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Modelling drifting Fish Aggregating Devices (FADs) trajectories arriving at essential oceanic and coastal habitats for leatherback and hawksbill turtles in the Pacific Ocean

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Executive Summary

Purse seine fishers using drifting Fish Aggregating Devices (dFADs) to aggregate and catch tropical tuna, deploy an estimated 46,000 to 65,000 dFADs per year in the Pacific Ocean. Major problems associated with this widespread fishing device are i) the potential entanglement of vulnerable marine fauna in dFAD netting and ii) marine pollution, with potential ecological damage via stranding on coral reefs, beaches, and other essential habitats. To explore and quantify the potential connectivity between dFAD deployment areas and important oceanic or coastal critically endangered leatherback (*Dermochelys coriacea*) and hawskbill (*Eretmochelys imbricata*) sea turtle habitats in the Pacific Ocean, we conducted passive-drift Lagrangian experiments using simulated dFAD drift profiles. Some connectivity between equatorial areas of dFAD deployments and essential sea turtle habitats was identified, although it was reduced when considering only areas where dFADs are currently deployed. Potential at-risk hotspots of dFAD interaction with sea turtle habitats are i) leatherback and hawskbill coastal habitats in the western Pacific (Indonesia, Papua New Guinea, and the Solomon Islands); ii) a large equatorial area south of Hawaiʻi, important for leatherback turtle foraging; and iii) the migration and leatherback feeding habitats in the tropical southeastern Pacific Ocean. Additional research is needed to better understand the entanglements of sea turtles with dFADs at sea and to quantify the likely changes in connectivity and distribution of dFADs under new management measures, such as using alternative dFAD designs that degrade, or changes in deployment strategy.

We invite WCPFC-SC19 to:

- Note the results on potential connectivity between known areas of dFAD deployment and sea turtle habitats in the central equatorial Pacific, archipelagic areas of the western warm pool, and the southeast Pacific Ocean gyre. Connectivity is large for all equatorial zones though is reduced when dFAD deployment/density hotspots are used to seed virtual dFADs.
- Given the overlap of dFADs with turtles oceanic and coastal habitats, no netting should be used in FAD construction to eliminate potential entanglement.
- Recognize the need for greater knowledge on at-sea interactions between active or abandoned dFADs and at-risk sea turtle populations.
- Support the continued analysis of observed and simulated dFAD trajectories to quantify the likely changes in connectivity and distribution of dFADs within the equatorial fishing grounds and higher latitude sea turtle habitats under proposed fully non-entangling, without netting, and biodegradable dFAD management measures.

1. Introduction

Purse seine fishers extensively deploy drifting Fish Aggregating Devices (dFADs) to aggregate and catch tropical tuna, with 46,000 to 65,000 FADs deployed in the Pacific Ocean annually, and 16,000–25,000 dFADs in the eastern Pacific Ocean (EPO) only, according to the latest estimates (Escalle et al., 2021a; Lopez et al., 2021). The main concerns related to the loss and abandonment of dFAD structures are i) marine pollution; ii) the potential risk of entanglement of sea turtles and other vulnerable marine fauna in dFAD netting while drifting at sea or when stranded; and iii) the potential impacts on fragile ecosystems via stranding events. Although direct bycatch of sea turtles is relatively low in purse seine fisheries as compared to other gear types (Bourjea et al., 2014; Montero et al., 2016; Moreno et al., 2023; Swimmer et al., 2020), the proliferation of dFAD use in the fishery is concerning given that the potential dFAD sea turtle entanglement in their netting is unknown. In addition, dFADs stranded in nearshore habitats or along the shoreline could potentially have indirect impacts on critical nesting or coral reef habitats for sea turtles. In this study, we further explore the potential for dFAD interactions (entanglement and nearshore habitat impacts), focusing on the critically endangered leatherback (*Dermochelys coriacea*) and hawksbill (*Eretmochelys imbricata*).

2. Methods

To explore and quantify the potential connectivity between dFAD deployment areas and important oceanic or coastal critically endangered leatherback and hawskbill sea turtle habitats in the Pacific Ocean, we conducted passive-drift Lagrangian experiments using simulated dFAD drift profiles and compared them with known important sea turtle foraging and nesting areas (Figure 1).

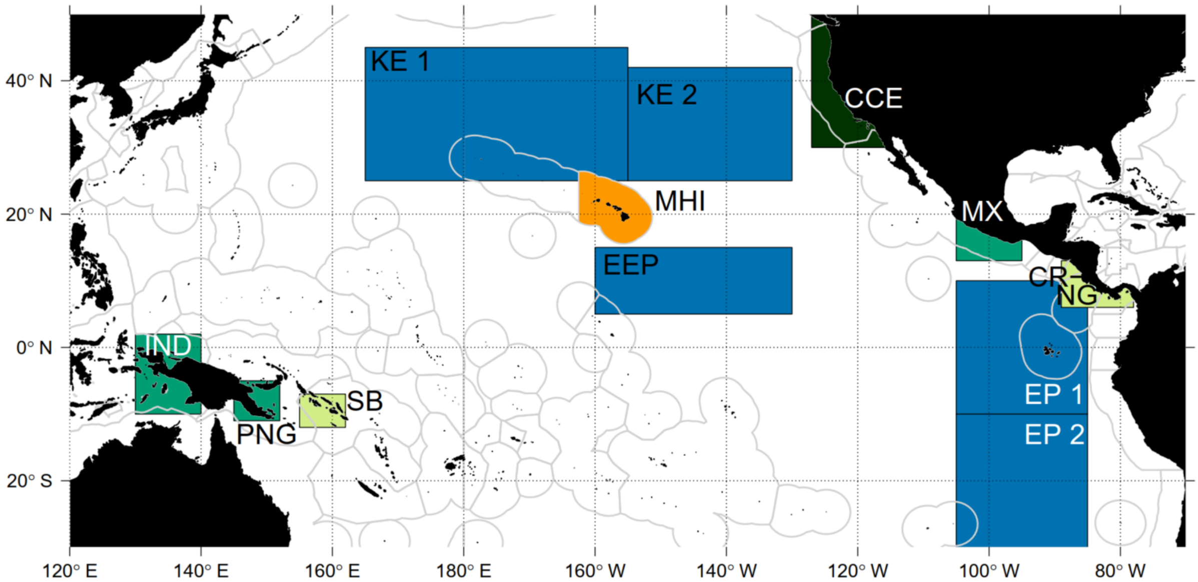

Figure 1. Spatial distribution of sea Turtle Zones used in the simulations and corresponding to important oceanic areas (blue) for leatherback turtles and coastal areas (green) for leatherback foraging (dark green), leatherback nesting (medium green), hawksbill nesting (orange), and leatherback and hawksbill nesting (light green). KE = Kuroshio Extension; EEP = Equatorial Eastern Pacific; CCE = California Current Ecosystem; IND = Indonesia; PNG = Papua New Guinea; SB = Solomon Islands; MX = Mexico; CR-NG = Costa Rica – Nicaragua; and EP = Eastern Pacific.

Lagrangian simulations were implemented using the Parcels framework (Delandmeter and van Sebille, 2019). Passively drifting Lagrangian particles, representing virtual dFADs (vFADs), were released evenly throughout the tropical, equatorial zone (scenario 1 – Figure 2) and dFAD deployment/ high density hotspot zones (scenario 2 - Figure 2), and forced forwards in time with a dFAD-type drift profile, driven by the top 50m current velocities (median dFAD net depth of 40m in the EPO and 50m in the WCPO (Escalle et al., 2017; Lopez et al., 2020)) from the Bluelink Reanalysis 2020 circulation model (BRAN2020 Chamberlain *et al.*, in review). New particles were seeded weekly during one year and left to drift for up to a further 2.5 years. Particles were seeded beginning July 2012 (ENSO neutral year), July 2010 (a moderate La Niña year), and July 2015 (a strong El Niño year).

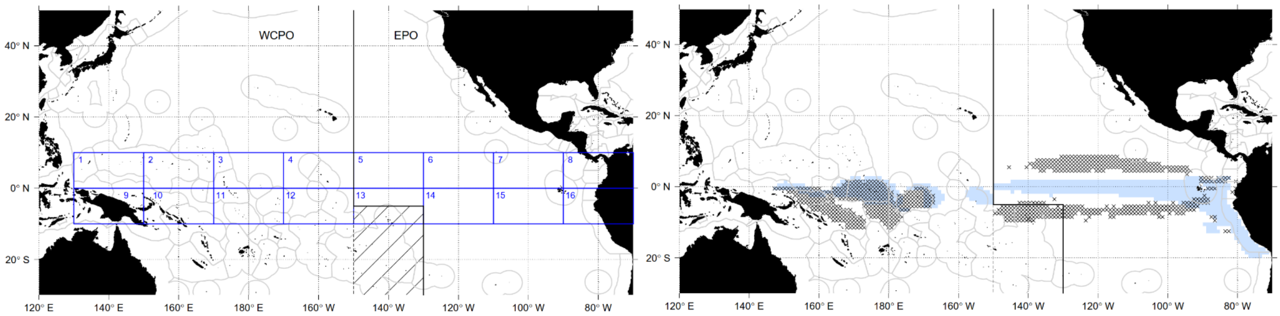

Figure 2. Spatial distribution of Equatorial Zones (left) and dFAD Zones (right) used in the simulations in Scenario 1 and 2, respectively. DFAD zones include main dFAD deployments areas (blue) and main dFAD densities areas (black crosses). The black line indicates the WCPFC and IATTC convention areas, the black dotted line the overlapping area between both convention areas.

Several areas were defined and used in the simulations to study connectivity between dFAD areas of deployment and sea turtle critical habitats. Two types of vFAD deployment zones, were used: i) the entire tropical equatorial zone from 10 °S to 10 °N divided into 16 large boxes of 20° longitude by 10° latitude (“Equatorial Zones” (EZ); Figure 2); and ii) specific hotspot areas where dFAD deployment and high density are known (“dFAD Zones” (FZ); Figure 2). This information was derived from observer and operational buoy data in both the WCPO and EPO (Parties to the Nauru Agreement (PNA) dFAD tracking database, 2016–2020; Inter-American Tropical Tuna Commission (IATTC) buoy database, 2018–2020 and IATTC observer database, 2016–2020). Cells corresponding to values of density and deployments above the 90th percentile were selected as hotspots for each convention area separately, due to different data types available for each convention area (Figure 2). Second, sea turtle habitat zones (“Turtle Zones” (TZ)) were determined (Figure 1) using maps available within the interactive Ocean Biodiversity Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) platform; scientific publications and expert opinions (Bailey et al., 2012; Benson et al., 2011; Laúd opo Network, 2020; SWOT, 2008).

3. Results and discussion

Corridors of connectivity between industrial dFAD fishing grounds and zones of important habitats for sea turtles were identified. In the WCPO, the small coastal sea turtle nesting habitats in Papua New Guinea (PNG) and the Solomon Islands (SB) consistently received and retained vFADs arriving from the southern equatorial regions of the WCPO (Figures 3, 4 and 5). The archipelagic Indonesian (IND) nesting habitat experienced similar high connectivity with vFADs arriving from mostly one region of the WCPO (the southwestern EZ 9), although the relatively low densities in this region suggest that while vFADs reach this region they do not remain there for extended periods. Finally, a large equatorial area, south of Hawaiʻi, an important leatherback turtle foraging habitat, exhibited large numbers of vFADs transiting when deployed in the equatorial zones north of the equator, from both the EPO and WCPO.

For dFADs deployed in the EPO, the main areas of concern appear to be the turtle habitats in the south-eastern Pacific Ocean (EP1 and EP2), corresponding to oceanic leatherback turtle migration and feeding grounds (Figure 4). Moderate accumulation of dFADs was also detected in the equator, coastal and oceanic habitats and nesting sites around Mexico, Costa Rica and Panama.

It should be noted that the connectivity patterns detected appear to be somewhat mitigated by the current deployment distribution of dFADs in the WCPO (Scenario 2; Figures 3, 4 and 5).

Additional research and analyses should be performed i) to better understand at-sea interactions between dFADs and sea turtle populations and potential entanglements; and ii) to quantify the likely changes in connectivity and distribution of dFADs within the equatorial fishing grounds and higher latitude sea turtle habitats, under proposed non-entangling and biodegradable dFAD measures or changes in dFAD deployment strategies.

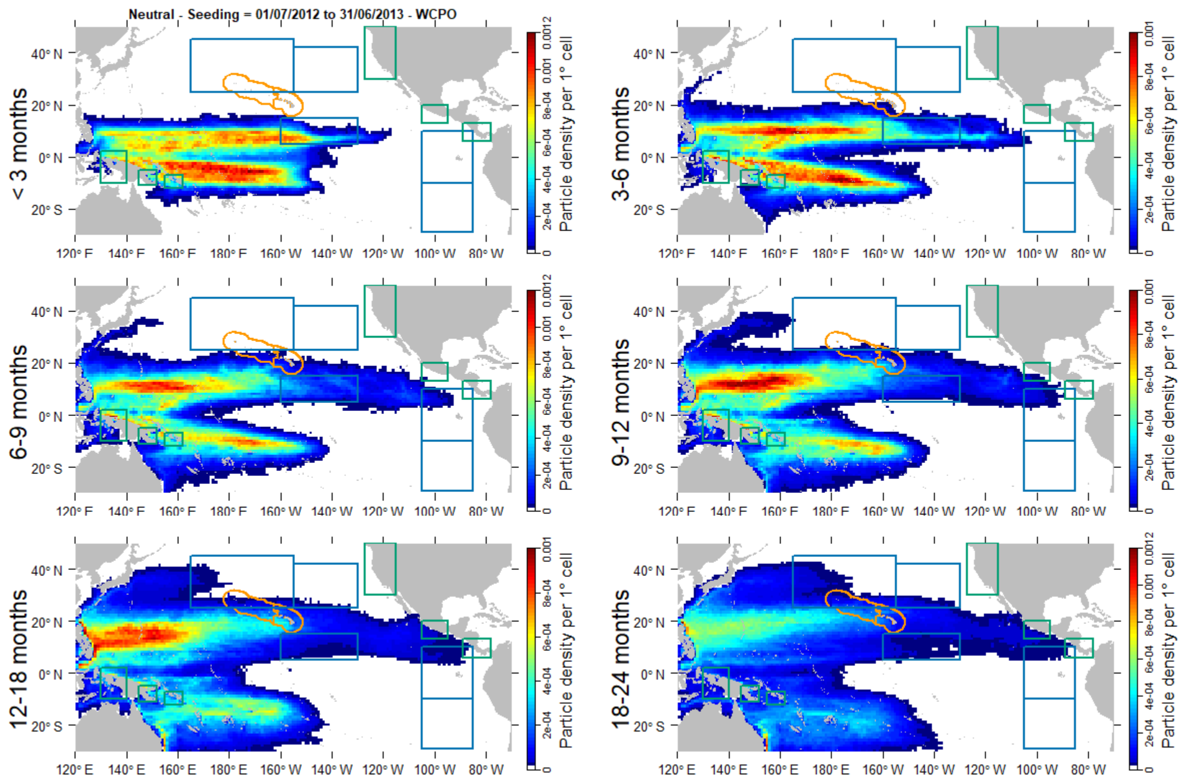

Figure 3. Time integrated spatial probability density for virtual particles (vFADs) deployed in Scenario 2 (deployment hotspots only), evenly across dFAD deployment hotspots in the WCPO during an ENSO neutral period considered combined and over six drifting periods after deployment.

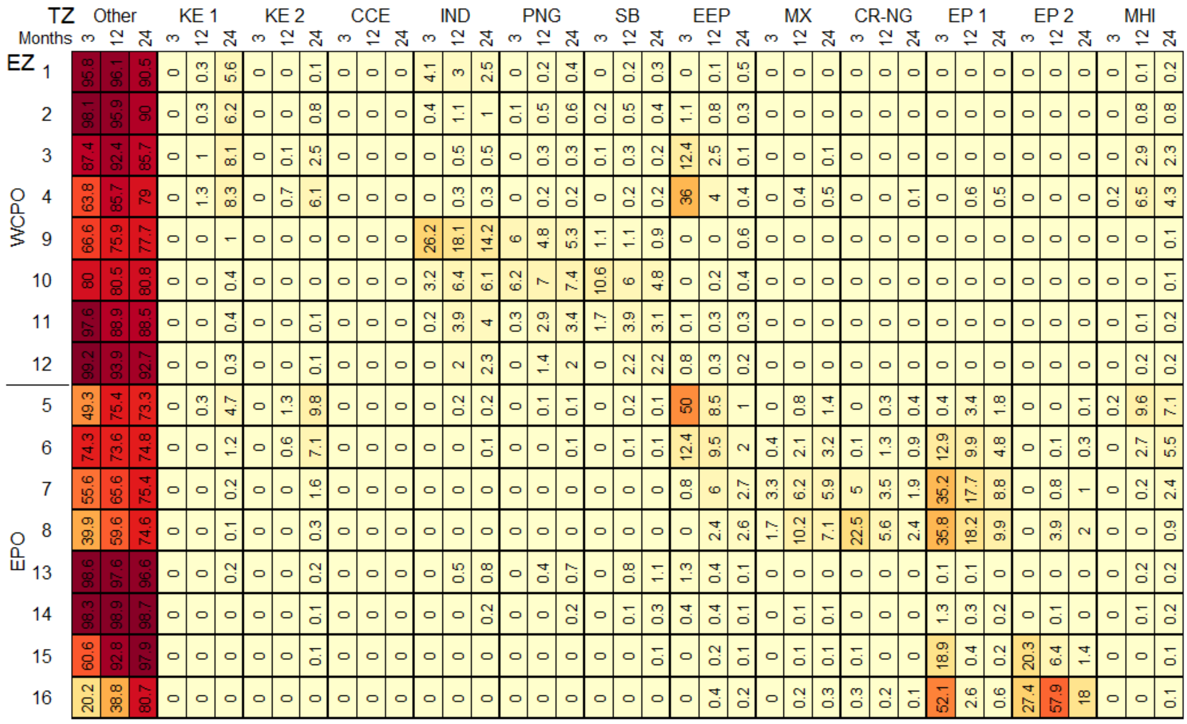

Figure 4. Percentage connectivity matrix of virtual particles during the three ENSO periods considered combined from Scenario 1, in which vFADs were evenly seeded in *Equatorial Zones* (*EZ* shown as rows) and arriving in sea *Turtle Zones* (*TZ* shown as columns) and within 3, 12 or 24 months (sub columns). Cells are coloured by the proportion of simulated particles arriving in each *TZ* by drift time. Other indicates any location outside of the specified *TZ*.

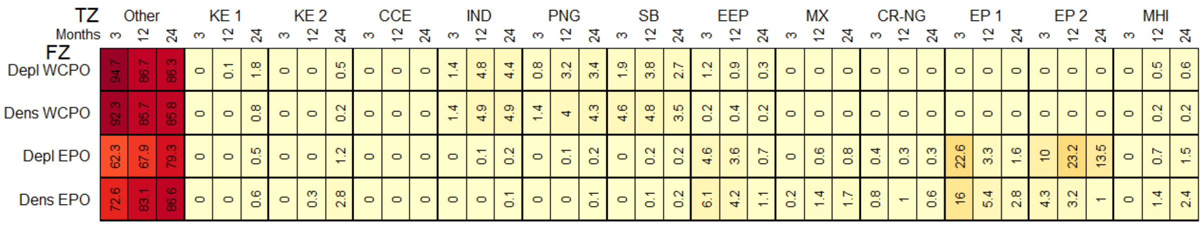

Figure 5. Percentage connectivity matrix of virtual particles during the three ENSO periods considered combined from Scenario 2, in which vFADs were seeded in known dFAD Zones (FZ; Depl = Deployment hotspot; Dens = dFAD density hotspot shown as rows) arriving in sea Turtle Zones (TZ shown as columns) and separated by drift time in months. Cells are coloured by the proportion of simulated particles arriving in each TZ by drift time. Other indicates any location outside of the specified TZ.

3. Conclusion

While our results indicate that dFADs deployed in equatorial purse seine fishing grounds are overlapping with important sea turtles and coastal habitats, more research is needed to exactly quantify how sea turtles are impacted by dFADs, particularly in the open ocean. Potential impacts on coastal areas, for Pacific sea turtle habitats, but also for other species, in terms of marine pollution, for example, still need to be further assessed as well. While Lagrangian simulations are a useful tool to assess the connectivity between some coastal zones and key areas of dFAD use, the extent of actual dFAD stranding events, and their ecological impacts, cannot presently be determined. Working with real dFAD trajectories and collecting in-situ additional data to quantify the number and consequences of these events should therefore be encouraged (Escalle et al., 2020). Finally, scientists in this project also worked with fleets operating in the EPO and WCPO to define guidelines to reduce the impact of dFADs on sea turtles, by designing best practices to reduce the loss and abandonment of dFADs, including improved dFAD designs and retrieval protocols for lost or abandoned dFADs, among others.

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Acknowledgments

In the EPO, dFAD density and deployment hotspots were identified using the IATTC buoy database (information reported to the IATTC under Resolution C-17-02) and the IATTC observer database. In the WCPO, hotspots of dFAD deployments and dFAD densities are derived from Escalle *et al.* (2021), which are based on the PNA dFAD tracking database. Passive drift simulations were run on resources and services from the National Computational Infrastructure (NCI), which is supported by the Australian Government. The authors thank Scott Benson, Maxime Lalire, Bryan Wallace and Irene Kelly for their participation to the Lagrangian simulation preparatory workshops; their expertise and advice helped design the experiment presented in this report. This project received funding under award NA20NMF4540142 from NOAA Fisheries Pacific Islands Regional Office. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA. We thank Steven Hare Pilling for valuable comments on an earlier version of the paper.

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