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UPDATED STOCK STATUS INDICATORS FOR SILKY SHARKS IN THE EASTERN PACIFIC OCEAN, 1994-2021

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CONTENTS

SUMMARY

The indices of relative abundance for large silky sharks (*Carcharhinus falciformis*) in the eastern Pacific Ocean (EPO), developed from bycatch-per-set data collected by on-board observers from purse-seine sets on floating objects and presented at the 10th meeting of the Working Group on Bycatch (BYC-10) in May 2020 (Document BYC-10 INF-A), were updated with data from 2021. Previous analyses (SAC-08-08a(i), Lennert-Cody *et al*. 2019) identified a correlation between north EPO indices, particularly for small (<90 cm) and medium (90-150 cm) silky sharks, and interannual variability in oceanographic conditions, and thus the indices for those size categories, and the "all silky sharks" combined category, were not updated because of concerns about bias. In both north and south EPO, the indices for large (>150 cm) silky sharks for 2021 were close to, or slightly above, the 2020 values. Because of recent increases in the number of sharks recorded by observers as released alive, indices for large silky sharks that included these data were also calculated, and showed a somewhat less pessimistic long-term trend. 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 discussed.

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 in the 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 used for monitoring the silky shark in the EPO and as a basis for management advice (SAC-05-11a), among them standardized bycatch-per-set (BPS) indices from the purse-seine fishery. In addition, the staff is collaborating in Pacific-wide silky shark assessment research, for which reliable indices of abundance are critical (Clarke *et al*. 2018).

Studies of variability in the purse-seine BPS indices (SAC-08-08a(i), Lennert-Cody *et al*. 2019) have suggested that recent large fluctuations, particularly in the north EPO index for small (<90 cm total length (TL)) and medium (90-150 cm TL) silky sharks, may be influenced by inter-annual variability in oceanographic conditions (*i.e.,* El Niño and La Niña events). Those analyses found that the correlation between silky shark indices and the Pacific Decadal Oscillation (PDO; 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 El Niño-Southern Oscillation (ENSO) events. Thus, the indices for small and medium silky sharks may be biased as indicators of stock status. The indices for large (>150 cm TL) 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 the indices for large silky sharks have been updated since the report in 2018.

The transition to an SSI 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 the on-board 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 with the tuna catch (Román *et al*. 2005), including counts of those released alive. It is believed that many of the sharks recorded as dead prior to 2005 would now be released alive and recorded as such, due mainly to the 2005 ban on "finning[1]" sharks (IATTC Resolution C-05-03) and the introduction of best handling practices, which include the immediate release of sharks brought aboard the vessel. Counts of sharks released alive were included in the indices for the "all silky sharks" combined size 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 observers' classification to size categories of sharks recorded as released alive, which the observer may have seen 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 most reliable 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 in computing the index.

This document presents two sets of indices for large silky sharks, for the EPO north and south of the equator, updated through 2021: one excludes data on live releases (for consistency with earlier reports) and the other includes those data. The index including live releases is considered more reliable, for reasons discussed below, and should be used as a basis for management advice. Finally, several research topics aiming at improving the silky shark purse-seine indices are identified.

2. DATA AND METHODS

Data on bycatches of silky sharks collected by IATTC observers aboard Class-6[2] purse-seine vessels during 1994-2021 were used to generate BPS-based indices of relative abundance for large silky sharks.

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

[2] Carrying capacity > 363 t

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), roughly reflecting life stages (juveniles correspond to the small and medium categories, adults to the large category). Counts of large silky sharks recorded as released alive from the deck of the vessel, available since late 2004, were also used in the analyses. Since 2010, the proportion of large silky sharks recorded as released alive has increased almost fivefold (Table 1), so two indices for large silky sharks are now computed, one excluding and one including large silky sharks recorded by the observer as released alive. (As noted above, in previous reports, animals recorded as released alive were included in the "all silky shark" category, but not in the individual size subcategories.) Annual summaries of the spatial distribution of bycatch rates during 1994-2021 are shown in Figure 1a-d.

BPS trends for large silky sharks in floating-object 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 floating-object 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 in reports prior to 2018 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

The 2021 index values for large silky sharks were similar or slightly above the 2020 values (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. These two indices (with and without live release data) may bracket the trend that would have resulted if finning, shark handling, and data recording practices had all remained unchanged since 1994. The trend based on counts of dead sharks only may be too pessimistic, given the increased efforts in recent years to release sharks alive. Conversely, the index that includes live-release data may be too optimistic, because live releases were not recorded prior to 2005; however, given the physical trauma caused by brailing[3] and the lack of emphasis on immediate release of sharks from the deck, combined with unrestricted finning practices, it is likely (but not certain) that few or no live releases occurred prior to 2005. Therefore, the index including live releases should be used as a basis for management advice.

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

[3] Recent studies (Poisson *et al*. 2014, Eddy *et al*. 2015, Hutchinson *et al*. 2015) indicate that sharks that are brought aboard the vessel in the brailer with the tuna catch suffer trauma leading to low post-release survival.

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, unless the effects of movement are explicitly modelled, including 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 of Clarke *et al*. (2018) could not 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 to evaluate movement hypotheses or estimate movement parameters.

As noted previously (SAC-07-06b(i), SAC-07-06b(iii), SAC-08-11), reliable catch data for all fisheries catching silky sharks in the EPO, indices of relative abundance for fisheries other than purse-seine (*e.g.,* longline fisheries, which take the majority of the catch), and composition data, by length/age and sex, continue to be vital. This is particularly the case given the increased concern about the reliability of the purse-seine indices. Progress is being made on collection of data from the artisanal fleets of Central America (SAC-11-14), where sampling programs are being implemented to collect data to estimate the species and size composition of the shark catch. A second phase of the ABNJ project is about to begin in 2022 with support to expand previous data collection improvements achieved in Central America to other EPO coastal CPCs (SAC-13 INF-Q, SAC-13-12). Estimates of absolute abundance, such as those derived from close kin mark-recapture (CKMR) methods, will be essential for putting the catch estimates in context with respect to fishing mortality rates and demographic parameters.

4. FUTURE WORK

To obtain indices of absolute abundance for the silky shark in the EPO, which would improve management advice for the stock, it is recommended that a feasibility study be undertaken for a CKMR program for the silky shark. Any CKMR program would have to be collaborative, involving coastal nations of the EPO and the Western and Central Pacific Fisheries Commission (WCPFC), because tagging studies conducted recently in the Pacific (Hutchinson *et al*. 2019; Schaefer *et al*., 2019) have shown the potential for considerable movement by silky sharks. Not only can CKMR be used to obtain estimates of absolute abundance for stock assessments, but it can provide information on stock structure. In addition, in conjunction with habitat modeling of fisheries data (*e.g*., Lopez *et al*. 2017), information obtained from CKMR studies may lead to a better understanding of the effects of changing ocean climate on silky shark abundance across the Pacific Ocean. Considerations for conducting CKMR for the silky shark in the EPO were presented in Document SAC-12-14.

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. 2019. 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. Generalized Additive Models, An Introduction with R. Chapman & Hall/CRC, 391pp.

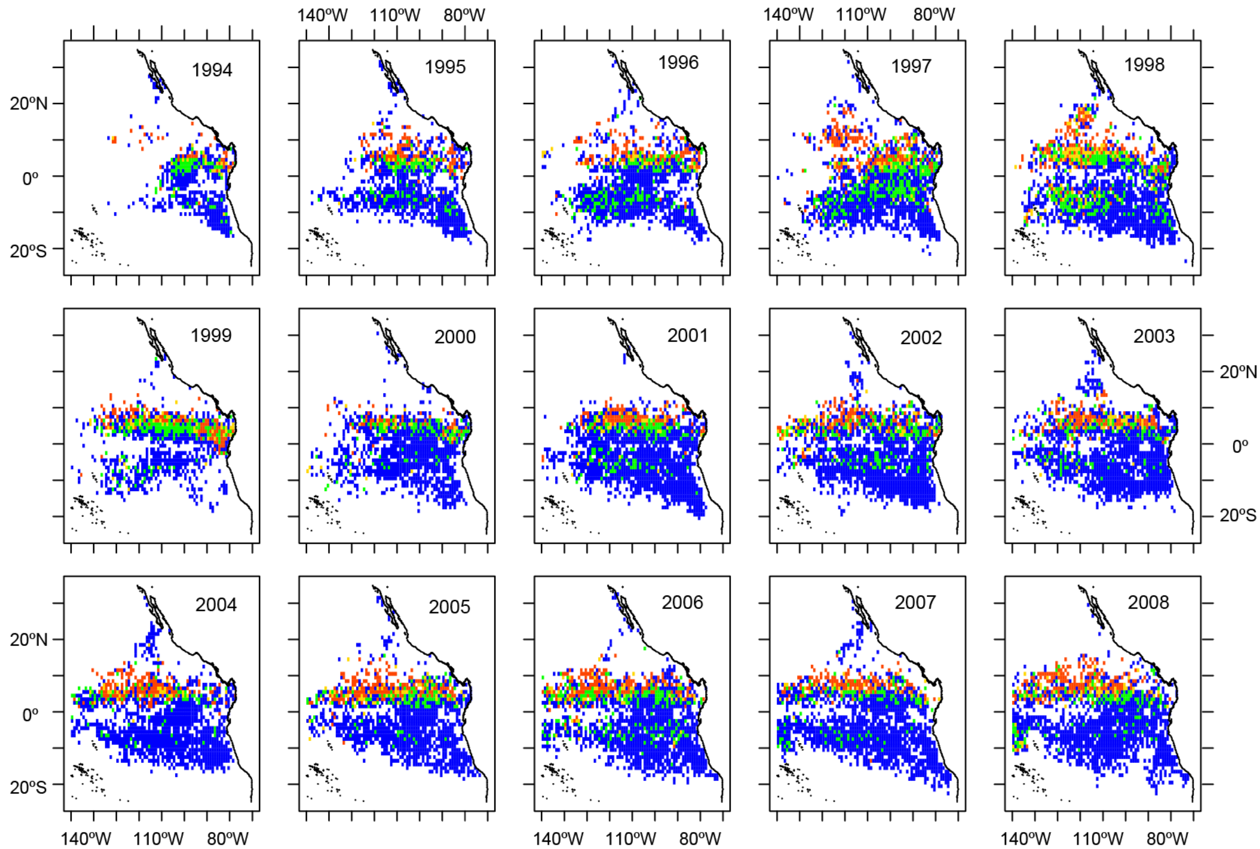

FIGURE 1a. Average bycatch per set, in numbers, of small (<90 cm total length) silky sharks in floating-object sets, 1994-2021, including live releases since late 2004. Sharks per set: blue, 0; green, ⩽1; yellow, 1-2; red: >2.

FIGURA 1a. Captura incidental media por lance, en número, de tiburones sedosos pequeños (<90 cm de talla total) en lances sobre objetos flotantes, 1994-2021, incluyendo liberaciones en vivo desde finales de 2004. Tiburones por lance: azul, 0; verde, ≤1; amarillo, 1-2; rojo, >2.

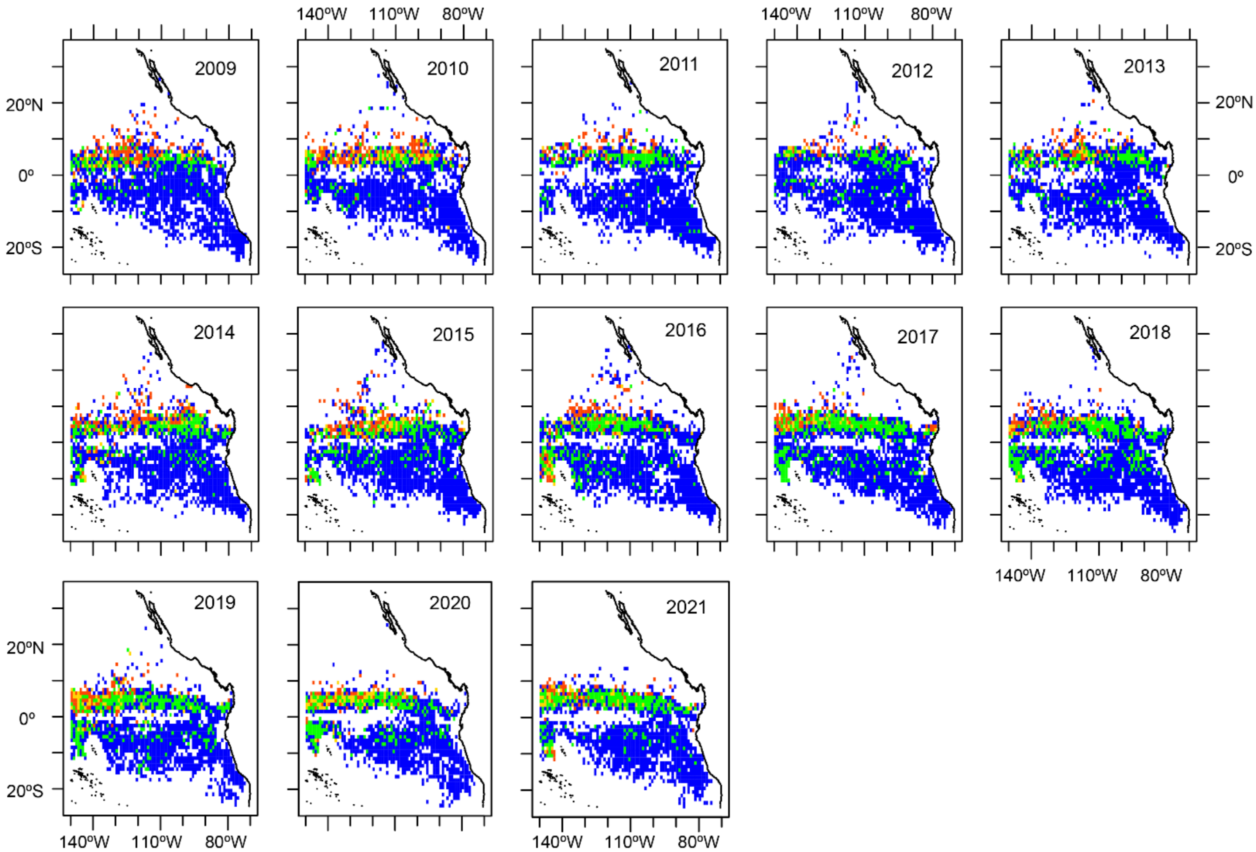

FIGURE 1a. (cont.)

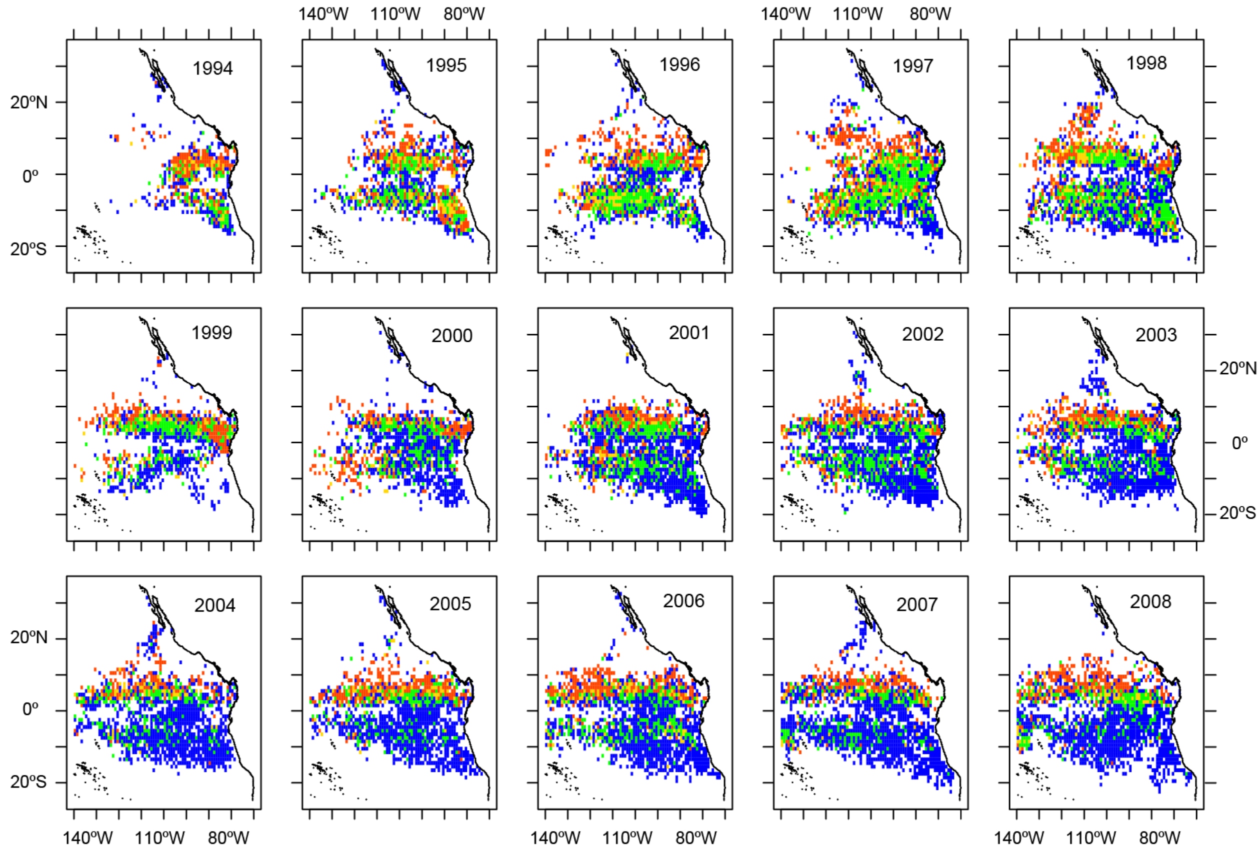

FIGURE 1b. Average bycatch per set, in numbers, of medium (90-150 cm total length) silky sharks in floating-object sets, 1994-2021, including live releases since late 2004. Sharks per set: blue, 0; green, ⩽ 1; yellow, 1-2; red: >2.

FIGURA 1b. Captura incidental media por lance, en número, de tiburones sedosos medianos (90-150 cm de talla total) en lances sobre objetos flotantes, 1994-2021, incluyendo liberaciones en vivo desde finales de 2004. Tiburones por lance: azul, 0; verde, ≤1; amarillo, 1-2; rojo, >2.

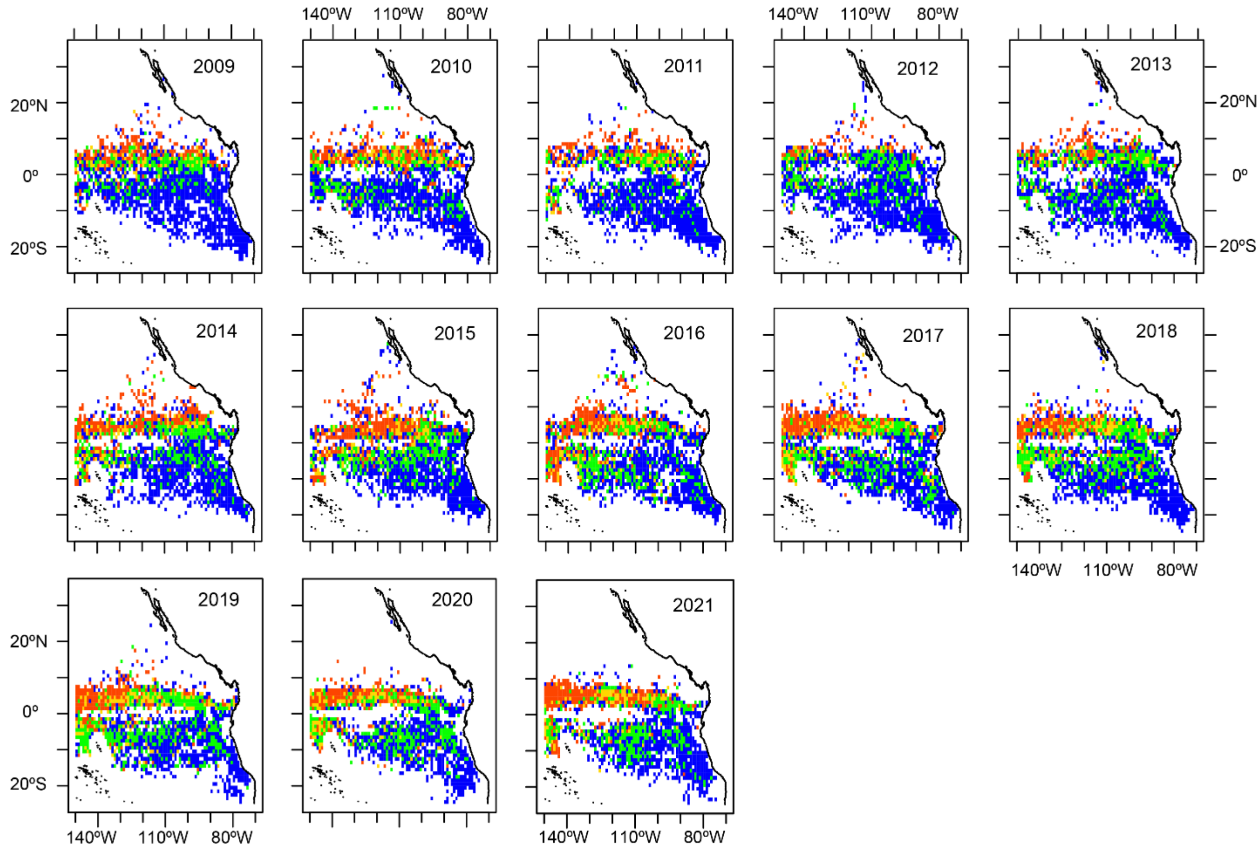

FIGURE 1b. (Cont.)

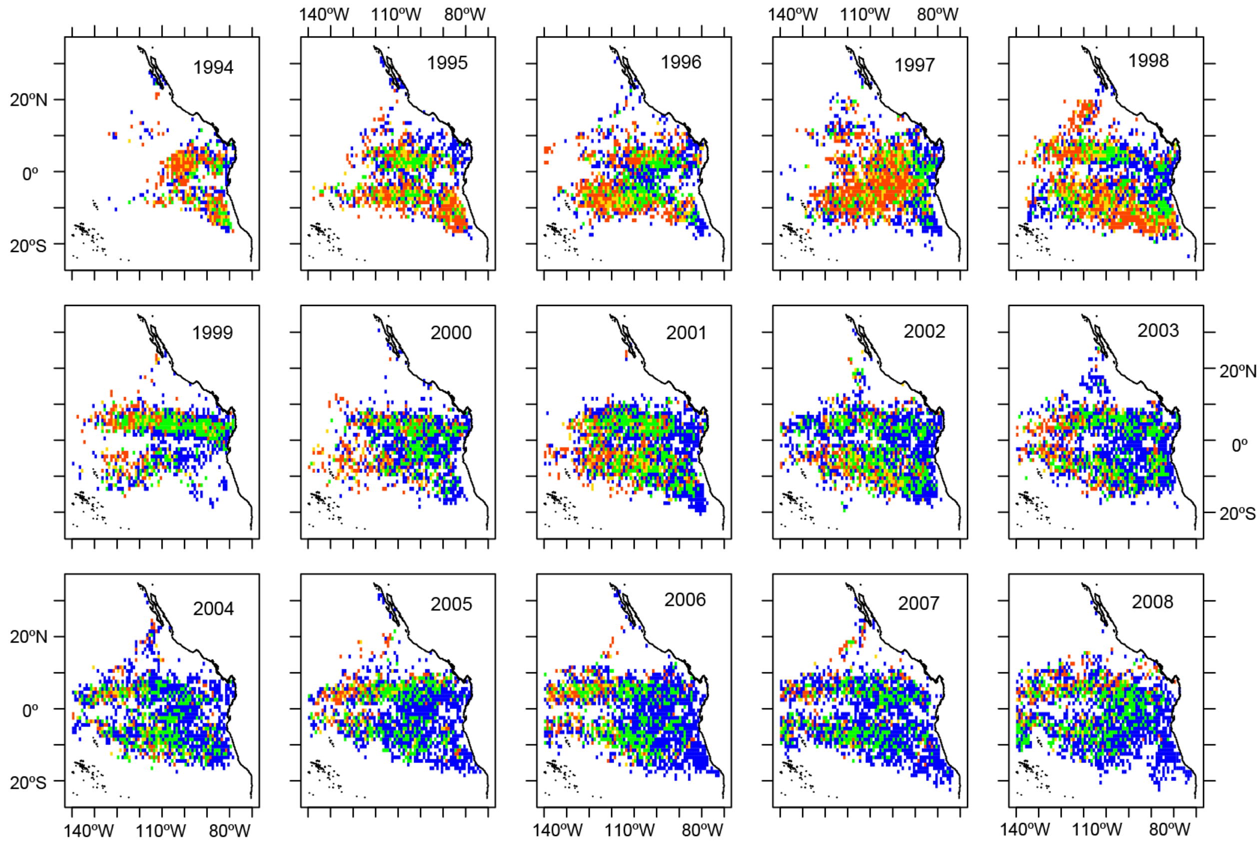

FIGURE 1c. Average bycatch per set, in numbers, of large (> 150 cm total length) silky sharks in floating-object sets, 1994-2021, including live releases since late 2004. Sharks per set: blue, 0; green, ⩽1; yellow, 1-2; red: >2.

FIGURA 1c. Captura incidental media por lance, en número, de tiburones sedosos grandes (> 150 cm de talla total) en lances sobre objetos flotantes, 1994-2021, incluyendo liberaciones en vivo desde finales de 2004. Tiburones por lance: azul, 0; verde, ≤1; amarillo, 1-2; rojo, >2.

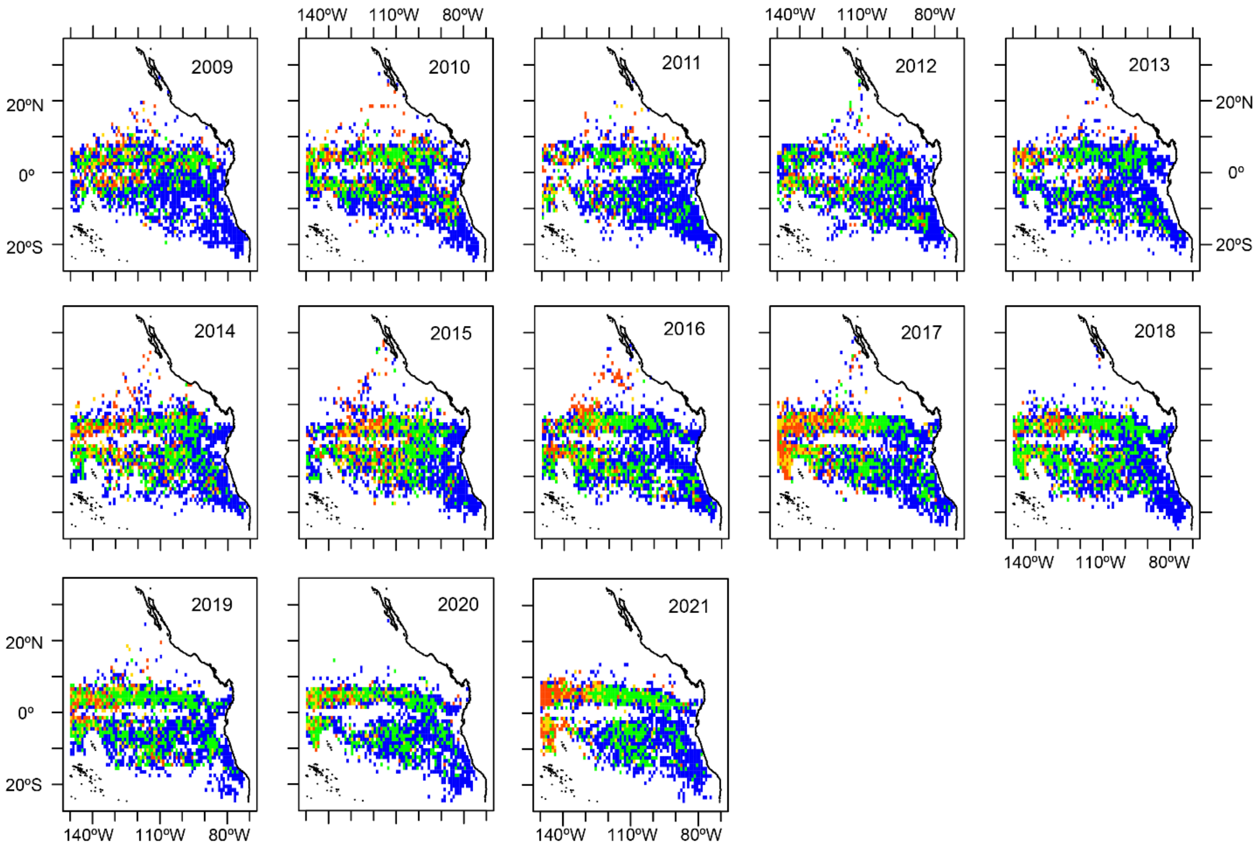

FIGURE 1c. (Cont.)

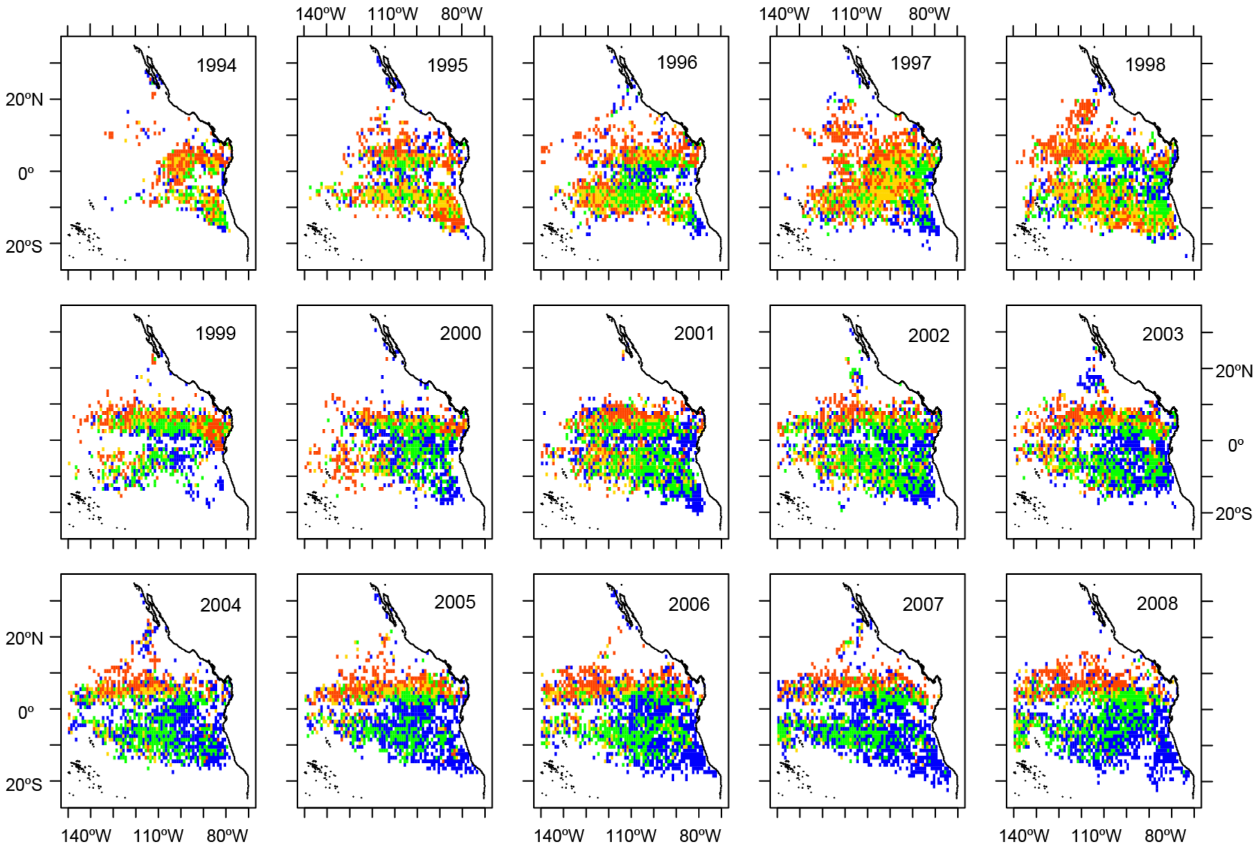

FIGURE 1d. Average bycatch per set in floating-object sets, in numbers, of all silky sharks, including live release since late 2004, for 1994-2021. Sharks per set: blue: 0; green: ≤2; yellow: 2-5; red: >5.

FIGURA 1d. Captura incidental media por lance, en número, de todos los tiburones sedosos en lances sobre objetos flotantes, 1994-2021, incluyendo liberaciones en vivo desde finales de 2004. Tiburones por lance: azul, 0; verde, ≤2; amarillo, 2-5; rojo, >5.

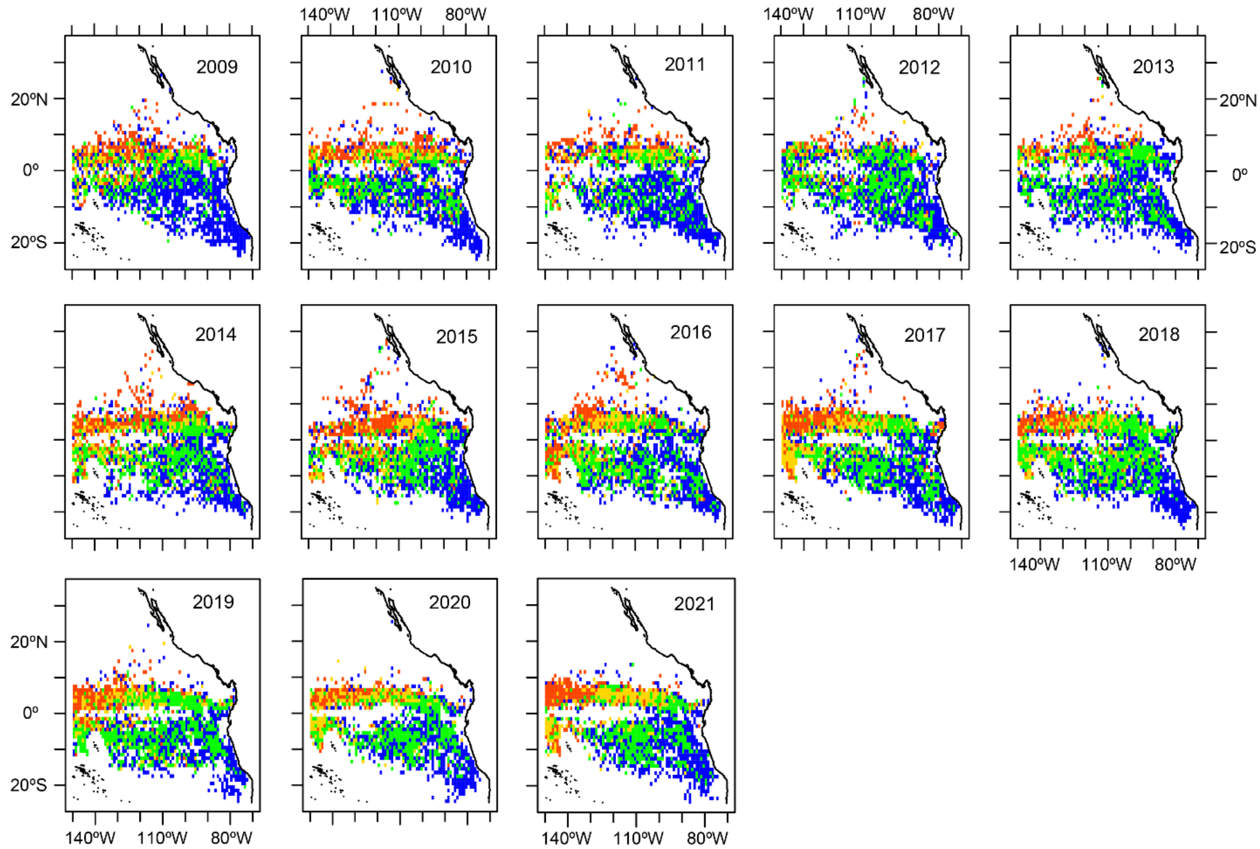

FIGURE 1d. (Cont.)

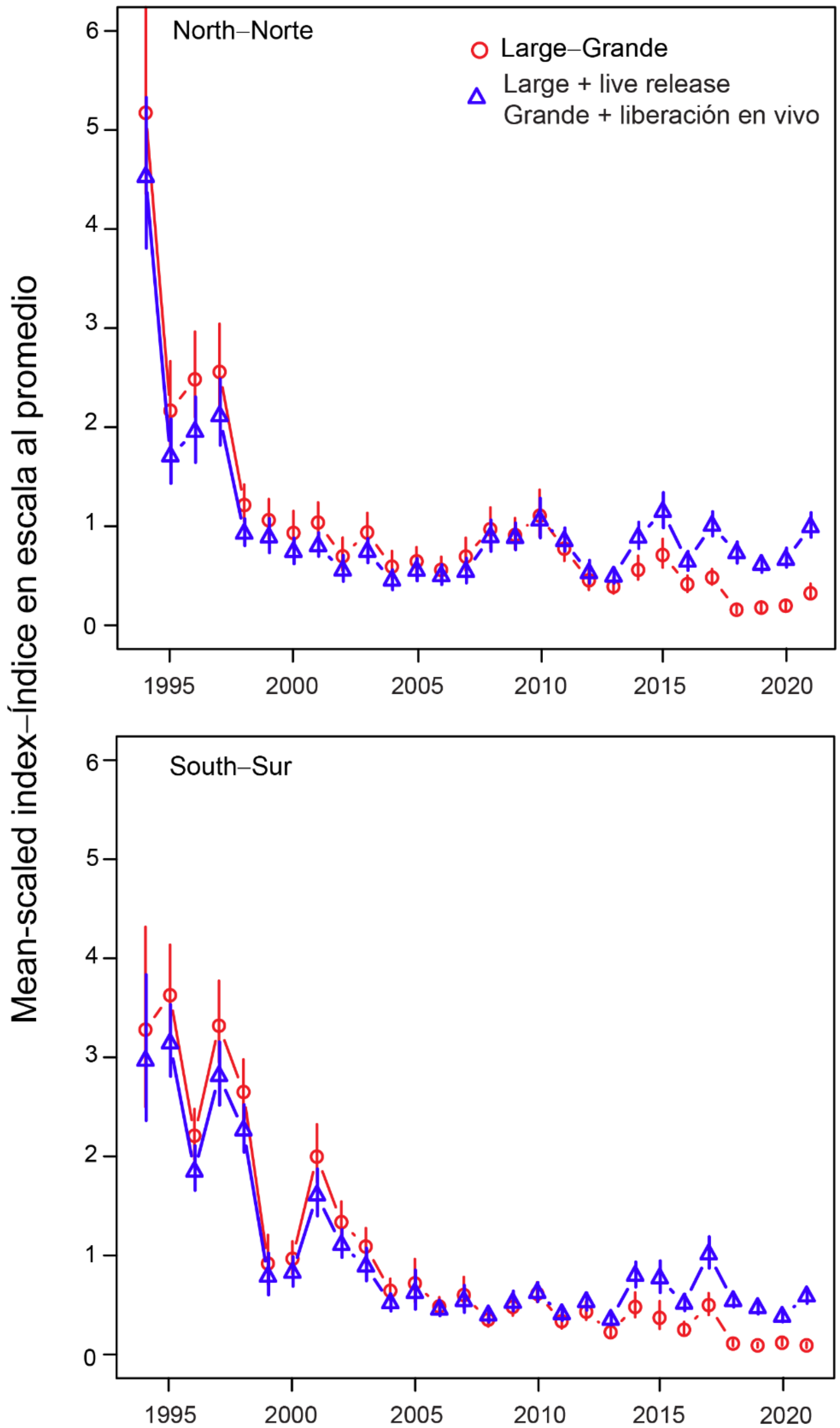

FIGURE 2. Mean-scaled standardized bycatch-per-set (BPS; in numbers of sharks per set) of large silky sharks in sets on floating objects, with and without live release, in the north (top) and south (bottom) EPO. Vertical bars indicate pointwise approximate 95% confidence intervals.

FIGURA 2. Captura incidental por lance (CIPL, en número de tiburones por lance) estandarizada de tiburones sedosos grandes en lances sobre objetos flotantes, 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, 2004-2021 (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, 2004-2021 (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
2019	46.2	69.2	79.6	67.2
2020	47.0	70.8	79.3	68.1
2021	50.8	68.8	80.3	69.7