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DYNAMICS OF FISH AGGREGATING DEVICES (FADS) IN THE EPO: A TRAJECTORY-BASED ANALYSIS

This document was produced by the IATTC staff in response to a FADWG-9 recommendation, endorsed by the SAC-16 that, *“Progress be made in analyzing the useful life of biodegradable FADs (‘bioFAD’), or that, in addition to the information provided by observers in the EPO, the IATTC scientific staff provide the Group with a more in-depth analysis, taking into account the information on the positions of buoys associated with FADs as well as relevant information from WCPFC observers.”*

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SUMMARY

In response to a FADWG-9 recommendation, this document examines the dynamics of drifting fish aggregating devices (FADs) in the eastern Pacific Ocean (EPO) to inform IATTC management of the FAD fishery. Expanding on the observer data-based FAD-09-02 work, it analyzes satellite buoy tracking data¹ shared with the IATTC under Resolution C-21-04 and C-24-01, covering 134,877 unique buoys tracked from 2022 through 2025. After quality control filtering, 100,474 buoys (74.5%) were eligible for fate analysis.

Only Manufacturer D buoys carry conductivity sensors that measure wet/dry status. Using these as a training set, we built a classification model that predicted wet/dry state for all other buoys with high accuracy (ROC AUC = 0.99; median per-buoy balanced accuracy = 0.97; 96.5% of true dry and 95.6% of true wet observations correctly classified on held-out test data).

The central finding is that most buoys—84.2% overall—were classified as wet (i.e. drifting)² at the time of their final observation. This pattern was consistent across both measured (94.3% wet) and model-predicted buoys (79.8% wet). A wet final observation indicates no direct evidence of recovery or stranding, suggesting the buoy was still drifting at sea when last detected. Conversely, a dry final observation may reflect recovery (e.g., intentional retrieval, reappropriation), stranding (e.g. beaching, on land), or transit on a vessel deck; the available data cannot distinguish among these outcomes. Most buoys had between 1–10 segments³, with each new segment implying a cycle of recovery and redeployment.

Spatially, dry terminal observations were concentrated near coastlines—along Central and South America, around the Galapagos, and along island-nation coastlines west of the IATTC Convention area—while buoys last observed in offshore waters almost exclusively ended in a wet state. Deployment location showed a weaker signal⁴, with buoys deployed in the northeast and parts of the southern EPO marginally more likely to end in a dry state. A total of 5,584 IATTC-deployed buoys were directly observed crossing into the WCPFC Convention area before being censored⁵ (likely an underestimate), and an additional 14,073 were last observed wet within $\pm 2^\circ$ of the 150°W boundary — a pattern consistent with censoring at the Convention Area boundary rather than recovery or sinking there. This behavior is strongly manufacturer-specific: the buoys of some specific manufacturer were almost always censored upon leaving the EPO, whereas other manufacturers' buoys continued transmitting. Combined, 23.4% of IATTC-deployed buoys with wet terminal observations either entered or likely drifted around or into the WCPFC Convention area.

We compared bio-FAD deployments to spatio-temporally matched conventional-FAD deployments within the core bio-FAD deployment area and found no clear differences in segment duration or distance traveled between the two types. The buoy tracking data do not include intrinsic information on FAD construction or design, so this comparison is limited to segments that could be matched to an observer-recorded FAD label.

Of the 100,474 truncation-filtered buoys, 64.7% appeared in the IATTC's deactivation database at some point, but only 27.5% had a record that could be matched within acceptable quality bands to the terminal observation; the remainder split between buoys absent from the deactivation database entirely (35.3%) and buoys with a deactivation record on file but no record matching the buoy's terminal observation

¹ See Glossary of Terms in Section 2.1 for definitions.

² See Glossary of Terms in Section 2.1 for definitions.

³ See Glossary of Terms in Section 2.1 for definitions.

⁴ See Glossary of Terms in Section 2.1 for definitions.

⁵ In this specific context, “censoring” (or censor) means the final observation (i.e. last recorded transmission) of a buoy within a segment, see Glossary of Terms in Section 2.1 for definitions.

(37.2%). Of all terminal buoys, 18.2% carried a coded reason (the rest were “Uncoded deactivation record”), with FAD outside areas the most frequent (8.6%).

Based on these findings, IATTC staff recommends four actions: (1) improve remote deactivation and reactivation reporting; (2) expand data reporting beyond the IATTC Convention Area for buoys deployed in the EPO; (3) continue Pacific-wide collaboration to reduce FAD loss and strengthen recovery programs; and (4) prioritize the exploration of spatial management options, recovery programs, and incentive systems.

1. INTRODUCTION

Use of drifting fish-aggregating devices (FADs) has become the predominant tuna fishing strategy in the eastern Pacific Ocean (EPO) for fleets targeting tropical tunas (IATTC, 2025, ISSF, 2025; Murua et al., 2023). FAD use has evolved substantially, from simple floating rafts in the early years of the fishery to now being equipped with satellite transponders and echosounders (Hall and Román, 2013; Lopez et al. 2014; Lopez et al. 2016; Cillari et al. 2018). These FADs are subject to an evolving list of IATTC management measures as of May 2026.

[Resolution C-25-01](#) (the current tuna conservation measure for 2026–2028) caps the number of active FADs per purse-seine vessel at 340 for large Class-6 vessels (well capacity $\geq 1,200 \text{ m}^3$), 210 for smaller Class-6 vessels, 85 for Class 4–5, and 50 for Class 1–3. A FAD is considered “active” when deployed at sea with its satellite buoy transmitting its location, which is tracked by the vessel, its owner, or operator. A 15-day FAD deployment ban applies prior to each CPC’s selected seasonal closure period.

[Resolution C-25-01](#) requires that vessels provide daily raw satellite buoy data—including GPS trajectory and echosounder information—to the IATTC Secretariat on a monthly basis with a 60–90-day delay. VMS data must also be reported every two months. Paragraph 22 and Annex II of C-25-01 additionally require CPCs to report all remote satellite-buoy deactivations to the Secretariat at monthly intervals with a 60–90 day delay, recording the date, time, location, and reason (signal loss, stolen FAD, beaching, temporary deactivation during closure, transferred ownership, FAD outside the designated areas, or other). Equivalent remote deactivation-reporting provisions were carried into the current resolution from the predecessor resolutions [C-21-04](#) (2022–2024) and [C-24-01](#) (2025–2026), covering the buoy-data window used in this analysis. These records populate the deactivation registry used in this analysis. Similar requirements exist for remote reactivations.

[Resolution C-23-04](#) established a stepwise transition from conventional to fully biodegradable FADs. Since 1 January 2025, mesh nets have been prohibited in all FAD components (non-entangling designs only). From 1 January 2026, at least one major component (surface or subsurface) must be made from biodegradable materials (Categories I–IV in the resolution’s classification). By 1 January 2029, FADs must be fully biodegradable except for plastic-based flotation components (Category I or II only). The Commission will decide in 2030 whether to mandate fully biodegradable FADs (Category I) by 2031.

[Resolution C-25-07](#) (amending and replacing C-24-06) prohibits tender vessels from operating in support of FAD fishing in the EPO and encourages voluntary FAD recovery programs. Recovery operations are limited to collection for disposal or recycling, with recovered FADs brought to port. The voluntary-recovery provisions are in effect through 31 December 2028, while initial results will be analyzed; the tender-vessel prohibition is not time-limited.

Effective management of FAD use in the EPO requires a clear understanding of FAD dynamics, including the spatio-temporal distribution of deployments/“active” FADs, the amount of time they spend in the water, the locations that they drift to, and their ultimate fate—whether they are recovered or continue

drifting until sinking or stranding. It also requires evaluating the effects of bio-degradable construction on these processes. [FAD-09-02](#) provided an initial assessment of FAD dynamics based on data collected by IATTC observers during fishing operations. A key strength of that study was the ability to track the physical infrastructure of a FAD across observations, leading to an important finding that the majority of FADs (>70%) were never observed again after their initial deployment. Although Class-6 tuna fishing vessels have 100% observer coverage, interactions with FADs involving vessels without onboard observers—such as smaller purse-seine vessels that are not required to carry an observer or those vessels fishing outside of the IATTC Convention area—are not covered by the data used in FAD-09-02, leaving important gaps in coverage.

This document builds on the insights of FAD-09-02 using buoy trajectory data made available through Resolution C-21-04 and C-24-01. Under these Resolutions, the IATTC has access to raw satellite transmissions from FADs (buoys) deployed from 2022–2025. While these data are at the buoy level, not FAD level, they provide an alternative and observer-independent means of tracking and analyzing FAD dynamics. Using these satellite buoy data, this analysis expands our understanding of FAD dynamics in the EPO, especially important to complement the fate of unobserved FADs. Recommendations on data collection improvements as well as considerations for future FAD-management prioritization are also provided. This document responds to a request from the 9th Meeting of the Ad Hoc Working Group of FADs, endorsed by the 16th Meeting of the Scientific Advisory Committee (SAC-16), recommending the IATTC scientific staff that *“Progress be made in analyzing the useful life of biodegradable FADs (‘bioFAD’), or that, in addition to the information provided by observers in the EPO, the IATTC scientific staff provide the Group with a more in-depth analysis, taking into account the information on the positions of buoys associated with FADs as well as relevant information from WCPFC observers”*.

2. METHODS

2.1 GLOSSARY OF TERMS

Throughout this document we use the following terminology:

- **Buoy:** An individual satellite tracking device attached to a FAD. Each buoy is identified by a unique buoy code and may be deployed multiple times over its lifetime, either on the same or different physical FADs. The buoy is also currently the FAD marker, as per Resolution C-19-01.
- **Wet:** A buoy classified as in the water, based on direct conductivity measurement or model prediction.
- **Dry:** A buoy classified as out of the water or not drifting. A dry status could indicate recovery (permanent or temporary retrieval, reappropriation), stranding (e.g. beaching, on land), or time on deck during transit. Importantly, “dry” is agnostic to cause—it describes what the sensor detects or model predicts.
- **Censoring (or censor/ed):** The final observation (i.e. last recorded transmission) of a buoy within a segment, regardless of its wet/dry status at that time. Censoring typically reflects the point at which tracking of that segment ends due to the buoy being turned off, official deactivation, geofencing, signal loss or other causes.
- **Turned off:** A buoy that has stopped transmitting data without an official deactivation report being filed. This may occur for various reasons, including manual switched off by the owner, battery depletion, or signal loss. "Turned off" is a subset of censoring (see above) and is distinct from official "deactivation" in the IATTC and buoy operational sense.
- **Segment:** A continuous period during which a buoy is estimated to be drifting in the water (wet), from the initial deployment/activation until it is retrieved, lost, or data transmission ends. A single buoy may have multiple segments if it is retrieved and redeployed/reactivated. Trivial dry events (e.g. brief removals for maintenance or checking) are not considered to break a segment.
- **Deployment:** The first wet observation of a segment, representing the point at which the buoy (and its associated FAD) was activated, entered the water and began drifting.
- **Soaking:** The subset of observations at-sea within a segment that excludes extended deck time. All wet observations are considered soaking, along with the first dry observation of each contiguous removal event (which marks the retrieval). Subsequent dry observations during the same removal are excluded (see Segmenting Algorithm below for details).
- **Quality band:** A tier describing how closely a deactivation-database record matches a buoy's terminal observation. "Exact" and "near" bands denote a match by buoy code with a time offset within an acceptable threshold (≤ 7 days); broader bands and unmatched cases are treated as failed pairings. Used throughout section 3.7 to summarize how reliably the deactivation registry tracks observed terminal events.

2.2 OVERVIEW

This analysis used a range of methods, which we briefly summarize here and describe in detail below. The primary data sources were the positions and associated sensor data transmitted by the satellite buoys (e.g. water temperature and wet/dry status for buoys equipped with conductivity sensors⁶). One of the main questions of interest is how many FADs are actively drifting in the water (*wet*) at any given time, for how long, and what are the dynamics and fate of these. At the time of this report, only buoys from one manufacturer (Manufacturer D, 30%) are equipped with a conductivity sensor that reports wet/dry status;

⁶ See Glossary of Terms in Section 2.1 for definitions.

the remaining 70% do not have a wet/dry sensor. To address this gap, we trained a machine learning classification model predicting wet/dry status using the Manufacturer D buoys as ground truth and used this model to classify the wet/dry status of all other buoys.

Unlike FAD-09-02, this analysis does not explicitly track individual FADs, but instead follows the trajectories of active buoys. Note that Resolution C-19-01 requires FADs to be marked using active buoys, and therefore, could be a good proxy of FAD dynamics in the water too. Because the same buoy can be deployed on multiple FADs over its lifespan, we needed a way to break each buoy's time series into discrete segments⁷ (e.g. a deployment, recovery, and subsequent re-deployment in a new location). We developed a segmenting algorithm based on the operational understanding of FAD deployments (plausible drifting speeds, time aboard deck for repairs or maintenance, etc.) and used it to partition the buoy observations into individual segments, where each segment represents a continuous drifting period between deployment and recovery (or loss).

Using this information, we subsequently performed a range of analyses on FAD dynamics. These included both descriptive statistics and quantitative analyses. In particular, we tracked the spatio-temporal dynamics of active buoys and estimated spatial maps of the probability that the final observation of a given segment or buoy ends in a *dry* state, which serves as a proxy for potential recovery or stranding. We also examined differences in dynamics between FADs constructed of conventional materials and those constructed of biodegradable materials (i.e., bioFADs), patterns in deployment location and rough associated risk, causes and patterns in deactivation reporting, rates of crossings to the western Pacific, and links to observed strandings and recovery programs.

2.3 DATA

The satellite transmission database contains 79,365,811 observations of 134,877 unique buoys from 2022–2025. We conducted minimal filtering of these data prior to inclusion in our models. The main filter was to remove observations clearly located inland. We first identified all points within 50 km of a coastline as candidate land points, using the highest-resolution 'naturalearth' land layer (10 m resolution); points greater than 50 km from any landmass were retained without further screening. We then applied a fine-scale filter to these candidates, removing any point found to be more than 1 km inland from an identified coastline. Points within 1 km of the coastline were retained to avoid excluding buoys stranded in mangroves, estuaries, reefs, or on beaches.

We also computed speed (knots) between consecutive observations as distance divided by elapsed time. A small number of observations (23 out of ~58 million) were removed because they had sustained speeds exceeding 200 knots over multi-hour intervals covering hundreds of nautical miles, consistent with air-freight transit of buoys. Remaining speed values above 20 knots—caused by GPS position error divided by short transmission intervals—were capped at 20 knots.

2.3.1 TEMPERATURE NORMALIZATION BY MANUFACTURER

Buoy manufacturers were identified from the buoy code. Manufacturers representing less than 1% of observations were grouped as "Other." Most observations (92%) included water temperature data measured by a sensor. However, only Manufacturer D buoys are equipped with a conductivity sensor measuring wet/dry state, meaning that the classification model must be based only on Manufacturer D buoys. Different buoys might position their water temperature sensors in different parts of the buoy, or have different levels of precision or bias. To correct for this, we fit a spatio-temporal model of reported water temperature as a function of buoy manufacturer using sdmTMB (Anderson et al. 2024), with the most common Manufacturer D sub-model as the reference level. The model included a spatio-temporal

⁷ See Glossary of Terms in Section 2.1 for definitions.

random field (AR1, 1-month auto-regressive process, by year-month) to absorb variation due to location, season, and inter-annual and seasonal trends, isolating the marginal effect of manufacturer on reported temperature. Manufacturer-specific offsets were then subtracted from the raw temperature readings, normalizing all buoys to the reference Manufacturer D scale before training the wet/dry detection model (Figure 2).

2.3.2 ADDITIONAL DATA SOURCES

We augmented the buoy tracking data with i) data from FAD-09-02, which includes data marking whether the FAD was a biodegradable “bioFAD”, ii) data on FAD strandings and recoveries from collaborators in the region, including the WCPO, and iii) with data on remote deactivations reported to the IATTC Secretariat under Resolutions C-21-04 and C-24-01.

FAD-09-02 contains observer records of FAD interactions, including whether each FAD is classified as a bioFAD or conventional FAD. To link this information with buoy trajectory data, we merged records using buoy codes, locations, and timestamps. This allowed us to compare buoy tracks associated with FADs constructed of either conventional or biodegradable materials. We constrained this analysis to the core bioFAD deployment area (defined as the set of 5° grid cells with the highest levels of observer-reported bioFAD deployments, identified using an elbow-detected threshold on the cumulative distribution of bioFAD deployments). By focusing on this subset, we minimized differences in location and time when FADs were deployed with intrinsic differences between the two FAD construction methods.

Voluntary data collection programs on FAD stranding and recoveries have been implemented by several Pacific Island Countries and Territories (PICTs) in the western and central Pacific Ocean (WCPO) in collaboration with the Pacific Community (SPC; see: [FAD-07 INF-A](#); [FAD-09 INF-A](#)). In this report, we incorporated regional data from WCPFC-SPC, France’s overseas territories (French Polynesia in the WCPO and Clipperton Atoll in the EPO), and the Galapagos Conservation Trust (GCT). Collaborators provided a list of buoys from SPC’s WCPO-wide database, and from GCT-Galapagos National Park Directorate partnership, which collects data on FAD strandings matched to records in IATTC’s tracking database. Each record included the buoy code, location and timestamp of the FAD/buoy recovery or stranding.

As described in the filtering process above (see section 2.3. Data), distance measurements between reported FAD recovery and strandings and the tracking database were made where applicable using the precise GPS coordinates provided in these external datasets. However, these positions were rounded to the nearest 1-degree latitude and longitude for plotting on a map.

C-21-04 and C-24-01 (now C-25-01) mandate the reporting of remote FAD deactivations. Remote deactivations are reported monthly by either the vessel or the buoy manufacturer. To incorporate these data, we merged reported deactivations with the buoy trajectory database using the buoy code and timestamp of deactivations. Since the timing of track transmissions and deactivations do not always exactly align, we used a fuzzy join process, classifying each match into one of three quality categories based on the absolute time offset between the reported deactivation and the nearest track transmission for that buoy: *exact* (within 24 hours), *near* (within 7 days), and *loose* (more than 7 days). We also matched purely on buoy code to examine the degree of overlap between the tracks and deactivation databases. In 2022, following the recommendation of the FADWG and the requirement of C-21-04, the IATTC Secretariat designed a dedicated remote deactivation/reactivation form (available on the IATTC website with accompanying tutorials) to standardize the reporting of buoy deactivations and reactivations. The Secretariat has also received many deactivation reports submitted by buoy manufacturers outside this form. This analysis incorporates all reported deactivations provided to the Secretariat, regardless of submission format; see Section 4.1 for the staff recommendation on improvements for future remote deactivation and reactivation.

2.4 WET/DRY CLASSIFICATION

The data consisted of buoys from multiple manufacturers. Manufacturer D buoys were equipped with a conductivity sensor that recorded whether the buoy was wet or dry at each transmission. Information on a buoy's status (i.e. wet or dry) was essential for dividing each buoy into segments separated by periods of meaningful removal from the water (for example, returning to port for reuse prior to redeployment in a new location). Throughout this report, the meaning of "wet" differs slightly between the two sources of wet/dry status. The Manufacturer D conductivity sensor reports wet whenever the sensor itself is in water, so a stranded but partially submerged buoy can register as wet. The model-predicted wet/dry status (described below), which incorporates both water-temperature signal and movement information, would generally classify such a stranded, non-drifting buoy as dry.

After filtering the data, 22% of observations included a direct wet/dry measurement of the buoy, meaning that the status of the remaining 78% had to be estimated.

We used the subset of observations with known wet/dry status to train a LightGBM model (a gradient boosting machine learning method) to classify each observation as wet or dry. Predictors included speed, water temperature, their lagged changes (delta and rolling values), the time interval between consecutive transmissions (delta hours), bearing and rolling bearing, hour of day (as sine/cosine components), and a marker for the first observation of each buoy. The transmission interval captures operator behavior—fishers typically configure more frequent pings when a FAD is actively soaking or the vessel is searching⁸ for it, for example, than when a buoy is on deck or in storage. We omitted latitude and longitude from the model because Manufacturer D buoys are concentrated within the eastern Pacific, making spatial predictors unreliable for classifying buoys drifting outside this region.

We first split the Manufacturer D data into training (80% of unique buoys) and testing (remaining 20%) sets using a grouped split (i.e., splitting by buoy ID rather than by individual observation) to prevent data from the same buoy appearing in both sets. We down sampled the majority class in the training data (wet) to achieve a reasonably balanced (roughly 3:1) ratio of wet to dry observations. For hyperparameter tuning, we drew a random 25% subsample of training buoys and applied grouped 5-fold cross-validation, selecting the parameter set that maximized the area under the precision-recall curve (PR AUC), which is more appropriate than ROC AUC for imbalanced classification problems as it focuses on minority-class (dry) performance. The final model was then fit on the full rebalanced training dataset using the selected parameters. We evaluated model performance on the held-out test set and selected a classification probability threshold that maximized balanced accuracy (the average of sensitivity and specificity). This classification model and threshold were then applied to predict the wet/dry status of all observations that lacked a conductivity-sensor reading.

2.5 SEGMENTING ALGORITHM

Combining the model predictions with the Manufacturer D data provides us with a wet/dry classification for all 79,365,811 observations. However, we cannot break observations of an individual buoy into segments based on wet/dry status alone. In some cases, the buoy appears to have only been dry for a few hours or less, without substantial movement, which should not result in the creation of a new segment. In other cases, data are missing, so while two sequential observations may both be wet, they may be separated by an implausibly large distance or time gap, suggesting a retrieval and redeployment occurred between transmissions. We note that this may be more of a "FAD-based" segment, designed to detect meaningful removals from the water. Even short removals may be enough to disturb the community of

⁸ See Glossary of Terms in Section 2.1 for definitions.

organisms associated with the FAD, so a more ecologically focused analysis might require a different segmenting algorithm.

We define a “segment” as a single continuous period of a buoy in the water—from the moment it enters the water until it leaves the water either permanently or for a meaningful amount of time. The segmenting algorithm works in three stages:

Stage 1 — Pre-processing. Before identifying break points, we compute summary statistics for each contiguous run of dry observations within a buoy. Specifically, we accumulate the cumulative distance traveled (in nautical miles) and elapsed time (in hours) during each run of dry observations. These cumulative distances are used in Stage 2 to distinguish brief stationary removals from meaningful transits that indicate a redeployment.

Stage 2 — Identify break points. Working through each buoy’s time-ordered observations, we flag a new segment boundary whenever any of three scenarios is detected:

1. **Long silence with displacement.** More than 50 days elapsed between consecutive observations and the displacement exceeds the maximum plausible passive drift distance (3 knots × elapsed hours). A buoy that reappears within plausible drift range after a transmission gap is retained in the same segment; one that reappears too far too have plausibly drifted is treated as a redeployment. *Example: a buoy transmits from 5°S 160°W, goes silent for two months, then reappears at 2°N 140°W, well beyond where equatorial currents could passively carry the buoy during that time period.*
2. **Implausible movement while classified as wet.** The buoy is classified as wet but is moving faster than passive drift allows, indicating vessel transport. We apply two checks: (a) speed exceeds a threshold (>5 knots for predicted buoys, >10 knots for sensor-equipped buoys) with displacement ≥ 5 nm; or (b) for predicted buoys, displacement since the previous observation exceeds the maximum plausible drift distance (3 knots × elapsed hours). The minimum displacement floor in (a) prevents false breaks from GPS jitter. *Example: a buoy classified as wet jumps 15 nm in 3 hours (5 knots)—consistent with a purse seiner carrying a FAD between sets rather than passive drift.*
3. **Significant dry event.** The buoy was removed from the water and either (a) traveled ≥ 25 nm cumulatively during the dry period, detected when it returns to water; or (b) remained on deck for ≥ 72 hours (3 days), detected mid-run. Check (a) finds vessel transits that end in redeployment (inferred from buoy trajectory only — VMS is not used); check (b) finds prolonged periods out of the water. Brief stationary removals (e.g., a few hours on deck during a set) do not trigger a break. *Example: a buoy is picked up at 8°S 160°W, spends four days on a vessel, and is redeployed at 2°S 90°W — both the distance (>25 nm) and duration (> 72 h) independently trigger a new segment.*

Any observation where none of these conditions are met does not trigger a break. The first observation of each buoy is never a break point.

Stage 3 — Enforce wet start. By definition, the first observation of a segment must be the buoy entering the water. After the initial segmenting pass, any leading dry observations at the start of a segment (i.e., rows that precede the first wet observation) are removed. Segments that contain no wet observations at all are dropped entirely. This ensures that every retained segment begins with a wet observation representing the buoy deployment event. The last observation of a segment, by contrast, may be either wet (if the buoy was still drifting when transmissions ceased) or dry (e.g. if the buoy was retrieved or stranded). Segments may still contain interior dry observations (e.g., brief removals that did not meet the 25 nm or 72-hour thresholds); these are retained as part of the segment.

After segmenting, we define an “active fishing” marker for each observation within a segment. All wet observations are marked as active. For contiguous runs of dry observations within a segment (i.e., brief removals that did not trigger a segment break), only the first observation of each dry run is marked as active; this observation represents the retrieval or stranding event itself. Subsequent dry observations in the same run are marked as inactive (deck time, post-stranding). Finally, trailing inactive observations are trimmed from each segment, so that every segment ends with an active observation (either the last wet observation or the dry event).

2.6 ANALYZING SEGMENTS

Based on the predicted wet/dry statuses and the segmentation, we analyzed segment dynamics. The deployment location of each segment is the first wet observation, and the censor location is the last observation⁹, whether wet or dry.

To characterize spatial connectivity (i.e., the final location of deployed FADs), we binned deployment and censor locations into a regular $5^\circ \times 5^\circ$ grid. For each deployment cell we computed the mean displacement to censor location (shown as drift arrows in [Figure 13](#)) and the full probability distribution over censor destination cells ([Figure 14](#), filtered to the cells accounting for 95% of final locations).

2.7 TRUNCATION FILTERING

The satellite tracking database has fixed temporal boundaries, which introduces two sources of bias in fate analyses. **Right truncation** affects buoys deployed near the end of the database: a buoy that has not been tracked for long enough has not had sufficient time for its lifespan to be observed. We set the right-truncation cutoff to the 75th percentile of observed buoy lifespans (see Results), excluding any buoy whose first observation falls within that window of the database end. **Left truncation** affects buoys that were already active when the database begins: their deployment event was not observed, so their deployment location and full trajectory are unknown. We flagged buoys whose first observation fell within 7 days of the database start date and whose initial classification was wet, indicating they were likely mid-deployment when tracking began rather than newly deployed. Both flags were applied at the buoy level and propagated to all observations, so that downstream fate tables, spatial models, and summary statistics were restricted to buoys with a higher likelihood of having their full trajectory captured within the database window.

2.8 SPATIAL PATTERNS

We used sdmTMB to fit spatio-temporal binomial generalized linear models (GLMs) to model the probability of a buoy’s final observation being dry as a function of location. Models include an intercept-only fixed effect with an anisotropic spatial random field estimated via SPDE mesh approximation, using a binomial family with logit link. Separate models were fit using deployment and censor locations to identify spatial variation in retrieval probability across the study area.

⁹ See Glossary of Terms in Section 2.1 for definitions.

3. RESULTS

3.1 DATA FILTERING

Of the 135,306 unique buoy IDs in the raw data, 134,877 (99.7%) remained in the analysis after land filtering and speed cleanup. Of those, 23,310 (17.3%) were excluded due to right truncation (deployed within 267 days of the database end, insufficient time to observe their fate) and 9,540 (7.1%) due to left truncation (already wet at the start of the database, so their initial deployment into the water was not observed). As a result, 100,474 (74.5%) eligible buoys were included for downstream analysis.

3.2 MANUFACTURER DISTRIBUTIONS

There were clear spatial patterns in the distribution of buoys manufactured by different companies. Manufacturer C buoys were the most broadly distributed over the eastern and western Pacific Ocean. Transmission from Manufacturer B and Manufacturer D buoys was shut off or not reported for most buoys west of the IATTC Convention area ([Figure 1](#)).

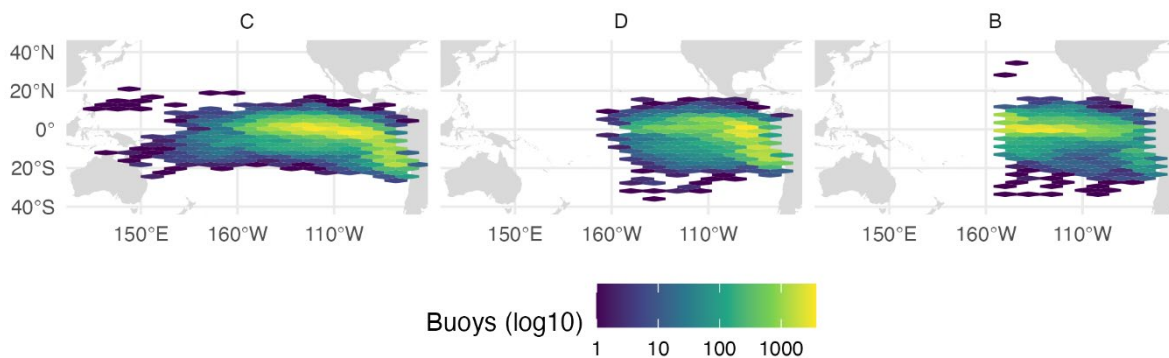


FIGURE 1. Spatial distribution of buoy deployments by manufacturer. Each panel shows a hex-binned density of deployment locations for a single manufacturer. Only the deployment (first wet) location of each buoy is used. Buoys are grouped to the high-level manufacturer (e.g., all sub-models from a given manufacturer are pooled into one panel).

The spatio-temporal model produces manufacturer-specific temperature offsets (Figure 2). These offsets represent the systematic difference in reported water temperature for each manufacturer relative to the reference model, after controlling for spatial location and year-month.

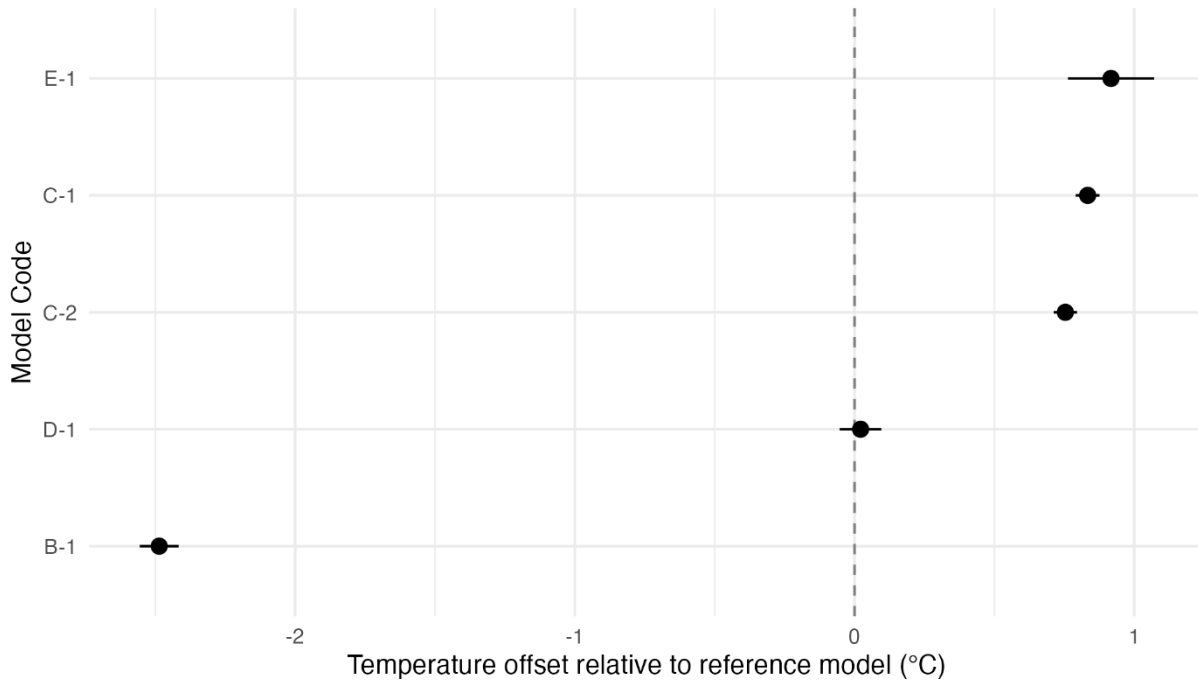


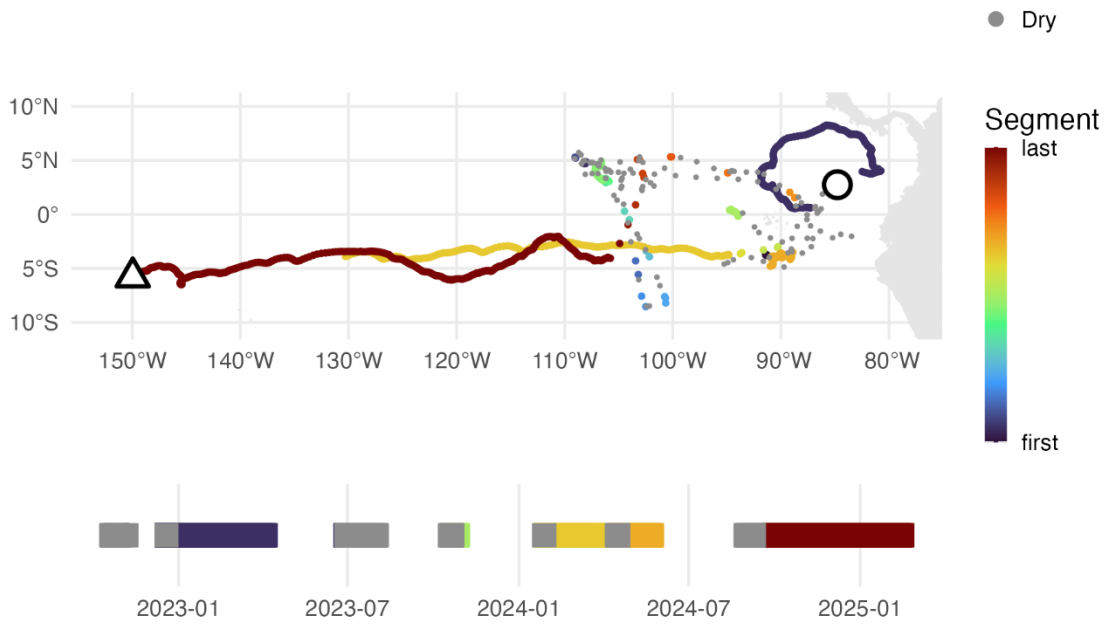
FIGURE 2. Estimated manufacturer effects on reported water temperature relative to the reference sub-model (Manufacturer D), controlling for spatial and temporal variation via a spatio-temporal random field. Positive values indicate the manufacturer’s sensors report warmer temperatures than the Manufacturer D reference at the same location and time.

3.3 WET/DRY CLASSIFICATION

Example buoy tracks colored by wet/dry status are provided in [Figure 3](#): left panel shows status observed from a Manufacturer D conductivity sensor, and right panel shows the model-predicted status.

Observed (sensor)

23 segments · start (circle): 2022-10-20 · end (triangle): 2025-02-15



Predicted (LightGBM)

2 segments · start (circle): 2023-12-08 · end (triangle): 2025-06-29

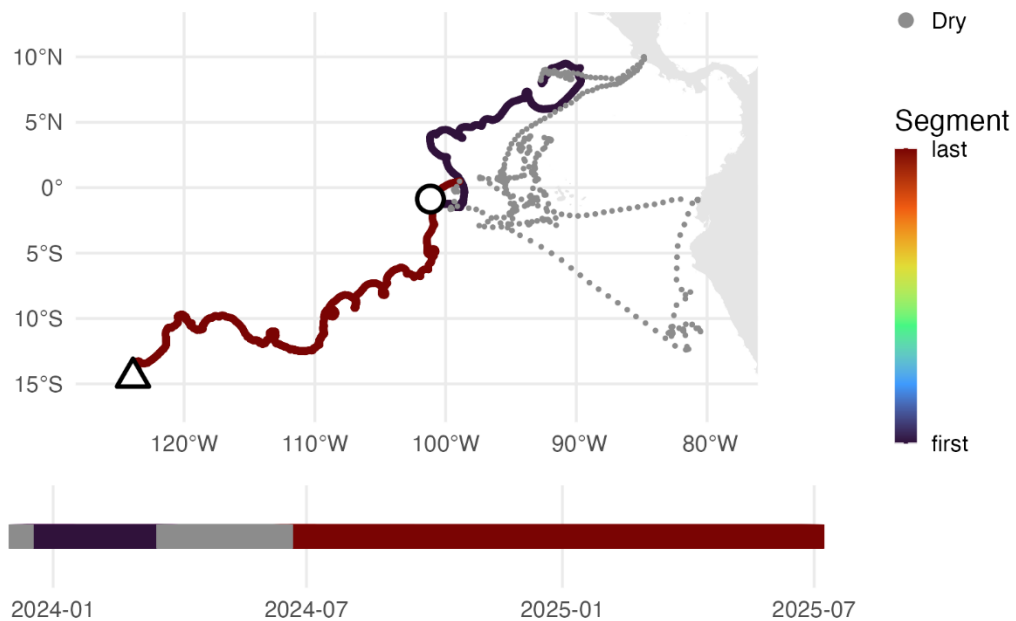


FIGURE 3. Example buoy track illustrating how the segmenting algorithm partitions a single buoy's observations into deployments. Each point is one observation, plotted at its reported position.

Colored points belong to a deployment segment, with color shading from dark purple (earliest) to red (latest) within that segment. Grey points are observations flagged as dry — typically pre-deployment transit, post-retrieval trailing, or sustained dry runs that triggered a segment break. A white circle marks the buoy's first observation overall and a white triangle the last, indicating direction of travel. The strip below the map shows the same wet/dry coloring along the time axis (colored = wet, grey = dry).

The wet/dry detection model performed well on the held-out test buoys (Figure 4). At the selected threshold (0.8, chosen by maximizing balanced accuracy), the model correctly classified 96.5% of true *dry* observations and 95.6% of true *wet* observations. Of the errors, 3.5% of true dry observations were missed (classified as wet), and 4.4% of true wet observations were incorrectly flagged as dry in the testing data held out from the training of the model.

The ROC curve (AUC = 0.99) summarizes the tradeoff between correctly detecting each class across all possible thresholds; an AUC of 1 would indicate perfect separation. Because dry observations are relatively rare (~8% of the test set), we also present a precision–recall curve for dry detection (Figure 4, bottom right). This curve shows how two quantities trade off as the classification threshold changes. The x-axis (“detection rate”) is the fraction of all truly dry observations the model successfully identifies. The y-axis (“reliability”) is the fraction of observations flagged as dry that are truly dry. At the far left of the curve, the model only flags observations it is very confident about—it finds few dry observations but is almost always right when it does. At the far right, the model flags aggressively to catch every dry observation, but many of those flags are false alarms on wet observations. A good model keeps reliability high even as detection rate increases (i.e. the curve hugs the top-right corner). A poor model’s reliability would collapse immediately. Our model maintained high reliability across most of the detection range, dropping off only when pushed to find the last and most ambiguous dry observations.

Performance was consistent across individual buoys in the test set. Balanced accuracy—the average of the correct classification rate for wet observations and the correct classification rate for dry observations, such that both classes contribute equally regardless of sample size—had a median per-buoy value of 0.97, and only 1.5% of buoys fell below 0.70 balanced accuracy.

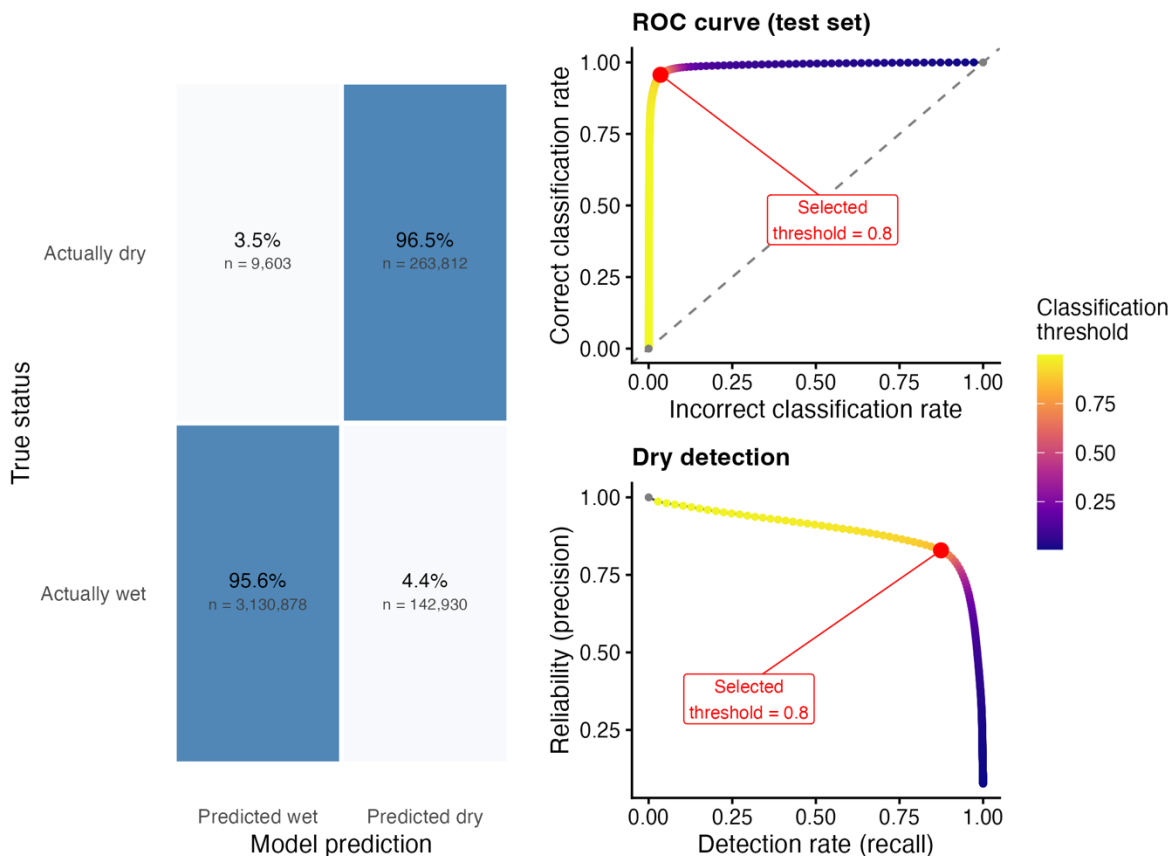


FIGURE 4. Left: Classification rates on the held-out test buoys. Cell values show the proportion of each true class assigned to each predicted class. Top right: ROC curve summarizing overall discrimination. Bottom right: detection rate vs. reliability for dry classification (precision–recall curve).

Because latitude and longitude were deliberately excluded from the model, spatial biases are possible (Figure 5). Given that the data are heavily imbalanced, we focused on spatial patterns in the ability to detect the minority class (dry). The model was more likely to miss dry events at the edges of the spatial domain, particularly in the southwest of the training data, though recall was not uniformly poor in this region. These spatial patterns highlight that the model can generate incorrect predictions in some regions.

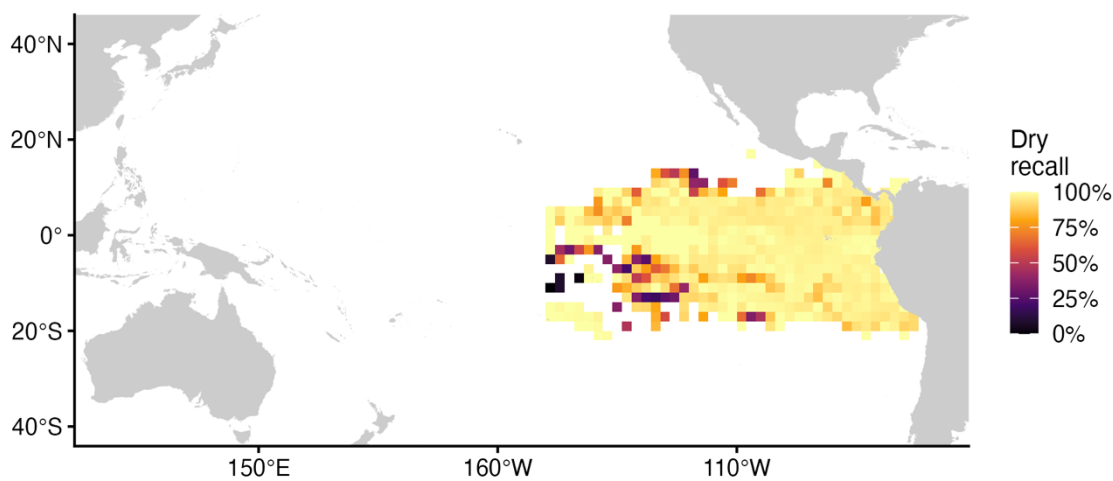


FIGURE 5. Recall (sensitivity) of the wet/dry detection model for dry observations on the test set, binned into 2° grid cells (minimum 10 dry observations per cell). Cells with too few minority-class (dry) observations were omitted.

3.3.1 UNSEEN RECOVERY EVENTS

A true new segment (besides the first segment of a buoy) can only begin after the preceding segment ended with a buoy being recovered from the water, i.e. the buoy was dry. If the preceding segment's last observation was instead classified as wet, one of four things must have happened: (a) the recovery occurred during a censoring period, or an area/period when data were not shared with the IATTC; (b) the recovery event was visible in the data used by the model but was misclassified as wet by the model; (c) the segmenting algorithm spuriously split a single continuous deployment into two segments; or (d) the retrieval and redeployment took place between satellite transmissions (i.e., censored buoy, signal loss), so no dry observation was ever visible to the model. Counting new segments whose preceding segment ended wet therefore provides a rough measure of how often within-lifespan recoveries fail to be captured correctly—conflating missed recoveries, model misclassifications, sampling-cadence-spatial gaps, and spurious segment breaks.

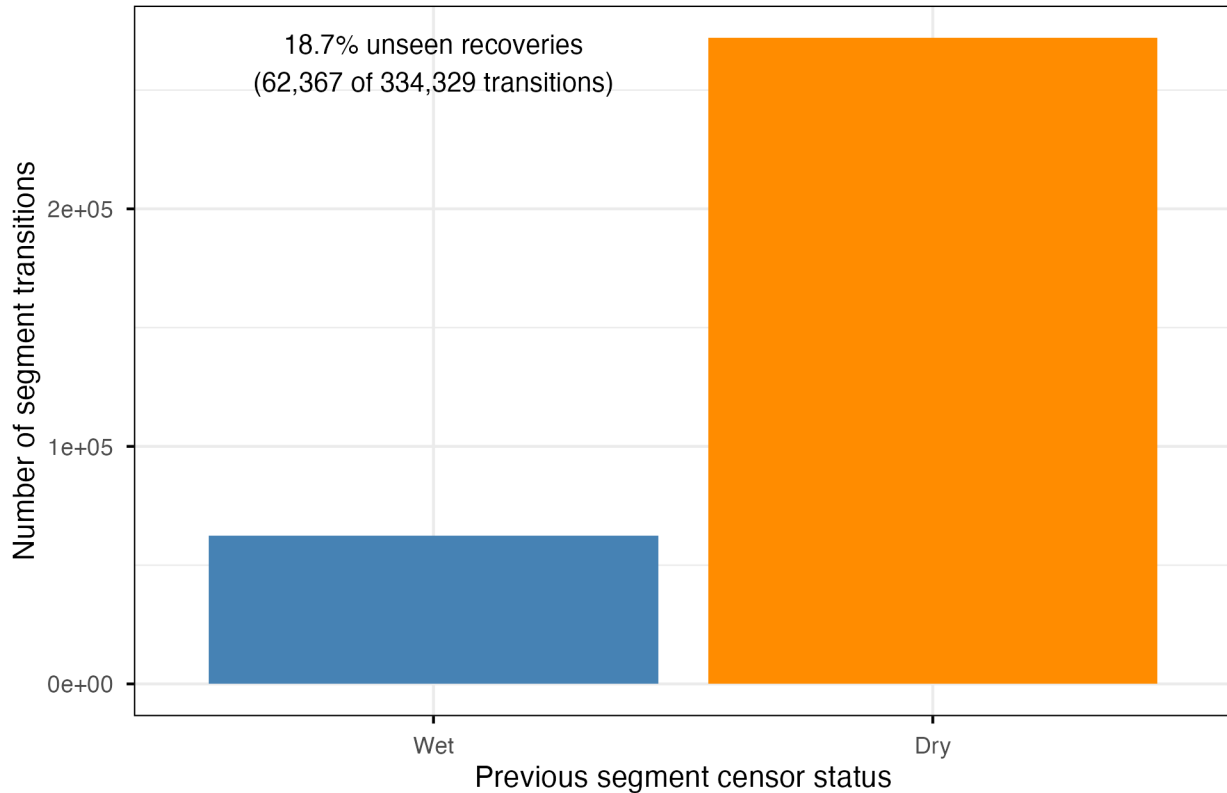


FIGURE 6. Wet/dry status at the end of each segment preceding a new segment on the same buoy. Segments that ended wet before a new segment began indicate an unseen recovery event (i.e. the buoy was removed and redeployed without the wet/dry detection from the model detecting the transition).

Of the 334,329 within-lifespan segment transitions, 62,367 (18.7%) followed a segment whose final observation was classified as wet. Splitting this rate by the source of that final observation is informative: among transitions where the prior segment ended with a directly measured (Manufacturer D) observation, 35.8% ended wet, versus only 13% for model-predicted observations.

The Manufacturer D rate is model-free, so the 35.8% can only reflect causes (a), (c), and (d); since there is no model, the cause cannot be a model misclassification (though it could be a temperature sensor error). Cause (c)—spurious segmentation of a continuous deployment—would require clearing the cumulative thresholds of the deck rule (≥ 25 nm of drift or ≥ 72 hours) during a genuinely uninterrupted wet-to-wet period, which is unlikely to happen often. Most of the Manufacturer D rate is therefore attributable to (a) and (d): retrievals occurring when the buoy is censored, during an IATTC data-sharing gap, or simply between satellite transmissions or potential signal loss (rare). Because the model-predicted rate is lower than the Manufacturer D rate, cause (b)—model misclassification—is ruled out as the main driver of the overall 18.7%; otherwise, the predicted-source rate would exceed the Manufacturer D rate and not fall below it.

These within-lifespan rates should not be read as a lower bound on how often a buoy's terminal (end-of-life) wet reading conceals an unreported retrieval. The diagnostic captures interactions during the active-use phase of a buoy's life — typically while it is inside the core fishing grounds, where buoys are handled more frequently. Terminal observations come from a later phase of the same buoys' life cycle: many have drifted out of the core fishing grounds, where opportunities for retrieval are far lower. Interaction rates observed during the active-use phase therefore do not translate directly to the terminal phase. The within-

lifespan rate is best read as a diagnostic on whether the model and segmenting algorithm can detect recoveries while a buoy is being actively used, not as an estimate of how often terminal wet readings mask an unobserved retrieval. It does, however, confirm that unseen retrievals occur.

3.3.2 WET/DRY MODEL FEATURE IMPORTANCE

Knots (i.e., speed) (rolling, raw, and change) were the most important predictors of the wet/dry detection model, followed by change in temperature and the reporting interval of the buoy (delta_hours) (Figure 7).

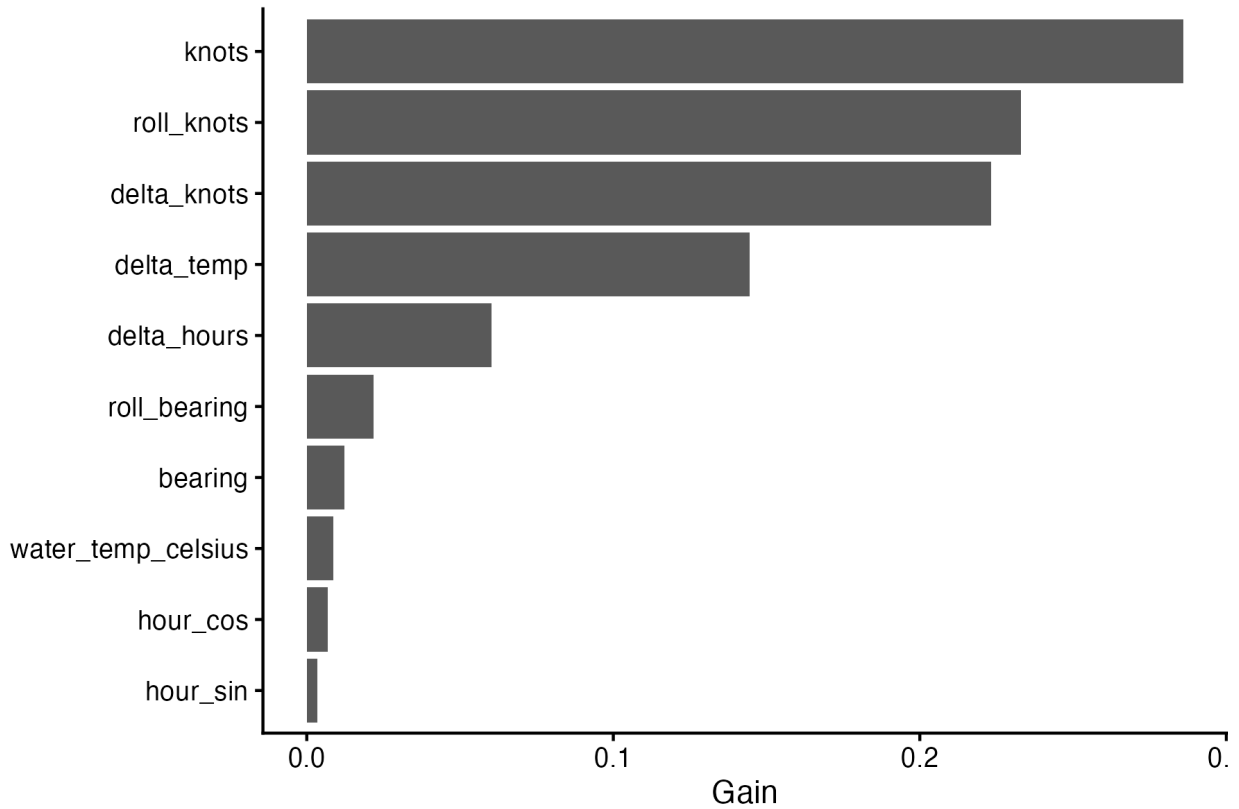


FIGURE 7. Feature importance for the wet/dry detection model. Bars show total gain attributable to each predictor across all tree splits; longer bars indicate predictors with greater influence on the classification.

3.4 BUOY LIFESPAN DYNAMICS

The spatial density of soaking observations was largely consistent across months, with little seasonal variation in deployment locations (Figure 8). The tendency for buoys to be censored around the IATTC convention boundary is evident in all months (note that data outside the Convention Area is not always reported, which can affect estimates). The general footprint of buoy deployments was stable over time, though deployments near the coast of Peru increased some in March and April (Figure 9).

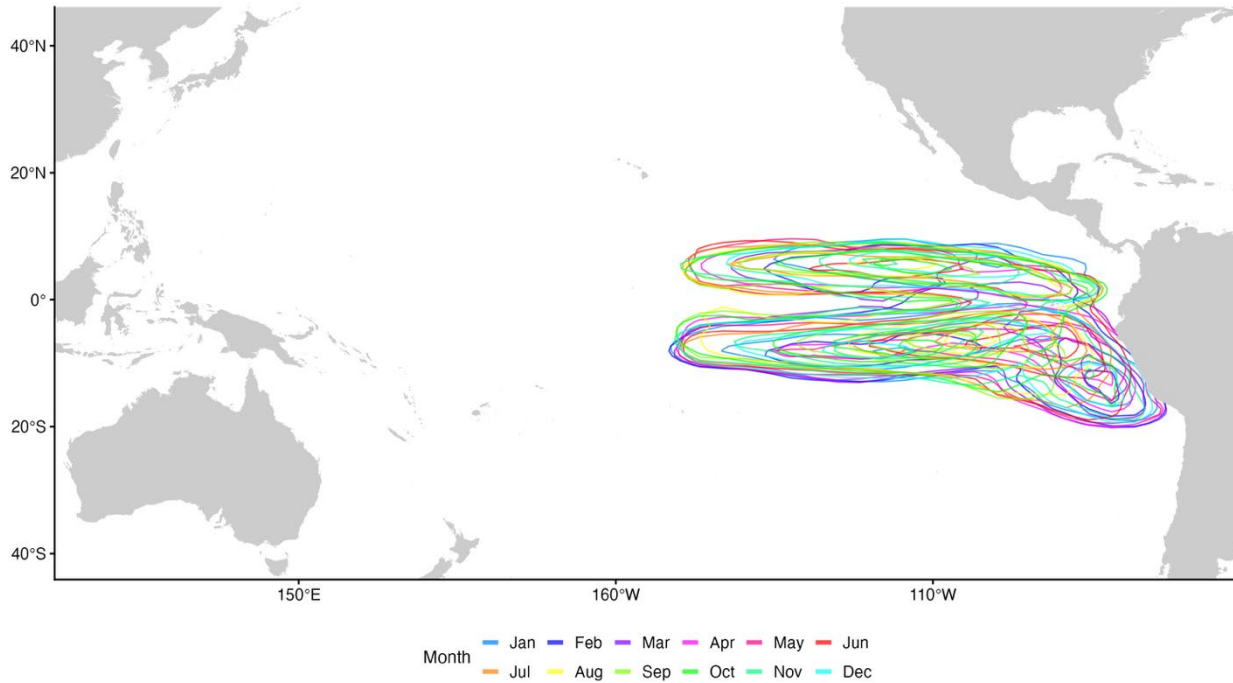


FIGURE 8. Spatial density contours of soaking observations by month, overlaid on a single map. Each color represents one month. The near-complete overlap of contour lines indicates minimal seasonal variation in deployment patterns.

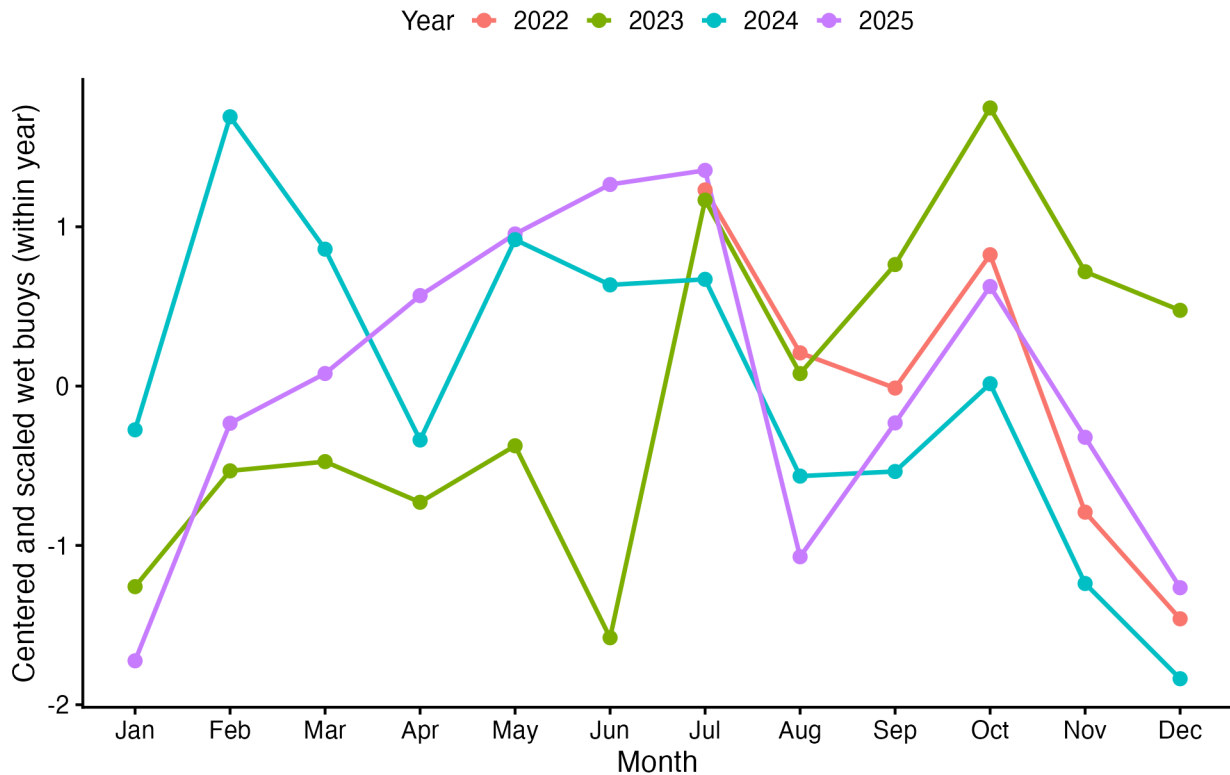


FIGURE 9. Unique wet buoys per month, centered and scaled within each year so that seasonal patterns are directly comparable across years of differing fleet size. January–June 2022 are excluded due to left truncation: the tracking data begins in 2022, so buoys already deployed before the observation window are under-represented until mid-year.

The vast majority of buoys had between 1 and 10 segments per buoy (multiple segments being indicative of recovery and re-deployment in a new place and time – i.e., reuse), and buoys whose final observation was wet were slightly more likely to have fewer segments ([Figure 10](#)).

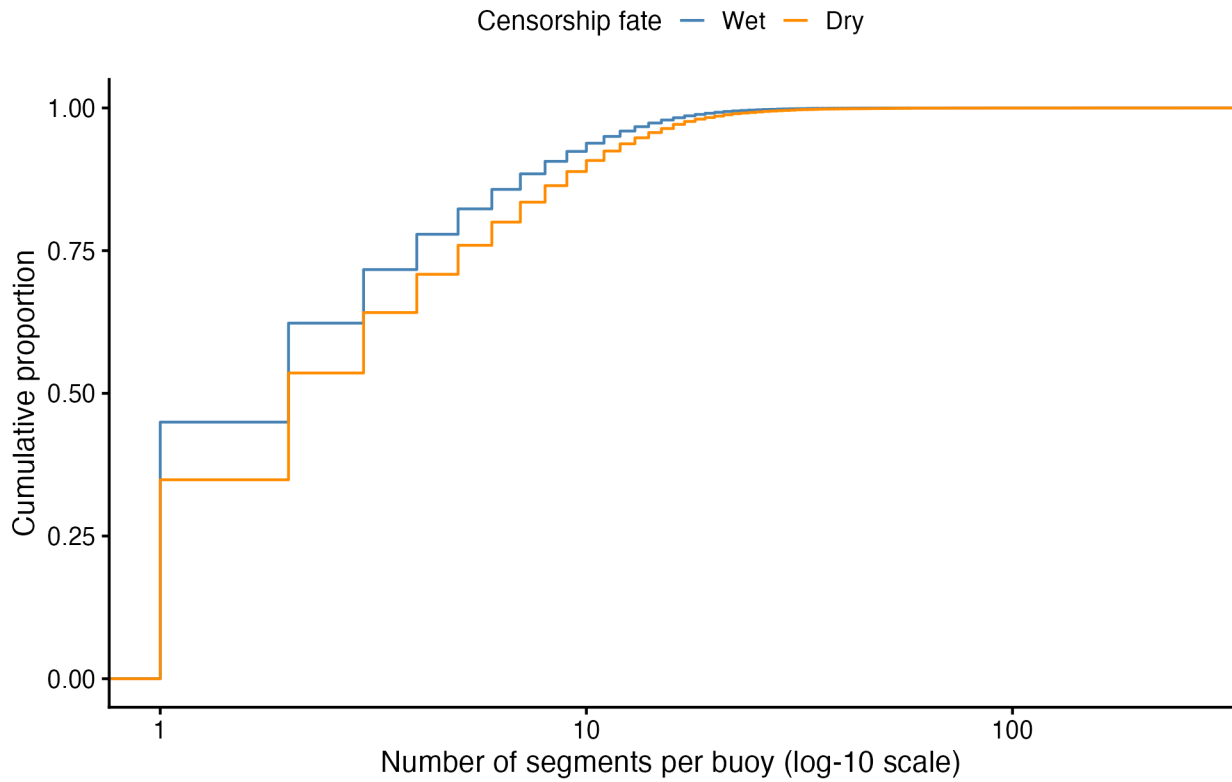


FIGURE 10. Distribution of segments per buoy, by censoring fate defined as the wet/dry status of a buoy’s final observation.

The median segment had 10 days of soak time, covering 238 nm. The median buoy soaked for a total of 177 days, covering a total of 2204 nm (Table 1, Figure 11).

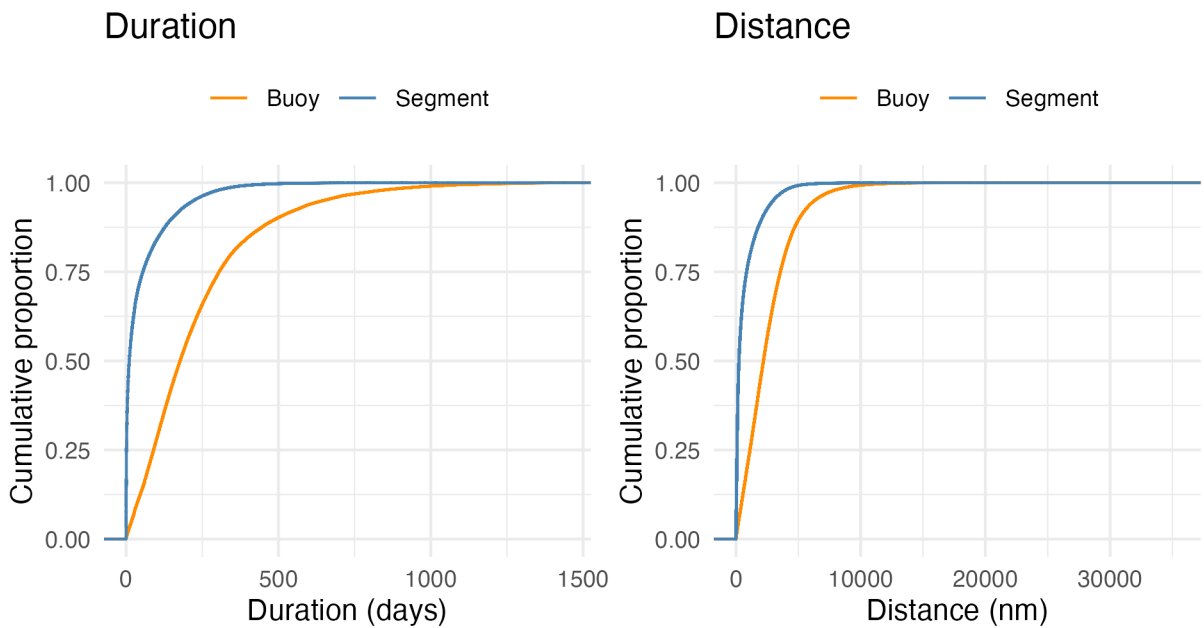


FIGURE 11. Cumulative distribution of active soaking duration and distance travelled at the segment level (individual deployments) and buoy level (total across all segments); restricted to fate-eligible buoys.

Table 1. Summary statistics of active fishing duration and distance at the segment and buoy level. Raw values are median, mean values in parentheses.

Level	N	Duration (days)	Distance (nm)
Segment	370,332	10 (47)	238 (700)
Buoy	100,474	177 (231)	2204 (2582)

3.4.1 SPATIAL PATTERNS

Censoring locations tended to occur further west than deployment locations, consistent with an overall pattern of westward equatorial drift. Buoys with wet/dry sensors (observed wet/dry status) had deployments and censoring locations concentrated in the eastern Pacific, while buoys without a wet/dry sensor (predicted wet/dry status) locations extended further west, reflecting the broader geographic range over which buoys lacking a conductivity sensor continued to transmit (Figure 12).

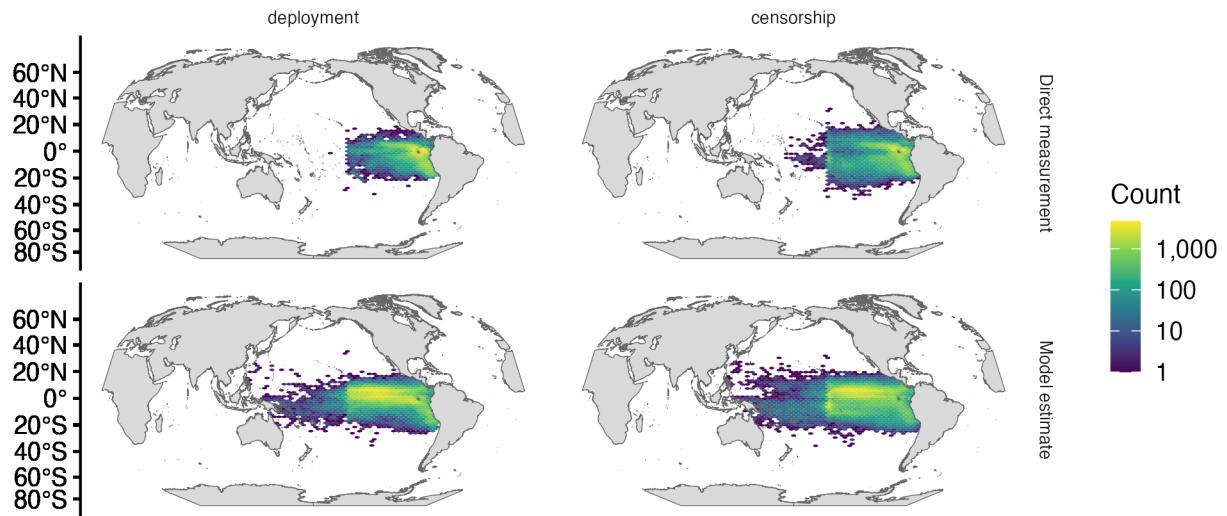


FIGURE 12. Spatial density of deployment and censoring locations by wet/dry source (observed via Manufacturer D conductivity sensor vs. model-predicted).

Mean buoy displacement from each 5° buoy deployment cell is shown as drift arrows (Figure 13). Each arrow starts at the center of a deployment cell and points toward the mean censor location for buoys deployed in that cell. Note that this does not mean that all buoys follow this trajectory, this is simply the average trajectory. A more nuanced view of trajectories is provided by the censor destination distributions for the most well-sampled deployment cells, ordered by number of buoys (Figure 14). Each facet shows one buoy deployment cell (red outline) and the 5° cells where those buoys were ultimately censored, filtered to the top 95% of destinations. These plots only include single-segment buoys, to avoid confusion from buoys recovered and redeployed in new locations. Note as well that these spatial patterns are a function of both oceanographic and fleet behavioral patterns. For example, Resolution C-25-01 states that buoys can be deactivated when drifting outside the fishing ground, for example, south of 10°S between

150°W and 100°W, and south of 15°S east of 100°W, the red dashed lines in Figure 13. We see that average trajectories also seem to end on these lines; this does not necessarily reflect that buoys are sinking or being recovered exactly as they cross south of these boundaries, but rather that the IATTC stops receiving transmissions from buoys drifting south of these lines. The ultimate fate of these buoys past these borders is unknown.

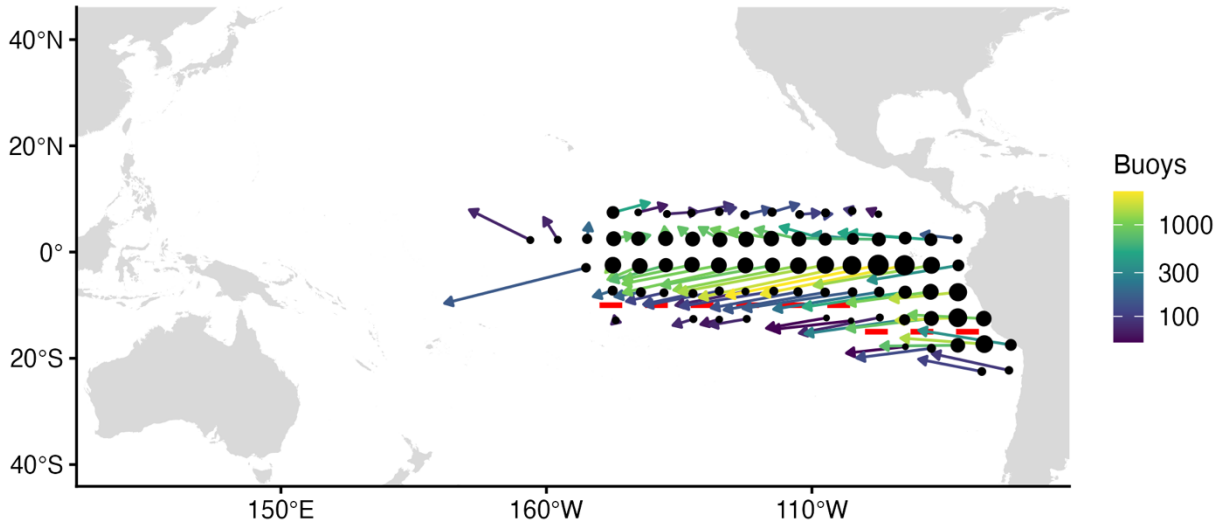


FIGURE 13. Mean buoy drift vectors per 5° deployment cell for single-segment buoys only. Arrow points from deployment cell center to mean censor location. Point size shows number of buoys. Dashed lines mark the southern boundary of the C-25-01 satellite-buoy fishing ground area (10°S between 150°W and 100°W; 15°S east of 100°W).

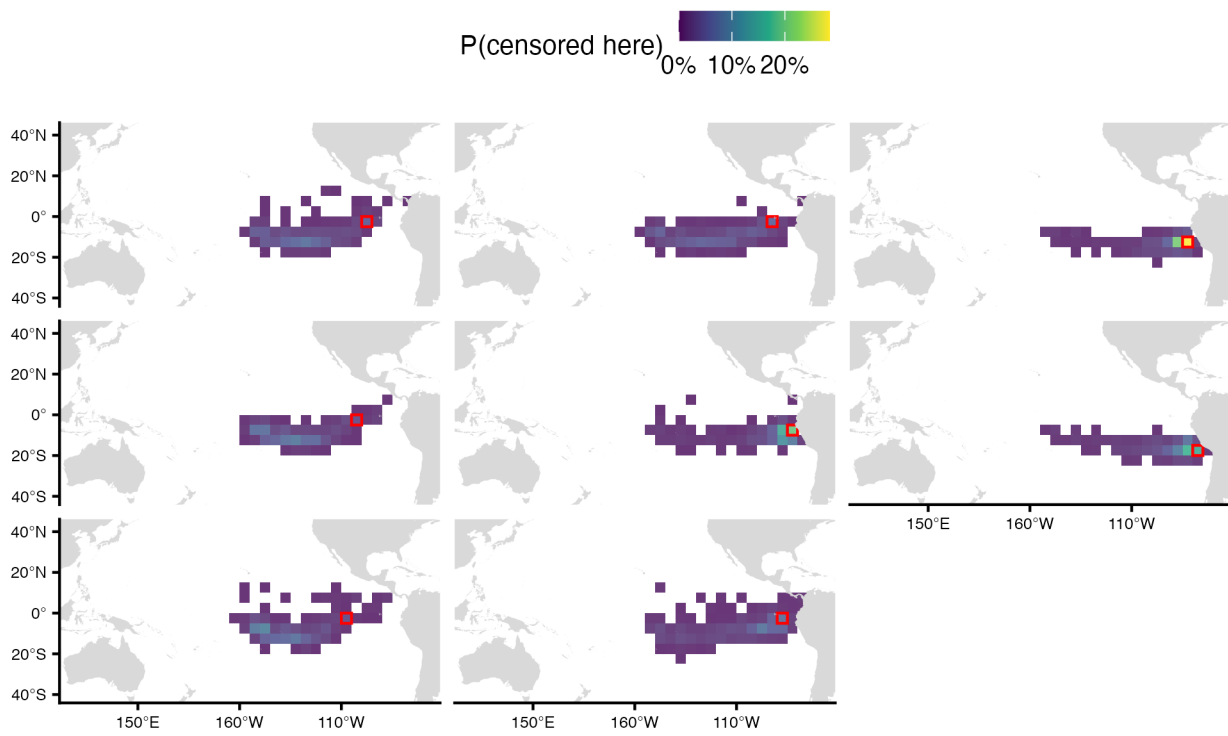


FIGURE 14. Censor destination distribution per 5° deployment cell for single-segment buoys only (red outline). Fill shows proportion of buoys from that deployment cell censored in each destination cell.

3.4.2 TERMINAL WET/DRY STATUS BY BUOY

Our approach analyzes whether the final observation of a given segment or buoy was wet or dry. A final wet observation indicates that the buoy was still soaking the last time IATTC received information. This means that we did not observe a recovery or stranding (i.e., although it could happen with a censored buoy; we do not know the ultimate fate of the buoy). A dry terminal observation indicates that the buoy was last observed in a dry state, e.g. transmitting from a vessel deck or from a stranding location (noting that for Manufacturer D–sensed buoys a “wet” classification can also occur if the buoy is stranded but its sensor remains submerged; the wet/dry model, which depends on both water signal and movement, would generally classify a stranded non-drifting buoy as dry). Overall, ~84% of the buoys’ final observations were estimated or observed to be wet, with ~16% dry at censoring (Figure 15).

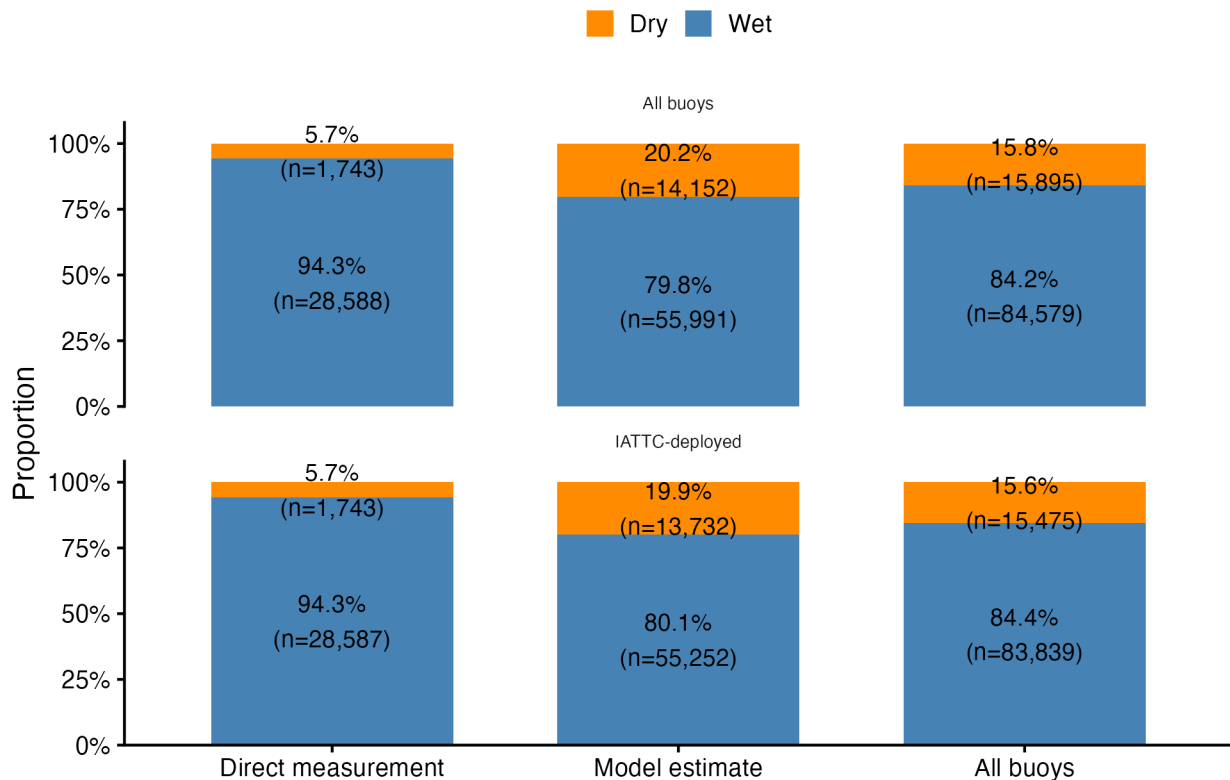


FIGURE 15. Wet/dry status at each buoy’s final observation, by wet/dry source and deployment region. IATTC-deployed includes only buoys whose first observation was east of 150°W.

We examined how these patterns of fate at censoring varied in space. Buoys whose final observation was in the offshore eastern regions of the IATTC Convention area had very low probability of being dry at their terminal observation (meaning that they were almost all last seen drifting). The probability of a dry fate was highest near coastlines, both along the coast of Central and South America and Galapagos, certain areas of French Polynesia, and increased west of the IATTC Convention area, particularly along coastlines and islands of the western Pacific. Note however that uncertainty is higher in the western Pacific due to lower sample sizes in this region (Figure 16).

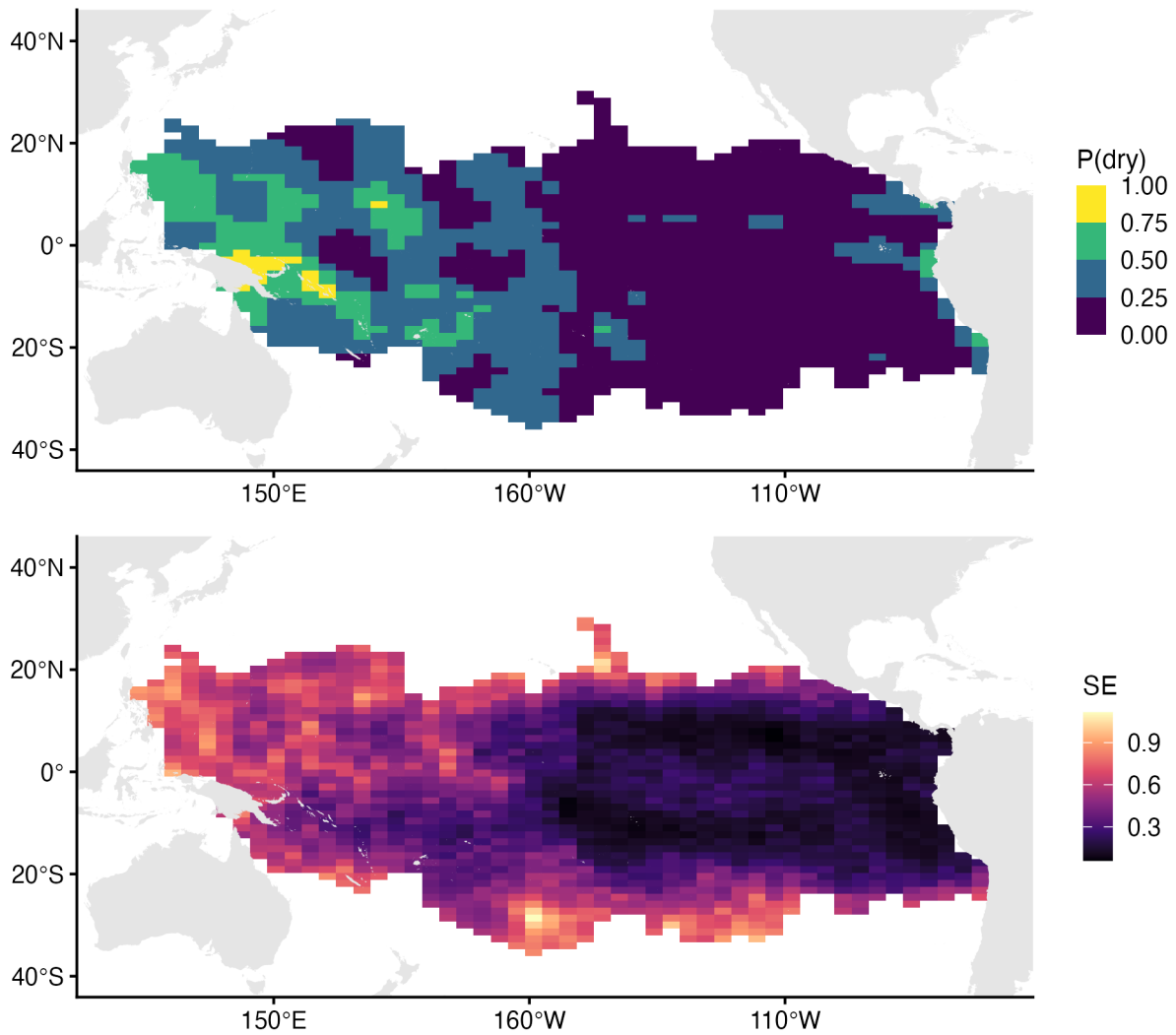


FIGURE 16. Estimated probability of dry fate at IATTC-deployed buoys' final (censoring) locations. Top: predicted probability surface from a spatial binomial GLMM. Bottom: standard error of predictions (higher SE indicates fewer observations in that area).

We ran a companion analysis to examine how the probability of a dry fate at censoring changed as a function of deployment location, not censoring location. We restricted this analysis only to buoys deployed in the IATTC Convention area. Buoys deployed in the northeast of the fishing grounds (off Central America) were slightly more likely to have a dry final observation, as were buoys deployed in a segment of the southeast, and a band in the southwest ([Figure 17](#)). However, these differences were small, suggesting that there was not a clear relationship between deployment location and terminal wet/dry status. A dedicated research project could look into this relationship further to explore spatial management options and inform recovery programs.

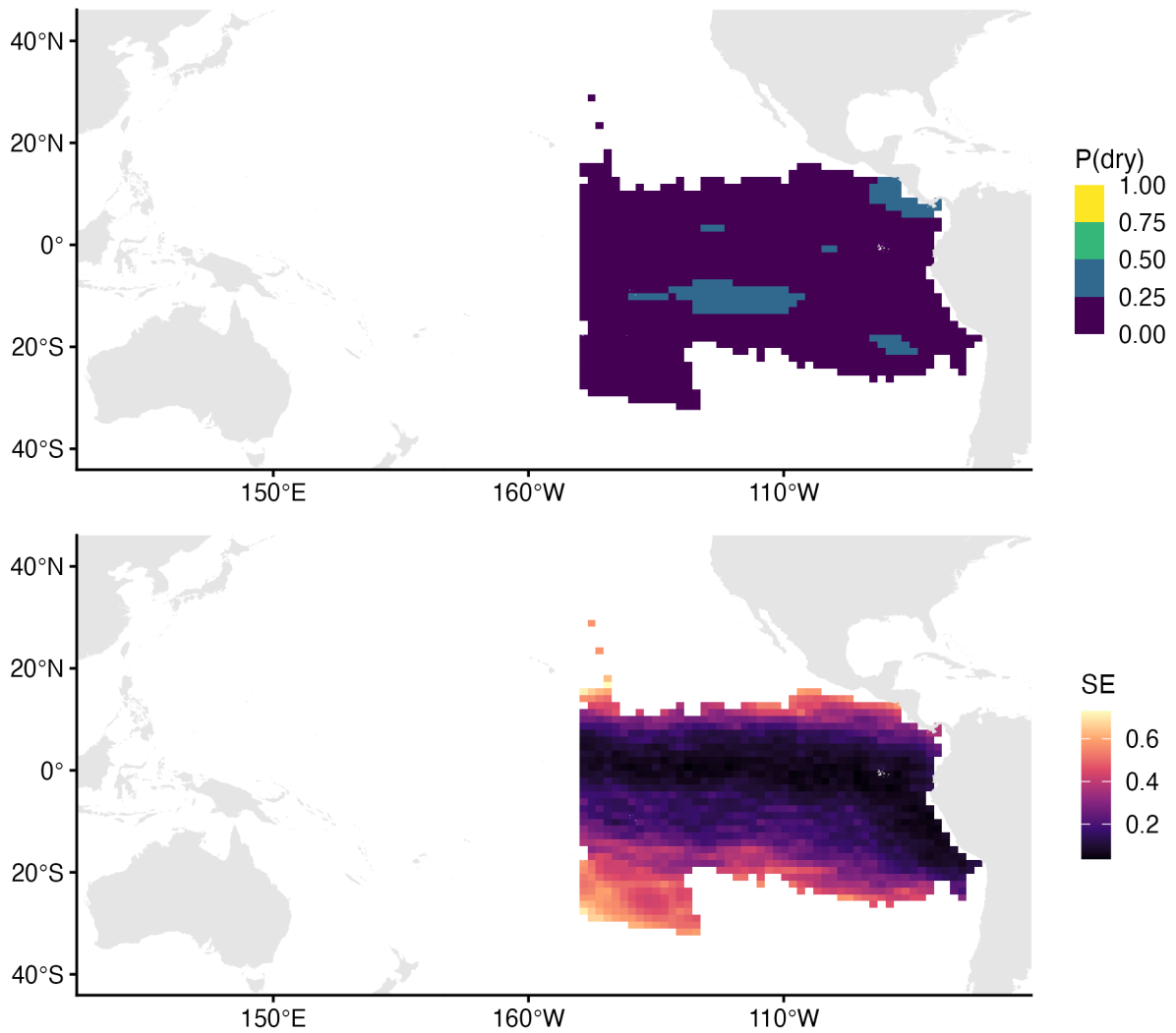


FIGURE 17. Estimated probability of dry fate at IATTC-deployed buoys' deployment (first) locations. Top: predicted probability surface from a spatial binomial GLMM. Bottom: standard error of predictions (higher SE indicates fewer observations in that area).

3.4.3 DEACTIVATION REPORTS

Under Paragraph 22 of Resolution C-25-01 (and the equivalent provisions in predecessor Resolutions C-21-04 and C-24-01), every deployed satellite buoy should generally generate at least one deactivation record over its lifetime, provided the circumstances to allow deactivation occur (note that deactivation as per the Resolution means that the buoy has lost the ability to transmit via satellite; a turned off buoy does not show up¹⁰ in the buoy database but still has the ability to transmit if turned on, unless fully deactivated). Deactivations are currently reported either via a specific form by the fleet monthly or by buoy manufacturers directly (with data on deactivation reason often missing). Of the 100,474 truncation-filtered buoys in our analysis, 64.7% appeared in the deactivation database at some point in their lifetime. The remaining 35.3% of buoys were never reported in the deactivation database, indicating that they were never deactivated, or that the deactivation was not reported to the IATTC. Looking at the same overlap from the other direction, of the 84,054 distinct buoys in the deactivation database whose deactivation date falls inside the tracks observation window (less the trailing 90-day buffer for the reporting delay noted above), 75.9% appear in the truncation-filtered tracks set. It is unclear why we do not have track data for the remaining 24.1% (e.g., buoy model and ID mismatches).

The terminal observation of each tracked buoy was cross-referenced against the deactivation registry via the nearest-in-time match per buoy (Figure 18). Of 100,474 buoys retained after truncation filtering, 27,610 (27.5%) had a deactivation record matched within the exact/near quality bands at their terminal row. The remainder split into two distinct failure modes: “no deactivation record” (35,487; 35.3% of terminal buoys), where the buoy is absent from the deactivation database entirely, and “deactivation record, no terminal pairing” (37,377; 37.2% of terminal buoys), where a deactivation record exists for the buoy but no exact/near match landed on its terminal observation. This second mode arises in two ways. First, the nearest-in-time match may attach to an interior track row rather than the terminal one. For example, a buoy whose ownership is transferred mid-trajectory generates a “Transfer of ownership” record at the time of transfer; if no further record is filed when the buoy is later lost, the existing record pairs to that interior transfer event rather than to the terminal observation. Second, the nearest match may land on the terminal row itself but at a time offset greater than seven days — for example, when an operator files the deactivation report a month after the buoy has stopped transmitting. A subset of the matched terminals fall into the “Uncoded deactivation record” bucket — entries that confirm a record exists but carry no specific reason code. Restricting to terminal matches with a coded reason (D0–D6) yields 18.2% of terminal buoys. The most frequently recorded coded reason was FAD outside areas (8.6% of terminal buoys). The spatial footprint of each reason (Figure 19) and its calendar-month distribution (Figure 20) illustrate where and when each reason dominates.

¹⁰ See Glossary of Terms in Section 2.1 for definitions.

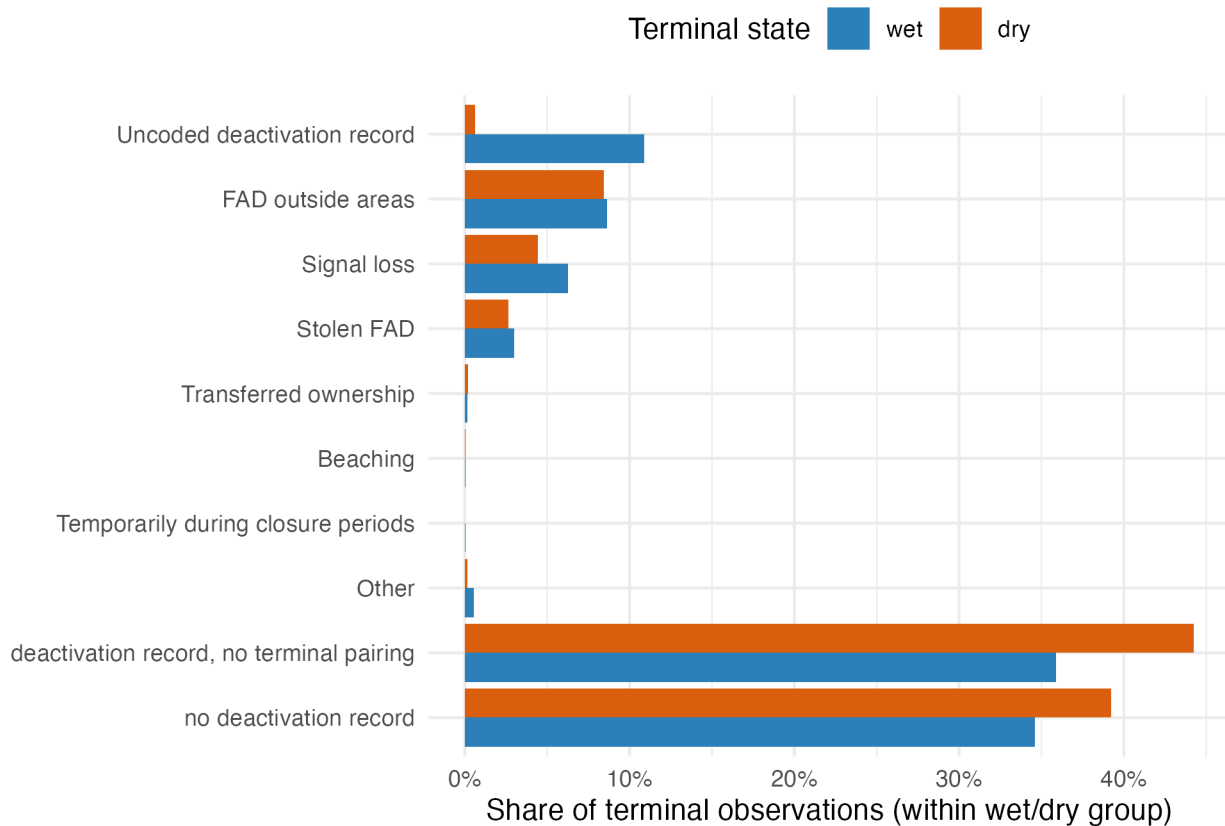


FIGURE 18. Distribution of reported deactivation reason at the terminal observation of each buoy, per terminal state, expressed as within-group proportions (bars within each terminal state sum to 100%). Coded reasons count only deactivation records whose nearest-in-time match fell within exact/near quality bands at the terminal row. Terminal rows without such a match split into “no deactivation record” (buoy never appears in the deactivation database) and “deactivation record, no terminal pairing” (buoy is in the database, but no exact/near match landed on the terminal row).

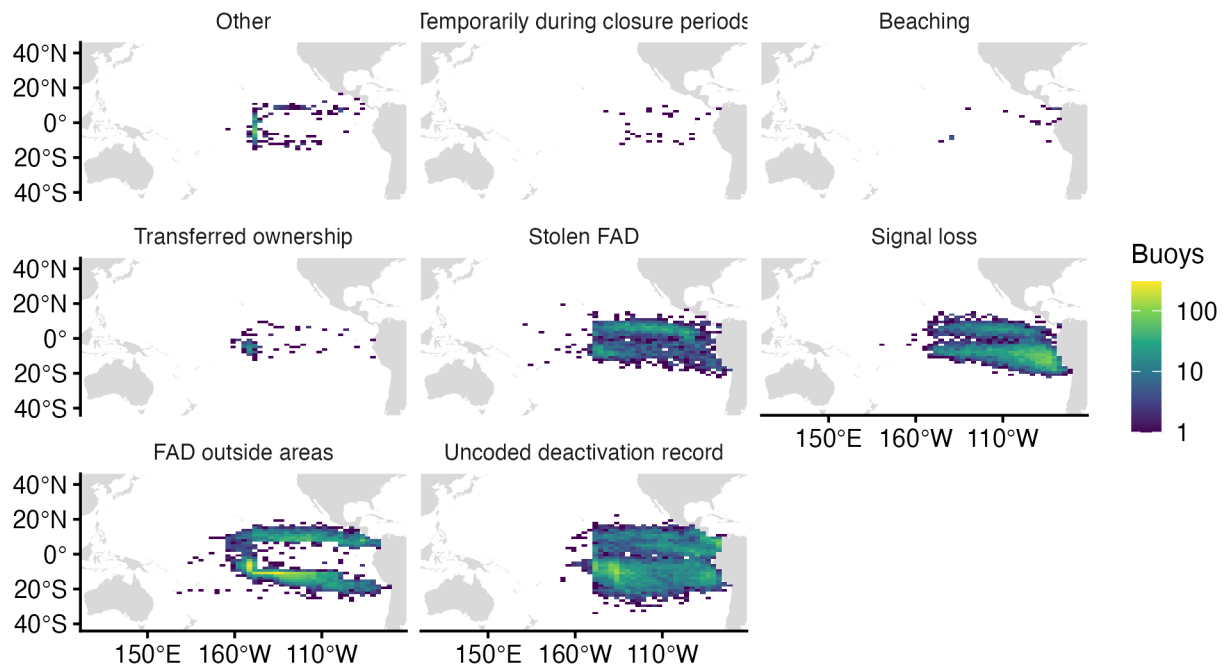


FIGURE 19. Locations of terminal buoy observations whose nearest-in-time deactivation record fell within exact/near quality bands, faceted by reported deactivation reason plus “other” and “uncoded deactivation record”.

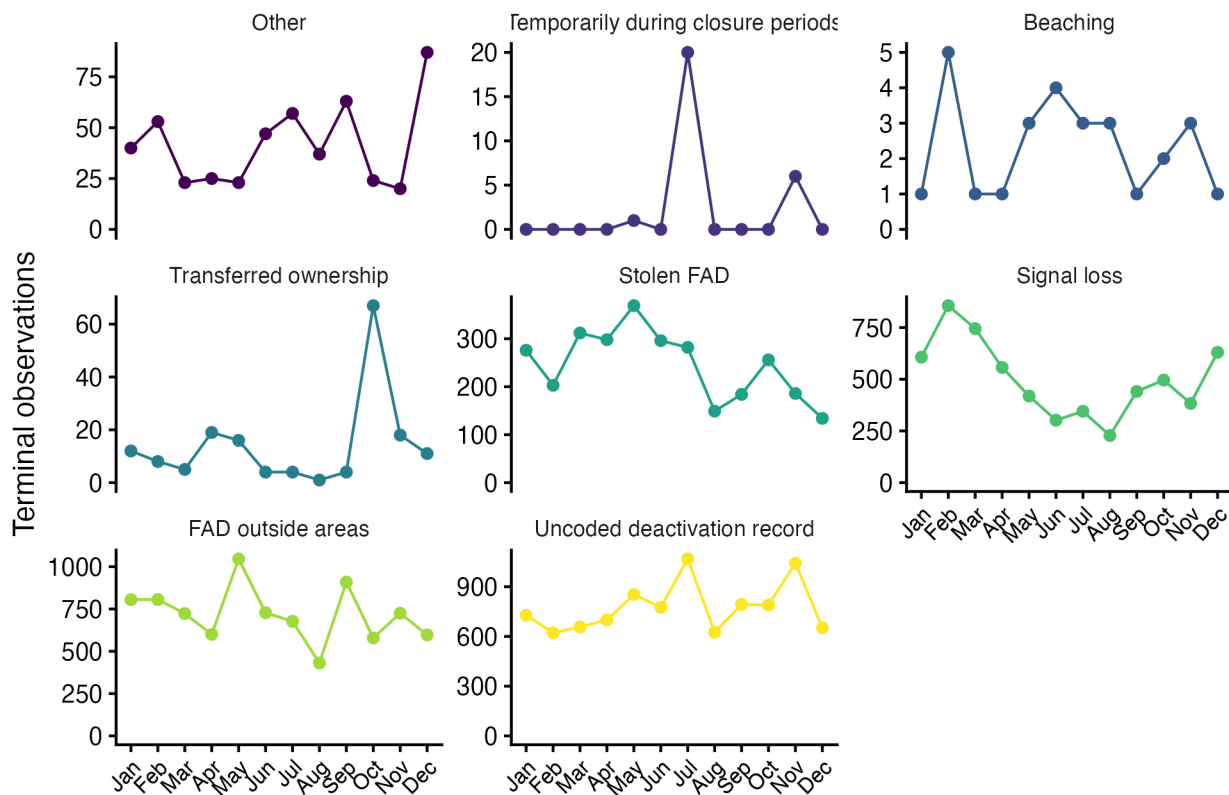


FIGURE 20. Calendar-month distribution of terminal buoy observations with a deactivation record matched within exact/near quality bands, pooled across years, by reported deactivation reason.

3.4.4 CROSS-CONVENTION SEGMENTS

While many buoys were censored upon leaving the IATTC Convention area, some continued transmitting, allowing us to examine patterns of buoy connectivity between the IATTC and WCPFC Convention areas (Figure 21). Of the 370,332 segments 5,062 (1.4%) deployed within the IATTC Convention area (east of 150°W) had their final observation in the WCPFC area (west of 150°W). At the buoy level, 5,584 of 100,474 buoys (5.6%) were first deployed in the IATTC area but had their final observation in the WCPFC area.

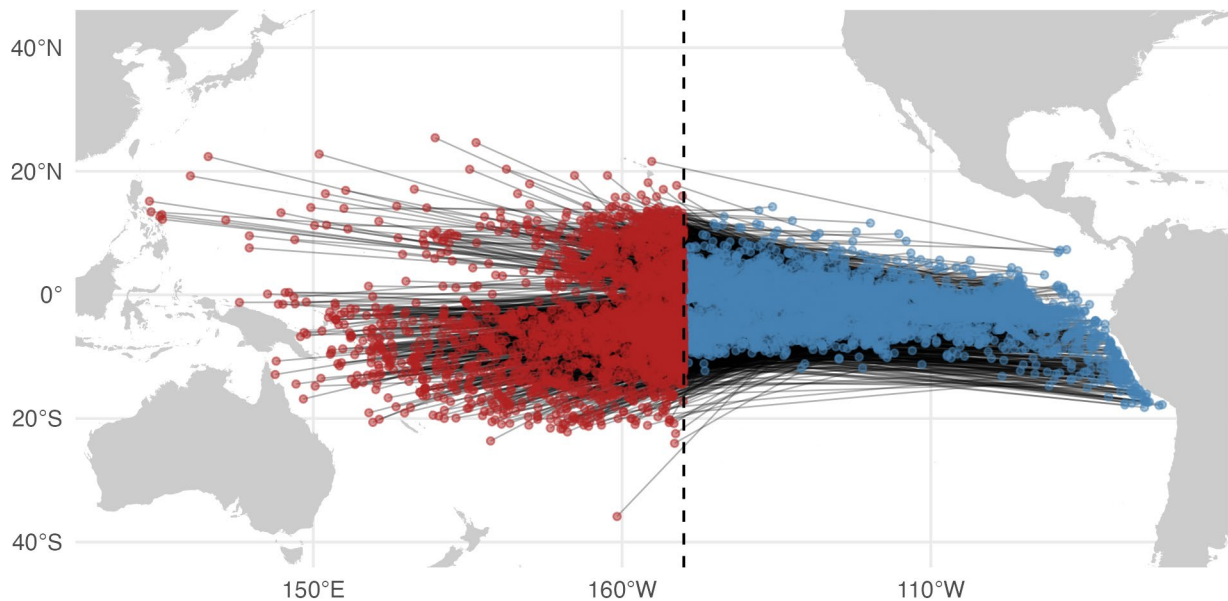


FIGURE 21. Segments that deployed in the IATTC Convention area (east of 150°W) but ended in the WCPFC area (west of 150°W). Lines connect deployment (blue) to censor (red) locations. Dashed line marks the 150°W boundary of the IATTC Convention areas.

Note though that this is an incomplete picture. Many buoys were censored as they approached or crossed the IATTC Convention boundary at 150°W. To quantify this, we identified IATTC-deployed segments and buoys whose final observation was classified as wet (i.e., the buoy was still drifting) and fell within $\pm 2^\circ$ of the boundary (148°W to 152°W).

Of 136,096 IATTC-deployed segments that were still wet at their final observation, 17,818 (13.1%) were last observed within $\pm 2^\circ$ of the 150°W boundary, suggesting censoring at the convention line. At the buoy level, 14,073 of 83,839 IATTC-deployed buoys with wet censor events (16.8%) were last observed near the boundary. The ultimate fate of these boundary-censored buoys is unknown. Given the average westward drift of buoys in the EPO, adding this number of boundary-censored buoys to the number of directly observed cross-convention buoys yields a total of 19,657 buoys (23.4%) that were observed to or were likely to have crossed west of the IATTC Convention area.

3.4.5 BIOFAD VS CONVENTIONAL FAD COMPARISON

The track data alone do not provide information about the nature of the FAD that the buoy is attached to. In addition, the same buoy can be attached to multiple different FADs over its lifespan. However, we were able to link this buoy database to the observed records of FADs and buoys reported in FAD-09-02. Based on this process, we identified buoy segments generated by our model that had at least a portion of that segment observed by an IATTC observer, and accessed the metadata on the FAD that the buoy was attached to as noted by the observer, including whether the FAD was a “bioFAD” (biodegradable FAD). Based on this, we identified segments in our analysis that we believe corresponded to a buoy deployment of a bio-FAD and compared those to comparable buoy deployments with conventional FADs.

We found no clear differences in the length or distance of bio-FADs and conventional FADs deployed in the core bio-FAD deployment area ([Figure 22](#)). Segments deployed in the core bio-FAD deployment area had no clear difference in either segment duration or distance traveled between conventional and bio-FADs ([Table 3](#)).



FIGURE 22. bioFAD core deployment cells (5° grid, ≥ 170 bio-FAD deployments per cell).

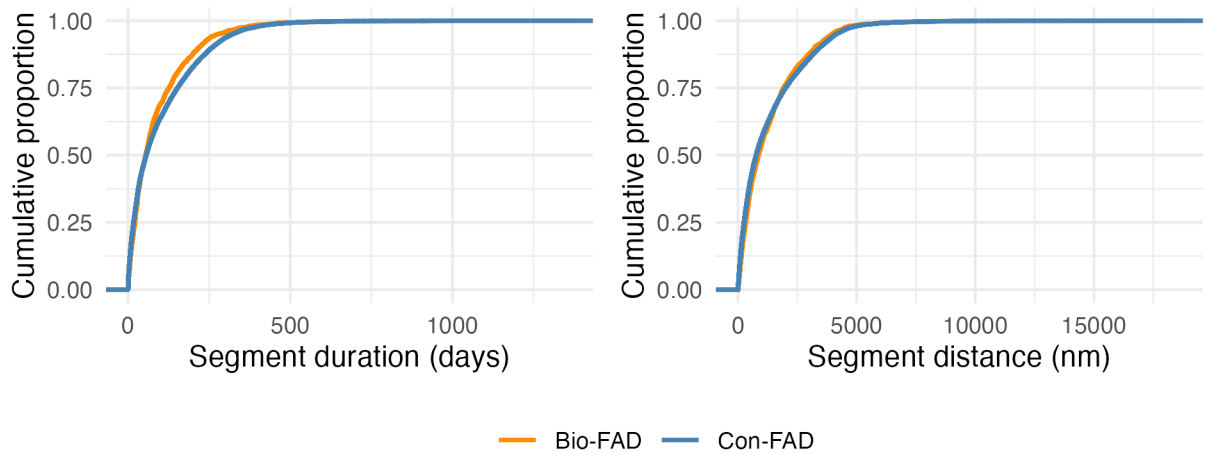


FIGURE 23. Cumulative distribution of segment duration and distance for bio-FAD and spatio-temporally matched conventional FAD segments. Conventional FADs restricted to bio-FAD core cells (≥ 170 deployments per 5° cell) and the same year range (2022-2024).

TABLE 2. Median bioFAD vs matched conventional FAD segment comparison, restricted to core bio-FAD cells. Average values in parenthesis.

FAD type	N	Duration, days	Distance, nm
Bio-FAD	2,556	54 (88)	863 (1333)
Con-FAD	32,311	56 (100)	765 (1327)

3.4.6 OBSERVED STRANDINGS, RECOVERIES, AND SIGHTINGS

The collaborator-sourced FAD encounter databases incorporated here (SPC-WCPFC, French Polynesia, Clipperton, and the Galapagos) record three distinct event types: *strandings* (a FAD resting ashore, on a reef or on land), *recoveries* (a FAD retrieved by an observer or partner program), and *at-sea sightings* (a FAD observed drifting or encountered on the water without recovery). These are not interchangeable: a sighting does not necessarily imply a stranding, and the distance between a buoy's final transmission and the reported encounter location can reflect either post-transmission drift to a beach or simply where a drifting buoy happened to be seen. We retained all three event types in the analysis below but used the general term "encounter" where the specific event class was not available or relevant.

We found 125 buoys that were observed in the FAD encounter databases that matched records in our buoy tracking database. It is important to stress that the relative rate of strandings with these data is unknown. We also do not know whether buoys last seen in the IATTC Convention Area that were later encountered west outside of this area drifted the whole time, or were recovered and redeployed in the WCPO at some time. However, these data show that there is clear potential for buoys (FADs as well) to travel vast distances between their last transmission and a subsequent encounter, and that buoys whose satellite transponders ceased transmitting near the Convention Area boundary — whether through deliberate shut-off, geofencing, or other causes — could be encountered, including as strandings, later on (Figure 24).

These linked records also provide an external check on the wet/dry classifier. Among matched buoys classified as dry at their last transmission, the median distance from that final position to the reported encounter location was 4 nm, whereas the 83% of matched buoys whose final observation was wet had a median distance of 1546 nm to their eventual encounter location, consistent with these buoys still drifting when transmissions ended. The separation between these two distributions suggests that the classifier is flagging terminal dry states reasonably close to a recovery or stranding event rather than arbitrarily along the drift trajectory, though the residual offset for dry terminals is consistent with several non-exclusive explanations: multiple strandings (e.g. stranding, loosening, and re-stranding), recovery followed by deposit on a beach or land where the buoy was then reported, at-sea sightings downstream of a dry terminal position, or model misclassification.

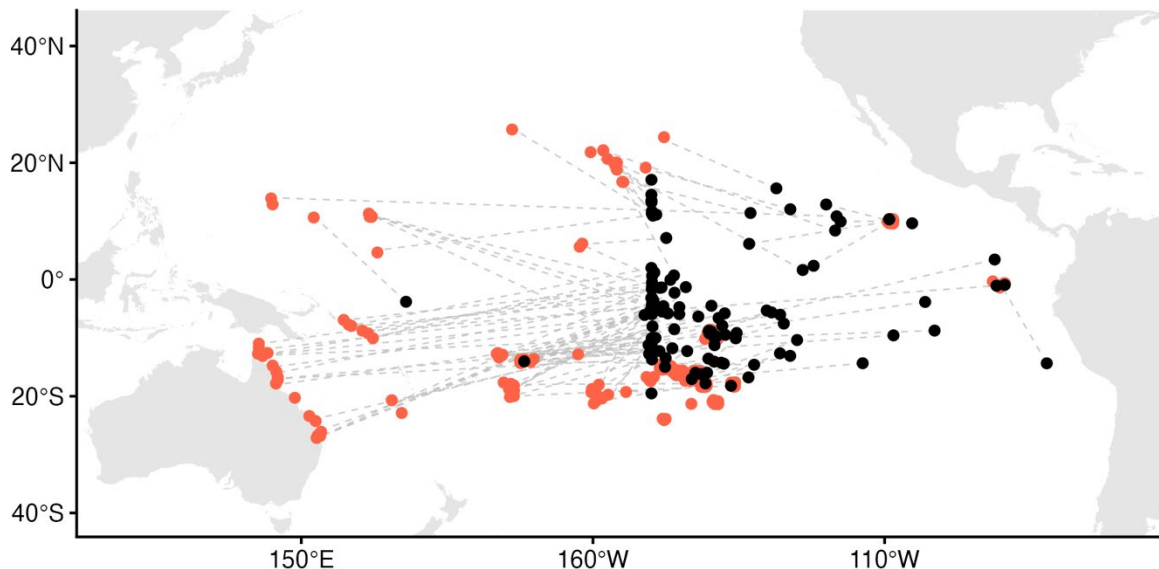


FIGURE 24. Reported “encounter” locations — strandings, recoveries, and at-sea sightings (red) — and final buoy observations (black) for buoys matched in the SPC-WCPFC, French Polynesia, Clipperton, and Galapagos FAD stranding and recovery databases.

4. DISCUSSION

The wet/dry detection model performed well by standard metrics (ROC AUC 0.99), using water temperature, speed, and transformations thereof (bearing, rolling bearing, temperature and speed deltas) as predictors. Several considerations temper the interpretation of these metrics.

First, the model is both trained and evaluated exclusively on Manufacturer D buoys, which have conductivity sensors providing ground-truth wet/dry status. If Manufacturer D buoys differ systematically from other manufacturers in their temperature sensors, deployment patterns, or transmission behavior, the real-world classification accuracy on buoys from other manufacturers may be lower than the test-set metrics suggest. There is no direct way to validate this in our study, since buoys from other manufacturers lack ground truth. However, the consistency of the core fate result across wet/dry sources (94.3% wet final observations for Manufacturer D vs. 79.8% for predicted) suggests the model is not significantly miscalibrated.

Second, aggregate metrics can mask poor performance on individual buoys. However, the per-buoy balanced accuracy distribution shows a median of 0.97, with only 1.5% of test buoys falling below 0.70. There is no long left tail of systematically misclassified buoys.

Third, while the wet/dry classification model performs well across every metric, it is still not perfect. The sheer volume of FADs means that even a model with >95% accuracy will incorrectly classify the wet/dry status of thousands of FADs (despite being correct for the vast majority).

Fourth, the meaning of a “wet” observation differs between Manufacturer D–sensed buoys and model-predicted ones. The Manufacturer D conductivity sensor only registers whether the sensor itself is in water, so a buoy stranded on a reef but still partially submerged can be reported as wet. The wet/dry model, by contrast, predicts wet/dry from a combination of water-temperature signal and movement; a stranded buoy that is no longer drifting is therefore likely to be classified as dry by the model even if its sensor were submerged. Counts of “wet” terminal observations for Manufacturer D buoys may thus include some stranded-but-submerged cases that the model would flag as dry.

Fifth, with the existing data, it is challenging to independently validate the segmenting algorithm based only on the available buoy tracking data; the buoy data allows for observed wet/dry status. Whether a run of dry observations represents a true break in a FAD's segment (e.g. recovery, transport via vessel to a new location, re-deployment) is not directly observed in these data. Therefore, segment-level results, such as the average number of segments per buoy, are only as reliable as the segmenting algorithm, which while logical and supported by the data based on visual inspection, cannot be directly validated with the data available in this study.

However, and despite the limitations mentioned above, this study intends to establish general large-scale patterns for thousands of buoys in a multi-flag and multi-behavior fishery that can expand beyond the EPO, a task that the current model and study achieve.

5. CONCLUSIONS AND RECOMMENDATIONS

This study set out to characterize the dynamics of drifting FADs in the EPO using satellite buoy tracking data shared with the IATTC under Resolutions C-21-04, C-24-01 and C-25-01, complemented by collaborator-sourced FAD encounter records and the IATTC's deactivation database. We examined several elements, six of which are interrelated — buoy wet/dry status, the relationship between deployment location and terminal fate, segmentation and re-use patterns, bioFAD versus conventional FAD behavior, EPO–WCPO connectivity, and deactivation patterns and reporting — that together provide the most comprehensive picture of EPO buoy (FAD) dynamics assembled to date. The main findings on each interconnected element are summarized below:

1. Wet/Dry model:

The classification model trained on Manufacturer D conductivity data predicted wet/dry state for buoys from other manufacturers with very high accuracy (ROC AUC = 0.99; median per-buoy balanced accuracy = 0.97). Applied across the fleet, 84.2% of buoys were classified as wet at their final observation, indicating that most buoys stop transmitting while still drifting at sea. Dry terminal observations — the subset most consistent with stranding or recovery — were spatially concentrated near coastlines: along Central and South America, around the Galápagos, in parts of French Polynesia, and along island coastlines west of the IATTC Convention area in the WCPO. These results provide quantitative, model-based support for stranding patterns previously reported only anecdotally in those regions.

2. Link to deployment locations

The companion analysis conditioning terminal fate on deployment (rather than censoring) location showed only weak signals. Buoys deployed off Central America, in a band of the southeast EPO, and in the southwest were marginally more likely to end in a dry state, but the differences were small. Overall, deployment location is not a strong predictor of terminal fate, and a dedicated study would be needed to support spatial management or inform recovery programs.

3. Segmentation and buoy re-use

20–40% of buoys appeared in only a single segment and were not seen again in the data, consistent with the magnitude of unobserved FADs after first deployment in FAD-09-02. At the same time, a substantial share of buoys were re-used multiple times: most re-used buoys generated between 2 and 10 distinct segments over their observed lifespan, with each new segment implying a recovery–redployment cycle. Together, these patterns indicate that the active EPO buoy fleet relies significantly on re-use of existing units, while a non-trivial share of deployed buoys exits the system after a single use.

4. BioFAD vs conventional FAD comparison

Restricting the comparison to the core bioFAD deployment area and matching bioFAD segments to spatio-temporally comparable conventional-FAD segments, we found no clear differences in segment duration or distance traveled between the two FAD types (median 54 vs 56 days; 863 vs 765 nautical miles). Within the limits of what buoy tracking data can resolve — which excludes intrinsic FAD construction information — bioFAD and conventional FADs behave similarly in terms of segmentation and movement.

5. EPO–WCPO connectivity

We document direct evidence of buoy connectivity between the IATTC and WCPFC Convention areas. Of the 370,332 segments deployed within the IATTC Convention area, 5,062 (1.4%) had their final observation west of 150°W; at the buoy level, 5,584 of 100,474 buoys (5.6%) were first deployed in the EPO and last observed in the WCPO. This is almost certainly a lower bound: an additional 14,073 IATTC-deployed buoys were last observed west within $\pm 2^\circ$ of the 150°W boundary, a pattern consistent with censoring at the Convention boundary rather than recovery or sinking there. Combining direct crossings with this near-boundary cohort, approximately 20% of IATTC-deployed buoys with wet terminal observations either entered or likely drifted around or into the WCPFC Convention area.

6. Deactivation patterns and reporting

Of the 100,474 buoys retained after truncation filtering, 64.7% appeared in the IATTC deactivation database at some point, but only 27.5% had a deactivation record matched within the exact/near quality bands at their terminal observation. The remainder split between buoys absent from the database entirely (35.3%) and buoys with a record that could not be cleanly paired to the terminal row (37.2%). Restricting to terminals with a coded reason yields 18.2% of buoys, with “FAD outside areas” the most frequently reported reason (8.6%). Loose matching recovers a meaningful additional share, but a substantial reporting gap remains. Strengthening the timeliness and completeness of remote deactivation and reactivation reporting — including for buoys that leave the IATTC Convention Area but continue transmitting — is a clear improvement opportunity identified by this analysis.

Taken together, these six elements describe an EPO buoy pool whose dynamics are increasingly visible but whose end-of-life or terminal fate, particularly outside the Convention area, remains partially obscured by reporting, geofencing, behavioral and operational practices. The data sharing established under C-21-04 and C-24-01 (now C-25-01) has enabled the analyses presented here; building on that foundation by tightening deactivation reporting, supporting continued transmission for buoys drifting beyond the Convention boundary, and linking buoy terminations to a Pacific-wide stranding and recovery database would close the principal remaining gaps and allow the development of informed FAD management practices, including spatial management opportunities, recovery programs and incentive systems.

Based on the above, the IATTC staff recommends:

Current deactivation and reactivation reporting practices leave a substantial share of buoys without a clean terminal pairing, and a clearer, more consistent reporting would help close that gap.

1. Improve remote deactivation and reactivation reporting, including the development of an updated reporting template — building on the existing form — or requiring automatic reporting by the buoy manufacturers.

Continued transmission outside the IATTC Convention Area would directly support improved analyses and inform recovery programs, model classification, segmentation, and connectivity models presented here.

2. Expand data reporting beyond the IATTC Convention Area for buoys deployed in the EPO, so that geofencing at 150°W (or any other operational boundary) does not obscure the analysis of active buoys after leaving the IATTC.

Because the EPO and the WCPO are connected, and FADs drift between Convention Areas, Pacific-wide collaboration is desirable and should be promoted, including via exchange of information and coordination of FAD stranding and recovery databases.

3. Continue Pacific-wide collaboration to reduce FAD loss and strengthen recovery programs, including coordination with WCPFC-SPC and other regional databases (e.g., French Polynesia, Clipperton, Galápagos).

FADs can generate environmental impacts, including by stranding in identified hotspot areas of the EPO and beyond. Some of these associated impacts could be mitigated by exploring ways that encourage operators to retrieve or use fewer FADs without compromising their operational strategies or target catch. Therefore, from a FAD-management perspective:

4. Prioritize the exploration of spatial management options, recovery programs, and incentive systems that reduce environmental impact of FADs.

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