DYNAMICS OF DRIFTING FISH AGGREGATING DEVICES USED IN THE LARGE-SCALE PURSE SEINE FISHERY OF THE WESTERN INDIAN OCEAN

IOTC Secretariat

Abstract

The paper provides an overview of the information available on the dynamics of drifting Fish Aggregating Devices (DFADs) and DFAD-related fisheries operating in the Indian Ocean, based on satellite-tracked buoy data made available to the IOTC since January 2020. In 2021, catches from large-scale purse seiners on drifting floating objects (FOBs) amounted to 410,000 t, representing 86.6% of the total industrial purse seine catch, 76.4% of the total purse seine catch, and 35.1% of the total catch of Indian Ocean tropical tunas. Between January 2020 and December 2022, the daily number of distinct satellite-tracked buoys monitored by the large-scale purse seine fishery of the western Indian Ocean varied between a minimum of 8,408 and a maximum of 11,536. Initial points of buoy trajectories, which reflect both a combination of DFAD deployments and transfers of buoys on FOBs encountered at sea by the purse seiners and their support vessels, cover the main fishing grounds of the purse seine fishery of the western Indian ocean. Trajectories of FOBs derived from daily buoy positions over that period show that the median distance travelled by a FOB was 2,562 km with some of them that travelled more than 20,000 km during their time at sea. The daily number of buoys activated in the fishery was on average of NA buoys per day during 2020-2022, with some large variability over the period. Since early January 2020, the cumulative number of buoys activated and attached to drifting FADs and natural floating objects has reached 25,690, 48,338, and 72,068 at the end of the months of December 2020, 2021, and 2022, respectively.

Introduction

The overarching objective of this paper is to provide participants at the 4th Working Group on FADs (WGFAD04) with an overview of the information available on the dynamics of drifting Fish Aggregating Devices (DFADs) and DFAD-related fisheries operating in the Indian Ocean. As little new information on fisheries catches has become available since the review of the statistics available on DFADs presented at the WGFAD03 and covering the period 1950-2021 (IOTC 2022a), this paper provides a quick recap on the catches of purse seine fisheries at global and ocean-basin scale and focuses on recent DFAD use and dynamics based on satellite-tracked buoy data made available to the IOTC since January 2020 (IOTC Res. 19/02).

Materials & Methods

Global catch data

Global catch data of the principal market tropical tunas (bigeye tuna, skipjack tuna, and yellowfin tuna) were compiled as part of the FIRMS Global Tuna Atlas in collaboration with the four tuna Regional Fisheries Management Organizations (RFMOs), i.e., the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Inter-American Tuna Commission (IATTC), the Western and Central Pacific Fisheries Commission (WCPFC), and the Indian Ocean Tuna Commission (IOTC). The contribution of fishing on drifting floating objects

(FOBs) to the total purse seine catches was estimated from the percentage of each fishing mode reported in the geo-referenced catch data.

IOTC data

Several fisheries data sets shall be reported to the IOTC Secretariat by the Contracting Parties and Cooperating Non-Contracting Parties (CPCs) as per the IOTC Conservation and Management Measures (CMMs) and following the standards and formats defined in the IOTC Reporting guidelines. Although not mandatory, the use of the IOTC forms is recommended to report the data to the Secretariat as these facilitate data curation and management.

Total retained catch data

Nominal catches of retained species have to be expressed in live weight equivalent and reported per year, Indian Ocean major area, fleet, and gear (IOTC Res. 15/02), and preferably reported using IOTC form 1RC.

Catch and effort data

Catch and effort data refer to geo-referenced data aggregated by year, month, grid area, fleet, gear, fishing mode, and species (IOTC Res. 15/02). IOTC forms 3CE and 3AR have been designed for reporting geo-referenced catch and effort data for industrial and coastal fisheries, respectively, while form 3SU is intended to be used to report information on fishing effort exerted by support vessels assisting large-scale purse seiners.

Geo-referenced catches for the three principal market tropical tunas (bigeye tuna, skipjack tuna, and yellowfin tuna) were raised to the best scientific estimates of total retained catches using all available information, including expert knowledge, and by either leveraging data from proxy fleets or adopting substitution schemes when the spatio-temporal information was not available for a given stratum. Based on the assumptions made in the procedure, the raised catch data set includes information on fishing mode for most catches reported for large-scale purse seine fisheries.

FOB-related data

IOTC form 3FA has been developed to report all data elements specific to activities on FADs (Appendix I), including deployments and sets made on FOBs in each time-area stratum, along with corresponding species-specific catches (IOTC Res. 15/02 and 19/02). The current IOTC classification for FOBs derived from para. 6c of IOTC Res. 15/02, which combines the nature of the FOB, the type of tracking system, and the presence of net webbing hanging underneath (see Appendix II), is considered to be less than adequate and potentially confusing, and is therefore in the process of being reviewed (Grande et al. 2018; IOTC 2022b).

FOB-tracking data

IOTC CPCs with fishing vessels using drifting FOBs have the obligation to report daily information on all active FOBs monitored at sea with satellite-tracked buoys since January 1st 2020 (IOTC Res. 19/02). The information to report to the Secretariat shall follow the structure and formats of IOTC form 3BU and contain the date of the month, the instrumented buoy ID, the assigned purse seiner, and one single daily position for each monitored buoy. The forms shall be compiled at monthly intervals and reported to the IOTC Secretariat with a time delay of at least 60, but no longer than 90 days from the end of the reference month.

Data coverage

This global data set covers the period from January 2020 to December 2022 except the buoys monitored by the Republic of Korea for the years 2020 and 2021 which have been recently reported to the Secretariat following non-standard formats (**Appendix III**). Work is ongoing to format the data and insert them into the IOTC database. In addition, the data set does not include any information for the six Kenyan-flagged purse seiners of around 50 m length overall which operated in the Indian Ocean between January 2020 and September 2021 despite some anecdotal evidence of the presence of electronic buoys on the vessels. Finally, no data have been reported for the large-scale purse seiners from I.R. Iran as they do not use satellite-tracked buoys due to international restrictions of access to satellite communication services applied to the country.

Shared buoys

As part of the fishing strategy of the purse seine companies, some buoys may be monitored by several vessels at the same time but information on buoys shared among purse seiners is not available for all fleets. Following the methodology defined by Maufroy and Goujon (2019) for dealing with multiple purse seiners monitoring the same buoys, each daily buoy position in the database was weighted by the number of purse seiners accessing the information.

FOB trajectories

Buoys deployed to track FOBs at sea may be re-used several times during their lifetime, as they can be retrieved from the water following fishing operations or when FOBs drift in areas considered to be unfavourable. To estimate the frequency of re-use of the buoys, as well as their transmission duration, we considered all buoys deployed at sea during a period of 48 consecutive months, excluding buoys that were in operation prior to January 2020 and buoys that could still be at sea after December 2022.

For each buoy, we reconstructed the different FOB trajectories at sea defined as series of uninterrupted successive positions with no temporal gaps in location data exceeding seven days, and with a distance between successive points of less than 861 km, i.e., the maximum observed distance travelled by a buoy during seven consecutive days. Observations associated with speed higher than 5.5 knots (corresponding to the 99.9% quantile of the data set) were also removed. Buoy deployments were associated to the first point of each trajectory, excluding all position data observed during the 3 first days of January 2020 which could refer to buoys deployed prior to the initial date of reporting to the Secretariat.

Results & Discussion

Catch trends

The global catch of tropical tunas taken in association with drifting FOBs has steadily increased since the mid-1960s and is largely dominated by the Western-Central Pacific Ocean (**Fig. 1a**). The Indian Ocean represented 23.3% of the global FOB purse seine catch in 2021 (**Fig. 1b**).

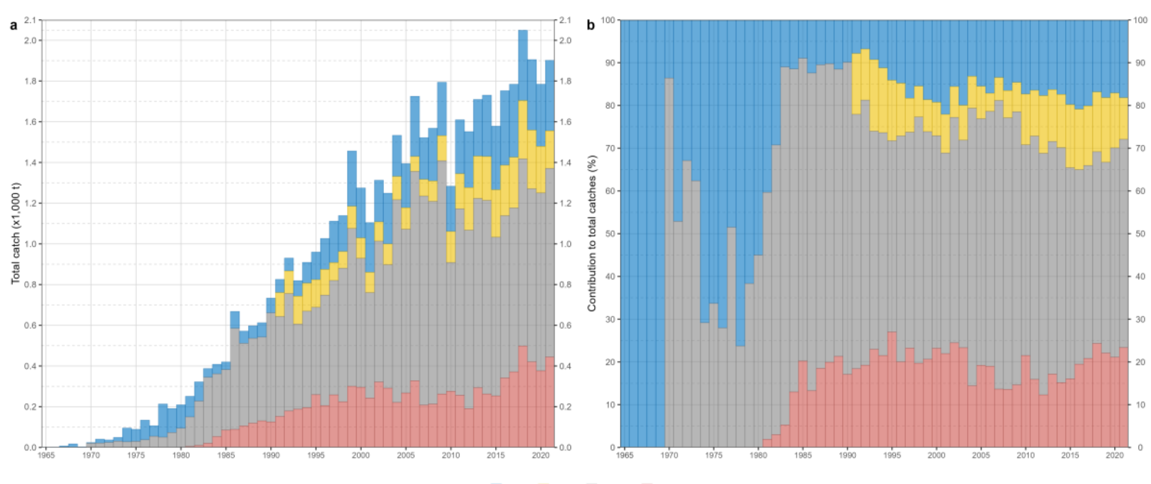

Fig. 1. Annual time series of (a) cumulative catches (metric tonnes; t) and (b) contribution of each tuna RFMO to the global catches of the three principal market tropical tunas (bigeye tuna, skipjack tuna, and yellowfin tuna) caught on schools associated with drifting floating objects for the period 1965-2021

Catches by large-scale industrial purse seiners steadily increased throughout the first two decades of exploitation to exceed 400,000 t during 2002-2006 (**Fig. 2**). Purse seine catches then showed a major decline to average levels of around 276,000 t per year between 2007 and 2015, before increasing to reach highest historical levels at around 483,000 t per year in recent years, excluding the year 2020 marked in particular by the COVID pandemic (**Fig. 2**). In 2021, catches from large-scale purse seiners on FOBs amounted to 410,000 t, representing 86.6% of the total industrial purse seine catch, 76.4% of the total purse seine catch, and 35.1% of the total catch of Indian Ocean tropical tunas.

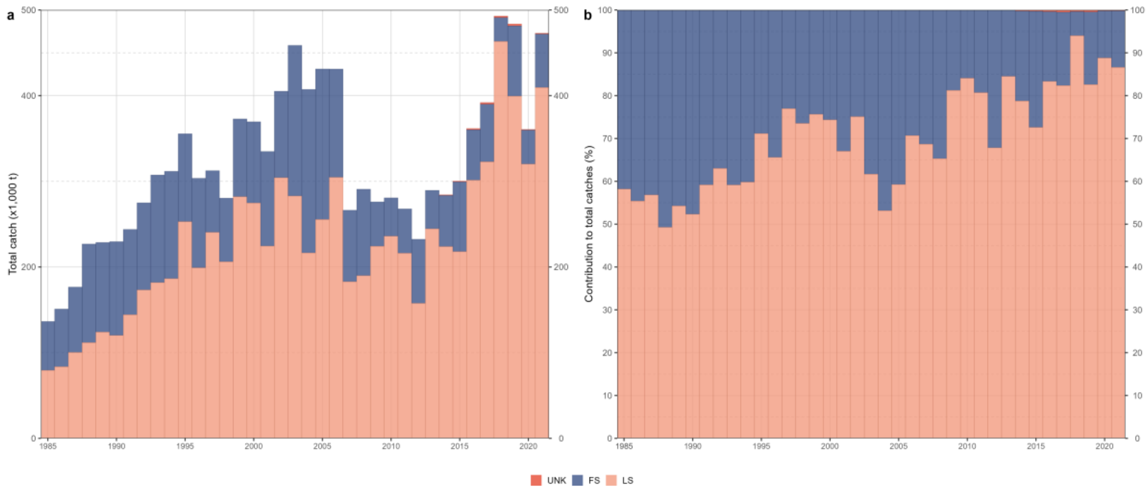

Fig. 2. Annual time series of (a) cumulative retained catches (metric tonnes; t) and (b) contribution of each fishing mode to the industrial purse seine catches of the three principal market tropical tunas (bigeye tuna, skipjack tuna, and yellowfin tuna) in the Indian Ocean for the period 1985-2021. LS = floating object-associated school; FS = free-swimming school; UNK = unknown

Buoys and FOB dynamics

Buoys reuse and FOB trajectories

The global dataset of daily buoy positions covers the period between 2020-2022 and includes 11,321,811 geographic positions collected from 83,222 distinct buoys. As of 30 December 2022, 0 buoys were still found transmitting in the waters of the Indian Ocean. Some buoys may be re-used after having spent some time in the water, i.e., they are deployed and drift at sea for some time, retrieved from the water, and eventually re-deployed at sea to track another FOB later. We identified 133,071 distinct trajectories in the data set. Considering the 47,458 buoys deployed between 2020-01-04 and 2022-01-03, we found that about 60% of the buoys were deployed only once throughout their lifespan, with more than 90% of the buoys described by three trajectories or less (**Fig. 3**).

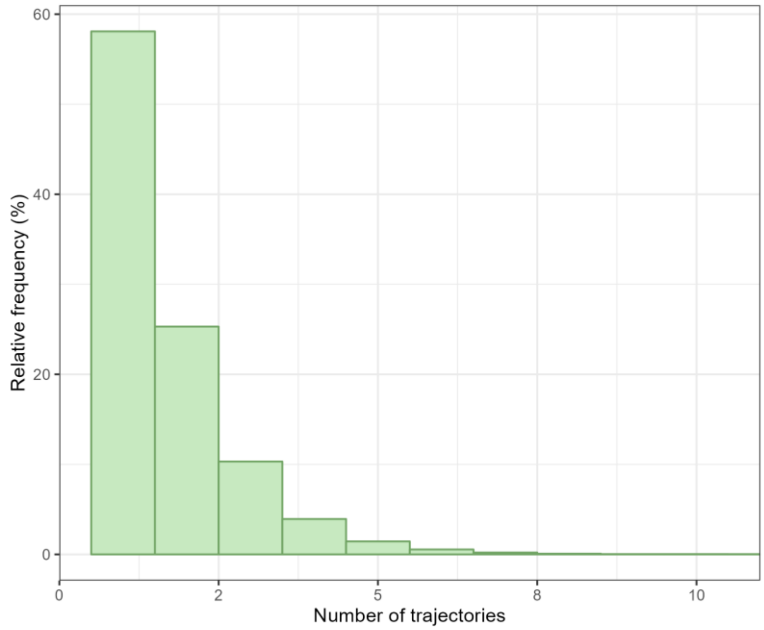

Fig. 3. Distribution of the percentage of numbers of trajectories per buoy used in the large-scale purse seine fishery of the western Indian Ocean for the period 2020-2022

To illustrate the reuse of buoys, we provide the example of the buoy SLX+328501 which travelled a total of 19,192 km (i.e., 10,363 nm) for a cumulative period of 657 days at sea (**Fig. 4**). The buoy was first deployed on 07 August 2020, travelling 4,203 km (i.e., 2,269 nm) until 22 December 2020, before being retrieved from the water. It was redeployed on 30 December 2020 and drifted at sea for 280 days, travelling a cumulative distance of 7,952 km (i.e., 4,294 nm). Finally, the buoy was re-deployed on 25 January 2022 and spent an additional time at sea of 239 days at sea, travelling a further distance of 7,037 km (i.e., 3,799 nm) (**Fig. 4**).

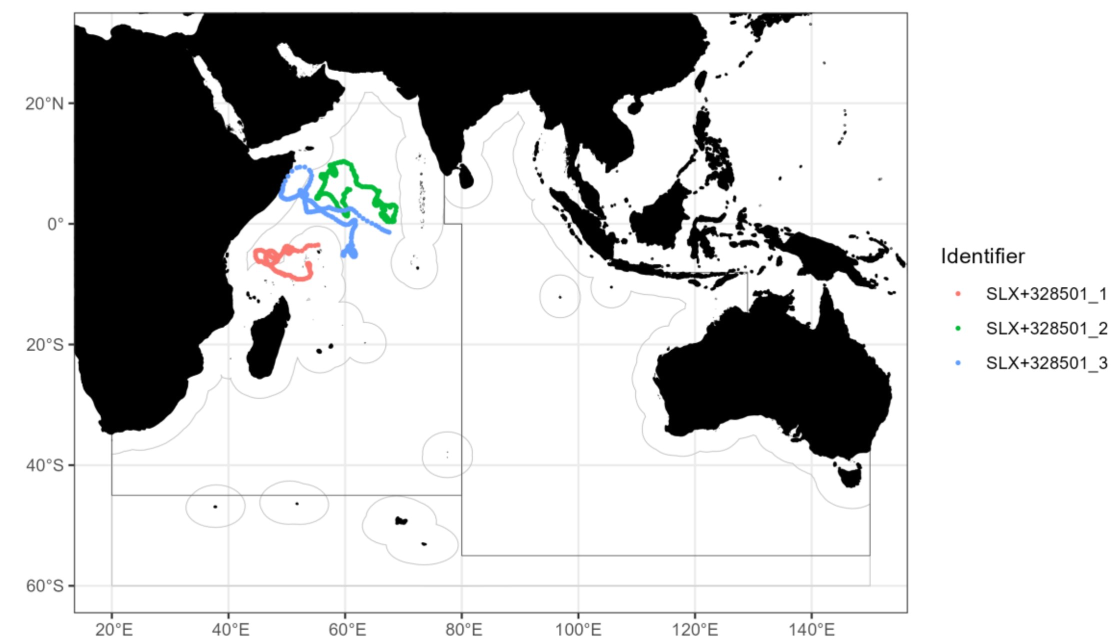

Fig. 4. Example of three distinct trajectories of FOBs equipped with the buoy SLX+328501 (see text for details)

FOB lifespan and distance travelled

Time spent at sea varies greatly between FOB trajectories. The median trajectory length is 64 days at sea while the longest trajectory is close to 900 days at sea (**Fig. 5a**). About 7.3% of the data set is comprised of buoys that transmitted information for less than one month. The very large majority of the FOBs travel less than 9 months, i.e., the 95th percentile of the values of time at sea in the sample is 262 days. The median distance travelled by a FOB is 2,562 km (i.e., 1,383 nm) with some of them that travelled more than 20,000 km (i.e., 10,799 nm) during their time at sea (**Fig. 5b**).

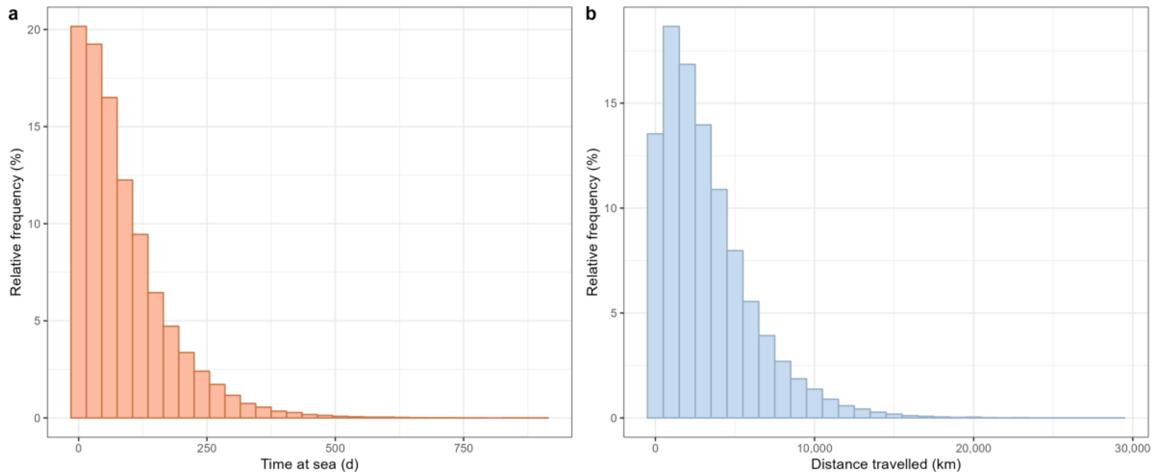

Fig. 5. Relative distribution of (a) time at sea (days; d) and (b) distance travelled (kilometres; km) of the satellite-tracked FOBs used in the large-scale purse seine fishery of the western Indian Ocean for the period 2020-2022

The distance travelled by the FOBs drifting at sea is proportional to the time spent at sea (**Fig. 6**). FADs have been shown to drift in near-surface currents and the large variability observed around the trend may be explained by the complexity and strong seasonality of the Indian Ocean oceanography (Schott et al. 2009; Imzilen et al. 2019).

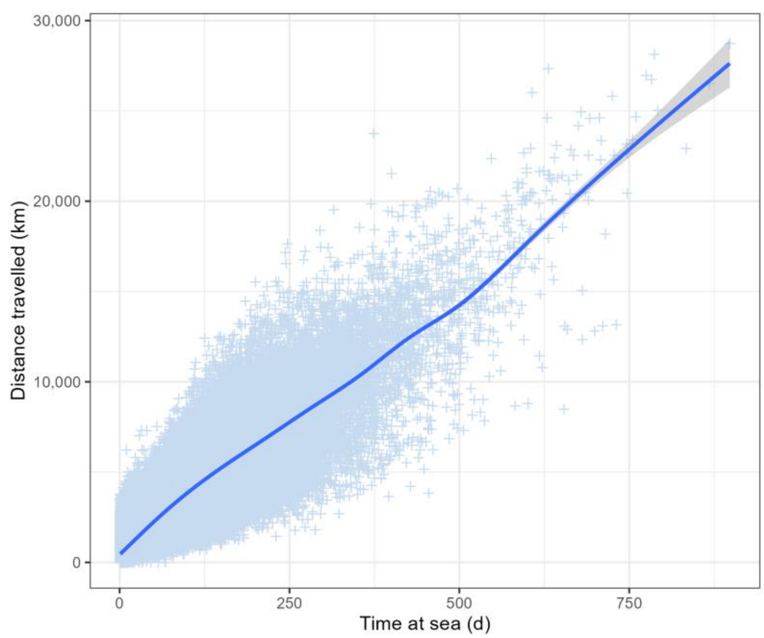

Fig. 6. Relationship between time at sea (days; d) and distance travelled (kilometres; km) by the satellite-tracked FOBs monitored at sea by the large-scale purse seiners of the western Indian Ocean for the period 2020-2022. The blue solid line corresponds to a generalized additive model fitted to the data to visualise the trend

Buoys use

Buoy-sharing strategies

Information on shared buoys available from the fleets of EU,France, EU,Italy, and Mauritius provides insight into the strategies of the industry to optimise the use of FOBs at sea in the context of reduced numbers of buoys available to the fishery. For these fleets, a procedure common among fishing companies has been put in place to share all buoys located east of 72°W in order to reduce the influence of the buoys located in the eastern Indian

Ocean on the individual buoy stock of each purse seiner (**Fig. 7**). Those buoys are considered out of reach to the vessels regarding the long distance and time required to go fishing in the eastern Indian Ocean fishing grounds which are less productive than their western counterpart. Accessing the information from all buoys may also create some incentive for some captains to take the chance of going fishing in the eastern Indian Ocean.

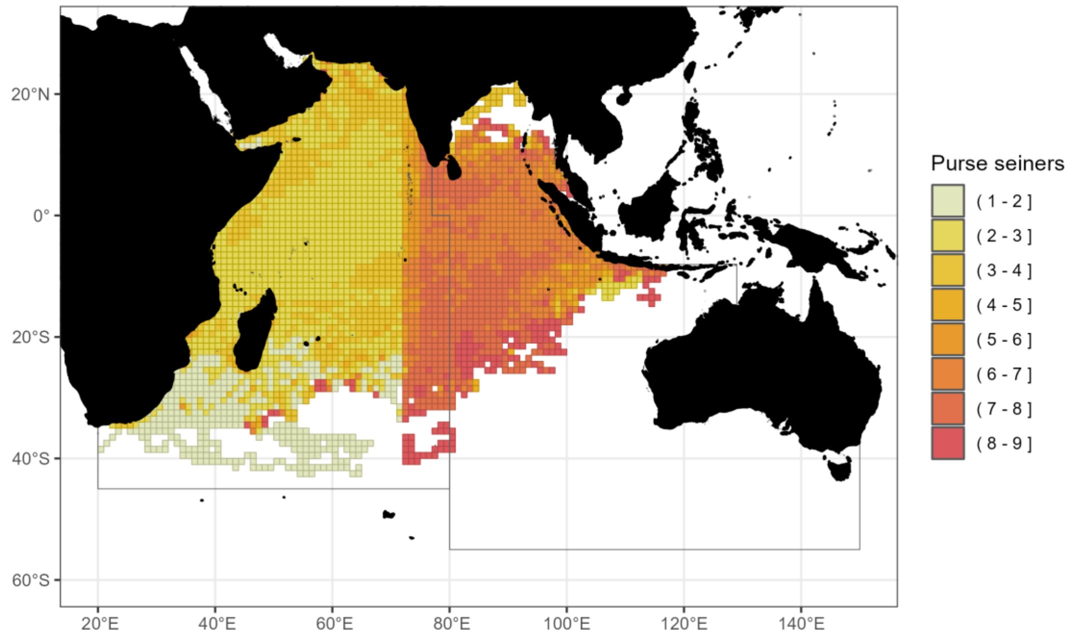

Fig. 7. Spatial distribution of the average number of purse seiners accessing buoy information in the large-scale purse seine fleets of EU,France, EU,Italy, and Mauritius for the period 2020-2022

Excluding all buoys located east of 72°W, we show that buoy information (i.e., both location and acoustic estimates of biomass around the FOBs) has been increasingly shared among purse seiners since early 2020. The average number of purse seiners accessing the information has increased from about 2.5 in early 2020 to almost 3.5 in late 2022, although with some variability over time (**Fig. 8**).

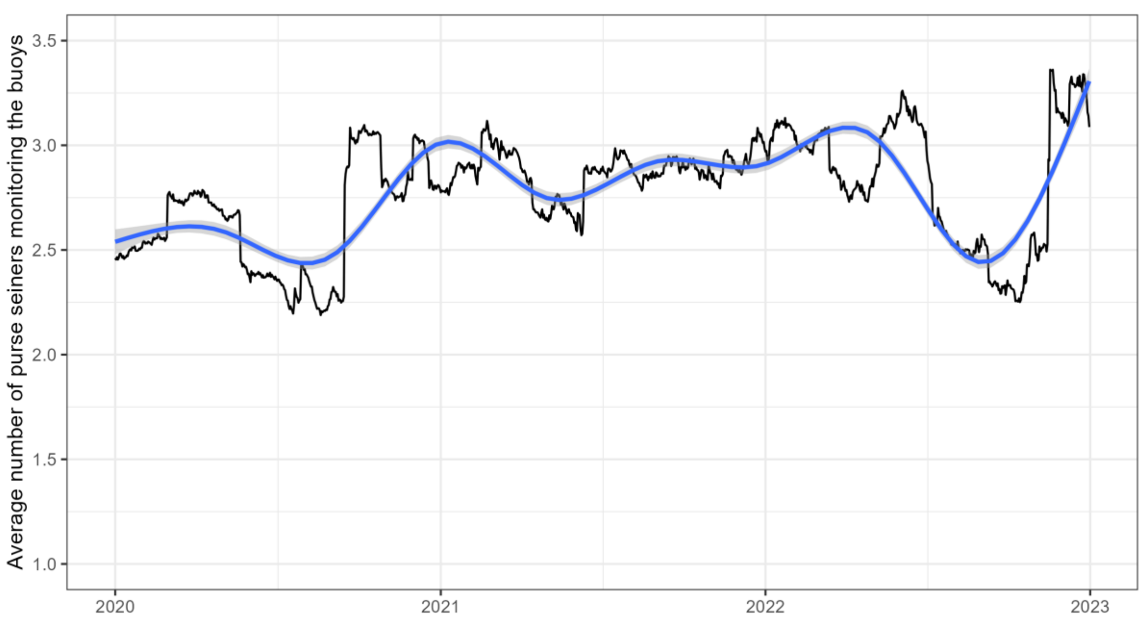

Fig. 8. Average number of purse seiners accessing buoy information in the large-scale purse seine fleets of EU,France, EU,Italy, and Mauritius for the period 2020-2022. The blue solid line corresponds to a generalized additive model fitted to the data to visualise the trend

DFAD deployments and buoy transfers

Buoy activations reflect both a combination of DFAD deployments and transfers of buoys on FOBs encountered at sea by the purse seiners and their support vessels, with the aim of anticipating FOB drift and the time of colonisation of the FOBs by tuna (Orue et al. 2019). Initial points of buoy trajectories cover the main fishing grounds of the purse seine fishery of the western Indian ocean (**Fig. 9**). The average quarterly distribution of buoy activations shows some seasonality with some variability between the hotspots of activations and the extent of the areas between quarters. Buoy activations observed along the equator west of 70° in the first quarter were made by the Japanese purse seine fishery which stopped operating in the Indian Ocean in March 2020. Almost no buoy activation has been reported to occur in the Mozambique Channel during the months of July-September for the period 2020-2022.

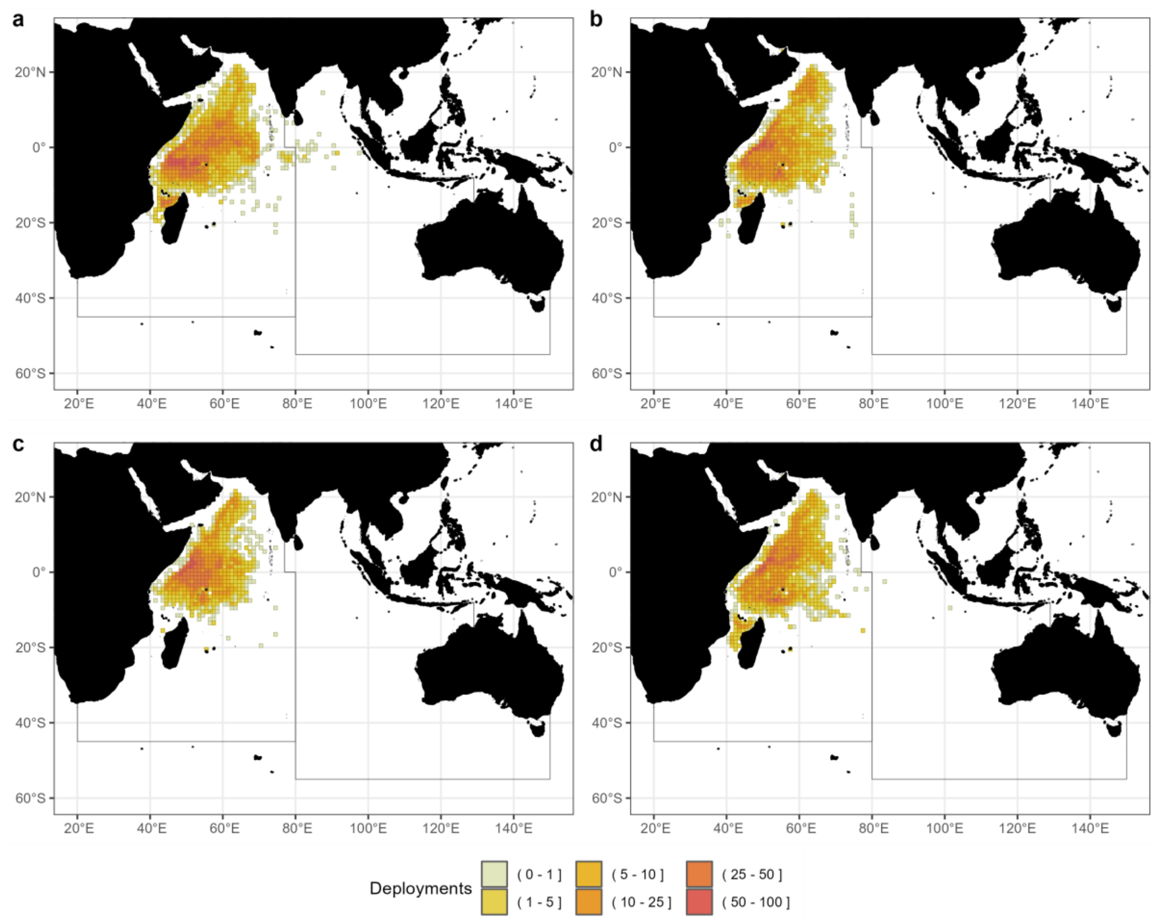

Fig. 9. Mean annual density of buoy activations (number of buoys per year and 1-degree grid area) representing both DFAD deployments and buoy transfers on FOBs encountered at sea in the large-scale purse seine fishery of the western Indian Ocean. (a) January-March, (b) April-June, (c) July-September, and (d) October-December

Buoys activations & DFAD fate

A total of 11,154 buoys were reported to be at sea and actively transmitting on the 1st of January 2020 when daily buoy information started to be reported to the Secretariat. Since then, the daily number of operational buoys showed large variability over time while highlighting a major decreasing trend at the end of 2022. Between January 2020 and December 2022, the daily number of distinct satellite-tracked buoys monitored by the large-scale purse seine fishery of the western Indian Ocean varied between a minimum of 8,408 and a maximum of 11,536.

Fig. 10. Daily number of satellite-tracked buoys in operation in the large-scale purse seine fishery of the western Indian Ocean for the period 2020-2022. The blue solid line corresponds to a generalized additive model fitted to the data to visualise the trend

Buoy turnover is highly dynamic in the Indian Ocean purse seine fishery, and buoys are constantly deactivated following fishing operations, drifting of FOBs outside purse seine fishing grounds, beaching or sinking, and transmission problems due to technical reasons. The daily number of buoys activated in the fishery, corresponding to both deployments of DFADs and transfers of buoys on FOBs encountered at sea, was on average of NA buoys per day during 2020-2022, with some large variability over the period and very high values (>320 per day) in early January 2020 and 2022 (**Fig. 11**). These large numbers of deployments may be explained by the fact that several purse seiners and support vessels were stopped at the end of each year, when they were likely to have reached their individual catch quotas and went back fishing at the start of the new year. Such pattern was not observed in January 2021 but occurred on the 26th of December 2022 with 170 buoys activated in that day (**Fig. 11**).

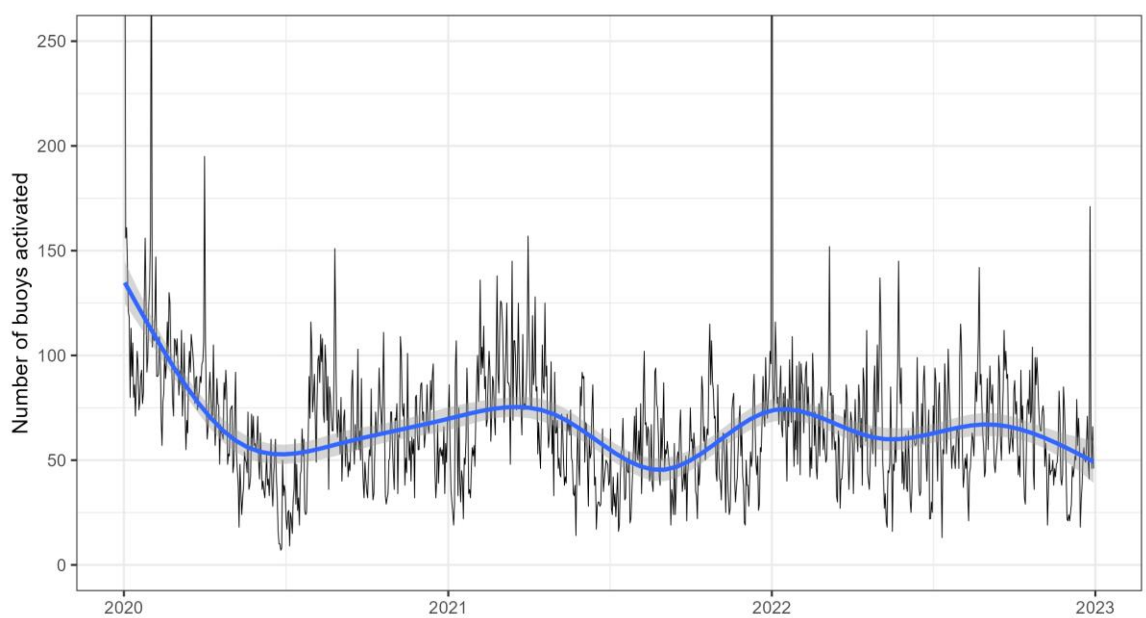

Fig. 11. Daily number of buoy activations for the period 2020-2022. The blue solid line corresponds to a generalized additive model fitted to the data to visualise the trend. The red rectangle covers the months of November-December 2022 when buoy data were incomplete

Since early January 2020, the cumulative number of buoys activated and attached to drifting FADs and natural floating objects has reached 25,690, 48,338, and 72,068 at the end of the months of December 2020, 2021, and 2022, respectively.

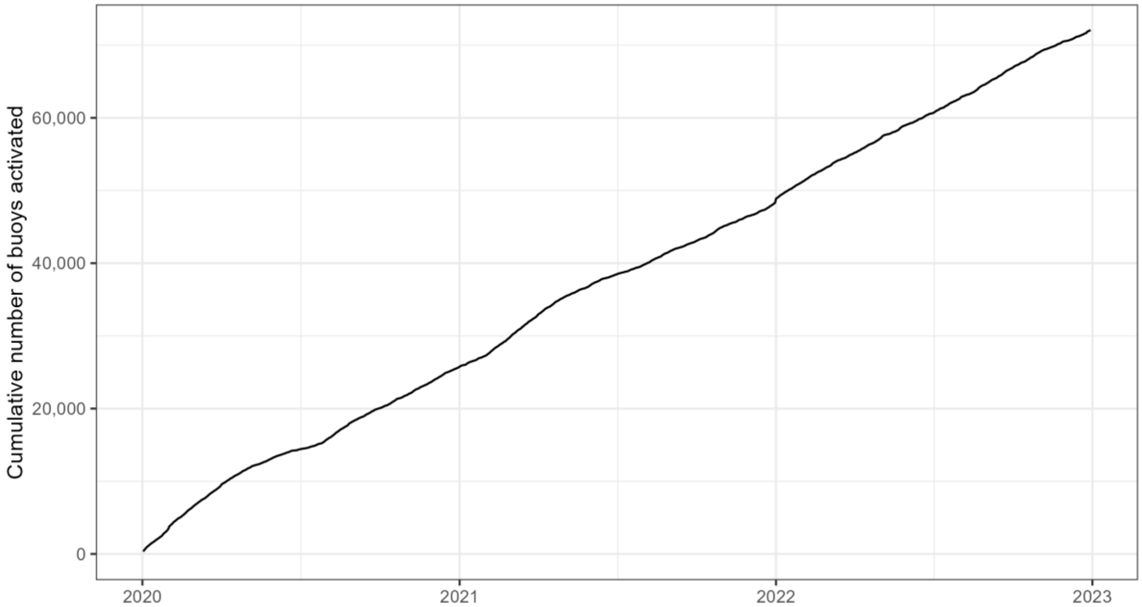

Fig. 12. Cumulative number of buoy activations in the large-scale purse seine fishery of the western Indian Ocean for the period 2020-2022

References

Grande, M., Ruiz, J., Baez, J.-C., Ramos, M.L., Krug, I., Zudaire, I., Santiago, J., Pascual, P.J., Abascal, F.J., Gaerner, D., Cauquil, P., Floch, L., Maufroy, A., Muniategi, A., Herrera, M., and Murua, H. 2018. Best standard for data collection and reporting requirements on FOBs: Towards a science-based FOB fishery management. IOTC, Victoria Mahé, 29 November - 01 December 2018. p. 23. Available from https://www.iotc.org/documents/WPTT/20/20.

Imzilen, T., Chassot, E., Barde, J., Demarcq, H., Maufroy, A., Roa-Pascuali, L., Ternon, J.-F., and Lett, C. 2019. Fish aggregating devices drift like oceanographic drifters in the near-surface currents of the Atlantic and Indian Oceans. Progress in Oceanography **171**: 108–127. doi:10.1016/j.pocean.2018.11.007.

IOTC. 2022b. Report of the 3rd IOTC ad hoc Working Group on FADs. IOTC, Virtual meeting, 03-05 October 2022. Available from https://www.iotc.org/documents/WGFAD/03/R.

IOTC. 2022a. Review of data on drifting Fish Aggregating Devices. IOTC, Virtual meeting, 03-05 October 2022. p. 55. Available from https://www.iotc.org/documents/WGFAD/03/03.

Maufroy, A., and Goujon, M. 2019. Methodology for the monitoring of FOB and buoy use by French and Italian tropical tuna purse seiners in the Indian Ocean. IOTC, San Sebastian, Spain, 21-26 October 2019. p. 23. Available from https://www.iotc.org/documents/WPTT/21/53.

Orue, B., Lopez, J., Moreno, G., Santiago, J., Soto, M., and Murua, H. 2019. Aggregation process of drifting fish aggregating devices (DFADs) in the Western Indian Ocean: Who arrives first, tuna or non-tuna species? PLOS ONE **14**(1): e0210435. doi:10.1371/journal.pone.0210435.

Schott, F.A., Xie, S.-P., and Jr, J.P.M. 2009. Indian Ocean circulation and climate variability. Reviews of Geophysics **47**: 46. doi:200910.1029/2007RG000245.

Appendices

Appendix I: IOTC classification of FOB-related activities

Tab. 1. Classification of activities related to drifting floating objects in use at the IOTC Secretariat

Code	Description
DD	Deployment of drifting FAD
DH	Retrieval/encounter and hauling of drifting FAD
DI	Retrieval/encounter, hauling, and intervention on electronic equipment of drifting FAD
DL	Loss of drifting FAD (tracking signal lost)
DR	Retrieval of drifting FAD

Appendix II: IOTC code list of FOB-related activities

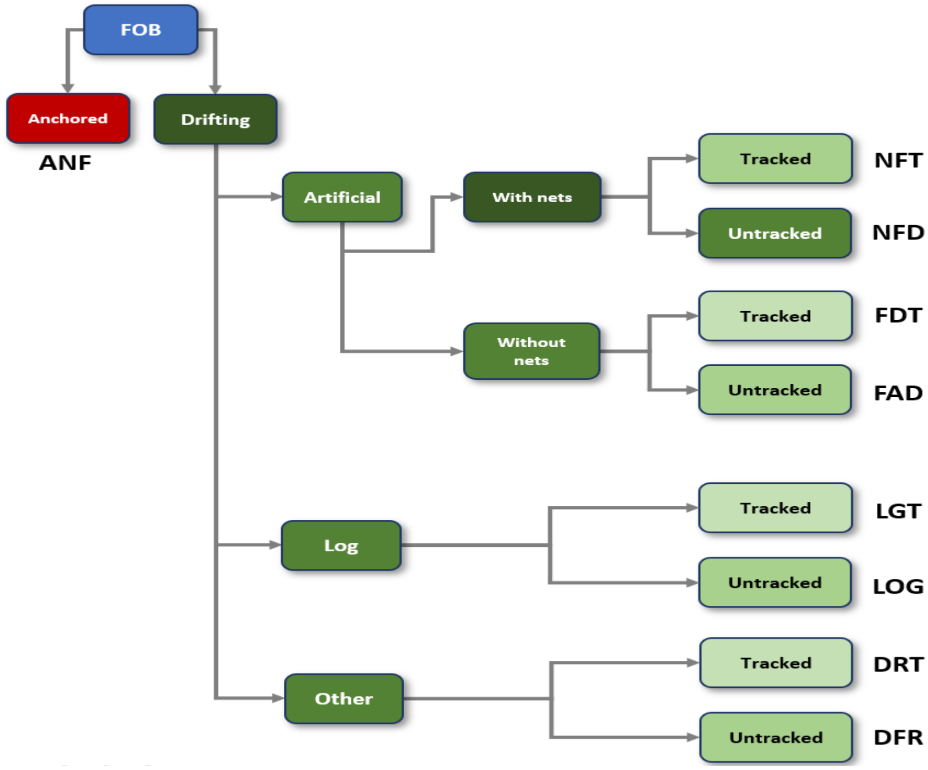

Fig. 13. Classification of types of drifting floating objects in use at the IOTC Secretariat

Tab. 2. Definitions of the types of drifting floating objects in use at the IOTC Secretariat

Code	Description
DFR	Other drifting objects NOT located using a tracking system (radio or satellite transmission) (e.g. dead animal, etc.)
DRT	Other drifting objects located using a tracking system (radio or satellite transmission) (e.g. dead animal, etc)
FAD	Drifting raft or FAD without a net NOT located using a tracking system (radio or satellite transmission)
FDT	Drifting raft or FAD without a net located using a tracking system (radio or satellite transmission)
LGT	Drifting log or debris located using a tracking system (radio or satellite transmission)
LOG	Drifting log or debris NOT located using a tracking system (radio or satellite transmission)
NFD	Drifting raft or FAD with a net NOT located using a tracking system (radio or satellite transmission)
NFT	Drifting raft or FAD with a net located using a tracking system (radio or satellite transmission)

Appendix III: Buoy data coverage

Tab. 3. Overview of the buoy position data set between 01 January 2020 and 31 December 2022 as available at the IOTC Secretariat. PS = Number of purse seiners. Note the same purse seiner may appear in different fleets in case of change of flag over the period considered. Buoys shared among the fleets of EU,France, EU,Italy, Mauritius, and Seychelles are repeated for each of them

YEAR	CPC	FLEET_CODE	PS	DAYS	POSITIONS	BUOYS
2020	EU	EUESP	15	366	1,459,581	14,242
2020	EU	EUFRA	11	366	3,086,904	8,546
2020	EU	EUITA	1	366	226,579	2,504
2020	JPN	JPN	2	88	4,353	109
2020	MUS	MUS	3	366	515,353	2,788
2020	SYC	SYC	13	366	1,406,849	13,394
2021	EU	EUESP	16	365	1,343,232	13,956
2021	EU	EUFRA	10	365	3,088,548	9,000
2021	EU	EUITA	1	365	285,636	3,494
2021	MUS	MUS	3	365	975,284	3,933
2021	SYC	SYC	13	365	1,491,882	13,728
2022	EU	EUESP	15	365	1,265,491	12,871
2022	EU	EUFRA	10	365	2,880,152	8,934
2022	EU	EUITA	1	365	255,214	3,315
2022	KOR	KOR	2	365	188,334	1,503
2022	MUS	MUS	4	365	915,327	4,054
2022	OMN	OMN	1	171	25,881	349
2022	SYC	SYC	13	365	1,110,494	11,841
2022	TZA	TZA	1	283	58,438	745