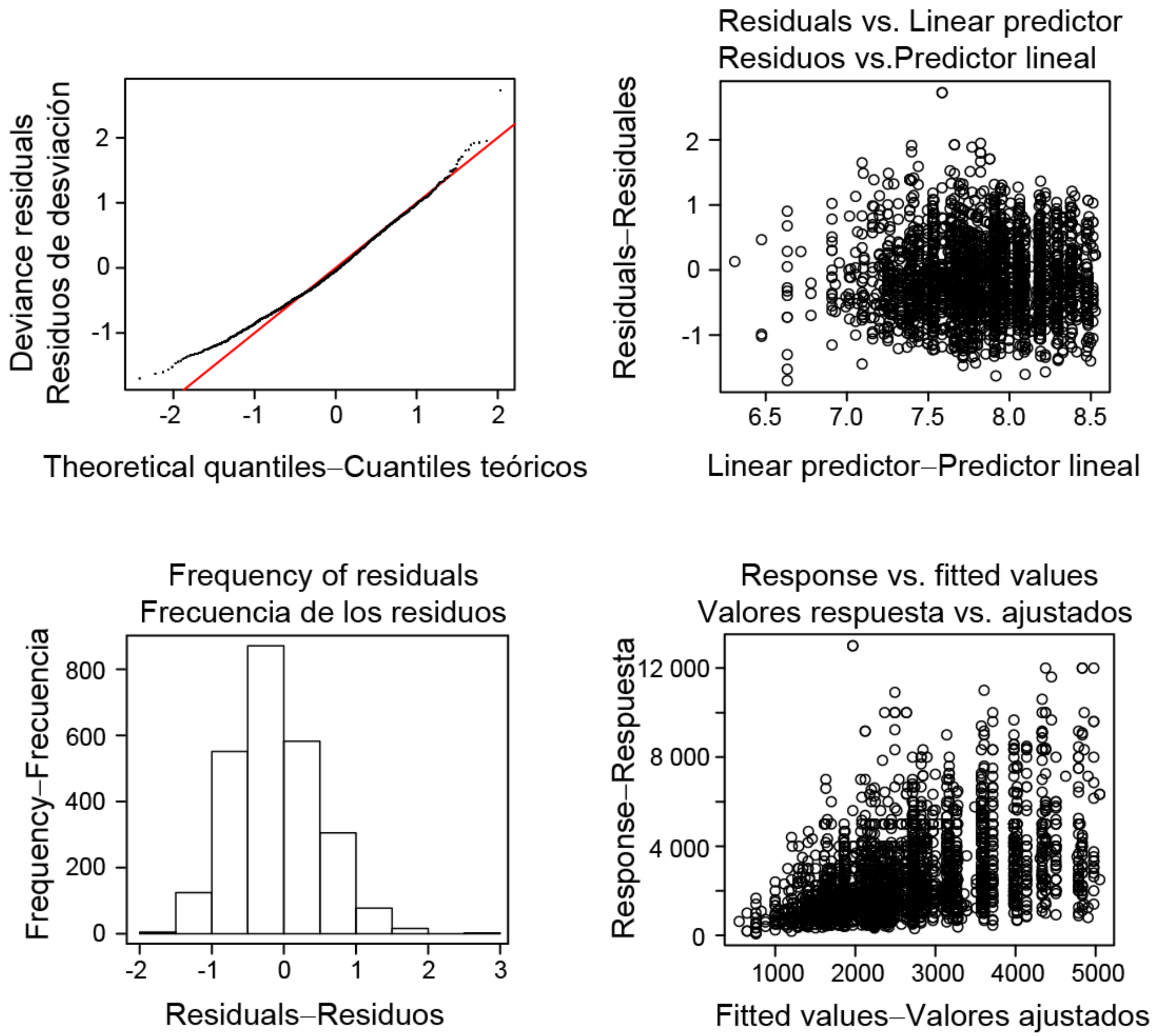

FIGURE A.7. Diagnostic plots for the GAM using CPUE in weight for the Peruvian artisanal fisheries operating in the Southern area during the later period (2011-2014). GAM assumed gamma distribution with log link.

FIGURA A.7. Graficos diagnósticos del MAG usando CPUE en peso de las pesquerías artesanales peruanas que operaron en el área Sur durante el periodo tardio (2011-2014). El MAG supuso una distribución gamma con función de enlace logarítmico.

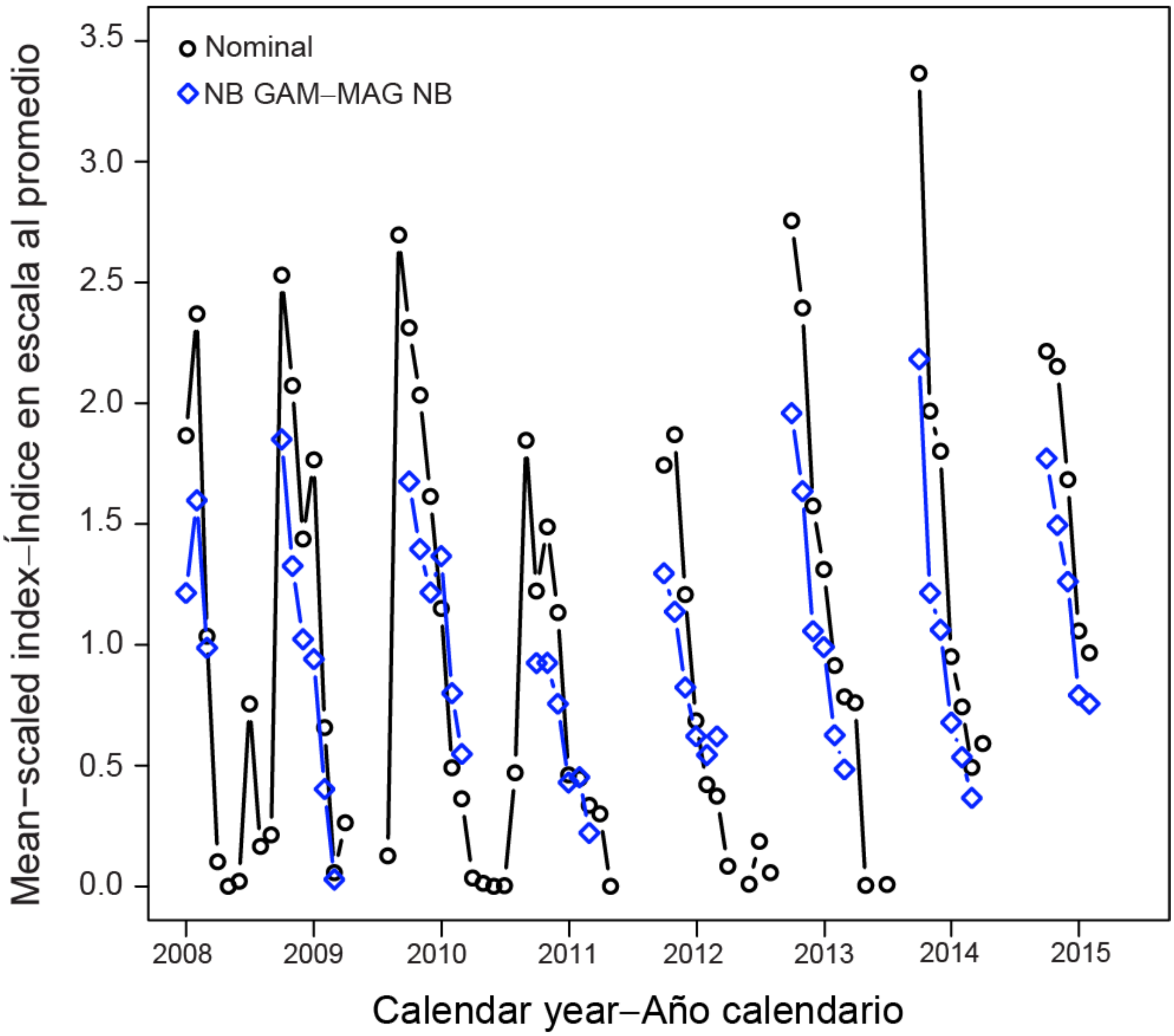

FIGURE A.8. Standardized CPUE from the negative binomial (NB) GAM for numbers of dorado caught by Ecuadorian artisanal fisheries (taking fishing effort into consideration). The nominal CPUEs are also shown.
FIGURA A.8. CPUE estandarizada del MAG binomial negativo (NB) de dorado, en número de pescados, por las pesquerías artesanales ecuatorianas (tomando esfuerzo de pesca en consideración). Se ilustra también la CPUE nominal.

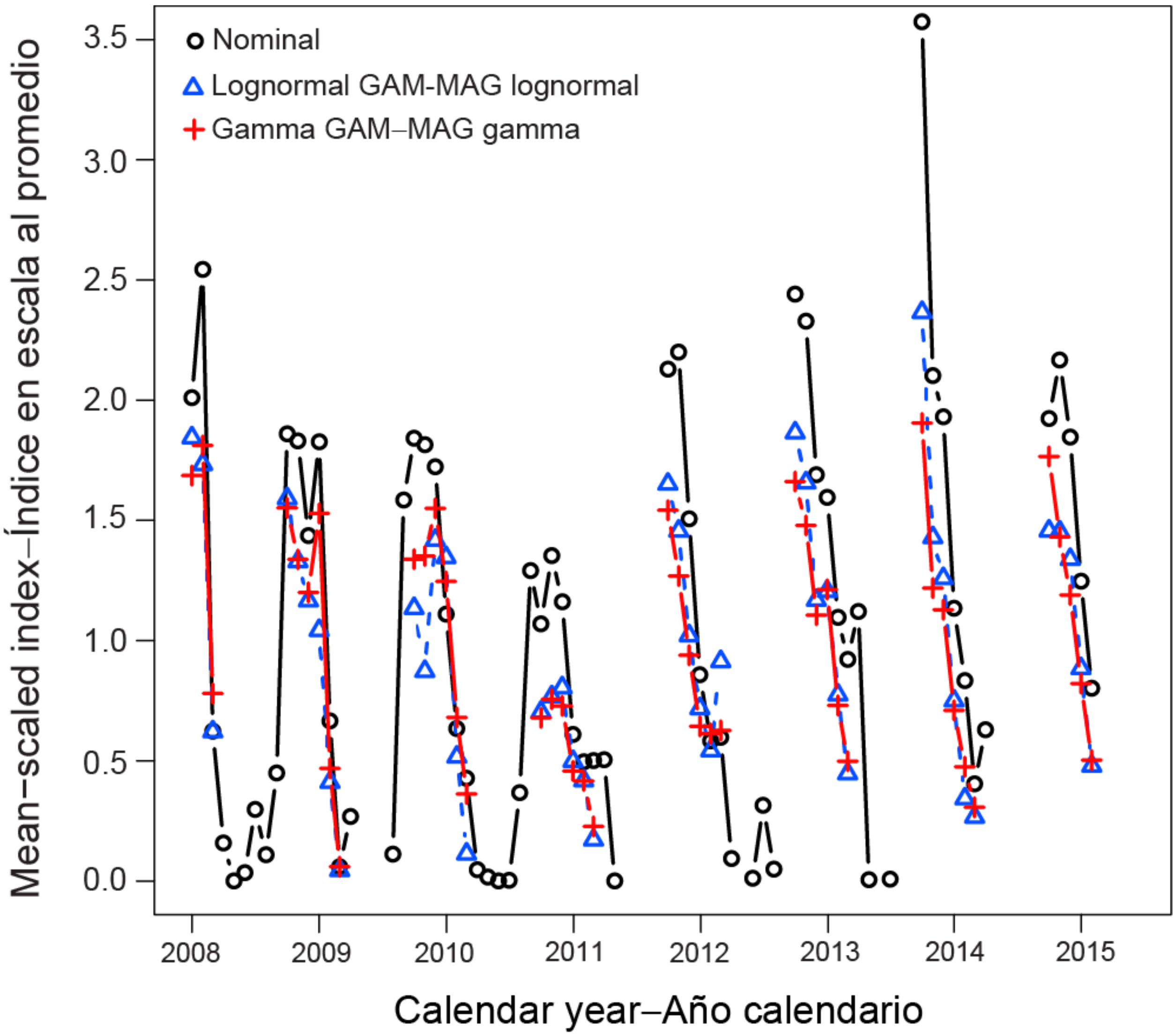

FIGURE A.9. Standardized CPUE from the lognormal and gamma GAMs for CPUE in weight of dorado caught by Ecuadorian artisanal fisheries. The nominal CPUEs are also shown.

FIGURA A.9. CPUE estandarizada de los MAG lognormal y gamma de CPUE en peso de dorado capturado por las pesquerías artesanales ecuatorianas. Se ilustra también la CPUE nominal.

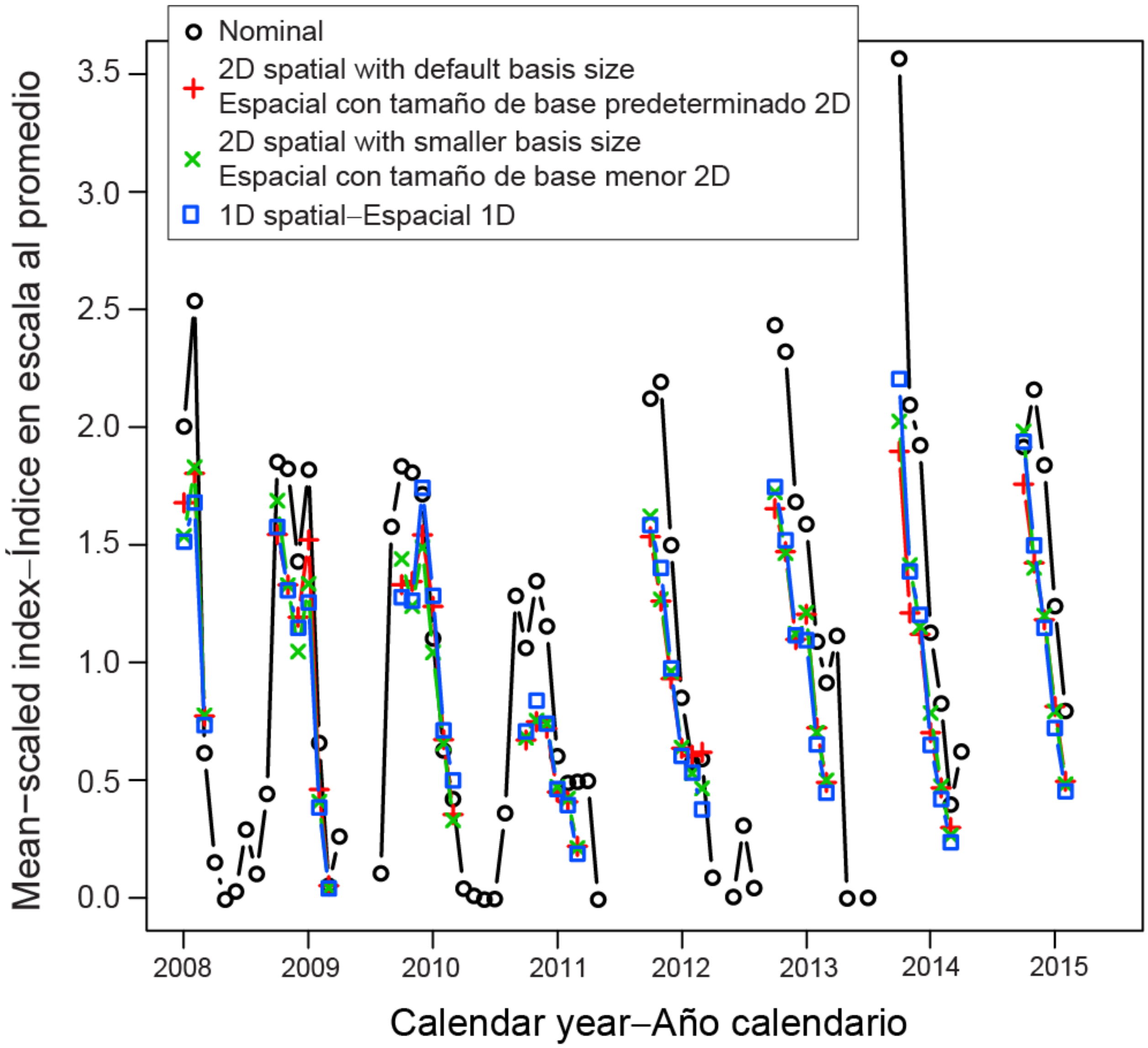

FIGURE A.10. Standardized CPUE from the gamma GAMs for CPUE in weight of dorado caught by Ecuadorian artisanal fisheries. GAM models with different configurations of spatial terms were used (see section 2.3.2). The nominal CPUEs are also shown.

FIGURA A.10. CPUE estandarizada de los MAG gamma de CPUE en peso de dorado capturado por las pesquerías artesanales ecuatorianas. Se usaron modelos MAG con distintas configuraciones de los términos espaciales (ver sección 2.3.2). Se ilustra también la CPUE nominal.

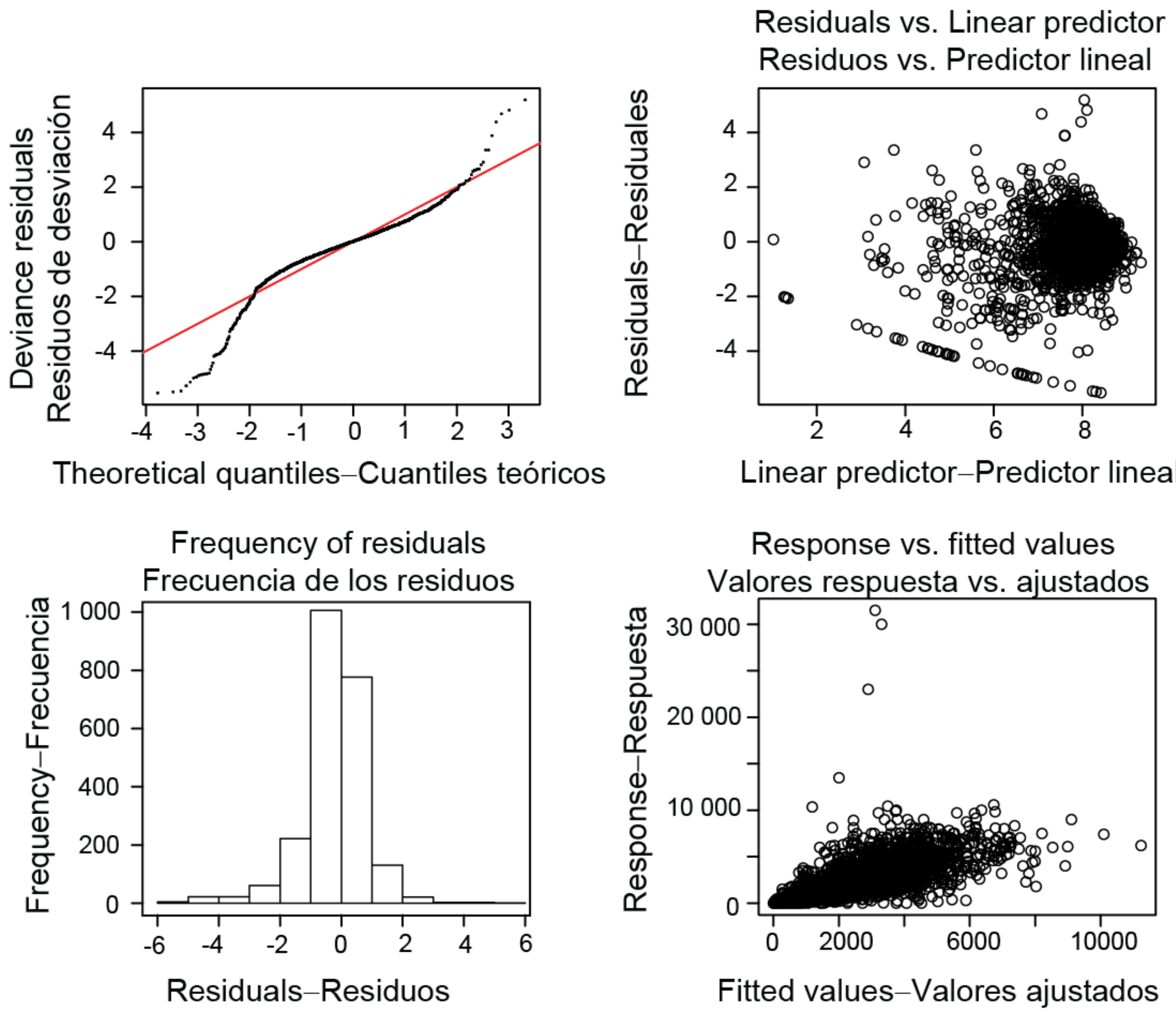

FIGURE A.11. Diagnostic plots for the negative binomial GAM for counts of fish caught by Ecuadorian artisanal fisheries (taking into consideration fishing effort).
FIGURA A.11. Gráficas diagnósticas del MAG binominal negativo de números de peces capturados por las pesquerías artesanales ecuatorianas.

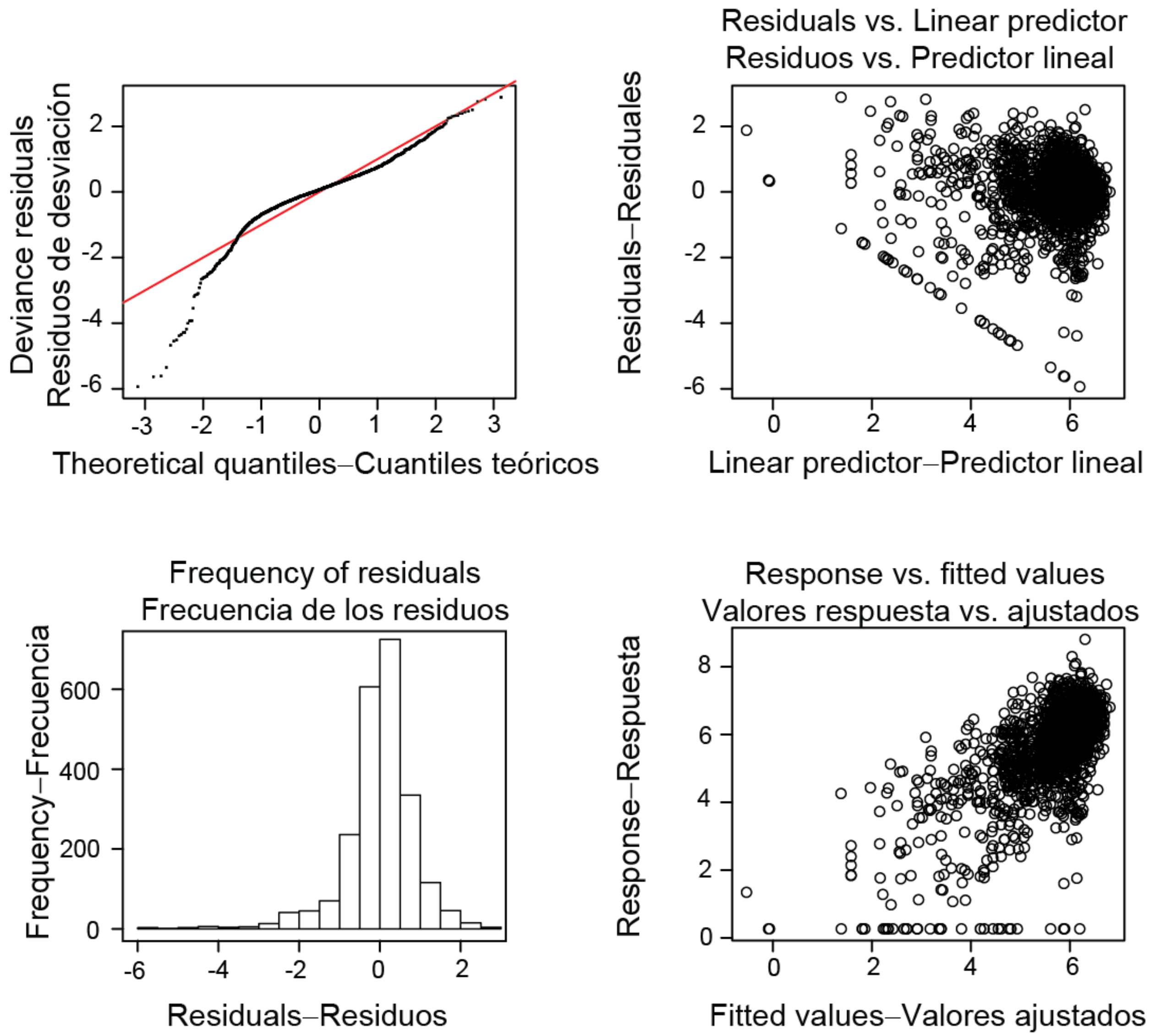

FIGURE A.12. Diagnostic plots for the lognormal GAM for CPUE in weight of dorado caught by Ecuadorian artisanal fisheries.

FIGURA A.12. Gráficas diagnósticas del MAG lognormal de CPUE en peso de dorado capturado por las pesquerías artesanales ecuatorianas.

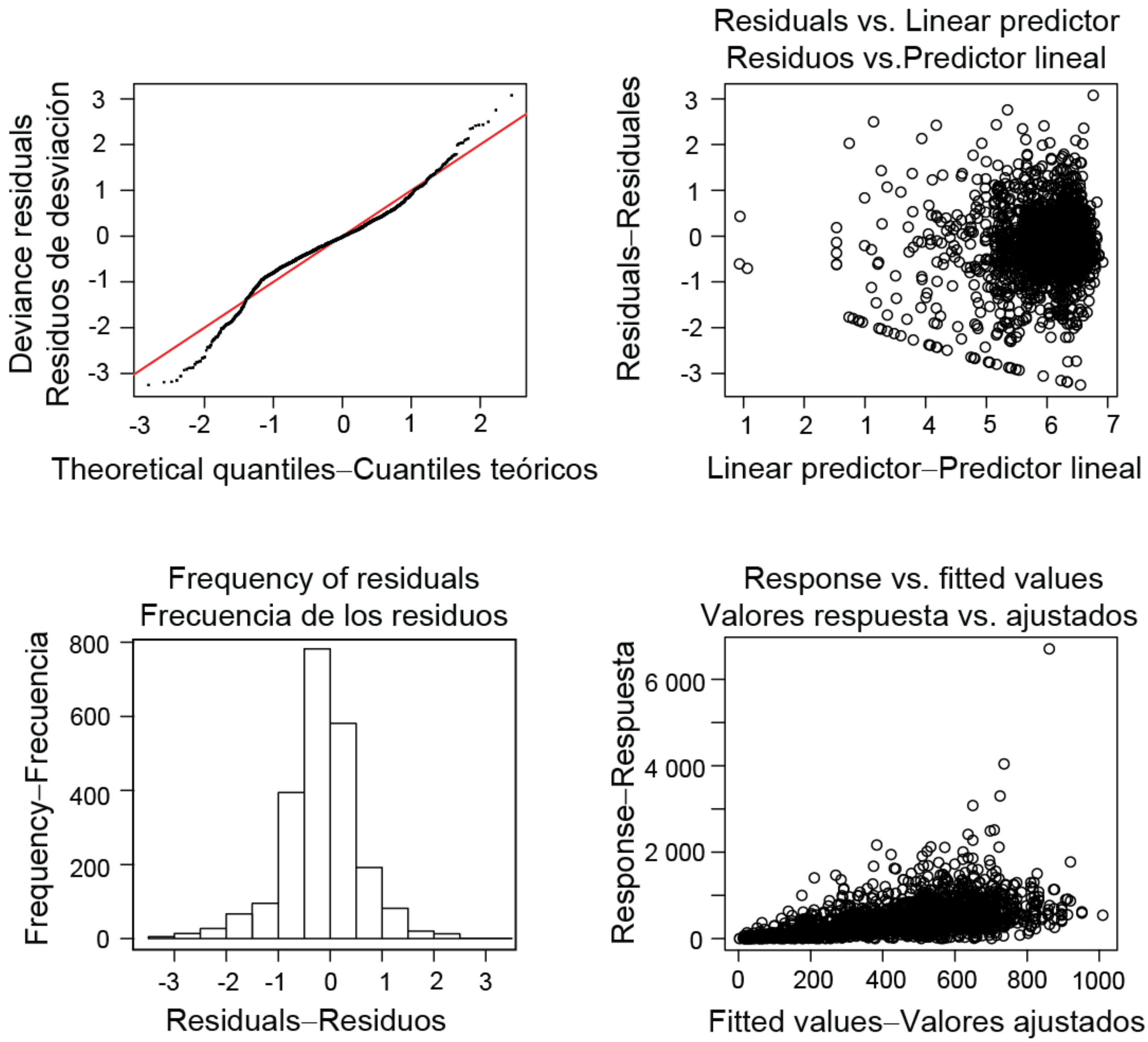

FIGURE A.13. Diagnostic plots for the gamma GAM for CPUE in weight of dorado caught by Ecuadorian artisanal fisheries.

FIGURA A.13. Gráficas diagnósticas del MAG gamma de CPUE en peso de dorado capturado por las pesquerías artesanales ecuatorianas.

Appendix-Anexo B.

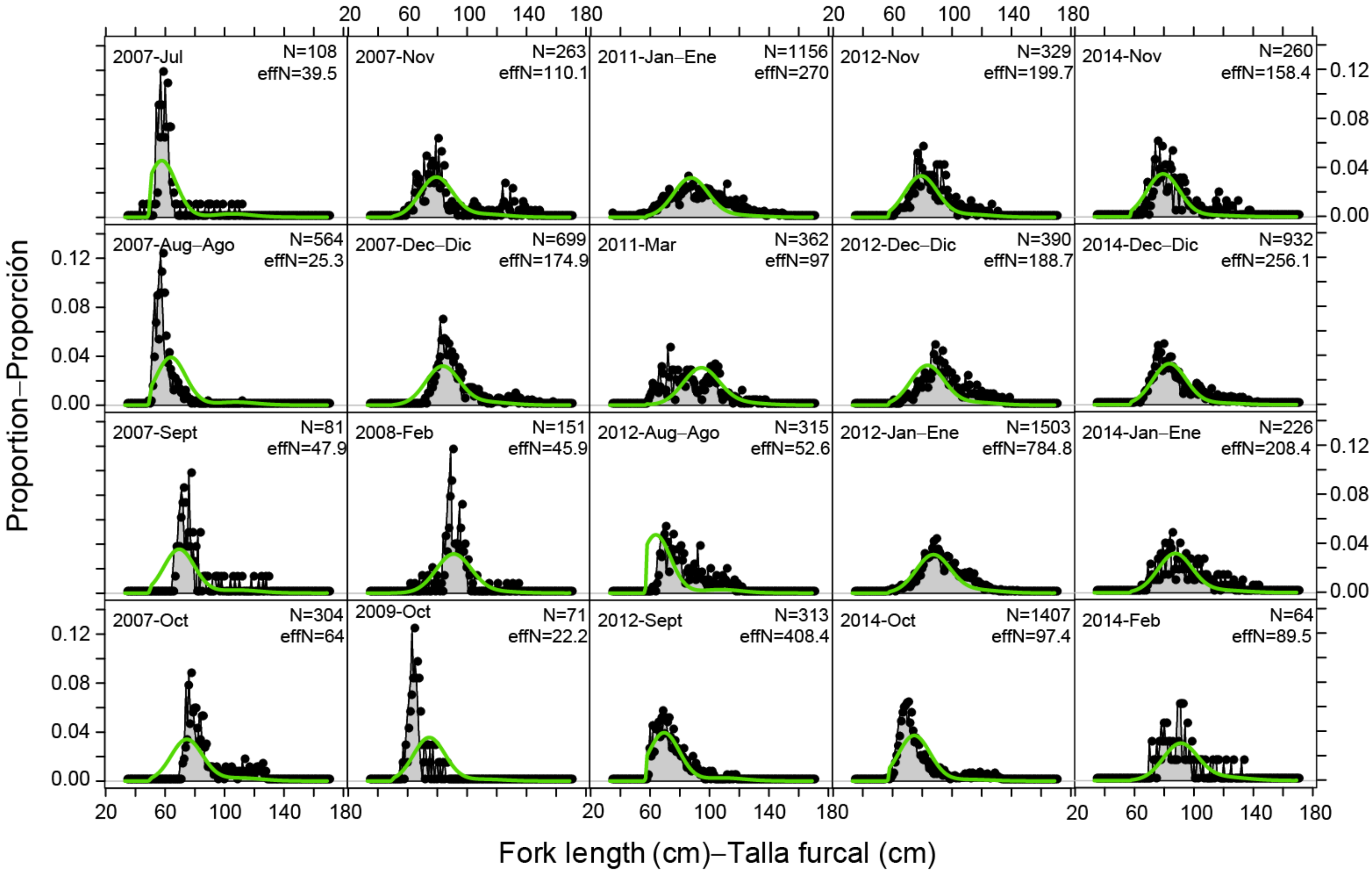

FIGURE B.1. Observed (black dots and grey areas) and predicted (green lines) length compositions of dorado caught in the Peruvian artisanal fishery (F1), July 2007-February 2014. Years are fishing years (July-June).

FIGURA B.1. Composición por talla observada (puntos negros y áreas grises) y predicha (líneas verdes) de dorado capturado en la pesquería artesanal peruana (F1), julio 2007-febrero 2014. Los años son años pesqueros (julio a junio).

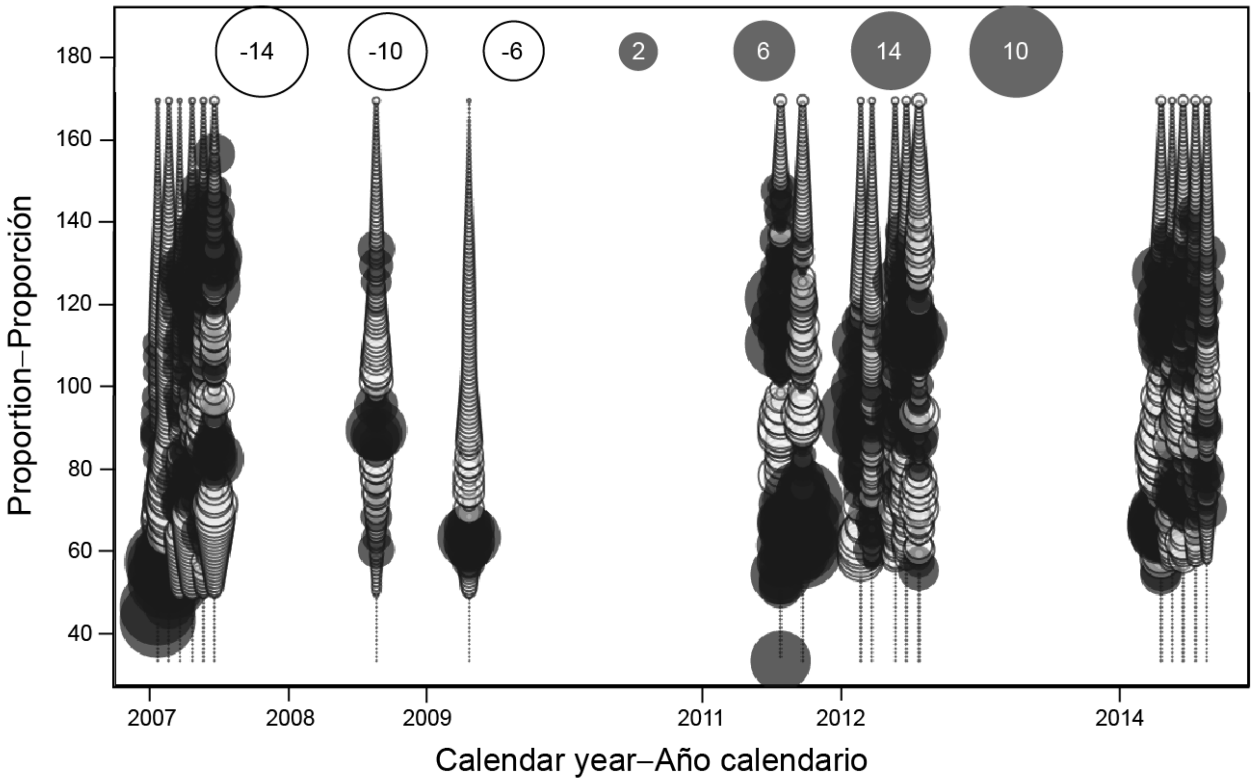

FIGURE B.2. Residuals of the length-composition fit to the Peruvian artisanal fishery (F1).
FIGURA B.2. Residuos del ajuste de la composición por talla a la pesquería artesanal peruana (F1).

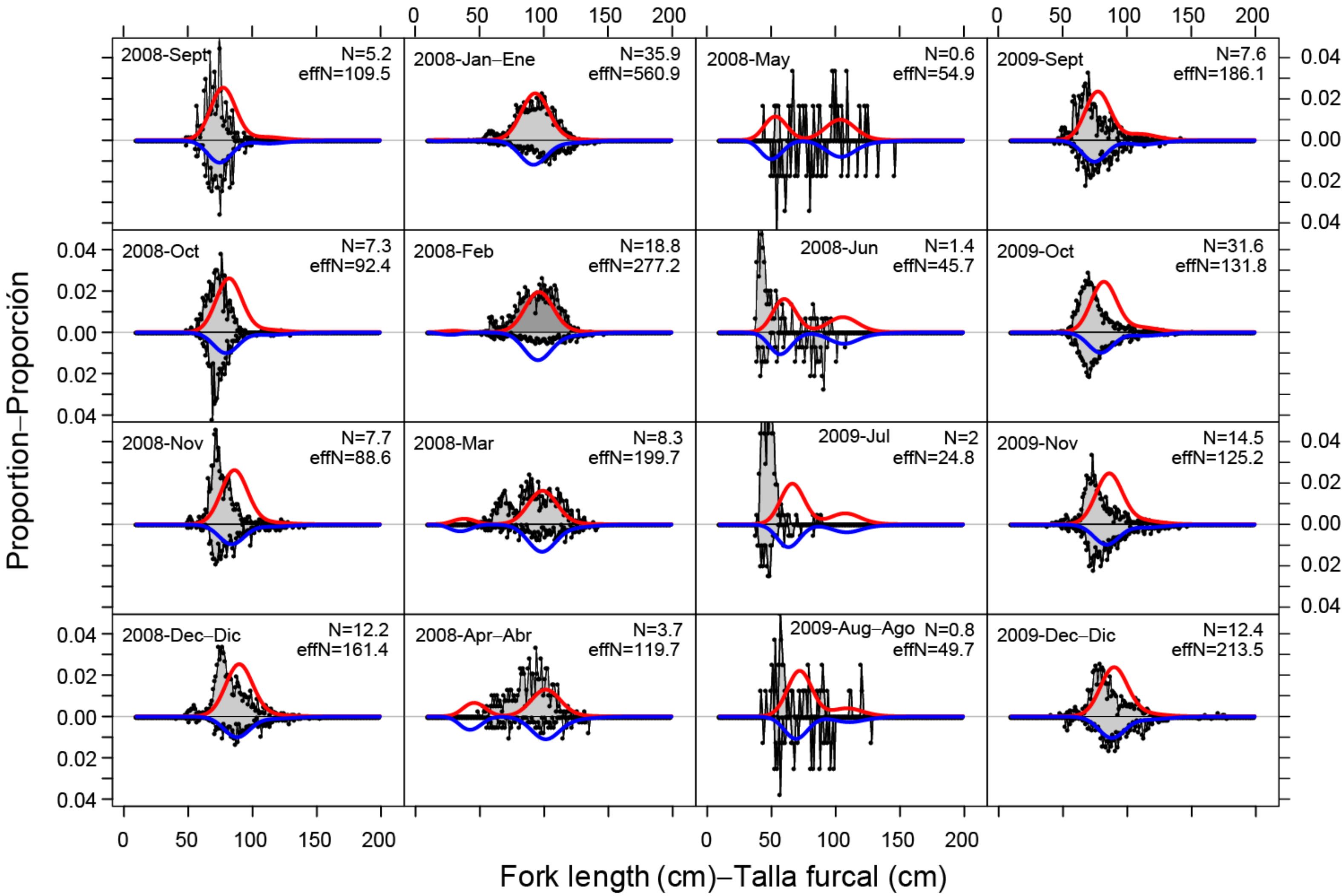

FIGURE B.3. Monthly fit to length-composition data in the Ecuadorean artisanal fishery (F2) for males (blue lines below horizontal line) and females (red lines above horizontal line), September 2008-December 2009. Years are fishing years (July-June).

FIGURA B.3. Ajuste mensual a los datos de composición por talla en la pesquería artesanal ecuatoriana (F2) para machos (líneas azules debajo de la línea horizontal) y hembras (líneas rojas por encima de la línea horizontal), septiembre 2008-diciembre 2009. Los años son años pesqueros (julio a junio).

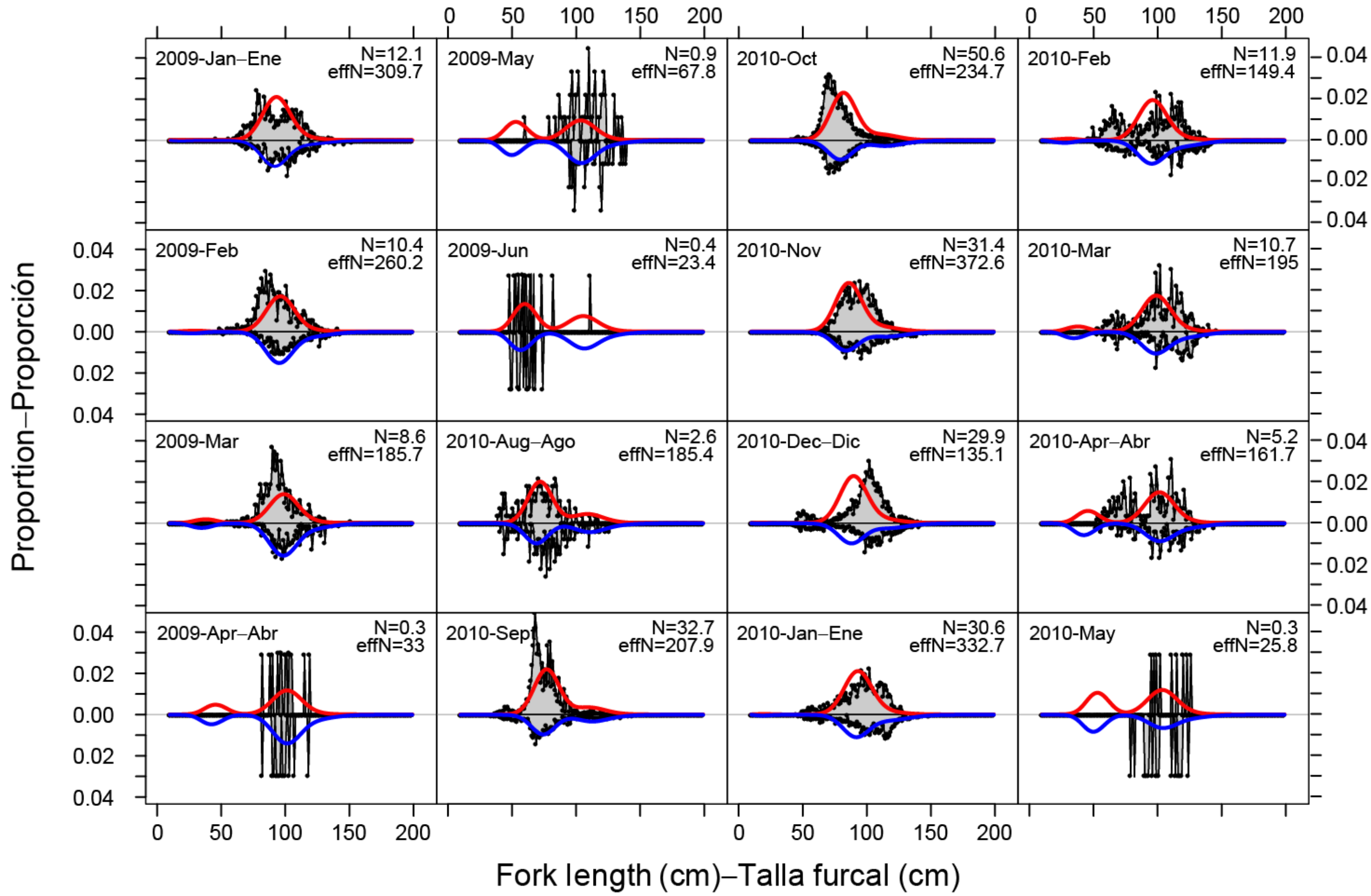

FIGURE B.3 (continued). Monthly fit to length-composition data in the Ecuadorean artisanal fishery (F2) for males (blue lines below horizontal line) and females (red lines above horizontal line), January 2009-May 2010. Years are fishing years (July-June).

FIGURA B.3 (continuación). Ajuste mensual a los datos de composición por talla en la pesquería artesanal ecuatoriana (F2) para machos (líneas azules debajo de la línea horizontal) y hembras (líneas rojas por encima de la línea horizontal), enero 2009-mayo 2010. Los años son años pesqueros (julio a junio).

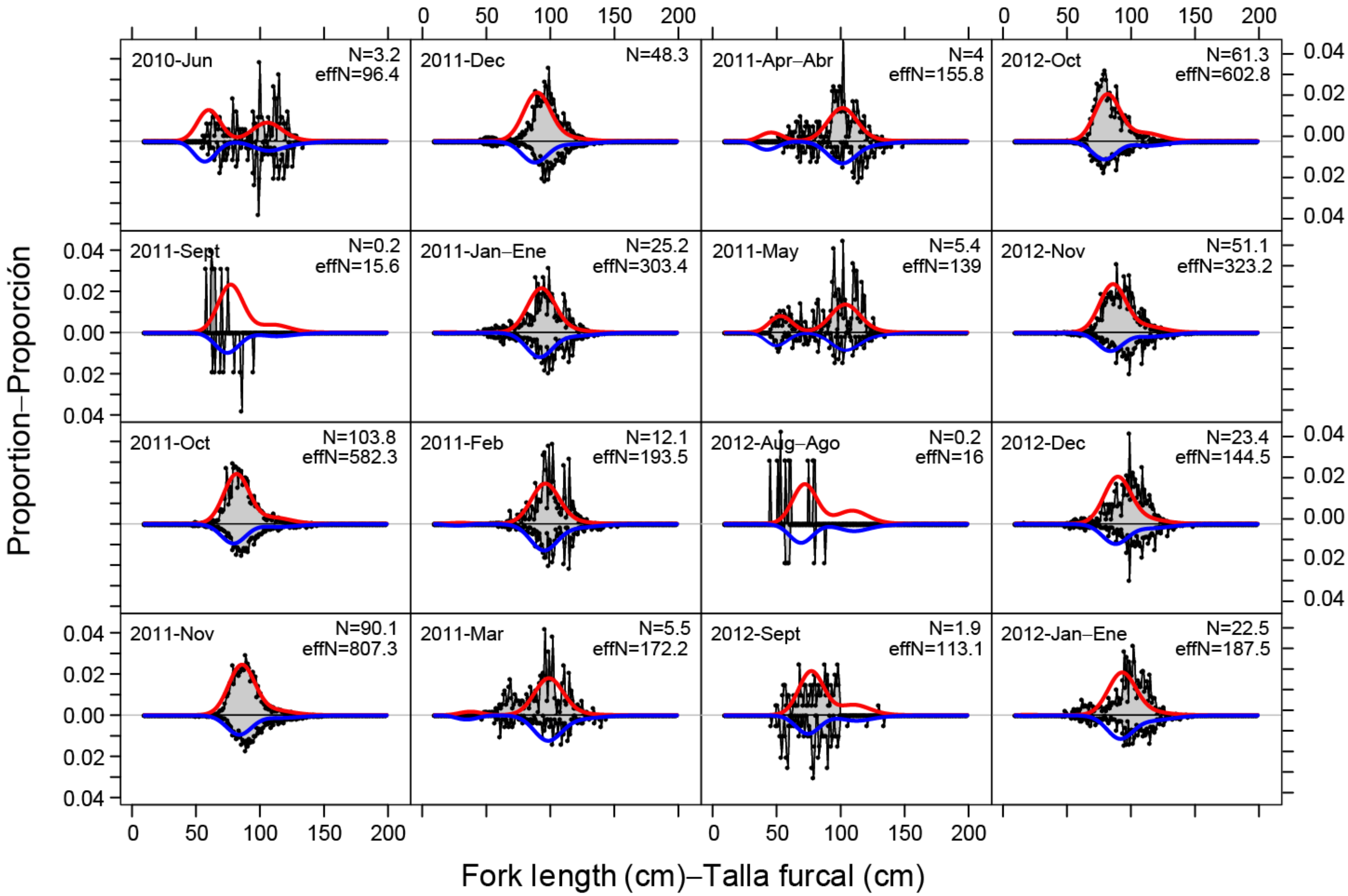

FIGURE B.3 (continued). Monthly fit to length-composition data in the Ecuadorean artisanal fishery (F2) for males (blue lines below horizontal line) and females (red lines above horizontal line), June 2010-January 2012. Years are fishing years (July-June).

FIGURA B.3 (continuación). Ajuste mensual a los datos de composición por talla en la pesquería artesanal ecuatoriana (F2) para machos (líneas azules debajo de la línea horizontal) y hembras (líneas rojas por encima de la línea horizontal), junio 2010-enero 2012. Los años son años pesqueros (julio a junio).

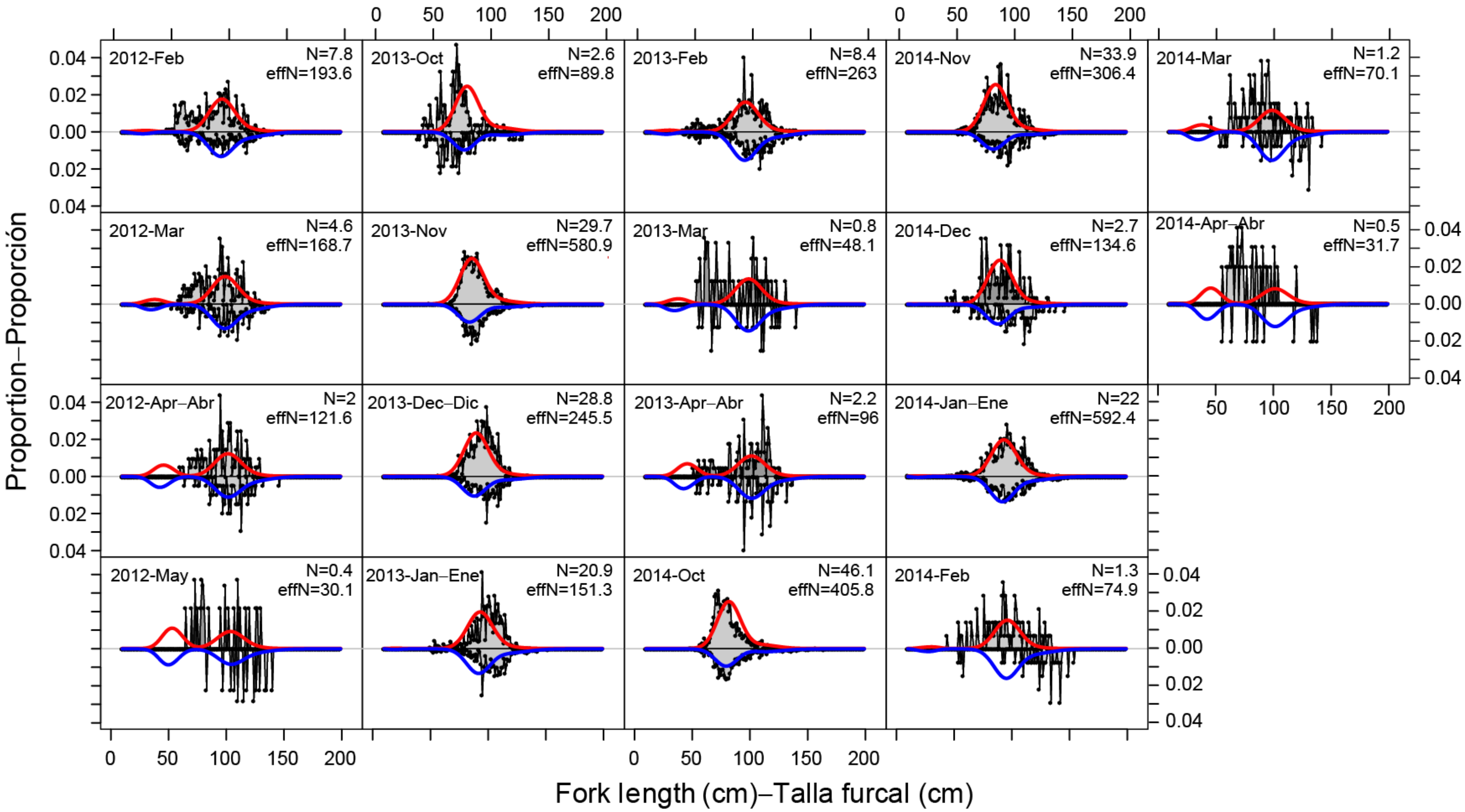

FIGURE B.3 (continued). Monthly fit to length-composition data in the Ecuadorean artisanal fishery (F2) for males (blue lines below horizontal line) and females (red lines above horizontal line), February 2012-April 2014. Years are fishing years (July-June).

FIGURA B.3 (continuación). Ajuste mensual a los datos de composición por talla en la pesquería artesanal ecuatoriana (F2) para machos (líneas azules debajo de la línea horizontal) y hembras (líneas rojas por encima de la línea horizontal), febrero 2012-abril 2014. Los años son años pesqueros (julio a junio).

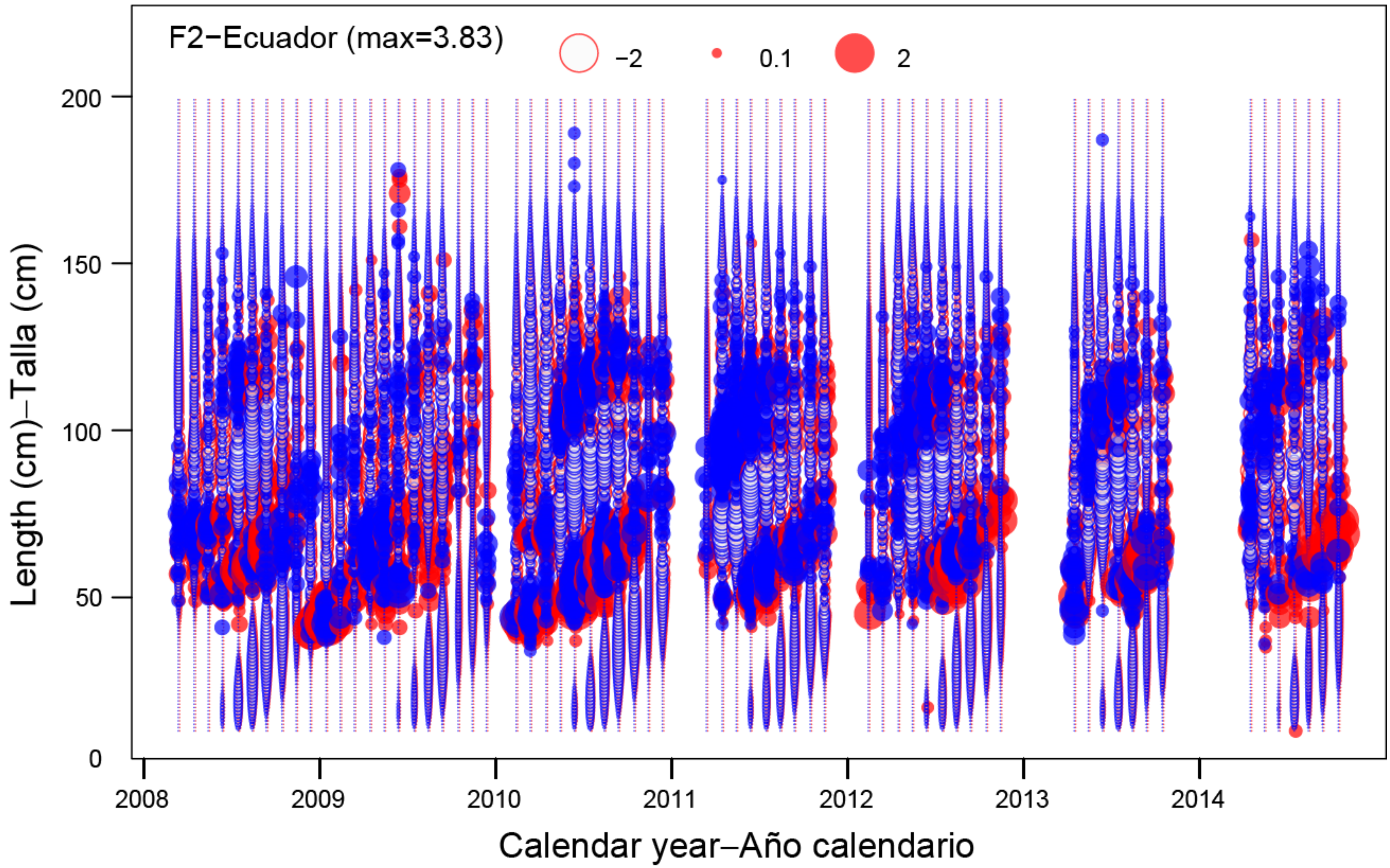

FIGURE B.4. Residuals of the fit to the length-composition data for the Ecuadorean artisanal fishery (F2); red: females; blue: males.

FIGURA B.4. Residuos del ajuste a los datos de composición por talla de la pesquería artesanal ecuatoriana (F2); rojo: hembras; azul: machos.