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Spatial and temporal description of drifting FAD use in the WCPO derived from analyses of the FAD tracking programmes and observer data

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Escalle L.[1], Hamer P.[1] and the PNA Office

[1] Oceanic Fisheries Programme, The Pacific Community (SPC), Noumea, New Caledonia

Executive Summary

This paper presents results from analyses of drifting Fish Aggregating Device (dFAD) use in the Western and Central Pacific Ocean (WCPO), based on information derived from dFAD tracking programmes and observer data. The aims of the paper are to improve the understanding of the use of dFADs in the WCPO, provide better scientific information on the impacts of dFADs and fishing on them; and ultimately inform dFAD management. Three different datasets were used: i) the Parties to the Nauru Agreement (PNA) FAD tracking dataset covering the 2016–2023 period; ii) a recent Western and Central Pacific Fisheries Commission (WCPFC) FAD tracking dataset, of voluntary submission by vessels, that only contained data from early 2023; and iii) observer data, with high observer coverage (average 76–98% of trips) from 2011–2019 but due to the impacts of COVID observer coverage was lower (14–46% of trips) in recent years.

After undertaking the filtering, processing and correction procedures, the PNA FAD tracking dataset consisted of 51.7 million transmissions from 107,011 buoys over the 2016–2023 period. As for previous years, areas outside PNA Exclusive Economic Zones (EEZs) are still often missing in 2023 (i.e., “geo-fenced”), which introduces bias to the analyses. Similarly, the WCPFC FAD tracking filtered dataset consisted of 2.5 million transmissions from 10,415 buoys in 2023. While only containing 2023 data, the WCPFC FAD tracking dataset included a larger spatial coverage of transmissions and presented more data available per vessel compared to the PNA FDA tracking dataset. In both datasets most of the buoys used were Satlink (68.6 and 81.8% for the PNA and WCPFC FAD tracking data, respectively); followed by Zunibal (15.7% and 0%); Kato (9.8% and 6.9%) and Marine Instruments (5.9% and 11.3%).

The number of buoy deployments estimated over 2016–2023 in the PNA FAD tracking database was of 174,665. It was of 11,319 in the first 3 months of 2023 in the WCPFC FAD tracking database. The number of buoy deployments per year, however, varied over time, with 18,000 to 33,000 buoys deployments (noting some deployments can be re-deployments of the same buoys) per year over 2016–2022 in the PNA FAD tracking database. The number of buoy deployments per year recorded by observers varied between 13,070 and 16,188 over 2011–2019, representing half to three quarters of the number of buoy deployments in the PNA FAD tracking data. The number of dFAD deployments recorded by observers was around half the number of buoy deployments recorded by observers. The spatial distribution of deployments, from the FAD tracking and observer datasets, showed the main deployment areas to be in Kiribati south of the Gilbert Islands, east of the Phoenix Islands, and the central part of the Line Islands; Nauru; and north of Tuvalu.

The average number of buoy deployments per year per vessel using the PNA FAD tracking data varied from 59 to 87 for 2016–2022 and 50 to 65 for 2011–2019 using the observer data. The 0.9 quantile (i.e., 90% of the vessels per year) is at 150–214 buoys deployed per vessel per year with a maximum of 540, as estimated from the PNA FAD tracking data (2016–2022); and 92–130 with a maximum of 430, as recorded by observer data.

The number of buoys transmitting per day has been between 4,500 and 6,700 over the last 2 years and the number of transmissions between 10,000 and 25,000 (PNA and WCPFC FAD tracking datasets). Since 2016, for the vessels transmitting FAD tracking data to PNA and WCPFC, the number of active buoys at-sea monitored per vessel per day ranged between 1 and 335. For the PNA FAD tracking data

in 2016–2023, the average number of active buoys at-sea monitored per vessel per day ranged at 30–45; and the 0.9 quantile at 70–115. For the WCPFC FAD tracking data in 2023, the average ranged at 50–55; and the 0.9 quantile at 115–130. All estimates are therefore below the limit of 350 buoys monitored per vessel per day, specified in CMM 2021-01, paragraph 23, while 90% of vessels were monitoring around a third of the buoy limit.

The average drift time and straight-line drift distance (i.e., displacement) per buoy were 3 months and 1,167 km, whereas the average active time (including on-board sections) was 7 months with an average distance between first and last transmitted position of 1,855 km. The highest buoy densities were in Kiribati south of the Gilbert Islands and around the Phoenix Islands; Nauru, Tuvalu; the eastern area of Papua New Guinea (PNG) and off the Solomon Islands, which also correspond to areas where a high number of associated sets occur. The dFAD density distribution using the PNA FAD tracking data clearly highlights the lack of data in some high seas' areas due to geo-fencing.

Investigation of buoy fates showed that 44.8% of buoys were abandoned, 6.0% were retrieved; 11.3% were stranded; and 37.6% were deactivated by the fishing company or the signal was lost within the fishing grounds and left drifting unmonitored at sea. Higher levels of stranding events were detected in Kiribati Gilbert Islands, Nauru, Tuvalu, PNG and the Solomon Islands. However, limited information is available outside the fishing grounds, due to geofencing and/or deactivation of buoys outside the main purse seine fishing areas. Potential hotspots of buoy deactivations were detected in the south of the WCPO (south of the Solomon Islands, Fiji and Vanuatu EEZ); and in the high seas area in the north of the WCPO (west of the Republic of the Marshall Islands EEZ). Accessing better information on the fate of dFADs, including in-situ information on stranding events, as well as the reason why a buoy is deactivated, is essential to better understand the impact that the high number of abandoned and lost dFADs may have on the environment.

We invite WCPFC-SC19 to:

- Note the spatial and temporal trends in dFAD use in the WCPO presented in this paper.
- Note the importance of complete FAD tracking data, including historical periods, to support scientific analyses and detect trends in dFAD use, and the limitation in the scientific analyses due to the current incomplete data.
- Note that 18,000–33,000 buoys are deployed (including re-deployments) per year over 2016–2022, and that the buoy deployments recorded by observers represent only half to three quarters of the number of buoys deployments estimated using FAD tracking data. The number of dFAD deployments that were recorded by observers was around half the number of buoy deployments, indicating high rates of dFAD appropriation and exchange.
- Note that, based on the information available, no vessel monitored more than 350 active buoys per day, current limit un *CMM 2021-01*; with 90% of the vessels monitoring less than 130 buoys per day.
- In order to verify compliance with *CMM 2021-01*, consider options for reporting the number of active buoys per vessel; as well as the number of dFAD/buoys deployed, retrieved and deactivated or lost at sea per vessel per year to inform management.
- Note that findings of this paper highlighted that more than 44% of buoys were estimated to be abandoned, 11% stranded, and 37% had an uncertain fate. Potential hotspots of buoy deactivations were also detected in the south of the WCPO and in the high seas area in the northeast of the WCPO.

1. Introduction

The use of drifting Fish Aggregating Devices (dFADs) by tropical tuna purse seiners has increased globally in the last few decades, particularly with the new technological developments to track dFAD locations such as satellite and echo-sounder buoys (Escalle et al., 2021; Fonteneau et al., 2013; Scott and Lopez, 2014). In the Western and Central Pacific Ocean (WCPO), dFADs are now the dominant form of floating objects that are set on by purse seiners (Williams and Ruaia, 2023). The number of dFADs buoys deployed/redeployed annually in the WCPO is estimated at 30,000–40,000 (Escalle et al., 2021). To reduce the impact of dFAD fishing on tuna stocks, specifically to manage the high capture rates of small bigeye tuna on dFAD associated sets (Harley et al., 2015), the Parties to the Nauru Agreement (PNA) and the Western and Central Pacific Fisheries Commission (WCPFC; hereafter 'the Commission') implemented an annual three to four months FAD closure, during which all dFAD-related activities (e.g., fishing, deployment, servicing) are prohibited (CMM-2018-01; WCPFC, 2018). In addition, in 2018, the Commission implemented a limit of 350 dFADs with activated instrumented buoys (activation on-board only) per vessel, at any given time (CMM-2017-01; WCPFC, 2017). Finally, to limit the impact of dFADs on the marine ecosystem, the Commission also adopted measures to use low-entanglement risk dFADs (CMM-2018-01; WCPFC, 2018) and non-entangling dFADs will become mandatory in 2024 (CMM-2021-01; WCPFC, 2021); and to promote the use of biodegradable material in the construction of dFADs (CMM-2021-01; WCPFC, 2021).

This paper presents indicators of dFAD use in the WCPO, based on information derived from dFAD tracking programmes and observer data. The aims of the paper are to improve the understanding of the use of dFADs in the WCPO, provide better scientific information on the impacts of dFADs and fishing on them; and ultimately inform dFAD management. In this paper, we present the data used and the processing methods performed on the raw data, where necessary, as well as a general description of the data available. We also present results from updated analyses of; i) spatio-temporal distributions of dFAD buoy deployments; ii) the temporal distribution of dFADs in the WCPO; iii) dFAD densities; iv) the fate of dFADs at their last buoy's transmission, including a focus on dFAD stranding.

2. Data used and their processing

2.1 PNA FAD tracking data

The Parties to the Nauru Agreement (PNA) FAD tracking trial programme has been in place since 2016 and has tracked satellite buoys attached to dFADs used by purse seine vessels licensed to fish in PNA Member waters. After considering the results from a trial period, PNA Members have agreed to the requirement that all dFAD buoys be registered and transmit regular position data to the PNA Office (PNAO) while a vessel is licensed to a PNA Member, including transmitting data from high seas areas between 20° North and 20° South within the WCPFC Convention Area. This requirement has been implemented since 1th January 2023.

As dFADs drift in the ocean, the associated electronics (i.e., GPS buoys or GPS and echo-sounder buoys) can be replaced making it difficult to follow individual dFADs. Therefore, for the purposes of this analysis we followed dFAD buoys with GPS satellite-positioning systems (referred hereafter as buoys), unless otherwise stated. Note that a buoy trajectory may not constitute a single dFAD track, but rather can be a single buoy track that could have been deployed consecutively on multiple dFADs.

Each transmission in the PNA FAD tracking data includes location, time, the 'owner' of each buoy (a fishing company or directly a vessel name), water temperature, course direction, and drifting speed. The raw buoy tracking dataset received by the PNAO contained duplications and errors, as well as transmissions from active buoys that were still on-board a vessel; therefore, the dataset needed to be filtered and processed before any analysis could be undertaken (see previous papers presented to SC for details: Escalle et al., 2017, 2018b, 2019b, 2020a).

Buoy positions at the end of their trajectories were investigated to study the fate of dFADs. The end of a trajectory was classified as: i) *stranded* if the last position was "at-sea" and within 12nm of shore (excluding positions located at less than 10km from major ports) and at least the last three positions where at 0m, <10m, or <100m from each other; ii) *recovered* if the last position was "on-board"; iii) *abandoned* if the last position was "at-sea" but outside the main purse seine fishing grounds or at certain periods of common deactivation such as during the closure or at the end of the year; and iv) *uncertain fate* if the last position was "at-sea" and within the main purse seine fishing grounds (141°W, 210°E, 8°N, 12°S), but the signal was lost for unknown reasons. To remove potential bias in the analysis due to buoys that might transmit again when data are loaded again in the near future, buoys with transmissions over the last 4 months of the dataset were excluded.

2.2 WCPFC FAD tracking data

Since January 2023, another source of dFAD tracking data has been provided to WCPFC, through the Pacific Community (SPC), the Commission's Scientific Services Provider. This is a voluntary submission from purse seine fishing companies, following the adoption by the International Seafood Sustainability Foundation (ISSF) Proactive Vessel Register Conservation Measures. This measure states that proactive vessels should report dFAD position data to the relevant Regional Fisheries Management Organization (RFMO) science bodies with a maximum time lag of 90 days, from 1 January 2023 (Management measure 3.7 Transactions with Vessels or Companies with Vessel-Based FAD Management Policies). As of June 30th 2023 242 purse seine vessels authorized to fish in the WCPFC convention area were present in the ISSF Pro-Active Vessel register (https://www.iss-foundation.org/vessel-and-company-commitments/proactive-vessel-register/proactive-vessel-register-pvr/pvr-vessel-list/).

Each transmission in the WCPFC dFAD tracking data includes location, time, vessel IMO and fishing company, water temperature, course direction, and drifting speed. Similar to the PNA FAD tracking data, the raw buoy tracking dataset is filtered and processed before any analysis (see previous papers presented to SC for details: Escalle et al., 2017, 2018b, 2019b, 2020a).

Buoy positions at the end of their trajectories were determined in the same way as for the PNA FAD tracking data (see section 2.1).

2.3 FAD-related information recorded by observers

Observers from the Pacific Islands Regional Fisheries Observer (PIRFO) programme record information linked to dFAD and buoy deployments, sets and any other activity on dFADs, such as servicing or recoveries. In 2011, a specific form, GEN-5 (Appendix 1) is used to collect information related to FADs, such as the nature of the FAD (artificial or natural, anchored or drifting), the dimensions (length, width and depth) and the materials used (for both the raft and for submerged appendages), as well as the unique ID number from the satellite buoy attached to a dFAD. The same year, the observer coverage requirement increased to 100%. This has substantially increased the amount of dFAD related information collected by observers. Between 2020 and 2023, however, the COVID-19 pandemic has greatly reduced the observer placements, leading to a large decrease in observer trips and information collected (Panizza et al., 2023). Positions from the deployment and recovery of dFADs and satellite buoys attached to dFADs, as well as dFAD fishing sets are used in this paper.

3. General description of the data

3.1 Data summary – PNA FAD tracking data

The PNA FAD tracking dataset used in this paper is comprised of transmitted locations and time stamps from buoys attached to dFADs, between 1st January 2016 and 28th February 2023 (data uploaded on 1st of June 2023). The raw dataset included more than 57.5 million transmissions from 116,543 satellite buoys.

The filtered dataset included 51,722,022 transmissions from 107,011 unique satellite buoys for analysis (Table 1), corresponding to annual estimates of active buoys between 14,816 buoys in 2016 and 25,354 in 2022 (Table 1, note that buoys may be active for several years, leading to the overall number of buoys in the dataset being lower than the sum of the annual numbers). In total, 301 vessel names were identified as buoy owners (187–244 per year), including purse seiners and support vessels; and 131 fishing companies (67–103 per year). Note that data received included only vessel names and fishing company names, with high levels of incorrect spelling, vessel IMO should be used in the future to avoid any mistakes and to be able to follow unique vessels even after name or flag changes. A total of 94.1% of the records presented the owner's vessel name, and 5.9% had only the fishing company known.

Table 1. Summary statistics from the PNA and WCPFC FAD tracking datasets, by year.

Year	Number of transmissions	Number of buoys	Number of deployments/re-deployments	Number of vessel names as buoy owners
2016 - PNA	4,936,937	14,816	18,225	187
2017 - PNA	9,201,601	21,685	21,568	201
2018 - PNA	7,875,662	23,343	21,914	205
2019 - PNA	6,347,559	21,651	32,630	194
2020 - PNA	4,303,896	22,310	18,964	244
2021 - PNA	9,477,140	24,202	26,819	241
2022 - PNA	8,152,559	25,354	30,128	229
2023 - PNA	1,427,268	10,766	4,417	200
Total - PNA	32,068,675	107,011[1]	174,665	301
2023 - WCPFC	1,825,122	10,266	11,319	123

[1] Note that buoys may be active for several years.

Data originated from four different satellite buoy companies: Satlink (68.6% of all buoys); Zunibal (15.7%); Kato (9.8%) and Marine Instrument (5.9%) (Figure 1).

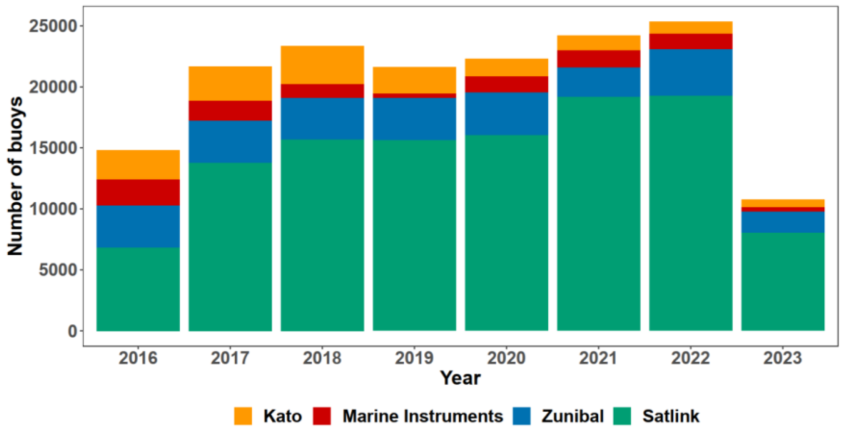


Figure 1. Number of satellite buoys (Kato, Marine Instrument, Satlink and Zunibal) used in the WCPO, as available in the PNA FAD tracking database, per brand company and year.

Note that the systematic modification of buoy transmissions has occurred with information outside PNA Exclusive Economic Zones (EEZs) being removed prior to data transmissions (i.e., "geo-fenced" FAD) throughout the whole 2016–2023 period. Geo-fenced buoys were identified as having no transmitted positions outside PNA waters.

3.1 Data summary – WCPFC FAD tracking data

The WCPFC FAD tracking dataset used in this analysis comprised transmitted locations and time stamps from buoys attached to dFADs, between 1st January 2023 and 31st March 2023 (data uploaded on 1st of June 2023). The raw dataset included more than 2.5 million transmissions from 10,415 satellite buoys. In total, 123 vessels were identified as buoy owners, including name and IMO; and 29 fishing companies. All buoys were linked to an owner vessel and fishing company.

The filtered dataset included 1,825,122 transmissions from 10,266 unique satellite buoys for analysis (Table 1). Data originated from three different satellite buoy companies: Satlink (81.8% of all buoys); Marine Instrument (11.3%); and Kato (6.9%). No data had been received from Zunibal at the time of this analysis.

4. Deployments

4.1 Temporal variability

The number of estimated buoy deployments in the PNA FAD tracking data varied over time (373 to 3,709 per month; Figure 2), with a total of 174,665 estimated over the study period. This corresponds to 18,225; 21,568; 21,914; 32,630; 18,964; 26,819; and 30,128 deployments estimated per year in the PNA FAD tracking database (Table 1 and Figure 3). Generally, besides some peaks at the beginning of the year in 2019 and one in 2021; as well as the decrease in deployments during the FAD closure periods, the number of buoy deployments per month remained relatively constant at around 2000 (Figure 2). During the FAD closure each year, although the number of buoy deployments decreased, a substantial number of deployments still occurred during that period (Figure 2). It should also be noted that geo-fencing of the data resulted in some bias in the deployment positions, with some estimated deployments corresponding to the first position of a geo-fenced buoy appearing at the border of the PNA EEZs (i.e., the buoy was likely deployed in a high sea zone).

The number of estimated buoy deployments in the WCPFC FAD tracking data for February and March 2023 was around 1,500 per month, with a total number of buoy deployments of 11,319 estimated in 2023.

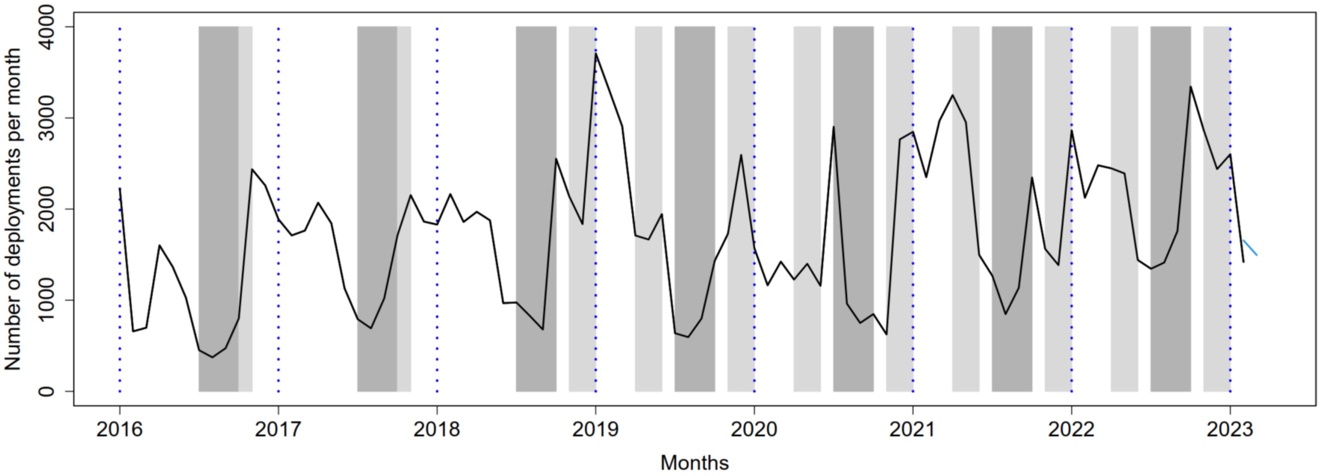


Figure 2. Estimated number of buoy deployments by month for the PNA (black) and WCPFC (blue) FAD tracking data. Grey areas correspond to the FAD-closure periods (dark grey: July—September in EEZ and high seas; and light grey: extra months in October or November—December or April—May in the high seas); grey vertical lines January1st each year. The first point of the WCPFC database corresponds to the start of the database and therefore not real deployments.

In terms of total number of deployments per year, information on the estimated buoy deployments was derived from the PNA FAD tracking data for the 2016–2023 period and WCPFC for 2023, as well as the number of dFAD and buoy deployments as recorded by observers since 2003 (Figure 3). For the 2016–2022 period, as per the PNA FAD tracking data, the number of buoy deployments (including re-deployments) per year varied from 18,225 to 32,630 (Figure 3 and Table 1).

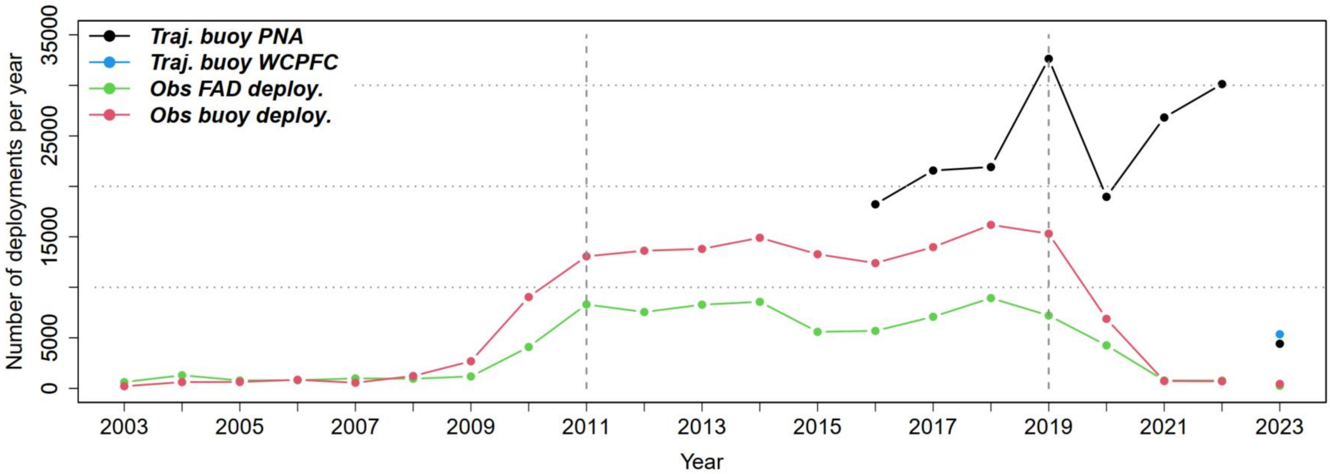


Figure 3. Estimated number of buoy deployments by year for the PNA (black) and WCPFC (blue) FAD tracking data; and the total number of dFAD (green) and buoy (red) deployments recorded by observers. Note that data for 2023 are still incomplete. The vertical dashed lines indicate the period with expected 100% observer coverage (2011–2019).

Regarding observer data, it should first be noted that complete data are only available from 2011 to 2019. Indeed, 2011 corresponds to the adoption of the 100% observer coverage requirement and the implementation of the GEN-5 form; and from 2020 to 2022, the observer coverage decreased significantly due to the COVID-19 pandemic (Panizza et al., 2023). For that 2011–2019 period, the number of buoy deployments recorded by observers varied between 13,070 and 16,188, representing 47% to 74% of the number of buoys deployments in the PNA FAD tracking data for 2016–2019. The number of dFAD deployments recorded by observers, however, varied between 5,594 and 8,935 (Figure 3). It is notable that the number of dFAD deployments recorded by observers are around half the number of buoys deployments (42–63%) from 2011–2019 (Figure 3).

In terms of number of deployments per vessel, the same databases were used (Figure 4). The average number of buoy deployments per vessel varied from 59 to 87 for 2016–2022 using the PNA FAD tracking data and from 50 to 65 for 2011–2019 using the observer data, while the average number of FAD deployments per vessel varied from 20 to 35 for 2011–2019 using the observer data. We also note that the 0.9 quantile is at 150–214 buoys per vessel per year, with a maximum of 540, as estimated from the PNA FAD tracking data (2016–2022); and 92–130 buoys per vessel per year with a maximum of 430, as recorded by observer data (2011–2019) (Figure 4).

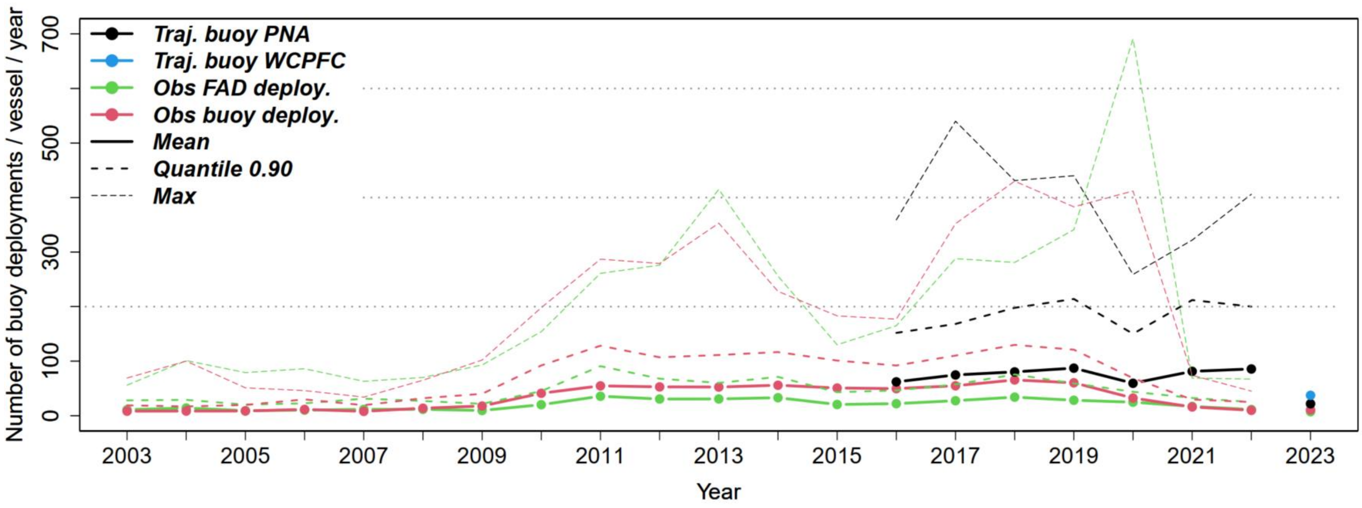
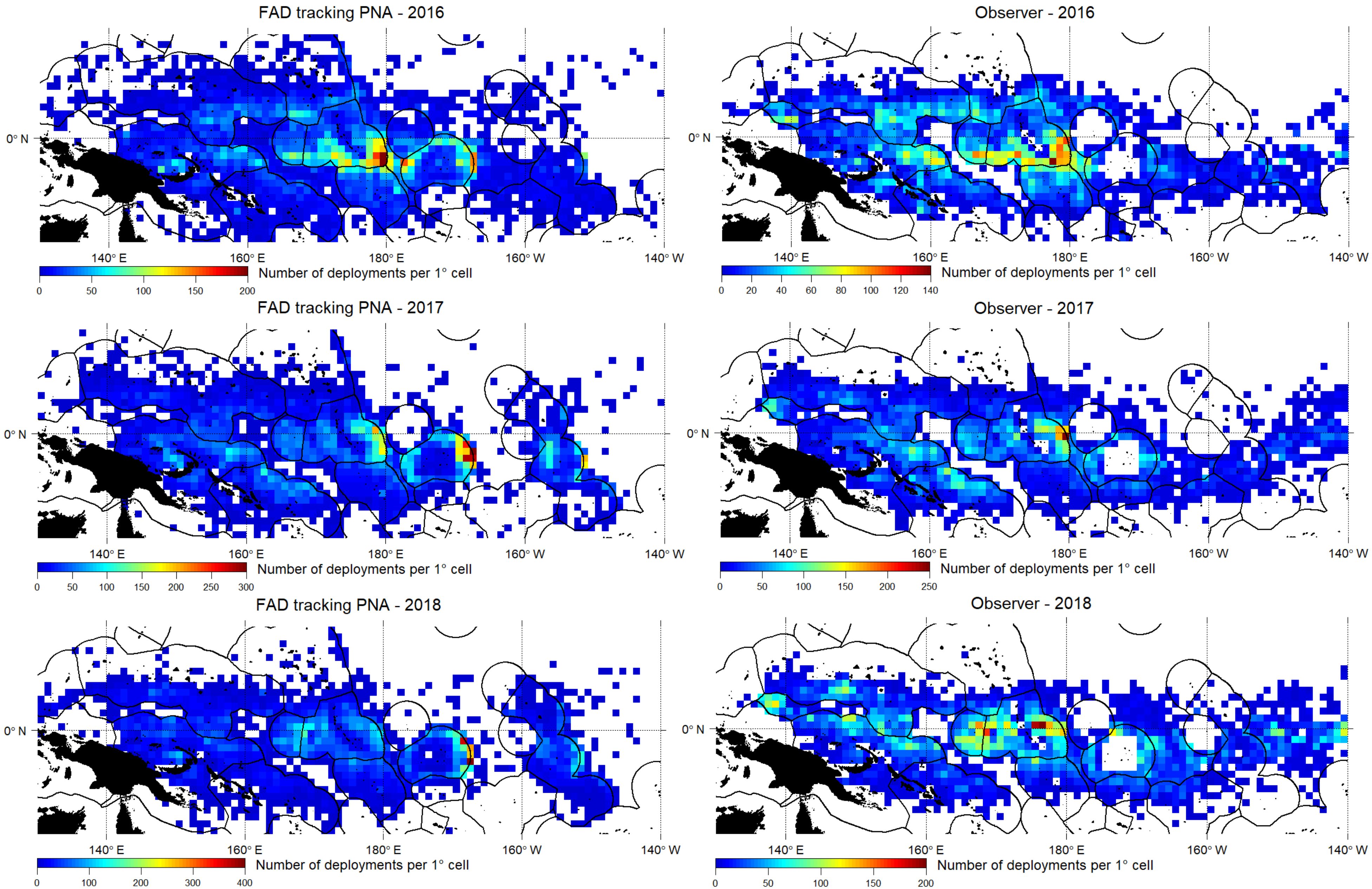


Figure 4. Estimated number of buoy deployments per vessel per year for the PNA (black) and WCPFC (blue) FAD tracking data; and the total number of dFAD (green) and buoy (red) deployments recorded by observers. Note that data for 2023 are still incomplete. The horizontal lines indicate levels of 100; 200 and 500 deployments per vessel.

4.2 Spatial variability

The spatial distribution of buoy (and dFAD for the observer data) deployments was investigated each year for the 2016–2023 period using the PNA and WCPFC (2023 only) FAD tracking data and observer data. A large proportion of the deployments occurred in Kiribati south of the Gilbert Islands and east of the Phoenix Islands, north of Tuvalu, Nauru, east of PNG and south-east of RMI (Figure 5). Differences between datasets are, however, detected. For instance, given that the PNA FAD tracking data is geofenced, deployments in the eastern high seas or dFADs drifting from the Eastern Pacific Ocean (EPO) would appear as a deployment at the border of the Line and Phoenix Islands or at the eastern boundary of the Marshall and Gilbert Islands. Hence in the observer and WCPFC FAD tracking data, deployments are detected in the High Seas between the Phoenix and Line Islands, and east of the Line Islands.


FAD tracking PNA - 2016
0° N
140° E
160° E
180° E
160° W
140° W
Number of deployments per 1° cell
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50
100
150
200
Observer - 2016
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140° E
160° E
180° E
160° W
140° W
Number of deployments per 1° cell
0
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40
60
80
100
120
140
FAD tracking PNA - 2017
0° N
140° E
160° E
180° E
160° W
140° W
Number of deployments per 1° cell
0
50
100
150
200
250
300
Observer - 2017
0° N
140° E
160° E
180° E
160° W
140° W
Number of deployments per 1° cell
0
50
100
150
200
250
FAD tracking PNA - 2018
0° N
140° E
160° E
180° E
160° W
140° W
Number of deployments per 1° cell
0
100
200
300
400
Observer - 2018
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0
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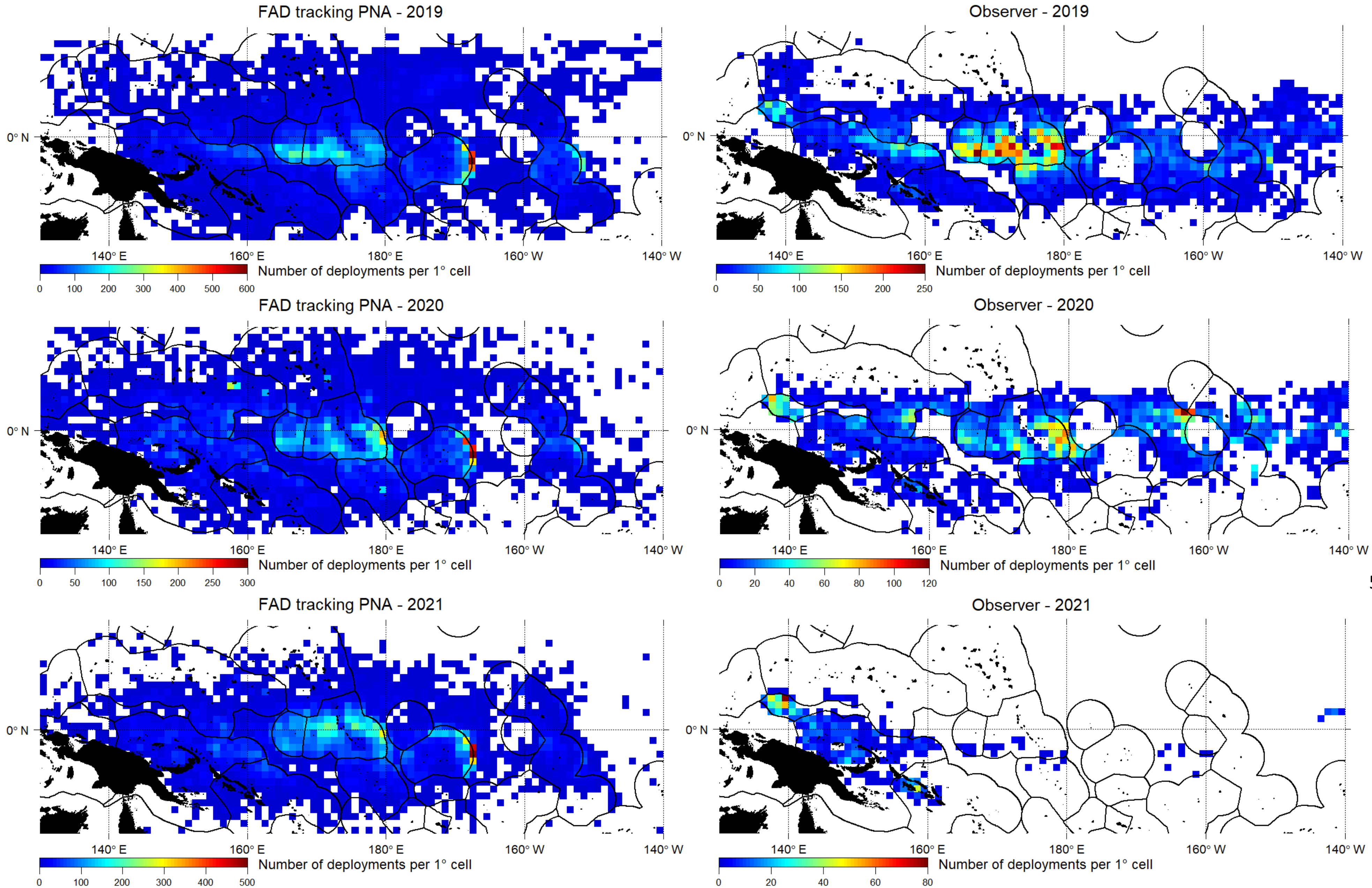
FAD tracking PNA - 2019
0° N
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160° W
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Number of deployments per 1° cell
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Observer - 2019
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180° E
160° W
140° W
Number of deployments per 1° cell
0
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250
FAD tracking PNA - 2020
0° N
140° E
160° E
180° E
160° W
140° W
Number of deployments per 1° cell
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Observer - 2020
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Number of deployments per 1° cell
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120
FAD tracking PNA - 2021
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Observer - 2021
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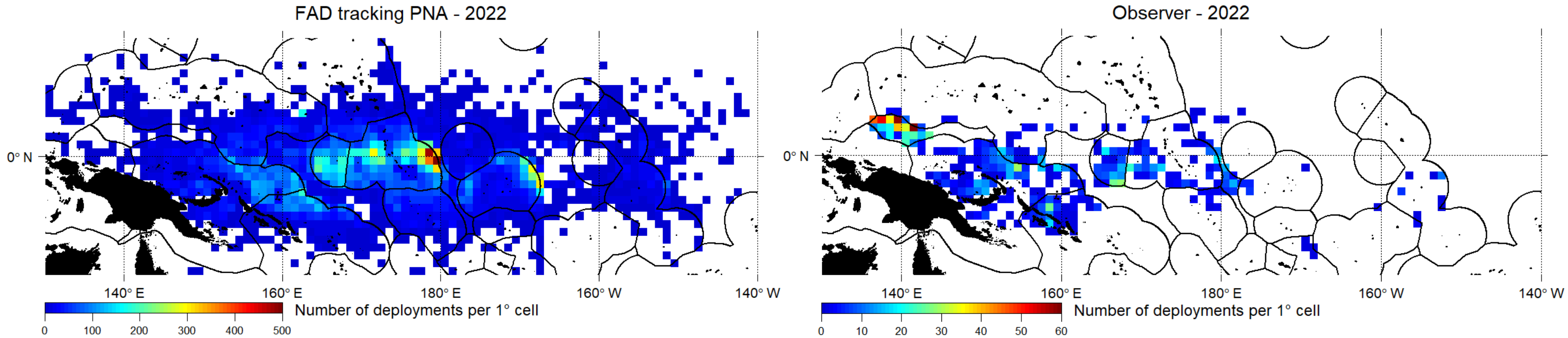


Figure 5. Number of buoy deployments estimated in the PNA FAD tracking data (left) and buoy and FAD deployments recorded by observers (right) per 1° grid cell per year over the 2016 –2022 period. Colour scale corresponds to the numbers of buoy deployments per 1° cell. Note the different scales between the PNA FAD tracking and the observer data.

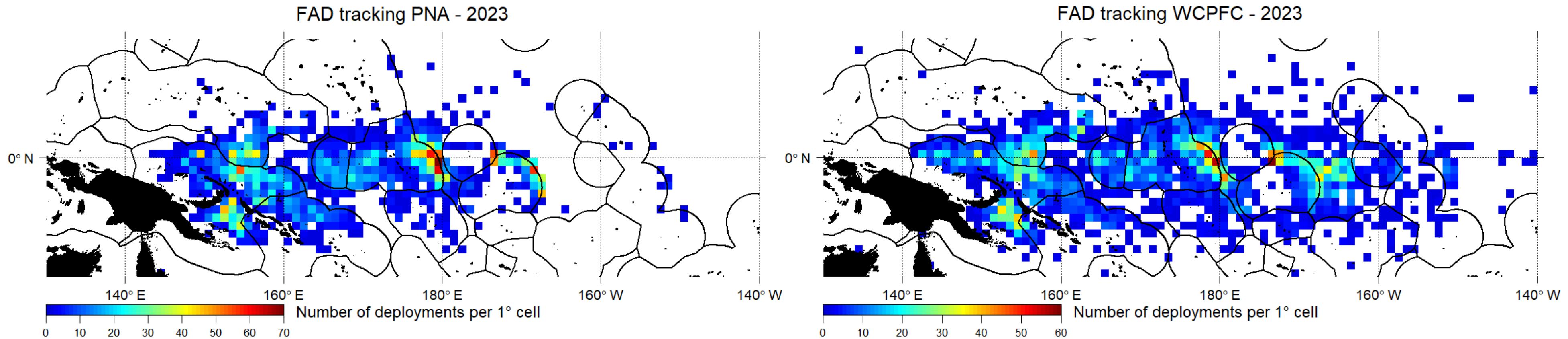


Figure 6. Number of buoy deployments estimated in the PNA FAD tracking data (left) and WCPFC FAD tracking data (right) per 1° grid cell in the first 3 months of 2023. Colour scale corresponds to the number of buoy deployments per 1° cell. Note the different scales between the PNA and WCPFC FAD tracking data.

5. Temporal distribution of dFADs

5.1 Temporal variability in transmissions

The 51,722,022 transmissions from the PNA FAD tracking filtered datasets were comprised of 22% on-board positions and 78% at-sea positions. An increase in the number of transmissions and number of buoys transmitting in the data set was detected after the first year of the program, assumedly linked to better data provision (Figure 7). In particular, the number of transmissions from drifting buoys (at-sea) doubled in 2017 (9.2 million compared to 5.0 million in 2016).

In 2017 and 2018, the number of transmissions per day was around 20,000–25,000, except during the FAD closure where a decrease in number of transmissions is detected each year. In 2019 and 2020, the number of transmissions per day was lower, at around 10,000–15,000. Nevertheless, the number of individual active buoys remained relatively constant from 2017 to mid-2020 at 4,500-6,000 per day, except for during FAD closure period where a decrease was detected (Figure 7). The decrease in transmissions despite the stable number of buoys transmitting implies that the patterns of transmission rate have changed since 2019 (Figure 7). A large decrease in the number of transmissions and number of buoys transmitting is detected for the last quarter of 2020, for unknown reasons, but could be linked to the COVID-19 pandemic. This is directly followed by a notable increase in both parameters during the first half of 2021, with up to 7,000 buoys transmitting per day and 40,000 transmissions per day. Since then, the number of buoys transmitting has been between 4,500 and 6,700; and the number of transmissions between 10,000 and 25,000. It should also be noted that some large short-term drops in both transmission and number of FADs active per day still occur, mostly at the end of some months (Figure 7). At the monthly level, the number of unique buoys transmitting at-sea ranges between 6,000 and 10,000 in the 2017–2023 period (Figure 8).

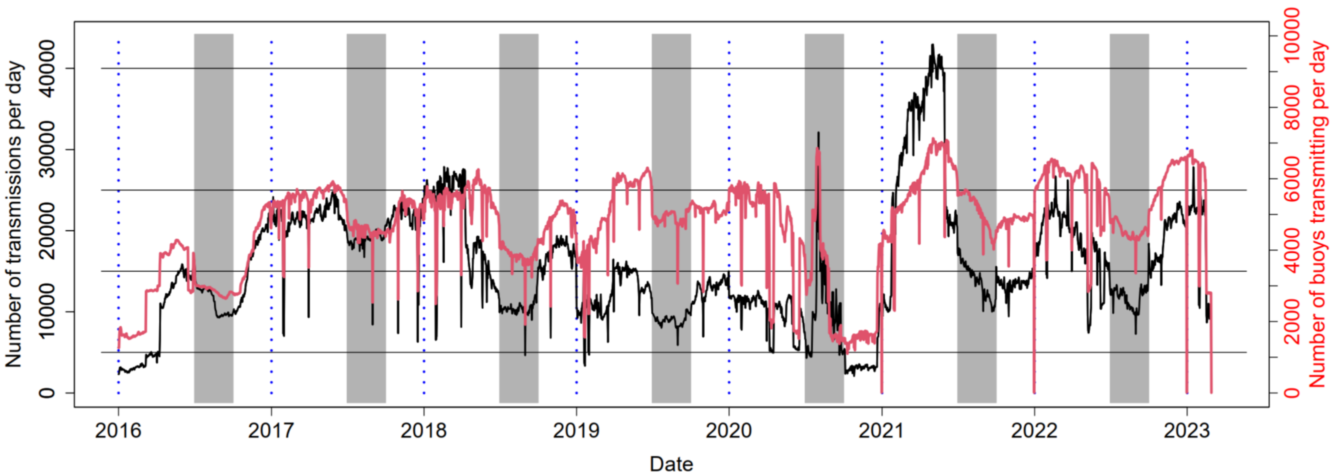


Figure 7. Number of transmissions (black line and y-axis 1) and unique buoys transmitting (red line and y-axis 2) daily from at-sea buoy positions only in the PNA FAD tracking dataset. Grey areas correspond to the FAD-closure periods (1st of July through 30th of September), and the grey dotted vertical denote January 1st. Vertical lines indicate levels of 5,000, 10,000 25,000 and 40,000 transmissions.

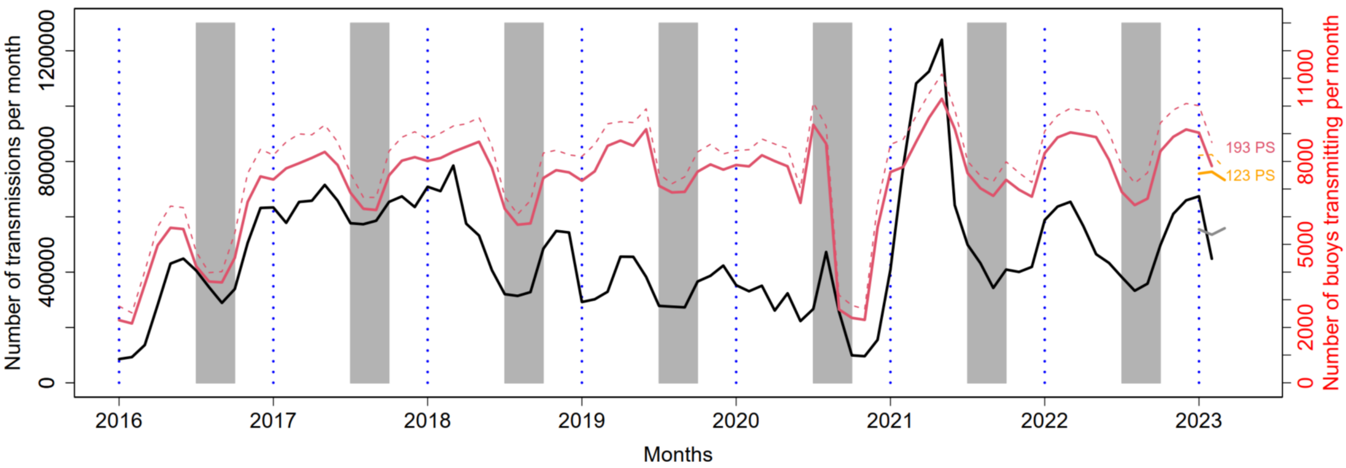


Figure 8. Number of transmissions (black and grey lines, y-axis 1) and unique buoys transmitting (red and orange lines, y-axis 2) monthly from at-sea buoy positions only in the PNA (black and red lines) and WCPFC (grey and orange lines) FAD tracking dataset. Dotted lines indicate the number unique buoys transmitting from both at-sea and on-board monthly. Grey areas correspond to the FAD-closure periods (1st of July through 30th of September), and the blue dotted vertical lines denote January 1st. 193 PS and 123 PS, indicates the number of purse seiners (PS) indicated as buoy owners in each database.

5.2 Time and distance at sea

The longevity of dFAD drift and the linear drift distance were examined. At-sea drift periods per buoy varied from less than 10 days to more than 5 years, with shorter times for buoys that were redeployed several times. The average drift time is around three months (97 days) with an average linear drift distance of 1,167 km, whereas the average active time (including on-board sections) was seven months (200 days) with an average straight-line distance between first and last position of 1,855 km (Figure 9).

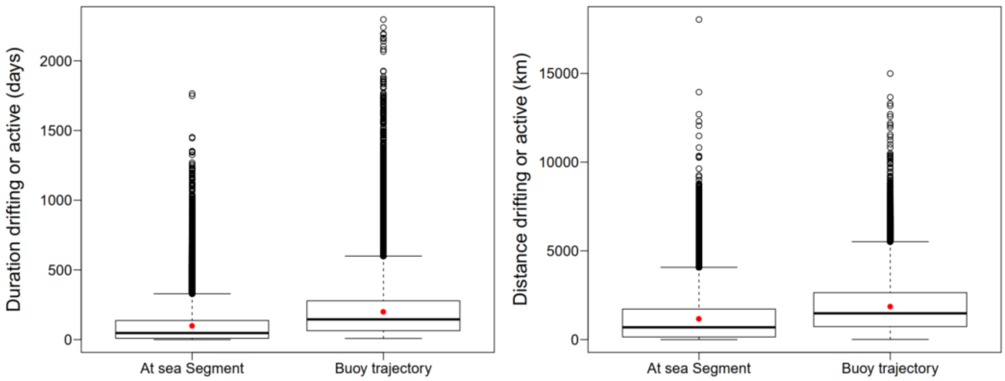


Figure 9. Duration (left) and distance (right) of drifting per FAD buoy trajectory (whole buoy trajectory, including on-board segments) or at-sea segments (on-board segments removed) in the PNA FAD tracking database. Red dots are the mean value and vertical bars the median and the boxes correspond to the lower and upper quartiles.

5.3 Number of buoys used per vessel

The number of active buoys per vessel was also investigated (Figures 10 and 11). Since 2016 and for the vessels transmitting FAD tracking data to PNA and WCPFC, the number of active buoys at-sea monitored per vessel per day ranged between 1 and 335 (Figure 10 and 11). The average was around 30–45; and the 0.9 quantile around 70–115, using the PNA FAD tracking data for 2016–2023. While the average ranged around 50–55; and the 0.9 quantile around 115–130, using the WCPFC FAD tracking data in 2023 (Figure 10 and 11).

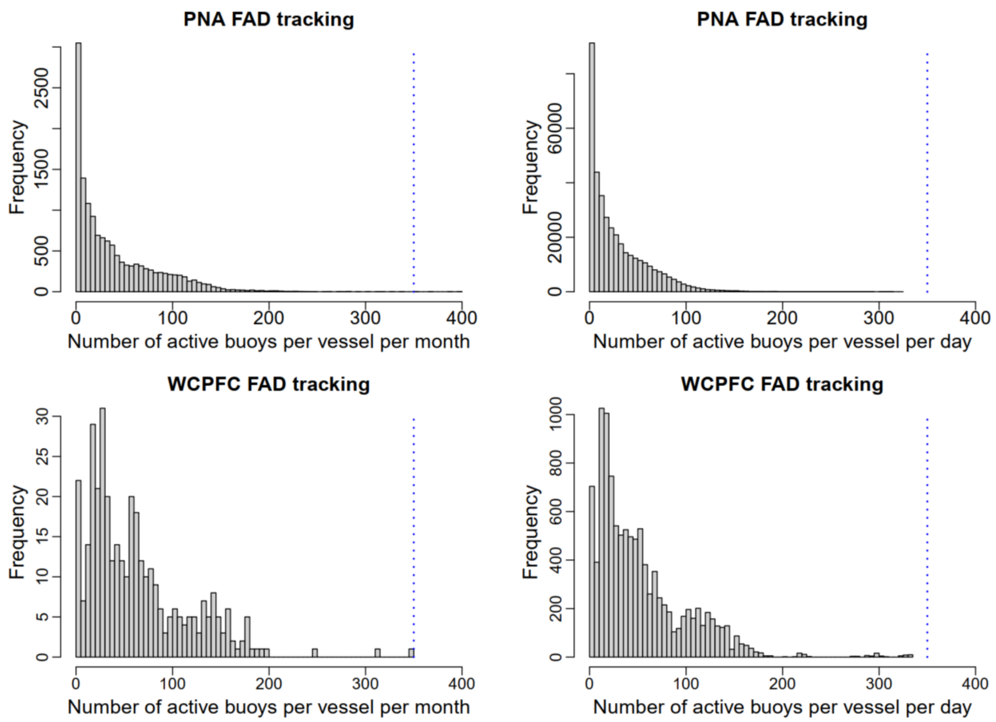


Figure 10. Histograms of the number of active buoys per month (left) or per day (right), per vessel (when vessel name was available) for the 2016–2023 period as recorded in the PNA FAD tracking data (top); and for 2023 as recorded in the WCPFC FAD tracking data (bottom).

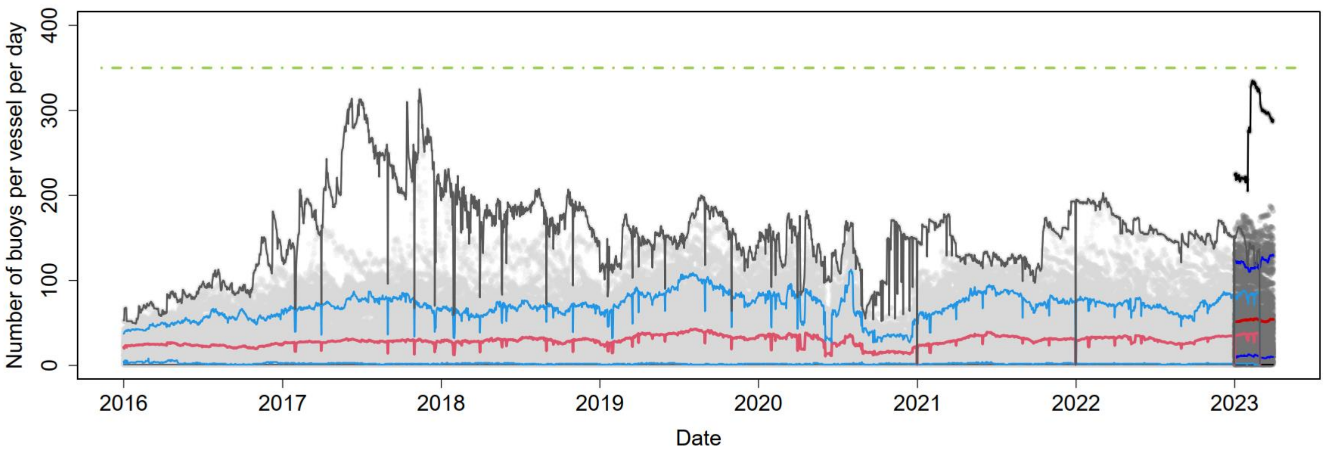
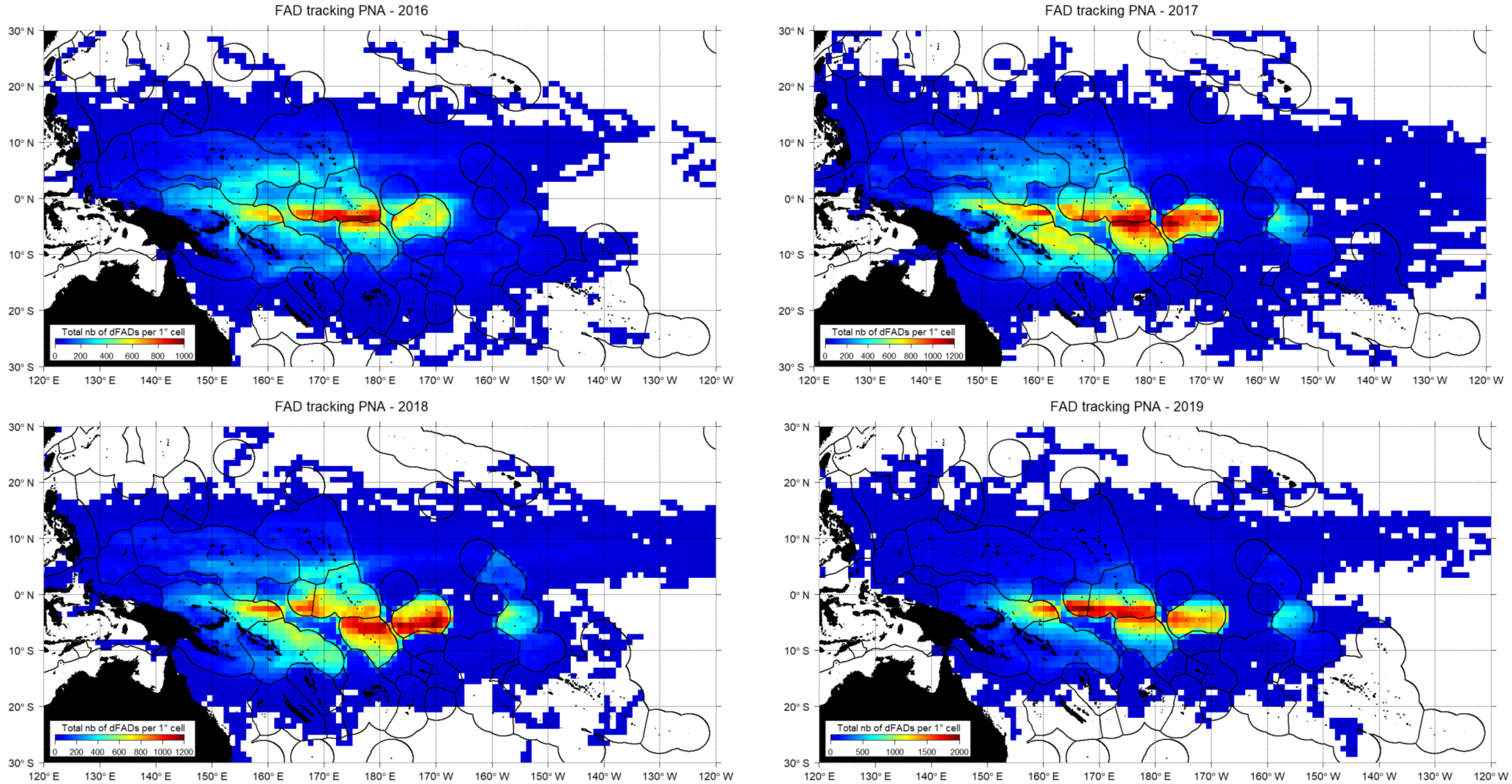


Figure 11. Number of buoys transmitting at-sea per vessel per day (grey dots) in the PNA (light grey, red, blue and black) and WCPFC (dark grey, red, blue and black) FAD tracking dataset. Red lines correspond to the mean number of buoys per vessel per day; blue lines the 0.1 and 0.9 quantiles, and black lines the minimum and maximum. The green dotted horizontal line indicates the level of 350 active buoys per vessels.

6. dFAD densities

The variability of dFAD density through space and time was investigated. The distribution of drifting buoys indicated those areas with highest dFAD density were in Kiribati south of the Gilbert Islands and around the Phoenix Islands; Nauru; Tuvalu; the eastern area of Papua New Guinea and off the Solomon Islands (Figure 12). These areas of high dFAD densities also correspond to areas where a high number of associated sets occur (see Figure 13). However, it should be noted that a non-trivial number of associated sets occur outside of these high dFAD densities areas, for instance in the southeast of the WCPO (Figure 13).


FAD tracking PNA - 2016
Total nb of dFADs per 1° cell
0 200 400 600 800 1000
FAD tracking PNA - 2017
Total nb of dFADs per 1° cell
0 200 400 600 800 1000 1200
FAD tracking PNA - 2018
Total nb of dFADs per 1° cell
0 200 400 600 800 1000 1200
FAD tracking PNA - 2019
Total nb of dFADs per 1° cell
0 500 1000 1500 2000
30° N
20° N
10° N
0° N
10° S
20° S
30° S
120° E 130° E 140° E 150° E 160° E 170° E 180° E 170° W 160° W 150° W 140° W 130° W 120° W

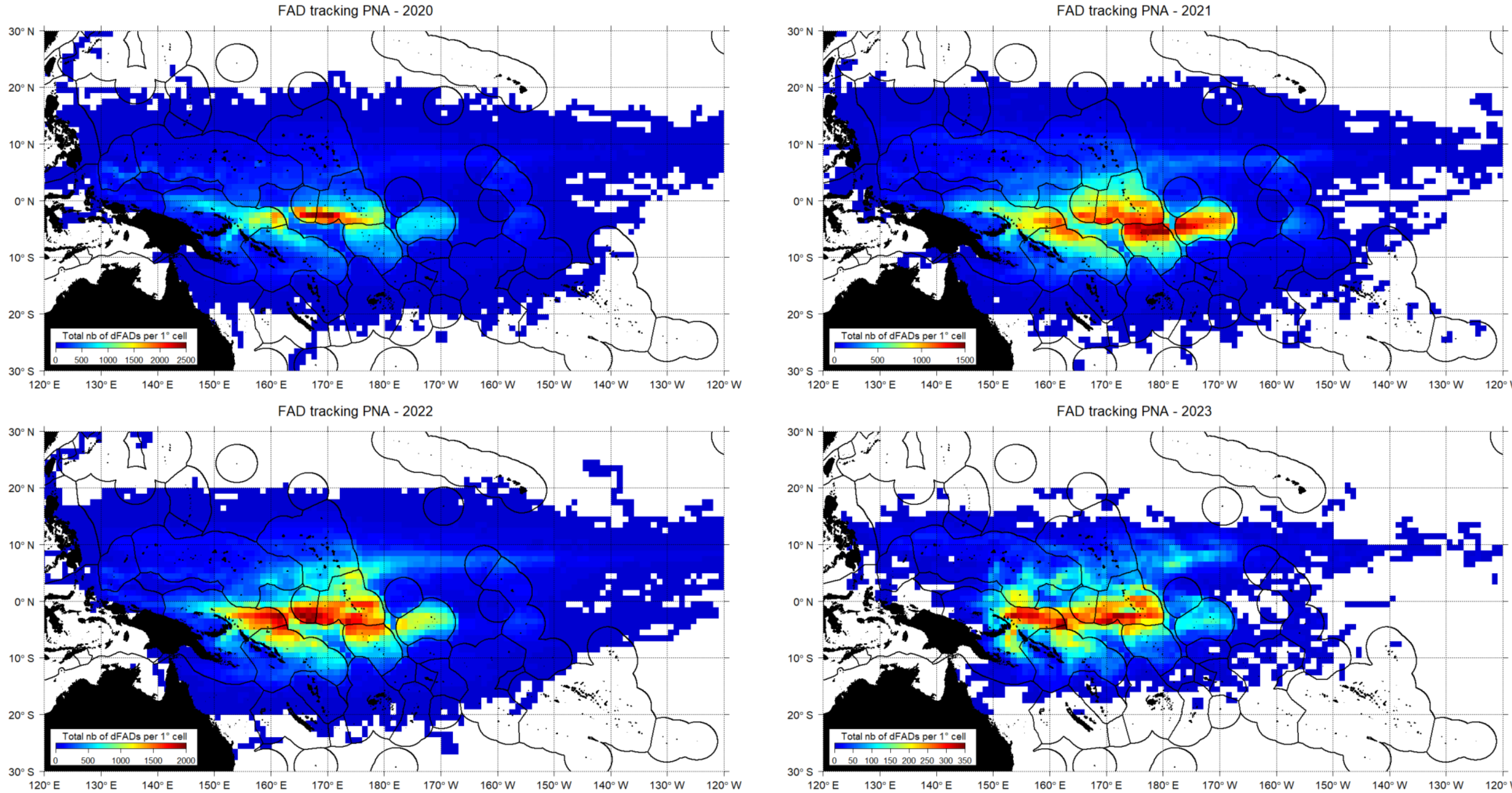


Figure 12. Density of the total number (nb) of dFAD satellite buoys transmitting at least once per year and per 1° grid cell over the 2016–2023 period, from the PNA FAD tracking database. Colour scale corresponds to the total number of buoys transmitting per 1° cell per year.

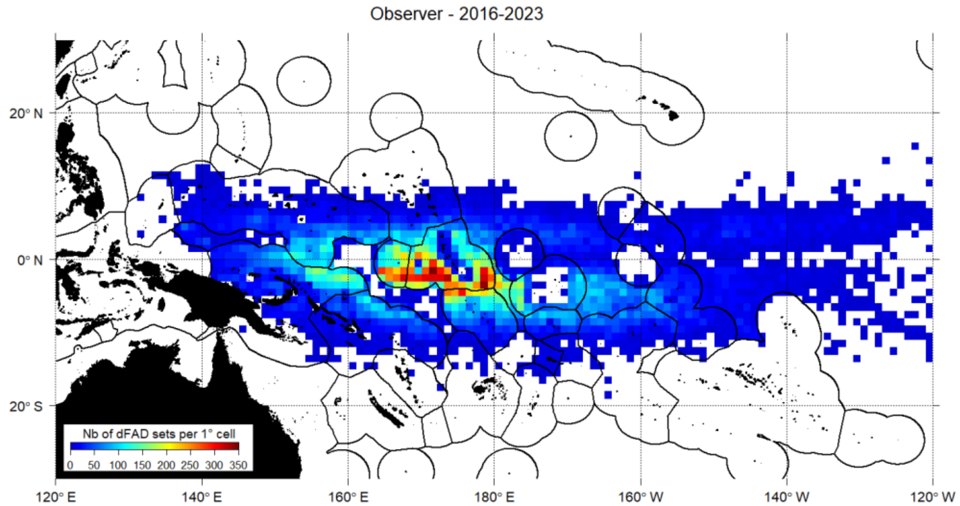


Figure 13. Number of dFAD sets recorded by observers over the 2016-2023 period. Colour scale corresponds to the total number of dFAD sets per 1° cell.

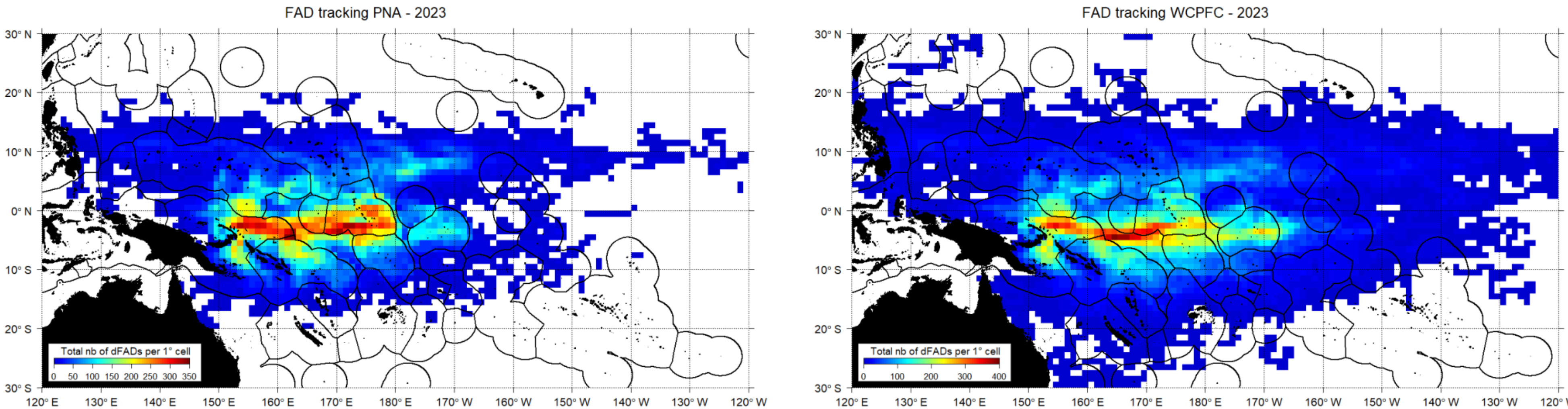


Figure 14. Density of the total number (nb) of dFAD satellite buoys transmitting at least once per year and per 1° grid cell in 2023, from the PNA (left) and WCPFC (right) FAD tracking databases. Colour scale corresponds to the total number of buoys transmitting per 1° cell per year.

Similar to the deployment maps, it is clear that in the PNA FAD tracking dataset we are missing information due to geo-fencing and periods of non-transmission, with very low dFAD densities in some areas outside PNA waters. This can readily be detected when comparing dFAD densities using the WCPFC FAD tracking data and the PNA FAD tracking data, for the first 3 months of 2023 (Figure 14). A larger spatial extent of buoy positions can be detected for the WCPFC data. Higher dFAD density can also be detected in the high seas between Tuvalu and Phoenix Islands EEZs and between the Phoenix and Line Islands EEZs. Accessing complete and unmodified dFAD tracking data in the future and for historical periods would allow for a broader and more comprehensive appreciation of the spatial extent and variation of dFAD densities.

7. Fate of FADs

The majority of buoys were classified as abandoned (44.8%), with 26.9% being abandoned within the fishing grounds of purse seiners at a specific time (end of the year or during the closure), and 17.9% outside the main fishing grounds (Figures 15 and 16). The number of buoys classified as uncertain fate at the end of their trajectories represent 37.6%, with 11.8% being buoys deactivated within 12nm from shore, indicating potential stranding in the near future. However, this should be interpreted with caution given that local currents can bring dFADs back to the fishing grounds or away from shore. A total of 6.0% of buoys were retrieved, however there is no indication of whether the vessel retrieving the buoy was the owner of the buoy, another purse seine vessel, or another vessel (for example when the recovery is close to shore). In addition, the map of recovered buoys in Figure 15 corresponds to the last position of the recovered buoys, which could be in a port. It would be more relevant to map the first position post-recovery of these buoys, which requires further data manipulation. Finally, 11.3% of the buoys were stranded, with most (9.6%) not moving at all at the end of their trajectories (Figures 15 and 16).

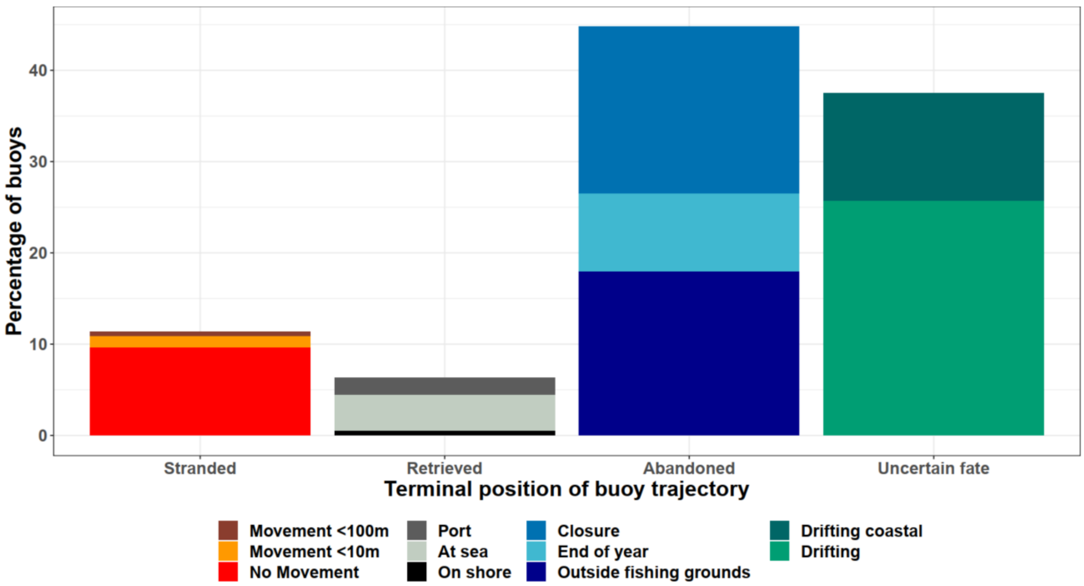


Figure 15. Percentage of buoys' terminal position from the PNA FAD tracking dataset and classified as stranded; retrieved by any vessel; abandoned (within or outside the general purse seine associated fishing grounds); or uncertain fate from 2016–2023. These results exclude buoys transmitting in the last 6 months of the database.

Overall, we estimated that 44.8% of buoys were abandoned; 6.0% were retrieved; 11.3% were stranded; 37.6% were deactivated by the fishing company or the signal was lost within the fishing grounds and left drifting unmonitored at sea. We hypothesise that the buoys with uncertain fate (i.e., dFADs found drifting within the main purse seine fishing grounds) with unexplained deactivation (classified as "uncertain fate") correspond to buoys that have sunk or flooded, buoys being disabled during dFAD appropriation by another vessel, or buoy malfunction. Except for the latter case, the remaining categories would not lead to dFADs floating unmonitored. Abandoned buoys, however, would remain in the water for an unknown period of time, and this number of unmonitored abandoned or lost dFADs cannot currently be taken into account when assessing dFAD densities, and when investigating the impact of dFAD density on tuna distributions, behaviour and CPUE patterns.

The spatial distribution of the different categories of buoy fates was studied, in particular comparing the fate of buoys from the PNA and WCPFC FAD tracking databases, (Figures 16 and 17). In terms of stranding events, higher levels are detected in Kiribati Gilbert Islands, Nauru, Tuvalu, PNG and the Solomon Islands. Although, it should be noted that limited information is available outside PNA EEZs, due to geofencing (Figure 16) and/or deactivation of buoys outside the main purse seine fishing areas (Figures 16 and 17). Higher numbers of buoys with uncertain fate or 'retrieved' are found within the main fishing grounds and areas of high dFAD density between PNG, Solomon Islands, Nauru, the Gilbert Islands and Tuvalu. In terms of abandonment, data from the PNA FAD tracking database mostly indicates hotspots of deactivation at PNA borders, such as south of the Solomon Islands, Tuvalu and Phoenix Islands EEZ, as well as northeast Palau, FSM and RMI (Figure 16). The WCPFC FAD tracking database complements this. Even with the 3-months of data available to date, potential hotspots of deactivation in the south of the WCPO (South of the Solomon Islands, Fiji and Vanuatu EEZ); and in the high sea area in the north of the WCPO (west of RMI EEZ) have been identified (Figure 17).

The number of buoys and dFADs retrieved by purse-seiners, as declared by observers, are similar to the number of deployments recorded by observers (Figures 3 and 18), with 10,000–13,000 buoys retrieved and 5,000–7,000 dFAD retrieved during the 2011–2019 period. This might be an indication of the extensive levels of dFAD appropriation and buoy exchange occurring in the WCPO. However, between 2,000 and 5,000 buoys and 1,000 to 2,000 dFADs are never retrieved, corresponding to 21 to 64% of buoys per year and 6 to 30% of dFADs. These levels are very different from the fate of buoys obtained using PNA FAD tracking data, and additional analyses should be performed using both data sources to better determine dFAD recovery rates.

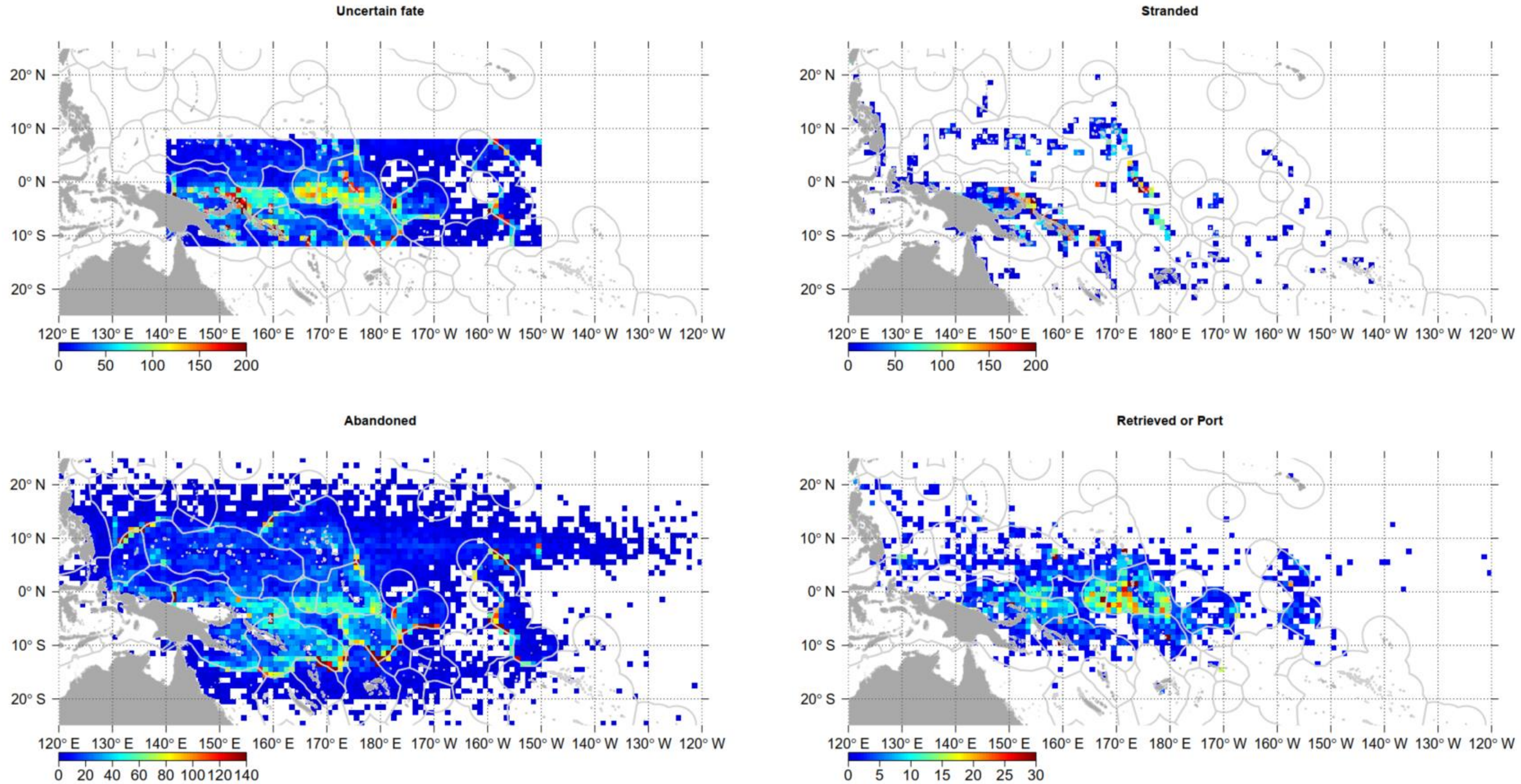


Figure 16. Density maps of last recorded position of each buoy in the PNA FAD tracking data: a) uncertain fate; b) stranded; c) abandoned; and d) retrieved or in port; for the 2016–2023 period.

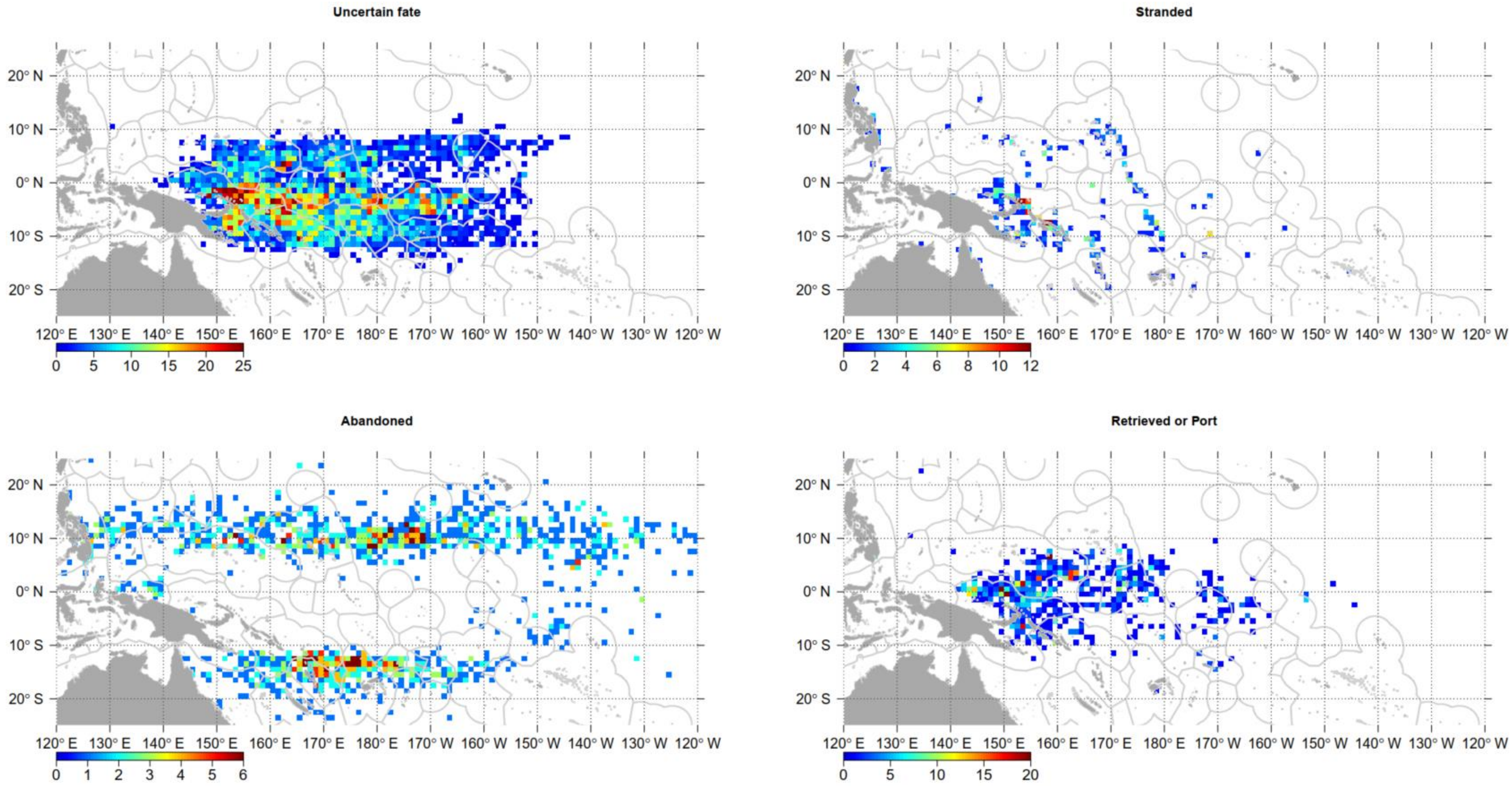


Figure 17. Density maps of last recorded position of each buoy in the WCPFC FAD tracking data: a) uncertain fate; b) stranded; c) abandoned; and d) retrieved or in port; in 2023.

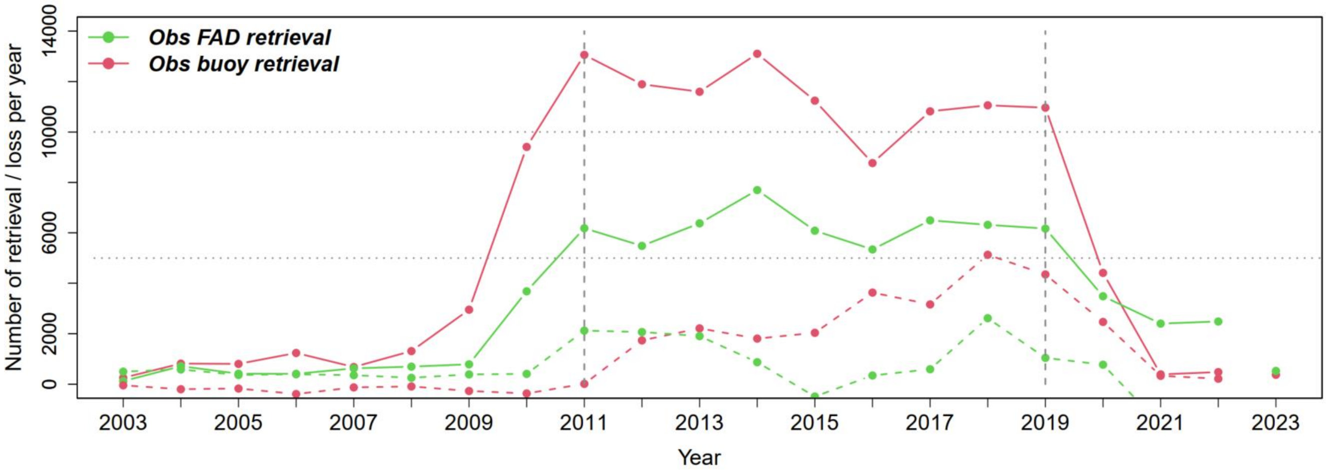


Figure 18. Number of dFAD (green) and buoy (red) retrieval recorded by observers (solid lines); and difference between number of deployments (see Figure 3) and number of retrievals recorded by observer (dash line), indicating potential number of dFAD and buoys never retrieved. Note that data for 2023 are still incomplete. The horizontal lines indicate levels of 5,000 and 10,000 retrievals/loss; and vertical dashed lines the period with 100% observer coverage (2011–2019).

8. Discussion and Conclusion

This paper presents results from analyses of dFAD use in the WCPO, using a combination of FAD tracking data and observer data.

The volume of data submitted to PNA, through the PNA FAD tracking programme has continued to increase overtime, with transmission from more than 25,000 buoys in 2022. However, the lack of full submission of the data by fishing companies and the editing of the data (geo-fencing) before submission to PNA is still occurring, limiting the analyses and outputs of potential interest to managers. This geofencing of buoy transmissions should be prevented by the recent adoption of the PNA 4th Implementing Arrangement, which requires that dFAD buoys are registered and transmit regular position data to the PNA while a vessel is licensed to a PNA Member, including transmitting data from high seas areas between 20° North and 20° South of the WCPFC convention area.

The recent voluntary submission of buoy position data to WCPFC, through the Scientific Services Provider, is another useful dFAD tracking dataset, that highlights the missing information in the PNA FAD tracking database. Similar number of transmissions and buoys transmitting were detected in both the WCPFC and PNA FAD tracking datasets for the first 3 months of 2023. While only containing 2023 data, this dataset included more data per vessel compared to the PNA FDA tracking dataset. In addition, a larger spatial coverage of transmissions is detected from the WCPFC data, allowing for better assessment of areas of buoy deployments, dFAD density and fate of dFADs. Complete and unmodified dFAD tracking data, which remain the most precise source of information regarding dFAD densities, number of FADs or buoys at-sea and fate of dFADs, is therefore key to provide unbiased trends of dFAD use. It is also critical to access this information for historical periods, in order to better characterise how dFAD use may have changed over time and hence provide adequate management advice.

Observer data are also a useful source of information on the spatial and temporal use of dFADs and buoys, and additional analyses would be useful to better characterise the link between dFAD and buoy deployments and retrievals and the trajectories of buoys from the dFAD tracking databases. The limited observer placements during 2020–2023 due to the COVID-19 pandemic has greatly decreased the data available, limiting the analyses that can be performed using observer data. Additional information regarding dFAD materials and designs used in the WCPO are investigated in a separate paper and provide key parameters to assess the effectiveness of management measures (Escalle et al., 2023). In general, there is a need for precise records of; i) every dFAD related activity (e.g., set, deployment, service, beaching), which would allow the matching with trajectories in the FAD tracking data; ii) dFAD and buoy deployment (given that dFADs themselves are marked); and iii) information on the dFAD (depth, width/length, design, materials). Priority should therefore still be given to obtaining high quality dFAD related information from observer or logsheet data. The FAD logsheet that has been developed by the PNA should assist in filling these gaps while reducing observers' workload, its wider use would help address some of the issues mentioned above. An overlap period, with high observer coverage should however be considered, so that detailed comparative analyses of data collected by observers and captains, through the new FAD logsheet can be performed.

The current paper has identified that based upon the information available, no vessel currently monitors more than 350 active buoys per day, with 90% of the vessels monitoring less than 130 buoys per day, while the average is 30–55 depending on the year and source of dFAD tracking data used. We acknowledge that these numbers might be underestimated, as it only represents data from 200 and 123 purse seiners for 2023, for the PNA and WCPFC FAD tracking databases, respectively. The tropical tuna CMM currently limits the number of active FADs, at any given time, to 350 per vessel (CMM-2021-01, paragraph 23[1]). Results from our analyses indicate that the current limit is not restricting the number of buoys that can be monitored by vessels, and a decrease in this number could be considered if the objective were to limit future increases in dFAD use. We can note that the use of 350 buoys at-sea by the 200 vessels transmitting FAD tracking data could lead to 70,000 dFADs at-sea at any time, which is ten times the current level detected in this study. Complete dFAD tracking data, including historical periods, should however be made available to evaluate an alternative active buoy limit for the WCPO.

With the tracking data currently available, the analyses presented in this paper also highlighted high levels of deployments, FAD density, buoy retrieval and signal loss for unknown reasons, within the core of the WCPO purse seine fishing grounds from PNG and the Solomon Islands to the east of Kiribati Phoenix Islands. Additional investigation of dFAD exchange, as well as distance between dFADs and dFAD density in relation to CPUE patterns should therefore be considered.

The current method to identify dFAD fates highlighted the high potential rate of dFAD abandonment (>40%) and dFAD stranding (11%). However, it is clear that the lack of complete dFAD trajectories underestimates the number of stranding events, specifically in non-PNA countries, as highlighted by

[1] A flag CCM shall ensure that each of its purse seine vessels shall have deployed at sea, at any one time, no more than 350 drifting Fish Aggregating Devices (FADs) with activated instrumented buoys. An instrumented buoy is defined as a buoy with a clearly marked reference number allowing its identification and equipped with a satellite tracking system to monitor its position. The buoy shall be activated exclusively on board the vessel. A flag CCM shall ensure that its vessels operating in the waters of a coastal State comply with the laws of that coastal State relating to FAD management, including FAD tracking.

preliminary assessment of fate using the more complete WCPFC FAD tracking data. However, even with a complete dFAD tracking dataset, buoys may be deactivated before reaching coastlines, leading to undetected stranding events. There has been a growing data collection effort in the WCPO to better quantify the number of stranding events, characterise these strandings and their impacts (Mourot et al., 2023), which will help fill in the gaps between deactivation and stranding. Two potential hotspots of dFAD loss and abandonment are detected in the south and north of the WCPO, using only 3-months of the WCPFC data. More focus should be made in the future on characterizing these potential hotspots of deactivation and stranding events. Finally, around 37% of buoys were deactivated while still in the main fishing grounds, for unknown reasons. Accessing better information on the fate of dFADs, including the reason why a buoy is deactivated, would be valuable to better understand the impact that the high number of abandoned and lost dFADs may have on the environment.

We invite WCPFC-SC19 to:

- Note the spatial and temporal trends in dFAD use in the WCPO presented in this paper.
- Note the importance of complete FAD tracking data, including historical periods, to support scientific analyses and detect trends in dFAD use, and the limitation in the scientific analyses due to the current incomplete data.
- Note that 18,000–33,000 buoys are deployed (including re-deployments) per year over 2016–2022, and that the buoy deployments recorded by observers represent only half to three quarters of the number of buoys deployments estimated using FAD tracking data. The number of dFAD deployments that were recorded by observers was around half the number of buoy deployments, indicating high rates of dFAD appropriation and exchange.
- Note that, based on the information available, no vessel monitored more than 350 active buoys per day, current limit un *CMM 2021-01*; with 90% of the vessels monitoring less than 130 buoys per day.
- In order to verify compliance with *CMM 2021-01*, consider options for reporting the number of active buoys per vessel; as well as the number of dFAD/buoys deployed, retrieved and deactivated or lost at sea per vessel per year to inform management.
- Note that findings of this paper highlighted that more than 44% of buoys were estimated to be abandoned, 11% stranded, and 37% had an uncertain fate. Potential hotspots of buoy deactivations were also detected in the south of the WCPO and in the high seas area in the northeast of the WCPO.

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