Drifting Fish Aggregating Devices in the Indian Ocean: Impacts, Management, and Policy Implications

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Abstract

The Indian Ocean has seen a significant increase in drifting fish aggregating devices (dFADs) used in purse seine fisheries, resulting in an exponential rise in tropical tuna catches. However, the negative impacts such as catches of juvenile tunas, increase in catches of non-targeted species, ghost fishing, and abandoned and lost fishing gear remain a significant concern of developing coastal States. The study examines the abundance and ecosystem consequences of abandoned, lost, and discarded fishing gear (ALDFG) dFADs in the Indian Ocean, focusing on their impact on the marine ecosystem, risks to marine ecosystems and the legality of these unauthorized ALDFG dFADs posing IUU fishing on the Somali coast. The study also critically evaluates the effectiveness of existing regulatory frameworks and governance mechanisms in addressing these issues. Investigating the prevalence of ALDFG dFADs in Somalia's waters, the paper underscores the failure of current Indian Ocean Tuna Commission (IOTC) dFAD management and governance frameworks to mitigate these impacts effectively. Over a six-month period, 63 dFADs were opportunistically recovered along the sample coastline, projecting an annual influx of approximately 160 dFADs, not one was fully compliant with IOTC regulations. The research further calculated a proportional number of dFADs per km per annum over the entire Somali shelf, estimating a total of approximately 1,439 dFADs recovered annually. The study's findings reveal explicit non-compliance with existing regulations, emphasizing the urgent need for enhanced monitoring, regulatory measures, and international cooperation to address the challenges posed by dFADs to marine ecosystems and the livelihoods of coastal communities.

Key Words:

dFADs, ALDFGs, IOTC, Somalia Coast, Marine Ecosystems,

1. Introduction

Over the past three decades, tropical tuna purse-seine fisheries have adopted, and become increasingly reliant upon, artificial drifting fish aggregating devices (dFADs) to increase their harvest efficiencies. In the Indian Ocean (IO), each purse seine vessel may legally deploy hundreds of dFADs each year to aggregate fish, making them easier to harvest (Wain et al., 2020). Between 2020 and 2022, the deployment of dFADs significantly increased from 25,690 to 72,068, with the daily count of satellite-monitored buoys within the large-scale purse seine fishery fluctuating between 8,408 and 11,536 (IOTC, 2023). The utilization of dFADs has sparked intense debate due to its ecosystem impacts that include growth overfishing of tuna populations (Bailey et al., 2013), ghost fishing (Filmalter et al., 2013), and plastic pollution (Davies et al., 2014; Hanich et al., 2019;

Burt et al., 2020; Gomez et al., 2020). As a result, the utilization and management of dFADs has sparked intense debate in Regional Fisheries Management Organization negotiations.

Floating objects at sea tend to aggregate tuna (skipjack, yellowfin juveniles and bigeye juveniles), and tuna-like species such as sharks and billfishes. This facilitates high volumes of catch and allows purse seine fleets to dominate tuna harvests globally, contributing to population decline. Furthermore, a staggering excess of 95% of yellowfin and bigeye tuna catches associated with dFADs are juvenile tunas (Rattle, 2020), with data by gear type highlighting that industrial purse seine fleets take the largest regional harvests of the Indian Oceans' yellowfin tuna stock, a population that has been overfished since 2015.

Moreover, dFADs result in higher catches of vulnerable non-target species compared to targeting free-swimming schools of tuna (Bromhead et al., 2003; Amandé et al., 2008; Amandé et al., 2010; Gilman, 2011; Leroy et al., 2012; Davies et al., 2014; Hanich et al., 2019; Gomez et al., 2020). Scientists have expressed concerns that the use of dFADs, especially their impact on tuna behavior, also creates uncertainties in scientific assessments through breaking assumptions of typical CPUE based statistical abundance estimates while also causing a dangerous "basin effect" with hyperstability of catches that can dangerously obscure stock declines (Martin et al., 2011; Fonteneau et al., 2013; Hall & Ramon 2013; Dupaix et al., 2021). Assessments of these concerns have been complicated by factors such as seasonal fluctuations in dFAD use and stock abundance, differing dFAD designs and the proliferation of dFAD use, meaning it is now practically impossible to compare data with pre-FAD baselines (Girard et al., 2004; Orue et al., 2019).

Finally, growing concerns about oceanic plastic debris have captured global attention (Borrelle et al., 2017), with some legal experts reporting that the current use of dFADs may violate international marine pollution laws, positioning harvests around these devices as potentially resulting from Illegal, Unreported, and Unregulated (IUU) fishing (Gomez et al., 2020; Churchill, 2021; Schatz, 2023). Furthermore, studies have identified dFADs as a major source of abandoned, lost, and discarded fishing gear (ALDFG) (Gilman et al., 2011, Burt et al., 2020). Their impacts include habitat degradation, food web disruption, and direct harm to marine species (Macfadyen et al., 2009; Filmalter et al., 2013; Davies et al., 2017). Studies have suggested that less than 20% of deployed dFADs may be eventually retrieved (Banks & Zaharia 2020), rather than lost or deliberately abandoned at sea, while the abandonment of dFADs at their modern regularity and scale of use results in global-scale oceanic plastic pollution. In the western central Pacific Ocean region, the statistics are worse, with likely less than 10% of deployed dFADs being retrieved, leading to a majority of these satellite tracked devices being lost or intentionally abandoned. This pollution is burdening coastal states financially, as they often bear the burden of clean-up costs (Burt et al., 2020; Purves et al., 2021), while causing ghost fishing and other ecosystem impacts that can continue for decades after abandonment. These issues have brought over 100 organizations together to demand improved dFAD management among purse seine fisheries operating in the IO (The Guardian, 2021).

To understand the extent and impact of dFAD use, this study will investigate the prevalence of ALDFG in one area of the IO where dFAD abundance is anecdotally high: within the waters of Somalia (**Figure 1**). The choice to focus on the Federal Republic of Somalia is grounded in the region's notable marine biodiversity, especially the rich populations of tropical tunas; the inherent fragility of its marine habitats biodiversity (Sumaila & Bawumia, 2014; Glaser et al., 2015; Cashion et al., 2018); and emerging data suggesting that the Somali coastline might be a major accumulation zone for ALDFG, as underscored by Zudaire et al. (2019) and Imzilen et al. (2022). We begin with a review of the use, impacts, and governance of dFADs in the IOgenerally, and then dive into the specifics of dFADs in the waters of East African coastal States. We then describe the study methods, followed by results, and a discussion of the results with consideration of the governance challenges facing member States of the Indian Ocean Tuna Commission (IOTC).

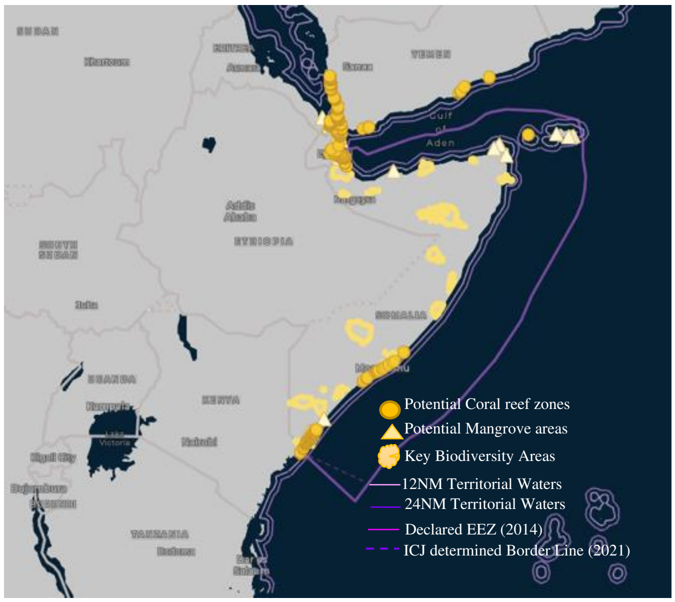

Figure 1: Mapping Somali Coastal Resources
Source: Secure Fisheries (Project Badweyn Map)

2. Background

2.1.dFADs in the Indian Ocean: Impacts and Governance Challenges

The IO is a diverse and productive ecosystem, home to almost one third of global coral reef cover and over 40,000 km^2 of mangroves (Wafar et al., 2011). For the 38 countries whose Exclusive Economic Zones (EEZs) encompass parts of this ocean, this biodiversity provides invaluable resources that have large contributions to economies and livelihoods. Tuna resources in the IO represent a vital economic asset for coastal states, offering significant contributions to their economies through fishing activities, employment, and export revenues. In 2021, the catch from large-scale purse seiners using drifting floating objects amounted to 410,000 tonnes. This figure represents 87% of the total industrial purse seine catch, and 35% of the total catch of the IO tropical tunas (IOTC, 2023). These statistics underscore the predominant role of dFADs in the purse seining sector and their significant contribution to overall tuna catch in the IO. Coastal communities within these states are intertwined with the ocean, critically relying on its health and the sustainability of its resources for their day-to-day survival. The current prevalence of dFAD use may threaten not only sustainability of the resource base (tuna), but also local livelihoods and the economic development opportunities of IO coastal states. Here we summarize the development of dFADs in the IO and speak to the challenges of governing them in this region.

dFADs have been increasingly used by tropical tuna purse seine fisheries since the mid-1990s. These artificial floating objects, designed to aggregate fish, have seen a significant increase in their use throughout the IO. This increase in use has been significant, with a notable rise in the number of dFADs from 2,250 in October 2007 to 10,300 by September 2013, demonstrating at least a fourfold increase in the number of dFADs over a 7-year study period (Maufroy et al., 2017). The widespread deployment of dFADs, combined with substantial use of GPS buoys to track these devices. For instance, the aggregate number of dFAD buoys released and activated has increased from 25,690 a year in 2020 to 72,068 in 2022 (IOTC, 2023). On any average day, the number of different satellite-tracked buoys, monitored by the large-scale purse seine fishery persisted between 8,408 and to 11,536 (IOTC, 2023). In the IO, over 80% of the sets currently made by the EU purse-seine fleet are on dFADs, highlighting the significant role these devices play in modern fisheries. This has led to a deeper understanding of the habitat characteristics and dynamics of pelagic species aggregated under dFADs, which is key to improving fishing practices (Orue et al., 2020). The increase in dFAD use over the past two decades has transformed fishing practices and prompted concerns over environmental impacts, necessitating sustainable management practices to mitigate adverse effects on tuna stocks and the open-ocean ecosystem.

The development of dFADs has considerably improved the searching efficiency of purse seiners, as noted by researchers (Davies et al., 2014). Overfishing on ‘free-swimming schools’, dFADs offer distinct advantages, allowing for quick location and minimization of search time and operating costs. Unlike free-swimming schools that necessitate daylight hours for location, FADs can be pinpointed at any time of day using a computer screen, enabling fishing operations at dawn. The latest generation of FADs is equipped with echosounders, providing skippers with daily or hourly estimates of biomass beneath the buoy. This feature enables skippers to confirm the presence of a school beneath a FAD before visiting it, further enhancing efficiency (Davies et al., 2014). Additionally, in some oceans such as the Atlantic and Indian, supply vessels collaborate with purse seine skippers to deploy and monitor dFADs using sonar and other fish-finding technologies, exemplifying the integration of advanced tools in modern fishing practices. This surge reflects a shift in fishing techniques and underscores the growing reliance on technological innovations to enhance fishing efficiency in the dynamic marine environment of the IO.

As the amount of dFAD use has increased in the IO, so too has the absolute volume of dFADs that remain uncollected, adding to the ocean's burden, exacerbating the plastic pollution crisis and affecting fragile marine ecosystems (Escalle et al, 2021; Borrelle et al., 2017; Purves et al., 2021). dFAD pollution doesn't just litter the ocean floor; it may also introduce harmful entities like microplastics into marine food chains, posing risks to both marine life and humans (Tutman et al., 2017). The significant pollution clean-up costs are also inequitably borne by coastal states (Burt et al., 2020; Purves et al., 2021) as the fleets deploying dFADs are often distant water fleets (for example the EU), but the abandoned dFADs typically end up beaching or polluting the waters of developing coastal States.

Not only has dFAD use increased, but dFADs themselves have undergone significant technological evolution in recent years. Modern purse seiners now equip dFADs with advanced geo-location tools and echosounder buoys, enhancing their fish-catching capabilities. These innovations include the transmission of real-time data on biomass aggregation via satellite communications. Advancements in dFAD technology include the introduction of buoys with enhanced capabilities, such as the M3i, M3i+, and M3iGO models, which incorporate Artificial Intelligence to improve fishing efficiency. These developments have enabled fleets to effectively deploy large nets, some spanning over 2 kilometers in length and reaching depths of 200 meters, significantly expanding their fishing range around each dFAD.

Furthermore, echosounder technology has advanced to the point of being able to discern species compositions beneath dFADs, allowing purse seine fleets to operate more efficiently and continuously. These species differentiation capabilities should enable industrial purse seine fleets to avoid setting on dFADs dominated by juvenile tunas, or those with a high abundance of aggregated bycatch species, but evidence of fleets using this technology to proactively fish more sustainably, rather than to maximize their overall multi-species catch volumes and financial value, remains lacking.

Despite these technological advancements, there are concerns regarding the transparency and accountability of dFAD operations, especially in the IO. Suspected instances of strategic and covert dFAD deployments have been noted, while intentionally sporadic use of vessel tracking technologies pairs with dFAD issues to likely facilitate illegal, unreported, and unregulated (IUU) fishing activities by industrial purse seine fleets, including within the Somalia EEZ (Rattle & Duncan-Jones 2022). Studies also indicate that a substantial number of dFADs remain adrift in the IO, often entering exclusive economic zones of countries without official permission (Hanich et al., 2019; Zudaire et al., 2019; Dupaix et al., 2021; Imzilen et al., 2022;). Many of these dFADs are abandoned outside designated fishing grounds, posing risks to marine ecosystems and potentially affecting the migratory routes of tunas and other pelagic species.

Governance of dFADs is a growing and complex challenge. Firstly, multi-level governance is in place due to the migratory nature of tuna species. As highly migratory species, their governance falls under regional international cooperative management structures through regional fisheries management organizations (RFMOs) (FSA 1995), but tuna fisheries also tend to be managed via domestic regulations or license conditions attached to vessel practices. The IOTC is the RFMO with an Area of Competence spanning the IO and therefore mandated to ensure sustainable fisheries for tuna and tuna like species in the study region. Established in 1996 under the Food and Agriculture Organization of the United Nations (FAO), the IOTC’s primary role encompasses the conservation and sustainable management of tuna and tuna-like stocks within this region. The IOTC's responsibilities involve conducting scientific research, establishing catch limits, and formulating strategies to minimize bycatch and preserve marine ecosystems. With 30 member countries and territories, including both IO coastal states and distant fishing nations, IOTC’s objective is to encourage sustainable management of fisheries within its remit.

To date, the current governance of FADs by RFMOs, including in the IO, is widely regarded as insufficient on a global scale: for example, IO studies including those by Davies et al. (2014), Hanich et al. (2019), and Gomez et al. (2020), have critically evaluated the efficacy of RFMOs in managing these devices and found effective management lacking. Some critics have specifically highlighted the inadequacy of the IOTC's measures, especially when contrasted against the magnitude of overfishing threats and addressing the ramifications of dFAD use and the regional importance of ensuring the sustainable use of tuna species in this region (Rattle, 2020). The IOTC's Resolution 19/02, for instance, only pertains to actively-fished or followed dFADs, meaning it does not cover the many dFADs that already make up ALDFG throughout the IO and may still be opportunistically fished whenever they are encountered, regardless of the status of their satellite communications (Zudaire et al., 2019; Gomez et al., 2020). Most recently, two thirds of IOTC members endorsed the implementation of Resolution 23/02 to improve dFAD management in the region. Unfortunately, in the following weeks, one third of IOTC member States objected to the same Resolution, which would limit dFAD numbers, improve reporting responsibility, and close parts of the region to dFAD fishing for 72 days. With one third objecting, the measure becomes non-binding and essentially ineffective. Notably, the change in appetite to implement this important measure is broadly considered to reflect political influence being administered by developed states with large purse seine fishing interests.

From a tuna sustainability standpoint, the most pressing concern of dFAD use centers around the disproportionate aggregation of juvenile fish. Floating objects tend to aggregate tuna (skipjack, yellowfin juveniles and bigeye juveniles), and tuna-like species such as sharks and billfishes. By skewing the catch towards juvenile fish, there's a significant reduction in the average size of the caught fish, limiting the yield per recruit (Gilman, 2011; Leroy et al., 2012). This also means that fisheries targeting adult fish, for example Japanese longliners, have their potential yield reduced if not enough juveniles are left to grow into adults. Furthermore, there is a hypothesis that dFADs set up 'ecological traps' (Schlaepfer, et al., 2002; Hale & Swearer, 2016), Fish, especially migratory species, find themselves drawn to these structures, often leading them away from their natural habitats, migration routes, and affecting their overall health (Hallier et al., 2008; Jaquemet et al., 2011).

2.2. Summarizing the impact of dFADs to East African coastal fisheries

For centuries, fishing has been a crucial source of livelihood for many coastal communities bordering the IO. For other countries, fisheries are seen as a new sector that can bring economic prosperity and development. For both types of countries, however, the introduction of modern fishing technologies, such as dFADs, puts into question the long-term potential of the marine ecosystem to support economies into the future (Gilman et al., 2021). A considerable number of these dFADs, once released, appear to end up stranded in the territories of the East African coastal states (Imzilen et al. 2022). Furthermore, there's increasing concern over the legality of certain fishing practices (Gomez et al., 2020; Churchill, 2021; Schatz, 2023). The relative lack of data reporting about dFAD numbers, locations and use is also being maintained through questionable claims of “commercial confidentiality” coming from the purse seine industry. For example, Rattle & Duncan-Jones (2022) have pointed out specific instances where purse seine fleets have overstepped their boundaries and engaged in unauthorized fishing within the waters of coastal states, but investigations have been complicated by the seemingly intentionally maintained scarcity of dFAD data and lacking transparency in purse seine fleets operations.

The study conducted by Imzilen et al. (2022) provides valuable understanding regarding the trajectories of drifting dFADs. Their research reveals that a notable proportion of dFADs diverge from their initial fishing areas within the IO and subsequently approach within approximately 50 kilometers of a port. This proximity is maintained on an average for just over 3 days. This may suggest that collecting these drifting dFADs might not only be feasible but also financially viable, particularly given the extensive ecological harm these devices may cause if left in the water.

Tropical purse seiners seem to have a targeted strategy wherein they release these devices outside the EEZ of Somalia, typically during the period from June to August (Imzilen et al. (2022). The underlying intention is to exploit the onshore currents, positioning the dFADs to drift through the primary fishing regions situated within Somalia's EEZ before they later drift out of Somali waters with valuable tuna aggregated beneath them for harvesting. This seemingly calculated move is also a tactic to bypass the potent monsoon-induced currents which dominate from July to December, as detailed by Schott et al. (2009). These currents, if not strategically avoided, could inadvertently push the dFADs further eastward. Given the patterns of marine currents, the peak fishing season using dFADs in this part of the IO falls between August and October.

The trajectory traced by the dFADs emanating from areas adjacent to the Somalia EEZ designated fishing zones is particularly noteworthy. Their path closely to the Somalia EEZ especially a 50 km to Mogadishu Port drifting to the African coastline, especially around regions like Tanzania and Mozambique. Within these specific geographic confines, the data points to an intriguing trend: a vast majority, ranging from 30% to an overwhelming 100% of these dFADs decisively depart from the fishing grounds, passing 50-kilometer port boundary. This pattern underscores the strategic fishing importance of these regions.

Notably, the majority of dFADs, especially those originating from the northwestern fringes of the designated fishing areas, tend to concentrate in and around the port of Mogadishu in Somalia. Imzilen et al. (2022) record the staggering passage of 1,641 (2012-2018) lost and abandoned dFADs. This movement not only makes the Somali coast a nexus of marine activity but also highlights it as a crucial epicenter for illegally discarded and systematically abandoned dFADs in the vast stretch of the IO. There is a maintained lack of accountability for ownership and responsibility to compensate for the true ecological cost of such practices, which has resulted in conflicts with conservation goals and management arrangements (Pons et al., 2023).

The regional socio-economic inequity resulting from industrial scale fisheries harvesting millions of juvenile tunas in financial support of foreign beneficial owners has also increasingly been in the media spotlight over recent years, with some stating that persisting dominance of oceanwide catch falling with industrial purse seine fleets represents a form of neo-colonialism.

To understand the magnitude and ecological consequences of the utilization of dFADs, we assess the prevalence of ALDFG within a particularly impacted segment of the IO, specifically the waters of Somalia. The rationale for concentrating on Somalia is multilayered, underpinned by the nation's remarkable marine biodiversity, which is notably characterized by substantial populations of tropical tunas. This decision is further justified by the inherent vulnerability of the region's marine biodiversity, as documented in works by Sumaila & Bawumia (2014), Glaser et al. (2015), and Cashion et al. (2018). Additionally, emerging evidence posits the Somali coastline as a principal deposition zone for ALDFG, a notion supported by the findings of Zudaire et al. (2019) and Imzilen et al. (2022).

3. METHODS

3.1.Introduction

This study analyzes the extent and impact of one type of ALDFG, namely dFADs, on Somalia's coastal regions. It focuses on understanding the environmental repercussions of dFADs and suggested methods to mitigate their effects. The research centers on four Somali beach sites: Jazeera, Liido, Warsheik, and Adale (**Figure 2**). These sites fall between 2.0070° N, 45.2841° E, and 2.758889° N, 46.328611° E with an overall distance of 230 km from Jazeera beach to Adale which covers approximately 6.90 % of Somalia's coastline or 0.459% of inshore fishing area. Conducted in two stages, an initial pilot in March 2022 was used to refine data collection methods, followed by a main study period from August to December 2022. Data were then organized and assessed electronically. These particular beach sites were selected due to reports from local fishermen and community heads about dFAD beaching incidents. Notably, three of these sites are vital nesting grounds for turtles and are home to crucial mangrove ecosystems.

The data collection process was divided into two phases: the pilot study and the main study. Data collection during the pilot study was conducted in an ad-hoc manner, where data were collected when dFADs were removed from where they had beached or stranded. The retrieved dFADs collected during this period were stored locally for later assessment. This phase of the study was conducted during March 2022. The main study was then conducted from August to December 2022 using standardized protocol for data collection (Annex II), which included photographs and descriptions of the dFAD. Fishers and community members were provided with a translated version of the data collection form to facilitate their understanding and implementation of the collection procedure. The project required fishers and local communities to report and recover ALDFG in the Somali waters or the coastal zones on the four beach sites.

The data collection form consisted of three main sections:

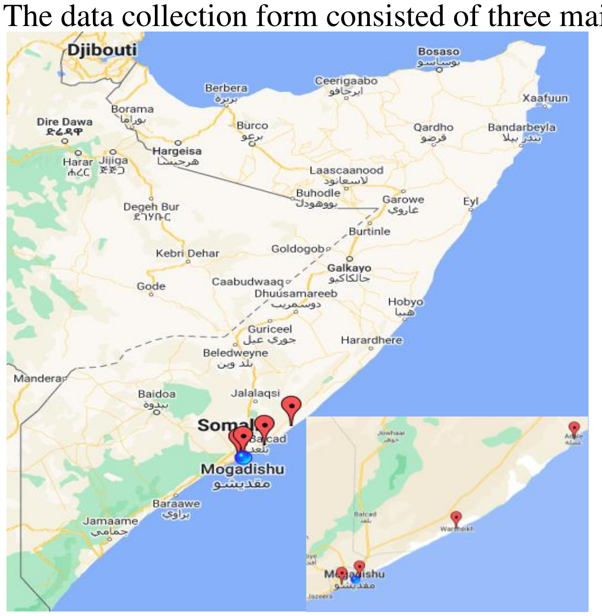

Figure 2: dFAD recovery site

1. **Location/Environment Recovered**: Information on the location and environment where the dFAD was recovered, such as the latitude and longitude, beach site name, habitat type.
2. **FAD Structure and Design**: Information on the dFAD structure and design, such as the type of dFAD, the materials used, the satellite buoy, raft cover, and sub-structural equipment.
3. **Observed Entanglement Events**: Information on any observed entanglement events, such as the number of fish, type, size and habitat entanglement.

The data were collected using the above protocol, and photographs were taken of all material of the recovered dFADs (the raft covers, satellite buoys, ropes, and all sub-structural equipment) and compiled through electronic versions for analysis.

3.2.Database Management and Analysis

Collected data were managed using electronic databases, with details stored in an Excel file. Images of the recovered ALDFG were analyzed following IOTC Resolution 19/02 requirements as the guide for compliance. Descriptive statistics were applied to the data to summarize the number of recovered dFADs, their materials, entanglement events, compliance, and geographic locations.

To understand the scale of dFAD strandings in Somalia, we estimated the prevalence of ALDFG in both space and time using the total number of recovered dFADs and the recovery area as our key parameters before scaling up the equation to cover the entire Somali shelf, assuming consistent density throughout and extrapolating this out to estimate the annual impact. Geospatial techniques were used to visualize the spatial distribution of the dFADs. Geospatial techniques were used to visualize the spatial distribution of the dFADs.

To understand the levels of compliance in the sample, they were assessed using 4 indicators of compliance based on IOTC Resolution 19/02 requirements as the guide:

- dFAD rafts must not include any meshed materials;
- dFAD aggregators must not include any meshed materials;
- dFAD buoys must be marked with the manufacturer's serial number; and
- dFAD buoys must be marked with the vessel's Unique Vessel Identifier (UVI) number from the IOTC.

Each dFAD recovered was measured against these metrics to assess how many were fully compliant with IOTC Resolution 19/02.

An examination of the entanglement events was conducted to assess the potential environmental impact of dFADs. Content analysis was applied to categorize and code the entanglement data, identifying marine habitats/species affected and the frequency of such events. The study's methodology aimed to give an in-depth analysis of the effect of ALDFG on the marine ecosystem, emphasizing their prevalence in the Somalia EEZ.

To estimate the prevalence of lost, abandoned, and discarded dFADs in Somalia's coastal areas, we used the total number of recovered dFADs and the recovery area as our key parameters. Specifically, we obtained data on the total number of recovered dFADs, and the recovery area. To calculate the daily recovery rate of dFADs, we first determined the total number of dFADs successfully recovered during the project. We then divided this total by the duration of the project. This process enabled us to derive the average number of dFADs recovered per day. Similarly, we were able to determine the average number of dFADs recovered by area by dividing by the total study area.

Recovery rate per day = Total number of recovered dFADs / Project duration

Density of recovered dFADs per km2 = Total number of recovered dFADs / Recovery area

4. RESULTS (1,100 words)

4.1 Recovery and density rates

Over the study period, 63 dFADs were recovered as stranded within the study area, which was 230 km of coastline. By dividing the total number of recovered dFADs by the project duration, which was 160 days, we established a recovery rate of 0.39375 dFADs per day, or 2.7 per week.

Recovered dFADs (Nr) = 63
Project duration (Pdy) = 160,
Recovery area ($Prarea$) = 230 km, and
Total Somali shelf area = 50,878Km^2

Recovery rate per day = Total number of recovered dFADs / Project duration
63 / 160 = 0.39375 dFADs per day

Estimations of dFAD stranding density along the 230km coastline, established by dividing the total number of recovered dFADs by the recovery area, gave a density of 0.2739 dFADs per km2.

Density of recovered dFADs per km2 = Total number of recovered dFADs / Recovery area
= 63 / 230 = 0.2739 dFADs per km2

Finally, we calculated the proportional number of recovered ALDFG in the entire Somali shelf area per annum by multiplying the total number of recovered dFADs by the ratio of the recovery area to the entire Somali shelf area. This gave us an estimated proportional number of 0.2859 dFADs per/km/annum.

Estimated total number of recovered dFADs per year = Proportional number of recovered dFADs in Somali shelf area per annum x Total number of dFADs in Somali shelf area per annum
= 1,438.91 dFADs per year (rounded to the nearest whole number)

To convert this to an estimated total number of recovered dFADs per year, we multiplied it by the total number of lost, abandoned, and discarded dFADs in the Somali shelf area per annum. This gave us an estimated total number of 1,439 dFADs that potentially drift into Somalia's EEZ as ALDFG per year. Following some of the ALDFG dFADs recovering during the project period. (**Figure 3**)

Figure 3: Photographs of Abandoned, Lost, and Discarded Fishing Gears dFAD recoveries in Somalia

4.2 Strandings

Of the 63 dFADs recovered, 43 (68 %) were recorded as beached after becoming stranded ashore and no longer free floating at sea. Of the total beached dFADs found during the assessment, about 17% of beaching events occurred in mangrove habitats, with half (49%) of events occurring on sandy beaches. The remaining 33% dFADs had the final positions in shallow coastal waters, with most being recovered within 500m from the shoreline on coral reefs or seagrass beds. Some beached FADs possibly impacted more than one type of habitat; for example, in some locations, a final position in the mangrove habitat would require the dFAD to first pass over coral reef areas to reach that position. In this case, over 50% of the dFADs were in this position and, therefore, had unknown impacts upon coral reefs or seagrass beds before beaching on the shoreline. However, Mogadishu (Liido beach) showed the highest number of beaching habitats, with half (49.21%) of all dFADs strandings being there, which also happens to be a sandy beach.

Table:1 Location summaries for dFAD recoveries

Area found	Area Coordination	Percentage	No
Liido Beach	2°02'16.3"N 45°21'37.9"E	49.21%	31
Adale beach	2°45'32.0"N 46°19'43.0"E	19.05%	11
Jazeera Beach	2.0070° N, 45.2841° E	17.46%	12
Warsheikh	2°17'46.7"N 45°47'46.3"E	14.29%	9
Total		**100.00%**	**63**

Of the recovered dFADs, 59 included a satellite/operational buoy and, of these, 4 were lone buoys that were no longer attached to a dFAD structure.

4.3 Compliance

Using the 4 indicators of compliance as above, we found that, out of the 63 dFADs recovered during the project period, none were fully compliant with the regulations of Resolution 19/02. None of the buoys had the IOTC vessel registration included, and for all buoys (?), the shade cloths were all either nets or meshed materials, also putting them in non-compliance.

The primary areas of non-compliance identified were the lack of UVI numbers on satellite buoys and the use of meshed materials, particularly in the rafts. Marking with the UVI is important for tracking FAD ownership and creating accountability. Instead of the number, many vessels appear to use abbreviations of their vessel name with varying degrees of clarity. The materials used to cover the raft of the recovered dFADs were mainly made of plastic material, with fishing nets and meshed shade cloth typically covering the surface. Substructures were often constructed of synthetic rope and netting hanging from the center of the floating raft to depths ranging from 14m to 33m, often with woven sacks, polystyrene tubes or rolled and tied bundles of nets attached.

Due to a lack of IOTC vessel ID numbers on dFAD buoys (as required through Resolution 19/02), despite device serial numbers being permanently market in large writing on each buoy, only 56 dFADs could be assigned to a vessel with a reasonable level of confidence. According to the findings, 42% of the 56 dFADs discovered were from Spanish-flagged vessels. Spanish fleets were responsible for the highest relative number of dFADs recovered in Somali waters through this study. Notably, the Seychelles owned the second highest number of FADs with 29% of the recovered dFADs coming from vessels with this flag. Notably beneficial ownership[1]of the vessels deploying those dFADs under the Seychelles flag was likely directed toward the EU. Tanzania, France and Mauritius had 9%, 8% and 1% dFADs associated with their vessels, respectively, and 11% lacked any clear mark that could enable tracing the dFAD to its responsible vessel (Table 2).

Table 2: Distribution of dFADs across the countries

Country (CPC)	**Number of dFADs Recovered**	**Percentage of Total dFADs Identified**
Spain	24	42%
Seychelles	16	29%
Tanzania	5	9%
France	4	8%
Mauritius	1	1%
Unattributed	6	11%

[1] In this context, ‘beneficial ownership’ likely refers to the individuals or entities who derive economic benefits from the deployment or use of dFADs in fishing operations. This explores how these beneficial ownership influence fishing practices, sustainability efforts, and the conservation of marine resources [Gokkon, B. (2021, September 17). Mongabay.https://news.mongabay.com/2021/09/for-sustainable-global-fisheries-watchdogs-focus-on-onshore-beneficial-owners/]"

Discussions with Somali fishing communities during this study also exposed anecdotal evidence that there is a high probability that many more beaching events of dFADs may have occurred during the study period, but that they were not included in the analyses and rather were disassembled so their components could be used for various purposes (particularly the solar panels in buoys and ropes) by coastal communities. This highlights the need for ongoing monitoring and analysis to improve local fisher awareness of the recovery program and provide a more comprehensive understanding of dFAD use, ownership, liability and its impact on the marine environment in the IO.

5. DISCUSSION

Our study confirms that the Somali EEZ is a significant location for dFADs as ALDFG and that there is systemic non-compliance evident throughout the purse seine dFAD fishery. The findings provide valuable insights into the potential abundance of dFADs that may continue to fish 'illegally' within the Somali EEZ, highlighting the urgent need for comprehensive monitoring and regulatory measures to address this issue. Somalia's EEZ is large and proximate to the main purse seine fishing grounds of the IO and with that in mind, it is not surprising that the highest evidence of ALDFG, is also concentrated along the Somali coastline.

This study tracked instances of ALDFG along a stretch of the Somali coast, as well as evaluated the compliance of these recovered dFADs with the IOTC Resolution 19/02. The outcomes of this research contribute to the rather new body of knowledge on the prevalence, impact, and need for management of ALDFG in Somali waters and, more broadly throughout the IO. During the project period from the month of March and August - December 2022, 63 dFADs were recovered and 100% did not fully comply with IOTC Resolution 19/02. The non-compliance observed suggests a widespread disregard for regulations to minimize the negative impacts of dFADs on marine ecosystems. The fact that the dFADs are mainly made of plastic and entangling materials while not being suitably marked, perhaps to intentionally obscure their ownership, further emphasizes the need for improved regulation and monitoring, as these devices continue to pose significant and long-lasting threats to marine biodiversity.

The data analyzed in the study also demonstrates the susceptibility of mangrove and coral reef habitats to beached dFADs. This is alarming as these habitats are vital for the survival and productivity of various marine species upon which coastal communities depend for nutrition and livelihood support on a daily basis, thus emphasizing the significant social-ecological implications of ALDFG. Furthermore, the finding that certain dFADs may impact multiple habitats indicates the potential for cascading effects on interconnected marine ecosystems.

Based on our calculations and assumptions, we estimate that 1,439 ALDFG could have been recovered per year in Somalia's coastal areas. Such findings call for strengthened surveillance and international cooperation to ensure adherence to dFAD fishing protocols and to safeguard marine ecosystems against the extensive dFAD impacts that persist in the meantime.

Our estimates serve as a foundational benchmark for comprehending the magnitude of the issue concerning ALDFG along the Somali coastline. It is imperative to acknowledge that these estimates are predicated on the hypothesis that the incidents of beaching are uniformly distributed across the entire coastline and that the duration of the study is indicative of the typical annual trends. Nevertheless, it is crucial to recognize that these figures are merely estimates. The actual frequency of beaching events might surpass these estimates due to several study limitations. These include the constrained scope of opportunistic recovery areas, the limited personnel allocated for the recovery of FADs, and the shortness of the observation period.

Importantly, our results suggest that substantial numbers of dFADs have illegally entered Somali waters, illegal in the sense that deploying countries did not have legal fishing rights within the Somalia EEZ historically or during the study period. Notably, dFADs are considered to be fishing from the moment of deployment into the water until they are recovered (Hanich et al., 2019; Gomez et al., 2020). Their current use could therefore be considered IUU fishing (Gomez et al., 2020). An additional concern is the lack of data reporting about dFAD numbers and locations being maintained through questionable claims of “commercial confidentiality” coming from the purse seine industry. Recent research (Rattle & Duncan-Jones 2022) elucidates instances of malpractices by purse seine fishing fleets, which have exhibited non-compliance with established maritime boundaries. Specifically, these fleets have been found to engage in unauthorized fishing operations within the jurisdictional waters of sovereign coastal nations. These identified breaches not only underscore the challenges in maritime governance but also highlight potential infringements on sovereign rights, potential threats to marine biodiversity, and potential destabilization of local fisheries' economic sustainability. This illegal fishing needs to be addressed as a priority issue, but the IOTC Compliance Committee remains yet to react to various submissions across multiple years to their meetings of evidence that non-compliant dFADs are continuing to strand in the waters of its coastal state members.

Furthermore, according to our findings, 42% of the 56 identified dFADs were from Spanish-flagged vessels. Rattle & Duncan-Jones (2022) highlighted that between the years 2017 and 2018, purse seiners from Spain harvested an approximate total of 330 tonnes of fish from EEZ of Somalia prior to the formal issuance of offshore licenses by the Somali authorities in two decades. The first license for foreign fishing in Somalia was issued in November 2019. Notably, before this period, the fishing endeavors by the European Union member state, Spain, within Somalia's EEZ were not conducted under any formal access agreement. This raises pertinent questions regarding marine governance, jurisdictional rights, and the ethics of international fishing operations. This illegal fishing by dFADs within developing coastal states waters is compounded by the potential that dFADs may actually drift back to the high seas with aggregated resources in tow, actually attracting fish outside of Somalia’s waters. IUU fishing poses significant threats to the sustainability of fish stocks, marine ecosystems, and the livelihoods of local fishing communities. This highlights the importance of regional dFAD, ownership, transparency, and data tracking systems along with enforced adherence to the national and international regulations in effectively addressing lost or abandoned and discarded dFADs. It also emphasizes the crucial role of effective traceability mechanisms in determining liability and ensuring compliance with regulations, as well as the important role that regulatory bodies need to play in terms of better enforcement and repercussions for those operating outside of regulations. All factors that were being addressed within IOTC Resolution 23/02, which was politically compromised and objected to following endorsement by two thirds of IOTC members.

The estimated number of ALDFG dFADs in this study represents a best estimate on the quantity of dFADs that may be present along Somalia's coast, but does not necessarily suggest that all of those have already stranded. We do contend, however, that the presence of the gear located and retrieved in this study, and the estimation calculated, do provide evidence that Somalia is a hotspot for illegal fishing by dFADs deployed by industrial scale foreign fleets. However, it is important to note that our estimates are based on certain assumptions, such as the assumption that the density of recovered dFADs is representative of the entire Somali shelf area. In reality, the density of ALDFG may vary across different areas of the Somali shelf, and may change over time due to various factors such as shifting fishing effort and ocean currents. The analysis presented in this study focused on a specific region within the Somalia EEZ, Mogadishu and three surrounding landing sites. While this provided valuable insights into the beaching events and compliance of recovered dFADs in this area, it is essential to acknowledge that the study's scope is not necessarily representative of the entirety of Somalia's EEZ. The EEZ of Somalia encompasses a vast ocean area, and dFAD beaching events may occur in various locations across the region with less or more frequency than estimated through this study. The study period was also limited to six months (including one moth a pilot study), which further affects the representation of beaching events as we do not know if these six months are representative of the entire year. Additionally, the opportunistic nature of data collection means that not all beaching events may have been recorded or reported, potentially leading to missing data and incomplete information on dFAD beaching occurrences.

To address these limitations, future studies could consider a more systematic approach to regional data collection, covering a larger geographical area and extending the study duration. The implementation of a standardized regional data collection protocol concerning the retrieval of ALDFG within the jurisdiction of the IOTC would help in capturing a more comprehensive picture of dFAD beaching events in the Somalia EEZ. This, in turn, would provide a more robust foundation for understanding the extent and impact of illegal dFADs, highlighting the importance of transparent dFAD management in the IO. Utilizing advanced tracking technologies and remote sensing methods could also enhance the data collection process, providing a more accurate estimate of the total number of beaching dFADs in the region. Incorporating the proportional number of beaching dFADs in the entire Somalia EEZ would add a significant layer of understanding to the study's findings, potentially highlighting additional hotspots of illegal dFAD and guiding the development of targeted management measures to address the issue comprehensively. While the current analysis provides valuable insights, it is essential to acknowledge its limitations and the need for further research to encompass the entire Somalia EEZ's dynamics related to illegal dFAD in countries waters.

6. CONCLUSION

This research study provides valuable insights into the problem of non-compliant IUU fishing dFADs in the coastal waters of Somalia. It brings to light the extensive prevalence of this issue and reinforces the urgent need for enhanced dFAD management measures, dFAD transparency, and to implement a more robust dFAD data tracking system to mitigate the harmful impacts of these devices on the IO.

It is highly concerning that our study found not even one of the 63 collected dFADs fully complied with the regulations of IOTC Resolution 19/02. This significant lack of compliance, especially concerning the use of non-biodegradable materials, has negative ecological repercussions for the entire ocean ecosystem. This highlights the critical need for stringent adherence to international standards and the adoption of enhanced management practices for dFADs, coupled with the enforcement of existing measures. The responsibility for such compliance extends to regulatory authorities, the vessels using dFADs, the fisheries and beneficial owners, as well as flag States. A noteworthy observation from our study is that all of these devices were found to have drifted into areas outside of any formal licensing agreements before ultimately being discovered along the shores of Somalia. This movement not only represents a breach of national territorial waters but also undermines Somalia's conservation efforts and facilitates IUU fishing activities. It is imperative to clarify that these devices had no authorization to operate within the Somali EEZ, which is a critical distinction in addressing the scope of IUU fishing and its repercussions.

The multifaceted issue of managing dFADs within the framework of the IOTC was underscored when a significant segment, approximately one-third, of IOTC member states expressed objections to the commission's proposed Resolution 23/02, aimed at enhancing the management of dFADs. It is noteworthy that, despite prolonged negotiations spanning many years, tangible progress on dFAD management has yet to be realized. Moreover, the IUU nature of dFAD fishing not only challenges the sovereignty of coastal States in the IO but also underscores the persistent effects of Neo-colonialism, where industrial fishing fleets, often from former colonial powers, exacerbate governance challenges and undermine regional and local conservation efforts. Thus, attention to this aspect through IOTC is essential to comprehensively address the importance of prompt and effective dFADs management in the region, taking into account the broader socio-economic and political dimensions influencing fisheries governance.

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Annex I: Somalia Data FAD retrieval Form

SONRREC FAD RETRIEVAL FORM (F10) – Somalia

QUESTIONS/INSTRUCTIONS
1 . CONTACT DETAILS
1.1 NAME: ( ) PHONE ( ) EMAIL ( )
2 . DETAILS OF FOUND OBJECT
2.1 CONFIRMATION - IS IT A FAD? ☐ YES ☐ NO DATE FOUND:
2.2 PHOTO OF THE RETRIEVED OBJECT [FAD00]
3 . LOCATION DETAILS
3.1 LOCATION FOUND: ( ) NAME/COORDINATES: ( )
3.2 DESCRIBE HABITAT/LOCATION
☐ OPEN OCEAN ☐ BEACH ☐ REEF SEAGRASS ☒ MEADOW ☐ MANGROVE
3.3 PHOTOS OF THE LOCATION [FAD00]
4. ENTANGLEMENTS
4.1 ENTANGLEMENT ANY CREATURES ENTANGLED? ☐ YES ☐ NO
☐ DEAD ☐ ALIVE
4.2 TYPE OF ENTANGLEMENTS ☐ FISH ☐ TURTLE ☐ SHARK ☐ DOLPHIN ☐ OTHER ( )
4.3 PHOTOS OF THE ENTANGLED CREATURE [FAD00]
5. FAD DETAILS
5.1 MARKS ON THE BUOY: ( ) MARKS ON THE FAD: ( )
5.2 RAFT DETAILS (*Material and Size)*
☐BAMBOO ☐WOOD ☐METAL ☐PLASTIC ☐FLOATS ☐TUBES ☐ROPES ☐STEEL ☐NETS
5.3 TAIL/SUBSTRUCTURE ATTACHED: ☐YES ☐NO ☐PARTIA ☐UNKNOWN
5.4 TAIL/SUBSTRUCTURE (*Material and Size)*
☐UNKNOWN ☐PALM LEAVES ☐OPEN NET MESH SIZE: ( )
5.5 PHOTOS OF RAFT, SUBSTRUCTURE, BUOY [FAD00]
6. EXTRA INFORMATION
6.1 IS THE FAD IS STORED? ☐YES ☐NO ☐REUSED ☐ OTHERS ( )
6.2 WEIGHT OF DIFFERENT COMPONENTS *(Kg)*
BUOY ( ) RAF ( ) TAIL/SUBSTRUCTURE ( ) ROPES ( )
7. SHARING & PRIVACY
7.1 CONSENT TO DATA USE AGREE TO TERMS ☐YES ☐NO
7.2 ALLOW SHARING ON SOCIAL MEDIA ☐YES ☐NO
7.3 COMPETITION FOR PRIZES ☐YES ☐NO
7.4. SIGN HERE AND CONTACT: PHONE:
Please submit completed forms and associated photographs to SONRREC, Hodan District, Opposite Jazeera University Campus three Mogadishu, Somalia. send an email to info@sonrrec.org

Annex II: Some of the stored recovered dFADs during the project

Figure. I: A local fishermen retrieving beached dFAD at Liido Beach in Mogadish

Figure. II: Stored of Retrieved dFAD Buoys

Figure III: Stored of Retrieved dFAD Buoys

Figure IV: Stored retrieved Raf of the dFAD

Annex III: Standardized data collection protocol

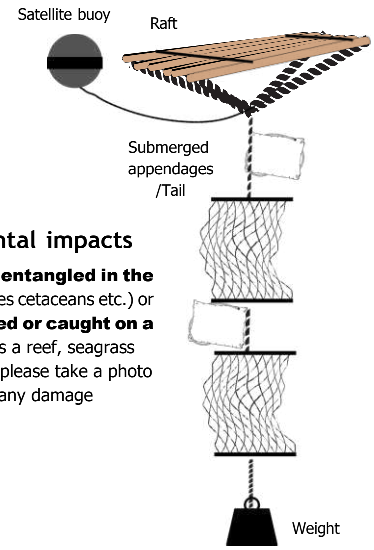
dFAD Data Collection Protocol

Key data points

- **Your contact details**
- **Date and time** (dd/mm/yyyy)
- **Location** (name of place, degrees and minutes/'what 3 words')
- **Environmental impacts**
- **Weight** (note wet or dry)
- **Dimensions of raft** and **lengths of substructure** if possible
- Indicate the **materials** used
- Please also **collect samples of the different materials** used for analysis

Environmental impacts

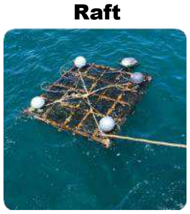
If there is anything **entangled in the dFAD** (fishes, turtles cetaceans etc.) or the dFAD is **beached or caught on a habitat,** such as a reef, seagrass meadow or beach, please take a photo of this and any damage



Key things to photograph

dFAD raft and tail

Raft



All together

Tail (all materials)

Underwater photographs using underwater cameras if possible.

Satellite buoy

All sides of satellite buoy

The dome

Codes and barcodes

Send everything to
info@sonrrec.org
WhatsApp +252 615991198
with your own **name and contact details**
or visit **www.sonrrec.org** and fill in the form there.