

Dispersal and Beaching Patterns of Drifting Fish Aggregating Devices (dFADs) as Marine Litter in the Northern of Gulf of Guinea

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Abstract

Purse seine fishers widely use drifting Fish Aggregating Devices (dFADs) to attract and capture tropical tuna across the world's oceans. While effective for fisheries, dFADs pose significant ecological risks, particularly through marine pollution and beaching. This study presents the first regional assessment of dFAD dispersal and beaching patterns as marine litter in the Gulf of Guinea, using GPS buoy track data from dFADs deployed by French purse seiners operating in the region between 2008 and 2014. Spatial analysis reveals substantial variability in drift trajectories, driven by differences in deployment density and regional ocean circulation. The highest beaching rates are observed in the northeastern Gulf of Guinea, likely influenced by the retroflexion of the Guinea Current and low deployment density. A second beaching hotspot occurs in the northern Gulf of Guinea, potentially affected by the Guinea Current and the eastward movement of mesoscale eddies. Beached dFADs pose severe ecological threats, especially in the Ivorian-Ghanaian upwelling zone, where high concentrations particularly in the northeast and around Cape Three Points overlap with key spawning habitats. This increases the risk of habitat degradation and disruption of critical fish populations. These findings highlight the urgent need for improved management strategies to mitigate the environmental impacts of dFADs in the region.

Keywords

Drifting Fish Aggregating Devices (dFAD), Current, Marine Pollution, Beaching, Fish Spawning

1. Introduction

Purse-seine fishers use drifting Fish Aggregating Devices (dFADs) to attract and

capture tropical tuna across the world's oceans. These devices are typically constructed from bamboo, plastic buoys, and plastic netting [1]. The average lifespan of a dFAD at sea is approximately 40 days [2]. Current estimates suggest that over 100,000 dFADs are drifting globally at any given time [3]. The widespread use of dFADs in tuna purse-seine fisheries has grown rapidly in recent years, driven by the adoption of GPS-equipped, satellite-transmitting tracking buoys. These devices provide fishers with real-time, remote access to the precise locations of individual dFADs [4], significantly improving the efficiency of tuna fishing operations. Moreover, the recent integration of echo sounders into tracking buoys has further enhanced their utility. This advancement allows fishers to remotely detect the presence of tuna beneath the surface and estimate the fishable biomass [5]. Together, these technological innovations have not only increased operational efficiency but also transformed how fishers interact with the ocean, enabling them to target tuna with unprecedented precision.

The increasing deployment of dFADs has led to a rise in the frequency of beaching incidents. As the use of dFADs expands, so too does the risk of these devices becoming beached on coastlines, causing environmental harm. [6] found that by preventing dFAD deployments in high-risk beaching areas, such incidents could be reduced by up to 40%. Furthermore, proactive measures such as implementing at-sea recovery programs for dFADs have shown promise in mitigating the environmental consequences of dFAD loss [7]. These programs have significantly reduced both the number of devices lost at sea and the likelihood of beaching. However, despite these efforts, dFADs remain vulnerable to ocean currents, which can carry them ashore, leading to grounding or beaching events. [2] estimated that approximately 10% of all dFADs deployed by French vessels in the Indian and Atlantic Oceans ultimately end up beached, contributing to significant marine pollution. Beaching events are particularly frequent in the Indian Ocean, with the highest occurrences observed in regions such as Somalia, the Seychelles, the Maldives, and Sri Lanka. A study by [8] tracking the movements of floating dFADs using GPS-equipped buoys found that French purse seiners operating in the Atlantic Ocean between 2007 and 2015 faced similar challenges. This study identified key beaching zones and examined how seasonal variations and deployment sites influenced beaching risk. Additionally, the impact of dFAD beaching extends to sensitive marine protected areas, such as the British Indian Ocean Territory (BIOT), raising concerns about the ecological consequences in these regions. In the Seychelles, [9] documented dFAD beaching events, providing valuable insights into the origins, characteristics, and locations of these stranded devices. Their research highlighted the difficulty of mitigating dFAD-related environmental impacts, as many of the devices came from vessels operating in nearby areas.

Lost or abandoned dFADs contribute significantly to marine pollution and pose serious risks to marine species and ecosystems. The materials used in dFADs can cause significant damage to vulnerable marine habitats and result in the entanglement of species such as turtles and sharks. [10] noted that the net mesh sizes used

in dFADs often pose particular dangers to turtles, particularly Olive Ridley Turtles (*Lepidochelys olivacea*), which are drawn to the floating structures, increasing their risk of becoming entangled. Furthermore, juvenile reef-associated species frequently seek shelter in FADs, making them vulnerable to pollution and habitat degradation when these devices drift into sensitive coastal environments [11]. These findings emphasize the need for improved management practices to prevent dFADs from drifting into critical areas and to protect endangered species from harm.

The beaching of dFADs and their subsequent impact on marine fauna, coastal fish habitats, and marine pollution has been largely understudied in the Gulf of Guinea, a region located in the eastern Tropical Atlantic Ocean. This region is characterized by dynamic oceanic conditions, including seasonal upwelling, which significantly influences regional climate, primary production, and local fisheries. Despite the implementation of FAD management measures by the International Commission for the Conservation of Atlantic Tunas (ICCAT), such as FAD management plans and data collection on dFAD usage, a considerable knowledge gap remains regarding the extent of dFAD loss in the Gulf of Guinea. The ecological consequences of dFAD beaching in this area remain unclear, posing critical questions about its potential impact on local marine ecosystems.

This study aims to conduct a regional assessment of drifting Fish Aggregating Devices (dFADs) in the Gulf of Guinea by analyzing their dispersal and beaching patterns using GPS buoy data from French purse seine fisheries (2008-2014). In addition to identifying beaching hotspots and the influence of ocean currents on drift trajectories, the study evaluates the potential ecological impacts of beached dFADs, particularly in relation to critical fish spawning habitats and sensitive coastal ecosystems within the region.

2. Material and Methods

2.1. Description and Monitoring of dFADs

Drifting Fish Aggregating Devices (dFADs) consist of a rectangular frame made from bamboo, metal, or a combination of both, covered with netting or canvas and buoyed by plastic floats for flotation. The subsurface components of the dFAD often consist of ropes or discarded purse-seine nets, which can extend up to depths of 100 meters [12]. A GPS-enabled tracking buoy is mounted on the structure to allow for satellite transmission of location data. These location updates are typically sent at intervals of two to four times per day but increase to 15-minute intervals or less when a vessel is detected nearby, enhancing real-time monitoring of dFAD movements.

Location data are collected and processed by the Institut de Recherche pour le Développement (IRD) through a formal agreement with the producer organization ORTHONGEL. The data are stored in a dedicated IRD database and follow the methodology outlined by [2].

For this study, we analyzed dFAD trajectory data collected in the Gulf of Guinea

from 2008 to 2014. The dataset includes a total of 10,236,658 georeferenced positions corresponding to 3667 individual dFADs. **Figure 1** displays the initial deployment locations of these devices, with the highest concentrations observed in the central region of the Gulf of Guinea (6°W-3°E, 4°S-4°N). Additional deployment hotspots were identified in the southeastern basin (6°E-9°E, 4°S-0°) and the western basin (12°W-6°W, 2°S-4°N). In contrast, fewer deployments were recorded in the northern Gulf of Guinea (6°W-3°E, 4°N-6°N) and the northeastern region (0°-8°E, 2°N-6°N).

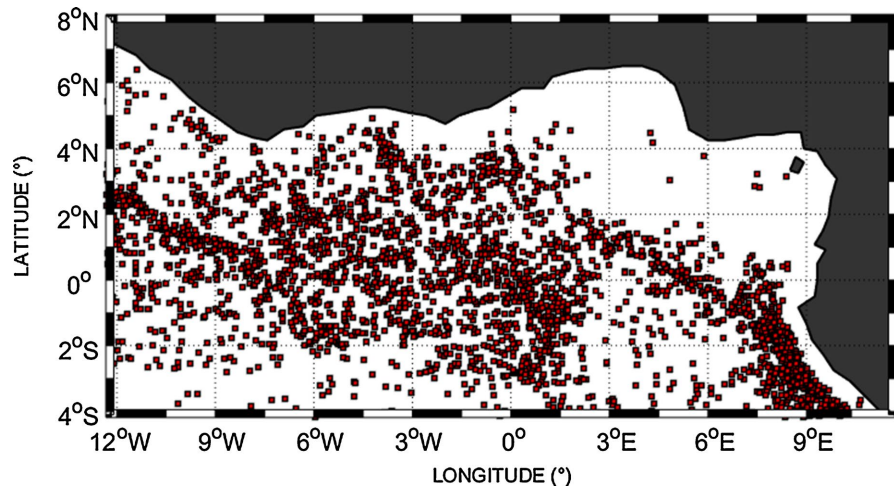


Figure 1. Initial deployment positions of drifting Fish Aggregating Devices (dFADs) in the Gulf of Guinea between 2008 and 2014. This map also defines the geographic boundaries of the study area.

2.2. Statistical Analysis

2.2.1. Absolute Dispersion of dFAD

Absolute dispersion [13] is defined as the distance between the initial position of the dFAD and its position at a given time t :

$$D_0(t) = \sqrt{(X_d(t) - X_d(t_0))^2 + (Y_d(t) - Y_d(t_0))^2} \quad (1)$$

where $(X_d(t), Y_d(t))$ represents the position of the dFAD at time t , and $(X_d(t_0), Y_d(t_0))$ is its initial position. Absolute dispersion quantifies the distance traveled by the dFAD from its origin to its position at time t . Absolute dispersion quantifies the distance traveled by a dFAD from its deployment point to a given time t , offering insights into its drift trajectory. This metric has been widely used to analyze movement behavior in Lagrangian studies of oceanic drifters and has been applied in previous dFAD studies [14] [15], validating its relevance and robustness. In our study, t corresponds to each recorded transmission time of the dFAD's position. However, when referring to beached dFADs, t specifically denotes the last known transmission before beaching occurred.

2.2.2. Traveled Distance of dFAD

Travelled distance is defined as the straight-line distance between two consecutive

positions of the dFAD at a given time t (where $t \neq 0$):

$$D_d(t) = \sqrt{(X_d(t) - X_d(t-1))^2 + (Y_d(t) - Y_d(t-1))^2} \quad (2)$$

where $(X_d(t), Y_d(t))$ represents the position of the dFAD at time t , and $(X_d(t-1), Y_d(t-1))$ its position at the previous time step. The travelled distance quantifies the straight-line distance covered by the dFAD between two consecutive points, providing valuable insights into its movement dynamics [16] [17].

2.2.3. Beached dFAD

The exact mechanisms behind the beaching of dFADs remain poorly understood. To investigate this phenomenon, we used beaching scenarios in our study. A dFAD is considered “beached” if its last known position of the dFAD’s track ends “at sea,” 5 to 100 km from the nearest coast. This approach is based on several previous studies [8].

3. Results

3.1. Example of Trajectory of dFAD

Figure 2 illustrates the trajectory of dFAD No. 52, with the red square indicating its deployment position at 1.34°S and 3.37°E. dFAD No. 52 was deployed on August 4, 2009, in the Gulf of Guinea. Initially, the dFAD drifts westward, moving between longitudes 5°W and 3°E and latitudes 3°S to 1°S. It then follows a prolonged northward drift from longitudes 5°W to 0° and latitudes 1°S to 4°N, before eventually beaching on the northern coast of the Gulf of Guinea.

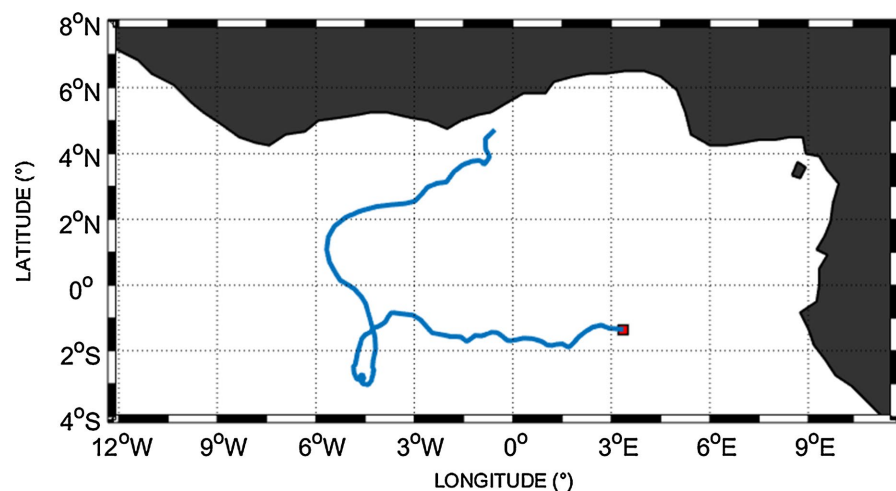


Figure 2. Trajectory of dFAD No. 52 in the Gulf of Guinea, showing the path of the device over time. The red square indicates the initial deployment position of the dFAD.

3.2. Spatial Density of dFADs Trajectories

To provide a comprehensive overview of the study period, we visualized the trajectory density of drifting dFADs using a $0.25^\circ \times 0.25^\circ$ grid covering the entire study area, as shown in **Figure 3**. This analysis reveals considerable spatial varia-

bility in dFAD density across different regions. The highest dFAD densities were observed in the southeastern and central parts of the study area. Notable high-density zones included the southeastern basin (6°E-8°E longitude, 4°S-0° latitude), where dFAD trajectories were particularly concentrated. The western region (12°W-9°W longitude, 2°N-4°N latitude) also exhibited significant density. Furthermore, the central region (6°W-6°E longitude, 4°S-3°N latitude) emerged as another area with a high concentration of dFADs. In contrast, regions such as the northern Gulf of Guinea (9°W-3°W longitude, 2°N-6°N latitude) and the northeastern sector (6°E-8°E longitude, 0°-6°N latitude) exhibited relatively lower trajectory densities.

3.3. Absolute Dispersion Density of dFADs

Figure 4 illustrates the absolute dispersion pattern density of dFADs, which reflects the distance between their initial and final positions. This metric provides insight into the regions where dFADs undergo the most active transport. The

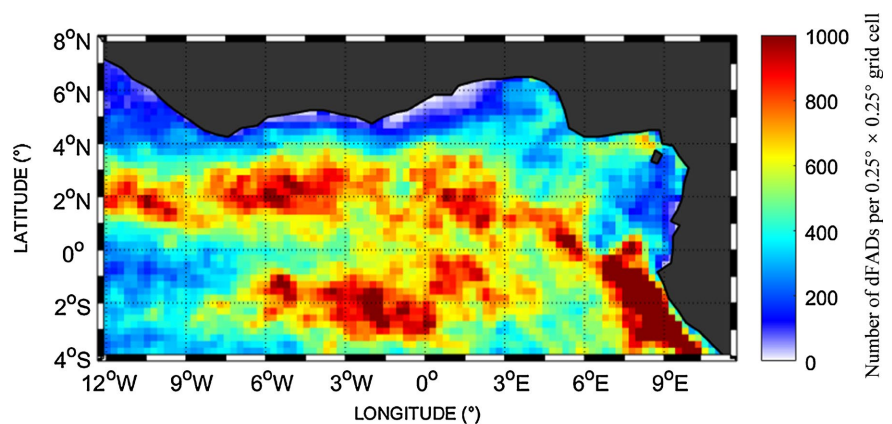


Figure 3. Spatial distribution of the density of dFAD trajectories, calculated as the total number of dFADs passing through each $0.25^\circ \times 0.25^\circ$ grid cell over the study period (2008-2014). The colorbar represents the number of dFADs per grid cell.

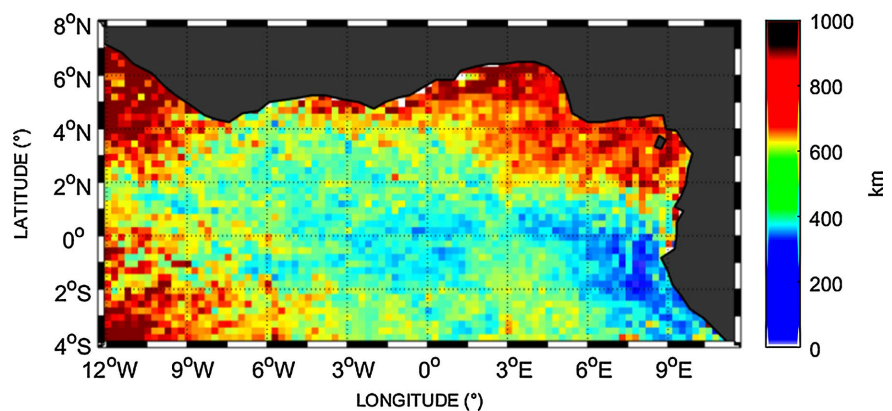


Figure 4. Spatial distribution of the density of dFAD absolute dispersion, calculated as the total distance between the initial deployment position and the position at a given time t within each $0.25^\circ \times 0.25^\circ$ grid cell. The colorbar represents the absolute dispersion (in kilometers) per grid cell.

southeastern region (6°E-8°E longitude, 4°S-0°N latitude) exhibits the lowest absolute dispersion, ranging from 0 to 200 km. Moderate dispersion is observed in the central basin (6°W-6°E longitude, 2°S-2°N latitude), with values ranging from 200 to 500 km. In contrast, significantly higher absolute dispersion values, ranging from 600 to 1000 km, are observed in the western region (12°W-9°W longitude, 4°S-7°N latitude), the northeastern region (3°E-8°E longitude, 2°N-6°N latitude), and the northern Gulf of Guinea (9°W-3°W longitude, 2°N-6°N latitude).

3.4. Traveled Distance Density of dFADs

As a complement to the analysis of absolute dispersion, **Figure 5** illustrates the density patterns of dFAD trajectories in terms of distances traveled. This map reveals significant regional variations in travel distances. The northern Gulf of Guinea, specifically the area between 9°W and 3°E longitude and 4°N to 6°N latitude, stands out with the longest travel distances, ranging from 25 to 30 kilometers. Following this, two regions exhibit intermediate travel distances between 15 and 20 km: the northwestern region (12°W to 9°W longitude, 0°N to 6°N latitude) and the northeastern region (3°E to 8°E longitude, 2°N to 6°N latitude). In contrast, several areas show significantly shorter travel distances. This is particularly true for the eastern region (6°E to 8°E longitude, 1°N to 4°N latitude) and the central zone (12°W to 3°W longitude, 4°S to 0°N latitude), where dFADs generally travel between 0 and 15 km.

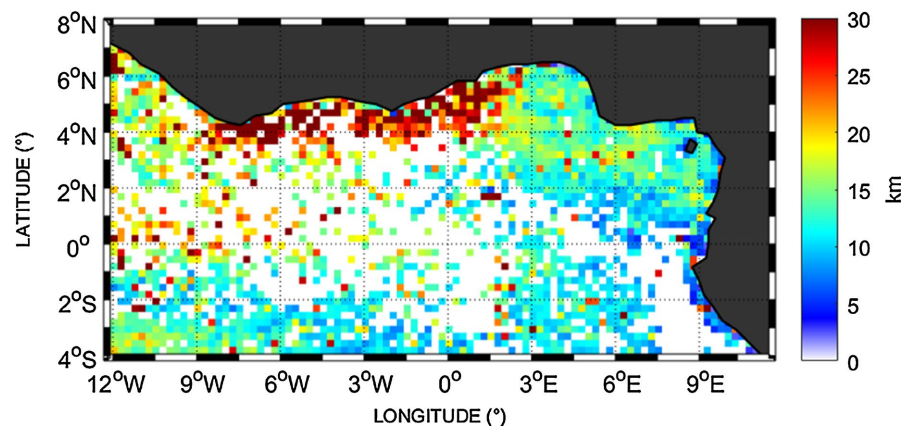


Figure 5. Spatial distribution of the density of dFAD traveled distances, calculated as the total distance traveled by dFADs within each $0.25^\circ \times 0.25^\circ$ grid cell during the study period (2008-2014). The colorbar represents the total traveled distance (in kilometers) per grid cell.

3.5. Spatial Density of Beached dFADs

Before proceeding with the spatial density analysis, it is important to note that, between 2008 and 2014, 23% of the dFADs deployed in the Gulf of Guinea ended up stranded along the coastlines. This stranding percentage provides context for the subsequent classifications and analysis of the beached dFADs in the region. The spatial density of beached dFADs was estimated using a $0.25^\circ \times 0.25^\circ$ resolu-

tion grid covering the entire study area, as depicted in **Figure 6**. This analysis indicates that beached dFADs are distributed along the entire coastline of the Gulf of Guinea, with notable regional variation in their concentrations. The highest densities are observed in the northeastern part of the study area, specifically between longitudes 3°E and 8°E, and latitudes 4°N and 6°N. A second region of significant concentration is located in the northern Gulf of Guinea, between 8°W and 0° longitude, within the 4°N to 6°N latitude range. While the density in this area is somewhat lower than that observed in the northeastern region, it still represents a substantial number of beached dFADs. In contrast, the southeastern region (6°E-8°E longitude, 4°S-0°N latitude) and the northwestern region (12°W-9°W longitude, 4°N-6°N latitude) exhibit relatively lower densities of beached dFADs.

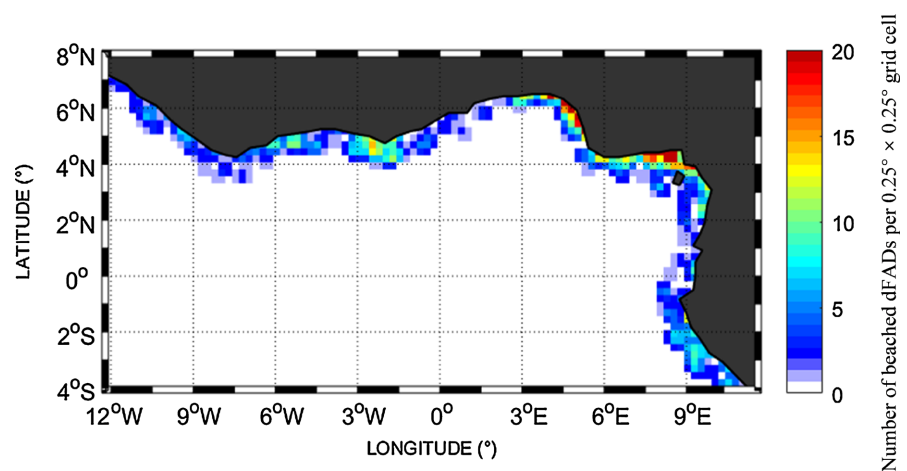


Figure 6. Spatial distribution of the density of beached dFADs, calculated as the total number of dFADs that became stranded within each $0.25^\circ \times 0.25^\circ$ grid cell during the study period (2008-2014). The colorbar represents the number of beached dFADs per grid cell.

3.6. Beached dFADs in the Ivorian-Ghanaian Upwelling

Key concerns associated with the loss and abandonment of FADs include their contribution to marine pollution and the increased risk of entanglement of marine fauna in FAD netting, both during drifting at sea and after beaching. Furthermore, beached dFADs pose a threat to vulnerable ecosystems, including coral reefs and critical spawning grounds for small pelagic fish in the northern Gulf of Guinea, an area where the coastal upwelling system is crucial for maintaining regional marine productivity. In this context, dFADs that beach along the coasts of the northern Gulf of Guinea can be considered marine debris, potentially impacting the spawning grounds of species such as *Sardinella aurita*, the dominant small pelagic fish in the region. To assess the spatial overlap between beached dFADs and key spawning habitats, four major inshore spawning areas were identified based on previous studies: Cape Palmas inshore (CaPin) between 3.4°E-5.5°E and 3°N-7°N, Cape Three Points inshore (CaTPin) between 0.5°E-3.4°E and 3°N-7°N, Mid-East Gulf of Guinea inshore (MEGGin) between 4°W-0.5°E and 3°N-7°N, and North-

East Gulf of Guinea inshore (NEGGin) between 8.4°W-4°W and 3°N-7°N. **Figure 7** presents the percentage of beached dFADs within these identified spawning regions relative to all the dFADs that beached in the Gulf of Guinea. The results (**Figure 7**) reveal that the NEGGin region recorded the highest proportion of beached dFADs (17%), followed by the CaTPin region (11.5%). The CaPin area accounted for 8%, while the MEGGin region exhibited the lowest percentage (3.8%).

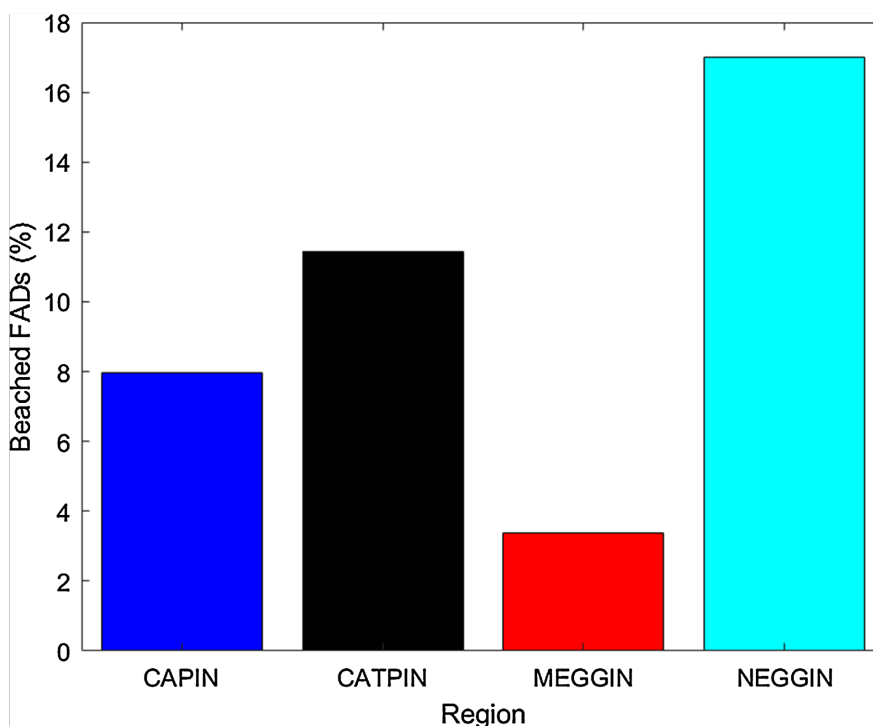


Figure 7. Beached dFADs in *Sardinella aurita* spawning areas along the Ivorian-Ghanaian Upwelling.

4. Discussion and Conclusions

The trajectory of dFAD No. 52 (**Figure 2**) highlights the significant contribution of dFADs to marine litter in the Gulf of Guinea. Initially drifting westward and later shifting northward, this dFAD traveled a considerable distance before beaching the northern coast. Such extensive displacement increases the probability of dFADs reaching ecologically sensitive coastal zones, where they can cause environmental harm through entanglement and pollution [10] [18].

Spatial analysis of dFAD trajectory densities across the Gulf of Guinea (**Figure 3**) reveals pronounced variability in drift patterns, suggesting that both deployment practices and oceanographic conditions strongly influence dFAD distribution [6] [7] [19] [20]. Areas of high trajectory density in the southeastern and central regions correspond with zones of intensive deployment, likely associated with targeted fishing activities. In contrast, the lower densities observed in northern and northeastern sectors may reflect limited deployment or prevailing current dy-

namics that inhibit dFAD retention.

The spatial heterogeneity in absolute dispersion and traveled distances provides key insights into regional ocean dynamics and the environmental risks posed by dFADs as marine litter. In the southeastern Gulf of Guinea (6°E-8°E, 4°S-0°N), dFADs exhibit minimal movement (**Figure 4** and **Figure 5**), characterized by the lowest absolute dispersion (0 - 200 km) and shortest traveled distances (0-15 km). This may reflect weak current velocities and high deployment density, which may result in physical clustering and entanglement among dFADs, effectively anchoring them. While this reduces the risk of widespread dispersion, it concentrates on environmental impacts such as localized pollution. The central Gulf of Guinea (6°W-6°E longitude, 2°S-2°N latitude) displays moderate dispersion (200 - 500 km), yet traveled distances remain similarly short (0 - 15 km). This pattern suggests a dynamic yet zonally constrained drift environment, likely dominated by the westward South Equatorial Current [21]. The directional consistency of this current limits meridional movement, thereby confining dFAD movement to narrow latitudinal bands. While this reduces broad spatial dispersal, it concentrates dFAD pathways, creating high-risk corridors for marine debris accumulation and interaction with coastal ecosystems. Three distinct regions exhibit the highest levels of dFAD dispersion (600 - 1000 km) and longest traveled distances (15 - 30 km), representing zones of elevated ecological risk. In the western Gulf of Guinea (12°W-9°W, 4°S-7°N), high dispersion is driven by the interaction of the eastward-flowing North Equatorial Countercurrent and the Guinea Current [22]. The interaction of these currents enhances horizontal transport, enabling dFADs to traverse diverse oceanographic regimes and increasing the likelihood of transboundary litter impacts, including beaching in remote or protected coastal areas. Similarly, the northern Gulf of Guinea (9°W-3°W, 2°N-6°N) exhibits high dispersion, likely resulting from a combination of lower deployment densities and complex local circulation. Features such as coastal upwelling, mesoscale eddies, and the persistent influence of the Guinea Current generate unpredictable drift trajectories [23] [24]. Reduced clustering in this region allows for greater drift freedom, resulting in more dispersed movement. In the northeastern Gulf of Guinea (3°E-8°E, 2°N-6°N), drift behavior appears to be influenced by the retroflexion of the Guinea Current [23], which redirects flow southward and westward. This hydrodynamic feature may extend and diversify dFAD trajectories, particularly in the context of low deployment densities.

The spatial distribution of beached dFADs along the Gulf of Guinea coastline reveals significant regional variation (**Figure 6**), similar to the findings of [8]. The highest densities of beached dFADs were observed in the northeastern part of the study area (3°E-8°E, 4°N-6°N), a region influenced by the retroflexion of the Guinea Current [25] and relatively low deployment density of dFADs. The retroflexion of the Guinea Current may increase the likelihood of beaching by redirecting dFADs shoreward, while the low density of deployments reduces the probability of entanglement or prolonged retention at sea. These combined factors make

the northeastern coast particularly vulnerable to marine litter accumulation from dFADs. [6] demonstrated that, in the Indian and Atlantic Oceans, the areas with the highest risk of dFAD beaching do not overlap with regions of highest deployment activity. A second area of concern is the northern Gulf of Guinea (8°W-0°, 4°N-6°N), where substantial dFAD beaching also occurs, albeit at slightly lower densities. In this region, cyclonic eddies exhibit a notable characteristic: eastward propagation [23]. The coastline constrains their northward movement, while the eastward-flowing Guinea Current prevents westward drift. As a result, these eddies become trapped along the coastline, increasing the probability of dFAD beaching, in addition to the effects of the Guinea Current itself. Moreover, the region is characterized by coastal upwelling, which may further promote beaching through increased dispersion of dFADs. In the southeastern part of the study area, this pattern is consistent with the previously observed limited movement of dFADs, which likely reduces the risk of beaching [6]. In the northwestern region, the lower beaching density is likely a result of stronger offshore transport mechanisms, predominantly driven by the westward-flowing South Equatorial Current, which enhances the likelihood of dFADs being carried away from the coastline.

The presence of beached dFADs in the Gulf of Guinea presents a significant environmental concern, especially for ecosystems. The northern Gulf of Guinea, with its coastal upwelling system, is particularly vulnerable to the negative impacts of dFAD accumulation. This upwelling supports high marine productivity, and the presence of beached dFADs could disrupt the reproductive activities of species such as *Sardinella aurita*, which are vital for local food chains and fisheries [26]-[28]. Spatial analysis reveals a concerning overlap between beached dFADs and key spawning habitats, with the highest concentration occurring in the North-East Gulf of Guinea, accounting for 17% of all dFAD beachings. Cape Three Points inshore follows closely with 11.5%, while other regions, such as Cape Palmas and the Mid-East Gulf, show lower percentages of beaching (Figure 7). When marine organisms consume synthetic materials, such as beached dFADs, these materials can enter marine food webs [18]. Beached dFADs, particularly those with rope and net components, are also known to physically damage sensitive marine habitats such as coral reefs and seagrass beds, and can pose risks to protected species. These materials may enter marine food webs [15], contributing to long-term ecological harm. This highlights the urgent need for effective management strategies to mitigate the environmental impact of dFADs. Without such measures, the delicate balance of the Gulf of Guinea's ecosystems, and the livelihoods that depend on them, will remain under threat.

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Author Contributions

H.A., Y.B., and D.K. organized and sampled the datasets, and conducted the analyses. All co-authors reviewed and contributed to the writing of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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