INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

TENTH MEETING

San Diego, California (USA)
13-17 May 2019

DOCUMENT SAC-10-17

UPDATED STOCK STATUS INDICATORS FOR SILKY SHARKS IN THE EASTERN PACIFIC OCEAN, 1994-2018

Cleridy E. Lennert-Cody, Alexandre Aires-da-Silva, Mark N. Maunder

CONTENTS

SUMMARY

The indices of relative abundance for large silky sharks (*Carcharhinus falciformis*) in the eastern Pacific Ocean (EPO), developed from bycatch-per-set in purse-seine sets on floating objects and presented at the 9th meeting of the Scientific Advisory Committee (SAC-09) in May 2018 (Document SAC-09-13), were updated with data from 2018. Previous analyses (SAC-08-08a(i), Lennert-Cody *et al*. 2019) identified a correlation between north EPO indices, particularly for small and medium silky sharks, and interannual variability in oceanographic conditions, and thus the indices for those size categories, and for all silky sharks, were not updated because of concerns about bias. In both the north and south EPO, the indices for large silky sharks for 2018 decreased to about their 2016 values, following an increase in 2017. Because of recent increases in the number of sharks recorded as released alive, indices for large silky sharks that included these data were also calculated, and showed a somewhat less pessimistic long-term trend. However, there is concern that the size category of sharks released alive may be poorly estimated, and thus the increase in live release could bias the indices by size. In addition, a recent Pacific-wide silky shark assessment (Clarke *et al*. 2018) highlighted the need for a better understanding of movements and stock structure of the species in the Pacific Ocean, and Project H.5.a could be expanded to include additional research on the effects of inter-annual variability in oceanographic conditions (*e.g*., El Niño and La Niña events) on silky shark distribution and movements. Considerations for future research, including some presented previously (SAC-07-06b(i), SAC-07-06b(iii), SAC-08-11) on improving shark fishery data collection in the EPO, are also presented.

1. BACKGROUND

An attempt by the IATTC staff in 2013 to assess the status of the silky shark in the EPO, using conventional stock assessment models, was severely hindered by major uncertainties in the fishery data, primarily total annual catch in the early years for all fisheries that caught silky sharks in the EPO (SAC-05 INF-F). Although the attempt 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 were compromised by gaps in the available data. Since a conventional stock assessment was not possible, in 2014 the staff proposed a suite of possible stock status indicators (SSIs) that could be considered for managing the silky shark in the EPO (SAC-05-11a), including standardized bycatch-per-set (BPS) indices from the purse-seine fishery.

Further studies of variability in the purse-seine BPS indices (SAC-08-08a(i), Lennert-Cody *et al*. 2019), however, suggested that recent large fluctuations, particularly in the north EPO index for small and medium silky sharks, may be influenced by inter-annual variability in oceanographic conditions (*e.g*., El Niño and La Niña events). Those analyses found that the correlation between silky shark indices and the Pacific Decadal Oscillation (PDO), which is an index of interannual-to-interdecadal variability of the Pacific Ocean climate, varied by shark size category and sub-region within the equatorial tropical Pacific. Correlations were highest for small and medium silky sharks in the western north EPO and in the Central and Western tropical Pacific, but decreased towards the coast in the north EPO. It was hypothesized that this spatial pattern in correlation may be due to movement of juvenile silky sharks across the Pacific as the eastern edge of the Indo-Pacific warm pool shifts location with ENSO events. Thus, the small and medium silky shark indices may be biased as indicators of stock status. The indices for large silky sharks, however, may be less susceptible to oceanographic influences because they were less correlated with the PDO, and were more spatially homogenous among sub-regions within the EPO. Therefore, only indices for large silky sharks have been updated.

The transition to a stock status indicator based only on data for large silky sharks required revision of the treatment of data on live releases. Prior to late 2004, silky sharks that were released alive would not have been recorded, because observers recorded only sharks that arrived on the deck of the vessel already dead or that died on the deck. In late 2004, observers started collecting detailed data on the size, sex, and fate of all incidentally-caught sharks brailed onto the deck of the vessel (Román *et al*. 2005), including counts of those released alive. However, it is believed that many of the sharks recorded as dead prior to 2005 would now be recorded as released alive, due mainly to the 2005 ban on "finning[1]" sharks (IATTC Resolution C-05-03) and the introduction of best handling practices, which include immediate release of sharks from the deck. Counts of sharks released alive were included in the indices for the "all" silky sharks category in previous reports (SAC-05-11a; SAC-06-08b; SAC-07-06b(i); SAC-08-08a(i); SAC-09-13) but not in the indices by size category, because of concerns about the accuracy of the length estimates of sharks recorded as released alive, which may be visible to the observer only from a distance and/or for a very short period of time. Despite this concern, the transition to the large silky shark index as the stock status indicator, combined with recent increases in the number of live releases recorded for large silky sharks (see below; Table 1), means that live release of large silky sharks must now be taken into consideration.

This document presents two sets of indices for large silky sharks, north and south of the equator, updated through 2018: one excludes data on live releases (as in previous indices) and the other includes those data. Also, several options for improving the purse-seine indices are discussed.

2. DATA AND METHODS

Data on floating-object (OBJ) sets collected by IATTC observers aboard Class-6[2] purse-seine vessels were used to generate BPS-based indices of relative abundance for large silky sharks. Observers record bycatches of silky sharks, which occur predominantly in floating-object sets (SAC-07-07b), by size category: small (<90 cm total length (TL)), medium (90-150 cm TL), and large (>150 cm TL). Counts of large silky

[1] Cutting the fins off sharks and discarding the carcass

[2] Carrying capacity > 363 t

sharks recorded as released alive from the deck of the vessel, available since late 2004, were also used in the analyses. Because of recent increases in the proportion of large silky sharks recorded as released alive (Table 1), two indices for large silky sharks were computed, one excluding and one including large silky sharks recorded by the observer as released alive. (As noted above, in previous years, results based on total silky shark bycatch included all live releases, but those based on small, medium and large silky shark bycatch did not.) Annual summaries of the spatial distribution of bycatch rates during 1994-2018, which include live releases since late 2004, are shown in Figure 1a-d.

BPS trends for large silky sharks in OBJ sets were estimated using previously-developed generalized additive models (GAMs) (Minami *et al*. 2007). A zero-inflated negative binomial GAM was used to model the bycatch data from OBJ sets because of the large proportion of sets with zero bycatch and the existence of sets with large bycatches. Predictors used in this model were: year (factor); smooth terms for latitude, longitude, time of set, and day of the year (to capture seasonal patterns); and linear terms for depth of the purse-seine net, depth of the floating object, sea surface temperature, natural logarithm of bycatches of species other than silky sharks, natural logarithm of tuna catch, and two proxies for local floating-object density. Trends for large silky sharks were computed from the fitted GAM, using an area-weighted approach. The annual index value was the sum of predicted BPS on a 1° grid, with values of covariates other than latitude, longitude and year fixed at their medians over the entire time period and spatial grid. The indices presented previously were based on the method of partial dependence (Hastie *et al*. 2009), which produces a data-weighted index. Data-weighted approaches give more influence in the trend estimation to areas with more sets, whereas the area-weighted approach gives equal weight to all areas, and is therefore preferred. As in previous years, trends were computed for the EPO north and south of the equator. Pointwise approximate 95% confidence intervals for the trends were computed from 500 simulated indices generated by resampling GAM parameters from a multivariate normal distribution with means, variances and covariances of the estimated model coefficients (Wood 2006), assuming known smoothing parameters and negative binomial scale parameters. Approximate 95% confidence intervals were obtained by applying the percentile method (Efron 1982) to the 500 simulated index values at each time point.

3. RESULTS AND DISCUSSION

Relative to 2017, the 2018 index values for large silky sharks show a decrease to about the 2016 level (Figure 2). In both the north and south EPO, the indices that include data on live releases show a somewhat less pessimistic long-term trend than those that do not include those data. The two sets of indices, with and without live release, may bracket the trend that would have been obtained if finning, shark handling, and data recording practices had all remained unchanged since 1994. The trend based only on counts of dead sharks may be too pessimistic, given the increased efforts in recent years to release sharks alive; these efforts may in part be due to IATTC resolutions restricting finning (C-05-03) and prohibiting retention of silky sharks by purse-seine vessels (C-16-06), and to the wide availability of guidebooks[3] on best handling practices. On the other hand, the index that includes live-release data may be too optimistic because any live release that occurred prior to 2005 was not recorded, although given the physical trauma caused by brailing[4] and a lack of emphasis on immediate release of sharks from the deck, combined with unrestricted finning practices, it is likely (but not certain) that little or no live release occurred prior to 2005.

[3] International Seafood Sustainability Foundation; http://www.issfguidebooks.org/downloadable-guides/

[4] Recent studies (Poisson *et al*. 2014, Eddy *et al*. 2015, Hutchinson *et al*. 2015) indicate that sharks that are loaded onto the vessel deck *via* a brailer with the tuna catch suffer trauma leading to low post-release survival.

Given the increase in the live releases of silky sharks in recent years (Table 1), and the possible differences by life stage in the effects of interannual variability in oceanographic conditions on silky shark abundance (Lennert-Cody *et al*. 2019), improving the estimates of size composition of silky shark bycatches is desirable. Prior to late 2004, shark length was always estimated, but since then, observers have attempted to measure the length of as many silky sharks as possible, and estimate the lengths of those they cannot. However, due to now-prohibited finning practices, sharks may have been more visible to the observer, and/or visible for a longer period of time, than they are now when released alive. It is not known if bias may have been introduced into the estimation of length with a transition to a greater proportion of animals released alive. Depending on the vessel, live release of sharks may happen in locations on the vessel's deck that are not clearly visible or accessible to the observer. If indices by size category (life stage) are to be used to monitor stock status, it is important to understand if and how live release affects the observers' ability to estimate shark length, and therefore potentially bias estimates of size composition. (Also, factors biasing estimation of size composition will affect estimates of total bycatch by size, as well as indices of relative abundance.)

Although the index for large silky sharks was found to be the least correlated with interannual variability in oceanographic conditions, it may still be influenced by changing ocean climate. Without knowledge of the specific environmental processes affecting the index, however, those processes cannot be explicitly modelled to mitigate bias. At present, the only option would be to include the PDO as a covariate in the BPS standardization model. This will introduce variability (and potentially bias) into the index as the empirical relationship between the PDO and BPS evolves with the addition of new data to both data sets. Moreover, without explicitly modeling the effects of movement, inclusion of the PDO in the BPS standardization model could be problematic because of confounding of the PDO and year effects, potentially biasing the estimated trend. Finally, the treatment of oceanographic processes will depend on whether they are believed to impact shark density (*via* movement, for example) or reflect environmentally-mediated changes in catchability. The Pacific-wide silky shark assessment by Clarke *et al*. (2018) was not able to fit to indices of relative abundance for the EPO and the western Pacific simultaneously, even though several scenarios for basin-scale movement dynamics were considered. This may indicate that movement is not driving the correlation of the silky shark indices with the PDO, or it may indicate model mis-specification; tagging data were not available for the Pacific-wide assessment model. Therefore, it is desirable that the planned work on Project H.5.a be expanded to obtain a better understanding of the effects of interannual variability in oceanographic conditions on silky shark distribution and movement in the tropical Pacific Ocean.

As noted previously (SAC-07-06b(i), SAC-07-06b(iii), SAC-08-11), obtaining reliable catch data for all fisheries catching silky sharks in the EPO, indices of relative abundance for other fisheries (especially longline fisheries, which take the majority of the catch), and composition data, by length/age and sex, continues to be vital. This is particularly the case given the increased concern about the reliability of the purse-seine indices.

4. FUTURE WORK

Based on the results presented in this document and other recent work, the following should be considered in the future work on silky sharks:

1. **Identify difficulties encountered by observers in estimating lengths of sharks released alive**, by conducting a formal survey of all observers to determine, among other things, where on vessels sharks are released, and how well the observer can see sharks recorded as released alive.
2. **Identify options for improving the shark length sampling protocol** for on-board observers.
3. **Investigate field study options, such as tagging studies, to evaluate the relationship between the**

abundance and distribution of silky sharks and interannual variability in environmental conditions in the tropical Pacific. Because of its scope, such a study would have to be collaborative, involving coastal nations of the EPO and the Western and Central Pacific Fisheries Commission (WCPFC). While tagging studies conducted recently in the Pacific (Hutchinson *et al*. 2019; Schaefer *et al*., *in press*) showed the potential for considerable movement by silky sharks, they cannot inform on whether movements are related to interannual variability in oceanographic conditions. Analysis of tagging data, in conjunction with habitat modeling of fisheries data (*e.g*., Lopez *et al*. 2017) would lead to a better understanding of the oceanographic processes that contribute to interannual variability in the silky shark indices.

4. **Expand Project H.5.a** to include additional research so as to better understand the correlation between silky shark indices and environmental indices.

REFERENCES

Clarke, S.C., Langley, A., Lennert-Cody, C.E., Aires-da-Silva, A., and Maunder, M. 2018. Pacific-wide silky shark (*Carcharhinus falciformis*) stock status assessment. WCPFC-SC14-2018/SA-WP-08. Western and Central Pacific Fisheries Commission Scientific Committee Fourteenth Regular Session, Busan, Korea, 8-16 August 2018.

Eddy, C., Brill, R., Bernal, D. 2015. Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. Fisheries Research 174: 109-117.

Efron, B. 1982. The Jackknife, the Bootstrap and Other Resampling Plans. SIAM #38. 92pp.

Hastie, T. Tibshirani, R., Friedman, J. 2009. The Elements of Statistical Learning, 2nd Edition. Springer. 745 pp.

Hutchinson, M.R., Itano, D.G., Muir, J.A., Holland, K.N. 2015. Post-release survival of juvenile silky sharks captured in a tropical tuna purse seine fishery. Marine Ecology Progress Series 521: 143-154.

Hutchinson, M., Coffey, D.M., Holland, K., Itano, D., Leroy, B., Kohin, S., Vetter, R., Williams, A.J., Wren, J. 2019. Movements and habitat use of juvenile silky sharks in the Pacific Ocean inform conservation strategies. Fisheries Research 210: 131-142.

Lennert-Cody, C.E., Clarke, S.C., Aires-da-Silva, A., Maunder, M.N., Franks, P.J.S., Román, M., Miller, A.J., Minami, M. 2019. The importance of environment and life stage on interpretation of silky shark relative abundance indices for the equatorial Pacific Ocean. Fisheries Oceanography28: 43 - 53.

Lopez, J., Alvarez-Berastegui, D., Soto, M., Murua, H. 2017. Modelling the oceanic habitats of silky shark (*Carcharhinus falciformis*), implications for conservation and management. IOTC-2017-WPEB13-34 Rev_1. (Available at: https://www.iotc.org/sites/default/files/documents/2017/08/IOTC-2017-WPEB13-34_Rev_1.pdf)

Minami, M. Lennert-Cody, C.E., Gao, W., Román-Verdesoto, M. 2007. Modeling shark bycatch: The zero-inflated negative binomial regression model with smoothing. Fisheries Research 845: 210-221.

Poisson, F., Filmalter, J.D., Vernet, A.-L., and Dagorn, L. 2014. Mortality rate of silky sharks (*Carcharhinus falciformis*) caught in the tropical tuna purse seine fishery in the Indian Ocean. Canadian Journal of Fisheries and Aquatic Sciences 71:795-798.

Román, M.R., Vogel, N.W., Olson, R.J., Lennert-Cody, C.E. 2005. A Novel approach for improving shark bycatch species identifications by observers at sea. Pelagic Fisheries Research Program Newsletter 10 (3):4-5.

Schaefer, K.M., Fuller, D.W., Aires-da-Silva, A., Carvajal, J.M., Martínez-Ortiz, J., Hutchinson, M.R. *In press*. Post-release survival of silky sharks (*Carcharhinus falciformis*) following capture by longline fishing vessel in the equatorial eastern Pacific Ocean. Bulletin of Marine Science.

Wood, S.N. 2006. Generalize Additive Models, An Introduction with R. Chapman & Hall/CRC, 391pp.

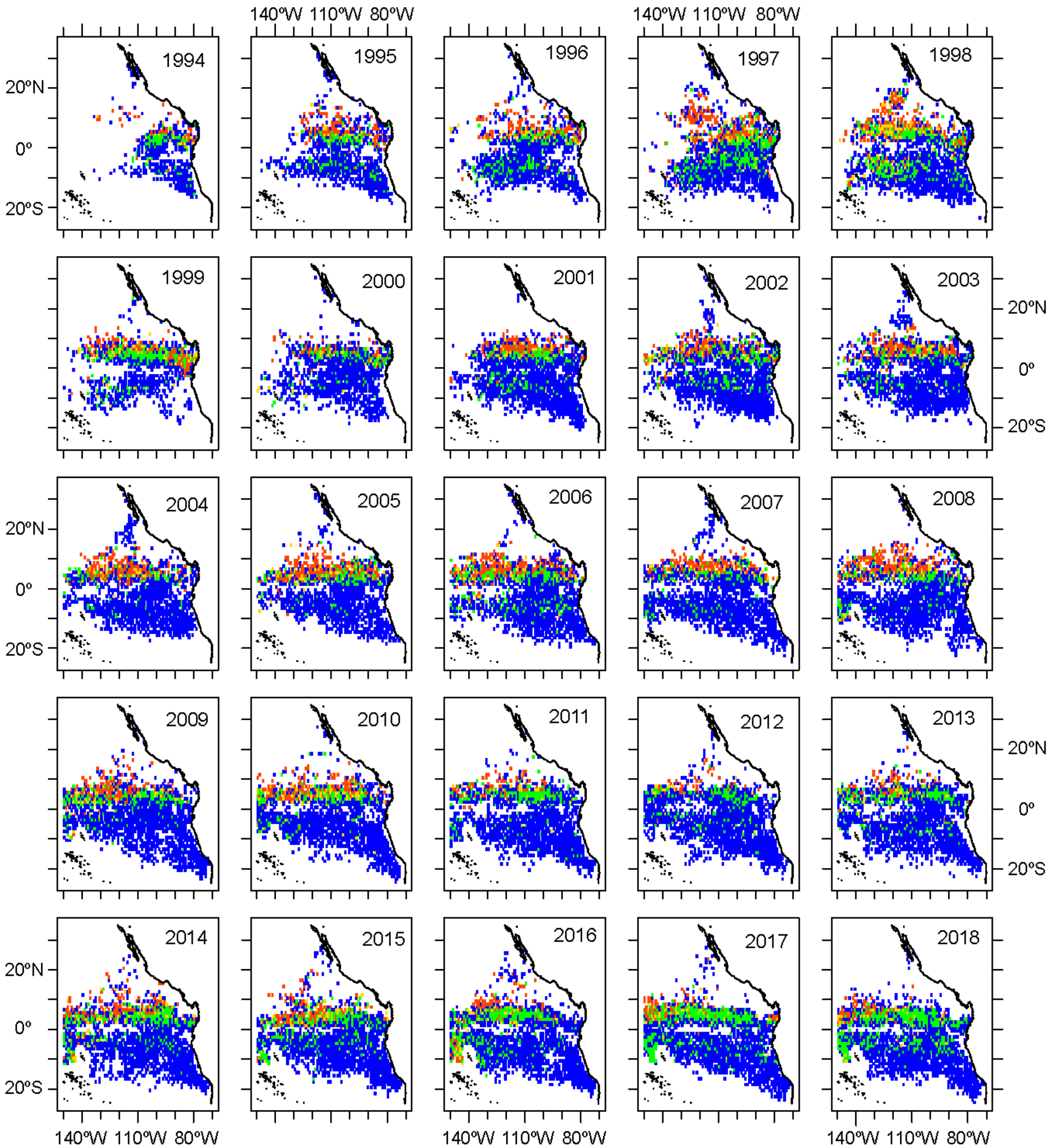

FIGURE 1a. Average bycatch per set in floating-object sets, in numbers, of small (< 90 cm total length) silky sharks, including live release since late 2004, for 1994-2018. Blue: 0 sharks per set, green: ⩽ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1a. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos pequeños (< 90 cm de talla total), incluyendo liberaciones en vivo desde finales de 2004, 1994-2018. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

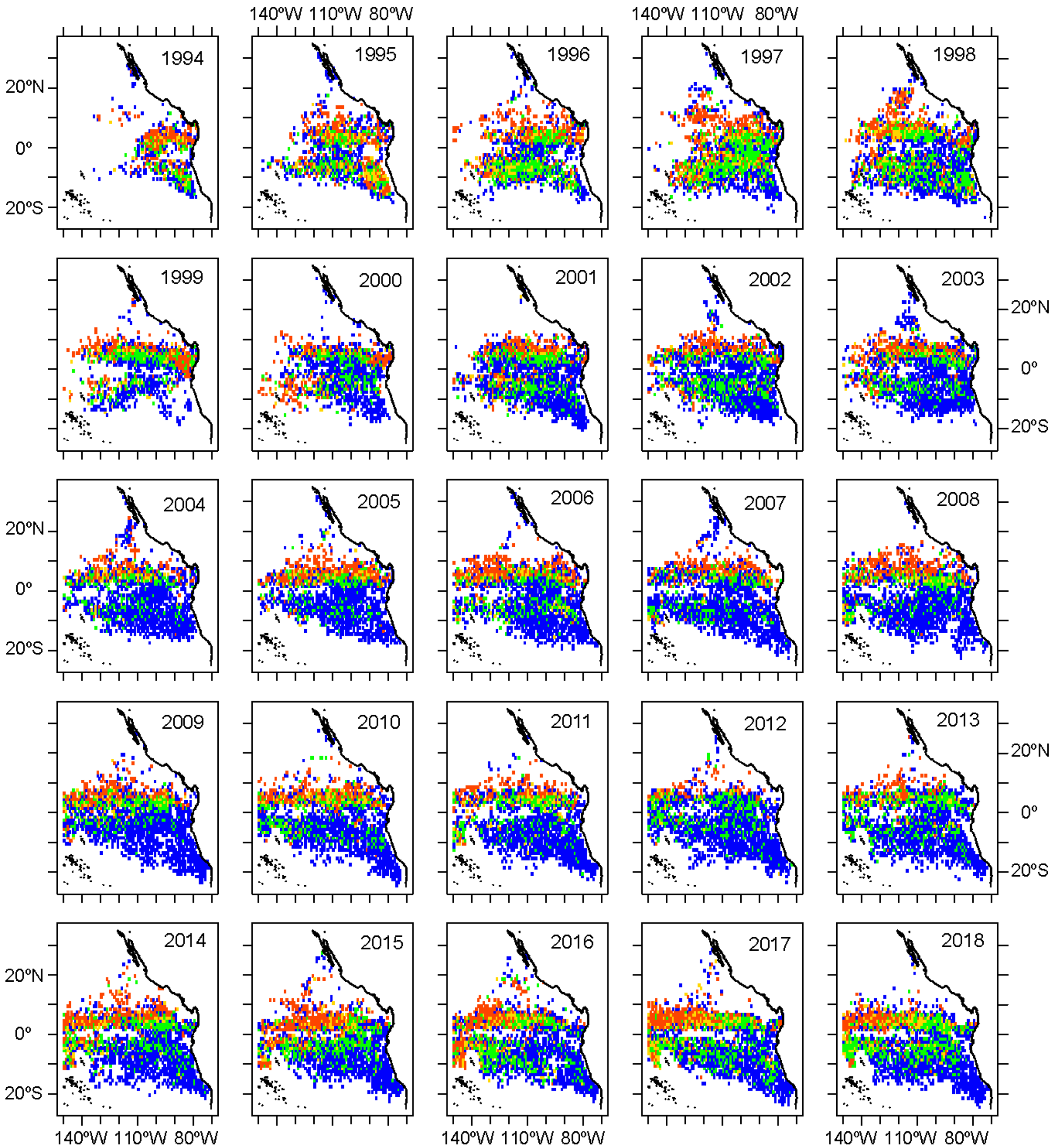

FIGURE 1b. Average bycatch per set in floating-object sets, in numbers, of medium (90-150 cm total length) silky sharks, including live release since late 2004, for 1994-2018. Blue: 0 sharks per set, green: ⩽ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1b. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos medianos (90-150 cm de talla total), incluyendo liberaciones en vivo desde finales de 2004, 1994-2018. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

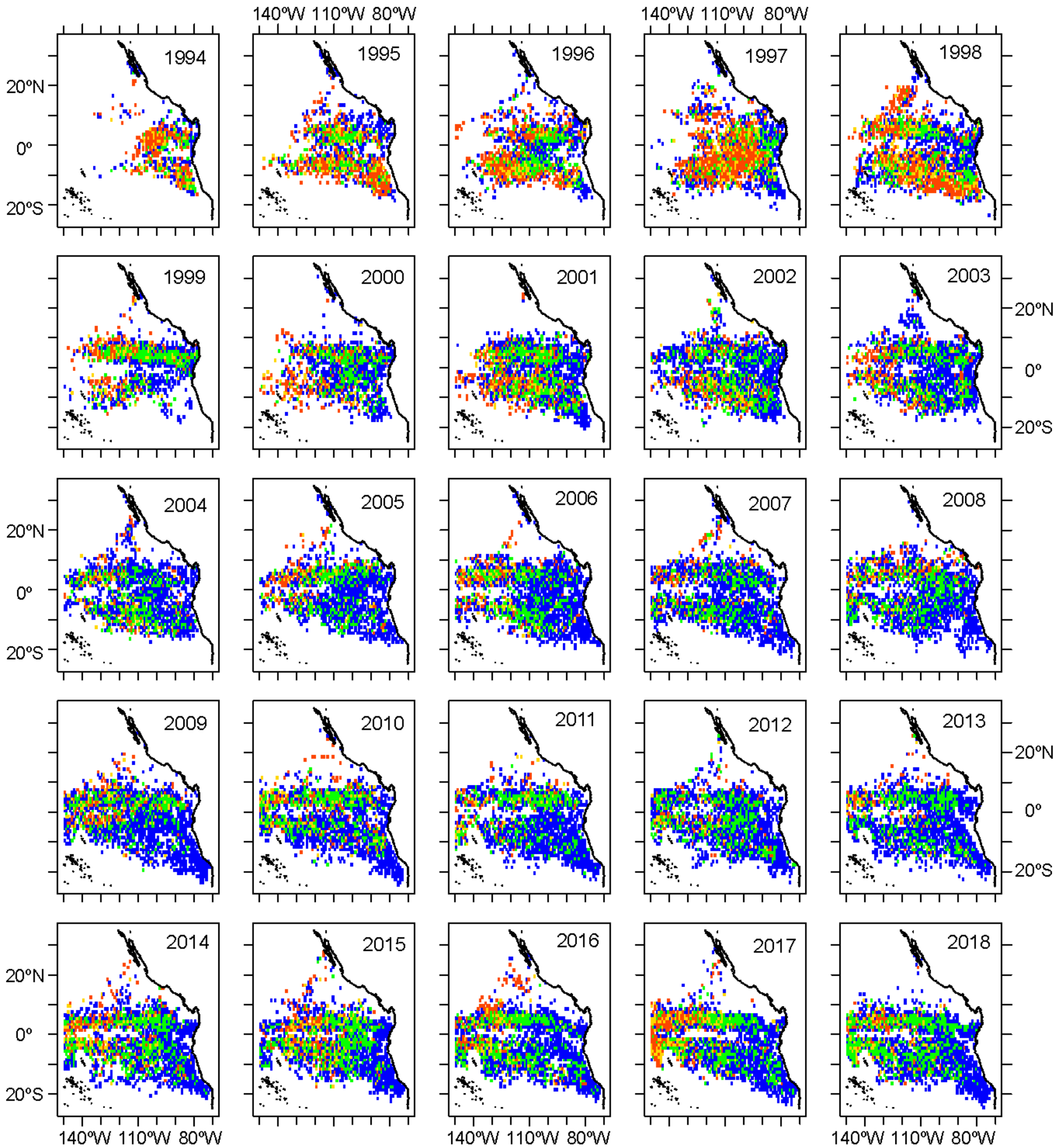

FIGURE 1c. Average bycatch per set in floating-object sets, in numbers, of large (> 150 cm total length) silky sharks, including live release since late 2004, for 1994-2018. Blue: 0 sharks per set, green: ⩽ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1c. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos grandes (> 150 cm de talla total), incluyendo liberaciones en vivo desde finales de 2004, 1994-2018. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

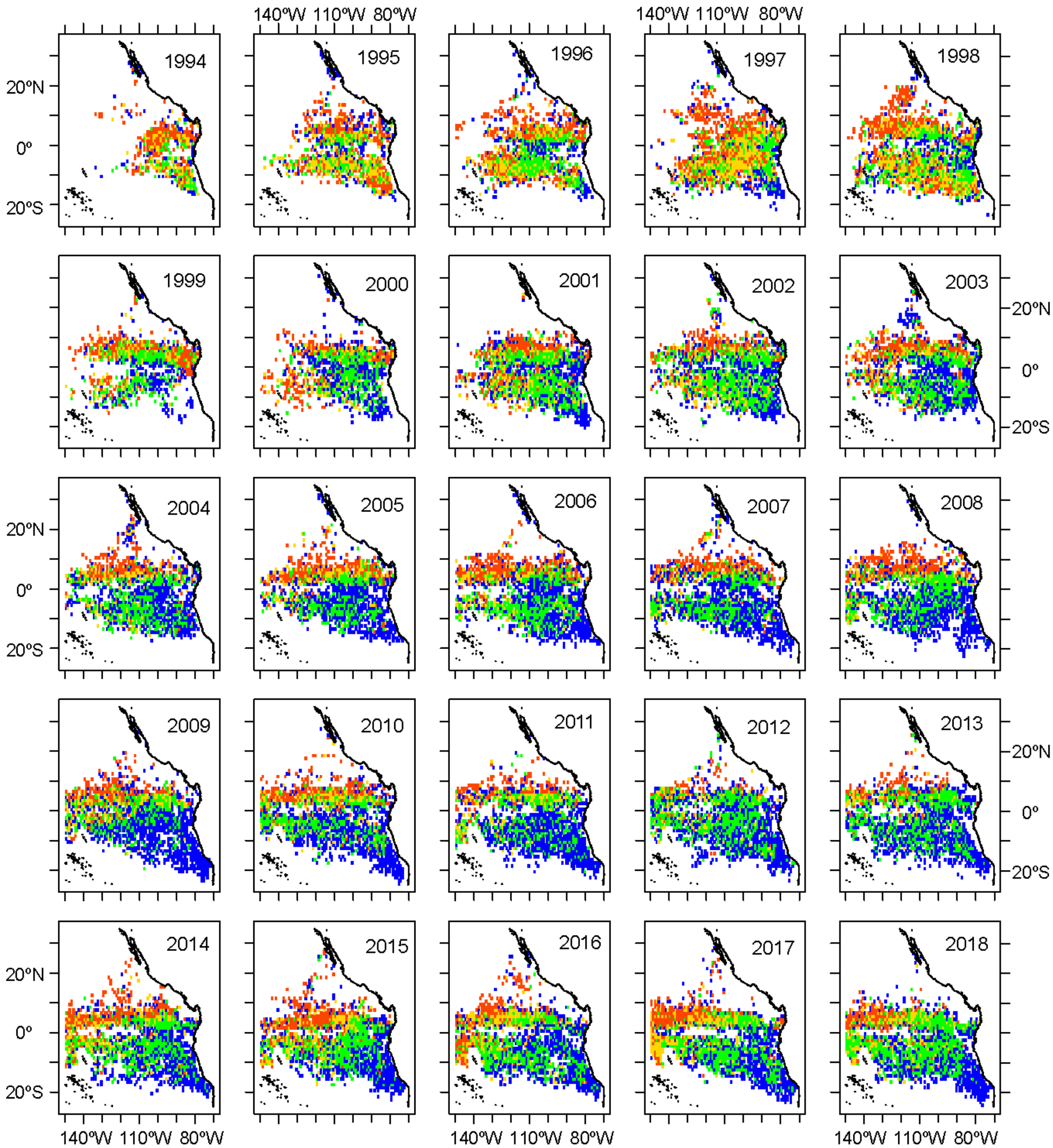

FIGURE 1d. Average bycatch per set in floating-object sets, in numbers, of all silky sharks, including live release since late 2004, for 1994-2018. Blue: 0 sharks per set, green: ⩽2 shark per set; yellow: 2-5 sharks per set; red: >5 sharks per set.

FIGURA 1d. Captura incidental media por lance en lances sobre objetos flotantes, en número, de todos tiburones sedosos, incluyendo liberaciones en vivo desde finales de 2004, 1994-2018. Azul: 0 tiburones por lance, verde: ≤ 2 tiburones por lance; amarillo: 2-5 tiburones por lance; rojo: > 5 tiburones por lance.

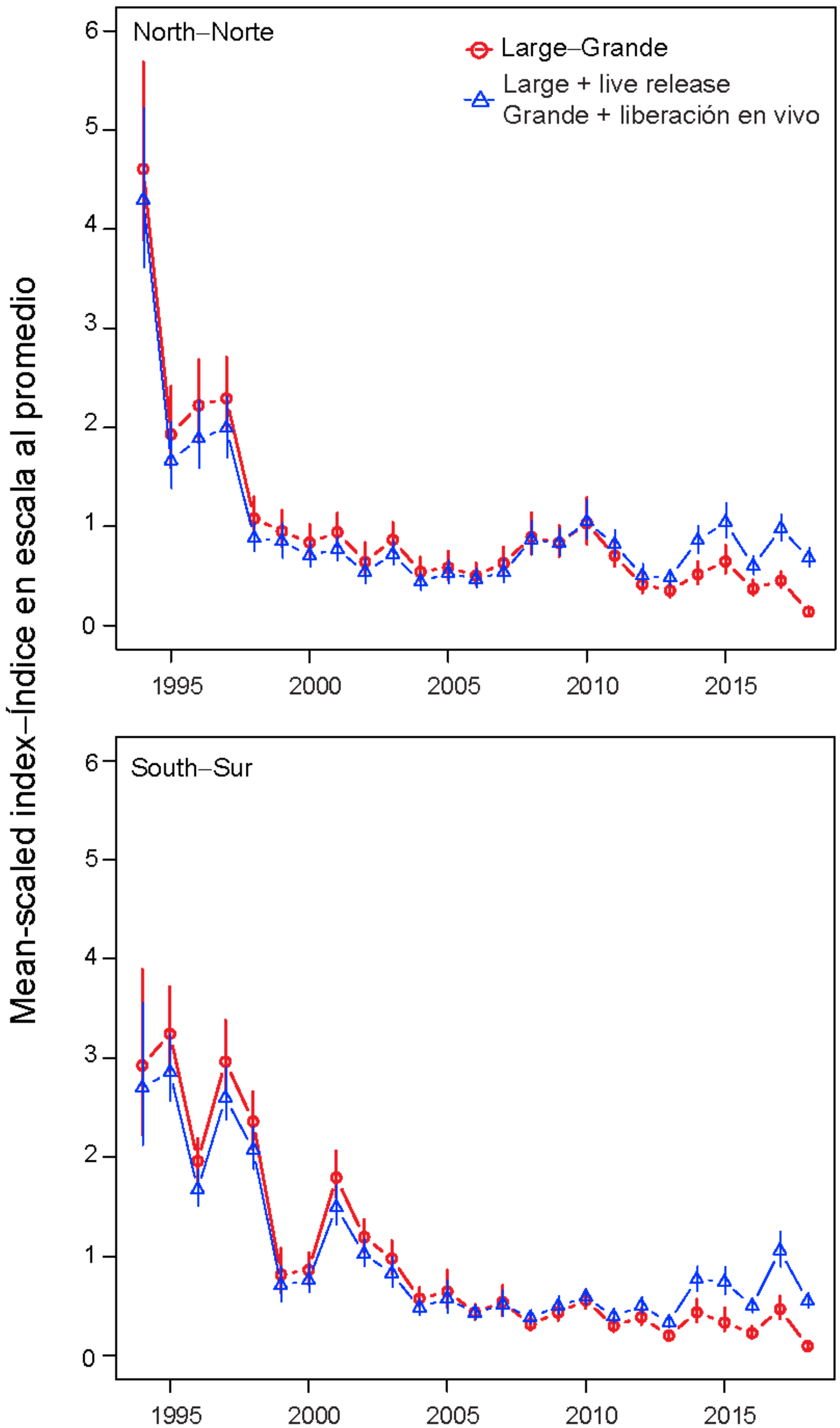

FIGURE 2a. Mean-scaled standardized silky shark bycatch-per-set (BPS; in numbers of sharks per set) in sets on floating objects for large sharks, with and without live release, in the north (top) and south (bottom) EPO. Vertical bars indicate pointwise approximate 95% confidence intervals.

FIGURA 2a. Captura incidental por lance (CIPL, en número de tiburones por lance) estandarizada en lances sobre objetos flotantes de tiburones sedosos grandes, con y sin liberación en vivo, en el OPO norte (arriba) y sur (abajo). Las barras verticales indican los intervalos de confianza de 95% puntuales aproximados

TABLE 1. Percentages of silky sharks recorded as released alive, by size category and for all silky sharks, in floating-object sets in the EPO, 2004-2018 (IATTC observer data). Data collection began in late 2004, so the data for 2004 are incomplete.

TABLA 1. Porcentajes de tiburones sedosos registrados como liberados vivos, por categoría de talla y para todos los tiburones sedosos, en lances sobre objetos flotantes en el OPO, 2004-2018 (datos de observadores de la CIAT). La recolección de datos comenzó a finales de 2004, por lo que los datos de 2004 están incompletos.

	Small	**Medium**	**Large**	**All**
	Pequeños	**Medianos**	**Grandes**	**Todos**
2004	2.9	0.9	0.1	1.4
2005	2.8	3.3	4.4	3.3
2006	5.4	4.9	8.1	5.6
2007	6.2	5.4	7.4	6
2008	3.9	6.2	12.4	6.2
2009	4.9	9.7	15.5	10.5
2010	13.4	17.3	17.5	15.7
2011	16.7	14.6	31.3	18.6
2012	10.3	17.2	28.6	20.1
2013	28.2	22.3	34.3	26
2014	29.4	34.5	45.9	36.5
2015	27.9	34.7	46.2	38.5
2016	32.2	38.9	44	38.6
2017	45.8	52.6	61.7	54.3
2018	43.4	64.8	85	65.5