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STOCK STATUS INDICATORS FOR SILKY SHARKS IN THE EASTERN PACIFIC OCEAN

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SUMMARY

The results of two recent genetics studies support assessing and managing the populations of silky sharks (*Carcharhinus falciformis*) in the western and eastern Pacific Ocean separately. One of the studies suggests a further division of silky sharks in the eastern Pacific Ocean (EPO) into two stocks, approximately along the Equator.

An attempt to assess the status of the silky shark in the EPO using conventional stock assessment models has been severely handicapped by major uncertainties in the fishery data, mainly regarding catch levels in the early years, which may be why the model is unable to explain the population declines observed in the early period of the assessment (1994-1998) (Document SAC-05 INF-F). Although this stock assessment attempt has produced a substantial amount of new information about the silky shark in the EPO (*e.g.*, absolute and relative magnitude of the catch by different fisheries and their selectivities), the absolute scale of population trends and the derived management quantities are compromised. Therefore, an alternative scientific basis for management advice is urgently needed. This document presents a suite of possible stock status (or stability) indicators (SSIs) which could be considered for managing the northern and southern stocks of silky sharks in the EPO.

Indices based on standardized catch-per-unit-effort (CPUE) in purse-seine sets on floating objects (CPUE-OBJ) are proposed as the best indicators for representing trends in the silky shark populations in the EPO, mainly on the basis of their wider spatial coverage of the floating-object fishery compared to other set types. However, indicators for other set types are also presented as a potential means to verify the trends of the CPUE-OBJ indicators.

For the northern stock, the CPUE-OBJ indicator shows an initial sharp decline over a wide spatial range (1994-1998), followed by a period of stability (1996-2006), and possibly increase (2006-2010). However, there are indications that any such increase has been reversed in recent years (2010-2013). These trends are corroborated by a different type of indicator (presence/absence) produced from other set types (dolphin and unassociated).

For the southern stock, the CPUE-OBJ indicator shows a sharp decline during 1994-2004, followed by a period of stability at much lower levels. These trends are also corroborated by presence/absence indicators based on other set types.

No stock status target and limit reference points have been developed for silky sharks based on these indicators. In addition, no harvest control rules have been developed and tested. At this point, the indicators cannot be used directly for determining the status of the stock or for establishing catch limits: they should be used in combination with other information for those purposes. In terms of management, it

is critical that precautionary measures be implemented immediately to allow silky sharks populations to rebuild in the EPO.

With respect to future research on SSIs for silk sharks, priority should be given to management strategy evaluation (MSE) work to identify the reference points and harvest control rules that will achieve the conservation goals for silky sharks in the EPO.

1. INTRODUCTION

Conventional stock assessment approaches (a surplus production and an age-structured model) have been applied to fishery data reconstructed for the silky shark in the eastern Pacific Ocean (EPO) (SAC-05 INF-F). The historic period of the assessment covered the years from 1993 to 2010, which missed the most recent period (2011-2013). An updated stock assessment that would include this period is not currently possible, for two reasons: first, some structural issues were identified in the stock assessment model, and these are difficult to overcome given the major uncertainties in the fishery data, in particular, in assumed levels of the early catch; and second, fishery data for the most recent period are not available for all fisheries assumed in the assessment model.

Given this situation, and the need to formulate management advice for silky sharks in the EPO, up-to-date information that can be used as an alternative to conventional data-rich stock assessments is urgently needed. This document describes a suite of stock status (or stability) indicators (SSIs) that can be used for this purpose.

SSIs are useful when conventional stock assessments are infeasible, but an indication of stock status is needed for management (see Document SAC-05-11c). The following SSIs can be easily produced from the data collected by observers aboard large[1] tuna purse-seine vessels operating in the EPO:

1. spatial distribution of silky shark bycatch per set (BPS) in purse-seine sets on floating-objects;
2. standardized catch-per-unit-effort (CPUE) of silky sharks in purse-seine sets on floating objects;
3. nominal proportions of positive sets (sets in which silky sharks are caught) for all purse-seine set types (on floating objects, dolphins, and unassociated tuna schools);
4. standardized indices of presence/absence of silky sharks in purse-seine sets on dolphins and unassociated schools; and
5. average length of silky sharks caught in by purse-seine sets, by set type.

The results of a recent mitochondrial-DNA study (Galvan-Tirado *et al.* 2013) show a slight genetic divergence between silky sharks in the western and eastern Pacific, which supports assessing and managing these two populations separately. Within the EPO, there are marked north-south differences in the length composition of the purse-seine bycatches of silky sharks (Roman-Verdesoto 2014; Roman-Verdesoto and Orozco-Zoller 2005; Watson *et al.* 2009). In addition, preliminary results from ongoing genetic studies (John Hyde, NMFS-SWFSC, pers. comm.) confirm the east-west separation proposed by Galván-Tirado *et al.* (2013), but they also strongly suggest that, for management purposes, silky sharks in the EPO should be divided into two stocks, aproximately along the equator. In the light of this, the best scientific information available, SSIs were constructed separately for the areas north and south of the equator ('Northern' and 'Southern' silky shark stocks).

In this document, "all" silky sharks means all silky sharks recorded by observers, regardless of whether they recorded their length and whether (from 2005 onwards) they were recorded as "released alive." Prior to 2005, observers did not record sharks released alive. The individuals recorded as released alive are included to the total bycatch because available information suggests it is unlikely that sharks brought aboard the vessel in the brailer survive once returned to the water (Poisson *et al.* 2014; IATTC

[1] Carrying capacity > 363 tons (IATTC size class 6)

unpublished data). A sensitivity analysis to determine the influence on the standardized trends for all silky sharks of excluding the live releases since 2005 found that there was very little difference over the 2005-2013 period between the trend that included live releases and the trend that did not. Although the level of live releases prior to 2005 is unknown, it is unlikely to have been higher than that recorded in 2005 (~5%), and therefore would have been unlikely to influence the overall trend prior to 2005.

2. NORTHERN STOCK

2.1. Spatial distribution of silky shark bycatch rates in purse-seine sets on floating objects

Spatial distribution maps provide a simple quantitative overview of changes through time in both species occurrence and abundance. For silky sharks, they are available for average bycatch-per-set (BPS) from purse-seine sets on floating objects in the EPO, for small (< 90 cm), medium (90-150 cm), and large (> 150 cm) size classes separately (Figures 1a-c), and all silky sharks (Figure 1d).

For all size classes north of the equator, there is an apparent reduction in bycatch rates (transition from predominantly red- and yellow-colored 1° areas to predominantly green- and blue-colored 1° areas). This reduction seems particularly strong in the most recent period (2011-2013), and apparently begins much earlier (around the mid-2000s) for large sharks.

2.2. Standardized catch-per-unit effort (CPUE) from purse-seine sets on floating objects

Standardized catch-per-unit-effort (CPUE) data from purse-seine sets on floating objects are available for the northern silky shark stock for the 1994-2013 period. A zero-inflated negative binomial (ZINB) regression model with smoothing (Minami *et al.* 2007) was used for the CPUE standardization, and standardized trends were estimated with the method of partial dependence (Haistie *et al.* 2009). Indices based on standardized CPUE in purse-seine sets on floating objects (CPUE-OBJ) are proposed as the best indicators for representing trends in the abundance of silky sharks in the EPO, for two reasons: the fishery on floating objects has a wider spatial coverage in the EPO than other set types, and silky sharks of all sizes are caught in sets on floating objects, although most of them are juveniles.

The indicator for the northern stock shows a large (70%) decline in CPUE during 1994-1998 (Figure 2). It is less pronounced (53%) if the 1994 estimate is excluded; the spatial distribution of the floating-object fishery is much narrower in that year compared to the subsequent years (Figure 1). During the following 8-year period (1999-2006) the trend is apparently stable, with low variability.

The indicator shows a gradual increasing trend during 2006-2010 (Figure 2). Results from a demographic analysis (SAC-05 INF-F) show that the average annual rate of increase observed during this period, about 14%, is plausible for silky shark populations in the EPO under two conditions: very low exploitation rates, and if the uncertainty (precision) of the estimates is considered (95% confidence intervals), which will substantially lower this estimate. The following factors could have contributed to this increasing trend: 1) IATTC tuna conservation resolutions, which restricted purse-seine fishing effort (C-04-09, C-06-02, C-09-01); 2) the significant decline in high-seas longline effort in the mid-2000s that resulted from a large spike in fuel prices; and 3) bans on shark finning in Central America, where there are important longline fisheries targeting sharks.

The observed annual rate of increase of 33% from 2009 to 2010 does not seem possible given the life-history and productivity of silky sharks in the EPO (SAC-05 INF-F), even taking into account imprecision in the estimates. This suggests that other factors (*e.g*. changes in catchability, environmental conditions, migrations) may have been in play, and might explain the markedly high CPUE observed in 2010.

The average value of the CPUE-OBJ indicator for 2011-2013 is 30% lower than that of 2006-2010, with a 63% decline between 2010 and 2012, similar to that observed during 1995-1998. These lower values indicate that the possible rebuilding trend observed during 2006-2010 has been interrupted. However, without reliable catch and effort data for this most recent period for all fleets catching silky sharks, the cause of the decline cannot be determined. It may be due to increased fishing mortality of silky sharks in the EPO since 2010, or environmental factors that reduce availability and catchability of silky sharks, or a combination of both.

Observers record catches of silky sharks by size class: small (< 90 cm), medium (90-150 cm), and large (>150 cm) (Figure 3a). The relative trends described above for all sharks (Figure 2) generally apply to the individual size categories. However, there is more inter-annual variability in the trends observed for small sharks, which is not surprising since the small shark class can be seen as a proxy indicator for recruitment (ages 0 and 1). The sharp decline seen for medium and large sharks during 1994-1998 is not as marked for small sharks, which suggests that recruitment has not been greatly affected over time. For better comparison of relative trends across size classes, Figure 3b presents the mean-scaled standardized CPUE.

Two possible explanations for this pattern – large declines in the spawning stock (large individuals) while recruitment appears unaffected – are some form of density-dependent compensatory mechanism and/or immigration of recruits into the EPO from other areas. The genetic studies are not clear about the division of the western and eastern Pacific Ocean stocks. The exception to this apparent stable recruitment pattern are the most recent three years (2011-2013), when recruitment was substantially lower than in previous years: the average recruitment levels for 2011-2013 were 63% lower than those for 2005-2010 (Figure 3a, b).

2.2.1. Spatial trends in standardized CPUE from purse-seine sets on floating objects

In order to investigate spatial trends within the northern EPO, where most of the silky shark catches take place, standardized CPUE was computed for four sub-areas (Figure 4a), by size class and for all sharks. For better comparison of relative trends across size classes, Figure 4b presents the mean-scaled standardized CPUE.

The standardized CPUE trends estimated for the northernmost sub-area, Area 1 (north of 8°N) are highly variable, and show a pronounced four-fold increasing trend since 2003, which is biologically unrealistic. This area includes only a small number of sets, as well as floating-object sets within the southward-flowing California Current (Figure 1), and this high catch variability, low effort, and highly variable oceanographic conditions may degrade the reliability of these indicators for Area 1. However, it should be noted that the standardized CPUE in this area shows 65% and 29% drops for small sharks and all sharks, respectively, during 2010-2013.

The northern equatorial band of the distribution of floating-object sets was partitioned into three areas: Area 2 (offshore), Area 3 (central), and Area 4 (inshore). The spatial analysis of trends reveals some important patterns for the northern stock.

First, the standardized CPUE trends for the central area (Area 3) are most similar to those described in section 2.2 for the northern stock (all sub-areas combined; Figures 2, 3a, b). This result is not surprising because the data set used in the trends analysis contains more floating-object sets in Area 3 than in any of the other three northern sub-areas, and the standardization procedure takes a data-weighted approach to trend estimation.

The sharp CPUE declines for all silky sharks during 1994-1998 are observed in all three equatorial areas (offshore, central and inshore), but the magnitude of this decline in the inshore area (30%) is less than in the central and offshore areas (86% and 72%, respectively).

The recent decline of the northern stock observed during 2010-2012 (Figure 2) is seen in all three equatorial areas (Figure 4a, b), whereas the slight recovery observed during 2012-2013 is observed only in the offshore and central areas. This may be due to higher exploitation rates in the inshore area, which is more accessible to land-based fisheries. However, there are only two data points, so it is too early to tell whether this recovery is real.

2.3. Presence/absence indicators by purse-seine set type

One possible concern about indicators based on catch per set in floating-object sets is that catch-rate indices are more prone to hyperstability biases. In the context of sets on floating objects, for example, it may be that the aggregation of fauna around the floating object has some form of "carrying capacity", and that its density can remain stable while the real abundance of the stock declines: the so-called "hyperstability" (Harley *et al.* 2001). However, this applies only to the target species, and would be important for bycatch species only if their abundance is related to the abundance of the target species.

An alternative to catch-rate based indicators are presence/absence indices, which are indicators of the probability of a positive fishing event (set), *i.e.*, a set in which at least one silky shark is caught (presence/absence). These presence/absence indicators have several advantages: they are independent of school/aggregation size, since they require only that an individual of a species be present in the catch, they are more easily obtained for gear types with low but patchy catch rates, and they are not influenced by a few sets with large catches. Presence/absence indicators are useful for purse-seine sets on dolphins and unassociated schools because the overall catch rate of silky sharks in these set types is very low compared to that in floating-object sets.

Figure 5 shows the nominal proportion of sets, by type, with one or more silky sharks present in the bycatch. The relative trends are similar for the different set types. Standardized presence/absence indices were computed with silky shark data from dolphin and unassociated sets. The probability of catching one or more silky sharks in a set was modeled using a logistic regression model that included smoothing. Standardized trends were estimated by partial dependence. In general, the relative trends in the these indicators are very consistent with each other (Figure 6); most importantly, they also coincide with the overall relative trends of the indicator based on floating-object CPUE proposed in section 2.2 as best representing the northern silky shark population trends (Figure 6).

2.4. Average lengths

In addition to the previously described CPUE and presence/absence indicators, the average length of silky sharks caught in purse-seine sets could also be considered as an indicator for monitoring the status of the stock. For example, a gradual decline in the average length may indicate that the adult segment of the stock is becoming depleted and that the fishery is moving towards the remaining younger segment of the stock. In contrast, an abrupt sharp decline of the average length may indicate a strong recruitment (cohort) passing through the fishery.

Observers aboard purse-seine vessels have taken actual shark length measurements since 2005, so average length indicators are available, by set type, for the 2005-2013 period.

During 2006-2011, the average length of silky sharks caught in sets on floating objects increased gradually (Figure 7), from 117 cm in 2006 to 126 cm in 2011; it declined about 8 cm during 2011-2013, but remained within previous historic levels (range of 113 to 126 cm).

The average length trends observed in dolphin and unassociated sets are more variable, but generally consistent with each other (Figure 7). There seem to be two periods for both fisheries: a more variable early period (2005-2008) with average length declining to about 149 cm, followed by a more recent period (2009-2013) with more stable average length at about 170 cm.

Without length data for the years prior to 2005, it is difficult to reconcile the average length patterns described above with the catch rate and presence/absence indicators. In addition, analysis by space and sex may help to understand trends in average length.

3. SOUTHERN STOCK

3.1. Spatial distribution of bycatch rates from purse-seine sets on floating objects

For the southern stock, there is a major decline in bycatch rates (transition from predominantly red- and yellow-colored 1° areas to predominantly green- and blue-colored 1° areas) (Figures 1a-d). This decline is particularly marked for medium and large sharks around the early- to mid-2000s (Figures 1b-c). These patterns are better quantified below from standardized CPUE indices.

Small individuals are relatively scarce in the southern area (Roman-Verdesoto, 2014; Roman-Verdesoto and Orozco-Zoller, 2005; Watson *et al.* 2009). It is uncertain where the recruitment to the southern stock originates.

3.1.1. Standardized CPUE from purse-seine sets on floating objects

The standardized CPUE indicator for all silky sharks in floating-object sets shows an 82% decline during 1994-2004 (Figure 2), followed by a period of stability, with very low variability, during 2004-2013. The trends for medium and large sharks are similar (Figure 3a, b).

3.1.2. Nominal presence/absence indicators by purse-seine set type

For floating-object sets, the nominal presence/absence indicator produces results similar to those of the CPUE-OBJ indicator (Figure 5), and the nominal indicator for unassociated sets shows the same general trend of a sharp early decline, followed by stability at a much lower level. The number of dolphin sets made in the southern region is very low; the nominal indicator shows high variability, and is more difficult to interpret.

In view of the low catch rates and sample sizes available from the southern area, standardized indicators of presence/absence were not computed for dolphin and unassociated sets.

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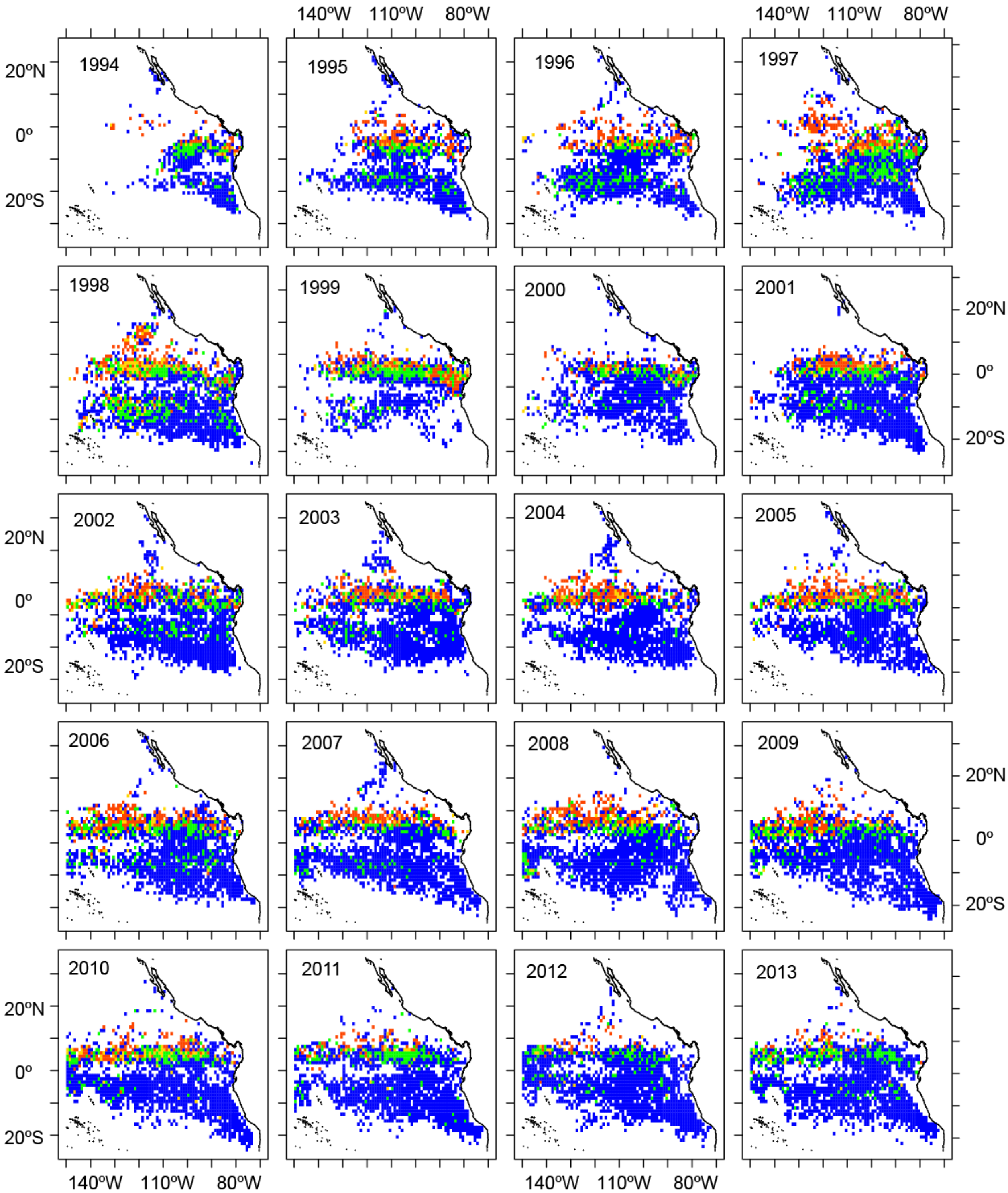

FIGURE 1a. Average bycatch per set in floating-object sets, in numbers, of small (< 90 cm total length) silky sharks, 1994-2013. Blue: 0 sharks per set, green: ≤ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1a. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos pequeños (< 90 cm de talla total), 1994-2013. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

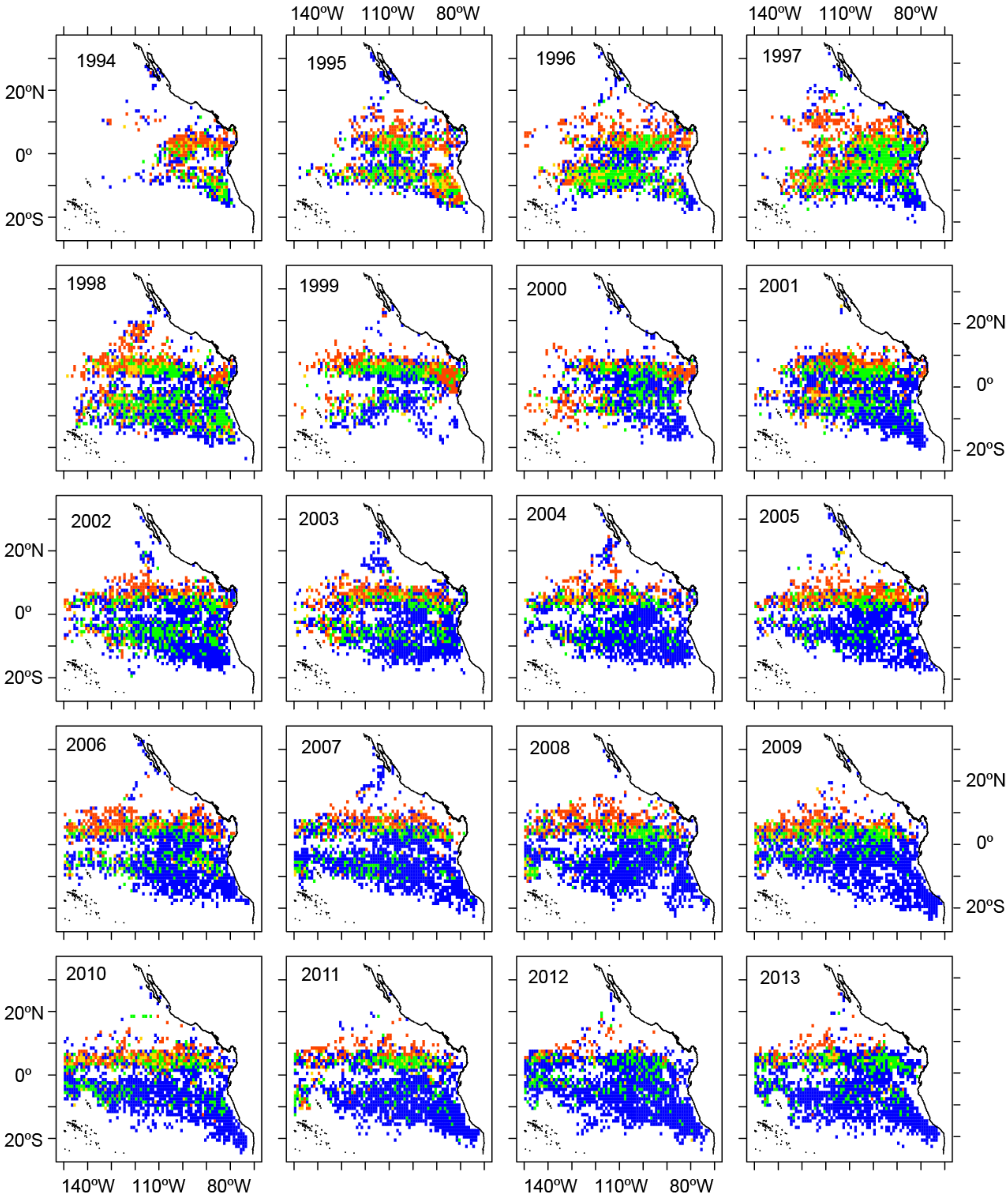

FIGURE 1b. Average bycatch per set in floating-object sets, in numbers, of medium (90-150 cm total length) silky sharks, 1994-2013. Blue: 0 sharks per set, green: ≤ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1ba. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos medianos (90-150 cm de talla total), 1994-2013. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

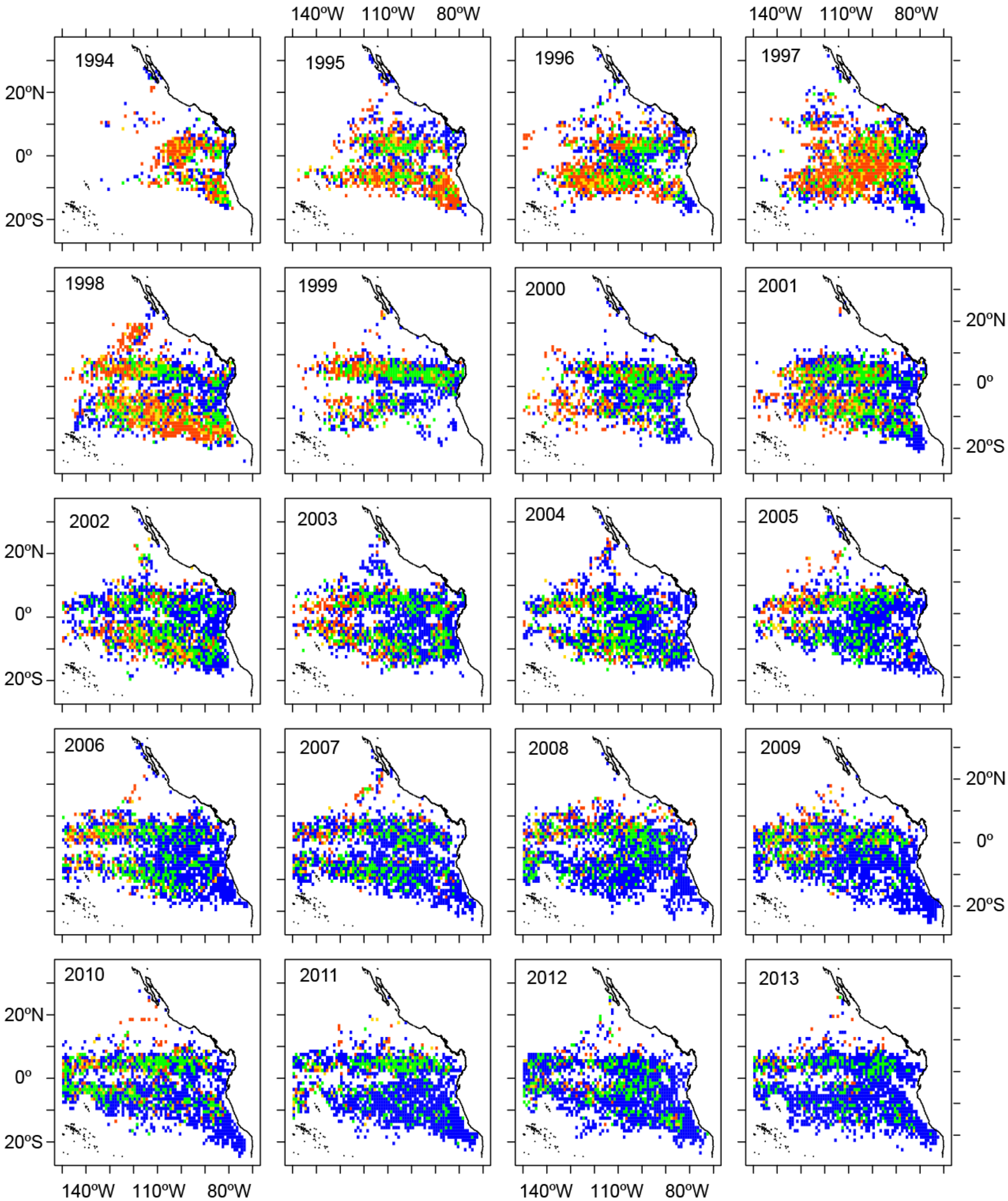

FIGURE 1c. Average bycatch per set in floating-object sets, in numbers, of large (> 150 cm total length) silky sharks, 1994-2013. Blue: 0 sharks per set, green: ≤ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1c. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos grandes (> 150 cm de talla total), 1994-2013. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

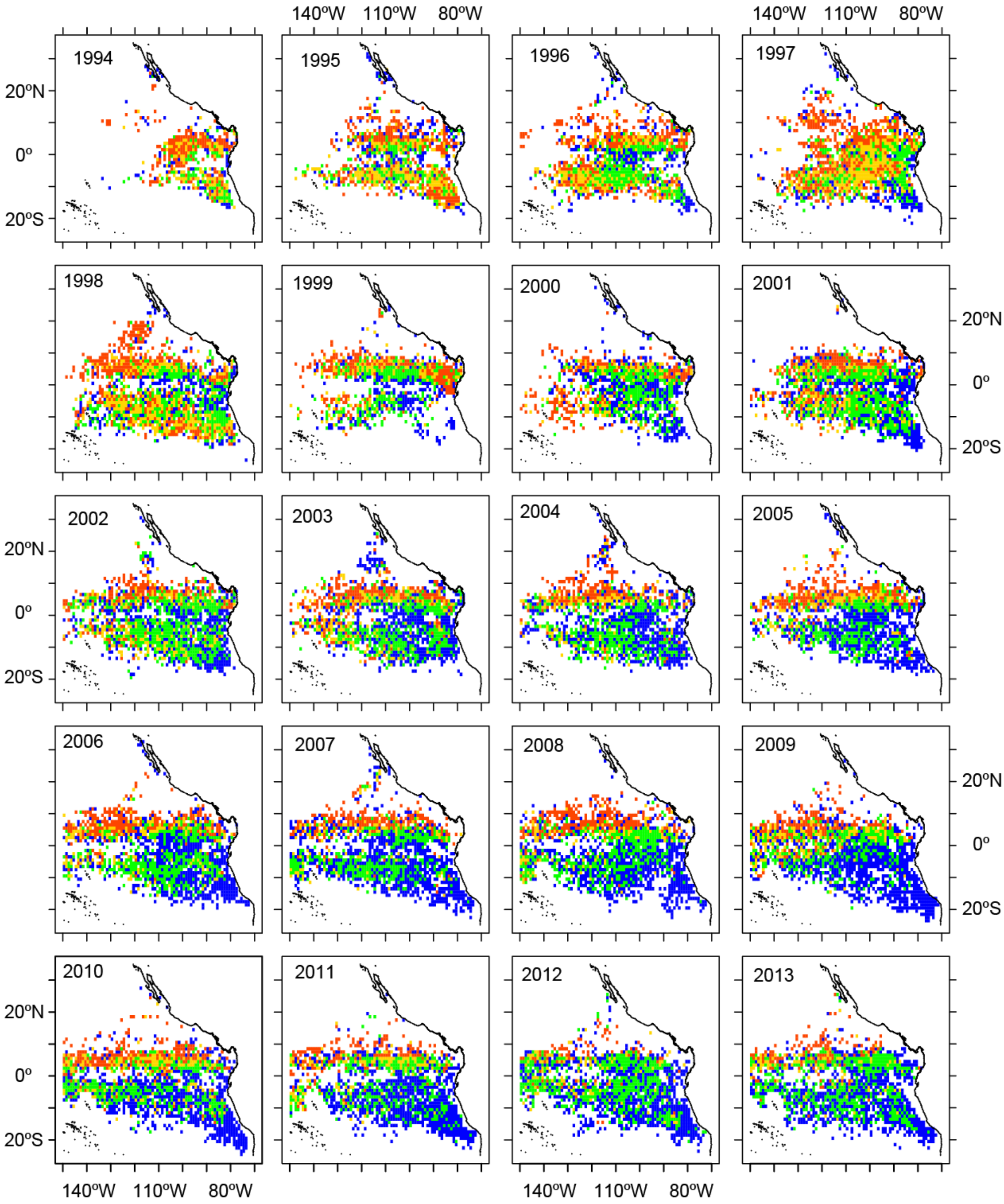

FIGURE 1d. Average bycatch per set in floating-object sets, in numbers, of all silky sharks, 1994-2013. Blue: 0 sharks per set, green: ≤2 shark per set; yellow: 2-5 sharks per set; red: >5 sharks per set.

FIGURA 1d. Captura incidental media por lance en lances sobre objetos flotantes, en número, de todos tiburones sedosos, 1994-2013. Azul: 0 tiburones por lance, verde: ≤ 2 tiburones por lance; amarillo: 2-5 tiburones por lance; rojo: > 5 tiburones por lance.

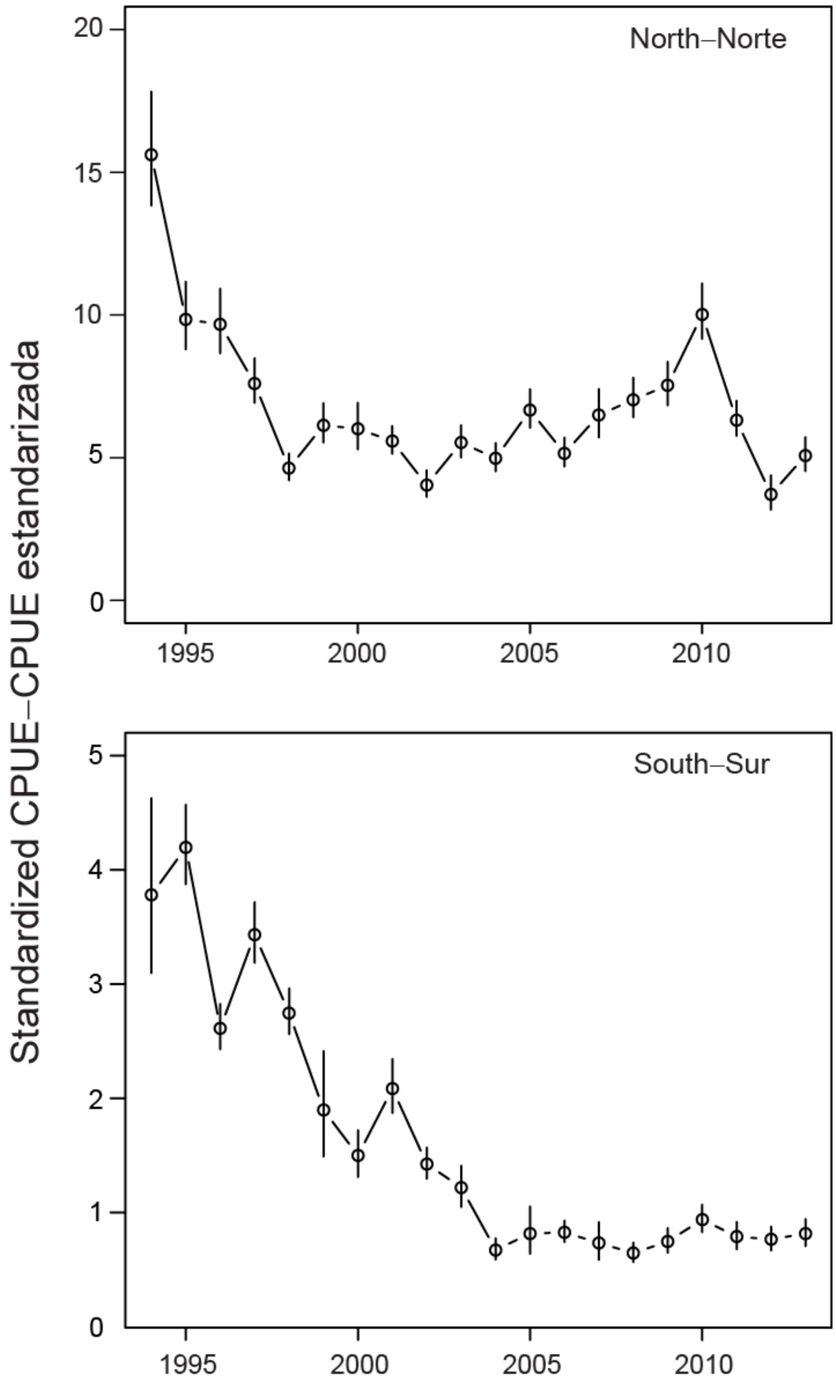

FIGURE 2. Standardized catch-per-unit-effort (CPUE, in number of sharks per set) of all silky sharks in floating-object sets for northern (top) and southern (bottom) EPO stocks. Approximate 95% pointwise confidence intervals were computed by resampling from the posterior distribution of estimated GAM coefficients, assuming known smoothing and scale parameters.

FIGURA 2. Captura por unidad de esfuerzo (CPUE, en número de tiburones por lance) estandarizada de todos los tiburones en lances sobre objetos flotantes de las poblaciones del OPO del norte (arriba) y sur (abajo). Se computaron los intervalos puntuales de confianza aproximados de 95% mediante un remuestreo de la distribución posterior de los coeficientes estimados del MAG, suponiendo parámetros de escala y suavización conocidos.

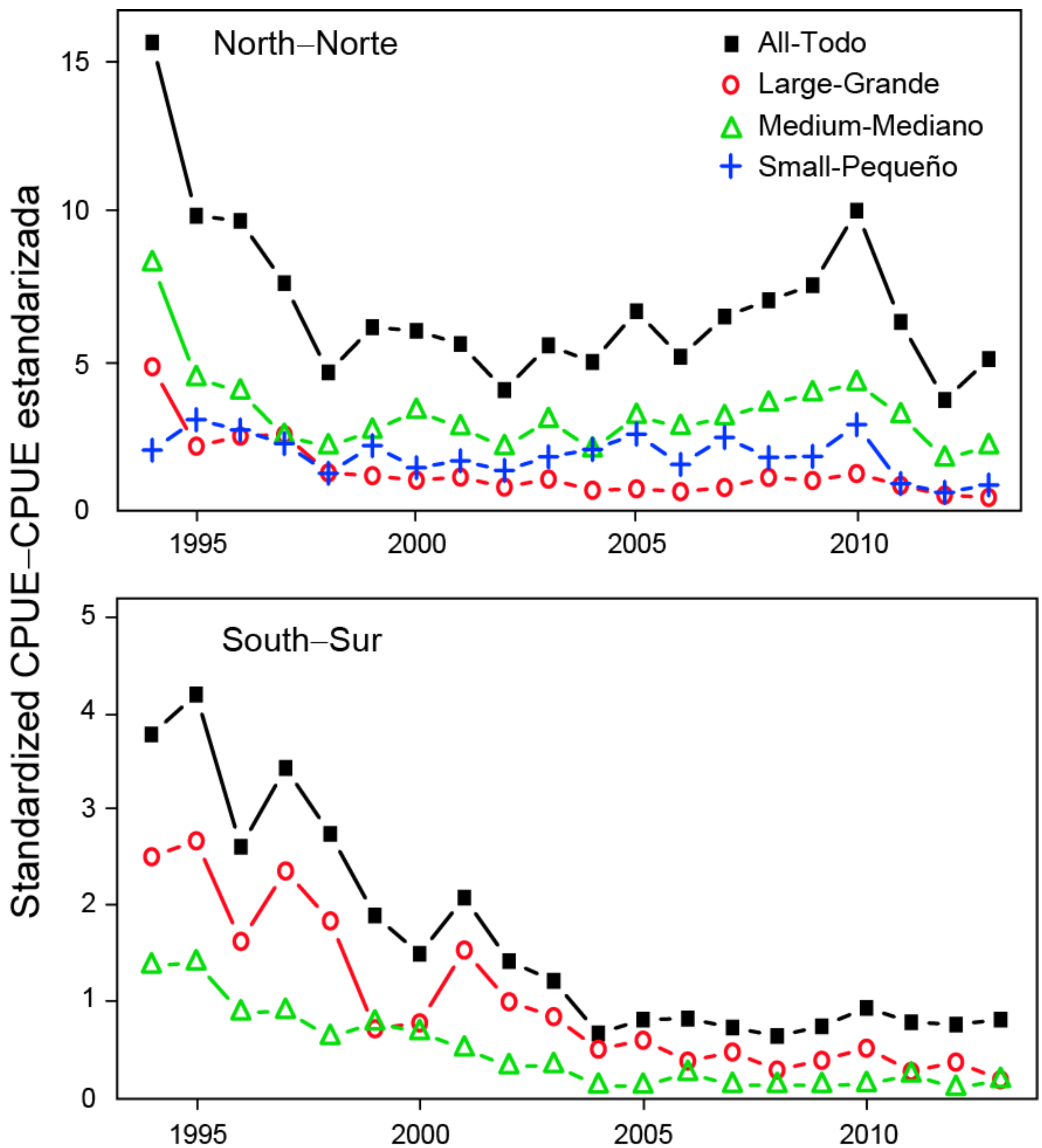

FIGURE 3a. Standardized catch-per-unit-effort (CPUE; in numbers of sharks per set) in sets on floating objects (OBJ) of silky sharks of different size classes (small, medium, large) and all silky sharks for northern (top) and southern (bottom) EPO stocks. No index was computed for small silky sharks in the south due to model instability caused by the low levels of bycatch in recent years; see Figure 1a.

FIGURA 3a. Captura por unidad de esfuerzo (CPUE, en número de tiburones por lance) estandarizada en lances sobre objetos flotantes (OBJ) de tiburones sedosos de distintas clases de talla (pequeño, mediano, grande) y todos los tiburones sedosos correspondiente a las poblaciones del norte (arriba) y sur (abajo) en el OPO. No se computó un índice para los tiburones sedosos pequeños en el sur debido a la inestabilidad del modelo causada por los bajos niveles de captura incidental en los años recientes (Figura 1a).

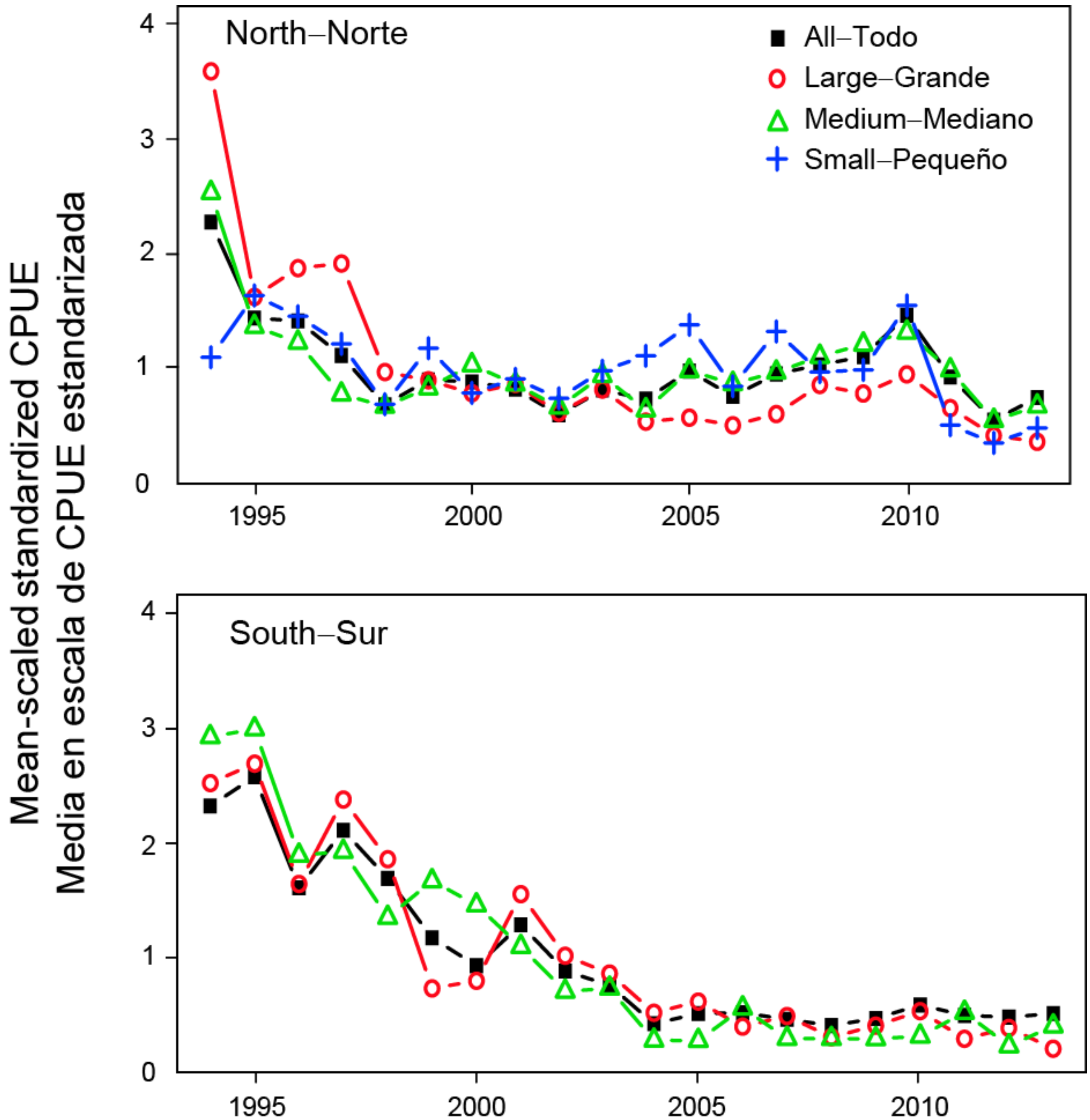

FIGURE 3b. Mean-scaled standardized catch-per-unit-effort in floating-object sets (CPUE-OBJ) (from Figure 3a) for silky sharks of different size classes (small, medium, large) and all silky sharks for the northern (top) and southern (bottom) EPO stocks. No index was computed for small silky sharks in the south due to model instability caused by the low levels of bycatch in recent years (Figure 1a).

FIGURA 3b. Captura por unidad de esfuerzo estandarizada en lances sobre objetos flotantes (CPUE-OBJ) en escala al promedio de tiburones sedosos de distintas clases de talla (pequeño, mediano, grande) y todos los tiburones sedosos correspondiente a las poblaciones del norte (arriba) y sur (abajo) en el OPO. No se computó un índice para los tiburones sedosos pequeños en el sur debido a la inestabilidad del modelo causada por los bajos niveles de captura incidental en los años recientes (Figura 1a).

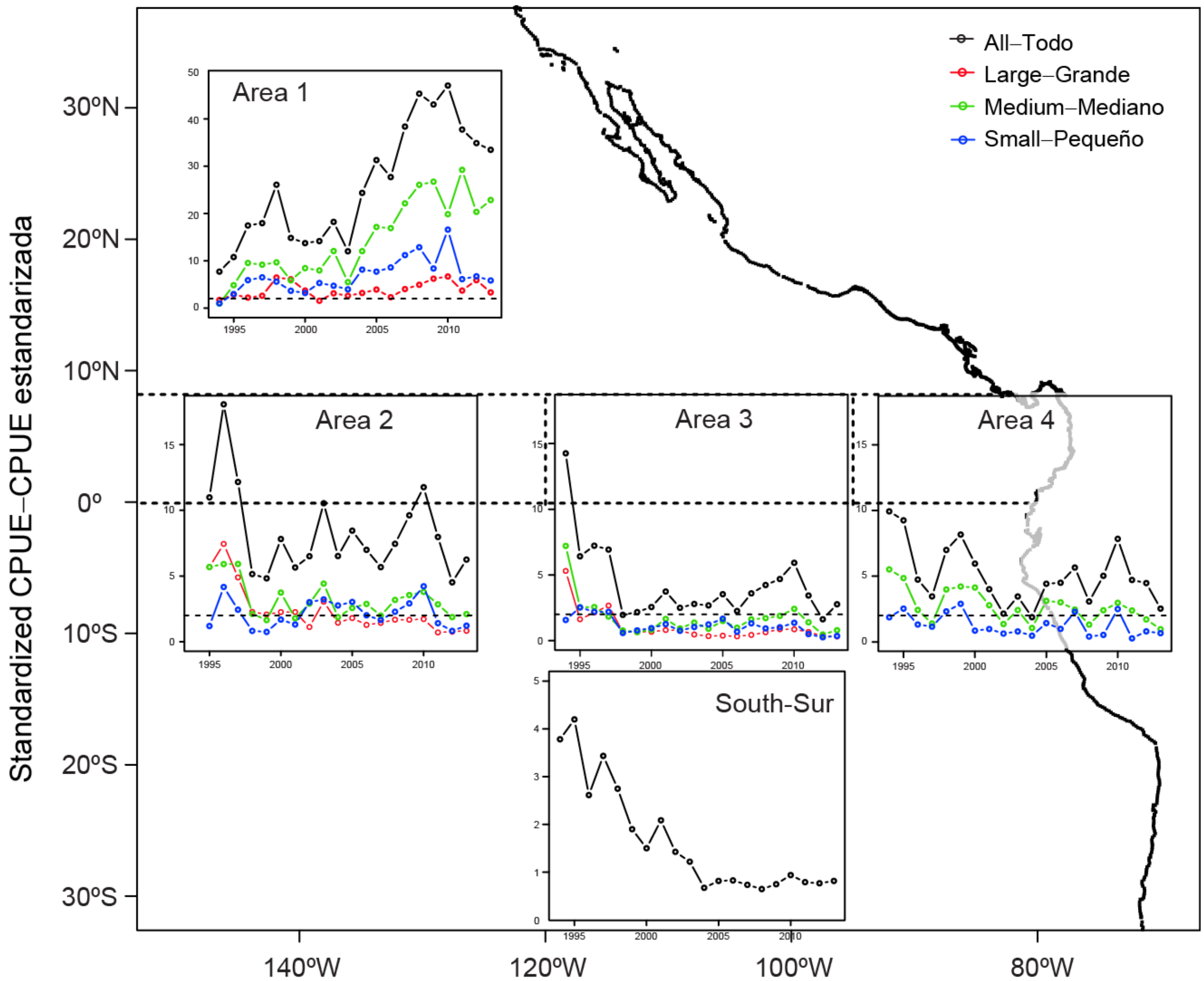

FIGURE 4a. Standardized catch-per-unit-effort in floating-object sets (CPUE-OBJ) of silky sharks, by area: north (Area 1); offshore (Area 2); central (Area 3); inshore (Area 4). No index for large sharks in Area 4 was obtained due to model instability. The trend in the southern area is from Figure 2.

FIGURA 4a Captura por unidad de esfuerzo estandarizada en lances sobre objetos flotantes (CPUE-OBJ) de tiburones sedosos, por área: norte (Area 1); alta mar (Area 2); central (Area 3); costera (Area 4). No se obtuvo un índice para los tiburones grandes en el Área 4 debido a inestabilidad del modelo. La tendencia en el área sur proviene de la Figura 2.

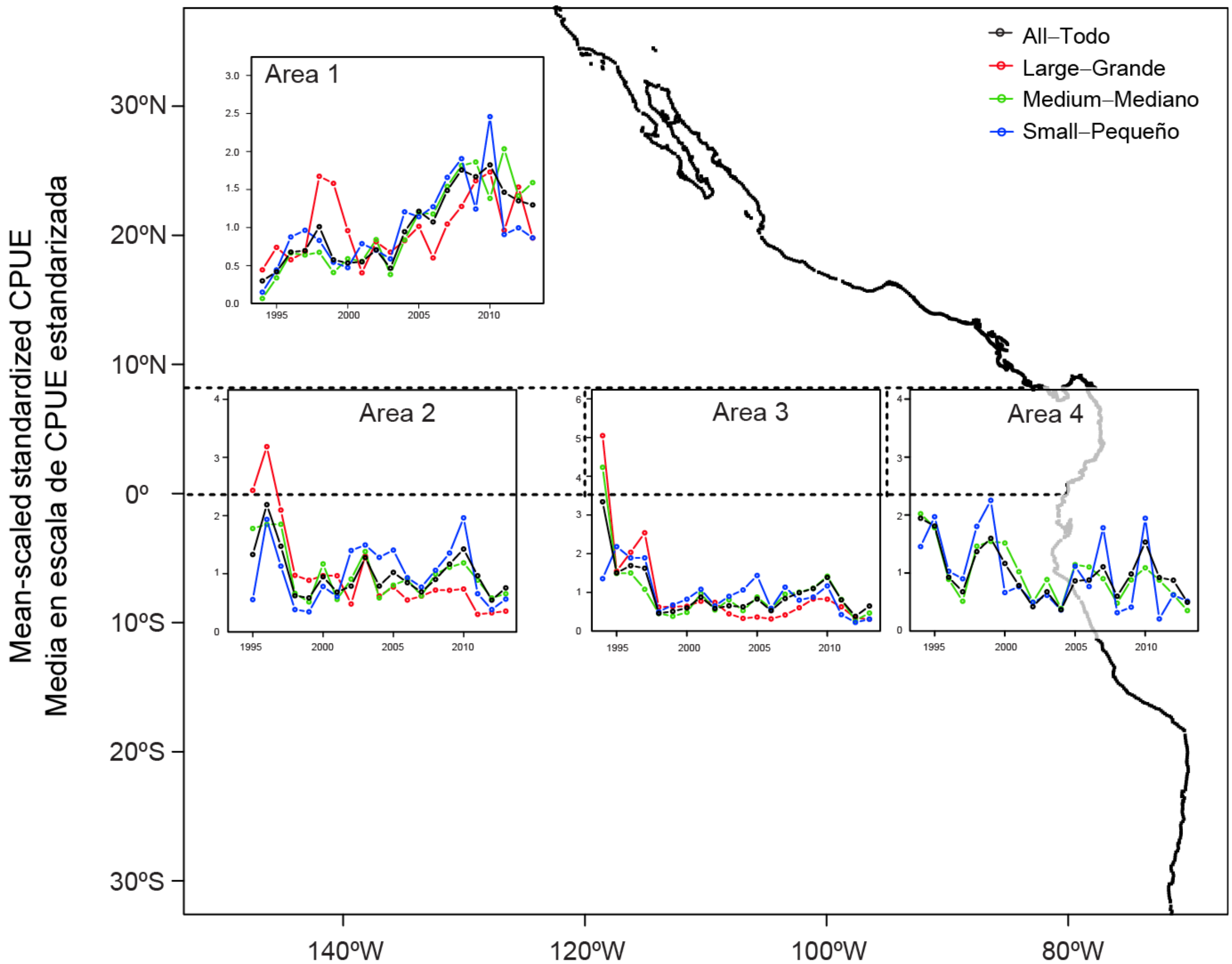

FIGURE 4b. Mean-scaled standardized catch-per-unit-effort in floating-object sets (CPUE-OBJ) of silky sharks, by area (Figure 4a): north (Area 1); offshore (Area 2); central (Area 3); inshore (Area 4). No index for large sharks in Area 4 was obtained due to model instability.

FIGURA 4b. Captura por unidad de esfuerzo estandarizada en lances sobre objetos flotantes (CPUE-OBJ) en escala al promedio de tiburones sedosos, por área (Figura 4a): norte (Area 1); alta mar (Area 2); central (Area 3); costera (Area 4). No se obtuvo un índice para los tiburones grandes en el Área 4 debido a inestabilidad del modelo.

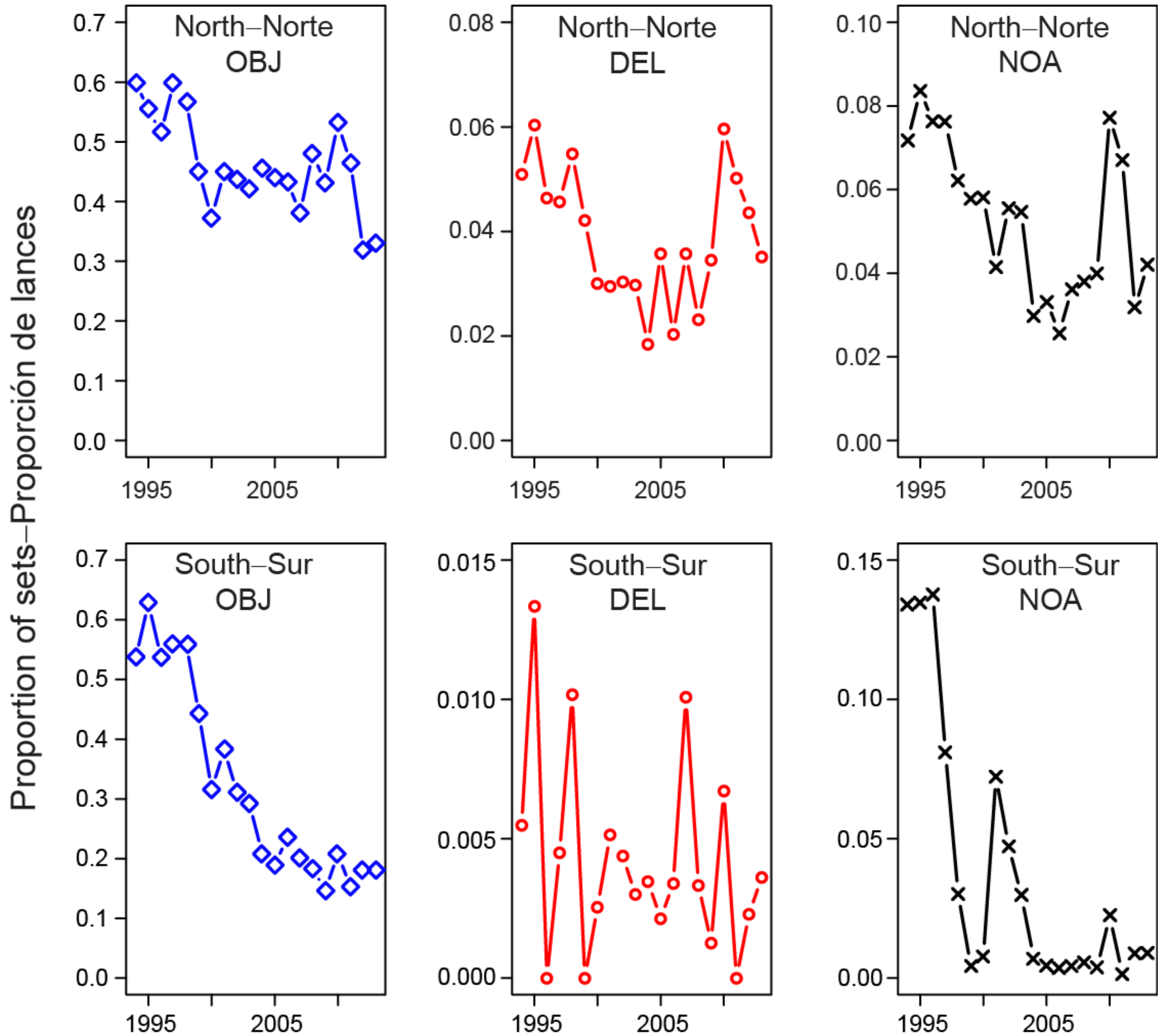

FIGURE 5. Nominal proportion of positive sets, by set type (floating-object (OBJ), dolphin (DEL), unassociated (NOA)), for the northern (top) and southern (bottom) stocks of silky shark in the EPO.

FIGURA 5. Proporción nominal de lances positivos, por tipo de lance (objeto flotante (OBJ), delfín (DEL), no asociado (NOA)), para las poblaciones del norte (arriba) y sur (abajo) del tiburón sedoso en el OPO.

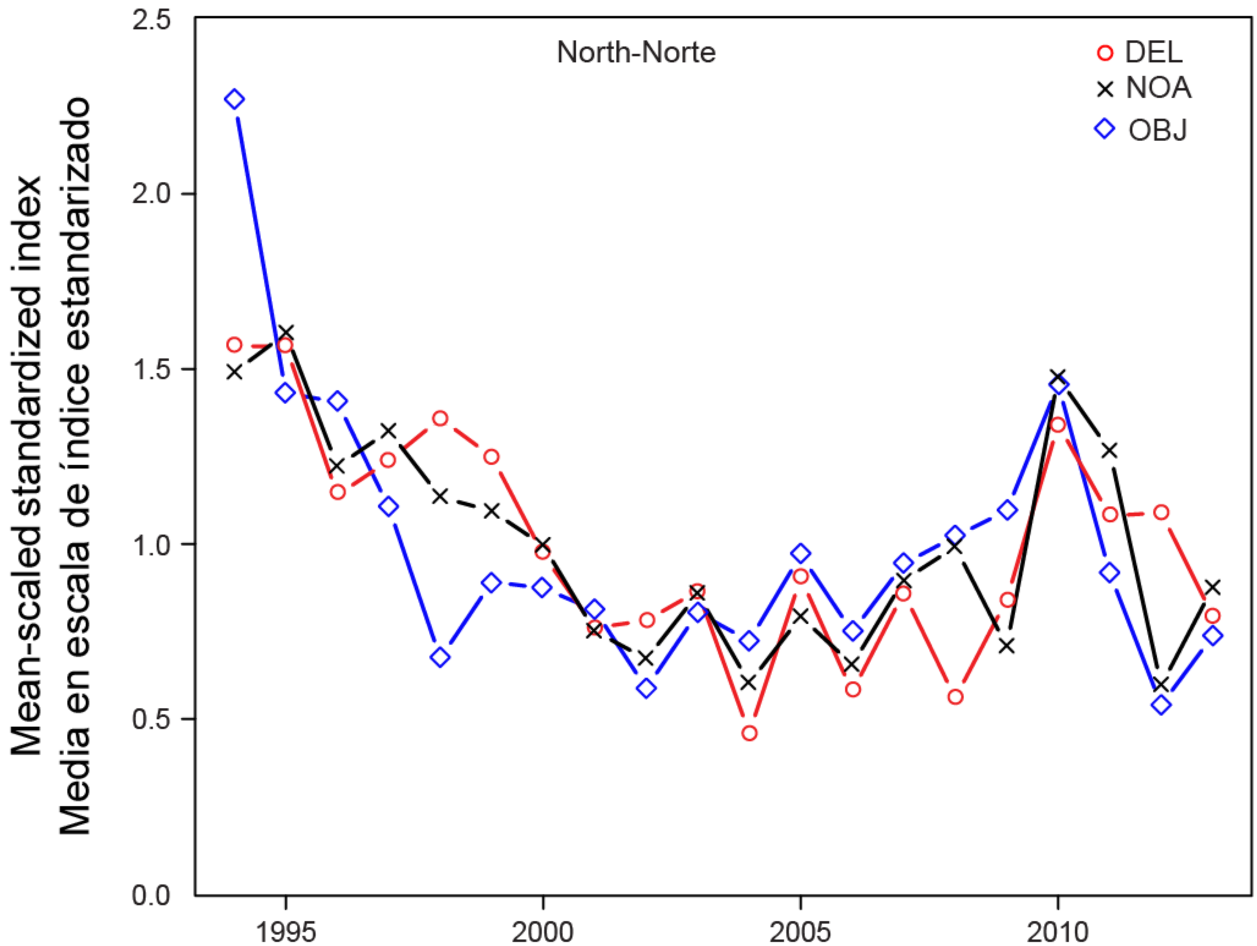

FIGURE 6. Comparison of stock status indicators (SSIs) for the northern silky shark produced for different purse-seine set types (floating-object (OBJ), dolphin (DEL), unassociated (NOA)).
FIGURA 6. Comparación de indicadores de condición de población (SSI) para el tiburón sedoso del norte producidos para distintos tipos de lance cerquero (objeto flotante (OBJ), delfín (DEL), no asociado (NOA)).

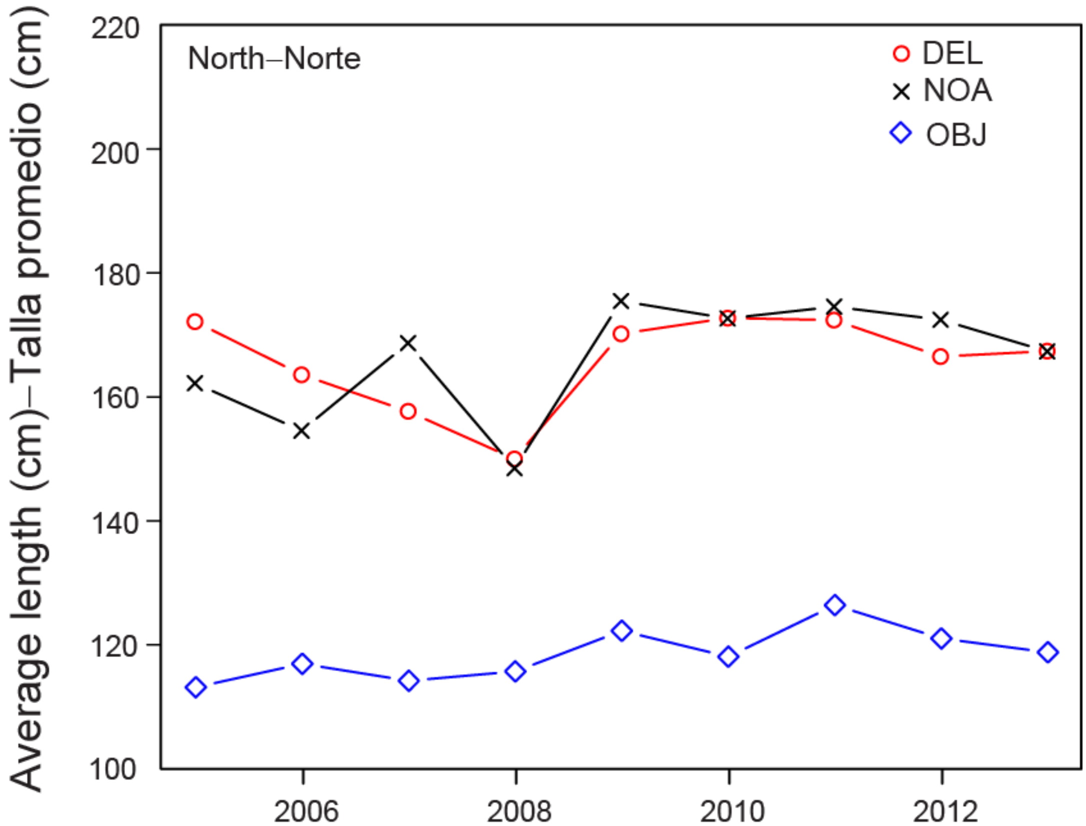

FIGURE 7. Average length (cm) of northern silky sharks caught in different purse-seine set types (floating-object (OBJ), dolphin (DEL), unassociated (NOA)), 2005-2013.
FIGURA 7. Talla promedio (cm) de tiburones sedosos del norte capturados en los distintos tipos de lance cerquero (objeto flotante (OBJ), delfín (DEL), no asociado (NOA)), 2005-2013.