Drifting Towards Inequity: Redesigning dFAD Governance for Transboundary Ecological Justice

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Abstract: The rapid expansion of drifting Fish Aggregating Devices (dFADs) in tropical tuna fisheries has generated growing ecological, governance, and compliance challenges, particularly in the Indian Ocean. In response, the Indian Ocean Tuna Commission (IOTC) adopted Resolution 24/02, mandating a regional dFAD Register to enhance transparency, standardize reporting, and limit ecological harm. This paper evaluates the IOTC's proposed registry design (IOTC-2025-S29-10_Rev1), identifying key technical and institutional gaps related to coastal state access, environmental harm logging, and enforceability. Drawing on recent empirical and policy literature, the analysis highlights how the current flag-state-centric architecture risks reinforcing historical inequities and undermines real-time accountability. The study proposes a set of structural and procedural enhancements including geospatial monitoring dashboards, timestamped audit trails, ecosystem impact logbooks, and compensation protocols to embed bilateral transparency, scientific review, and ecological responsiveness into the registry's operational logic. The paper concludes by outlining a pathway for developing a technically robust, inclusive, and enforceable dFAD governance framework aligned with IOTC Resolution 24/02.

1. Introduction

Drifting fish aggregating devices (dFADs) have rapidly become a cornerstone of tropical tuna fisheries, with industrial purse-seine fleets deploying an estimated 1.4 million satellite-tracked buoys between 2007 and 2021 (Schiller et al., 2025). These devices now drift across one-third of the world's oceans, frequently stranding in the coastal waters of more than 100 jurisdictions. Notably, while over 100 strandings have been reported in 31 maritime jurisdictions, only 14 of these legally permit dFAD use. In total, over 14,700 dFAD strandings have occurred across 104 jurisdictions, with the Seychelles, Somalia, and French Polynesia alone accounting for 43% of all recorded events (Schiller et al., 2025). This geographic concentration underscores a broader regulatory failure by regional fisheries management organizations (RFMOs), as dFADs continue to contribute to marine pollution and habitat degradation. Despite ongoing efforts to reduce entanglement and marine litter, persistent challenges, such as unregulated deployments, juvenile tuna bycatch, and limited accountability for lost gear, remain unresolved (Hallier & Gaertner, 2008; Pons et al., 2023; Sheik Heile et al., 2024).

In the Indian Ocean, these challenges are especially acute. Regional fleets increasingly deploy sophisticated dFADs equipped with GPS buoys and echo-sounders to maximize tuna catches. However, this technological escalation has worsened juvenile tuna mortality (Hallier & Gaertner, 2008); ghost-fishing (Filmalter et al., 2013); bycatch of non-target (Davies et al., 2014; Escalle et al., 2014), abandoned gear (Gilman, 2015); and marine debris accumulation. Many dFADs drift unauthorized into coastal states' Exclusive Economic Zones (EEZs).

The IOTC has introduced measures to mitigate dFAD impacts. Since 2019, it has mandated daily tracking of active dFADs and promoted biodegradable designs. However, these measures vary in ambition and clarity a harmonized definition of biodegradable dFADs is still lacking (Zudaire et al., 2023). In 2024, it adopted a framework banning non-biodegradable dFADs, covering vessel deployments, and establishing a regional dFAD registry to enhance oversight (Sheik Heile et al., 2024). This global-to-regional context raises a critical question: Is the IOTC's dFAD Register effectively designed to address ecological harm, management gaps, and the disproportionate burdens placed on coastal states in the Indian Ocean?

The adoption of IOTC Resolution 24/02, marked a critical policy shift to reduce the ecological and operational impacts of dFADs in the Indian Ocean. This binding measure-imposed controls on the number of active buoys per vessel, mandated the use of biodegradable and non-entangling dFAD materials, and called for the development of a centralized regional dFAD Register to monitor deployments and enforce compliance (IOTC, 2024). In response, the IOTC proposed the *dFAD Register: Design Specifications* (IOTC, 2025), outlining a digital system to track dFAD identifiers, deployments, and buoy metadata via reports from flag Contracting Parties/Cooperating non-Contracting Parties (CPCs) and buoy owners. While this proposal advances data standardization and quota monitoring, it remains flag-state-focused, failing to address spatial governance needs, enforcement challenges, or environmental liabilities borne by coastal CPCs. Furthermore, the design lacks integrated mechanisms to log beaching events, lost gear, or ecological harm in coastal EEZs and denies non-flag states equitable access to tracking data, a critical oversight given their role in mitigating dFAD impacts. As the IOTC operationalizes Resolution 24/02 through this registry, a pressing question arises: Can a system that centralizes authority in flag CPC and buoy owners, while sidelining coastal states' capacity to document harm or enforce accountability, genuinely reconcile industrial efficiency with transboundary ecological justice?

Despite its stated aims of enhancing transparency and sustainability, the current dFAD Register proposal (IOTC, 2025) prioritizes the operational logics and reporting frameworks of flag states and buoy manufacturers, sidelining the governance needs and lived realities of coastal CPCs. Coastal states, particularly in the western Indian Ocean, bear the ecological and logistical burdens of dFAD deployments including beached devices, damage to coral reefs and mangroves, and marine litter accumulation in nearshore environments (Davies et al., 2014; Hanich et al., 2019; Burt, et al., 2020; Gomez et al., 2020; Sheik Heile et al., 2024). Yet the proposal fails to equip coastal CPCs with tools for real-time monitoring within their EEZs or systematic logging of beaching events and abandoned gear recovery.

This oversight persists despite evidence that Somalia and Seychelles, experience among the highest global dFAD stranding densities (Schiller et al., 2025). More than one-third of dFAD beaching's in the Seychelles occurred in coral habitats (MacMillan et al., 2022). In Somalia's Exclusive EEZ, where dFAD use is not legally permitted, it is estimated that approximately 1,395 ALDFG units could be recovered annually (Sheik Heile et al., 2024). Scholars stress that developing states disproportionately shoulder environmental cleanup costs (Burt, et al., 2020; Banks & Zahari, 2020; Purves et al., 2021), while lacking access to compensation mechanisms or sovereignty over dFAD-related data.

Furthermore, registry data access is governed by a confidentiality framework that elevates commercial interests above scientific transparency and coastal states' rights to monitor foreign activities in their maritime zones. Without binding provisions for equitable data sharing, ecological harm documentation, or enforcement support, the Register risks codifying a regime of unequal surveillance and responsibility in transboundary fisheries governance.

This paper critically evaluates the technical and operational design of the IOTC's proposed dFAD Register, as mandated by Resolution 24/02. While the Register advances standardized tracking through digital identifiers and buoy metadata reporting (IOTC, 2025), its current framework exhibits critical gaps in three areas: (1) real-time, EEZ-level monitoring capabilities for coastal states; (2) automated logging of beaching events and gear loss; and (3) interoperability with coastal enforcement systems. Drawing on empirical analyses of dFAD stranding densities (Schiller et al., 2025), bycatch rates (Davies et al., 2014), and non-compliance trends (Sheik Heile et al., 2024), this study identifies how these technical shortcomings undermine the Register's efficacy in addressing ghost fishing, marine debris, and juvenile tuna mortality. For instance, the lack of API integration with coastal surveillance networks prevents real-time alerts for unauthorized dFAD incursions into EEZs, while the absence of geofenced deactivation protocols exacerbates gear abandonment.

To address these gaps, the paper proposes actionable technical revisions, including satellite-based drift modeling to predict stranding risks, blockchain-enabled ownership tracing for lost gear, and mandatory biodegradable materials compliance checks via the registry. While equity considerations such as coastal state access to tracking data and cost-sharing for gear retrieval, are necessary for operational fairness, the paper prioritizes solutions that align with the IOTC's mandate for evidence-based, technocratic governance. By bridging these technical-operational gaps, the proper Register could reduce dFAD washout in high-stranding zones (Escalle et al., 2019; Schiller et al., 2025), directly supporting the IOTC's sustainability targets. Ultimately, this analysis contributes a roadmap for optimizing the dFAD Register's functionality, ensuring it operates as a practical tool for mitigating ecological harm while balancing the jurisdictional realities of transboundary tuna fisheries.

2. IOTC's dFAD Register Proposal (IOTC-2025-S29-10_Rev1)

The IOTC's proposed establishes a regional dFAD Register to operationalize Resolution 24/02, focusing on traceability via Unique dFAD Identifiers (UDIs) and lifecycle event logging (registration, deployment, deactivation) as per Annex 1 (IOTC, 2025 p. 28). The system centralizes data from buoy owners and flag CPCs, relying on private tracking systems (e.g., buoy manufacturers' platforms) for real-time buoy metadata (IOTC, 2025 pp. 10–13) (see Fig. 1). Flag CPCs validate submissions, but the proposal lacks automated cross-checks with IOTC's e-RAV vessel database to verify vessel compliance (IOTC, 2025 p. 14). The Register's architecture (IOTC, 2025 pp. 6–7) uses a centralized repository where flag CPCs and buoy owners submit metadata (UDI, deployment coordinates, vessel ID) via interactive or bulk uploads (IOTC, 2025 pp. 18–20). While the system flags quota breaches (IOTC, 2025 p. 14), it lacks automated geofencing to alert coastal CPCs of dFAD entries into their EEZs or API integration with coastal surveillance tools (IOTC, 2025 pp. 22–23). For example, buoy owners can report deployments 24 hours post-activation (IOTC, 2025 p. 13), but delayed submissions are only flagged as "late" without penalties, risking data lags in high-traffic zones like Somalia and Seychelles EEZs.

The Register's flag-state-centric model (IOTC, 2025 pp. 6–7) restricts coastal CPCs to passive roles. Coastal states cannot access real-time dFAD trajectories in their EEZs, or log beaching events directly, despite Resolution 24/02's mandate to mitigate ecological harm. For instance, the proposal's "optional" monitoring dashboard (IOTC, 2025 p. 25) excludes EEZ-specific alerts, forcing coastal CPCs to rely on delayed flag-state notifications. While buoy owners report deployments via bulk templates (IOTC, 2025 p. 20), coastal CPCs lack tools to audit submissions against satellite-derived stranding data, creating accountability gaps.

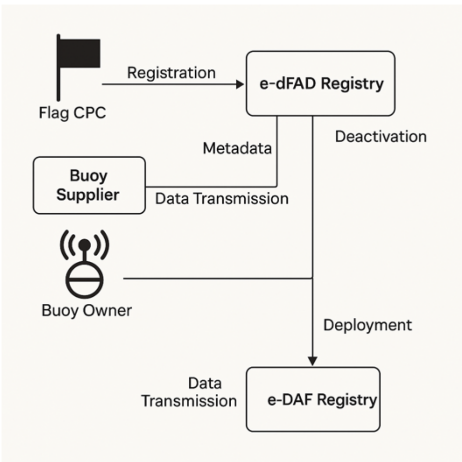
The proposal centralizes data governance under flag CPCs, requiring coastal states to request access via focal points (IOTC, 2025 pp. 6-7, 22). However, the system's confidentiality rules, block coastal CPCs from viewing vessel names or deployment locations of foreign dFADs in their EEZs. For example, non-flag CPCs cannot query dFADs by EEZ boundaries or automate retrieval requests for non-compliant gear (IOTC, 2025 p. 16). Although the Register allows bulk exports (IOTC, 2025 p. 25), coastal CPCs lack integration with national enforcement databases to cross-reference reported deactivations with observed strandings. Current dFAD tracking relies on instrumented buoys with GPS transponders and echo sounders (IOTC, 2025 p. 4). Instrumented buoys typically transmit data, such as location, deployment activity, and object classification to proprietary platforms managed by buoy suppliers, as implied in the IOTC's definition of buoy ownership roles and user profiles (IOTC, 2025, p. 10). While the proposal integrates these data streams, it does not mandate standardized formats for buoy metadata (e.g., manufacturer, model), creating potential interoperability gaps (IOTC, 2025, p. 10).

Resolution 24/02 mandates flag CPCs to register dFADs in two phases: pre-deployment metadata (Registration Phase, IOTC, 2025 p. 12) and operational updates (Activation Phase, p. 13). However, the system does not automate cross-checks between registered vessels (e-RAV database, IOTC, 2025 p. 5) and buoy ownership, risking mismatches. For instance, a vessel marked "inactive" in e-RAV could still deploy buoys if flag CPCs delay updates[1] (IOTC, 2025 p. 14).

[1] The system lacks automated cross-checks between e-RAV vessel status and buoy deployment permissions, creating a risk of outdated information persisting. Notably, the system issues only a warning, rather than a blocking error, if a vessel's registration is outdated. As a result, a vessel incorrectly listed as active due to delayed CPC updates may still

The Register relies on self-reported data validated annually by flag CPCs (IOTC, 2025 p. 21), but lacks third-party verification mechanisms (e.g., AIS cross-referencing, IoT sensors). Coastal CPCs cannot audit buoy trajectories (IOTC, 2025 p. 22) or access manufacturer-level diagnostic data (IOTC, 2025 p. 10), limiting their ability to detect false deactivation reports (IOTC, 2025 p. 15). For example, a buoy owner could report a dFAD as "retrieved" while it drifts into a coastal EEZ, with no independent means for verification (IOTC, 2025 p. 16).

Fig. 1: Technical Architecture of IOTC dFAD Register Proposal



This figure represents the current form of the IOTC's proposed dFAD Register as outlined in the 2025 design specifications. It illustrates how key actors, Flag CPCs, Buoy Suppliers, and Buoy Owners, interact with the registry, clarifying the intended flow of registration, metadata transmission, and operational reporting. While the system is structured to enable traceability and activity logging, it currently relies on non-blocking validations and delayed cross-verification, which introduces risks such as data mismatches, outdated vessel statuses, and inconsistent metadata formats. The figure highlights these procedural and governance limitations inherent in the present proposal under Resolution 24/02.

3. Proposed Enhancements for Coastal CPC Inclusion

To address operational deficiencies in the proposed dFAD Register, the system could better prioritize a real-time geospatial dashboard equipped with satellite-linked GPS tracking and automated geofencing algorithms (see Fig. 2). This dashboard would enable coastal CPCs to monitor dFAD trajectories within their EEZs and trigger alerts via API integration when devices breach predefined ecological zones (e.g., coral reefs, <5-15 km from shore). Data interoperability ensured through standardized formats (e.g., ISO 19130-1:2023 for geospatial metadata) [2] should govern bidirectional exchanges between flag and coastal CPCs to prevent fragmentation.

deploy buoys. This design vulnerability reflects the system's reliance on manual updates from flag CPCs and its use of non-blocking validations for vessel activity status.

[2] ISO 19130-1:2023 defines the metadata structure for positioning information derived from remote sensing systems, such as instrumented buoys. Applying such standardized formats is critical to ensure data compatibility across CPC systems and the IOTC Register. However, Flag CPCs often resist full interoperability, citing concerns over strategic fishing intelligence, jurisdictional control, and the potential misuse of buoy data by Coastal States. These tensions necessitate strong protocols for controlled, bidirectional exchange to balance transparency with sovereignty.

Concurrently, the Register could better embed an Environmental Harm Logbook to document geo-referenced dFAD incidents (e.g., beaching coordinates, ghost fishing mortality, coral abrasion) linked to Unique Identifiers (UDIs) via blockchain hashing. This module should adopt a relational database structure (e.g., PostgreSQL/PostGIS) to enable automated drift modeling (e.g., HYCOM ocean current simulations) and generate compliance reports aligned with IOTC Resolution 24/02. Without these enhancements, coastal states lack the technical capacity to mitigate non-compliant dFAD recoveries (e.g., Somalia's 100% non-compliance rate; Sheik Heile et al., 2024) or quantify ALDFG accumulation in EEZs.

Second, the Register could better implement a *tiered transparency model* structured around Role-Based Access Control (RBAC) to reconcile proprietary fleet data protections with coastal CPCs' jurisdictional rights. Coastal CPCs should receive unrestricted API access to dFAD trajectories within their EEZs including raw GPS coordinates and ownership metadata, while independent researchers gain anonymized access via differential privacy protocols (e.g., k-anonymity) to enable stock assessments without compromising fleet operations a framework successfully piloted in the WCPFC's FAD registry (Escalle et al., 2021).

A blockchain-enabled dispute resolution module could better be integrated to allow coastal CPCs to submit timestamped challenges to flag-state reports (e.g., falsified deactivation records) using UDI-linked evidence from the Environmental Harm Logbook. Compensation claims would leverage smart contracts to automate liability adjudication under the polluter-pays principle, with payouts triggered by predefined criteria (e.g., dFAD stranding within 30 days of deactivation). This system aligns with the EU's Environmental Liability Directive (2004/35/EC) and addresses systemic accountability gaps, such as coastal states inability to recover costs from non-compliant dFADs.

Finally, the Register could better enforce *mandatory design reporting* through standardized digital templates that require buoy owners to submit verified construction schematics (e.g., raft dimensions, netting mesh size), biodegradability certifications (ASTM D6400 standards), and non-entanglement compliance scores (e.g., FAO Code of Conduct 8.4.3). Satellite buoy transmissions (e.g., GPS fixes, battery status) must be cross-referenced with time-stamped visual inspections using image recognition APIs (e.g., TensorFlow for debris analysis) and blockchain-validated community ALDFG dFADs reports from coastal and small island states communities (see Fig. 3). Empowering coastal communities with IoT-enabled toolkits (e.g., GPS-linked tablets using ODK Collect) enables systematic, geotagged documentation of stranded dFADs. By scanning QR-coded UDIs, community monitors can auto-feed structured data into the centralized Environmental Harm Logbook, ensuring traceability, compliance transparency (Escalle et al., 2021), and bottom-up contributions to RFMO governance.[3] A recent report from the Mourot et al., (2025) notes that community reporting of dFAD strandings in Pacific Island Countries is primarily conducted via manual forms submitted to fisheries

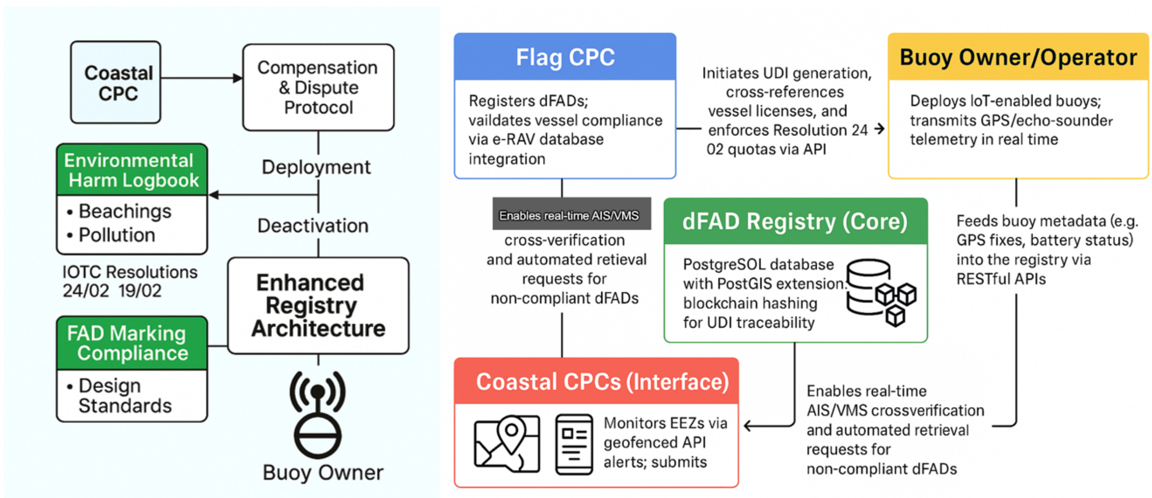
[3] *As of 2024, the Inter-American Tropical Tuna Commission (IATTC) is the only RFMO operating a community-based FAD recovery initiative modeled after the FAD Watch program, integrating real-time geofencing alerts, stakeholder coordination, and beaching prediction tools. No comparable programs exist in WCPFC, IOTC, or ICCAT, though pilot efforts have been initiated in Seychelles.*

officers and later digitized. While this approach has yielded over 3,500 records, the report recommends adopting mobile or IoT-based systems to enhance data efficiency and spatial accuracy. Participatory science programs could incentivize recoveries through smart contracts that allocate tokenized rewards (e.g., fishery credits) for verified retrievals a model piloted.

Without these enhancements, particularly interoperability between satellite telemetry and community inputs the Register will fail to operationalize IOTC Resolution 24/02 biodegradability mandates or mitigate the Indian Ocean's ALDFG dFAD non-compliance rate (Zudaire et al., 2018; Zudaire et al., 2021; Sheik Heile et al., 2023).

To translate the Section 3 framework into actionable technical systems, Tables 1 and 2 describe the core architecture and protocols of the proposed dFAD Register. Table. 1, defines the roles of key actors: Flag CPCs (data validation via e-RAV integration), Buoy Owners (IoT telemetry submissions), and Coastal CPCs (EEZ geofencing alerts), within a PostgreSQL-based registry. Table. 2, specifies the data protocols (e.g., RESTful APIs for interoperability, SHA-256 blockchain hashes for UDI traceability) and system tools (e.g., HYCOM drift modeling, RBAC tiers) required to operationalize equity-driven governance.

Fig. 2: Reforming the dFAD Registry: From Flag-Centric Control to Equity-Based Design



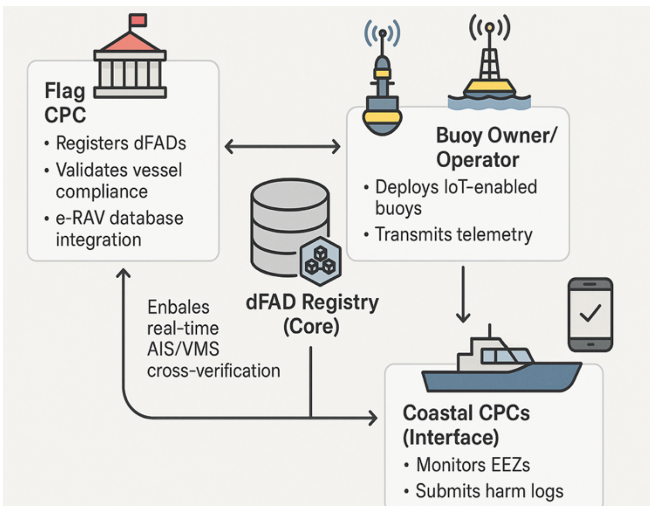
This figure is a proposed enhanced equity-based architecture. The existing model limits data control to flag CPCs and buoy owners, restricting visibility and oversight for coastal states. In contrast, the enhanced design integrates coastal CPCs through real-time dashboards, environmental harm logbooks, and compliance tracking for FAD marking standards. It introduces structured mechanisms for compensation, scientific transparency, and ecosystem-based logging. This architecture promotes inclusivity, traceability, and accountability, addressing regulatory gaps in the current system and aligning with IOTC Resolution 24/02.

Table 1: Core System Flow

System Component	Primary Function	Technical Flow Contribution
Flag CPC	Registers dFADs; validates vessel compliance via e-RAV database integration	Initiates UDI generation, cross-references vessel licenses, and enforces Resolution 24/02 quotas via API validations.

Buoy Owner/Operator	Deploys IoT-enabled buoys; transmits GPS/echo-sounder telemetry in real time	Feeds buoy metadata (e.g., GPS fixes, battery status) into the registry via RESTful APIs.
dFAD Registry (Core)	PostgreSQL database with PostGIS extension; blockchain hashing for UDI traceability	Central repository with SHA-256 blockchain audit trails; integrates HYCOM drift models for stranding risk analysis.
Coastal CPCs (Interface)	Monitors EEZs via geofenced API alerts; submits harm logs via ODK Collect mobile app	Enables real-time AIS/VMS cross-verification and automated retrieval requests for non-compliant dFADs.

Fig. 3: Digital architecture of an integrated dFAD governance system.



This figure illustrates the technical workflow among key stakeholders involved in dFAD registration, monitoring, and compliance. The system centers on a PostgreSQL-based registry with PostGIS extension and blockchain hashing, which serves as the core repository for telemetry and registration data. Flag CPCs initiate dFAD registration and vessel compliance validation through e-RAV integration and API-based enforcement of Resolution 24/02. Buoy owners transmit real-time GPS and echo-sounder data via RESTful APIs, feeding the registry with spatial and performance metadata. Coastal CPCs interface with the system through geofenced alerts and mobile data collection tools, enabling real-time AIS/VMS cross-verification and the submission of ecological harm logs. This architecture supports decentralized oversight, immutability of compliance records, and spatially-aware decision-making across jurisdictions.

Table 2: Data Protocol Enhancements

Protocol/Component	Technical Function	Technical Alignment
EEZ Geofencing & Alert	GeoJSON boundary layers with 5-15 km[4] buffers; triggers SMS/email alerts via Twilio API	Integrates with Global Fishing Watch for real-time enforcement.
Two-Way Data Confirmation	Blockchain-validated submissions (Hyperledger Fabric); metadata tags (ISO 19115)[5]	Ensures coastal CPCs can contest flag-state data using timestamped community reports.

[4] Geofencing buffers (e.g., 5 km) are proposed in spatial management to reduce dFAD beaching risks in tuna fisheries; real-time alerts enhance early intervention (Imzilen et al., 2021).

[5] Blockchain-validated submissions refer to data entries such as dFAD deployments, deactivations, community-reported ALDFG (Abandoned, Lost, or Discarded Fishing Gear) events, and vessel compliance logs—that are cryptographically recorded on Hyperledger Fabric, a permissioned blockchain framework designed to support secure, auditable transactions within trusted institutional environments. Once submitted, these records become immutable, thereby ensuring traceability, accountability, and integrity in compliance monitoring and dispute resolution among flag states, coastal CPCs, registry authorities, and independent researchers. Each submission is accompanied by ISO 19115-compliant metadata, which standardizes key attributes such as

Timestamped Event Logging	ISO 8601 timestamps; immutable audit trails via Ethereum blockchain[6]	Enables forensic analysis of dFAD lifecycles (e.g., deployment-to-stranding duration).
Audit Trail Access	Read-only SQL queries with RBAC (Role-Based Access Control) [7] tiers	Coastal CPCs audit flag-state compliance; researchers access aggregated datasets via OAuth 2.0.
Environmental Harm Logbook	PostgreSQL/PostGIS relational tables; geo-tagged UDI linkages	Quantifies coral reef damage and ALDFG accumulation rates
FAD Marking Compliance	ASTM D6400 biodegradability certifications; netting mesh size (FAO 8.4.3)	Automated flagging of non-compliant designs during registration
Compensation & Dispute	Smart contracts (Solidity); payout triggers (e.g., stranding within 30 days)	Adjudicates claims under EU Environmental Liability Directive (2004/35/EC)
Public/Scientific Access	Differential privacy (k=10 anonymization)[8]; GraphQL API for aggregated datasets[9]	Researchers model bycatch mortality; public dashboards display EEZ stranding hotspots (e.g., Seychelles).

geolocation, timestamp, data provenance, and quality descriptors. This metadata structure facilitates interoperability across national regulatory systems, regional fisheries management organizations, scientific repositories, and environmental observation platforms. Collectively, these technologies establish a tamper-proof, verifiable record system accessible to all stakeholders in accordance with their access rights and functional roles.

[6] All events in the system are precisely timestamped using a global standard (ISO 8601) and permanently stored on the Ethereum blockchain, creating a tamper-proof audit trail. This ensures full traceability and accountability in the management of drifting FADs.

[7] **Tiered RBAC** means users are grouped into roles (e.g., Observer, National Authority, Scientist), and each role has limited, defined access. For example:

- Coastal CPCs (Cooperating Parties to the Commission): Can view full logs of dFADs in their EEZ. For example, Somalia's (coastal State) Full audit logs for its EEZ and can View all dFADs that entered Somali waters.
- Flag States: Can view all their own dFAD deployments. For example, Seychelles (flag state) See its own vessel deployments how many dFADs vessel SC-47 deployed in 2025.
- Researchers: See only anonymized regional trends aggregated data. For example, Download CSV: Monthly dFAD density in Western Indian Ocean. Researchers must log in through trusted credentials (e.g., university account, institutional email) to get access. It ensures that only verified and authorized individuals can view the data.

[8] **Differential privacy (k=10 anonymization)** ensures individual records—such as dFAD reports or community submissions—cannot be traced back to specific sources. By introducing slight randomness, the system protects privacy without compromising analytical value. With *k=10* anonymization, each entry is indistinguishable from at least nine others, reducing the risk of re-identification. This allows researchers to analyze patterns like FAD strandings or bycatch trends without exposing vessel identities or reporter details.

[9] **GraphQL API** is a modern method of querying data through a flexible interface.

- Unlike traditional REST APIs that return fixed responses, GraphQL allows users to request exactly the data fields they want, in the structure they need.
- It improves performance, reduces data transfer, and supports complex queries efficiently.

While aggregated datasets are grouped summaries rather than raw data.

- For example: Instead of seeing every individual dFAD report, a researcher might get:
  - "Monthly dFAD beaching events per EEZ"
  - "Total coral reef damage by region"

For Practical Example a researcher could use the GraphQL API to ask: "Give me the total number of dFAD strandings in the Western Indian Ocean in 2024, grouped by EEZ." They would get accurate summaries, but not:

- The exact GPS locations,
- Flag state vessel names,
- Or identifiable community contributors.

Flow Sequence	1. UDI registration → 2. IoT telemetry ingestion → 3. HYCOM drift modeling → 4. Smart contract-triggered alerts	End-to-end traceability from deployment to liability resolution; aligns with *IATTC's* FADWatch framework.

4. Conclusion

A recent global assessment by Schiller et al. (2025) highlights how concentrated and uneven dFAD impacts have become: 43% of global strandings occur in just two IOTC coastal states, with a total of 14,782 strandings, and densities exceeding 1 device per kilometer of coastline in Seychelles. These events severely impact coral reefs, mangroves, and other sensitive habitats. Yet only 14 of the 31 jurisdictions with over 100 strandings legally permit dFAD use signaling widespread regulatory failure, while the burden of cleanup, monitoring, and ecological damage falls almost entirely on these coastal states.

We do not cite their study as the foundation of our analysis, but their findings confirm what we're already seeing in the Indian Ocean, including what our own study of Somalia shows: 100% of recovered dFADs were non-compliant with IOTC rules, and many caused harm to coral reefs and mangroves (Sheik Heile et al., 2024).

Given the scale of the problem and the ongoing community-based recovery initiatives in Somalia, Seychelles, and the Maldives, there is a clear opportunity to standardize dFAD retrieval protocols across the Indian Ocean (Sheik Heile et al., 2023). We are proposing real-time telemetry, geofencing, community-reporting apps, and basic blockchain-based traceability are not speculative or exorbitantly costly. In fact, the estimated cost of operationalizing these improvements would be similar with the total implementation cost of the IOTC's current proposal, which itself is already resourced and adopted (see IOTC-2025-S29-10_Rev1E). The cost of doing nothing or of persisting with a passive, flag-state-centric registry is far greater: both in terms of ecological damage and long-term management credibility.

These gaps are compounded by the Register's reliance on self-reported data, absence of blockchain-enabled traceability, and failure to integrate coastal surveillance networks (e.g., VMS/AIS). Consequently, coastal states shoulder all cleanup costs (Burt et al., 2020; Purves et al., 2021) while lacking tools to enforce accountability.

A fundamental shift in regulatory practice is urgently required: passive reporting mechanisms must transition into systems of active compliance enforcement. To this end, integrating IoT-based telemetry (e.g., GPS and echo-sounder feeds), HYCOM drift modeling for predicting stranding trajectories, and PostgreSQL/PostGIS spatial databases linked to blockchain-validated audit trails into the architecture of the dFAD Register would enable real-time monitoring, automated geofencing alerts, and immutable traceability of ownership. These technical enhancements are not discretionary but are essential prerequisites for implementing the biodegradability requirements established under IOTC Resolution 24/02. Such measures are critical to addressing the documented rise in cumulative buoy activations in the Western Indian Ocean, from 25,690 in 2020 to 72,068 in 2022, indicating a nearly threefold increase in dFAD use (IOTC, 2023), as well as the 14,782 annual dFAD strandings (Imzilen et al., 2022) and Somalia's 100% rate of non-compliant dFAD strandings (Sheik Heile et al., 2024).

For the IOTC to uphold its mandate as a steward of transboundary fisheries, it must prioritize equity-driven reforms, granting coastal states sovereign access to EEZ tracking data, mandating universal biodegradable standards, and instituting binding retrieval protocols. Without these measures, the Register risks institutionalizing the very asymmetries it seeks to resolve, jeopardizing both marine biodiversity and the livelihoods of coastal communities. The Indian Ocean's escalating dFAD crisis demands nothing less than transformative, technology-integrated accountability.

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