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STATUS OF SKIPJACK TUNA IN THE EASTERN PACIFIC OCEAN IN 2011

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CONTENTS

1. SUMMARY

This report presents the most current stock assessment of skipjack tuna (*Katsuwonus pelamis*) in the eastern Pacific Ocean (EPO). Several alternative methods are used to assess the status of skipjack tuna: a) fishery and biological indicators; b) analysis of tag data; c) a length-structured stock assessment model; d) a Spatial Ecosystem and Population Dynamic Model (SEAPODYM). The results of all four of these methods are compared when evaluating the status of skipjack in the EPO.

Skipjack are distributed across the Pacific Ocean, and it is likely that there is a continuous stock throughout the Pacific Ocean, with exchange of individuals at a local level, although large-scale movements are thought to be rare. The bulk of the catches of skipjack are made in the eastern and western regions; the purse-seine catches are relatively low in the vicinity of the western boundary of the EPO at 150°W. The movements of tagged skipjack generally cover hundreds, rather than thousands, of kilometers, and exchange of fish between the eastern and western Pacific Ocean appears to be limited. Movement rates between the EPO and the western Pacific cannot be estimated with currently-available tagging data. In some analyses the EPO is divided into six independent sub-regions to accommodate spatial structure of the population and fishery dynamics.

Stock assessment requires substantial amounts of information and the information varies depending on the method used. The methods applied to skipjack require a variety of information, including data on retained catches, discards, indices of abundance, the size compositions of the catches of the various fisheries, tagging data, and oceanographic data. In addition, assumptions have to be made about processes such as growth, recruitment, movement, natural mortality, selectivity, and stock structure.

Biomass, recruitment, and fishing mortality are estimated to be highly variable over time. The estimates are uncertain and differ among the alternative assessment methods. A large recruitment appears to have

entered the population in 1999, and led to increased biomass in that year, but the increase was temporary, due to the short-lived nature of skipjack. Biomass appears to have been above average in recent years, but this may differ among regions, as indicated by differences in CPUE. SEAPODYM estimates annual biomass of skipjack 30cm or larger cycling between 1,800,000 t and 2,350,000 t from 1998 to 2008, but the quality of these estimates has yet to be determined. The average weight of skipjack has generally been declining since 2000, however the trend differs among regions. Previous assessments using a catch-at-length analysis (A-SCALA) to assess skipjack tuna in the EPO were considered preliminary because: 1) it was unknown if catch-per-day-fished for purse-seine fisheries is proportional to abundance; 2) it is possible that there is a population of large skipjack that is invulnerable to the fisheries; and 3) the structure of the EPO stock in relation to the western and central Pacific stocks is uncertain. These issues are also relevant to the current assessment.

Previous assessments estimated that maximum yields are achieved with infinite fishing mortality because the critical weight is less than the average weight at recruitment to the fishery. However, this is uncertain because of uncertainties in the estimates of natural mortality and growth. For this reason, no traditional reference points are available for skipjack tuna in the EPO. Consequently, indicators and reference levels have been used to evaluate the status of the stock. The main concern with the skipjack stock is the constantly increasing exploitation rate. However, exploitation rate appears to have leveled off in recent years and the effort has declined. The data- and model-based indicators have yet to detect any adverse consequence of this increase. The average weight was below its lower reference level in 2009, which can be a consequence of overexploitation, but it can also be caused by recent recruitments being greater than past recruitments or expansion of the fishery into areas occupied by smaller skipjack. Any continued decline in average length is a concern and, combined with leveling off of catch and CPUE, may indicate that the exploitation rate is approaching or above the level associated with MSY. The tagging analyses for regions A and C, length-structured model for region B, and the SEAPODYM analyses do not provide any information that indicates a credible risk to the skipjack stock(s).

Key Results

1. There is uncertainty about the status of skipjack tuna in the EPO.
2. There may to be differences in the status of the stock among regions.
3. There is no evidence that indicates a credible risk to the skipjack stock(s).

2. DATA

The data used differ among the four methods used to assess skipjack in the EPO. In general, Catch, effort, and size-composition data, plus biological data, were used to conduct the stock assessments. The data for 2011, which are preliminary, include records that had been entered into the IATTC databases by April 2011. All data are summarized and analyzed on a monthly or annual basis. In some analyses the data are separated into six areas, which are used to represent independent stocks, based on aggregating the yellowfin market measurement (length-frequency sampling) areas. The regions are defined in Table 2.1 and illustrated in Figure 2.1. Tagging and oceanographic data were used in some of the assessment methods.

2.1. Definitions of the fisheries

Three fisheries are defined for each stock modeled in the stock assessment of skipjack. The first two are defined on the basis of purse-seine set type: sets on schools associated with floating objects and unassociated schools. The third fishery is used to represent small discarded skipjack. Catch from other fisheries (purse seine on dolphin associated schools, longline, and pole-and-line) are added to the unassociated fishery.

2.2. Catches

To conduct the stock assessment of skipjack tuna, the catch and effort data in the IATTC databases are stratified in accordance with the region and fishery definitions described in Section 2.1 and shown in Table 2.1. “Landings” is catch landed in a given year even if the fish were not caught in that year, and “retained catch” is the catch that is taken in a given year and not discarded at sea. “Catch” is used for either total catch (discards plus retained catch) or retained catch; the context determines the appropriate definition.

All three types of data are used to assess the stock of skipjack. The removals by the floating-object and unassociated fisheries are retained catch, plus some discards resulting from inefficiencies in the fishing process. Removals by the discard fisheries are only discards resulting from sorting the catch taken by the floating-object and unassociated fisheries.

Trends in the catch of skipjack in the EPO during each quarter from January 1970 to December 2011 are shown in Figures 2.2a and 2.2b. It should be noted that there were substantial surface fisheries for skipjack prior to 1970. One main characteristic of the catch trends is the increase in catch taken since about 1993 by purse-seine sets on fish associated with floating objects, especially fish-aggregating devices (FADs). The proportion of the catch taken by the floating-object and unassociated fisheries differs among regions.

2.2.1. Discards

For the purposes of stock assessment, it is assumed that skipjack are discarded from catches made by purse-seine vessels because of inefficiencies in the fishing process (when the catch from a set exceeds the remaining storage capacity of the fishing vessel) or because the fishermen sort the catch to select fish that are larger than a certain size. In either case, the amount of skipjack discarded is estimated with information collected by IATTC or national observers, applying methods described by Maunder and Watters (2003a). Regardless of why skipjack are discarded, it is assumed that all discarded fish die. Maunder and Watters (2001) describe how discards were implemented in the yellowfin assessment.

Estimates of discards resulting from inefficiencies in the fishing process are added to the retained catches. No observer data are available to estimate discards prior to 1993, and it is assumed that there were no discards due to inefficiencies before that time. There are periods for which observer data are not sufficient to estimate the discards, in which case it is assumed that the discard rate (discards/retained catches) is equal to the discard rate for the same quarter in the previous year or, if not available, a proximate year.

Discards that result from the process of sorting the catches are treated as separate fisheries, and the catches taken by these fisheries are assumed to be composed only of fish that are less than 60 cm in length (Figure 2.2c). Maunder and Watters (2001) provide a rationale for treating such discards as separate fisheries.

2.3. Indices of abundance

Indices of abundance were derived from purse-seine catch and effort data. The catch per unit of effort (CPUE) for the purse-seine fisheries was calculated as catch divided by number of days fished. The number of days fished, by set type, was estimated from the number of sets, using a multiple regression of total days fished against number of sets by set type (Maunder and Watters 2001). The CPUE time series for the different fisheries and regions are presented in Figure 2.3.

2.4. Size-composition data

The fisheries of the EPO catch skipjack of similar sizes. Figure 2.4 shows the average length frequency distribution for the six regions and Figure 2.5 shows the time series of average length for each of the six regions.

2.5. Tagging data

Tag release and recapture data from eight trips on pole-and-line vessels between 1973 and 1981 are available. Release information is available in summary form from printed records. Releases were coastal and north of the equator. The recapture information is available in an electronic data base. Detailed information such as length at release is not currently available in electronic form. Tag identification numbers are not available in electronic form for releases, so the recaptures can be matched only to the release trip, and not to the specific details of release (*e.g*. month). Tag release and recapture data from several trips by pole-and-line vessels between 2000 and 2006 are available in the IATTC database. Releases are limited in spatial extent to an area close to the equator.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The IATTC staff has used a growth rate of 24 cm per year, from Forsbergh (1989), in its yield-per-recruit modeling of skipjack. Bayliff (1988) used tagging data to calculate the estimates for the parameters of the von Bertalanffy growth equation. However, the results of sensitivity analyses performed by Bayliff (1988) indicated that the estimates of the parameters were imprecise.

Maunder (2002a) estimated growth for the northern and southern coastal areas separately, using a version of the more flexible Richards growth curve, and also estimated the variation in growth, allowing the creation of growth transition matrices for use in a size-structured model.

The weight-length relationship of skipjack in the EPO is $W = (5.5293 \times 10^{-6})L^{3.336}$, where W = weight in kilograms and L = length in centimeters (Hennemuth, 1959).

3.1.2. Natural mortality

Attempts to estimate the natural mortality rate (M) of skipjack, and the many problems associated with these studies, are discussed by Wild and Hampton (1994). The IATTC staff has used a value of 1.5, on an annual basis, for M in yield-per-recruit analyses (Anonymous, 2000: 69). In contrast to yellowfin and bigeye tuna, skipjack do not show an increase in the proportion of males for older fish (Schaefer 2001). Hampton (2000), using tagging data, obtained estimates of natural mortality for skipjack in the western Pacific Ocean (WPO) that were higher for old and young individuals. The results showed much higher natural mortality rates for skipjack of sizes less than 40 cm and greater than 70 cm. The estimates from the WPO (Hampton 2000) were used to develop a length-specific natural mortality curve to use in the assessment (Figure 3.1). Hampton’s estimates of high natural mortality for old skipjack may be an artifact of the tagging data due to older fish moving out of the fishery. Therefore it is assumed that natural mortality is constant over large sizes. Hampton’s estimates of high natural mortality for young skipjack may also be an artifact of the tagging data due to tagging mortality, and a lower natural mortality rate is used here.

3.1.3. Recruitment and reproduction

Information on the reproduction of skipjack in the EPO is given by Anonymous (1998: 26) and Schaefer (2001). Spawning is fairly widespread between about 15°N and 10°S from the coast of the Americas to about 130°W at sea-surface temperatures (SSTs) equal to or greater than 24°C. It is assumed that skipjack tuna can be recruited to the fishable population during every month of the year. No strong assumptions are made about the relationship between adult biomass (or abundance) and recruitment in the stock assessment of skipjack. An assumption is made, however, about the way that recruitment can vary around its average level.

3.1.4. Movement

Information of the movements of skipjack in the EPO is given by Schaefer *et al*. (1961), Fink and Bayliff (1970), Hunter *et al*. (1986), and Schaefer (2009). The percentage of skipjack released in the western Pacific that were at liberty 0 to 30 days, 31 to 180 days, and more than 180 days that traveled more than

500 nautical miles are 0, about 5, and about 30, respectively. Twenty-seven tagged skipjack released in the EPO have been recaptured in the central or western Pacific (Bayliff, 1988: Appendix 2), but no tagged skipjack released in the central or western Pacific have been recaptured in the EPO. It should be recognized that the amounts of tagged fish recaptured at various locations are dependent on the amounts of fishing effort in those locations. If tagging experiments are initiated where the fishing effort is heavy the distances moved by the fish that are recaptured are likely to be less than they would have been if the tagged fish had been released in areas of both heavy and light fishing. Nevertheless, for the purposes of the current assessment, it is assumed that skipjack move within the EPO or sub-populations, as appropriate, at rates that are rapid enough to ensure that the sub-population is randomly mixed at the start of each month of the year. It is assumed that skipjack do not move among sub-populations.

3.1.5. Stock structure

Skipjack occur throughout the tropical and subtropical waters of the Pacific Ocean, and it is known that there is considerable exchange of fish among areas. The stock structure of skipjack has been studied by various methods, including analyses of catch statistics, life history, tagging, biochemical genetic data, and data on the chemical composition of the otoliths of the fish. Research in these fields has been conducted by many organizations, including the IATTC, the South Pacific Commission (now the Secretariat of the Pacific Community; SPC), the U.S. National Marine Fisheries Service (NMFS), and various organizations in Japan. The research results pertinent to a solution to this problem were examined by Argue (1981), and the conclusions were discussed in detail by Anonymous (1984: 88-91). In summary, there were two principal hypotheses for skipjack in the Pacific Ocean. The separate-subpopulation hypothesis stated that there are two or more genetically-distinct subpopulations of skipjack in the Pacific Ocean, and the clinal hypothesis stated that separate subpopulations of skipjack do not exist in the Pacific Ocean, but that there is isolation by distance, i.e. the probability of any two fish interbreeding is an inverse function of their distance from one another. It was concluded by Argue (1981) that the available data did not favor either the separate-subpopulation or the clinal hypothesis. Subsequent studies, described by Anonymous (1995: 69-71) have not furnished information that would serve better as the basis for management decisions. (Those studies should not be considered as futile, however, as the information from them may eventually be combined with information to be gathered in the future to achieve a greater understanding of the stock structure of skipjack in the Pacific Ocean.) For the purposes of stock assessment, it is assumed that skipjack in the EPO do not interact with skipjack in the western and central Pacific. For the purposes of some analyses, it is assumed that there are six non-interacting sub-populations in the EPO.

3.2. Environmental influences

The influences of some environmental variables on the apparent abundance of skipjack in the EPO have been studied by Forsbergh (1989). The abundance of skipjack larvae in the central and western Pacific approximately doubles with each 1-degree increase in SST from 23°C to a maximum of 29°C. The catches of skipjack by surface gear tend to be reduced during El Niño episodes, however, due to the fact that during such times the depth of the thermocline increases, so that the fish spend less time at the surface than during anti-El Niño periods (Joseph and Miller, 1989).

A previous stock assessment (Maunder and Watters 2002a) included the assumption that oceanographic conditions might influence recruitment of skipjack tuna in the EPO. To incorporate the possibility of an environmental influence on recruitment of skipjack in the EPO, a temperature variable was incorporated into the previous stock assessment model to determine whether there is a statistically-significant relationship between this temperature variable and estimates of recruitment. Maunder (2002b) conducted the correlation outside the stock assessment model using SST and the Southern Oscillation Index and found no relationship between recruitment and the environmental variables.

The SEAPODYM assessment method (Senina *et al.* 2008, Lehodey *et al.* 2011) uses environmental data to force productivity and movement as discussed in the next secton.

4. STOCK ASSESSMENT

Several alternative methods are used to assess the status of skipjack tuna in the EPO: a) fishery and biological indicators; b) analysis of tag data; c) length-structured stock assessment model; d) a Spatial Ecosystem and Population Dynamic Model (SEAPODYM).

4.1. Assessment methods

4.1.1. Indicators

Since the stock assessments and reference points for skipjack in the EPO are uncertain, developing alternative methods to assess and manage the species that are robust to these uncertainties would be beneficial. Maunder and Deriso (2007) investigated some simple indicators of stock status based on relative quantities. Rather than using reference points based on MSY, they compared current values of indicators to the distribution of indicators observed historically. They also developed a simple stock assessment model to generate indicators for biomass, recruitment, and exploitation rate. Maunder (2012a) updated their results to include data up to 2011. To evaluate the current values of the indicators in comparison to historical values, they use reference levels based on the 5th and 95th percentiles, as the distributions of the indicators are somewhat asymmetric. Eight data- and model-based indicators are evaluated: catch, catch-per-day-fished by floating object fisheries, catch-per-day-fished by unassociated fisheries, standardized effort, average weight, relative biomass, relative recruitment, and relative exploitation rate. These indicators are presented for the whole EPO stock.

4.1.2. Analysis of tag data

The IATTC carried out numerous tagging experiments during the 1950s to the early 1980s, and then resumed a limited amount of tuna tagging again beginning in 2000. These data have not been used in the stock assessments of skipjack tuna except to provide information on growth rates (Bayliff 1988; Maunder 2002a). Maunder (2012b) conducted a preliminary analysis of the tagging data to investigate its information content about exploitation rates. The tag data were analyzed using a tag attrition model comparing observed and predicted tag recoveries. The tag dynamics is modeled using a population dynamics model that is essentially the same as those used in stock assessments. The model differs in that recruitment is tag releases and factors such as tag loss, tagging related mortality, and reporting rate are modeled. Estimates are only available for regions A and C. The estimates of exploitation rates are highly uncertain.

4.1.3. Length-structured stock assessment model

Maunder (2012c) developed a length-structured model for assessing skipjack tuna. This model differs from the standard age-structured model approach used for assessing yellowfin and bigeye tuna, implemented using Stock Synthesis. The ageing data for skipjack tuna is unreliable, and growth information is based on tagging length-increment data. Growth based on length-increment data is ideally suited for length-structured models, and is problematic for age-structured models. The EPO is divided into six stocks and each stock is analysed separately. The model is fitted to CPUE-based indices of relative abundance and length-composition data.

There is insufficient information in the CPUE and length-composition data to produce reliable estimates of skipjack stock size. In all but one region (Region B off the coast of Ecuador) the estimates of abundance and exploitation rates were unrealistic. The selectivity or growth rates are sufficiently different among stocks that sharing selectivity information from region B for the other regions also produces unrealistic estimates. Therefore, results from the length-structured stock assessment model are only presented for region B.

4.1.4. Spatial Ecosystem and Population Dynamic Model (SEAPODYM)

A Spatial Ecosystem and Population Dynamic Model (SEAPODYM) that fits to a variety of data sources (Senina *et al*. 2008) has been applied to skipjack tuna in the Pacific Ocean (see Lehodey *et al*. 2011 for details). The analysis differs from Lehodey et al. (2011) in that the analysis: 1) used the latest available SODA 2.1.6 variables; 2) switched to MFCL-2010 length-at-age estimates; 3) scaled the Western and Central Pacific Ocean (WCPO) stock to MFCL estimates via fixing recruitment and mortality coefficients; and 4) used asymmetric Gaussian functions for purse-seine selectivities instead of sigmoid selectivities. Biomass estimates for the EPO only are used in this assessment.

The SEAPODYM model is a two-dimensional coupled physical–biological interaction model at the ocean basin scale, and contains environmental and spatial components used to constrain the movement and the recruitment of tuna. The model combines a forage (prey) production model with an age-structured population model of the fishery target (tuna predator) species. All the spatial dynamics are described with an advection– diffusion equation. Oceanographic Input data sets for the model are sea-surface temperature (SST), oceanic currents and primary production that can be predicted data from coupled physical–biogeochemical models, as well as satellite-derived data distributions. Recent improvements include rigorous parameter optimization using fisheries data (size composition and abundance indices), which are based on methods used for contemporary stock assessment models (Senina *et al*., 2008).

4.2. Assessment results

The results of each of the assessment methods are described below.

4.2.1. Fishing mortality

The fishing mortality estimates from the tagging analysis are highly variable over time (Figure 4.1). The maximum monthly fishing mortality was 0.65 for the historic data (1973-1981 releases in region A) and 0.20 for the recent data (2000-2006 releases in region C). The mean monthly (annual = monthly times 12) fishing mortality was estimated as 0.049 (0.588) and 0.025 (0.300), respectively. There is a large amount of uncertainty in the estimates of monthly fishing mortality with CVs around 40% to 140%. The estimates of approximate average and maximum monthly fishing mortality rates for region B from the length-structured stock assessment are higher, 0.13 and 2.37, respectively (Figure 4.2). The fishing mortality was estimated to be high in the late 1970s and the early 1980, but considerably lower in recent years (*e.g.* monthly (annual = monthly times 12) average of 0.06 (0.74) from 1998 to 2008). The average annual approximate fishing mortality during 1998-2008, calculated from the annual catch and the annual SEAPODYM biomass estimates, is 0.12 (Figure 4.3). The standardized effort, a measure of exploitation rate, and the relative exploitation rate from the indicator analysis has been increasing since 1985, but dropped in recent years (Figure 4.4).

4.2.2. Recruitment

The indicator analysis estimates that recruitment was much lower until 2002, except for a large recruitment in 1999 (Figure 4.4). The length-structured model for region B estimates highly variable monthly recruitment with a very large recruitment in 1999, but does not estimate recent recruitment to be substantially higher than prior recruitment (Figure 4.5).

4.2.3. Biomass

The indicator analysis estimates that biomass was much lower until 2003, except for a large biomass in 1999 (Figure 4.4). The length-structured model for region B estimates highly variable monthly biomass with a very large biomass in 1999 and generally increasing biomass since 1980 (Figure 4.6). SEAPODYM estimates annual biomass of skipjack 30cm or larger cycling between 1,800,000 t and 2,350,000 t from 1998 to 2008 (Figure 4.7).

4.2.4. Average weights of fish in the catch

The indicator analysis estimates that the average weight of skipjack has been declining since 2000, and in 2009 was below the lower reference level, but increased slightly in 2010 and 2011 (Figure 4.4). The trend in average length differs among regions (Figure 2.5).

4.3. Comparison to previous assessment

Maunder and Harley (2005) used an age-structured, catch-at-length analysis (A-SCALA) to assess skipjack tuna in the EPO. The analysis method and its technical details are described in IATTC Bulletin, Vol. 22, No. 5 (2003). The assessment was still considered preliminary because 1) it was unknown if catch-per-day-fished for purse-seine fisheries is proportional to abundance, 2) it is possible that there is a population of large skipjack that is invulnerable to the fisheries, 3) the structure of the EPO stock in relation to the western and central Pacific stocks is uncertain. However, the results from their assessment were more consistent among sensitivity analyses compared to the previous assessment.

5. STOCK STATUS

Maintaining tuna stocks at levels that will permit the MSY is the management objective specified by the IATTC Convention. The IATTC has not adopted any target or limit reference points for the stocks that it manages. Previous assessments have found that yield per recruit is maximized by catching skipjack at the smallest size observed in the catch. In combination with the lack of evidence of a stock-recruitment relationship, this indicates that very high fishing mortality rates and very low biomass levels would be associated with MSY. The previous assessment (Maunder and Harley 2004) estimated that maximum yields are achieved with infinite fishing mortality because the critical weight is less than the average weight at recruitment to the fishery. However, this is uncertain because of uncertainties in the estimates of natural mortality and growth. For this reason, no traditional reference points are available for skipjack tuna in the EPO. Consequently, indicators and reference levels have been used to evaluate the status of the stock.

The main concern with the skipjack stock is the constantly increasing exploitation rate until recently. Exploitation rate appears to have leveled off in recent years and the effort has declined. The data- and model-based indicators have yet to detect any adverse consequence of this increase. The average weight was below its lower reference level in 2009, which can be a consequence of overexploitation, but it can also be caused by recent recruitments being greater than past recruitments or expansion of the fishery into areas occupied by smaller skipjack. Any continued decline in average length is a concern and, combined with leveling off of catch and CPUE, may indicate that the exploitation rate is approaching or above the level associated with MSY.

The tagging analysis for regions A and C, length-structured model for region B, and the SEAPODYM analysis do not provide any information that indicates a credible risk to the skipjack stock(s).

6. FUTURE DIRECTIONS

6.1. Collection of new and updated information

Conducting a well-planned and executed comprehensive tagging study is probably the only way to provide an adequate stock assessment for skipjack tuna in the EPO.

6.2. Refinements to the assessment model and methods

Integrating the tagging data into the length-structured stock assessment model can potentially improve the results. However, uncertainty in the fishing mortality estimates from the tagging analysis indicate that any improvements will be minor. Sharing information among stocks has the potential to improve estimates for the regions that have little information in their data. However, initial analysis suggest that differences in selectivity and/or growth among regions may prevent the sharing of selectivity parameters. The catchability of the CPUE index of relative abundance might be shareable among regions if the CPUE is calculated as the sum of the CPUE across 1x1 degree squares in a region. This method has been used for longline CPUE in the WCPO.

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REFERENCES

Anonymous. 1984. Annual Report of the Inter-American Tropical Tuna Commission 1983: 272 pp.

Anonymous. 1995. Annual Report of the Inter-American Tropical Tuna Commission 1994: 296 pp.

Anonymous. 1998. Annual Report of the Inter-American Tropical Tuna Commission 1996: 306 pp.

Anonymous. 2000. Annual report of the Inter-American Tropical Tuna Commission, 1998: 357 pp.

Argue, A.W. (editor). 1981. Report of the Second Skipjack Survey and Assessment Programme workshop to review results from genetic analysis of skipjack blood samples. South Pacif. Comm., Skipjack Survey and Assessment Programme, Tech. Rep. 6: v, 39 pp.

Bayliff, W.H. 1988. Growth of skipjack, *Katsuwonus pelamis*, and yellowfin, *Thunnus albacares*, tunas in the eastern Pacific Ocean as estimated from tagging data. Inter-Amer. Trop. Tuna Comm., Bull. 19: 307-385.

Fink, B.D., and W.H. Bayliff. 1970. Migrations of yellowfin and skipjack tuna in the eastern Pacific Ocean as determined by tagging experiments, 1952-1964. Inter-Amer. Trop. Tuna Comm., Bull. 15: 1-227.

Forsbergh, E.D. 1989. The influence of some environmental variables on the apparent abundance of skipjack tuna, *Katsuwonus pelamis*, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 19: 429-569.

Joseph, J., and F. R. Miller. 1989. El Niño and the surface fishery for tunas in the eastern Pacific. Japan. Soc. Fish. Ocean., Bull. 53: 77-80.

Hampton J. 2000. Natural mortality rates in tropical tunas: size really does matter. Can. J. Fish. Aquat. Sci. 57: 1002-1010.

Hennemuth, R.C. 1959. Additional information on the length-weight relationship of skipjack tuna from the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 4: 23-37.

Hunter, J.R., A.W. Argue, W.H. Bayliff, A.E. Dizon, A. Fonteneau, D. Goodman, and G.R. Seckel. 1986. The dynamics of tuna movements: an evaluation of past and future research. FAO Fish. Tech. Pap. 277: 1-78.

Lehodey, P., Senina, I., Calmettes, B., Hampton, J., Nicol, S., Williams, P., Jurado Molina, J., Ogura, M., Kiyofuji, H., and Okamoto, S. 2011. SEAPODYM working progress and applications to Pacific skipjack tuna population and fisheries. WCPFC-SC7-2011/EB-WP 06 rev. 1.

Maunder, M.N. 2002a. Growth of skipjack tuna (*Katsuwonus pelamis*) in the eastern Pacific Ocean, as estimated from tagging data. Inter-Amer. Trop. Tuna Comm., Bull. 22: 93-131.

Maunder, M.N. 2002b. Status of skipjack tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 3: 135-200.

Maunder, M.N. 2012a. Updated indicators of stock status for skipjack tuna in the eastern Pacific Ocean. SAC3.

Maunder, M.N. 2012b. Preliminary analysis of historical and recent skipjack tuna tagging data to explore information on exploitation rates SAC3

Maunder, M.N. 2012c. A length based meta-population stock assessment model: application to skipjack tuna in the eastern Pacific Ocean. SAC3.

Maunder, M.N. and Deriso, R.B. 2007. Using indicators of stock status when traditional reference points are not available: evaluation and application to skipjack tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 8: 229-248.

Maunder, M.N. and Harley, S.J. 2005. Status of skipjack tuna in the eastern Pacific Ocean in 2003 and outlook for 2004. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 5: 109-167.

Maunder, M.N. and G.M. Watters. 2001. Status of yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 1: 5-86.

Maunder, M.N. and G.M. Watters. 2003. A-SCALA: an age-structured statistical catch-at-length analysis for assessing tuna stocks in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 22: 433-582.

Schaefer, K.M. 2001. An assessment of skipjack tuna (*Katsuwonus pelamis*) spawning in the eastern Pacific Ocean. Fish. Bull. 99: 343-350.

Schaefer, K.M. 2009. Stock structure of bigeye, yellowfin, and skipjack tunas in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 9: 203-221.

Schaefer, M.B., B.M. Chatwin, and G.C. Broadhead. 1961. Tagging and recovery of tropical tunas, 1955-1959. Inter-Amer. Trop. Tuna Comm., Bull. 5: 341-455.

Senina I., Sibert J., & Lehodey P. (2008). Parameter estimation for basin-scale ecosystem-linked population models of large pelagic predators: application to skipjack tuna. Progress in Oceanography, 78: 319-335.

Wild, A. and J. Hampton. 1994. A review of the biology and fisheries for skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean. FAO Fish. Tech. Pap. 336 (2): 1-51.

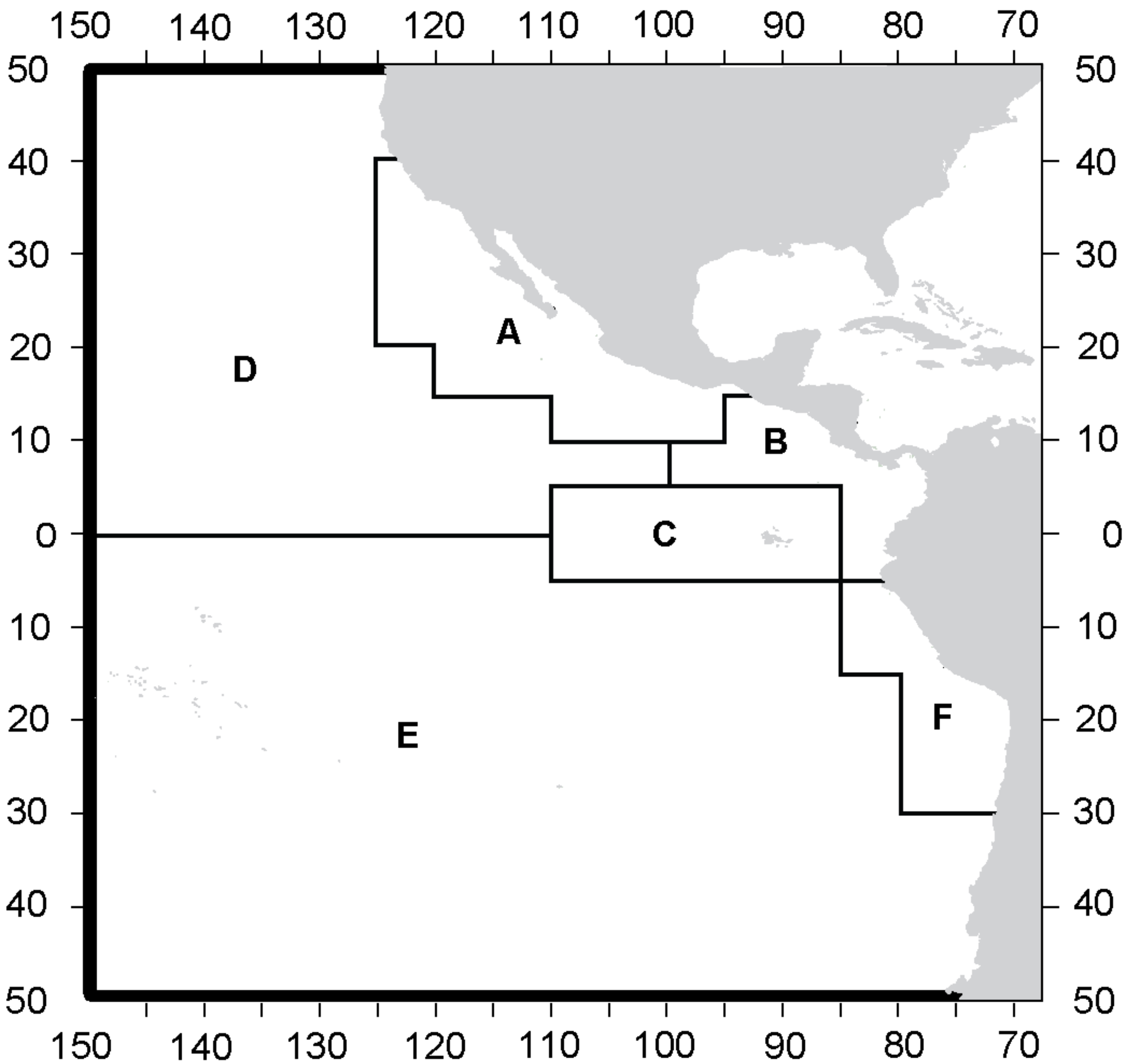

FIGURE 2.1. Spatial extents of the sub-stocks (regions) defined for the stock assessment of skipjack tuna in the EPO.
FIGURA 2.1. Extensión espacial de las subpoblaciones (regiones) definidas para la evaluación del atún barrilete en el OPO.

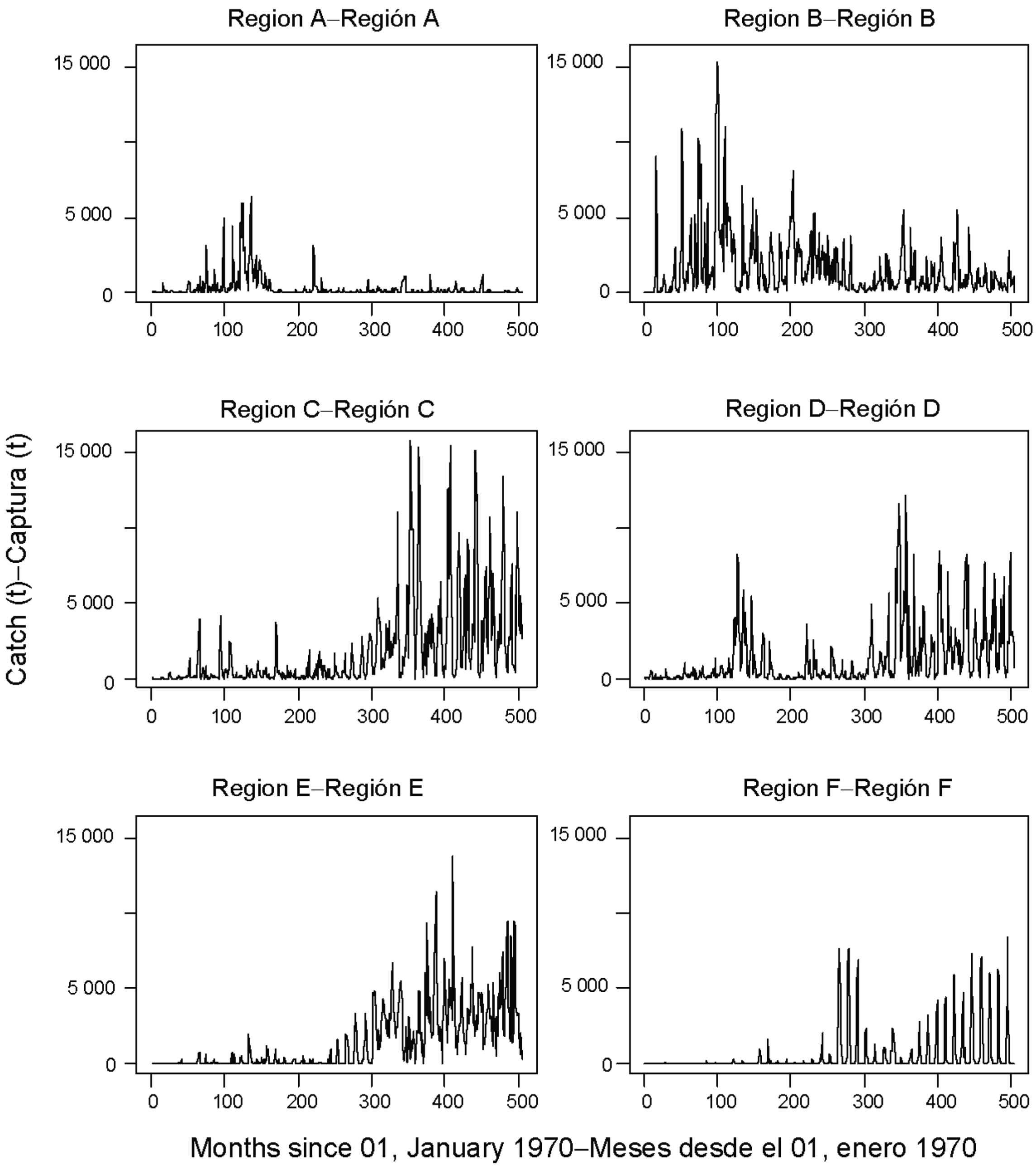

FIGURE 2.2a. Monthly catches in purse-seine sets on floating objects, by region.
FIGURA 2.2a. Capturas mensuales en lances cerqueros sobre objetos flotantes, por región.

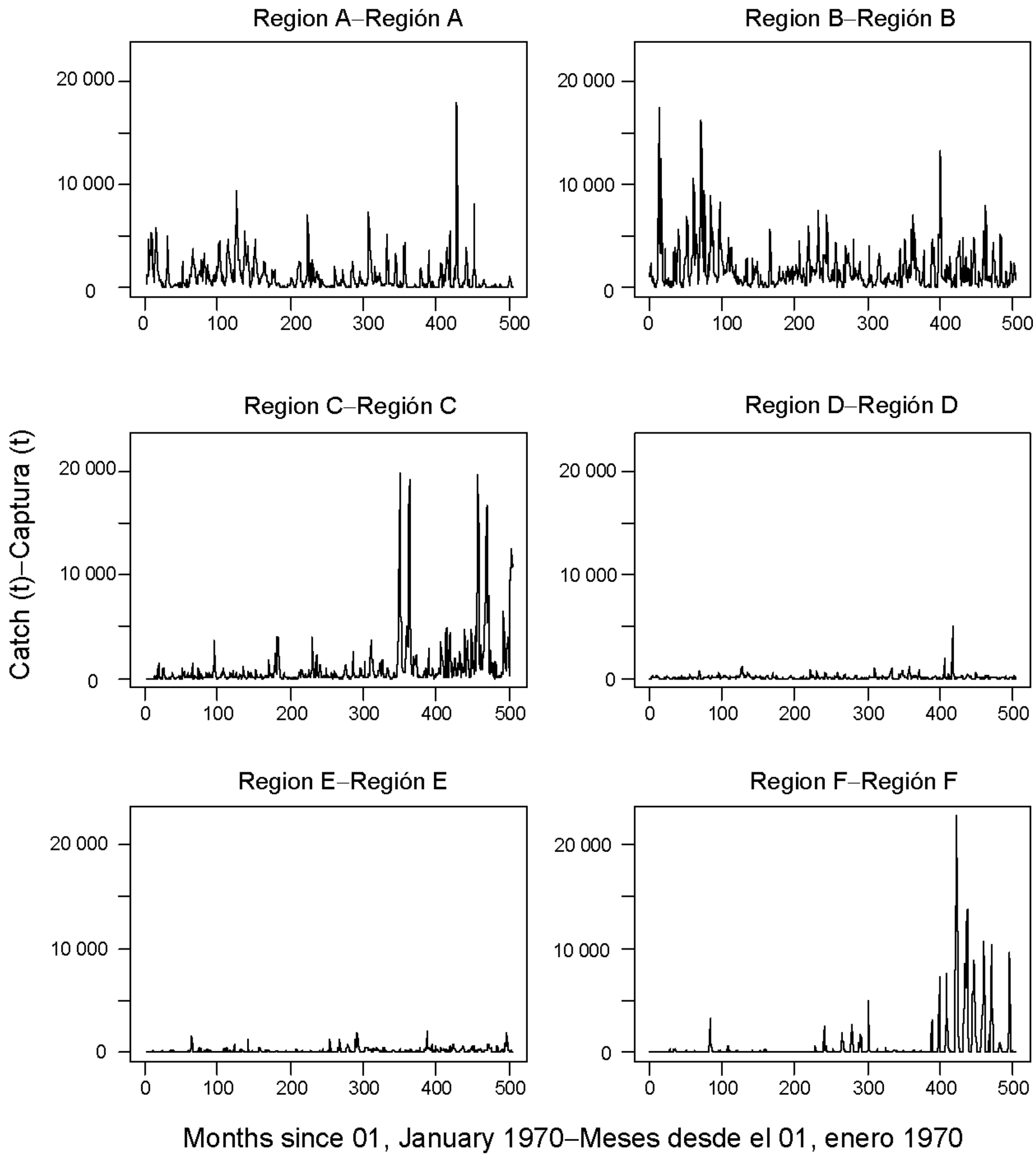

FIGURE 2.2b. Monthly catches in purse-seine sets on unassociated tunas, by region.
FIGURA 2.2b. Capturas mensuales en lances cerqueros sobre atunes no asociados, por región.

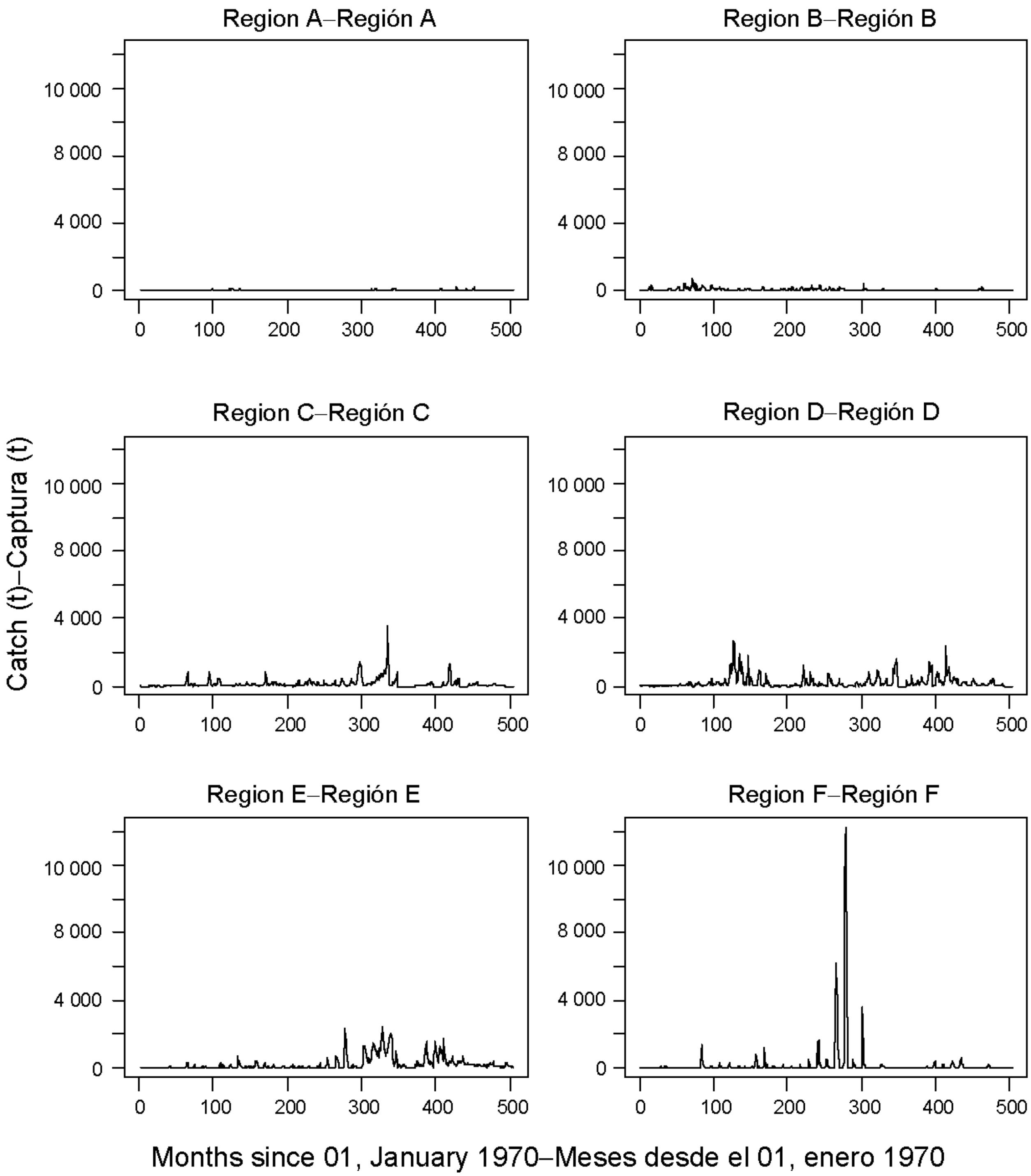

FIGURE 2.2c. Monthly discards of small skipjack, by region.
FIGURA 2.2c. Descartes mensuales de barriletes pequeños, por región.

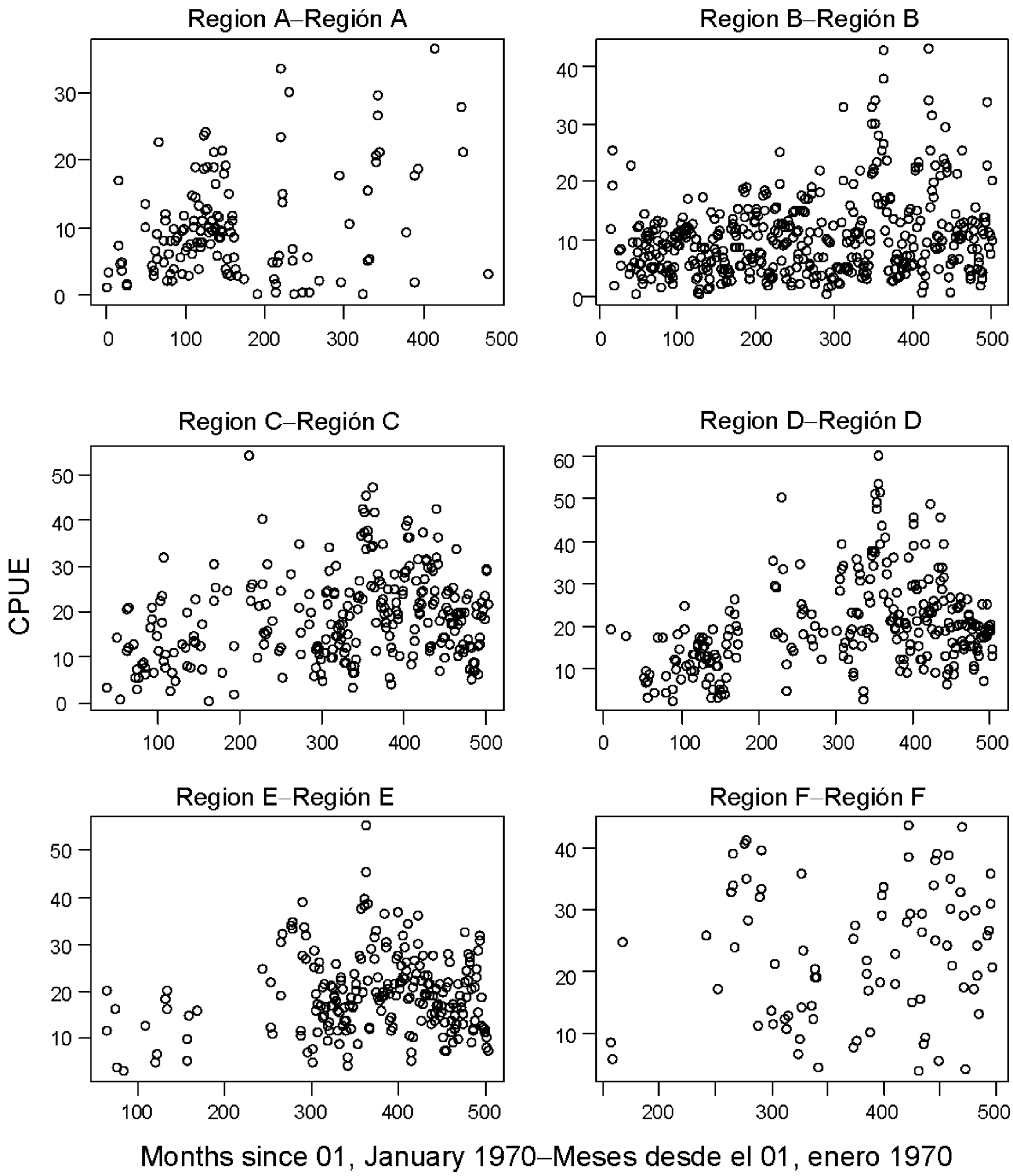

FIGURE 2.3a. Monthly CPUEs for the floating-object fisheries, by region.
FIGURA 2.3a. CPUE mensuales de las pesquerías sobre objetos flotantes, por región.

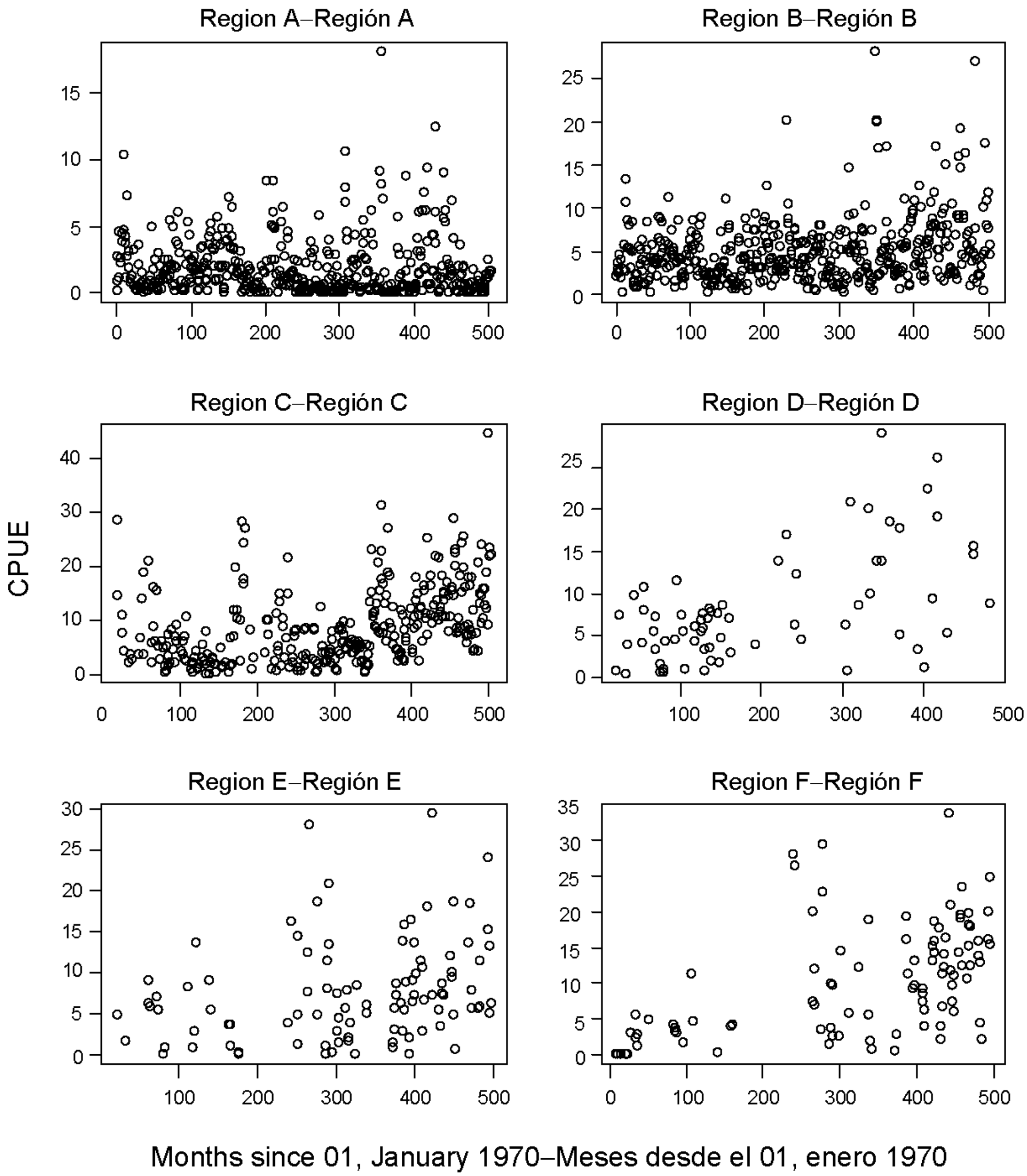

FIGURE 2.3b. Monthly CPUEs for the unassociated fisheries, by region.
FIGURA 2.3b. CPUE mensuales de las pesquerías no asociadas, por región.

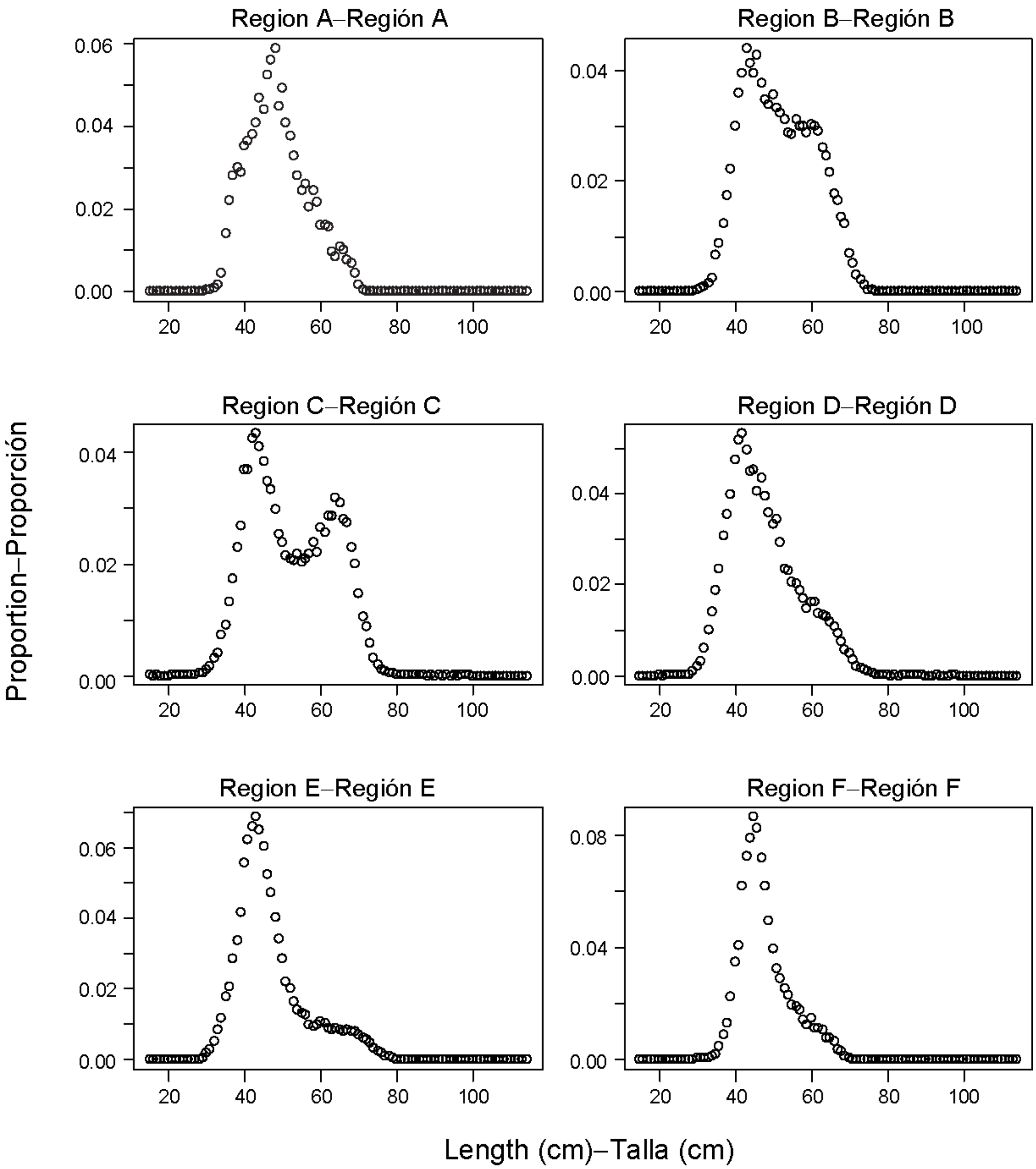

FIGURE 2.4. Average length-composition data, 1970-2011, for the floating-object fishery, by region.
FIGURA 2.4. Datos de composición por talla media, 1970-2011, de la pesquería sobre objetos flotantes, por región.

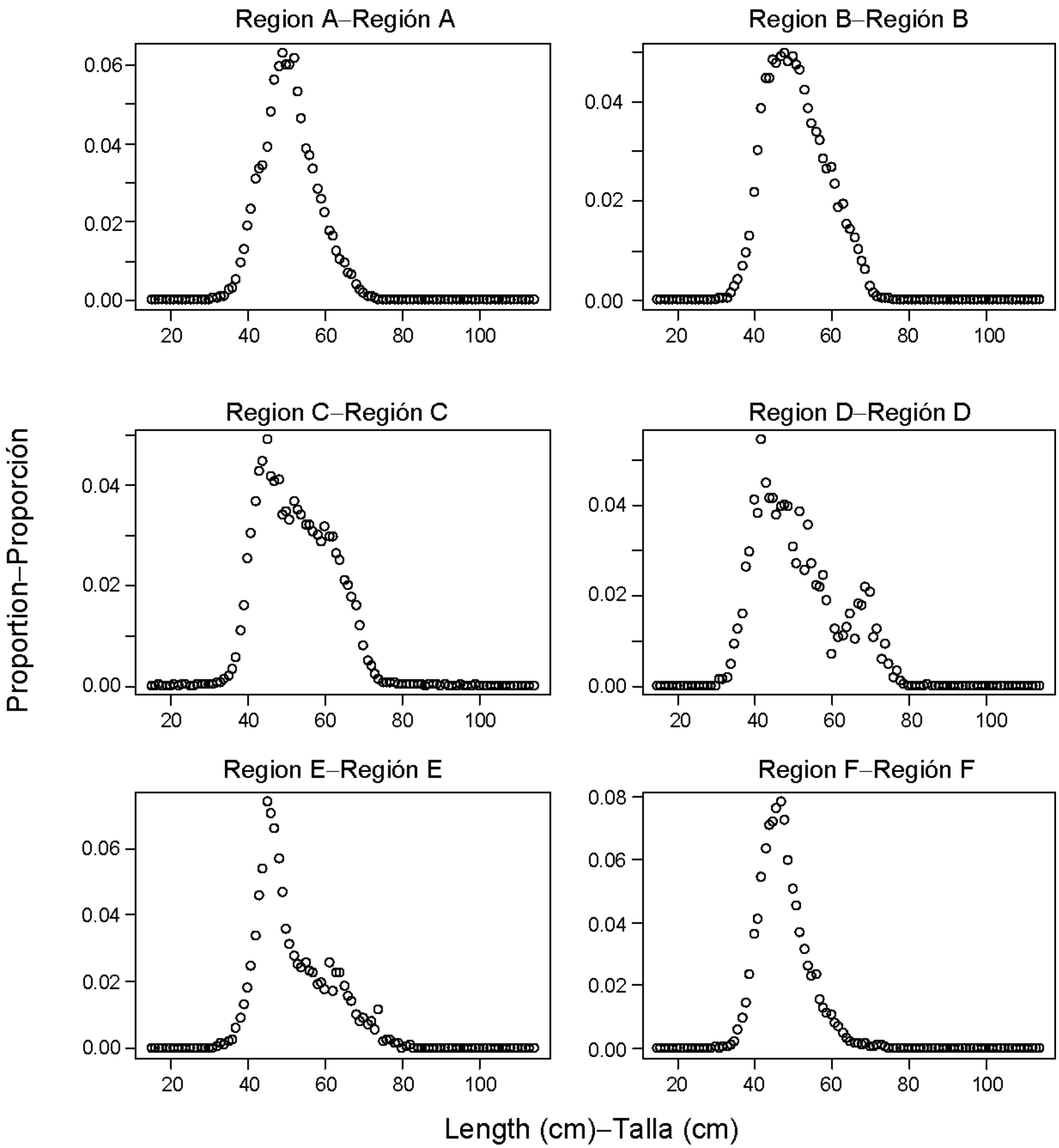

FIGURE 2.4, (continued).
FIGURA 2.4. (continuación)

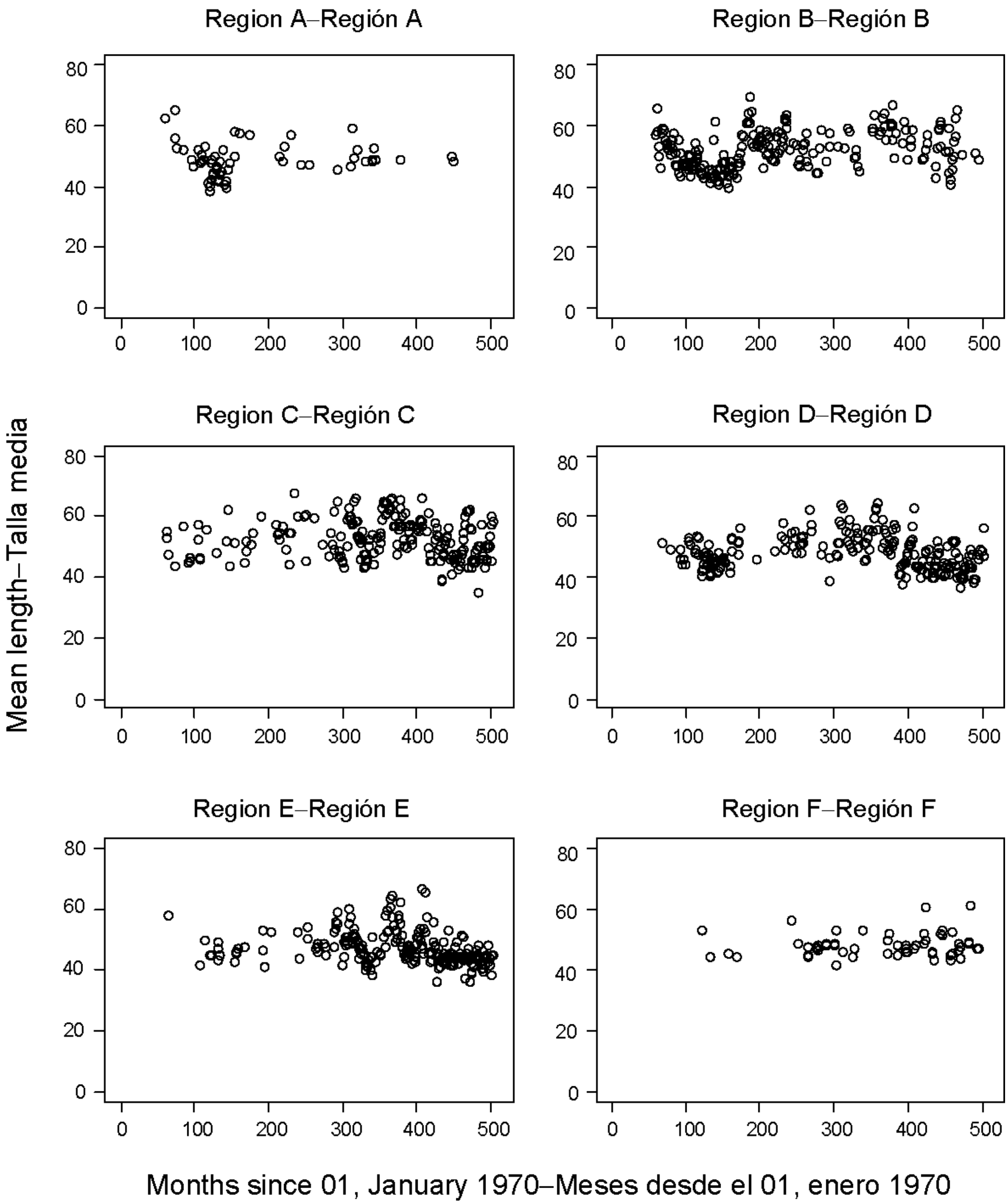

FIGURE 2.5a. Estimated average length of skipjack tuna caught in purse-seine sets on floating objects, by region.

FIGURA 2.5a. Talla promedio estimada del atún barrilete capturado en lances cerqueros sobre objetos flotantes, por región.

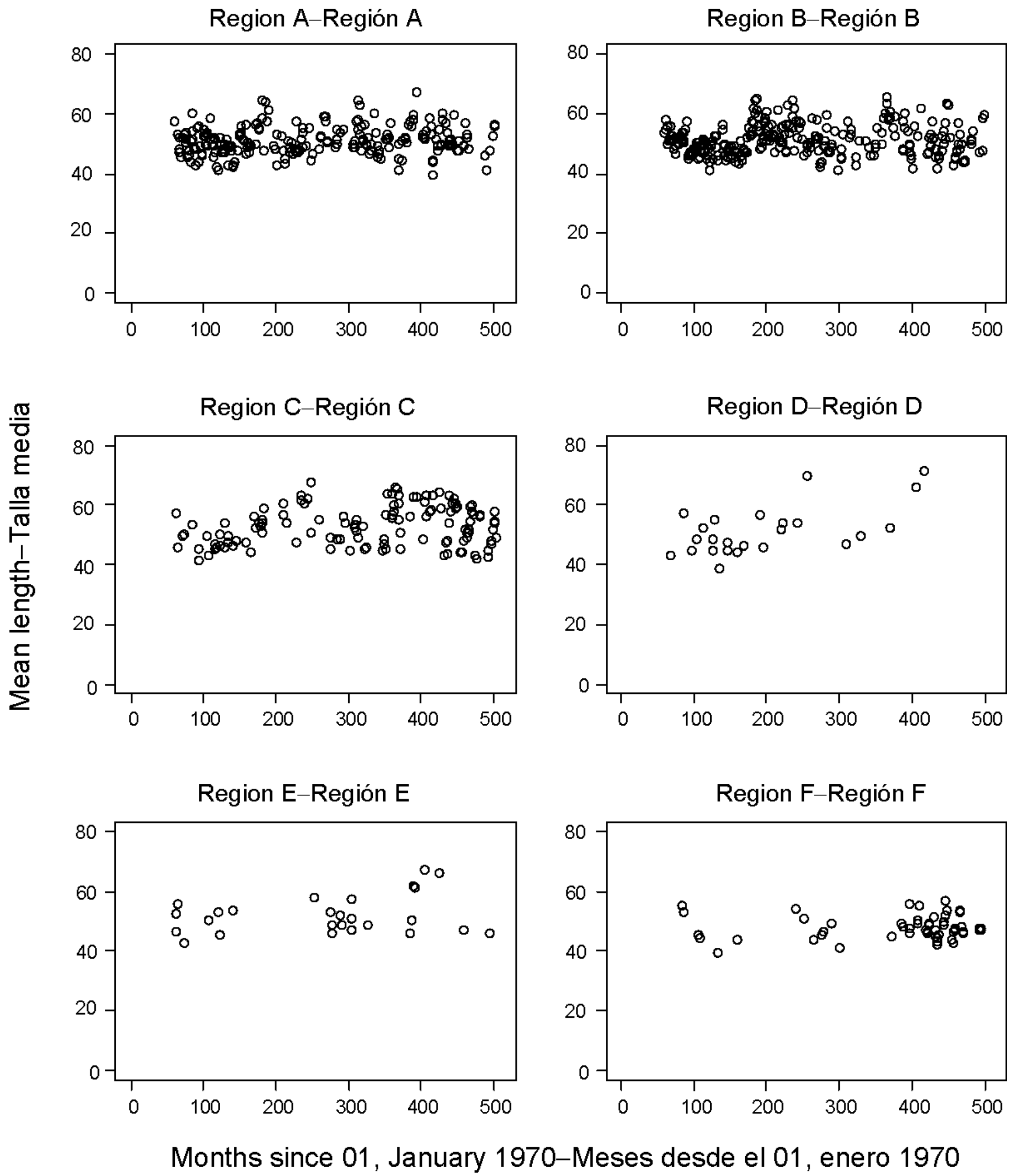

FIGURE 2.5a. Estimated average length of skipjack tuna caught in purse-seine sets on unassociated tunas, by region.

FIGURA 2.5a. Talla promedio estimada del atún barrilete capturado en lances cerqueros sobre atunes no asociados, por región.

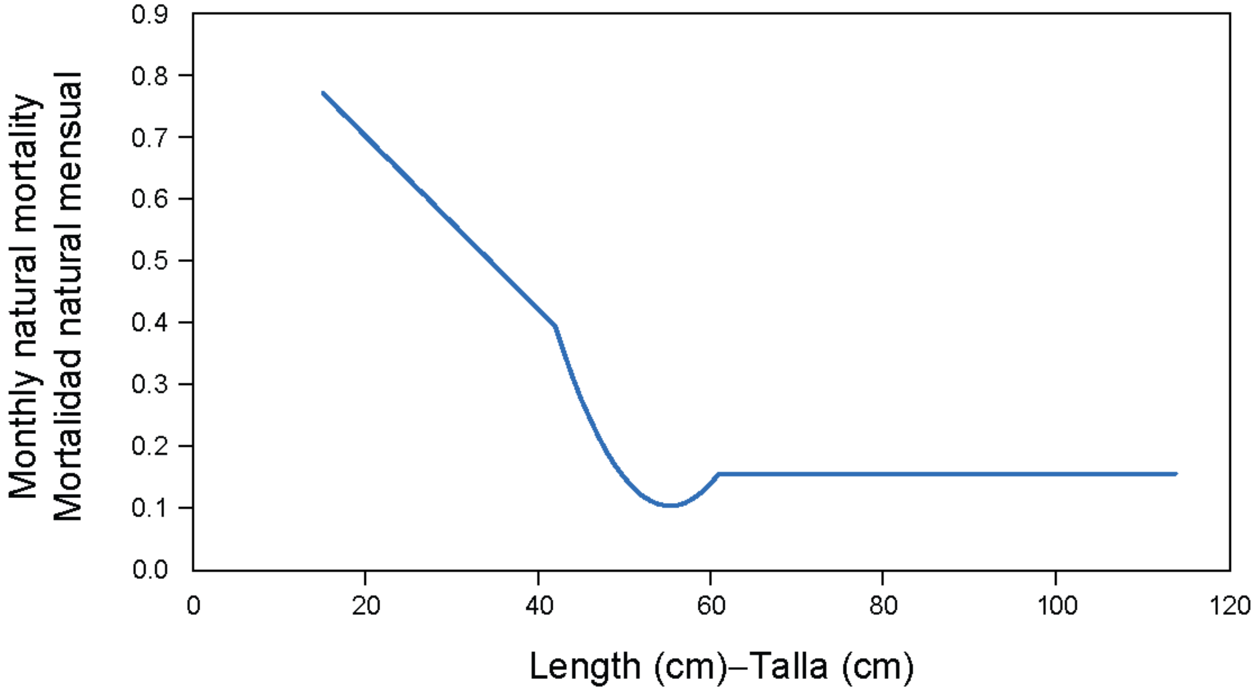

FIGURE 3.1. Rates of monthly natural mortality (*M*) used for the length-structured assessment of skipjack tuna.

FIGURA 3.1. Tasas de mortalidad natural (*M*) mensual usadas para la evaluación por talla del atún barrilete.

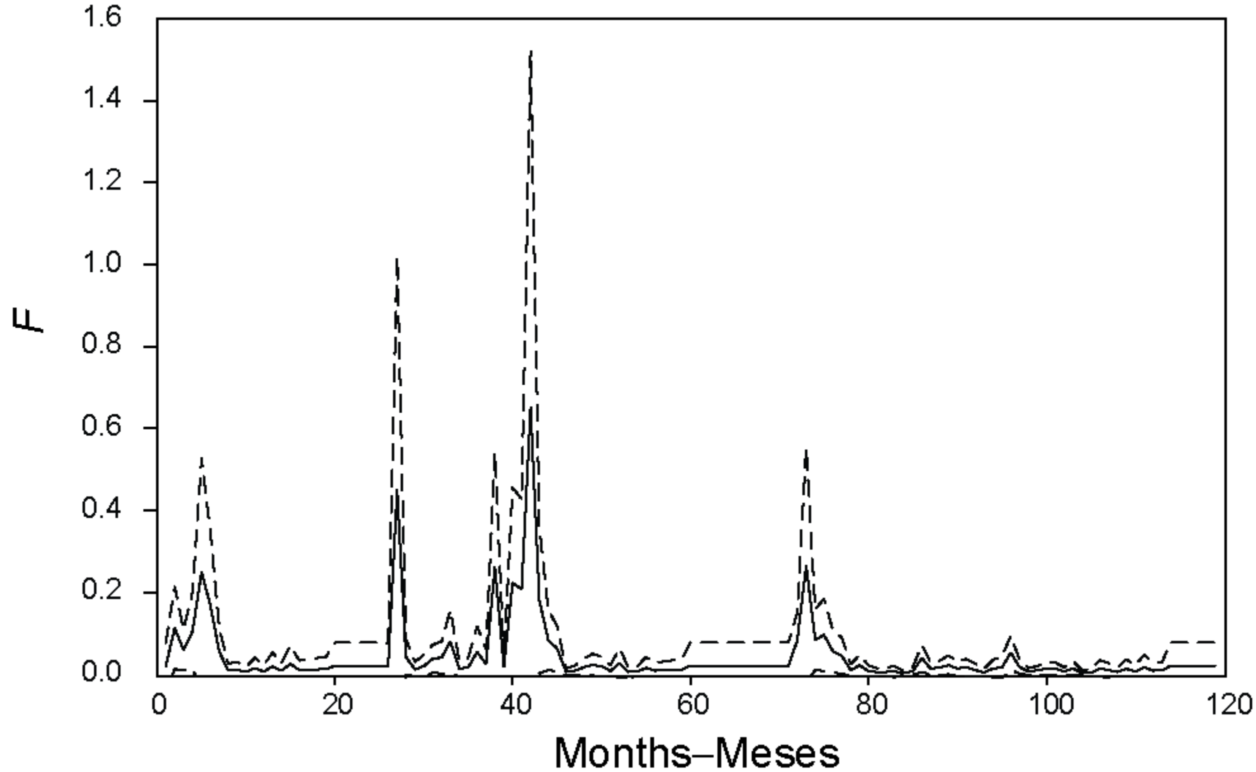

FIGURE 4.1a. Estimates of fishing mortality (*F*). with 95% confidence intervals, for the historic tag data. Time is in months since June 1973 (month 1).

FIGURA 4.1a. Estimaciones de la mortalidad por pesca (*F*), con intervalos de confianza de 95%, para los datos de marcado históricos. Tiempo en meses a partir de junio de 1973 (mes 1).

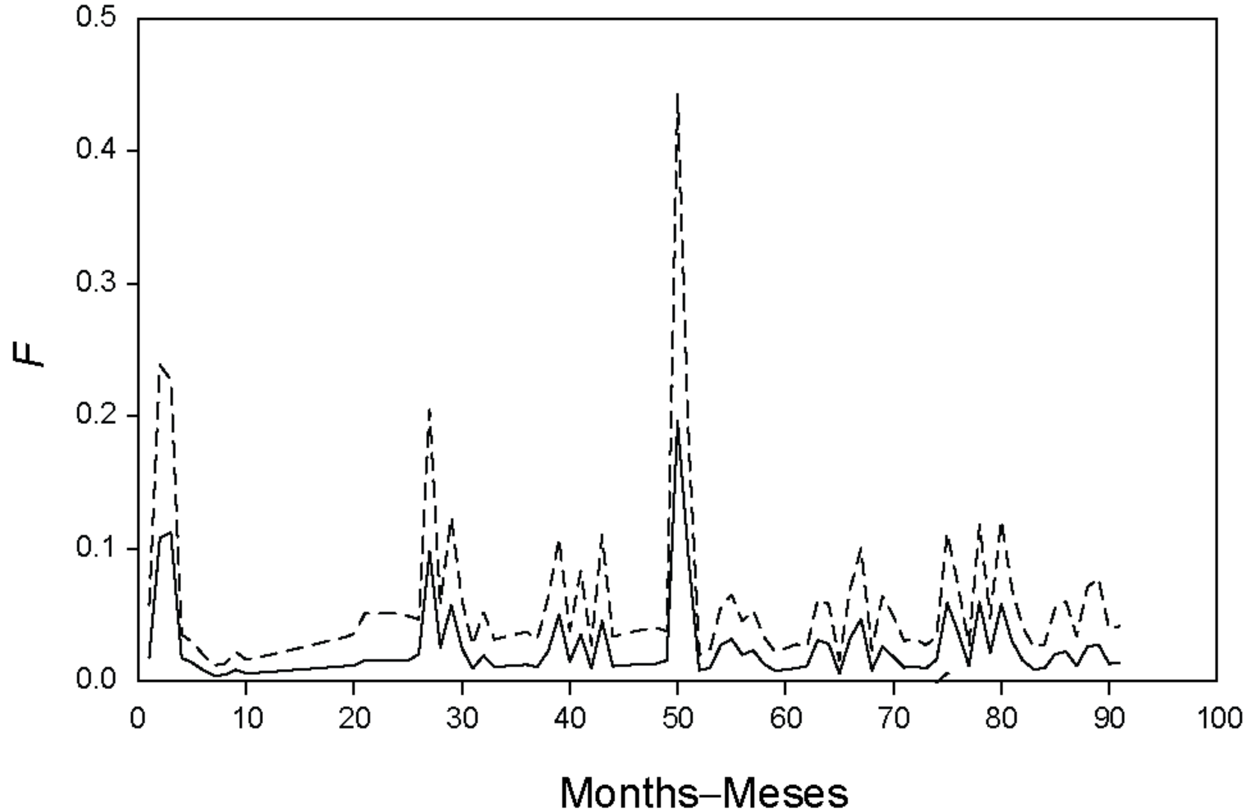

FIGURE 4.1b. Estimates of fishing mortality (*F*). with 95% confidence intervals, for the historic tag data. Time is in months since April 2000 (month 1).

FIGURA 4.1b. Estimaciones de la mortalidad por pesca (*F*), con intervalos de confianza de 95%, para los datos de marcado recientes. Tiempo en meses a partir de abril de 2000 (mes 1).

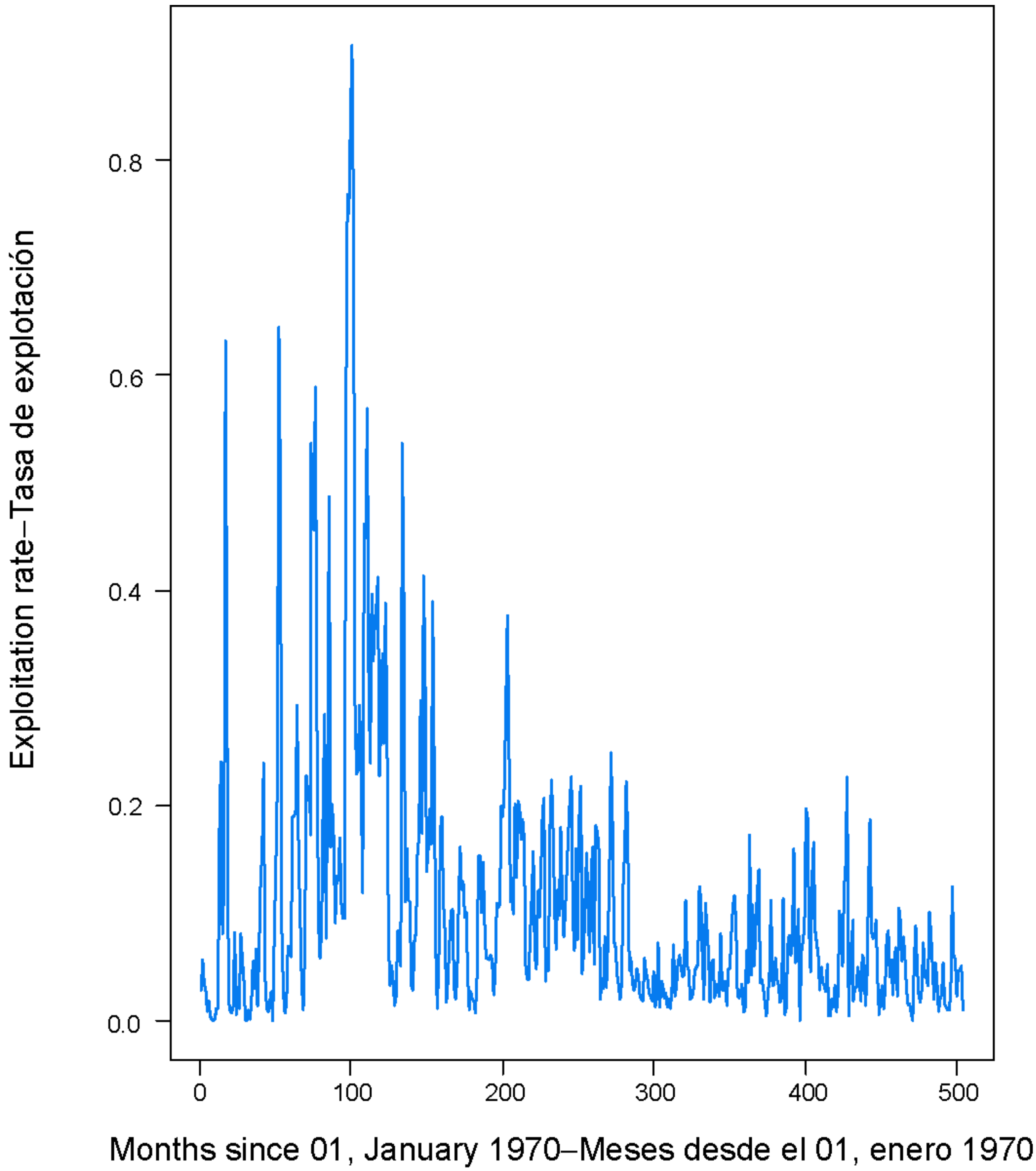

FIGURE 4.2. Monthly exploitation rate for region B estimated using the length-structured stock assessment model.
FIGURA 4.2. Tasa de explotación mensual correspondiente a la región B, estimada con el modelo de evaluación basado en talla.

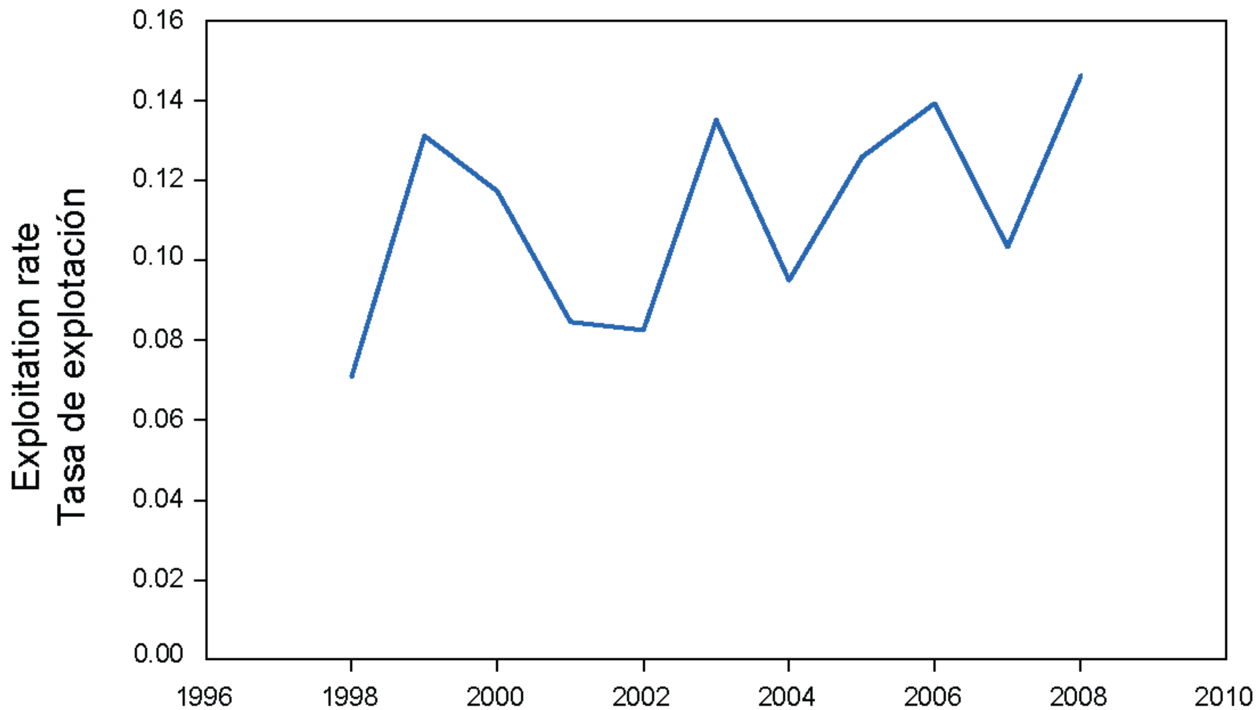

FIGURE 4.3. Annual exploitation rate of skipjack in the EPO, estimated by SEAPODYM.
FIGURA 4.3. Tasa de explotación anual de barrilete en el OPO, estimada con SEAPODYM.

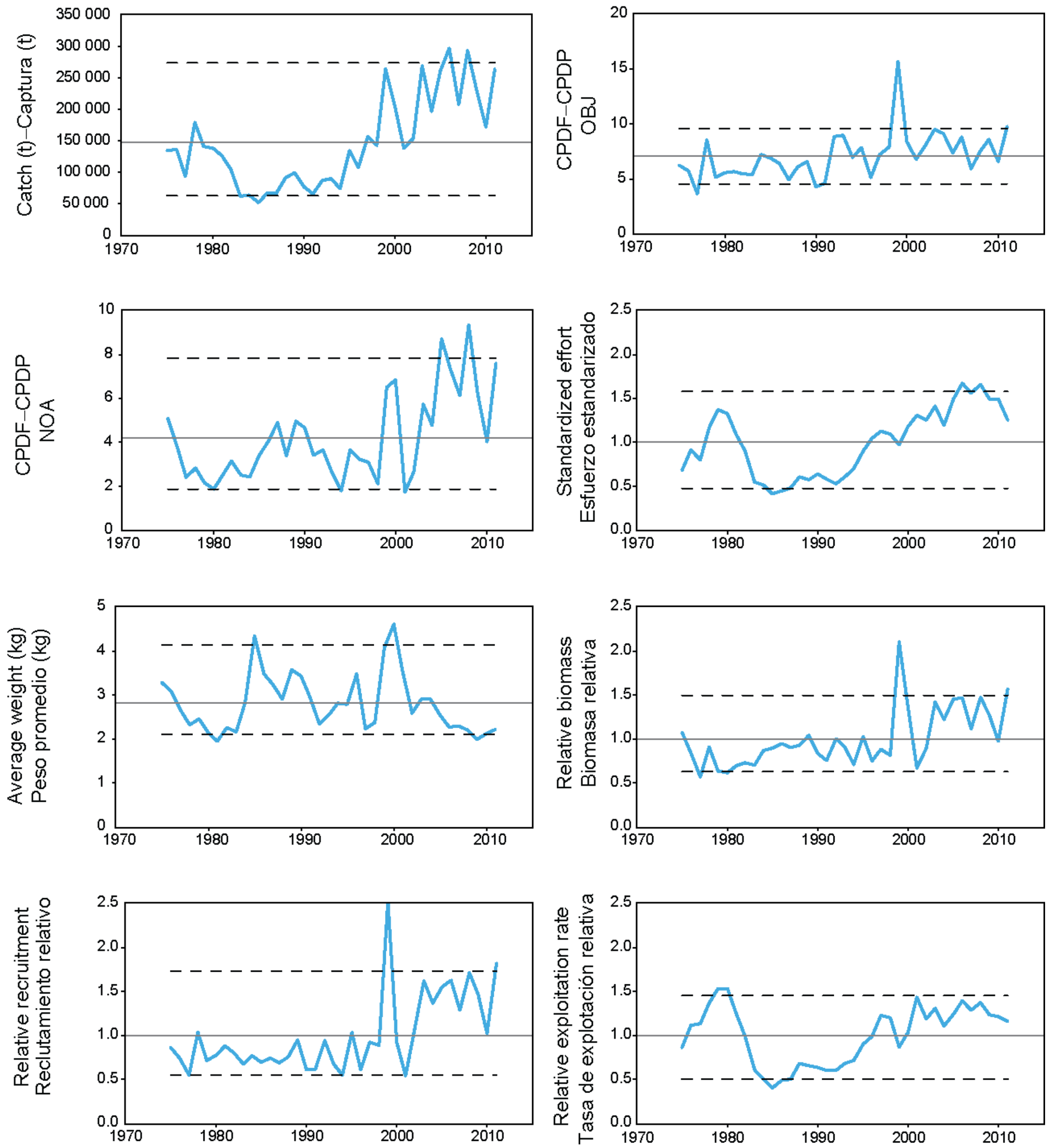

FIGURE 4.4. Indicators of stock status for skipjack tuna in the EPO. OBJ: floating-object fishery; NOA: unassociated fishery. All indicators are scaled so that their average equals one.

FIGURE 4.4. Indicadores de la condición de la población de atún barrilete en el OPO. OBJ: pesquería sobre objetos flotantes; NOA: pesquería no asociada. Se escalan todos los indicadores para que su promedio equivalga a uno.

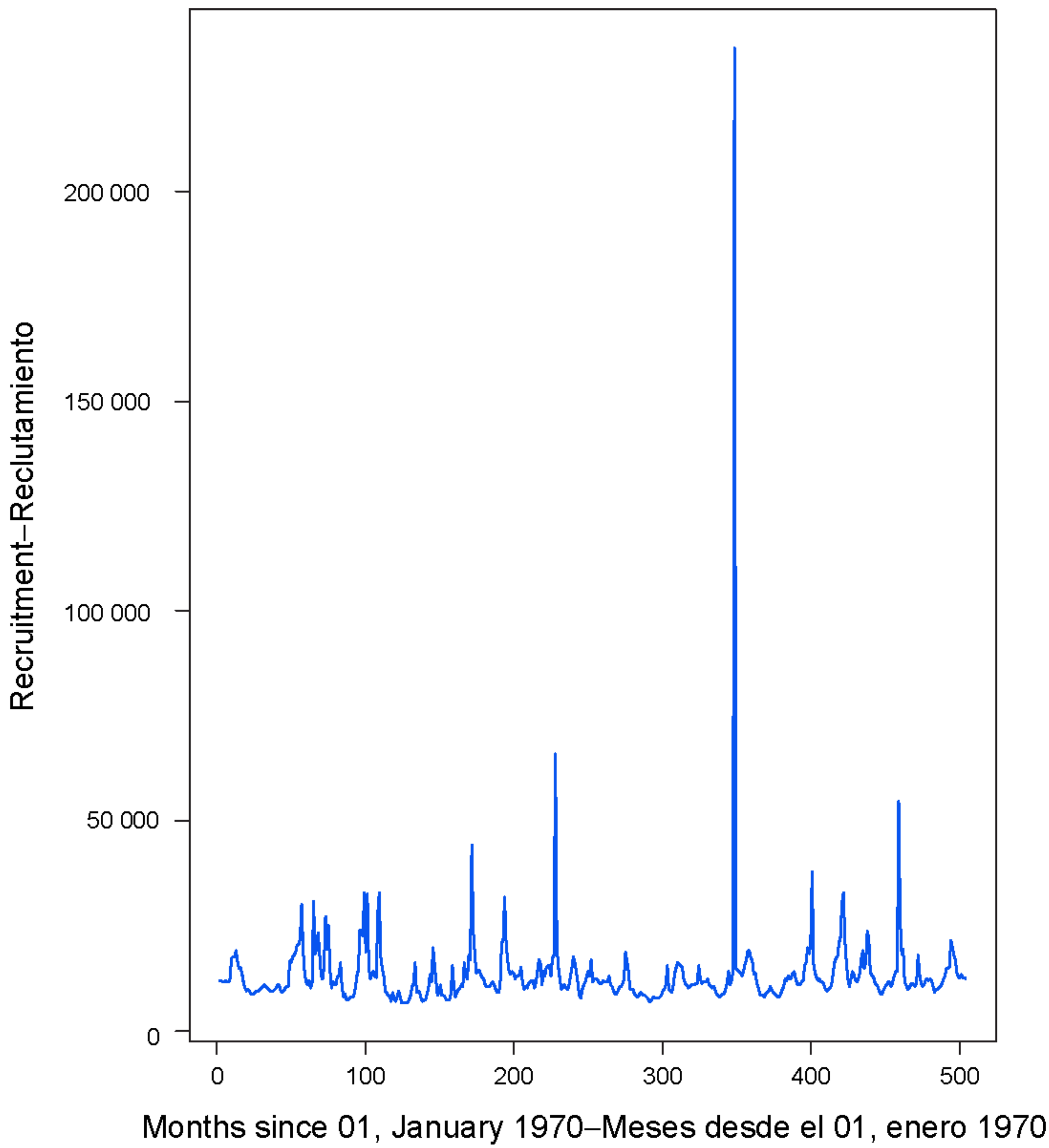

FIGURE 4.5. Monthly recruitment in region B, estimated by the length-structured model.
FIGURA 4.5. Reclutamiento mensual en la región B, estimado con el modelo basado en talla.

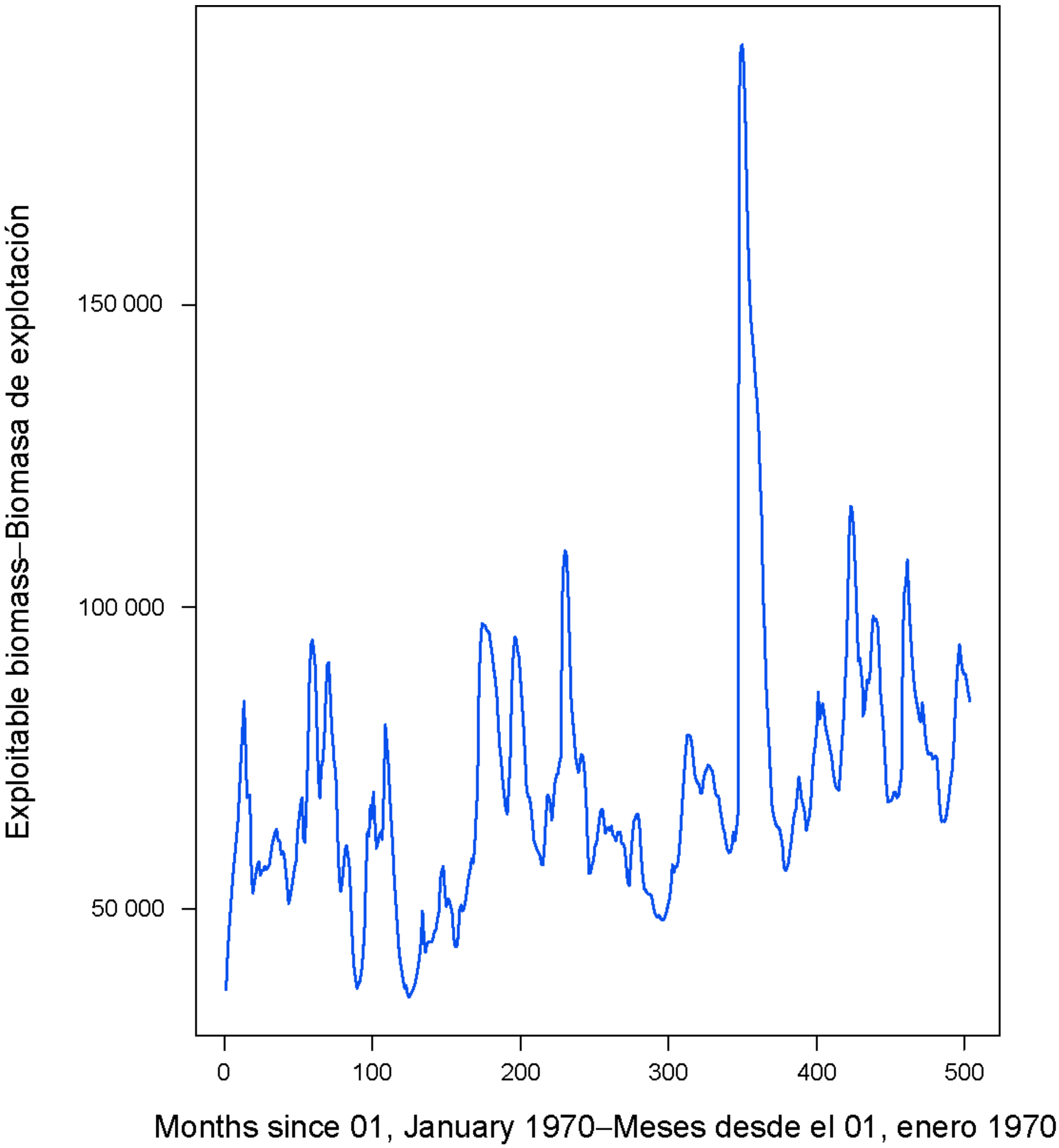

FIGURE 4.6. Exploitable biomass for the unassociated fishery in region B, estimated by the length-structured assessment model.
FIGURA 4.6. Biomasa explotable para la pesquería no asociada en la región B, estimada con el modelo basado en talla.

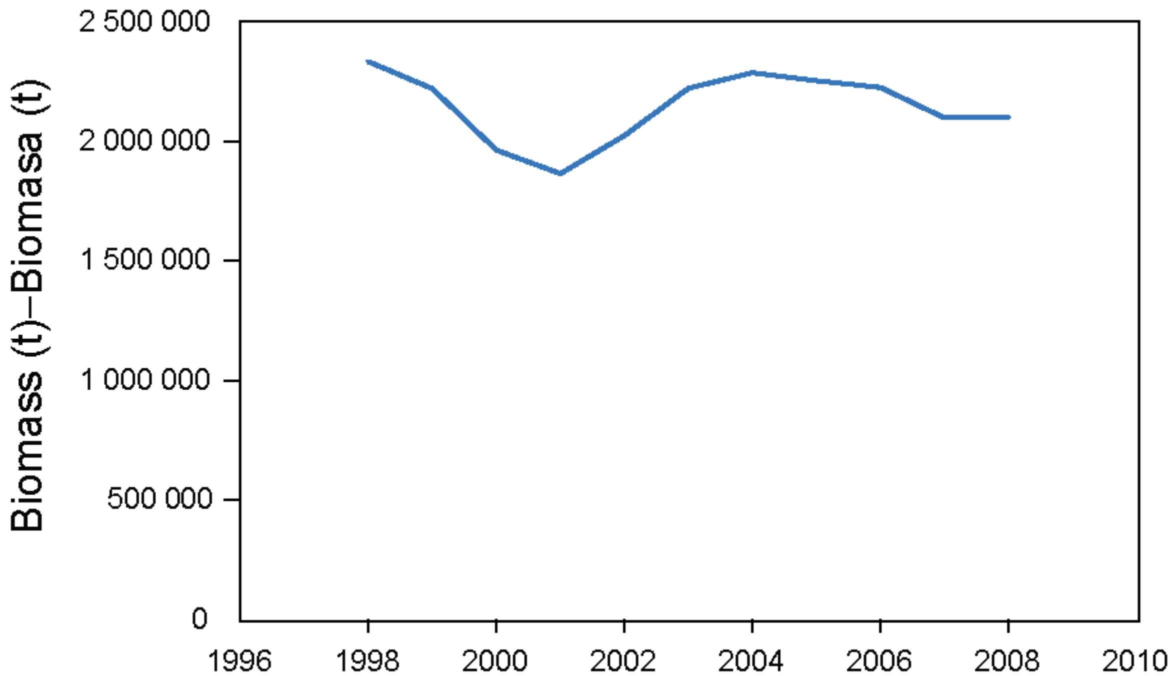

FIGURE 4.7 Biomass of skipjack 30 cm and larger in the EPO estimated by SEAPODYM.
FIGURA 4.7. Biomasa de barrilete de 30 cm de talla o más en el OPO, estimada con SEAPODYM.

TABLE 2.1. Regions defined for the stock assessment of skipjack tuna in the EPO. The sampling areas are shown in Figure 2.1.
TABLA 2.1. Regiones definidas para la evaluación de la población de atún barrilete en el OPO. En la Figura 2.1 se ilustran las áreas de muestreo.

Region **Región**	**Description** **Descripción**	**Sampling areas** **Areas de muestreo**
A	Inshore north Costera norte	1,2,4,8
B	Inshore central Costera central	5,6
C	Central	7,9
D	Offshore north Alta mar norte	3,10
E	Offshore south Alta mar sur	11,12
F	Inshore south Costera sur	13