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A short-lived FAD in the Pacific: Implications and adaptations in the move to biodegradable fish aggregating devices

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ABSTRACT

The development of biodegradable drifting fish aggregation devices (FADs) in tropical tuna fisheries will reduce marine pollution and, potentially, stranding events when FADs are abandoned or lost. Using estimated FAD deployment densities across the entire Pacific Ocean, we examine the relative change in FAD loss out of equatorial fishing zones, under differing FAD lifetime scenarios, by simulating FAD drift over two years.

When FADs physically degrade after one year, we found that the greatest reduction in FADs lost out of the fishing ground was in the Western and Central Pacific. However, we also found a two-to-four-fold increase in the number of FADs that will prematurely degrade whilst still potentially operational. These results are discussed in the context of mitigating FAD impacts on marine debris, the need to repair and maintain FADs, and the potential for a future, compensatory effort of deploying increased numbers of FADs by fishing fleets.

1. Introduction

The use of drifting fish aggregating devices (FADs) represents a major fishing strategy for tropical tunas globally (Pons et al., 2023). Since the 1990s, FAD deployment has increased sharply, particularly following the 2010 introduction of satellite-linked echosounder buoys, which allow vessel owners to remotely monitor fish aggregations and optimize catches (Lopez et al., 2014). Annual deployments now reach up to 65,000 in the Pacific Ocean alone (Escalle et al., 2021; Lopez et al., 2024), prompting growing concern over their ecological impacts on both target and non-target species and marine ecosystems (Leroy et al., 2013). These impacts include increased catch of undersized yellowfin and bigeye tuna in associated aggregations (Scutt Phillips et al., 2017), increased bycatch of vulnerable sharks, rays and turtles (Lezama-Ochoa et al., 2017), and contribution to marine pollution from loss, abandonment and discarding of FAD rafts (Escalle et al., 2023b; Mourot et al., 2023). Their widespread use also raises questions about potential habitat modification, effects on tuna migration and biology, and shifts in fishing strategies and catch dynamics (Pons et al., 2023). While some are recovered, many are left to drift or are abandoned when they exit fishing operational ranges, becoming marine debris. These abandoned FADs often collect in debris accumulation zones or strand in sensitive coastal and coral reef habitats, particularly in the Pacific (Escalle et al., 2023a; Escalle et al., 2019; Lopez et al., 2024; Mourot et al., 2023).

To mitigate these impacts, biodegradable FADs (bio-FADs) have been developed and tested over the past decade (Murua et al., 2023) Several Regional Fisheries Management Organisations (RFMOs) have adopted recommendations or mandates supporting their use. The Inter-American Tropical Tuna Commission (IATTC) targets full transition to bio-FADs—excluding synthetic flotation materials—by 2030 (IATTC C-23-04), while the Indian Ocean Tuna Commission (IOTC) and the International Commission for the Conservation of Atlantic Tunas (ICCAT) mandate 100 % biodegradable FADs by 2029 and 2028 respectively (IOTC Res 24/02; ICCAT Rec 24–01). The Western and Central Pacific Fisheries Commission (WCPFC) have issued non-binding guidelines to encourage adoption (WCPFC CMM-2023-01). Across RFMOs, bio-FADs are defined as structures composed of renewable lignocellulosic or certified marine-biodegradable bio-based materials. Common trial materials include cotton (*Gossypium hirsutum*), manila hemp (*Musa textilis*), sisal (*Agave sisalana*), and fique (Furcraea andina) (Moreno et al., 2023; Murua et al., 2023; Roman et al., 2023; Wang et al., 2021), selected for their biodegradability, sustainability, and availability. Controlled studies show these materials degrade within a year in shallow environments such as coral reefs (Moreno et al., 2019).

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Although FAD designs vary, trials show that biodegradable materials do not compromise fishing performance relative to conventional FADs (Moreno et al., 2023; Murua et al., 2023; Roman et al., 2023). Traditional FADs consist of a floating surface structure, a submerged tail extending 30–80 m, and a satellite-linked GPS buoy (Escalle et al., 2023b; Lopez et al., 2024, 2014). Early bio-FAD designs mimicked these configurations using organic materials such as cotton and manila hemp but showed degradation within 3–4 months due to structural stress (Murua et al., 2023; Roman et al., 2023). Fishers in the Pacific Ocean prefer FAD lifetimes of up to one year to ensure adequate fish aggregation and utilization (Moreno et al., 2016).

A recent innovation, the jelly-FAD, improves durability by optimizing buoyancy and structural design while situating components below the surface, reducing wave-induced stress. These FADs have demonstrated operational lifespans exceeding 11 months, meeting fishery needs while also reducing environmental risks to reefs (Moreno et al., 2023).Evidence suggests that deployment location and drift trajectory, rather than FAD structure itself, are the primary drivers of tuna aggregation (Moreno et al., 2023, 2016; Roman et al., 2023; Wang et al., 2024).

Although bio-FADs offer a potential solution to marine debris, they are inherently shorter-lived than conventional FADs. Components of conventional FADs—especially satellite buoys—have been observed drifting for up to eight years (Mourot et al., 2023; Royer et al., 2023)}, whereas bio-FADs are designed to degrade within months. A FAD's *operational lifetime* refers to the period during which it remains within the purse-seine fishing grounds of the owning company, typically between 8°N and 8°S (Vidal et al., 2024). This period ends either when the FAD exits this region—at which point it is considered *lost*—or when it physically disintegrates, marking the end of its *physical lifetime*. These distinctions are critical for evaluating the consequences of bio-FAD adoption.

Despite improvements in tracking, data on FAD densities and trajectories remain sparse, particularly once FADs exit equatorial fishing grounds. However, stranding hotspots have been identified in regions such as French Polynesia and Papua New Guinea (Escalle et al., 2023b; Escalle et al., 2019). Oceanographic simulations reveal that FAD drift and loss vary by region and season, which in turn affects the extent to which bio-FADs can reduce marine debris (Scutt Phillips et al., 2019).

Adoption of bio-FADs may also influence fishing operations. If degradation occurs prematurely, FAD availability may decline, potentially driving up deployment rates to maintain catch levels. Without best practices for sharing or repair, this could increase the overall number of FADs in use, elevating costs and reducing sustainability. Fleet behaviour varies: some vessels operate within defined regions, while others cross both WCPFC and IATTC jurisdictions (Lopez et al., 2024). FADs drifting beyond a vessel's range may be sold, monitored for re-entry, or abandoned via GPS deactivation (IATTC Resolution C-24-01). Therefore, the operational impacts of reduced FAD lifespans will differ by fleet and region.

To better understand these dynamics, ocean circulation models offer valuable tools for predicting FAD drift. Lagrangian simulations are particularly effective in tracing trajectories, identifying loss corridors, and highlighting marine debris hotspots (Escalle et al., 2019; Imzilen et al., 2023, 2022; Scutt Phillips et al., 2019). These approaches can inform regional strategies for FAD management and help anticipate the implications of bio-FAD deployment.

Here we implement a passive FAD drift simulation using a high-resolution ocean circulation model to address the following questions regarding a transition from non-biodegradable FAD designs to bio-FADs:

1. How will the spatial distribution of operational FADs leaving the equatorial Pacific fishing ground change?
2. What are the primary loss corridors from the equatorial fishing ground, and how might these change?
3. Which areas within the fishing ground are most affected by premature bio-FAD degradation?

2. Methods

2.1. Lagrangian simulation

Passive drift simulations were used to simulate the movement of particles, representing virtual FADs, with a similar drift profile to real FADs. Lagrangian simulations were implemented using the Parcels framework (Delandmeter and van Sebille, 2019) and ocean current data from the Bluelink Reanalysis 2020 ocean circulation model (Chamberlain et al., 2021). Parcels provides a Python package that combines the benefits of a high-level, interpreted programming language with Just-In-Time compilation of Lagrangian advection kernels in C for efficient code execution.

The top 50 m of ocean current velocities were used to reflect currents experienced by FADs, considering a median FAD depth of 40 m in the EPO and 50 m in the WCPO (Escalle et al., 2023b; Lopez et al., 2024). The model domain covered the whole Pacific Ocean from 120°E to 90°W and from 50°N to 30°S, with current velocities at a 1/10° grid resolution, and used only physical ocean currents to force the virtual FAD particles, similar to past studies on simulated FAD drift (Escalle et al., 2024; Imzilen et al., 2018; Scutt Phillips et al., 2019). To estimate broad-scale patterns of FAD dispersal at the ocean-basin level, we did not incorporate fine-scale hydrodynamic processes such as Stokes drift or windage, as these require detailed information on the spatial and temporal distribution of FAD designs, which is not available at the Pacific Ocean scale. Likewise, our basin-scale current velocities do not resolve local dynamics that influence coastal interactions or beaching, and such events were therefore excluded from the simulations.

These virtual FADs were seeded in areas based on the annual average number of observed FAD deployments derived from (Escalle et al., 2023a) (Parties to the Nauru Agreement dFAD tracking database, 2016–2020) in the WCPO and the IATTC observer database (2016–2020) in the EPO (Lopez et al., 2024). These tracking data were used solely to define deployment locations, as they did not provide full coverage of the equatorial Pacific. Some regions lacked data entirely, and certain buoys were deactivated once FADs drifted beyond the fishing grounds of their associated companies.1/10° grid cells corresponding to values of density and deployments per cell above the 90th percentile of all deployments in the Pacific, separated by convention area, were selected to simulate deployments.

Particles were randomly seeded weekly and continuously in deployment cells, with relative probability equal to that of observed deployment density, for 10 years, starting January 1st 2007 until the 31st December 2016. These dates were chosen to provide a range of sequential ENSO phases across the simulation, in order to capture the general annual and interannual drift patterns of FADs in the Pacific. As measures such as FAD closure periods have been introduced, removed, and changed over time, we did not include such spatiotemporal dynamics in our seeding design in order to capture general FAD drift dynamics that may occur in the future. Using parcels, these particles were then moved using a fourth-order Runga-Kutta advection scheme by the physical ocean current forcing, with a six-hour timestep and weekly result archiving. Output from all years were merged by particle drift time rather than an absolute date, up to a maximum physical lifetime of two years, in all figures and tables for examination. Seasonal results were divided by the quarter of deployment, and then combined across all years.

2.2. Lifetime scenarios

We define key stages in a FAD's lifecycle. *Deployment* is the initial placement of a FAD in the ocean, intended to drift within or toward the owner's fishing grounds. Its *operational lifetime* begins when it can aggregate tropical tunas within the equatorial zone, regardless of echosounder buoy ownership. During this period, it may be accessible to any vessel, though only the buoy owner monitors it. The *operational lifetime* ends when the FAD drifts out of the equatorial fishing zone and is considered *lost* or when it reaches its *physical lifetime*, that is, the breakdown of its structural materials. This breakdown can occur either while still operational or after drifting beyond the fishing ground.

Results were separated into trajectories of differing physical lifetimes to assess position of particles after certain drift periods. We used a 'status quo' scenario where FADs drift with a physical lifetime of two years, which is assumed to be representative of the typical, physical lifetime of conventional FADs based on skipper knowledge (G. Moreno, personnel communication) and trajectory data (Escalle et al., 2023a, 2023b). We then used 4- month, the current physical lifetime of bio-FADs with similar designs to conventional FADs; and 9- and 12-month lifetimes, the physical lifetime requested by fishers in the Pacific Ocean and currently achievable using some bio-FAD designs (e.g., the jelly-FAD design). Results from bio-FAD lifetimes were compared to the status quo scenario. To assess and summarize our results regarding the distribution of FADs after the different physical lifetimes defined, we divided the equatorial zone into 16, 20 × 10° rectangles centred around the equator and the line between WCPFC and IATTC convention areas, generally encompassing entire EEZs and representing the main fishing locations by fleet. We considered FADs drifting outside this zone as effectively non-operational, marking the end of their operational lifetime. Even if they later drift back into the fishing zone, we assume their GPS buoy monitoring would have been deactivated upon leaving the fishing zone, and therefore considered lost.

2.3. Analyses

Simulation outputs consisted of virtual FAD positions over all time periods, grouped by individual drift-time rather than absolute date. To assess the operational lifetime and loss of FADs from the fishing grounds (the area divided into 16 boxes covering the equatorial Pacific), we calculated the spatial density of FADs in the Pacific Ocean, under the different physical lifetime scenarios. We also examined the proportion of all FADs leaving this area via each corridor of these equatorial zones, that is the corridor through which they move from the fishing zone into the wider Pacific where they are considered lost. These proportions are show alongside the continued retention of operational FADs within the fishing zone and compared these values between the status quo and different reduced physical lifetime scenarios. Finally, we calculated mean time until loss from the fishing ground by 1° cell and the relative reduction of operational FADs that were originally deployed within each equatorial zone, due to premature degradation or breakage under the different physical lifetime scenarios compared to the status quo.

Where spatial densities over a particular lifetime scenario were shown, all positions for each virtual FAD were equally weighted during their physical lifetime. When losses from the equatorial fishing ground are shown, these are proportions of all virtual FADs that drifted outside the equatorial zone during their physical lifetime, and relative changes in those proportions, for a given scenario.

3. Results

3.1. Spatial density

The status quo scenario (2-year physical lifetime) shows widespread diffusion of FADs throughout the Pacific between 20°N and 30°S, with concentrations of FADs between 0 and 10°S west of 180°, and around 10°N 155°E in the WCPO, and between 10°S and 20°S in the EPO (Fig. 1). Reducing the physical lifetime of FADs to 9 months to one year reduces the concentration of FAD density to almost exclusively within the equatorial fishing ground, with only the southern EPO and northern WCPO showing any large, concentrated, lost FAD density outside of this area. At only 4 months of drifting (Fig. 1), almost all FADs are contained within a band defined by 10°S to 10°N, with the majority distributed in the southern WCPO.

3.2. Drift-time to FAD loss

The mean time for FADs exiting the equatorial fishing zone showed longitudinal, and some latitudinal, differences by location of deployment (Fig. 2). The greatest mean time for FADs remaining operational were for those deployed north of the equator east of 120°W, and south of the equator west of 140°W, with the longest, consistent operational times seen for FADs deployed in the easternmost zone 8 of the EPO. Areas with the lowest retention times following FAD deployment were located in the southern, far easterly EPO regions 15 and 16, and the

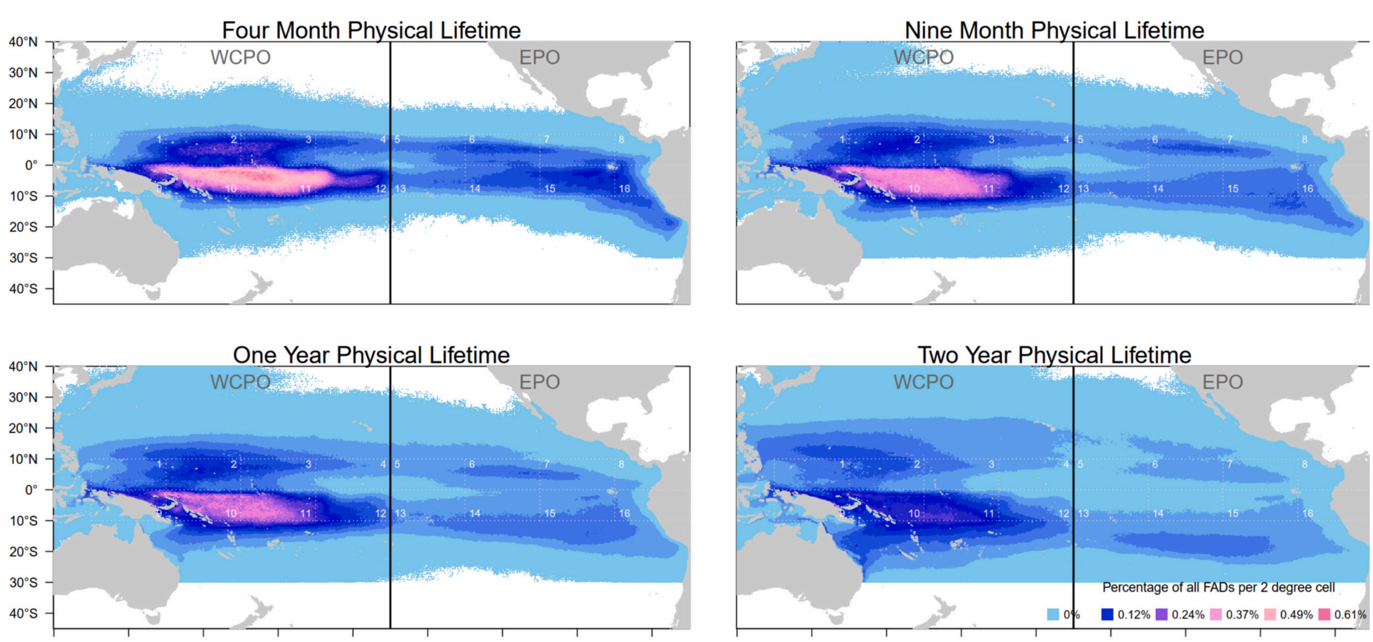

Fig. 1. Spatial plots of average FAD density after continuous deployments during 2007–2016, under different lifetime scenarios.

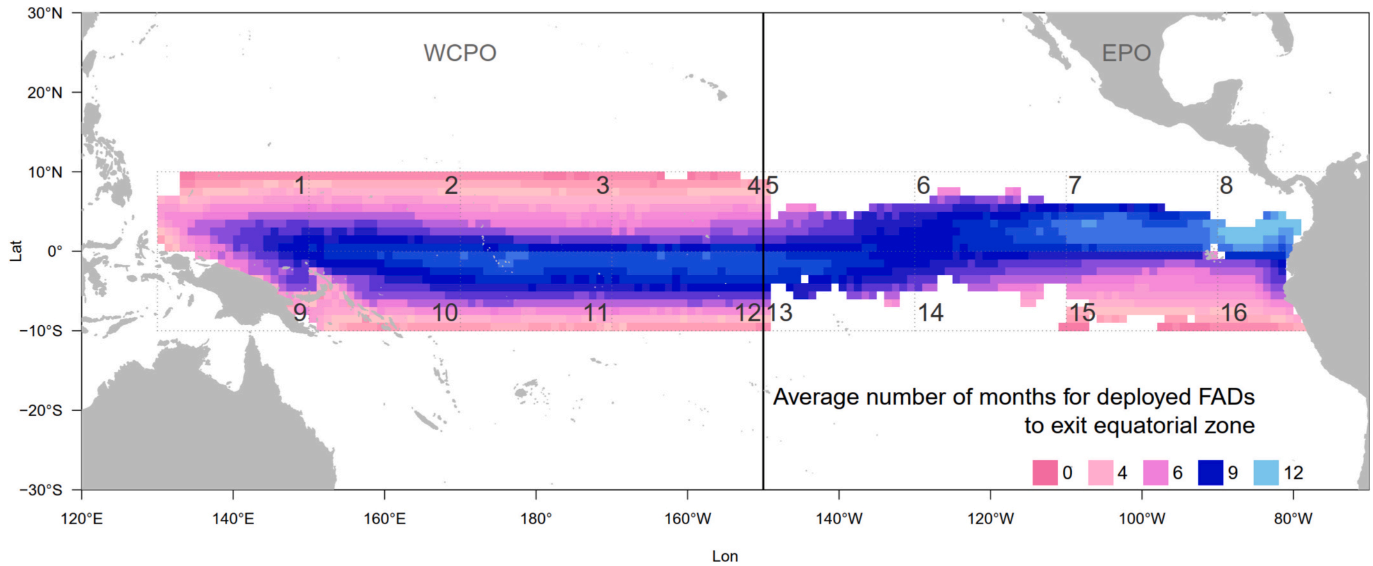

Fig. 2. Average time for simulated FADs to leave the equatorial fishing zone, across all time-periods and shown by one-degree cell of deployment.

northeastern WCPO regions 3 and 4. In general, FADs deployed near the equator took on average 9 to 10 months to leave the fishing zone and become lost. Some seasonality was present when examining simulation results by quarter of deployment, across all years (supporting information, Fig. S1). This was most apparent in the northern EPO regions 5 to 7, where during April and May, FAD deployments typically remained operational within the equatorial fishing ground for 2 to 4 months longer than average. From October to December, the opposite was true for deployments in this area, with FADs becoming lost outside the equatorial zone 2 to 3 months sooner than the average over all time periods.

3.3. Corridors of FAD loss

Under the status quo scenario, greater levels of FAD drift out of the fishing ground were present in the WCPO compared to EPO (Fig. 3). The corridors of greatest FAD loss are out of the Solomon (region 10; 13.5 %) and Gilbert Islands (region 11; 14.4 %) areas between 150°E and 170°W in the south WCPO, which are also responsible for some of the largest proportion of FAD deployments. The northern WCPO (regions 1, 2 and 3) also presented rates of FAD loss from 7.5 % to 9.7 %. In the EPO, the largest corridor of FAD loss was between 110°W and 150°W in the north (regions 5 and 6) and 90°W and 130°W (regions 14 and 15) in the south, with 3.7–4.7 % and 4.7–5 % loss in the northern and southern hemispheres, respectively. By two years, only 7.2 % of deployed FADs were

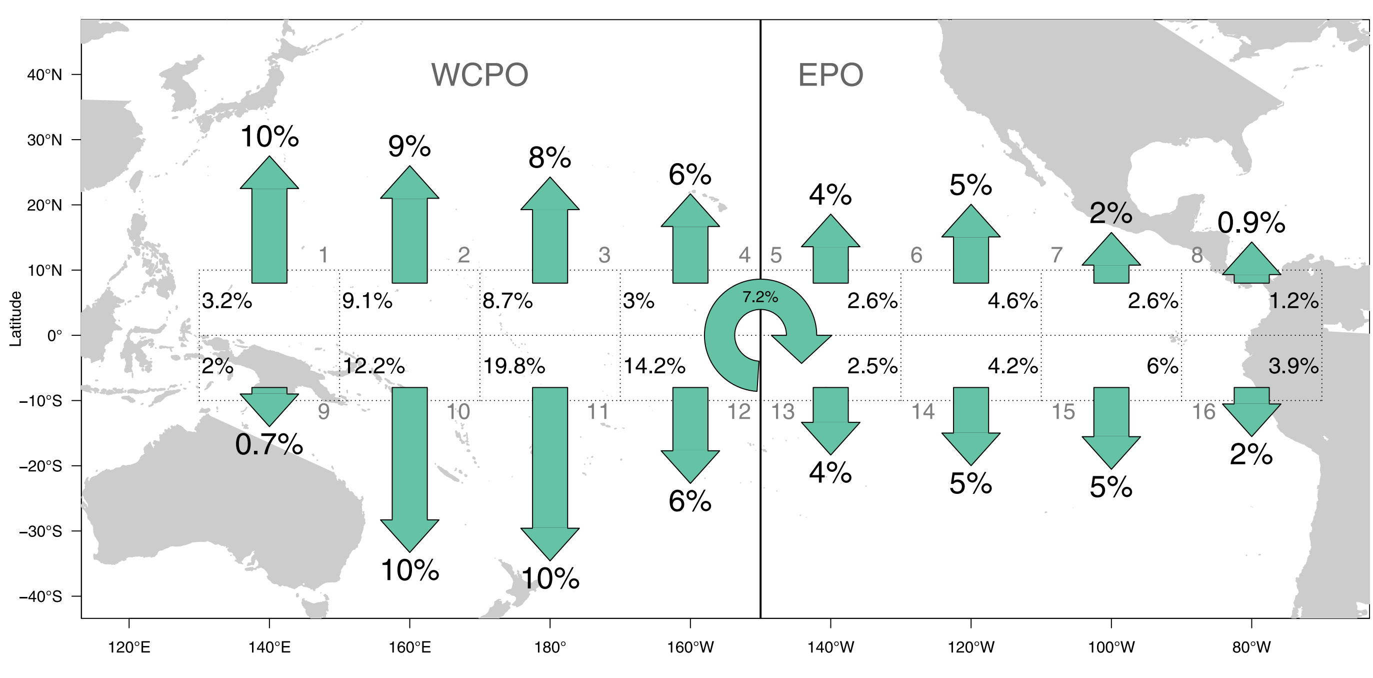

Fig. 3. Proportion of 'status quo', two-year lifetime FADs equatorially deployed that exit each fishing zone (numbered boxes) via loss corridors (arrows) or remain within the equatorial area at the end of their lifetime (circular arrows). The percentage of FADs initially deployed in each fishing zone is shown inside the equatorial boxes.

still drifting within the equatorial fishing zone.

When compared to the status quo scenario, the median reduction in total percentage of FADs lost out of each equatorial zone was 0.6 % and 1.2 %, for one year and nine-month lifetime scenarios, respectively (Fig. 4). This increased to 3.8 % when physical lifetimes were only four months. The equatorial regions that were most consistently affected by reductions in lost FADs were regions 10 and 11, with total reductions of lost FADs out of the fishing zone of between 2 and 10 %, when physical lifetimes were assumed to be 12 to 4 months, respectively. The northern warm-pool zones 1 and 2 around Palau and the Federated States of Micronesia were also reduced corridors of FAD loss, responsible for a 2–3 % reduction in total lost FADs leaving each region, assuming a one-year physical lifetime. In the EPO, the northern equatorial region 6 and southern central zones 13 and 14 were the most affected by reduced FAD physical lifetimes, although these only contributed to a total reduction across all three zones of 1.3 % of all lost FADs, under the one-year physical lifetime scenario.

Overall, the total reduction in all lost FADs out of the Pacific equatorial fishing ground was 16.1 %, when FADs had a one-year physical lifetime, composed of 13.3 % and 2.8 % for the WCPO and EPO, respectively. Conversely, compared to the 7 % estimated for the status quo scenario, the increase in potential loss of operational FADs due to degradation (i.e., end of the physical lifetime) whilst still in the fishing zone was considerable: 16 % to 31 % when FADs had a one-year to nine-month lifetime, and 69 % when a four-month lifetime was assumed (Fig. 4). This corresponded to a 224 %, 426 % and 956 % relative increase prematurely lost operational FADs, for 12-, 9- and 4-month physical lifetimes, respectively.

3.4. Loss of operational FADs by deployment region

The reduction in operational FADs due to reduced physical lifetimes under our bio-FAD scenarios can be separated by each region in which FADs are originally deployed, providing an indication of which deployment regions may be most affected by a switch to the use of bio-FADs. Overall, the median reduction in operational FADs due to the end of their physical lifetime compared the status quo was 16 % (one year), 32 % (nine months), and 72 % (four months), for all deployment regions (Fig. 5). The region of deployment with the consistently largest subsequent loss of potentially operational FADs was region 8 in central America (29–90 %), followed by region 7 (23–86 %), region 11 (Gilbert Islands and Tuvalu; 22–70 %), region 12 in the central Pacific (Kiribati Line islands; 20–78 %), region 10 around the Solomon Islands' EEZ (20–61 %), and then region 13 (Marquesa's, French Polynesia; 18–84 %) and region 6 (19–83 %) for all physical lifetime scenarios. The median loss in operational FADs when assuming a one-year physical lifetime was 14 % for those deployed in the WCPO, and 16 % for those in the EPO (Fig. 5).

4. Discussion

In this study, we assessed the potential impacts of transitioning to bio-FADs on marine debris reduction and fishing operations, identifying regions most affected. Our simulations, however, rely on several key assumptions. The passive drift simulation uses integrated currents over 50 m depths but excludes processes such as windage, Stokes drift, or sub-grid scale diffusion. Virtual FADs are assumed to drift like massless water parcels, ignoring effects of shape, hydrodynamics, biofouling, and surface forces. Similar approaches relying solely on current velocities have successfully replicated spatial FAD distribution dynamics (Escalle et al., 2019; Imzilen et al., 2018; Scutt Phillips et al., 2019). Nonetheless, raft degradation due to sea state, storm activity, and current strength—particularly in bio-FADs—remains poorly understood. These processes, along with variations in FAD design and material durability, may substantially influence both drift dynamics and physical lifespan. Further research should investigate how sea state and construction influence degradation rates. In particular, design elements such as appendage length and raft configuration may significantly affect FAD drift through interactions with near-surface shear or current layers (Zhang et al., 2024). To address uncertainty in the variability of physical FAD lifetimes, we examined a range of potential lifetime scenarios applicable to future bio-FAD use.

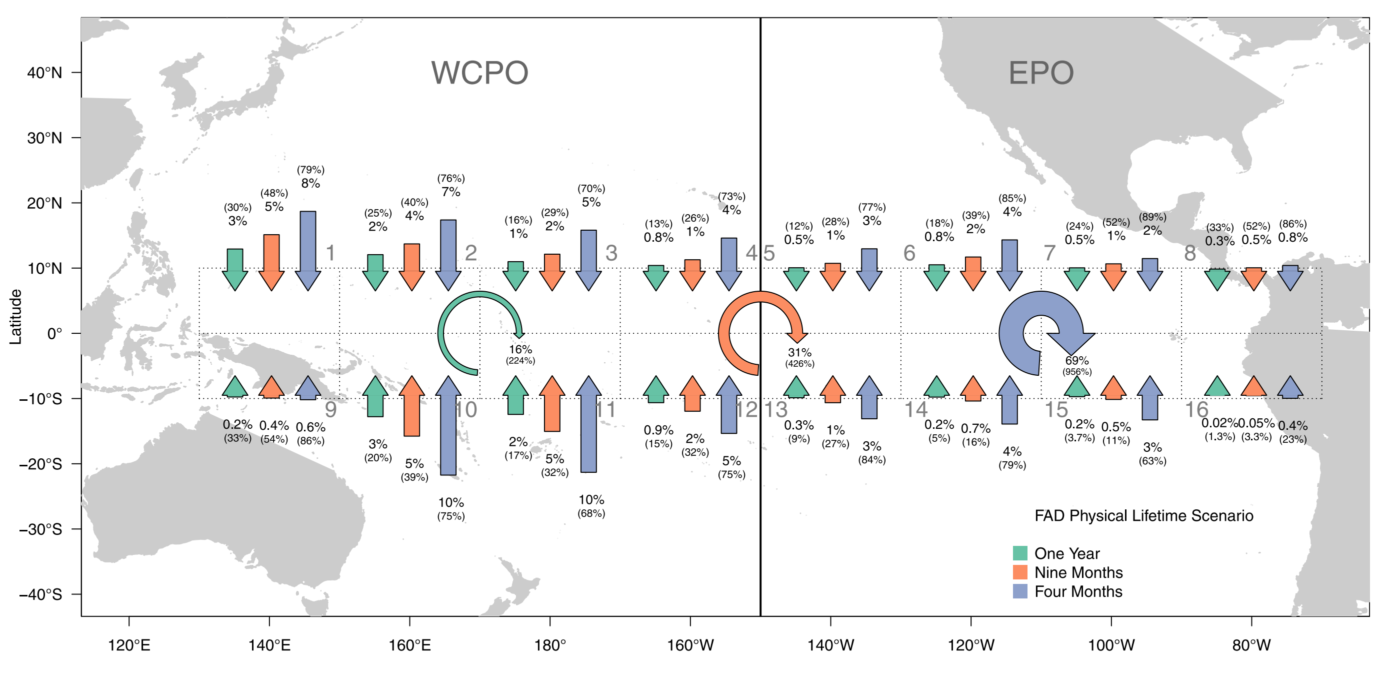

Fig. 4. Changes in FAD loss from each equatorial fishing zone compared to the two-year lifetime status quo (arrows), under differing bio-FAD lifetime scenarios. The absolute reduction in percentage FAD loss (from Fig. 3) is shown for each zone, with the relative decrease given in parentheses. Within the equatorial area, the relative increase in FADs reaching the end of their physical lifetime while still retained in the fishing zone is indicated (circular arrows).

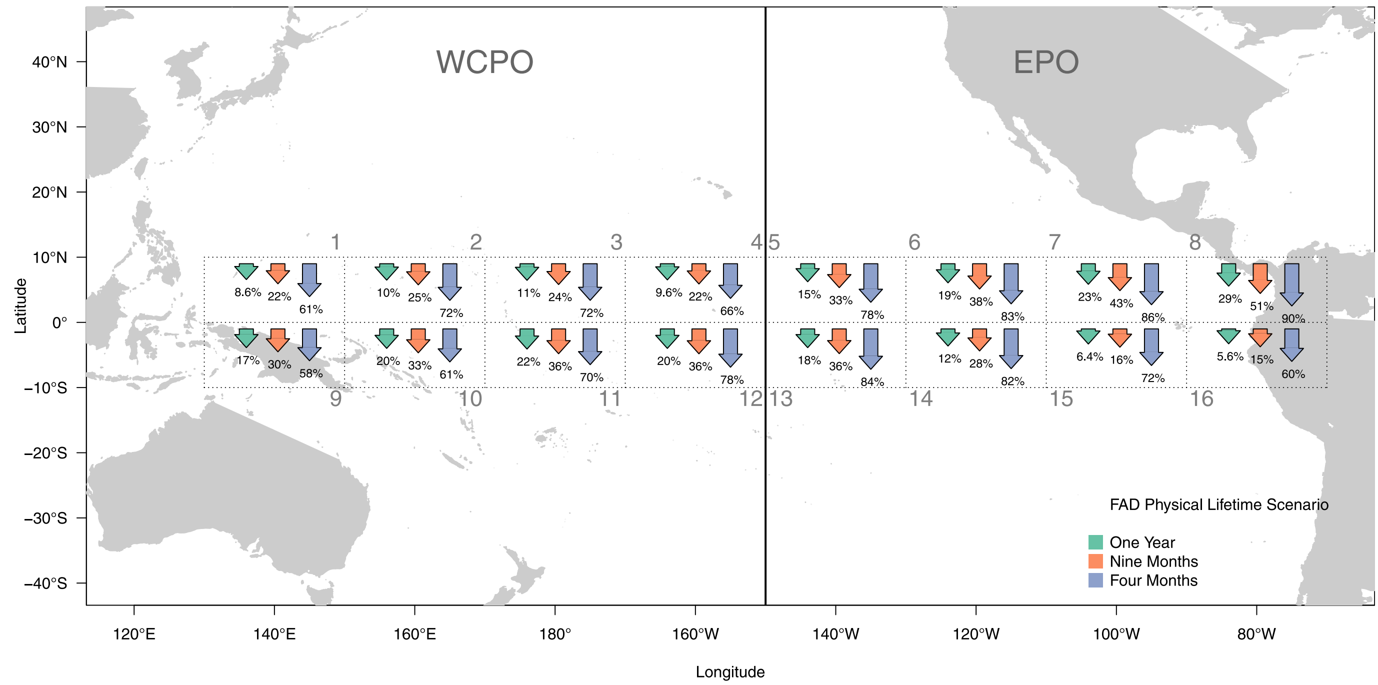

Fig. 5. Relative reduction in operational FADs within the equatorial fishing zone due to shortened physical lifetimes, compared to the status quo scenario, separated by equatorial fishing zone of initial deployment.

Our predictions depend on regional oceanography and the assumed spatial deployment distribution. Deployment locations were sourced from observer and FAD trajectory data (2016–2020), covering major fishing grounds and fleets, though data gaps exist (Escalle et al., 2023a). Deployment patterns also vary intra- and interannually due to oceanography, fishing strategies, and legal agreements (Escalle et al., 2023a). We defined FADs as 'abandoned' marine debris upon exiting the equatorial band (10°N–10°S), but this may oversimplify fleet-specific practices. For example, in the EPO, some FADs drifting into the North Equatorial Counter Current may re-enter fishing grounds via eddies, delaying deactivation. Moreover, the operational lifetime of a FAD is often constrained not by latitude but by company-specific fishing zones. In the IATTC area, FADs drifting west of 150°W may be deactivated despite remaining within the equatorial band, unless transferred to another fleet (Escalle et al., 2023a). As such, many FADs become marine debris based on operational, not physical, limits.

Our results indicate that bio-FADs with physical lifetimes of 9–12 months could reduce FAD loss outside the equatorial zone by over 30 %. While some components may continue drifting after disintegration, their potential to cause pollution, reef entanglement, or ecological harm is substantially reduced. However, areas like the Solomon Islands, Papua New Guinea, and Tuvalu (Escalle et al., 2019), already within the equatorial fishing zone, are likely to be affected by FADs for which degradation has not yet begun, making the benefits of biodegradability less evident in such cases. Nonetheless, bio-FADs will disintegrate significantly earlier than conventional plastic-based designs, which may persist in coastal and oceanic ecosystems for years. Prevailing equatorial currents typically drive FADs westward and southward, eventually pushing them into higher latitudes through dynamic ocean features. Currently, most FAD losses occur in the WCPO, particularly along the southern EEZ boundaries of Solomon Islands and Papua New Guinea, a pattern consistent with trajectory data (Escalle et al., 2024, 2023a). The northern WCPO also exhibits corridors of considerable FAD loss to the north of the EEZs of the Federated States of Micronesia and Republic of the Marshall Islands, although some may re-enter the fishery eastwards through the equatorial counter current (Escalle et al., 2024).

Shorter bio-FAD lifetimes significantly reduce these losses. Reductions of 30–48 % were observed in Palau and FSM (Region 1), and 25–40 % in the Marshall Islands (Region 2), where FADs may otherwise feed into the Kuroshio Current and disperse debris widely. Reductions of 17–39 % in southern WCPO regions (region 10 and 11), excluding Papua New Guinea, were noted under 9 to 12-month lifetimes. In contrast, southern EPO regions, which currently lose 14.9 % of deployed FADs, showed only modest reductions, despite links to debris accumulation in the South Pacific Gyre and stranding in French Polynesia (Mourot et al., 2023).

A key trade-off in adopting bio-FADs is the premature loss of operational rafts, impacting fleet efficiency and catch stability depending on the degree of FAD reliance. Using average annual deployment data (Escalle et al., 2023a; Lopez et al., 2024), our one-year lifetime scenario predicts annual losses of 9000 WCPO-deployed FADs and 3000 EPO-deployed FADs (Table 1). These figures reflect aggregate impacts at the fleet level rather than vessel-specific losses (Fig. 5). FAD-based

Table 1
Estimated, annual FAD losses by deployment zone due to premature breakdown of operational FADs within the equatorial fishing ground, assuming a one-year physical lifetime reduced from a status-quo of 2 years.

	Equatorial Zone	Premature loss of operational FADs	Totals
WCPO	1	205	
	2	680	
	3	750	
	4	190	
	9	266	
	10	1819	
	11	3362	
	12	2149	**9421**
EPO	5	314	
	6	613	
	7	409	
	8	292	
	13	360	
	14	411	
	15	300	
	16	173	**2873**
			12,293

fishing has become a stable and widespread strategy, inherently involving some level of loss or abandonment. In this context, using biodegradable materials remains one of the most effective mitigation measures. Alternative measures to reduce FAD loss, abandonment and stranding have also been investigated through potential changes in deployment number, areas and strategies or recovery programs (Capello et al., 2023; Escalle et al., 2019; Imzilen et al., 2021; Maufroy et al., 2015).

For fishers, the most immediate consequence of premature FAD degradation is reduced ability to plan fishing trips efficiently. Increased distances between viable FADs may lead to greater fuel consumption and associated economic costs. Opportunistic use of FADs deployed by other companies is common in FAD-based fishing strategies (Lennert-Cody et al., 2018), so reductions in FAD lifetimes are likely to have collective implications. Fleets that deploy only a small number of FADs but rely heavily on locating those deployed by others may be especially affected. This includes cases where FADs drift from the IATTC into the WCPFC region, either being targeted opportunistically or transferred between fleets. This could lead to an increased deployment of FADs by fleets that currently "recycle" those deployed by others, following the established limits on active FADs, ranging from 50 to 340 per vessel depending on vessel category in the IATTC region (IATTC Resolution C-24-01) and up to 350 per vessel in the WCPFC region (CMM 2023–01). The effect of reduced FAD density in the equatorial zone on tuna behaviour, distribution, or catchability remains unclear, as tuna responses to varying drifting FAD densities are not well studied (Dupaix et al., 2024). While research has focused on tuna aggregations around anchored and drifting FADs (Pérez et al., 2020; Scutt Phillips et al., 2017), it is unknown if lower FAD densities could lead to larger tuna schools forming around fewer FADs, partially offsetting impacts on catchability (Nooteboom et al., 2023). However, habitat changes are not solely driven by FAD deployment—natural floating objects density influenced by climate variability or strong climatic events can also affect tuna behaviour and fishing efficiency (Dupaix et al., 2024).

These potential impacts of bio-FAD use on fishing operations should be further investigated by simulation of different fleet strategies using models such as *Poseidon*, a coupled agent-based bio-economic model. The model's adaptive agent-based framework could simulate and evaluate the complex scenario of transitioning to bio-FADs, assessing social, biological, and economic trade-offs (Bailey et al., 2019). For example, Central America may experience 31–52 % loss of operational FADs under bio-FAD scenarios. However, inshore fleets here often employ mixed free-school and FAD strategies, and already lose many FADs as they drift beyond operational ranges (Lopez et al., 2024), representing only ~1 % of simulated totals.

Conversely, the southern WCPO around the Solomon and Gilbert Islands, comprising over 30 % of Pacific deployments, faces 30–47 % losses. This region's less consistent current systems and high FAD exchanges suggest operational lifetimes are already below the two-year baseline (Escalle et al., 2023a). Nonetheless, losses could drive significant strategy shifts, with ~12,000 fewer operational FADs annually across the Pacific.

Compensating for these losses by increasing deployments would raise operational costs and potentially worsen FAD stranding in hotspots within the equatorial zone, like Tuvalu and the Solomon Islands. Such efforts might also conflict with RFMO limits on active FADs or deployments (Imzilen et al., 2021). Alternatively, improved bio-FAD repair, redeployment, and collaborative fleet strategies could help extend operational lifetimes while maintaining environmental benefits (ISSF, 2023). Repair and reuse efforts not only prolong FAD usability but also reduce the risk of abandonment. While bio-FADs degrade more rapidly than conventional FADs, their reduced long-term persistence offers significant benefits for marine ecosystems. Simulation modelling, like ours, could guide spatial management measures, 'FAD recovery' programs, which are already encouraged by three tuna RFMOs, and sustainable bio-FAD reuse initiatives (Zudaire et al., 2018).

5. Conclusion

Much work still remains to understand how different FAD designs respond to physical ocean systems, particularly in the context of fine-scale hydrodynamic forcing, the robustness of passive drift simulations, and drift performance and their influence on dispersion pathways and interactions with land (Escalle et al., 2019; Imzilen et al., 2023; Zhang et al., 2024). Regardless of modelling exercises used, such as the one we have presented here, it is clear that a systemic shift to the use of bio-FADs will result in not only decrease marine pollution and its associated impacts but also lead to potential losses in operationally viable FADs. Our study here has indicated those areas that are most likely to be affected by this shift in the Pacific Ocean, and highlighted that fleets deploying only small numbers of FADs or that rely heavily on transferred FADs deployed on the east of their fishing ground will be in most need of adaption for their operations.

Considerable uncertainty still exists in the quantifiable, spatiotemporal nature and strategy of both FAD deployment and utilization by fishing fleets at a regional and ocean-basin level. Improving the dialogue between fishery stakeholders, alongside improved data sharing and collaboration with scientists and managers, will likely lead to an improved use and lower environmental impact of FADs. Anticipating the impacts of such changes in fishing operations is important in an industry that has the capacity to be highly adaptive and reactionary, often at rate faster than that of management bodies. We propose that this be the priority area of focus for future research, particularly for those fleets operating in the areas we have highlighted as most impacted in this study.

CRediT authorship contribution statement

Joe Scutt Phillips: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lauriane Escalle:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Data curation, Conceptualization. **Hilario Murua:** Writing – review & editing, Methodology, Funding acquisition. **Jon Lopez:** Writing – review & editing, Methodology, Data curation. **Gala Moreno:** Writing – review & editing, Project administration, Methodology, Funding acquisition.

Declaration of competing interest

All authors declare that they have no known financial or personal relationship interests that could influence the work and results reported in this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2025.118130.

Data availability

Data will be made available on request.

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