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FLOATING-OBJECT FISHERY INDICATORS

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SUMMARY

The importance of monitoring the FAD fishery as a whole has widely been claimed by scientists, managers and other stakeholders. Based on the recommendations and guidelines of the joint technical Working Group on FADs (Lopez 2019), as well as the repeated requests by some member countries on the production of specific data and analyses (*e.g.* IATTC-93 INF-A), this document compiles for the first time a comprehensive series of spatial and temporal indicators for the FAD fishery in the EPO with the aim to better monitor and assess its potential impacts in the short, medium and long term. The indicators have been grouped into 8 categories: catch and effort, activities on FADs, satellite buoy-based indices, capacity, technology, ecosystem impacts, socio-economic, and biology, ecology and behavior indicators. This document will also serve to identify and shape data collection and reporting needs on FADs and prioritize future actions for conservation and management of target and non-target species.

1. INTRODUCTION

The tropical tuna purse-seine fishery in the Eastern Pacific Ocean (EPO) is one of the biggest in the world, with recent annual catches exceeding 600,000 tons (SAC-11-03). Also, recently, about 60% of the catches correspond to the floating object (OBJ) fishery, which includes man-made fish aggregating devices (FADs) and natural objects (logs). However, the vast majority of activities conducted by purse seiners (*e.g.* sets, deployments) since mid-90s are on FADs (SAC-11-03).

Despite being a very efficient fishing tool, the continual increase in the use of FADs by the purse seine fishery raises the possibility of several potential negative impacts on ecosystems and tuna populations. Examples include i) a reduction in yield per recruit of some tuna species, ii) increased bycatch and perturbation of pelagic ecosystem balance, iii) increased amount of marine debris and stranding events on sensitive habitats, and, iv) alteration of the normal movements of the species associated with FADs (Dagorn *et al*. 2012; Escalle *et al*. 2019). Because of the multi-dimensional potential impacts of the fishery, it must be holistically monitored through a series of comprehensive metrics and indicators that capture its evolution and dynamics at different spatial and temporal scales. Considering a wide variety of indicators can improve both the assessment of the impacts of the fishery and the utility and interpretation of the results, whereas single indicators can be misleading and lead to conservation measures that do not meet management objectives.

The importance of monitoring the FAD fishery as a whole has widely been claimed by scientists, managers and other stakeholders, who, during the 1^{rst} joint t-RFMO Working Group (WG) on FADs meeting in Madrid in 2017, agreed to establish a small technical working group (TWG) to progress on key areas for future action. These aspects, largely technical or of scientific nature, range from the development of harmonized definitions to the coordination of regional and international research plans, but also include the development of fishery indicators, a task led by the IATTC staff within the TWG since 2018. An extensive list with more than 40 indicators grouped in 8 categories (Table 1), from catch and effort to ecosystem indicators (Lopez 2019), was presented and discussed during the 2nd joint t-RFMO Working Group on FADs meeting in San Diego in 2019. The process resulted in 4 of the categories considered as "major" priority indicators: catch and effort, activities on FADs, satellite buoy-based indices, and capacity (Table 1). Indicators related to the technology onboard and ecosystem impacts were classified as "moderate" priority level. Socio-economic and biology, ecology and behavior indicators, although important, were considered as "minor" priority level by this first assessment, particularly due to the difficulties to regularly obtain reliable and significant amounts of data on these matters.

Based on the recommendations and guidelines of the TWG (Lopez 2019), as well as the repeated requests by some member countries on the production of specific data and analyses (*e.g.* IATTC-93 INF-A), this document compiles for the first time a comprehensive series of spatial and temporal indicators for the FAD fishery in the EPO with the aim to better monitor and assess its potential impacts in the short, medium and long term. It will also serve to identify and shape data collection and reporting needs on FADs and prioritize future actions for conservation and management of target and non-target species.

TABLE 1. A list of the indicator types considered by Lopez *et al*. 2019 and discussed and prioritized during the 2nd joint t-RFMO working group on FADs.

Indicator Type	Priority level (1 Major, 2 Moderate, 3 Minor)
Catch and effort	1
Activity	1
Buoy/FAD use	1
Capacity	1
Technology	2
Ecosystem Impacts	2
Socio-Economic	3
Biology, Ecology and Behavior	3

2. MATERIALS AND METHODS

2.1. Data

Three main datasets were used in the study:

a. 2014-2019 AIDCP observer data for Class-6 vessels, which contain FAD-related information such as deployment, origin, and object characteristics, as well as on fishing activities on FADs. This dataset was used to estimate the indicators in the following categories: fleet behavior, activities, and technology.
b. Catch and effort data for all vessels (Classes 1-6), from observers and vessel logbooks. This dataset was exclusively used to estimate catch and effort indicators, including catch by set type, catch by species, and number of OBJ sets, among others.
c. Daily active buoy data for 138 vessels (Classes 1-6) reporting under Resolution C-17-02 during 2019. Daily vessel coverage and reporting rates vary by size class and month (min = 112, mean = 127, max = 138), with not all vessels present in the active buoy dataset at any one time. See 2019 report of the Review Committee for further details on data reporting rates and categories. This dataset was used to estimate the indicators in the buoy-based indices category.

Indicators for categories biology, ecosystem impacts and capacity were not estimated in this study but extracted from the fishery report (SAC-11-03) and the Ecosystem and Bycatch consideration report (SAC-11-14). The indicators included in this document refer mainly to FADs, unless the contrary is specified.

2.2. Methods

Because the degree to which each vessel fishes on OBJ is vessel-specific, all the indicators were, when possible, broken down into different OBJ-usage categories (see section 3.1. below for details) to better understand and detect the fishery evolution and dynamics.

All the indicators were estimated for 2019 and averaged for the previous five years (*i.e.* 2014-2018) to allow comparison between periods and detect potential anomalies; the exceptions are catch and effort indicators, which are taken from the FSR and have longer time series. In addition, yearly indicators were also estimated, as well as trip (*e.g.* activities within the trip), quarterly (*e.g.* activities), monthly (*e.g.* buoy-densities) or daily (*e.g.* total active buoys) indicators, when appropriate and depending on data availability, quality and resolution. A 1°x1° cell resolution was used to estimate spatial indicators. Summary statistics, convex hull areas (*i.e.* density areas where 66% of the activites of the fleet occur), and boxplots, as well as frequency and density histograms were also estimated to describe the general trends of many indicators, particularly those based on observer data to depict cluster-specific dynamics (see section 3.1 for clustering details).

When observer data were used to estimate indicators, data corresponding to Class 1-5 vessels and Class-6 vessels conducting less than 5 OBJ sets per year were not included based on the following reasons: i) few Class-6 vessels conduct less than 5 sets per year and their impact is negligible compared to the rest of the FAD-oriented vessels, which are the focus of this document; ii) Class 1-5 vessel data are not collected systematically for the whole fleet, lack consistency (*e.g.* voluntary versus mandatory programs, yearly differences in coverage and quality, time series), and in the past, have typically corresponded to vessels that needed to carry an observer for specific reasons (*e.g.* certification purposes, closure fishing), and thus, the representativeness of these data remains unkown. The latter is of particular importance as the FAD form 09-2018[1] (a logbook designed to be used by skippers of small vessels; Res C-19-01) intends to collect the most significant FAD-oriented data for Class 1-5 vessels (*e.g.* activities, bycatch of sensitive species, FAD characteristics). However, the reporting ratio and the quality of the data currently being provided on the FAD form is inadequate for this component of the fleet, and thus, no valid assumptions can be made at this stage. Moreover, not all vessels are reporting buoy data under Resolution C-17-02 (see point c in section 2.1). Because of this, the indicators estimated using only Class-6 data (*e.g.* activities), or using data partially reported (*e.g.* buoy-based indices), are understimates. Nonetheless, we believe that those indicators represent well Class-6 vessels patterns and depict properly overall trends for the whole fleet.

Specifics on the exceptions, rules and assumptions considered in the development of each indicator, if any, are specified for each indicator below.

3. INDICATORS

3.1. Fleet behavior

To identify fleet segments among Class-6 vessels based on their fishing strategies, a cluster analysis was conducted using operational characteristics related to OBJ fishing (number of vessels per year included in the analysis: min = 128, max = 156, mean = 145). Only Class-6 vessels making at least five OBJ sets per year during 2014-2019 were considered (for convenience, detailed results of the cluster are only shown for the analysis year, 2019). The methodology described in Lennert-Cody *et al*. (2018) was applied, where vessels were grouped into different fleet segments based on the following variables: (i) proportion of OBJ sets by object "origin" category (FADs deployed by the vessel on the current trip or a previous trip; FADs deployed by other vessels, either "given" by another vessel or encountered opportunistically, "taken"; unmonitored drifting objects – presumably natural objects such as logs); (ii) proportion of sets made by type (on tuna associated with dolphins, "DEL"; on unassociated schools of tuna, "UNA"; on OBJ); and (iii) proportion of OBJ sets made in the western EPO (west of 100°W).

The cluster analysis indicated several clear vessel groupings with different fishing behaviors (Figs 1-2). There are three main clusters in the dendrogram produced by the cluster analysis, labelled Clusters A-B-C. Cluster A is comprised of vessels for which about 30% or more of their sets were DEL, with many making almost exclusively DEL sets. Most of the OBJ sets made by the vessels in Cluster A tended to be on FADs that were "taken" or were on unmonitored drifting objects, presumably logs. The majority of OBJ sets conducted by vessels in Cluster A were west of 100°W. The number of vessels in Cluster A ranged from 25 to 54 in the study period and the 2019 value was 40 (Figs 1-2). Cluster B is comprised of vessels that primarily made OBJ sets, with a few vessels also making UNA sets and almost no vessels making DEL sets. OBJ sets of the vessels in Cluster B tended to be west of 100°W and were primarily on FADs deployed by the vessels themselves or on FADs that were "given". The number of vessels in Cluster B ranged from 40 to 64 in the study period and the 2019 value was 49 (Figs 1-2). Cluster C is comprised of vessels that mostly made a lesser proportion of OBJ sets and a greater proportion of UNA sets, as compared to the vessels in

[1] Download at https://www.iattc.org/Downloads.htm

Cluster B, with few vessels making DEL sets. Vessels in Cluster C tended to make more OBJ sets east of 100°W and a greater proportion of their OBJ sets were on FADs that were "taken" or were on unmonitored drifting objects, presumably logs. The number of vessels in Cluster C ranged from 27 to 79 in the study period and the 2019 value was 57 (Figs 1-2). The patterns for 2019 are similar to those found by (Lopez *et al*. 2019) for 2018 and by Lennert-Cody *et al*. (2018) for 2012-2015, suggesting that these fleet segment characterizations are not the result of an anomalous year. All three fleet segments seem to represent different OBJ-fishing strategies (*e.g.* Cluster B – nearly pure OBJ-oriented, fishing FADs monitored by themselves, so there should be, for example, a clear connection between active FADs and number of sets). Therefore, the cluster analysis results were used to break down the indicators by cluster when possible, so that a better understanding of the relationship between the different metrics and the trends included in this document is possible.

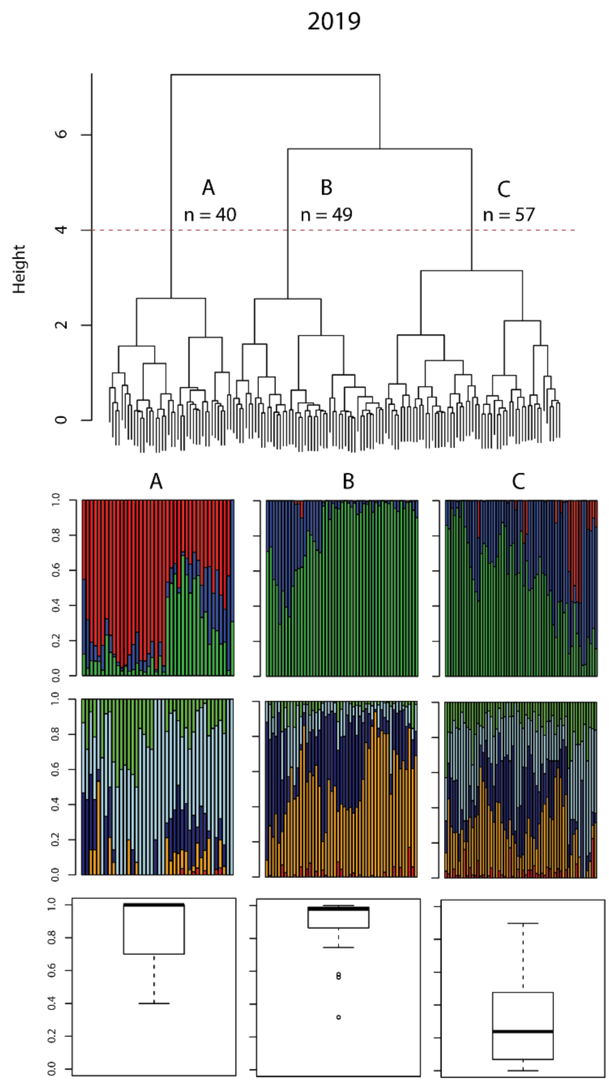

FIGURE 1. **Fleet segments identified by the cluster analysis, 2019. Cluster A, B and C include 40, 49 and 57 vessels, respectively.**

FIGURE 2. **Evolution of the proportion of Clusters A, B, and C, 2014-2019.**

3.2. Catch and effort

The catch (section 3.2.1; catch by set type, Fig. 3; catch by species in mt and numbers, Fig. 4-5; spatial distribution of catches, Fig. 6) and effort (section 3.2.2; Number of set per set type, Fig. 7; OBJ sets by class, Fig. 8; Sets by OBJ type, Fig. 9; Cumulative number of OBJ sets, Fig. 10) indicators included in this section were taken/modified/updated from documents SAC 11-03, SAC 11-05 and IATTC-93 INF-A, whereas the catch per set indicators (section 3.2.3; Fig. 11) were estimated using Class-6 observer data only to depict cluster-specific differences based on different OBJ-fishing strategies.

3.2.1. Catch

3.2.1.a Catch by set type

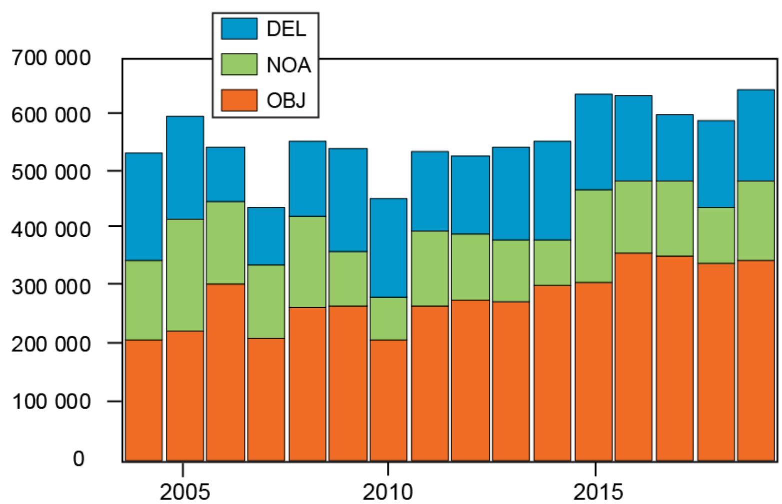

FIGURE 3. **Evolution of purse-seine catches, by set type (OBJ: floating object; DEL: dolphin; NOA: unassociated), 2004-2019. Source: Document SAC-11-03, Table A-7.**

3.2.1.b Catch by species (in weight)

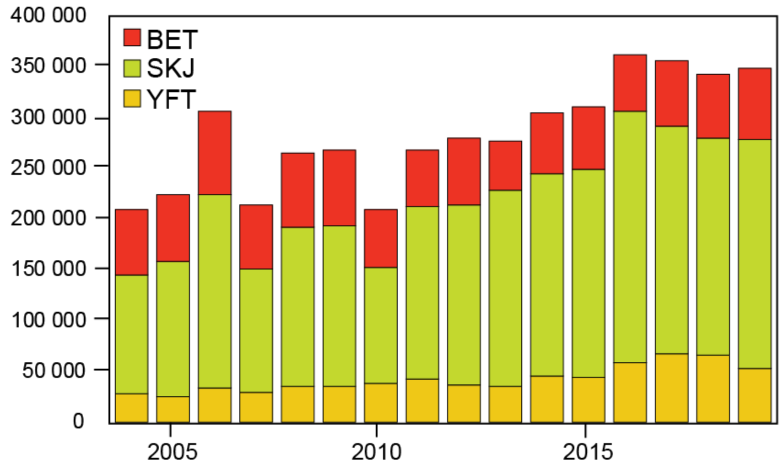

FIGURE 4. **Evolution of purse-seine OBJ catches (mt), by species (BET: bigeye; SKJ: skipjack; YFT: yellowfin), 2004-2019. Source: Document SAC-11-03, Table A-7.**

3.2.1.c Catch by species (in numbers)

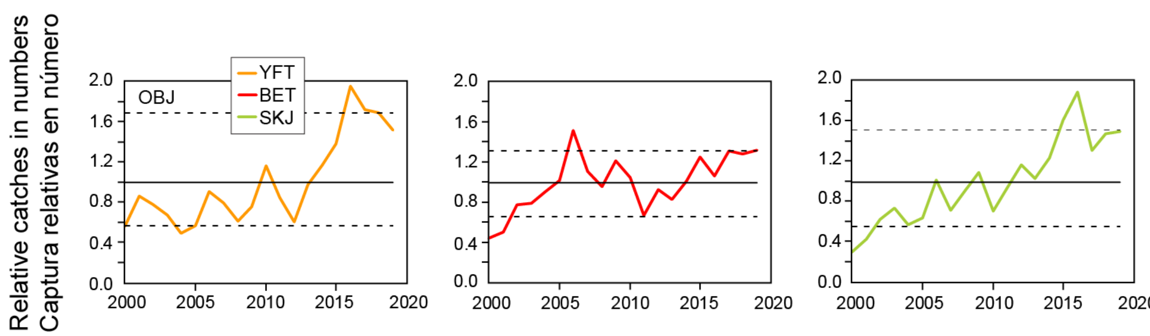

FIGURE 5. **Indicators based on purse-seine catch in numbers, 2000-2020. Source: Document SAC-11-05, Fig 2b.**

3.2.1.d Spatial distribution of OBJ catches

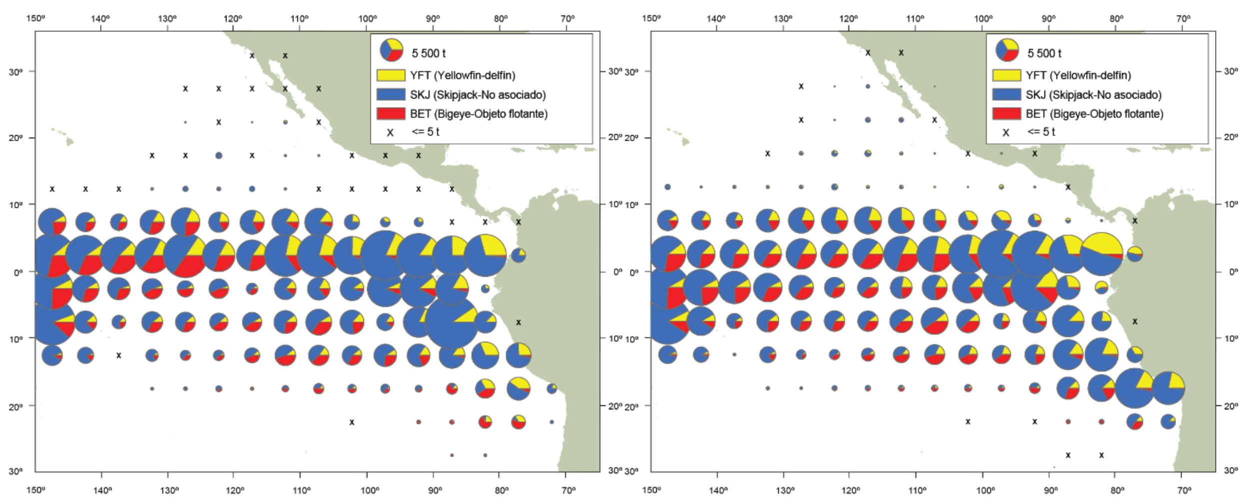

FIGURE 6. **5°x5° purse-seine catches on OBJ by species for 2019 (left panel) and the 2014-2018 averages (right panel).**

3.2.2. Effort

3.2.2.a Number of set per set type

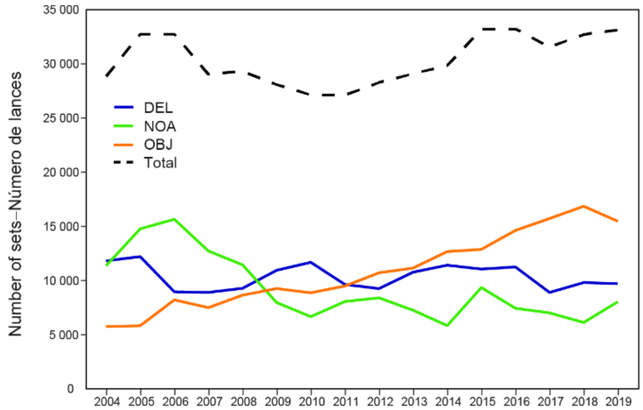

FIGURE 7. **Evolution of the number of purse-seine sets, by set type (OBJ: floating object; DEL: dolphin; NOA: unassociated), 2004-2019. Source: Document SAC-11-03, Table A-7.**

3.2.2.b OBJ sets by class

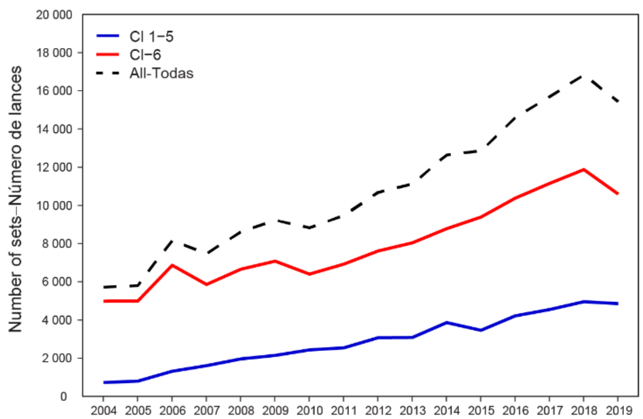

FIGURE 8. **Evolution of the number of floating-object sets by Class 1-5 and Class 6 vessels, 2004-2019. Source: Document SAC-11-03, Table A-7.**

3.2.2.c Sets by OBJ type

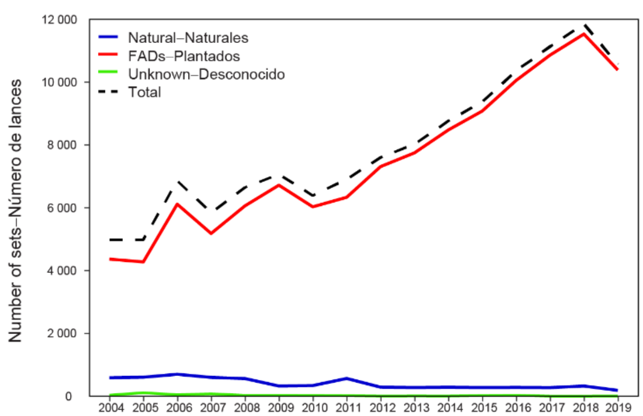

FIGURE 9. **Evolution of the number of floating-object sets by Class-6 vessels, by type of floating object, 2004-2019. Source: Document SAC-11-03, Table A-8.**

3.2.2.d Cumulative number of OBJ sets

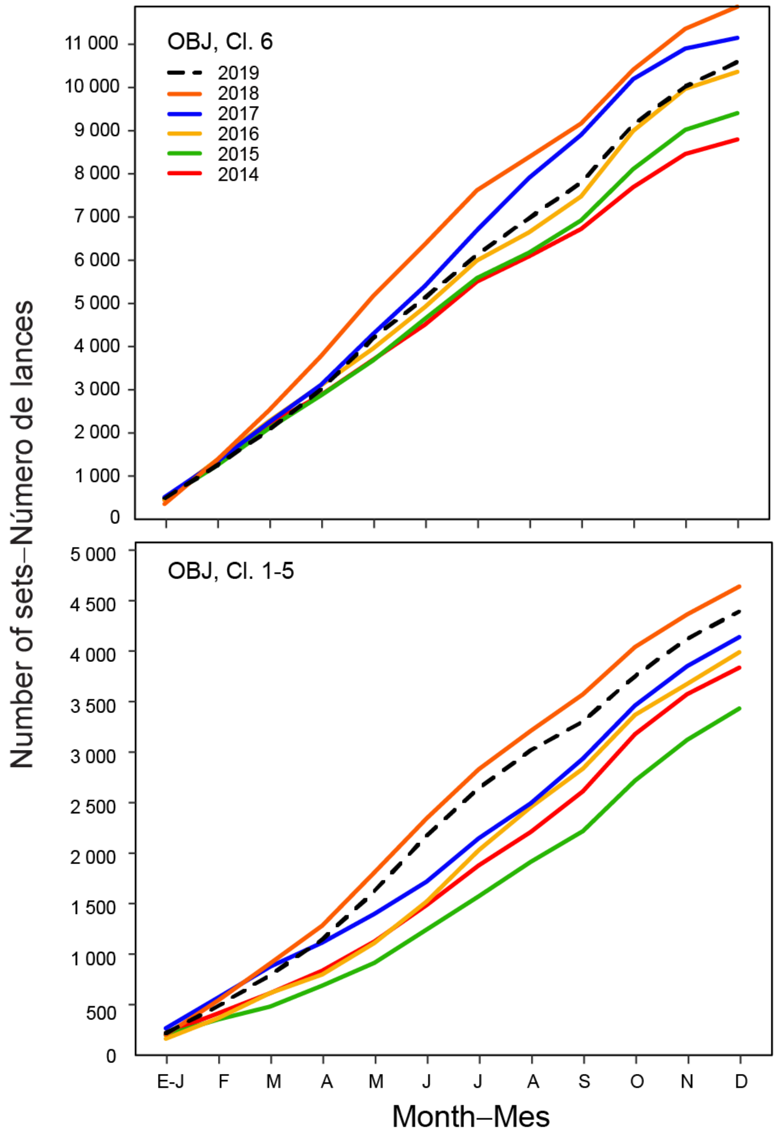

FIGURE 10. **Cumulative number of floating-object (OBJ) sets, by month, 2014-2019: Class-6 vessels (top); Class 1-5 vessels (bottom). Updated from Document IATTC-93 INF-A.**

3.2.3. Catch per set

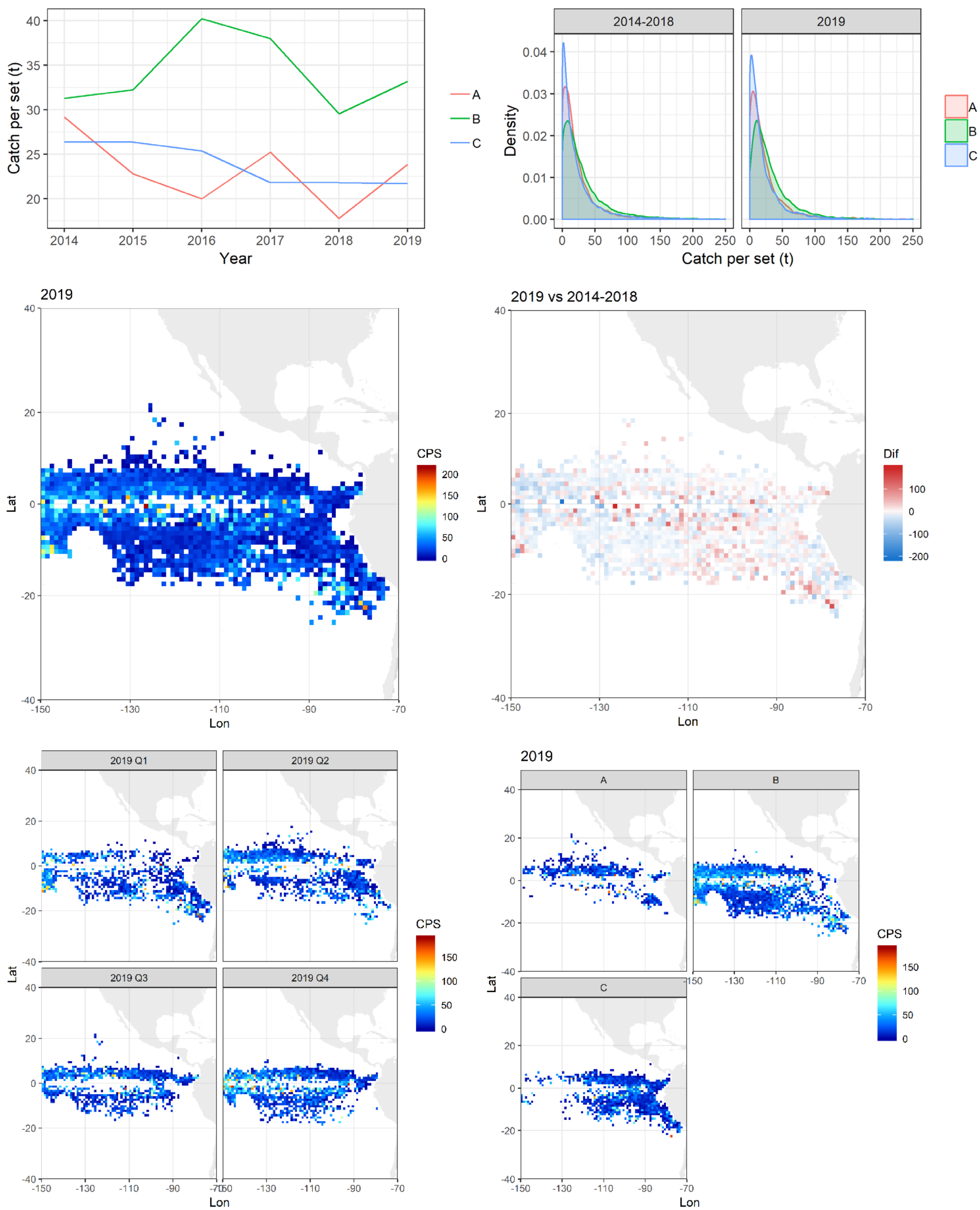

FIGURE 11. **Top left: Evolution of catch per set, by cluster, 2014-2019 (see section 3.1 for details); Top right: Density plot of catch per set for 2014-2018 average and 2019, by cluster; Center left: average catch per set, by 1°-area, for 2019; Center right: differences of average catch per set, by 1°-area, 2019 vs 2014-2018; Bottom left: average catch per set, by 1°-area and quarter, for 2019; Bottom right: average catch per set, by 1°-area and cluster, for 2019**.

3.3. Activity

The indicators in this section were estimated for all activities, based on OBJ origin information and fishing activity records from observers, for the whole Class 6 fleet, by trip and vessel (section 3.3.1, Table 2), and by cluster (section 3.3.2, Table 4), as well as by cluster, vessel and trip for activities of special interest: sets, deployments and encounters (Tables 3, 5; section 3.3.3, Fig. 12). Because of their importance, sets, deployments and encounters were also analyzed in detail for the whole fleet, by cluster, spatially (section 3.3.4-3.3.8, Figs 13-17), and within the trip (section 3.3.9, Fig. 18). For encounters indicators (sections 3.3.7-3.3.8; Figs. 16-17), deployments and OBJ sets were disregarded, as results were otherwise completely driven by those activities and would hinder any interesting spatial and temporal patterns. In these cases, encounters reflect the evolution and the areas where FADs where visited but led to no OBJ sets or floating-object deployments/re-deployments. A spatial indicator of the differences between encounters and OBJ sets was also computed to highlight areas where objects presence was associated with subsequent fishing, or the lack of it. Similarly, the evolution of the different floating-objects locating methods was also estimated for encounters and sets, by cluster (section 3.3.10, Fig. 19), to inform different OBJ-oriented strategies.

3.3.1. General activity table

TABLE 2. Class 6 vessels activities on floating-objects, 2019 and 2014-2018 averages. Included, for information, the number of vessels and trips in the analysis.

Year	Own Now	Own Prev	Dep	Given	Taken	Adrift	Unk	Oth	Enc	Sets	Ves	Trips
2014-2018	18	7657	17410	3768	6959	2736	3	3	40296	10144	145	662
2019	35	6288	23780	3744	6816	2823	16	5	45680	10474	146	669

TABLE 3. Class-6 vessel floating-object deployment, encounter and OBJ set average rates, by vessel and trip, for 2019 and 2014-2018.

Year	Deployments		Encounters		Sets	
	Vessel	Trip	Vessel	Trip	Vessel	Trip
2014-2018	120.1	26.3	277.9	60.9	70.0	15.3
2019	162.9	35.5	312.9	68.3	71.7	15.7

3.3.2. Activity table by cluster

TABLE 4. Class 6 vessel activities on floating-objects, by cluster, for 2019 and 2014-2018 averages. Included, for information, is the number of vessels and trips in the analysis.

Year	Cluster	Own Now	Own Prev	Dep	Given	Taken	Adrift	Unk	Oth	Enc	Sets	Ves	Trips
2014-2018	A	3	155	259	199	970	446	1	0	2084	955	37	134
	B	6	5126	12317	1983	2275	563	1	2	23509	4926	49	221
	C	10	2375	4834	1586	3715	1728	1	1	14703	4262	58	307
2019	A	4	134	166	262	1288	373	16	2	2292	1294	40	132
	B	21	4144	17919	1960	2193	525	0	0	28475	5008	49	216
	C	10	2010	5695	1522	3335	1925	0	3	14913	4172	57	321

TABLE 5. Class-6 vessel floating-object deployment, encounter and OBJ set average rates, by cluster, vessel and trip, for 2019 and 2014-2018.

Year	Cluster	Deployments		Encounters		Sets	
		Vessel	Trip	Vessel	Trip	Vessel	Trip
2014-2018	A	7.0	1.9	56.0	15.6	25.7	7.1
	B	249.3	55.8	475.9	106.5	99.7	22.3
	C	82.8	15.7	251.8	47.8	73.0	13.9
2019	A	4.2	1.3	57.3	17.4	32.4	9.8
	B	365.7	83.0	581.1	131.8	102.2	23.2
	C	99.9	17.7	261.6	46.5	73.2	13.0

3.3.3. Evolution of activities by cluster

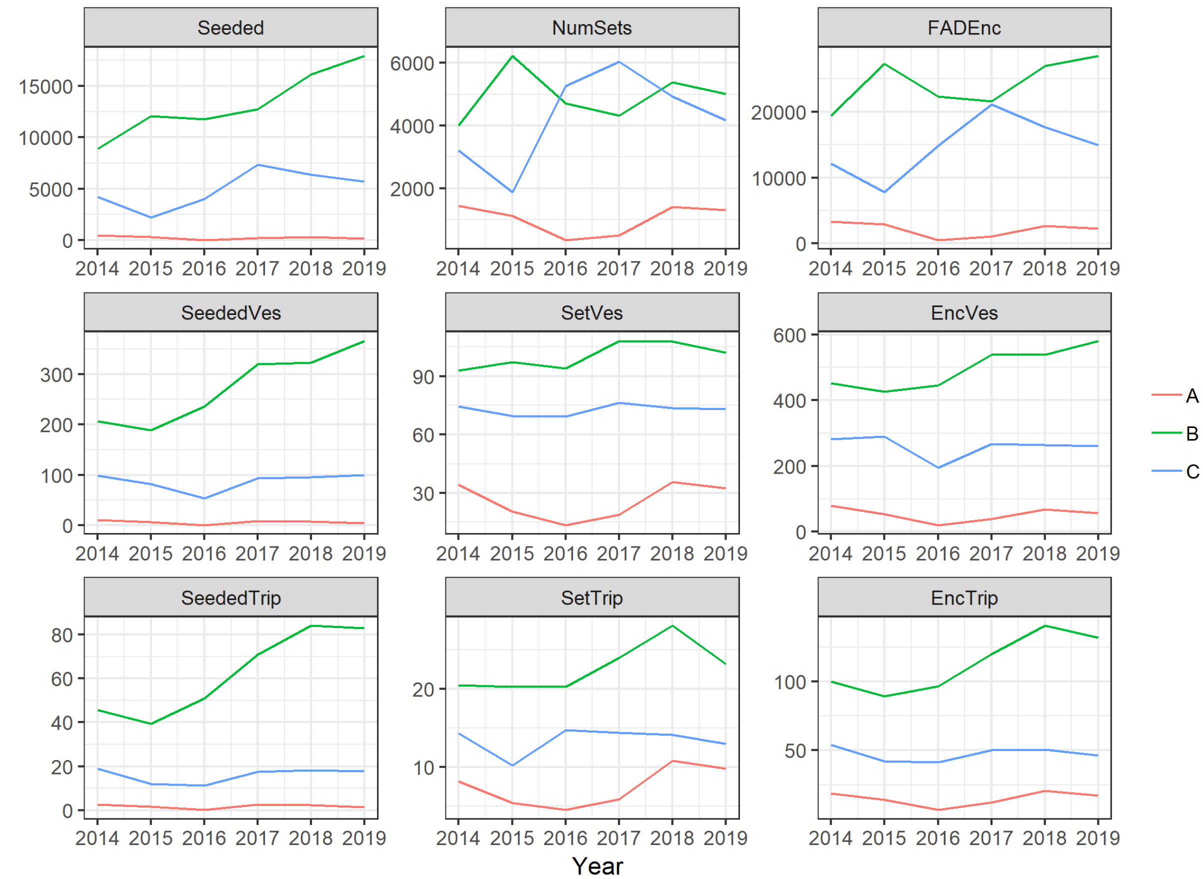

FIGURE 12. **Top: Evolution of floating-object deployments, sets and encounters, by cluster, 2014-2019; Center: Evolution of floating-object deployments, sets and encounters, by cluster-vessel average, 2014-2019; Bottom: Evolution of floating-object deployments, sets and encounters, by cluster-trip average, 2014-2019.**

3.3.4. OBJ sets

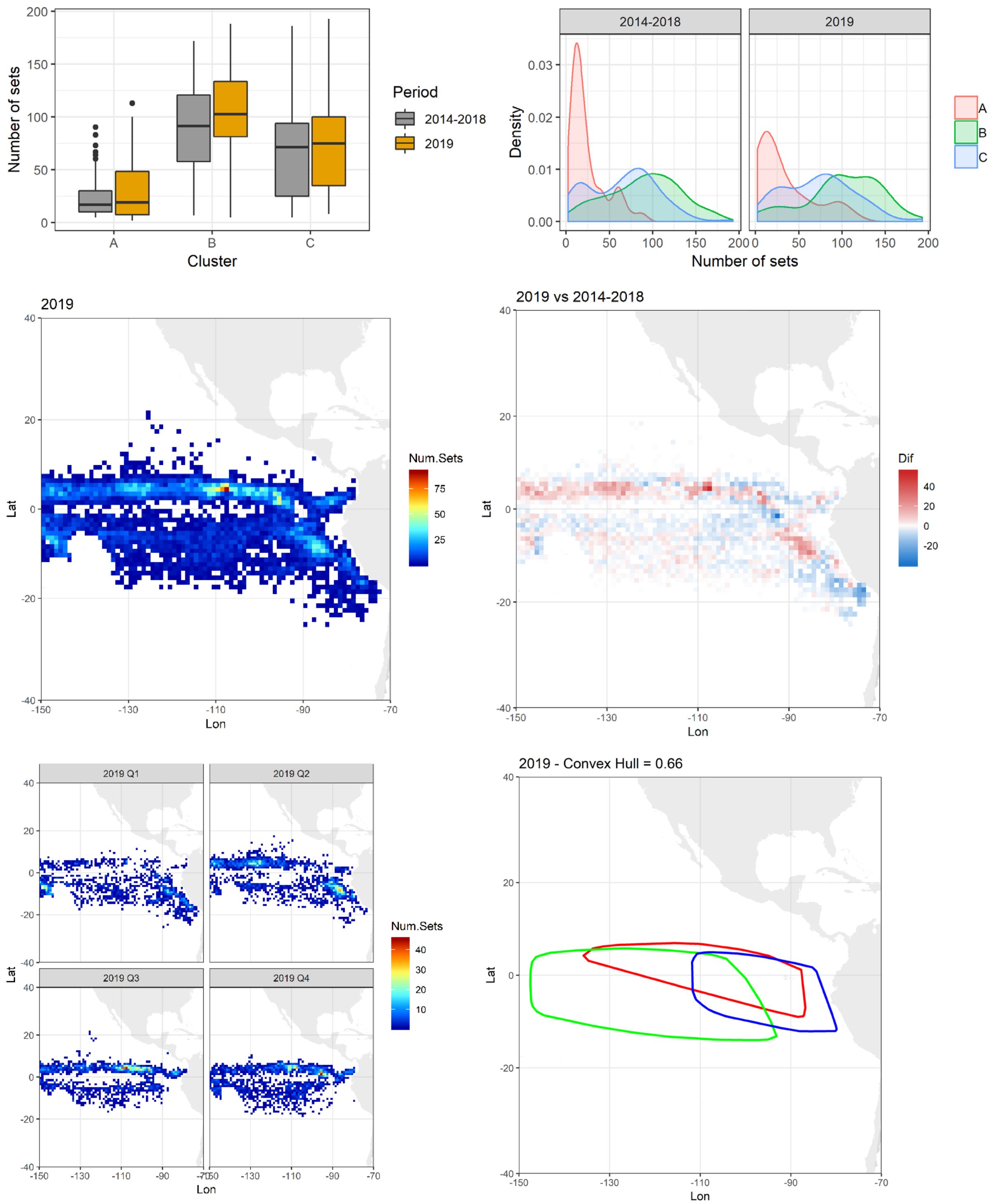

FIGURE 13. **Top left: Boxplots of the number of OBJ sets per vessel, by cluster, 2014-2018 average and 2019; Top right: Density plot of OBJ sets per vessel for 2014-2018 average and 2019, by cluster; Center left: number of OBJ sets, by 1°-area, for 2019; Center right: differences of OBJ sets, by 1°-area, 2019 vs 2014-2018 average; Bottom left: number of OBJ sets, by 1°-area and quarter, for 2019; Bottom right: convex hull estimates of 66% of OBJ sets, by cluster (Red = A, Green = B, Blue = C), for 2019.**

3.3.5. Set time

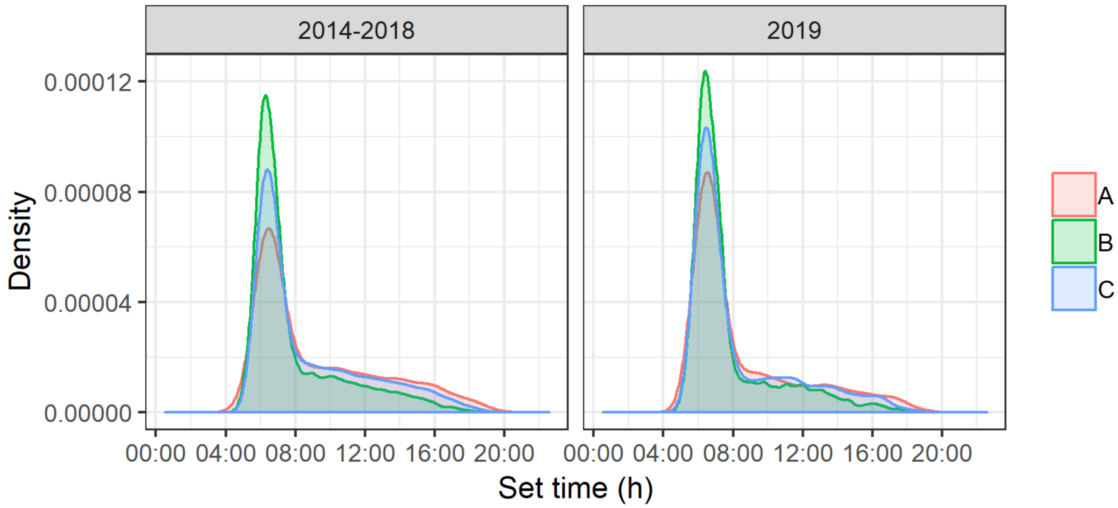

FIGURE 14. **Density plot of OBJ set time, by cluster, 2014-2018 average and 2019.**

3.3.6. Deployments

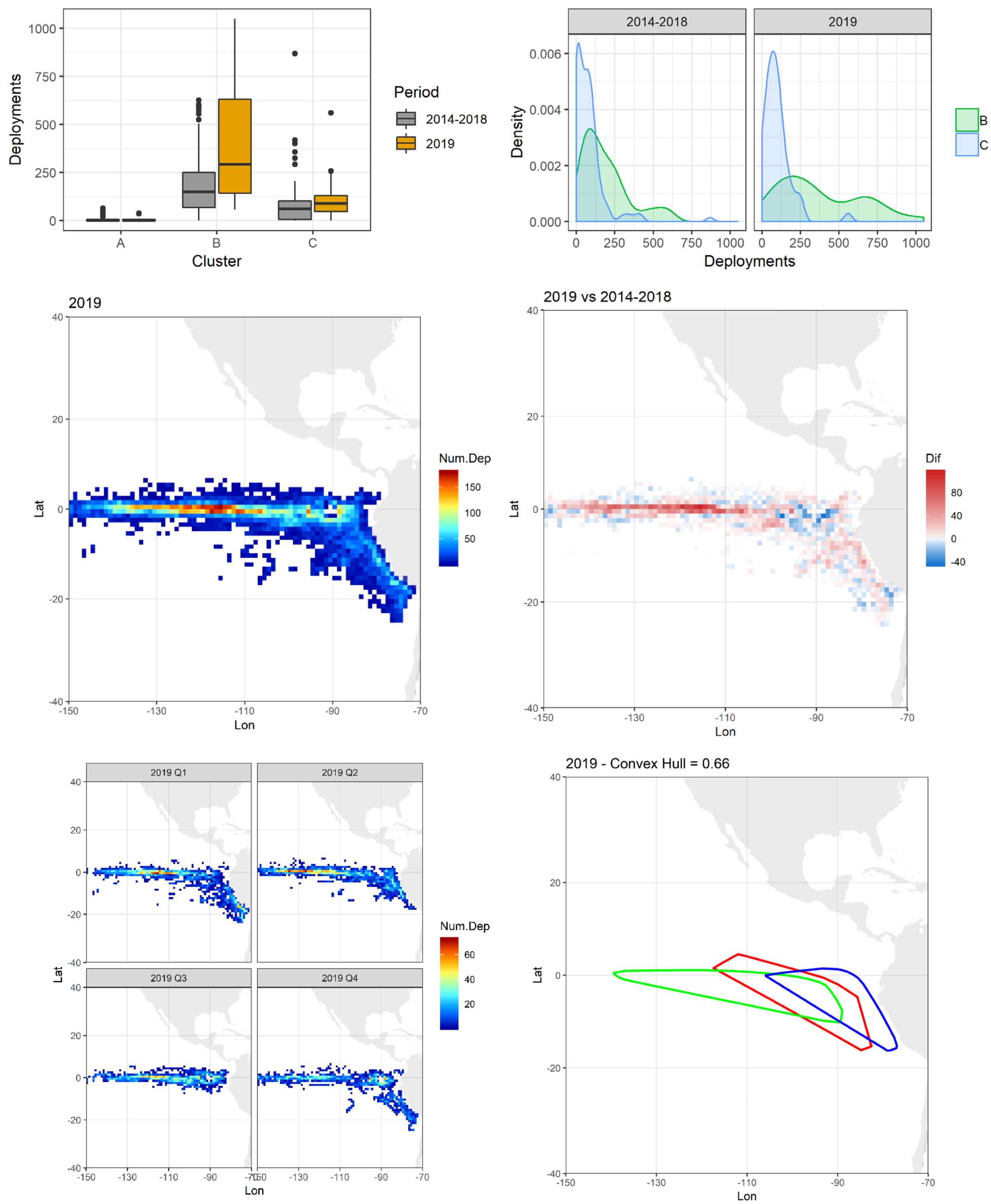

FIGURE 15. **Top left: Boxplots of the number of deployments per vessel, by cluster, 2014-2018 average and 2019; Top right: Density plot of deployments per vessel for 2014-2018 average and 2019, by cluster; Center left: number of deployments, by 1°-area, for 2019; Center right: differences of deployments, by 1°-area, 2019 vs 2014-2018 average; Bottom left: number of deployments, by 1°-area and quarter, for 2019; Bottom right: convex hull estimates of 66% of deployments, by cluster (Red = A, Green = B, Blue = C), for 2019.**

3.3.7. Encounters

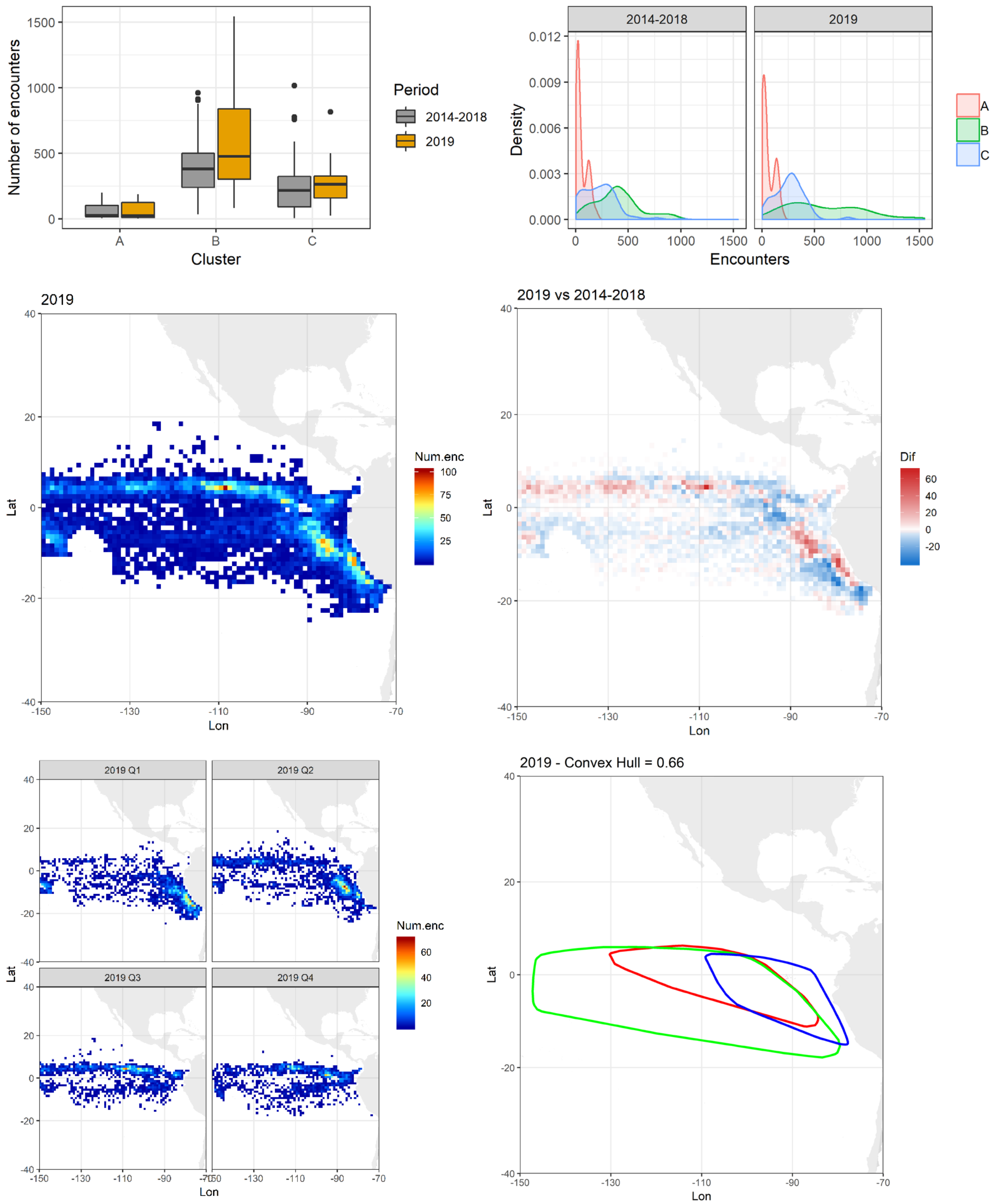

FIGURE 16. **Top left: Boxplots of the number of OBJ encounters per vessel, by cluster, 2014-2018 average and 2019; Top right: Density plot of OBJ encounters per vessel for 2014-2018 average and 2019, by cluster; Center left: OBJ encounters, by 1°-area, for 2019; Center right: differences of OBJ encounters, by 1°-area, 2019 vs 2014-2018 average; Bottom left: OBJ encounters, by 1°-area and quarter, for 2019; Bottom right: convex hull estimates of 66% of OBJ encounters, by cluster (Red = A, Green = B, Blue = C), for 2019.**

3.3.8. Encounters versus sets

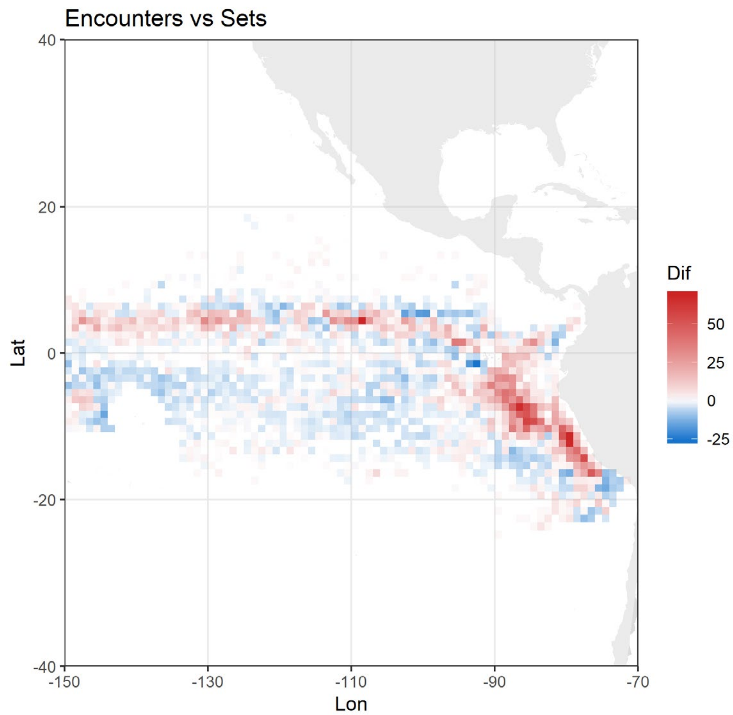

FIGURE 17. Differences between the number of OBJ encounters and the number of OBJ sets, by 1°-area, 2019. Red areas denote hotspots of floating objects visits with no fishing activity associated. Blue cells, instead, denote areas where visits led to fishing sets.

3.3.9. Activity dynamics within the trip

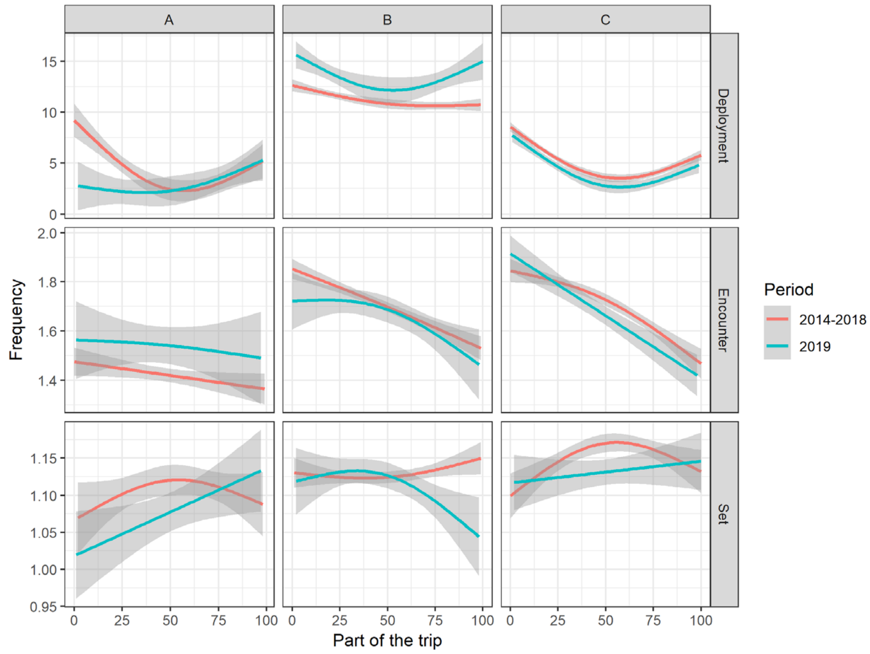

FIGURE 18. Evolution of floating-object deployment, encounter and set activities (number of each activity) within the trip, 2014-2018 averages and 2019. Only trips with a duration of 25-90 days were considered, quantiles 5 and 95, respectively. Trips were divided into 100 equal parts for standardization purposes.

3.3.10. Evolution of location method

FIGURE 19. Evolution of locating methods for OBJ encounters and sets, by cluster, 2014-2019.

3.4. Buoy-based indices

The indicators in this section have been estimated using buoy data for 138 Class 1-6 vessels reporting in 2019 (44 and 94 vessels for Class 1-5 and Class 6, respectively). Because the limits on the number of active

FADs per vessel (*i.e.* active buoys) are class-specific, as established by Resolution C-17-02 [2], the indicators in this category have been estimated for each class-limit, when appropriate (sections 3.4.1-3.4.2, Table 6, Fig. 20). In addition, the indicators in this category have been only estimated for 2019, as the time series starts in 2018 and interpretaions on the evolution can be misleading. Future work will extend the analyis period to consider longer time series, when data are available.

Although not all vessels that deploy FADs comply with the requirement of Resolution C-17-02 to report daily FAD data, and some do so only intermittently, observer data indicate that reporting rates for vessels deploying and fishing on their own FADs are high (median 85%; average 83%). Reporting rates for Class 1-5 vessels cannot be estimated, as that fleet segment does not routinely and systematically carry observers, as noted above. The staff considers that extrapolating from these data to estimate the total number of FADs is not advisable, since the fishing strategies used by vessels vary by capacity, company, flag, season, or a combination of these and other factors, and the assumptions that would have to be made may lead to misleading results and interpretation. They do not represent total FADs at sea, because (a) buoys can be deactivated remotely but the FAD remains at sea, and (b) not all vessels report, so these are probably underestimates.

3.4.1. Daily active buoys per vessel:

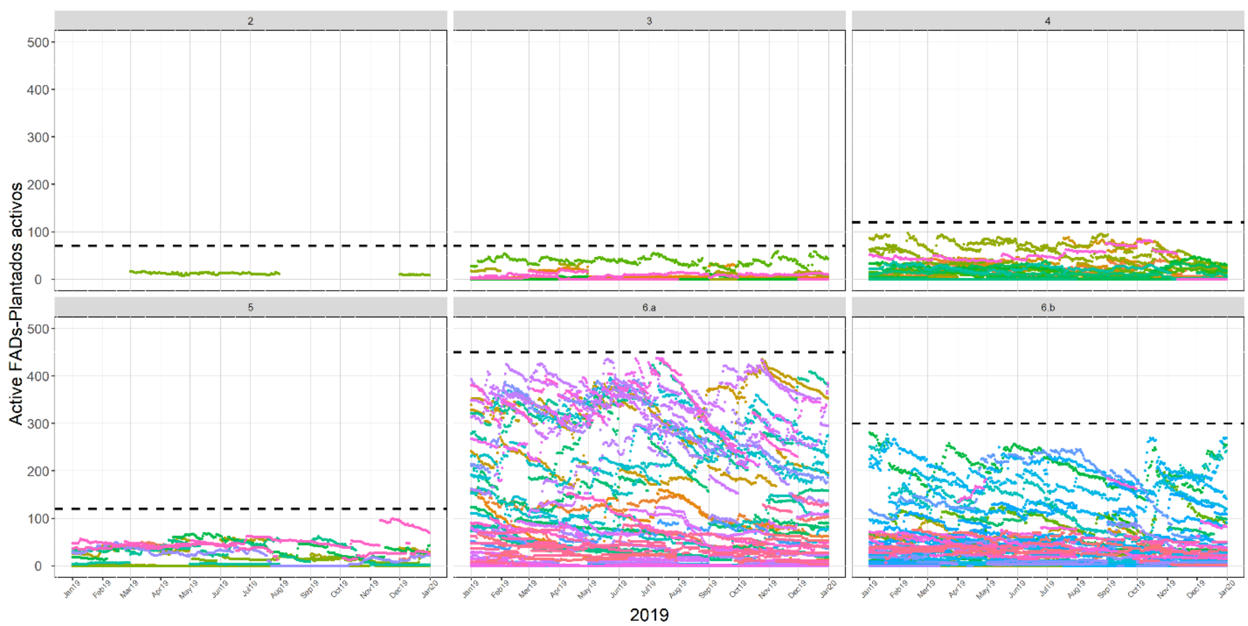

FIGURE 20. Evolution of daily active FADs per vessel and class, 2019. Each color represents a vessel (138 total). Points are used to show data reporting gaps per vessel. The following class and class-limits are considered: Class 6 ≥ 1,200 m^3 = 450 (6.a in the figure); Class 6 < 1,200 m^3 = 300 (6.b in the figure); Class 4-5 = 120, Class 1-3 = 70.

[2] Class 6 (⩾ 1,200 m^3) = 450; Class 6 (< 1,200 m^3) = 300; Class 4-5 = 120, Class 1-3 = 70

3.4.2. Annual and monthly statistic:

TABLE 6. Monthly and annual minimum, mean, maximum, and standard deviations of active FADs (*i.e.* buoys), by class-limit, 2019. The analysis includes 46 Class-6 <1200 m^3, 48 Class-6 ≥ 1200 m^3, 35 Class-4-5, and 9 Class-1-3 vessels.

	Class 1-3				Class 4-5				Class 6 < 1200				Class 6 >1200			
Month	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD
Jan	1	9.7	48	13.3	1	25.2	94	21.6	1	51	281	64.6	1	146.8	409	122.4
Feb	1	10.1	54	15.2	1	24.5	97	18.4	1	51.7	247	56.5	1	148.5	425	135.1
Mar	2	15.9	47	11.7	1	26.5	93	16.5	1	54	258	54.1	1	140.5	426	129.7
Apr	1	17.2	41	11.9	3	30.6	85	15.6	1	63.5	239	51.7	1	152.2	396	125.8
May	1	11.6	45	14	1	27.6	88	22	1	52.9	256	61.7	1	156	435	142
Jun	1	13	48	13.4	1	28	78	19.4	1	53.4	252	63.5	1	154.4	437	140.7
Jul	3	15.2	55	15.6	1	26	88	21.6	1	52.4	246	60.4	1	153.9	438	137.8
Aug	1	12.4	44	11.3	1	26	95	22.6	1	49.5	245	57.7	1	155.1	403	127.2
Sep	4	15	33	9.1	1	31.6	94	21.8	2	66.5	202	54.6	1	149.7	422	119.9
Oct	1	13.1	41	12.5	1	23.8	84	21.7	1	50	269	60.1	3	146.9	435	133.7
Nov	1	12.4	59	15.5	1	20.7	100	20.8	1	52.7	212	61.7	1	139.4	416	123.9
Dec	2	12.7	58	12.7	1	18.9	94	17.8	1	49.6	270	62.6	1	119.9	409	116
Annual	1	13.2	59	13.3	1	25.9	100	20.2	1	53.9	281	59.5	1	147	438	130.3

3.4.3. Daily total active buoys

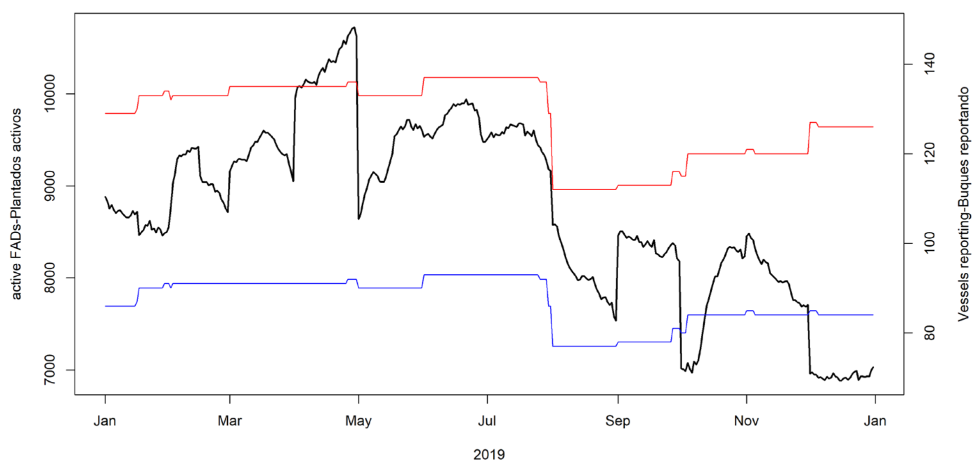

FIGURE 21. Number of active FADs reported by the purse-seine fleet in 2019 (black line) and number of vessels reporting daily (red: total; blue: Class-6 vessels). Includes 94 Class-6 vessels, 11 Class-5, 24 Class-4, 8 Class-3, and 1 Class-2. The number of total vessels reporting daily ranged from 112 to 138 (median = 133, average = 128. The number of total daily active buoys reported in 2019 ranged from 6881 to 10725 (median = 8743, mean 8752).

3.4.4. Monthly buoy densities

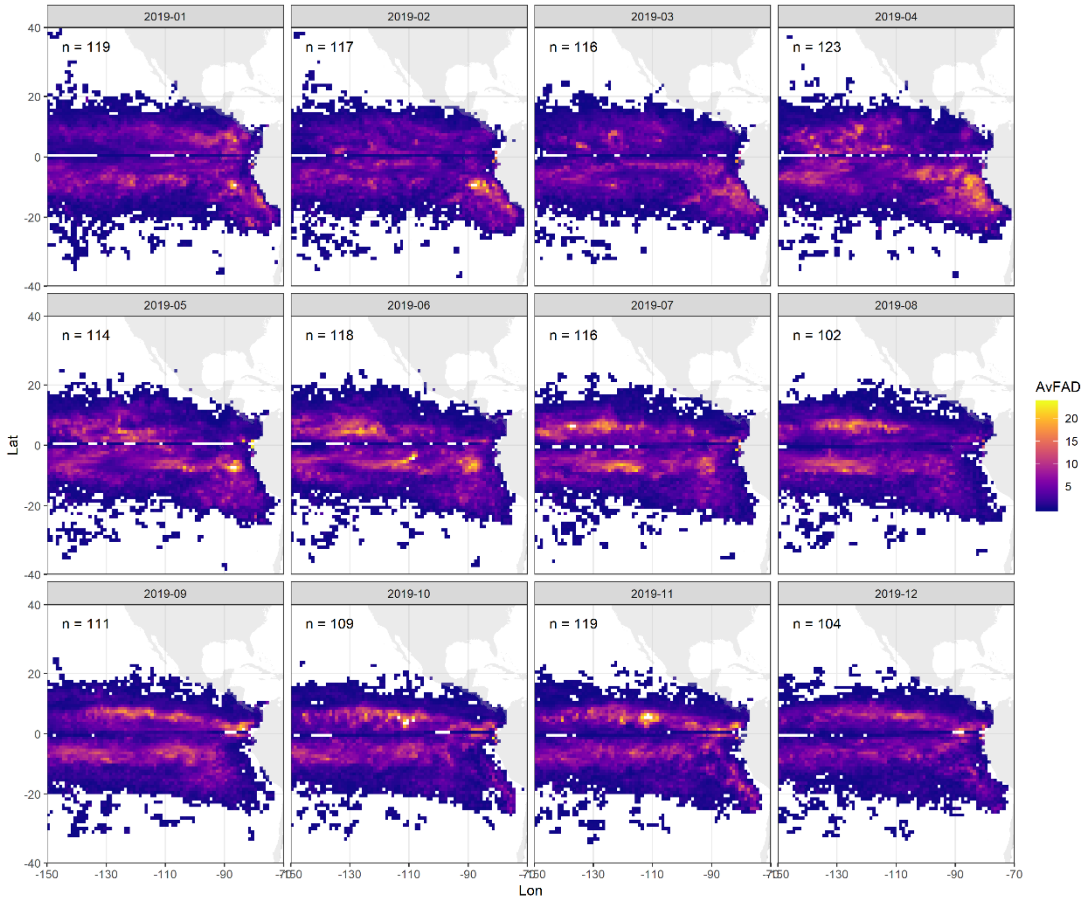

FIGURE 22. Average number of active FADs, by 1°-area, reported by between 102 and 123 vessels (mean = 114), by month, during the January-December 2019 period.

TABLE 7. Total number of active FADs in the EPO, reported by between 102 and 123 vessels (mean = 114), by month, and average, 2019. Number of active FADs ranged from 7155 to 10797 (average = 8944). Values correspond to those shown in Figure 22 above. Although very similar, these numbers do not match exactly the values provided in Figure 21 as the number of vessels reporting INF1 (daily active FADs per vessel) and INF2 (spatial distribution of active FADs per vessel)[3] is not necessarily the same.

Month	Sum of average active FADs	Number of vessels
Jan	9158	119
Feb	8064	117
Mar	7768	116
Apr	10797	123
May	9663	114
Jun	10117	118
Jul	9828	116
Aug	8417	102
Sep	9243	111
Oct	8447	109
Nov	8673	119
Dec	7155	104
Average	8944	114

3.4.5. Annual buoy densities

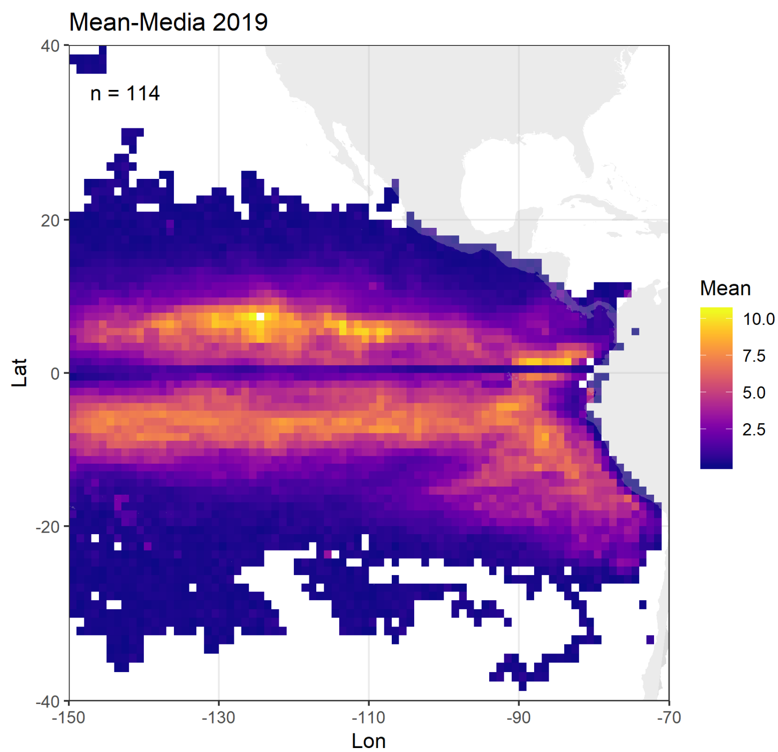

FIGURE 23. Average number of active FADs, by 1°-area, reported by between 104 and 123 vessels (mean = 114) during the January-December 2019 period.

[3] INF1 and INF2 are active FADs (*i.e.* buoys) reporting formats developed by the WG on FADs and the IATTC staff (as requested by Res. C-17-02). INF1 intends to report daily active FADs per vessel, whereas INF2 reports the spatial distribution of average active buoys per vessel, by 1°-area.

3.5. Capacity indicators

The IATTC uses well volume, in cubic meters (m^3), to measure the carrying capacity of purse-seine vessels. When reliable well volume data are not available for a purse-seine vessel, it is calculated by applying a conversion factor to its capacity in tons. In 2019, the estimated carrying capacity is 265,085 m^3 for a total of 261 purse seine vessels (Figure 24).

The cumulative capacity at sea during 2019 is compared to those of the previous five years in Figure 25.

The monthly values of the averages of the total well volumes at sea (VAS), in thousands of cubic meters, are estimated at weekly intervals by the IATTC staff. The average monthly VAS values for 2009-2018 and 2019 were slightly over 141,000 m^3 (60% of total capacity) and about 146,000 m^3 (55% of total capacity), respectively.

The figures and indicators in this category were taken from section 6.1 of SAC-11-03 (Tables A-10, A-11a, A-11b and A-12; Figs. 2-3).

3.5.1. Carrying capacity

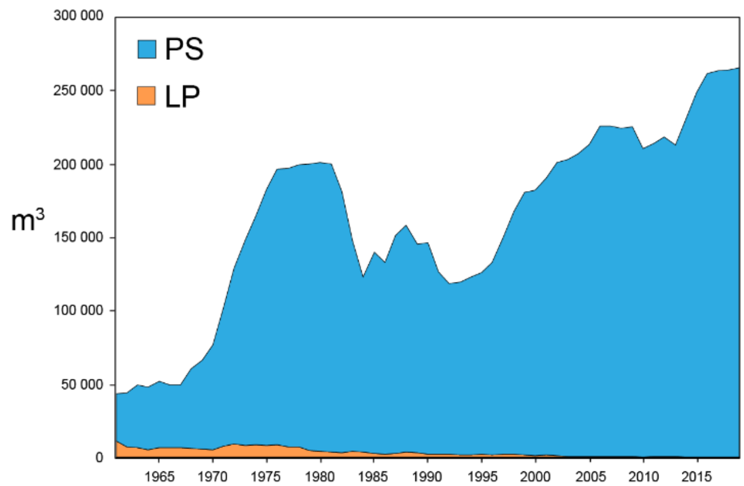

FIGURE 24. Carrying capacity, in cubic meters of well volume, of the purse-seine and pole and line fleets in the EPO, 1961-2019. Source: SAC-11-03 (Fig. 2).

3.5.2. Cumulative capacity

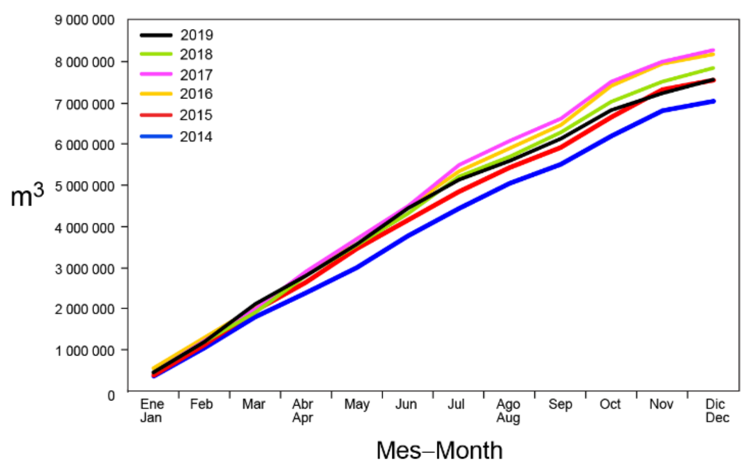

FIGURE 25. Cumulative capacity of the purse seine and pole and line fleet at sea, by month, 2014-2019. Source: SAC-11-03 (Fig. 3).

3.6. Technology

Fishing efficiency is known to be related to the gear and onboard technology used by vessels. Because of that, in this first approximation, a series of indicators showing the evolution of FAD designs (*e.g.* FAD depth), net size (*i.e.* depth), as well as their spatial distribution have been analyzed. Only information related to deployments and fishing sets was used to estimate FAD depth (Fig. 26) and net size (Fig. 27) indicators, respectively. Besides, the proportion of trips using specific technologies, by cluster (Fig 28), was analyzed to inform the evolution of OBJ-oriented fishing strategies in the study period.

3.6.1. FAD depth

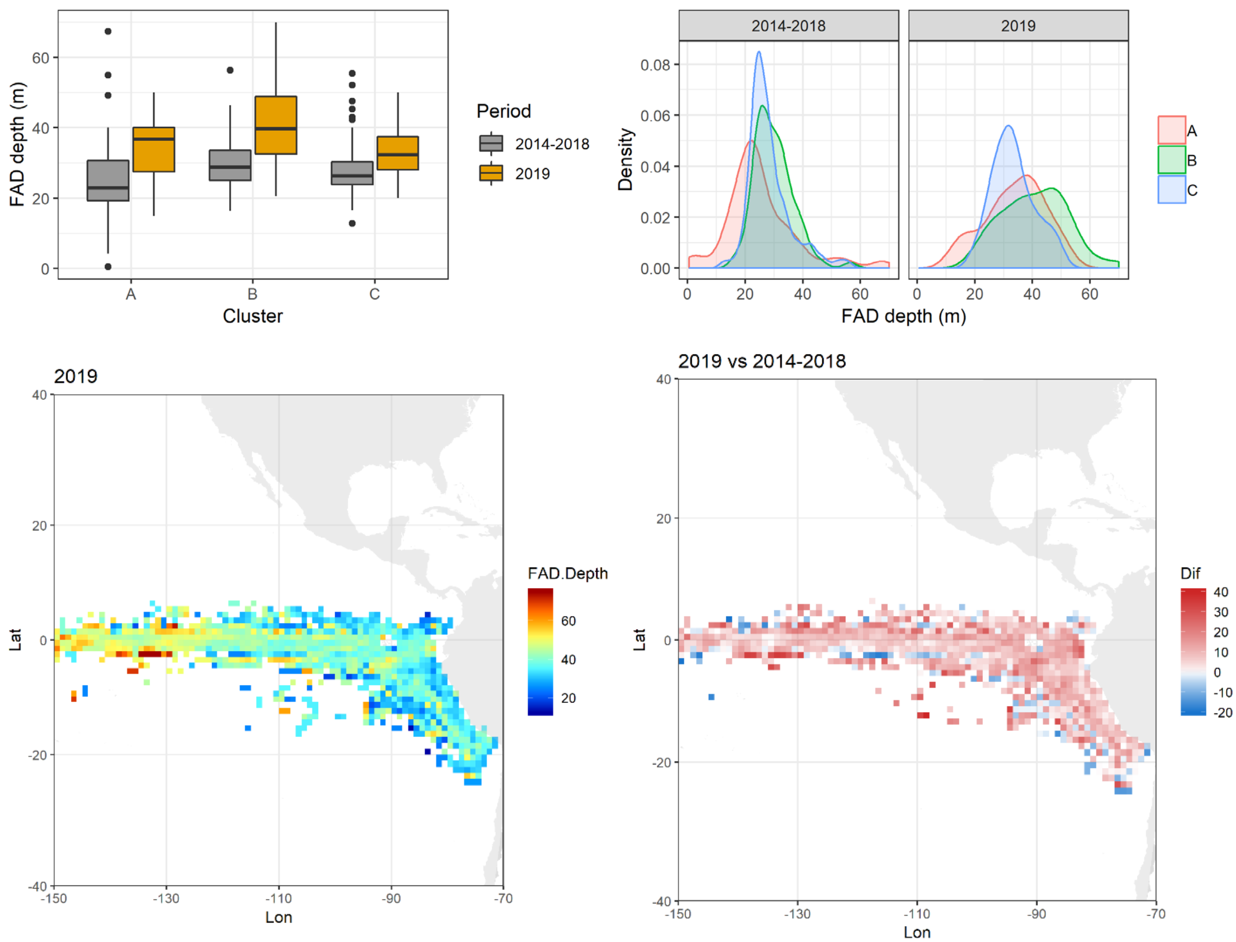

FIGURE 26. Top left: Boxplots of FAD depth for deployments, by cluster, 2014-2018 average and 2019; Top right: Density plot of FAD depth for deployments, 2014-2018 average and 2019, by cluster; Bottom left: average FAD depth, by 1°-area, for 2019; Center right: differences of FAD depth, by 1°-area, 2019 vs 2014-2018 average. All indicators are in meters. A clear tendency of deploying deeper FADs is observed in 2019, compared to the average of the previous five years (2014-2019).

3.6.2. Net size

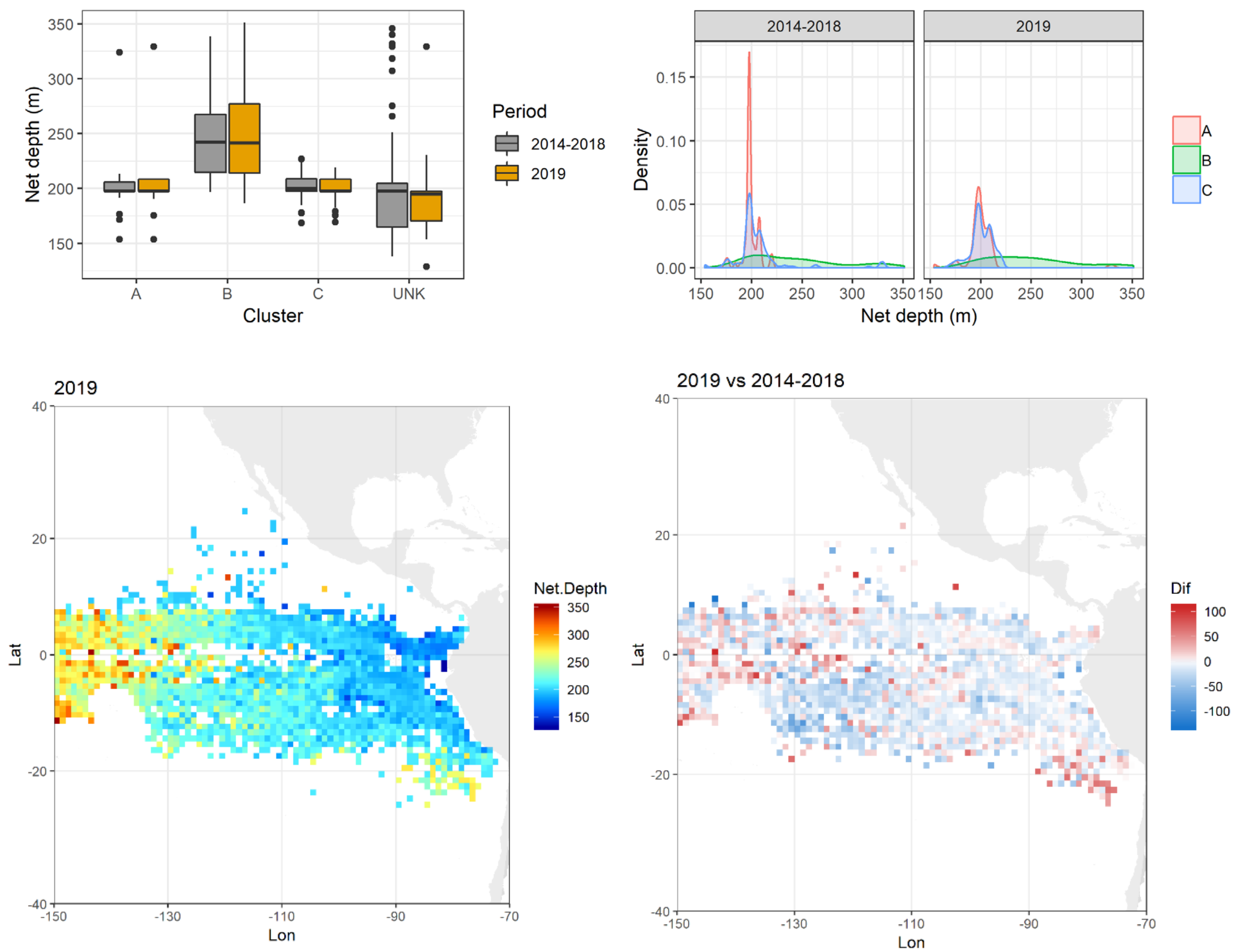

FIGURE 27. Top left: Boxplots of the net depth used in OBJ fishing sets, by cluster, 2014-2018 average and 2019; Top right: Density plot of the net depth used in OBJ fishing sets, 2014-2018 average and 2019, by cluster; Bottom left: average net depth used in OBJ fishing sets, by 1°-area, for 2019; Center right: differences of the net depth used in OBJ fishing sets, by 1°-area, 2019 vs 2014-2018 average. All indicators are in meters. A clear tendency of fishing with deeper nets is observed for higher longitudes in 2019.

3.6.3. Onboard equipment

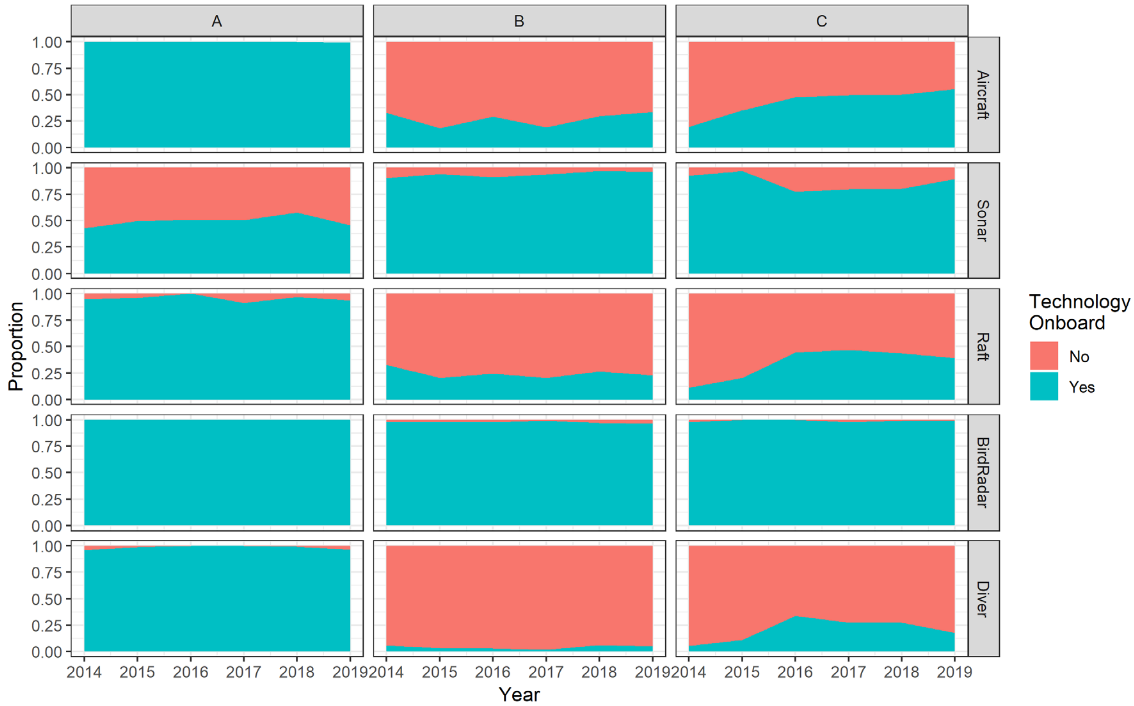

FIGURE 28. Evolution of the proportion of trips using different technologies, by cluster, including the use of aircrafts, sonars, rafts, bird radar and divers. Although some of these technologies have traditionally been used for dolphin fishing (*e.g.* raft, divers, aircrafts), they have been included in the analysis, as are an important component of the technology used by some clusters (see section 3.1 for details on clustering).

3.7. Ecosystem impacts

The Ecosystem and Bycatch considerations document (SAC 11-14) is an extensive review of many different aspects of the tuna fisheries in the EPO. Of particular importance are the estimates of bycatch ratios for the different components of the purse-seine fishery, including the OBJ fishery. Appendix 1 shows 2019 bycatch ratios of the OBJ fishery for the most important group of species, from elasmobranchs to turtles.

3.8. Biology indicators

Length-frequency samples are necessary to obtain age-structured estimates of the populations for various purposes, primarily for the integrated modeling that the staff uses to assess the status of the stocks. Length-frequency samples are obtained from the catches of purse-seine vessels in the EPO by IATTC personnel at ports of landing in Ecuador, Mexico, Panama, and Venezuela. The methods for sampling the catches of tunas are described in the appendix of Suter (2010).

Historical long-term time series of size-composition data for yellowfin and bigeye are available in the Stock Assessment Reports, and the average length stock status indicators are available for the three tropical tuna species in SAC-11-05. In this document, data on the size composition of OBJ catches during 2014-2019 are presented (Fig. 29). The indicators in this section were extracted from SAC-11-03, section 5.

3.8.1. Size composition of tuna catches

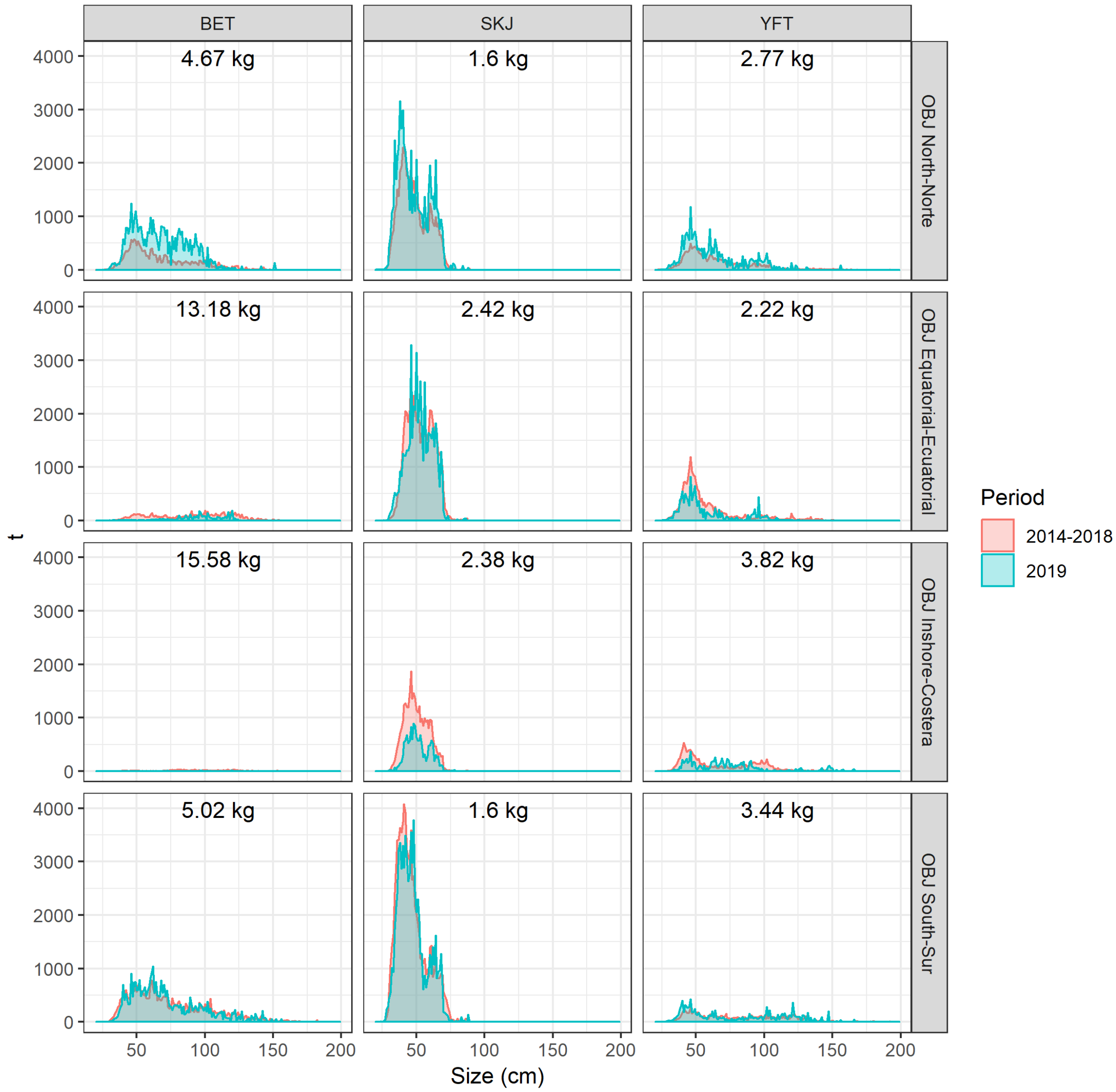

FIGURE 29. Estimated size compositions of bigeye, skipjack and yellowfin caught in the EPO, 2019 and 2014-2018 averages for each purse seine fishery defined by the IATTC staff for analyses of tropical tunas in the EPO (see Figure A-5 of SAC-11-03 for details on the designated areas). The value at the top of each panel is the average weight of the fish in the samples for 2019. Source: SAC-11-03.

4. FUTURE PROSPECTS

Although this document presents the first holistic assessment for the OBJ fishery in the EPO through a set of ~50 indicators, there is still room for improvement. Some of the categories, particularly the socio-economic, the ecosystem impacts, or the biology-ecology and behavior are underrepresented due to the difficulties to systematically obtain large amounts of reliable data. Future versions of this document will try to extend the number of indicators to meet the TWG recommendations (Lopez 2019). Indeed, the staff is currently involved in projects that could produce additional indicators. Examples are the buoy-derived abundance index (*i.e.* a pilot project in collaboration between the IATTC staff, AZTI, OPAGAC and Cape fisheries), the quantification of the impact of stranding events in sensitive areas by lost or abandoned

FADs (project M.5.b), and the analysis of class 1-5 vessels observer data voluntarily collected in TUNACONS vessels.

The data collected through different methodologies and used to produce the indicators in this document have proven to be remarkably useful for the monitoring of the OBJ fishery and its evolution. However, many key aspects remain unknown. For example, catch per set analyses are purely descriptive and have not been standardized. The staff has reiterated the need of collecting additional data (*e.g.* high-resolution buoy data, including buoy ID) to connect databases and advance the scientific analysis and management advice. However, this information is not available for the staff yet. We hope that initiatives like this work are well received by the scientific community and stakeholders in general, and that will help promote, potentially, data exchange between institutions for a better assessment of fishery impacts and sustainability.

In addition, the staff is planning to increase interaction with the fishing community, an endless source of first-hand information about the stock, the environment, and the fishery in general. Skippers workshops have been conducted over the years with the participation of the staff members for different reasons. We see those forums as a great opportunity to build capacity, but also increase staff’s sensitivity to changes in the fleet behavior and strategy, the species, or the dynamics of the environment in a more tangible and immediate way. Because of that, starting in 2020, workshops may be accompanied with a series of brief questionnaires on the most urgent matters, as well as basic questions about the fishery. Results of those consultations will be included in this document in the future too.

5. RECOMMENDATIONS

This section will be developed in the due course and will match the reccomendations for the FAD fishery in the future staff recommendations document, including data collection and any other matters, as needed.

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Suter, J. M. (2010). "An evaluation of the area stratification used for sampling tunas in the eastern Pacific Ocean and implications for estimating total annual catches." La Jolla, CA, Inter-American Tropical Tuna Commision, 114pp. (Special Report, 18).

APPENDIX 1. OBJ bycatch rates, 2014-2019.

Source: from SAC-11-04, Tables J-2 to J-6.

TABLE 8. Purse-seine interactions and mortalities reported by onboard observers in numbers of turtles for size-class 6 vessels with a carrying capacity >363 t (2014–2019). Data for 2019 are considered preliminary. Adapted from SAC-11-04, tables J-2a and J-2b.

Year	*Lepidochelys olivacea,* olive ridley		*Chelonia agassizii, Chelonia mydas,* eastern Pacific green		*Caretta caretta,* loggerhead		*Eretmochelys imbricata* hawksbill		*Dermochelys coriacea* leatherback		Unidentified turtles	
	Int.	*Mort.*	*Int.*	*Mort.*	*Int.*	*Mort.*	*Int.*	*Mor.*	*Int.*	*Mort.*	*Int.*	*Mort.*
2014	307	3	69	0	26	1	7	0	7	0	135	1
2015	201	2	55	0	28	0	3	0	4	0	182	0
2016	367	4	82	0	19	0	15	0	2	0	339	2
2017	291	2	50	0	33	0	9	0	2	0	280	0
2018	169	2	58	2	19	0	8	0	3	0	177	0
2019	210	1	87	0	15	0	7	0	-	0	221	0
Average	258	2.3	67	0.3	23	0.2	8	0.0	4	0.0	222	0.5

TABLE 9. Estimated purse-seine OBJ catches in metric tons (t) of sharks for size-class 6 vessels with a carrying capacity >363 t (1993–2019). Data for 2019 are considered preliminary. "Other sharks" include whale shark (*Rhincodon typus*), basking shark (*Cetorhinus maximus*) and unidentified sharks (Euselachii). Adapted from SAC-11-04, table J-3.

	Carcharhinidae				**Sphyrnidae**			
Year	***Carcharhinus falciformis*** **silky shark**	***Carcharhinus longimanus*** **oceanic whitetip**	***Prionace glauca*** **blue shark**	**Other requiem sharks**	***Sphyrna zygaena*** **smooth hammerhead**	***Sphyrna lewini*** **scalloped hammerhead**	***Sphyrna mokarran*** **great hammerhead**	***Sphyrna* spp. hammerheads nei**
2014	422	2	1	13	35	23	1	14
2015	540	3	<1	31	32	9	<1	9
2016	488	5	<1	35	24	12	5	11
2017	665	4	<1	54	11	8	<1	6
2018	398	3	<1	28	11	7	<1	6
2019	392	5	<1	26	17	11	1	5
Average	**484**	**4**	**1**	**31**	**22**	**12**	**2**	**9**

Continued

					Lamnidae		**Triakidae**		
Year	***Alopias pelagicus*** **pelagic thresher**	***Alopias superciliosus*** **bigeye thresher**	***Alopias vulpinus*** **thresher shark**	***Alopias* spp. thresher shark, nei**	***Isurus* spp. mako sharks**	**Lamnidae spp. mackerel sharks, porbeagles nei**	**Triakidae spp. houndsharks nei**	**Other sharks**	**All sharks**
2014	<1	<1	<1	<1	2	-	-	24	540
2015	<1	<1	<1	<1	<1	-	-	18	645
2016	<1	<1	<1	<1	1	-	-	19	602
2017	<1	<1	-	<1	<1	-	-	16	766
2018	<1	<1	<1	<1	2	-	-	5	460
2019	<1	<1	-	<1	<1	-	-	6	465
Average	<1	<1	<1	<1	**2**	-	-	**15**	**580**

TABLE 10. Estimated purse-seine OBJ catches in metric tons (t) of rays for size-class 6 vessels with a carrying capacity >363 t (1993–2019). Data for 2019 are considered preliminary. “Other rays” include Chilean torpedo (*Torpedo tremens*), Pacific cownose (*Rhinoptera steindachneri*), and unidentified eagle rays (Myliobatidae). Adapted from SAC-11-04, table J-4.

Year	***Mobula thurstoni*** **Smoothtail manta**	***Mobula mobular*** **Spinetail manta**	***Mobula munkiana,*** **Munk's devil ray**	***Mobula tarapacana*** **Chilean devil ray**	***Mobula birostris*** **Giant manta**	**Mobulidae spp. Mobulid rays, nei**	***Pteroplatytrygon violacea*** **Pelagic stingray**	**Dasyatidae spp. Stingrays, nei**	**Oth rays**	**All rays**
2014	<1	16	<1	<1	<1	1	<1	<1	-	20
2015	<1	3	<1	1	<1	1	<1	<1	-	7
2016	<1	<1	<1	1	4	3	<1	<1	-	10
2017	<1	3	<1	<1	5	7	<1	<1	-	18
2018	<1	3	<1	1	5	6	<1	<1	-	17
2019	<1	2	<1	3	<1	4	<1	<1	-	11
Average	<1	**5.4**	<1	**1.5**	**4.6**	**3.6**	<1	<1	-	**13.8**

TABLE 11. Estimated purse-seine OBJ catches in metric tons (t) of large fishes for size-class 6 vessels with a carrying capacity >363 t (2014–2019). Data for 2019 are considered preliminary. “Other large fishes” include unidentified mackerels (Scombridae), luvar (Luvarus imperialis), and large fishes nei (not elsewhere identified). Adapted from SAC-11-04, table J-5.

Year	**Coryphaenidae spp. Dorado**	***Acanthocybium solandri*** **Wahoo**	***Elagatis bipinnulata*** **Rainbow runner**	***Seriola*** **spp. Amberjacks nei**	***Caranx*** **spp. Jacks, crevalles nei**	***Seriola, Caranx*** **spp. Amberjacks, jacks, crevalles nei**	***Molidae*** **spp. Molas nei**
2014	1,777	517	15	6	3	2	3
2015	1,167	357	15	6	9	2	6
2016	949	318	26	12	4	7	10
2017	1,555	335	18	12	4	4	8
2018	1,483	230	20	62	9	2	5
2019	1,207	201	21	12	5	3	2
Average	**1,356**	**326**	**19**	**18**	**6**	**3**	**6**

Continued

Year	***Lobotes surinamensis*** **Tripletail**	***Sphyraenidae spp.*** **Barracudas**	***Lampris spp.*** **Opahs**	**Gempylidae *spp.* Snake mackerels nei**	**Bramidae *spp.* Pomfrets nei**	**Other large fishes**	**Unidentified fishes**	**All fishes**
2014	2	<1	-	-	-	<1	<1	2,327
2015	2	<1	-	-	<1	<1	2	1,568
2016	2	<1	-	<1	-	<1	<1	1,328
2017	5	<1	-	-	-	<1	1	1,944
2018	3	<1	-	-	-	<1	-	1,816
2019	2	<1	-	-	-	<1	<1	1,455
Average	**3**	**<1**	**-**	**<1**	**<1**	**<1**	**2**	**1740**

TABLE 12. Estimated purse-seine OBJ catches in metric tons (t) of small forage fishes for size-class 6 vessels with a carrying capacity >363 t (2014–2019). Data for 2019 are considered preliminary. "Epipelagic forage fishes" include various mackerels and scad (*Decapterus* spp., *Trachurus* spp., *Selar crumenophthalmus*), Pacific saury (*Cololabis saira*), and tropical two-wing flyingfish (*Exocoetus volitans*). "Other small fishes" include various Tetraodontiformes, driftfishes (Nomeidae), Pacific chub mackerel (*Scomber japonicus*), Pacific tripletail (*Lobotes pacificus*), remoras (*Echeneidae*), longfin batfish (*Platax teira*), and small fishes not elsewhere identified (nei). Adapted from SAC-11-04, Table J-6.

Year	***Auxis* spp.** **Bullet and frigate tunas**	**Balistidae, Monacanthidae spp. Triggerfishes and filefishes**	**Kyphosidae** **Sea chubs**	**Epipelagic forage fishes**	**Small Carangidae spp.** **Carangids, nei**	**Other small fishes**
2014	297	325	8	3	<1	1
2015	177	140	8	6	<1	1
2016	189	416	10	21	<1	3
2017	131	83	7	3	<1	<1
2018	276	54	<1	5	<1	<1
2019	182	57	<1	5	<1	<1
Average	**209**	**179**	**8**	**7**	**1**	**2**