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The Distribution, Composition, and Management of Drifting Fish Aggregating Devices (Dfads) in the North Atlantic Ocean

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By
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Abstract

Drifting Fish Aggregating Devices (dFADs) are a gear accessory utilized on a global scale by commercial fishers to increase catch size and efficiency of target pelagic fishes such as tuna and dolphinfish. Despite their widespread use, there are few scientific estimates of the total number of abandoned or beached dFADs in the Atlantic Ocean and Caribbean Basin or the compliance of dFAD use with t-RFMO recommendations. Previous studies have utilized the modeled drift trajectories of dFADs to predict beaching probability and location, but this study is the first of its kind, analyzing true beaching events. This study identifies the beaching location, composition, and ICCAT Rec. 19-02 compliance of stranded dFADs in the western North Atlantic and Caribbean Sea using citizen science data reported over social media. Abandoned, lost, or otherwise discarded (ALDFG) dFADs were reported on the shores of the Gulf of Mexico, along the Atlantic coast of the United States and 17 Caribbean island nations, with reports as distant as Scotland, Ireland, and Brazil. Sixty-one (22.8%) dFADs were reported as having beached in United States National or State Parks, MPAs (both domestic and foreign), as well as foreign conservation areas. Furthermore, a total of 119 (61.03%) of photo-documented dFADs were non-compliant. It is my recommendation that the distribution of abandoned lost, and otherwise discarded dFADs be surveyed in the North Atlantic Ocean to gain better understanding of the scope of dispersal and construction. Additional research is necessary to determine best practices of identification marking schemes and ALDFG recovery incentives.

Keywords: Drifting FAD, ICCAT recommendations, t-RFMO, Marine debris, ALDFG

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First and foremost, I'd like to extend my gratitude to those individuals that have reported FADs from around the Atlantic Ocean. Without your efforts, this project would never have taken off. I am incredibly grateful for the support and knowledge offered to me by my committee throughout the entirety of this process. Thomas Pitchford, this project would never have been possible without your curiosity and tenacity. I am both honored and baffled that you permitted a first-time researcher to take over your carefully cultivated dataset. Dr. Rosanna (Zan) Milligan, without your assistance, this project would have taken a great deal longer and I would still be deciding which statistics to run. Dave, Dr. Kerstetter, Boss, Captain-thank you for challenging me, for bringing me to far too many RFMO workshops, and for having me drive to Homestead more times than anyone in their right mind should. Thanks for the drinks, the words of encouragement, the professional insight, the laughs, and the ever-optimistic feedback. Mom, Dad, Jaclyn-your words of encouragement over the past 26+ years have kept me grounded while ensuring I still dream big. Madds, you've kept me sane, talked me off countless ledges and believed in me unconditionally since the day we met. Doug, thank you for stopping my spirals, for reminding me that "no one knows what they're doing, especially at 25", and for holding my hand for two years. To my friends, thank you for your continued support, you've offered shoulders to lean on, reasons to laugh, and insight into the world of academia. I'm so proud to have worked alongside all of you over these past three years.

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Introduction

Several species of tuna have high economic value and serve as critical sources of nutrition and income in both developed and developing countries (Gershman et al. 2015). Commercial tuna fishing catches have increased from less than 500,000 metric tons (mt) through the 1950's to approximately 4 million mt in 2002, valued at USD $5 billion (Bayliff et al. 2005). The total annual catch of tropical tuna globally has remained relatively consistent thereafter, with a total catch of ~4.57 million mt in 2012 and 5.2 million mt by 2018, valued at USD $40.8 billion (McKinney et al. 2020). Of this harvest, approximately 60% was caught by purse seine vessels (Fig. 1), and 65% (or ~1.98 million tonnes) of that purse seine catch was taken off floating objects (Scott and Lopez 2014; ISSF 2020). In the equatorial Atlantic Ocean, purse seine vessels typically target bigeye tuna (*Thunnus obesus*), skipjack tuna (*Katsuwonus pelamis*), and yellowfin tuna (*Thunnus albacares*) (Scott and Lopez 2014). In 2012, 13% of yellowfin, 35% of bigeye, and nearly 80% of skipjack tuna harvested by purse seine vessels were caught using floating objects (FOBs) in the Atlantic Ocean (Scott and Lopez 2014).

For thousands of years, humans have been utilizing floating debris to enhance fishing success worldwide (Gershman et al. 2015). Flotsam, as well as felled trees, palm fronds, and other floating debris, are commonly known to attract a variety of marine species to the shelter they offer in the pelagic zone where little natural refuge can be found. Fish Aggregating Devices (FADs) function in the same manner, attracting various species to the protection beneath a floating or neutrally buoyant object (Maufroy et al. 2015). The term FAD encompasses any floating object that has been purposefully deployed with the intent to enhance fishing success, though some fishers refer only to man-made floating objects as FADs (MRAG 2017). FAD fishing by artisanal fleets became common in the late 1980s, and shortly after, purse seine vessels began to utilize thousands of drifting FADs (dFADs) annually in the Atlantic Ocean (Scott and Lopez 2014).

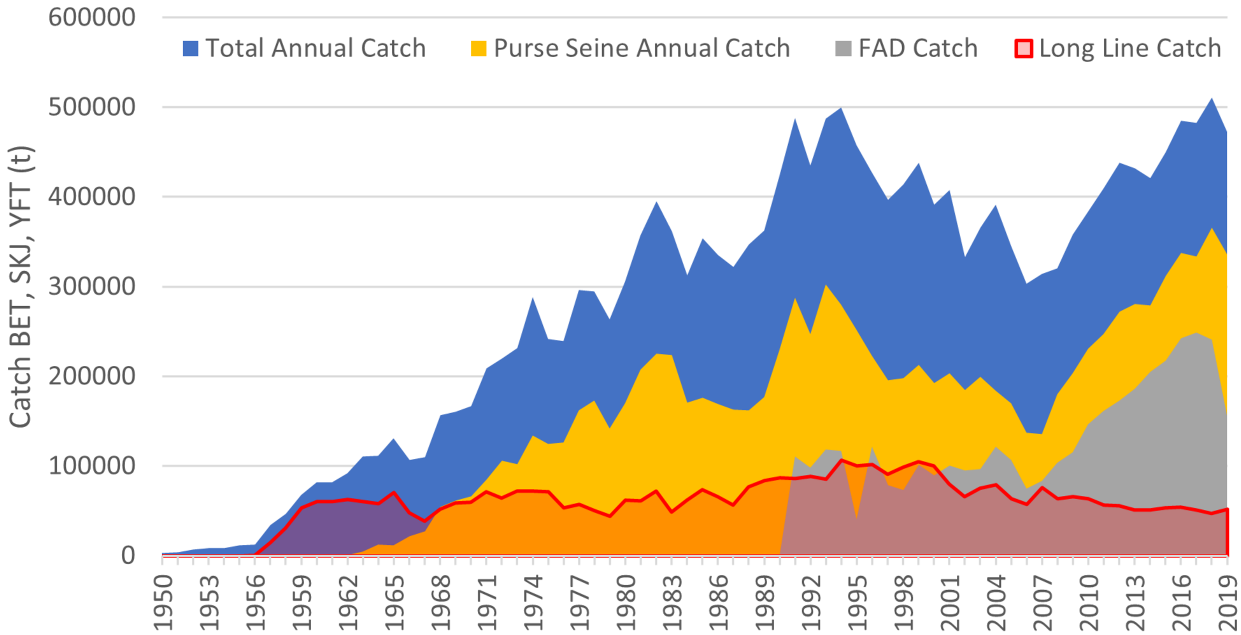


Figure 1. Total annual catch of bigeye tuna (*Thunnus obesus*), skipjack tuna (*Katsuwonus pelamis*), and yellowfin tuna (*Thunnus albacares*) by all flag nations by all gear types (blue), annual catch by purse seine vessels (yellow), annual catch of FAD sets (grey), and annual catch from pelagic long line (red line) from 1950-2019 in the Atlantic Ocean and adjacent seas (ICCAT Nominal Catch Information). Annual catch measurements are in metric tonnes (mt).

In 2012, it was estimated that between 81,000 and 121,000 drifting FADs are deployed worldwide annually and since 2011, the number of dFADs deployed in the Atlantic and Indian Oceans have increased fourfold (Gershman et al. 2015; Maufroy et al. 2017). Drifting FAD sets are deployed by purse seine vessels and are allowed to drift freely (often referred to colloquially as “soaking”), typically while being monitored remotely. The structure of a dFAD encourages the aggregation of various species, including tuna beneath the floating structure, enhancing the catch size and efficiency of purse seine fishing. Purse seine nets are deployed around a dFAD which is then pulled back on board with the catch for eventual retirement or redeployment (Hanich et al. 2019). This fishing technique has been adapted worldwide at industrial scales (Beverly et al. 2012).

Modern FADs are simply surface or sub-surface platforms that vary in construction method. Materials used for dFAD platforms (also referred to as “rafts” or “floats”) range from commercially manufactured plastic discs to home-made rafts of miscellaneous items such as bamboo, PVC (polyvinyl chloride) pipes, ethylene vinyl acetate floats, high-density polyethylene (HDPE), and polyethylene terephthalate (PET) containers or bottles that are bound together with synthetic netting and rope. Most designs also have subsurface components, often referred to as “aggregators” or “curtains”, to further increase attraction of small fishes and other prey while improving the ability to catch currents and drift further (Fig. 2), thus increasing both range and aggregating more fishes (Maufroy et al. 2015). Longer aggregators have greater surface area, thus generating greater drag and reducing the speed at which as dFAD drifts with currents and allows biomass to accumulate in greater amounts. In the Atlantic Ocean, dFAD curtains are typically 80-100 m long, with greater depth of gear associated with a greater risk of entanglement and beaching events not restricted to shorelines, such as those that become entangled with corals and can no longer drift freely (Curnick et al. 2020). Biomass begins to aggregate around the subsurface components roughly fourteen days after deployment, with engagement peaking at approximately 40 days (Jayakody and Pieris 2003; Orue et al. 2019). A cover of mesh netting or shadecloth on the platform is often incorporated to maintain the integrity of the dFAD and reduce the impact of weathering.

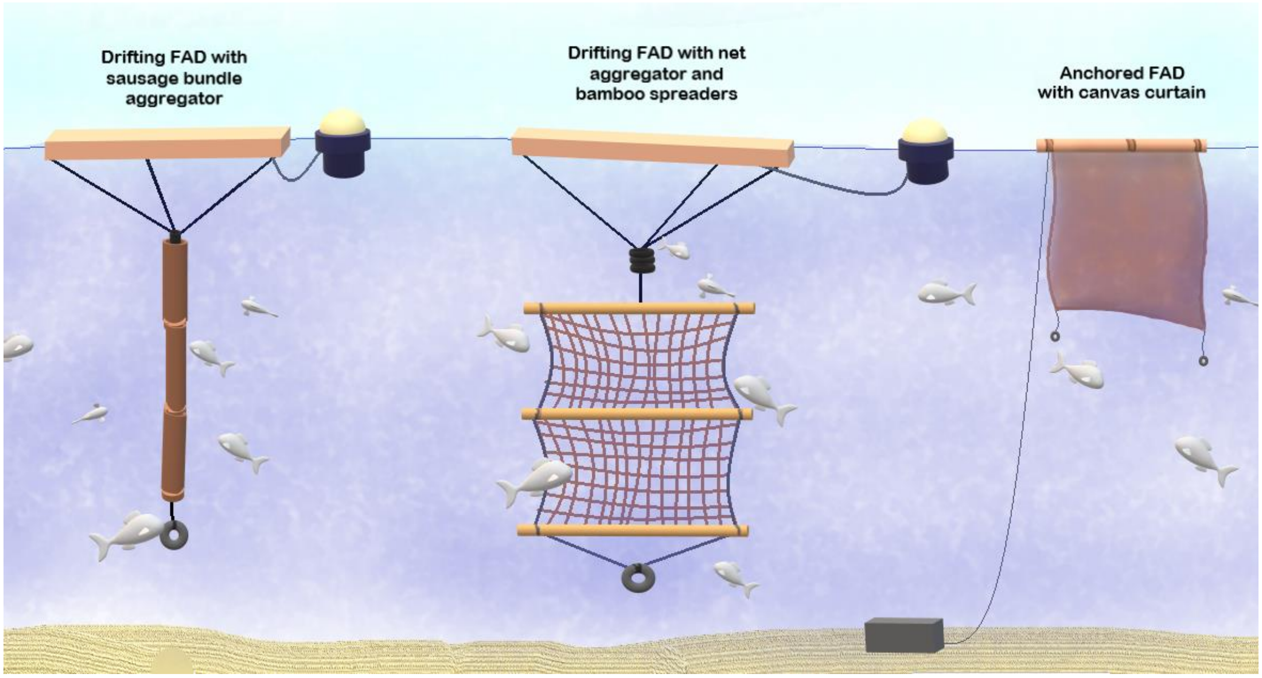


Figure 2. Examples of typical construction of drifting FADs with sausage bundle aggregators (left), drifting FADs with net aggregators and bamboo spreaders (middle), and anchored FADs in the Atlantic Ocean (right). Drifting FAD models vary by ocean basin. Drifting FADs are commonly composed of a platform of various material, ranging from bamboo, plastic jugs, and manufactured plastic discs to provide buoyancy and shelter to target species, a satellite-linked beacon buoy to allow remote tracking and a curtain of netting and ropes beneath the platform to increase attraction of target species. Anchored FADs are commonly composed of PVC pipes or a bamboo pole for buoyancy, with netting or burlap sacks draped beneath serving as an attractant to target species, and an anchor to secure the aFAD.

The design of FAD platforms dictates the cost of construction, with homemade rafts costing very little, as materials are often readily available, and manufactured platforms retailing at approximately USD $1900 (J.J. Chicolino Co. 2020). The satellite-linked GPS buoys that are frequently associated with dFADs are used by large-scale purse seine fisheries and allow fishers to remotely track dFAD location. The use of radio beacon buoys to track dFADs became commonplace in the mid-1980s and into the 1990s. These buoys were replaced in the early 2000s by solar-powered GPS-equipped buoys (Imzilen et al. 2021). The majority of contemporary models of satellite-linked beacon buoys have an echo-sounder incorporated that monitors the presence or absence of an aggregation beneath the buoy with sonar and transmits the data via satellite to the fisher. The average retail price of these buoys ranges from USD $1000 to $1500 with bulk rates available. Occasionally, buoys are stolen from deployed FADs by competing vessels to replace the buoy with one of their own to harvest more target species (Baske et al. 2012). Anchored FADs (aFADs) are generally used by artisanal fishers in nearshore areas and do not have associated tracking buoys.

In the Atlantic Ocean, European and Asian commercial fishing vessels commonly deploy dFADs along the west coast of Africa, typically off the coasts of Côte d'Ivoire, Ghana, and Gabon (Maufroy et al. 2015). Drifting FADs are also deployed on a smaller scale by artisanal fishers in the Caribbean Sea. The dFADs deployed off the African coast are allowed to drift westwards across the Atlantic, with both location and aggregations monitored remotely by vessels utilizing the satellite-linked beacon buoys attached to the rafts. Occasionally, a dFAD can drift too far to be recovered in a financially practical manner, or may become damaged in some way, resulting in the loss or abandonment of the FAD. Additionally, dFADs that drift west of 30° W are less likely to be recovered by the deploying vessel as they drift out of fishing grounds (Maufroy et al. 2015). It is estimated that the average cost to a fishing vessel of recovering "lost" dFADs is approximately USD $1125 ± $75, approximately equivalent to the cost of a satellite-linked FAD buoy (Banks and Zaharia 2020). This monetary expense is accompanied by the cost of time spent not fishing for target species and the subsequent loss of catch and profit. In these scenarios, the dFAD is often abandoned by the vessel, and the satellite beacon buoys are subsequently deactivated, ceasing all transmissions from the buoy. These abandoned dFADs then drift with prevailing currents and wind patterns, with some eventually washing ashore, sinking, or becoming entangled with marine organisms. The intentional deactivation of the satellite-linked beacon buoys affiliated with dFADs is banned under MARPOL Annex V, as the intentional discharge or disposal of fishing gear is prohibited (MARPOL 1987). As of 2015, approximately 20% of intergovernmental organizations (IGOs) had mandatory efforts in place to mitigate and monitor abandoned, lost, or otherwise discarded fishing gear (ALDFG), though this number has since expanded, as Regional Fisheries Management Organizations (RFMOs) have added resolutions that include the recovery of abandoned gear such as FADs (Gilman 2015).

Although FADs may be lost or abandoned for a variety of reasons, they often result in negative impacts that are also commonly associated with other ALDFG, including megafauna entanglement, ghost fishing, socioeconomic costs, and the introduction of plastics to the marine environment. Over one-third of all marine debris in the oceans are ALDFG or other marine-based litter (Consoli et al. 2020). FADs that have been abandoned or lost continue to pose a threat to marine life, as they do during active deployment and monitoring because they are a type of passive gear, meaning that they do not require regular maintenance to serve their intended purpose (Morena et al. 2018). The environmental impacts of dFADs, both active and derelict, are amplified by the prolific use of durable, synthetic materials in dFAD construction such as nylon ropes and netting, as well as exposure-resistant plastics. A study conducted by the Island Conservation Society of the Seychelles documenting beached FADs on St. Francis Atoll found that 39% of FADs had become entangled with coral, and over 70% of all FADs observed were composed of synthetic materials (Zudaire et al. 2018). The presence of more FADs made of synthetic materials than biodegradable materials may be a result of manufactured materials being more durable and less susceptible to extreme weathering and sinking over pronged periods of exposure. Although some research in the Indian Ocean (Filmalter et al. 2013; Stelfox et al. 2016) details the construction of dFAD rafts, there has been little effort in the Atlantic Ocean to do the same.

FADs with subsurface aggregators pose an additional entanglement risk to organisms such as sea turtles, sharks, marine mammals, and various fishes, as well as corals and other benthic species when they enter shallow waters (Gilman 2011). A study of megafauna entanglement reported reptiles, pinnipeds, cetaceans, elasmobranchs, and sirenians entangled in ghost fishing gear (Stelfox et al. 2016). In the Indian Ocean alone, an estimated 480,000 to 960,000 silky sharks (*Carcharhinus falciformis*) were annually killed as a result of dFAD entanglements based on data collected between 2010 and 2012 (Filmalter et al. 2013). In the Atlantic Ocean, bycatch from FADs set for tropical tuna accounts for 2-8% of total catch by weight (Scott and Lopez 2014). Filmalter et al. (2013) also found that dFADs, both active and abandoned, generated a mortality rate in sharks that was five to ten times greater than that of active purse seining in the Indian Ocean. Megafauna entanglements in FADs are difficult to quantify because dead animals will often fall off the gear or be removed by scavengers after approximately two days, resulting in a small window in which to observe the entanglement (Filmalter et al. 2013). The transition from traditional FAD construction techniques and materials to non-entangling, biodegradable models is thought to be one of few feasible methods of significantly reducing the risk of entanglement with dFADs, particularly after they become ALDFG (Morena et al. 2018).

Though bycatch and entanglement are prominent effects of abandoned dFADs, both operational and derelict FADs contribute to overfishing and stock depletion (Hanich et al. 2019). Skipjack, bluefin, and albacore tuna stocks are not overfished in the Atlantic, while yellowfin and bigeye stocks are overfished, and bigeye are also subject to overfishing (ICCAT 2019). As a result, annual catch limits for bigeye have been reduced from 65,000 mt in 2016, to 62,500 mt in 2020, and 61,500 mt in 2021, though the total allowable catch for yellowfin has remained consistently 110,000 mt since 2012 (ICCAT Rec. 16-01, 19-02). Overfishing of juvenile tuna from dFADs is also of concern in the Atlantic Ocean and may result in loss of potential yield or a reduction in the number of reproductively active individuals (Davies et al. 2014). There is no discrimination between juvenile and mature individuals caught by purse seine vessels utilizing dFADs. Most tunas caught from FADs are less than 70 cm in fork length (Marsac et al. 2000). Bigeye tuna are considered mature at a fork length (FL) of approximately 100 cm, at roughly three years, while yellowfin tuna are considered mature at 104 cm FL, and skipjack tuna mature at approximately 45-50 cm FL (ICCAT 2019 SCRS Report 9.1 YFT; ICCAT 2019 SCRS Report 9.2 BET; ICCAT 2019 SCRS Report 2.1.3 SKJ). The increased proportion of catch consisting of juvenile tuna in the eastern Atlantic Ocean has caused a stock-wide reduction in yield per recruit of bigeye and yellowfin tuna, although the true extent of this is unknown, as juvenile bycatch is often unreported (Dagorn et al. 2013).

While derelict fishing gear presents a persistent threat to mobile species that traverse the water column, it can also negatively impact sessile, benthic marine life. In the Mediterranean

Sea, the mean density of marine litter recorded by a remotely operated vehicle (ROV) was 4.63 items/100 m^2 (Consoli et al. 2020). Seafloor ALDFG made up 96.8% of all marine litter recorded in their study, and FAD ropes comprised 81.1% of all litter observed, making this FAD component the most prolific item recorded. Litter-fauna interactions were commonplace, with 47.6% of debris items having at least one engagement. FAD ropes were again the most common item, accounting for 88.6% of all litter-fauna interactions. There are two regulations in place that manage FAD fishing in the Mediterranean, the first being a time-area closure from January through August throughout the entirety of the Mediterranean. Additionally, Malta has restricted FAD fishing to designated zones. Despite these ordinances, the Mediterranean faces similar problems to that of the Atlantic Ocean, where there are few efforts to mitigate FAD use and environmental impacts, and there is no incentive to remove FADs after use or at the close of the season (Consoli et al. 2020). Studies suggest that removal of abandoned FADs from pelagic waters may be cost-prohibitive, particularly with derelict FADs that have sunk (Schled et al. 2016).

As the number of dFADs deployed globally continues to increase, the number of Marine Protected Areas (MPAs) is also rising. The passive nature of dFADs is occasionally exploited by fishers that deploy dFADs outside MPAs with the knowledge that currents will carry the gear through restricted waters. Vessels then navigate around MPAs and fish off the FADs that have aggregated target species within the MPA boundaries. This risk of passive dFAD fishing through MPAs was studied in the Chagos Archipelago, a cluster of 14 shallow atolls located in the Indian Ocean south of the Maldives. Curnick et al. (2020) modeled dFAD trajectories from 16 origin locations outside the archipelago, and found that in > 14 days, 37.51% posed a risk of beaching or traversing the MPA though the risk decreased over time. A total of 8.13% of the dFADs modeled beached under all deployment circumstances with temporal and spatial variations (Curnick et al. 2020).

Abandoned, lost, or discarded dFADs are often subject to intense weathering as a result of their prolonged time at sea. As a result, they can begin to degrade and introduce macro (> 5 mm in size) and micro (< 5 mm in size) plastics to the environment as a result of physical weathering and photodegradation. Reports of lone satellite linked beacon buoy and lone rafts, in addition to full dFADs composed of both a buoy and a raft, have been made from around the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico, often believed to be the result of physical or photo degradation according to reports received by the CFTP. Traditional FAD platforms constructed of bamboo are often built using hundreds of meters of synthetic rope and netting that are susceptible to degradation under extreme conditions and contribute to marine debris and ghost fishing. Octagonal rafts with floats composed of 5 L plastic jugs and containers are common in the Atlantic, where they are predominately utilized by Spanish fleets, where they are referred to as "parrilla octagonal", translated literally to "octagonal shelf" (Zudaire et al. 2019). In 2016, the Spanish technology company Zunibal created the Zunfloat™, a reusable manufactured plastic disc intended to generate a lesser impact on the marine environment than previous FAD platforms (Zunibal 2020). Zunibal touts the Zunfloat™ as a recyclable and reusable product that is resistant to deformation, does not degrade with sunlight or in seawater, and produces less waste and less environmental impact (Zunibal 2020). To date, there not been any published research substantiating these claims. JJ Chicolino SL, a Spanish company specializing in the production of fishing and aquaculture gear, has recently begun manufacturing a similar, supposedly non-entangling dFAD raft (JJ Chicolino 2020).

Atlantic dFAD deployment typically occurs in the waters around the Gulf of Guinea off the African coast (Angel et al. 2014). Deploying in this region allows commercial dFADs to be passively transported by the Southern Equatorial Current or other smaller, regional currents and be passively carried through the pelagic waters that are commonly inhabited by a variety of tuna species. This methodology requires minimal effort from fishers, though there is no definitive certainty regarding the path a deployed dFAD may take. The trans-Atlantic movement of dFADs is likely aided by equatorial surface currents flowing west from the west coast of Africa towards the east coast of North and South America (Fig. 3). Water, biota, and marine debris have the potential to be swept into the Greater Caribbean region by these currents, and carried further north by the Caribbean Current, Gulf of Mexico Loop Current, Florida Current, and the Gulf Stream, respectively, though there are no estimates as to the percentage of dFADs that remain in the gyre or are transported further north (Fratantoni; Renner 2004). These currents express very little seasonal variation, though loop current eddies are periodically generated, returning to the Gulf of Mexico rather than the Florida Straits, and seasonal differences in the number of dFAD beaching events are not related to changes in prevailing currents, as is possible in the Indian Ocean (Bourles et al. 1999, Imzilen et al. 2021).

The influence of prevailing ocean currents is not solely restricted to trans-basin transport but is also believed to contribute to beaching events of marine debris and ALDFG. The speed of slower coastal currents may also affect the levels of stranded derelict fishing gear, with slow currents likely contributing greater amounts of marine debris to beaches, as floating objects remain in the region longer in areas of reduced mean current velocity (Storrier et al. 2007). Specific to the western North Atlantic Ocean, the Caribbean current has the lowest mean current speed as determined by satellite-tracked surface drifters (31 cm s^{-1}), while the Loop Current in the Gulf of Mexico, the Florida Current, and the Gulf Stream have mean surface current speeds of 61 cm s^{-1}, 97 cm s^{-1}, and 60 cm s^{-1}, respectively (Fratantoni 2001). Average current speeds, directionality, and other components are subject to change as they interact with coastlines, the seafloor, wind, and other external factors, therefore they are not always accurate predictors of the coastal flows that result in dFAD strandings. The distance of stranding locations to local sources of marine debris is also a contributing factor to the amount of debris in a coastal environment. Human coastal population and commercial fishing activity are considered the main regional drivers of marine-based coastal debris in the Atlantic Ocean (Ribic et al. 2010). In addition, the density of marine debris has been observed to be greater on the windward shores of Caribbean islands than the leeward side as a result of prevailing winds and currents bringing more debris to those locations (Debrot et al. 1999).

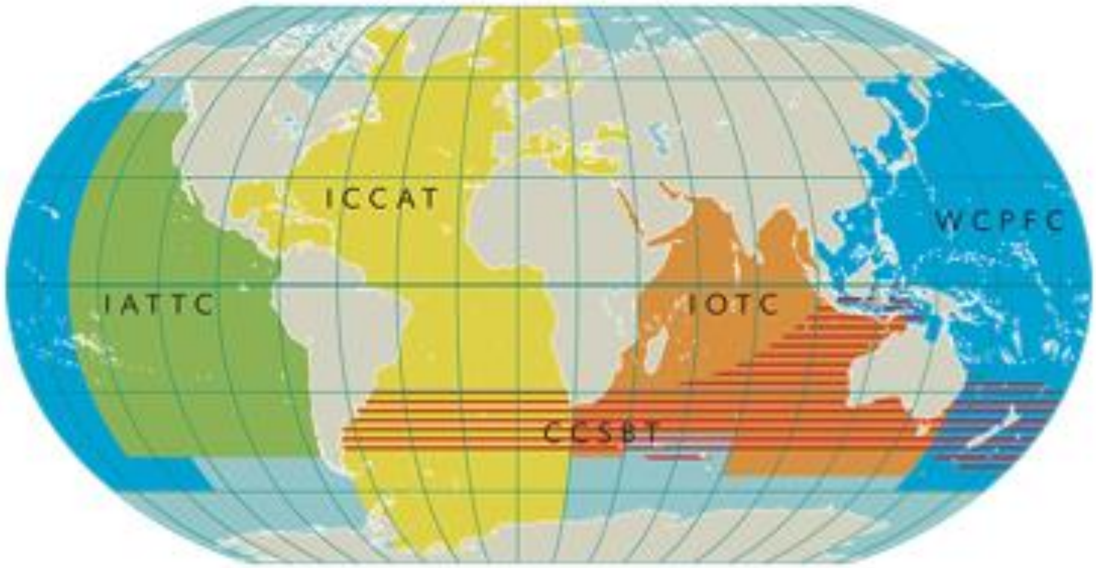


Figure 3. A visual representation of designation of tuna Regional Fisheries Management Organization's waters are depicted as follows-ICCAT waters are yellow, the fishing grounds overseen by IOTC are orange, IATTC regulated waters are shown in, WCPFC waters are dark blue, and CCSBT water is designated by red stripes (Source: Maribus 2013).

Few modelling studies predicting dFAD distribution have been conducted globally, though several basin-wide studies have been completed in the Atlantic and Indian Ocean. In 2015, Maufroy et al. attempted to predict the stranding locations of abandoned dFADs in the Western Atlantic Ocean, though this study did not consider the stranding of Atlantic dFADs on North American or Caribbean shores. Maufroy et al. (2015) used the GPS positions of the satellite-linked beacon buoys of dFADs deployed by French purse seine vessels operating in the Atlantic and Indian Oceans from 2007 to 2011 to identify the primary region and season of Atlantic and Indian Ocean dFAD deployment, as well as the total extent of their drift. Mean "at-sea drift speed" was found to be 1.3 $m\ s^{-1}$, providing a mean rate for researchers to apply to dFADs to attempt to recreate the path taken to the final stranding location. It was determined that on average, dFADs deployed in the two basins drifted for 39.5 days and travelled 1285.5 km before recapture or stranding, with an estimated 9.9% of all deployments ending with beaching events and outliers beaching on South American coasts (Fig. 4).

A similar paper by Imzilen et al. (2021) modelled the trajectories of dFADs and suggested that limiting regions of dFAD deployment would reduce beaching events in the Indian and Atlantic Oceans. The trajectories of 12,000 dFADs deployed between 2008 and 2017 by French fleets off the coast of Mauritania, Gabon, and Angola were tracked until retrieval, loss, or a beaching event occurred. In that time, a total of 19-22% of all deployed dFADs were beached, this percentage stabilizing at ~22% after 2013. This stability is thought to be related to the increased use of echosounder buoys during this time, the deactivation of unproductive buoys to remain under RFMO quota, and reduced capacities on the number of dFAD buoys per vessel. Imzilen et al. (2021) found that that the majority of dFADs became stranded along the West African coast and along the Gulf of Guinea, while beaching events in the Caribbean and along the coast of Brazil were considered sporadic. This estimated beaching of ~19-22% of all dFAD deployments, in combination with the estimated total number of annual, global dFAD deployments determined by Baske et al. (2012), suggests that there could be as many as 15,390-26,620 dFADs lost annually worldwide. Because there have not been any studies of the distribution of beached dFADs in the Atlantic and Greater Caribbean utilizing definite stranding data as opposed to projected trajectories and simulations, this study is the first of its kind. The use of observational studies to validate the results of predictive modelling studies such as that of Maufroy et al. (2015) and Imzilen et al. (2021) is considered highly important, though often challenging due to the physical limitations and difficulties affiliated with the collection of observational data (Chassignet et al. 2018). These studies serve to ensure that predictive models "reflect reality" and can be used in future predictions with limited uncertainty (Eker et al. 2018).

The five tuna Regional Fisheries Management Organizations (t-RFMOs) have stated their intention to reduce the impact of abandoned and lost FADs through the introduction of a variety of resolutions and recommendations (Table 1). In addition, these t-RFMOs committed to a collaborative effort called the Kobe Process (named for the inaugural meeting in Kobe, Japan), whose purpose is to enhance the collaboration and cooperation between The Indian Ocean Tuna Commission (IOTC), Inter-American Tropical Tuna Commission (IATTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), the Western and Central Pacific Fisheries Commission (WCPFC), and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT[1]). The t-RFMOs IOTC, IATTC, ICCAT and WCPFC began to regulate the use of dFADs in 1999 and have continued to research and periodically update Conservation and Management Measures (CMM), Resolutions, and Recommendations (hereafter referred to as regulations), including IATTC Res. 99-07, WCPFC CMM 2008-01, ICCAT Rec. 11-01, and IOTC CMM 12/08 (Fig. 5). Though these regulations were implemented to reduce the impact of active dFADs, they also serve to indirectly reduce the impact of derelict dFADs as ALDFG.

[1] The CCSBT, while one of the five t-RFMOs, does not have any fisheries utilizing dFADs and thus does not have any regulations regarding their use. The CCSBT will not be discussed further in this study.

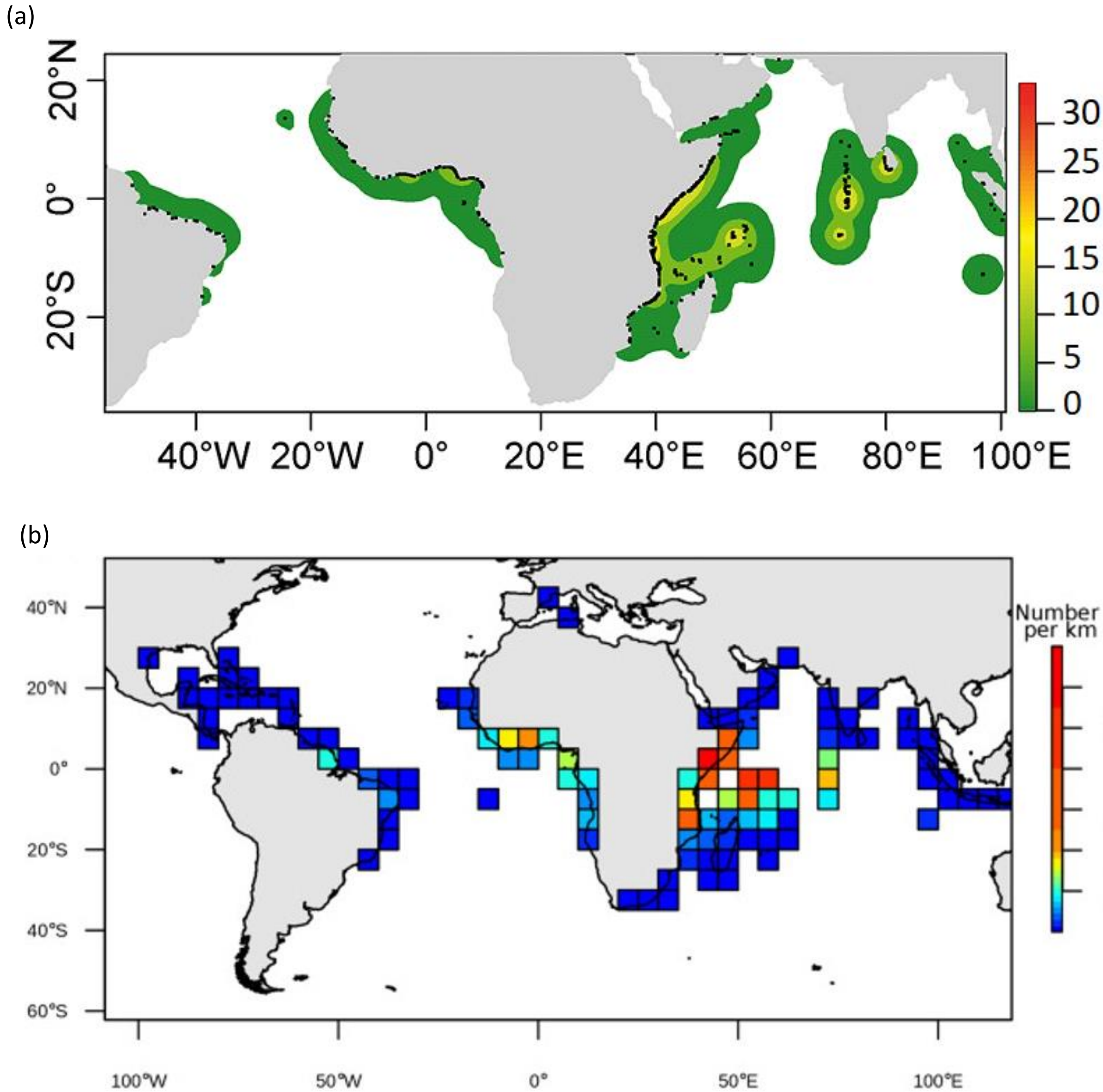


Figure 4. The beaching location of French dFAD buoys from predictive modelling studies based on rate of movement. The smoothed densities of dFAD strandings in the Western Atlantic Ocean for the period of 2007-2011 (a). Black dots correspond to individual stranding locations (Source: Maufroy et al. 2015). The number of French dFAD beaching events recorded per km of continental shelf edge in each 5◦x5◦ grid cell for the period 2008–2017 (b) (Source: Imzilen et al. 2021).

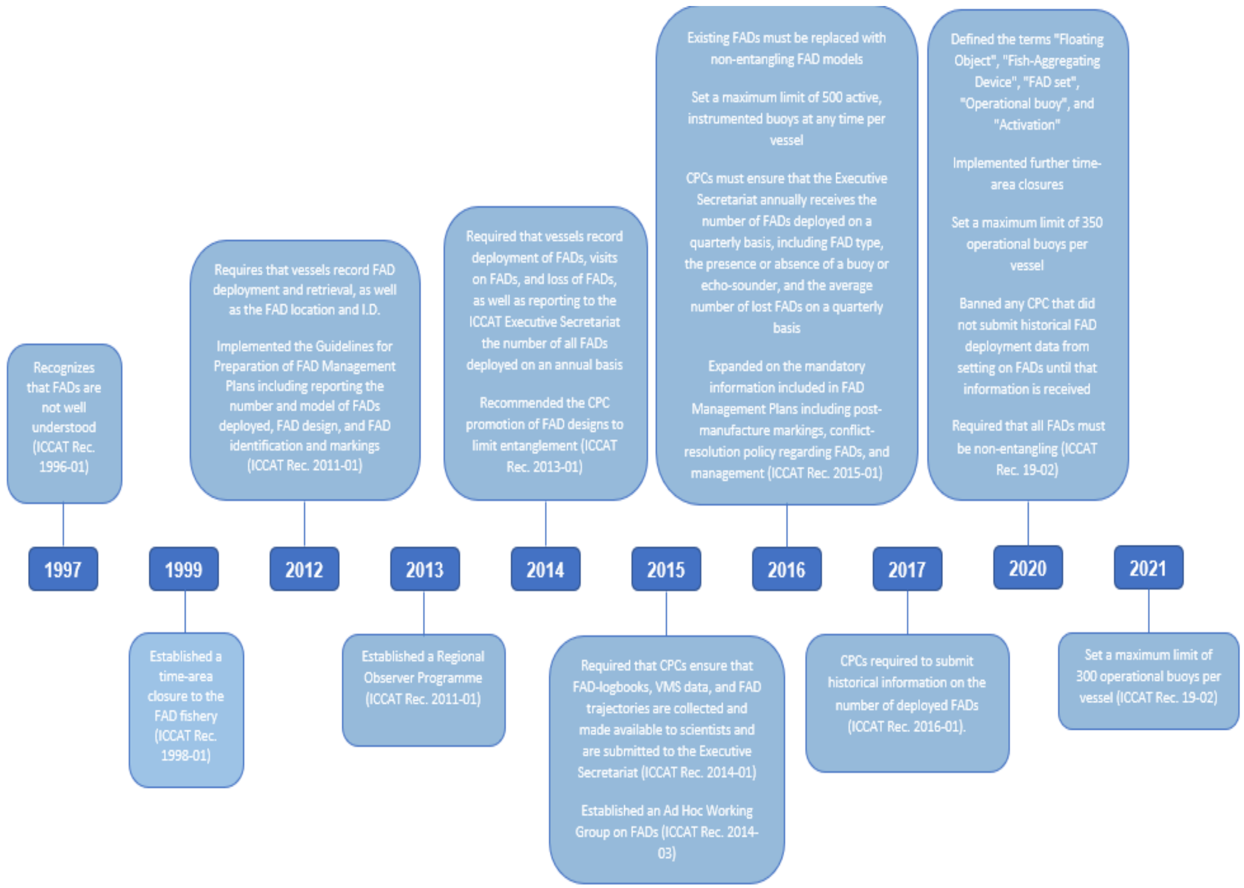


Figure 5. A timeline of ICCAT Recommendations regarding FAD use, construction, and management from 1997 to present. Active measures implemented in 2020 (ICCAT Active Recommendations, Resolutions, and Other Decisions, ICCAT Rec. 19-02).

In order to reduce the entanglement risk of dFADs, ICCAT requires that all dFADs be not covered, or covered in a material that does not pose a risk of entanglement. Additionally, sub-surface dFAD components may not include entangling materials such as netting, but rather should be made of materials such as ropes or canvas. However, ICCAT Rec. 19-02 does not require that outdated and non-compliant dFADs be recovered by deploying vessels and updated or replaced to meet the new standards of construction. This likely results in a number of lost and abandoned dFADs being non-compliant with regard to new regulations of construction methods and materials. Surveys in the Seychelles have revealed problems with the t-RFMO recommended aggregator design. So-called "sausage-style" curtains, which are composed of mesh netting rolled into bundles to reduce entanglement risk, are under scrutiny because as they endure exposure, they often unravel, and the fine mesh netting can tear, creating larger holes that increase the risk of entanglement. As a result of such dFAD degradation, the International Seafood Sustainability Foundation (ISSF 2020) redefined non-entangling FADs (NEFADs) as "Fish aggregating devices that are constructed with no netting material... For a FAD to be completely non-entangling, it must use no netting materials either in the surface structure (raft) or the submerged structure."

ISSF further distinguishes FADs that use netting that is intended to have minimal entanglement risk "such as using netting tied in bundles or using small size netting (< 7 cm stretched mesh) are now called "lower entanglement risk FADs (LERFADs)" (ISSF 2015). Balderson and Martin (2015) found that in the Seychelles, 39% of dFADs were entangled and "beached" on reefs. Of these dFADs, 23.8% used synthetic rope as the aggregator, while 48.9% used netting. Of those not beached on coral, 37% had coral entangled in the aggregator, and 100% were made of netting. Nearly half (46%) of dFADs that used sausage nets also had corals entangled, suggesting that such LERFADs may not be sufficiently mitigating the threat of entanglement with sessile marine organisms. Of the 214 dFADs surveyed, 40% did not have a buoy attached, likely as a result of weathering.

Satellite-linked beacon buoys are often used to identify dFADs as the property of individual vessels or fleets. Vessel names, buoy serial numbers, or alphanumeric series are often etched or painted on the dome of the buoys to denote ownership, though this method of marking is not consistent across all participants in the fishery. Ownership and accountability remain pertinent policy issues, with very few requirements or incentives regarding the reporting, deployment, recovery, or labelling of FADs by the various t-RFMOs. All FADs are required to be marked with a unique identifying code of numbers, often the serial number of the affixed satellite-linked beacon buoy, though further guidance is inconsistent between t-RFMOs (WCPFC CMM 2018-01; IATTC Res. 19-01; ICCAT Rec. 19-02; IOTC CMM 19/02). A total maximum number of active and deployed FADs has been independently set by each t-RFMO (Table 1). ICCAT Rec. 19-02 states that all buoys affiliated with dFADs must be legibly marked post-manufacturing with the buoy's unique serial number, though no elaboration has been made regarding the method of such markings.

"The FAD Management Plan for a CPC purse seine and baitboat fleets must include the following: … Radio buoys markings and identifier (requirement for serial numbers) …if FAD marking and associated beacon/buoy ID are absent or unreadable, the FAD shall not be deployed" (ICCAT Rec. 19-02).

There is no further ICCAT guidance regarding the method of marking a buoy, though IOTC and IATTC make additional specifications pertaining to details such as the material used to create the post-manufacture mark (e.g., epoxy-based paint marker) or the size of the post manufacture marking. IOTC has stated the intention to create a series of guidelines regarding the identification marking scheme of dFADs, though ICCAT, IATTC, and WCPFC have not publicized such plans to develop a comprehensive dFAD buoy marking scheme despite their membership in the Kobe Process. The identifying marking on FADs are intended to assist in identifying FADs after deployment, and to incentivize vessels and flag states to retrieve all FADs. Under the jurisdiction of the four t-RFMOs, all dFADs retrievals are to be documented, however, there are no outright requirements that all deployed FADs must be retrieved. Reporting of lost FADs is required by ICCAT, IATTC and IOTC, though the consequence of failing to do so is not stated (IATTC Res. 19-01, ICCAT Rec. 19-02, and IOTC CMM 19/02). It should be noted that enforcement of RFMO regulations is typically left to individual Contracting Parties and Cooperating Non-Contracting Parties (CPCs); there is no centralized enforcement agency for these organizations.

Table 1. Current RFMO Conservation and Management Measures, Recommendations and Regulations as specified by the most recent RFMO compendium as follows; Western and Central Pacific Fisheries Commission (CMM 2018-01, CMM 2020-01), Inter-American Tropical Tuna Commission (Resolutions C-19-01, C-17-02, C-16-01), International Commission for the Conservation of Atlantic Tunas (Rec. 16-01, Rec. 17-02, Rec. 19-02, 20-01), and the Indian Ocean Tuna Commission (CMM 19/02). Note that resolutions by IATTC are binding, while ICCAT's recommendations are considered binding, as are IOTC's and WCPFC's conservation and management measures (Unterweger, 2015). *Maximum number of FADs/Buoys per vessel under IATTC jurisdiction is dependent on vessel class; Class 6 (1,200 m^3 and greater): 450 FADs, Class 6 (<1,200 m^3): 300 FADs, Class 4-5: 120 FADs, Class 1-3: 70 FADs (IATTC 2019; ICCAT 2020; IOTC 2020; WCPFC 2020).

RFMO	Max. No. FADs/ Buoys per vessel	No. Active FADs at any given time	Required Reporting of lost FADs	Use of Non-Entangling FADs	Use of Biodegradable materials	Unique I.D. Marking on FADs Required
Western and Central Pacific Fisheries Commission	N/A	350	Unspecified	Required	Recommended	Yes
Inter-American Tropical Tuna Commission	N/A	70-450*	Yes	Recommended	Recommended, research ongoing	Yes
International Commission for the Conservation of Atlantic Tunas	N/A	300	Yes, annual basis	Required	Recommended, research ongoing	Yes
Indian Ocean Tuna Commission	500 buoys	300	Yes, annual basis	Required	Recommended, research recommended	Yes

In past years, monitoring the compliance of various aspects of dFADs, such as the construction, identification marking, and their deployment has gained support amongst t-RFMOs. Due to the pelagic nature of dFAD deployment, and the limited number of mandatory recommendations regarding the marking of buoys and platforms, there are numerous challenges that arise in the effort to monitor dFAD use. The use of fisheries observers has been recommended by several t-RFMOs, governmental organizations, and non-governmental organizations (NGOs) (Gilman et al. 2018; Zudaire et al. 2019), though there are multiple difficulties including physical challenges such as proximity to gear and suboptimal weather on board a vessel that fisheries observers face (Gilman et al. 2018). Other suggested methods of mitigating dFAD impact and increasing compliance include, but are not restricted to financial incentives, seasonal time-area closures, mandatory recovery, as well as enforcement of other pre-established, mandatory t-RFMO recommendations (Fonteneau et al. 2015). Ownership and dFAD accountability are common issues with such mitigation efforts, as dFAD marking schemes are not public knowledge and attributing responsibility for problematic dFADs can be challenging. Additionally, dFADs are often not marked to indicate ownership, and when they are, many are illegible or do not adhere to mandatory t-RFMO marking regulations (Gilman et al. 2018; Baske and Adam 2019). Post-manufacture markings that meet ICCAT specifications are often not beneficial in determining ownership of dFADs, as these marks contain the serial number of the buoy, but the vessel or entity to which the serial number is registered is not public information. To address this gap in knowledge, we developed a citizen-science reporting mechanism, the Caribbean FAD Tracking Project (CFTP), using a social media platform to collect photographs depicting the marking schemes of satellite-linked beacon buoys and the construction of affiliated dFAD rafts, which were then evaluated regarding compliance with mandatory ICCAT Rec. 19-02.

By studying the distribution and composition of ALDFG FADs, both the commercial tuna industry and fisheries researchers can gain insight into the true breadth of the impacts of such gear. Fish aggregating devices are utilized on a large-scale globally, with an estimated 18,000 dFAD deployments occurring in the Atlantic Ocean annually (Escalle et al. 2021). Approximately 10-22% of all FAD deployments in the Atlantic Ocean end with a beaching event, resulting in roughly 1,800-3,960 dFADs beaching along Atlantic shores and reef tracks every year, a number that is increased further by the failure to recover many dFADs. Due to the nature of dFAD use and monitoring, as well as the structure of active mandatory t-RFMO recommendations, it is challenging to identify and attribute ownership and responsibility for dFADs and their environmental and socio-economic impacts. The Caribbean FAD Tracking Project serves as a centralized reporting agency for ALDFG dFADs in the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico. By analyzing various aspects of the reported FADs, it is possible to better understand the shortcomings of current FAD management, and to validate predicted beaching events from modelling studies that may be utilized in future FAD management.

Methods

Study Area and Caribbean FAD Tracking Project

In 2015, Thomas Pitchford, a wildlife biologist with the Florida Fish and Wildlife Conservation Commission, began independently researching and documenting the reporting of beached dFADs in the western Atlantic in an effort to establish a pattern and substantiate claims that dFAD strandings on Florida beaches were not isolated incidents. As a result of both the geographic scale and the nature of this study, data collection was nearly exclusively supported by citizen science, keyword internet searches, and public reporting. Reports were accepted from any location in the Atlantic Ocean and Caribbean Sea, though the majority of reports are made from Caribbean nations and the southern United States. This research was founded on keyword searches including terms such as “bamboo raft found ashore”, “strange buoy on beach”, “mystery raft”, and eventually encompassed terms that were written on stranded buoys. Searches were conducted on sites such as Instagram, Facebook, Twitter, Flickr, independent blogs, and Google image search. Once finding such “reports” online, Pitchford would contact the person who posted the information in order to determine details such as the find date, the exact location of the FAD, and any other pertinent information and photos that were then recorded in a spreadsheet. Photographs were cataloged by find date, finders name and a brief description of the FAD. Any online report that did not receive a supplementary response was not included in the dataset. Both the find date and the report date were noted, as many dFADs were discovered well before they were reported to the CFTP.

In April 2019, Thomas Pitchford turned over his data to the Caribbean FAD Tracking Project, and now serves as a point of contact between the Caribbean FAD Tracking Project and citizen scientists. At this point, I became solely responsible for the addition, analysis, and upkeep of this dataset (https://nsuworks.nova.edu/faelab/1/). Using the data Pitchford had collected, I created a flyer detailing common elements of dFADs, their use, and information we hoped to receive in a report. This flyer (Appendix I), along with a statement of intention, was distributed to various public and private entities along the Atlantic coast of Florida, as well as to various Caribbean nations including state environmental agencies, sea turtle conservation programs, and beachcomber groups (Appendix II). A month later, in May 2019, I created and published a Facebook page titled the Caribbean FAD Tracking Project (www.facebook.com/fadtrackers) as well as an email account (fadtrackers@gmail.com). The nature of these accounts is to serve as a reporting platform for the public around the Caribbean Sea and North Atlantic Ocean.

In February, March, April, May, July, October, November, and December of 2020, at least 32 articles highlighting dFAD strandings and the affiliated environmental impacts and featuring the Caribbean FAD Tracking Project were published by various newspapers and conservation organizations (Appendix III). In November of 2020, the United Nations Environmental Programme Ninth meeting of the Scientific and Technical Committee (STAC) to the Protocol Concerning Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean Region cited the CFTP in their implementation of the Action Plan for the Conservation of Marine Mammals (MMAP) in the Wider Caribbean: A Scientific and Technical Analysis (Vail and Borobia 2020). This estimated number of publicity events is a conservative approximation, as the Caribbean FAD Tracking Project did not consistently receive notification that we were to be featured. Increases in the number of reports received in the months that the CFTP was featured by a media outlet were observed, though increases in the number of reports were not consistent with the number of publications per month (Fig. 6). The Caribbean FAD Tracking Project did not contact any media outlets; all articles were conceived prior to the news source contacting the Caribbean FAD Tracking Project or were published without the knowledge of the Caribbean FAD Tracking Project.

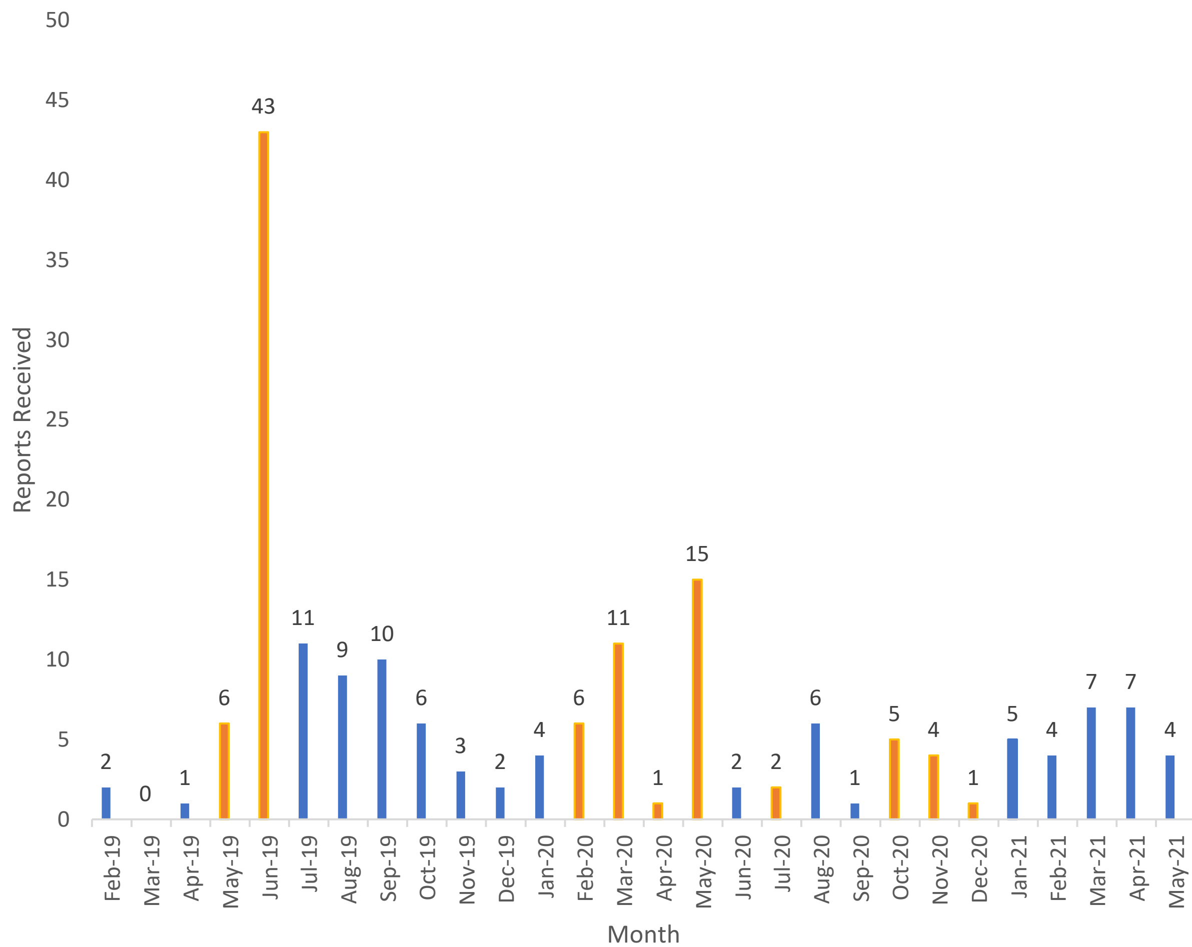


Figure 6. The number of reports received per month by the Caribbean FAD Tracking Project via all methods of communication (Email, personal communication, Facebook). Months when the Caribbean FAD Tracking Project was subject to known external publicity are shaded orange, while months with no known publicity are shaded blue.

Mapping, photograph, and data analysis

Photographs of all reported FADs were requested, though some reports made prior to the establishment of CFTP did not include a photograph (n = 72), and those reports were not included in the analysis of compliance of dFAD buoys. Photos were utilized to substantiate reports made, and confirm the construction materials of dFAD platforms, the make and model of buoys, and post-manufacture buoy markings. Reported dFADs were initially categorized as “lone buoy”, “lone raft”, or “full FAD” – the last term meaning both a raft and a tethered buoy. Rafts were then further categorized as home-made or manufactured, then further broken down by material (e.g., jugs, bamboo, aFAD[2], and PVC) or manufacturer (e.g., Zunibal or JJ Chicolino Co.), or were documented as unspecified in the case of reports that did not include sufficient information or a photograph (Fig. 7). Photographs were again used to determine the make and model of buoys, and any photo that did not clearly depict the buoy were designated as uncertain. Buoys were categorized by manufacturer (e.g., Zunibal, Marine Instruments, SatLink, Thalos, or of uncertain design). Photographed post-manufacture marking on the buoys were recorded and were then categorized as legible, partially legible, illegible, or absent – the last term meaning that the buoy bore no post-manufacturing marks. Reports were then classified by one of three levels of compliance: compliant, non-compliant and uncertain compliance.

The designation of compliance of dFAD platforms and GPS buoy markings were made with reference to ICCAT Rec. 19-02. FAD platforms were studied to determine whether there was a cover or subsurface component made of netting. Only those images that explicitly depicted one of these infringements were designated as non-compliant and were subsequently analyzed. All partially legible, illegible, and absent markings were designated as non-compliant with ICCAT Rec. 19-02 which states that the serial number of the buoy must be marked on the protective dome of the buoy as a method of identification and must be legible. The location of reports that did not specify beaching coordinates were designated based on additional information provided in the report including street names, nearby residential addresses, bays, and beaches. Approximate find locations were denoted as such in the data set. Maps of dFAD distribution versus conservation areas, dFAD material and dFAD compliance were created with

[2] For the purposes of this study, anchored FADs, (aFADs) were categorized as a “Material”, because they were included in the larger category “Home-made FADs”. This designation is made because the construction methods and design of the four observed home-made FAD “materials” differed.

ArcGIS ArcMap 10.8 (ESRI 2019). "USA_Parks" feature service by ESRI 2020, "Caribbean Marine Protected Areas and management effectiveness polygon_data_only_" layer package provided by World Resources Institute 2011, "Major Ocean Currents" feature service provided by NOAA 2016, and "Protected Areas" feature service by TCN et al. 2019 were used to generate a figure comparing the distribution of reported FADs and protected areas such as State and National Parks and Marine Protected Areas.

Statistical analyses were run in RStudio 4.0.3 (RStudio Team 2020). Chi-square tests were used to determine if there were differences in the number of beached FADs of various materials, and the number of compliant, non-compliant and uncertain FADs with regard to ICCAT Rec. 19-02. Additionally, chi-square tests determined if there were differences in the number of beached dFADs reported during hurricane season or the dry season, if publicity affected the number of reports made to the CFTP, and if there were differences in the number of beached dFADs reported from various geo-political regions around the North Atlantic Ocean (United States, Caribbean, Central America, South America, Mid-Atlantic, and Europe). Multivariate Analyses of Variance (MANOVA) were run to determine if there were significant differences in the type of raft (aFAD, Bamboo, JJ Chicolino Co., Jugs, PVC, Unspecified, and Zunibal) over time (1999-2021). A MANOVA was also used to determine if there were differences in the number of compliant, non-compliant, and "uncertain" FADs over time.

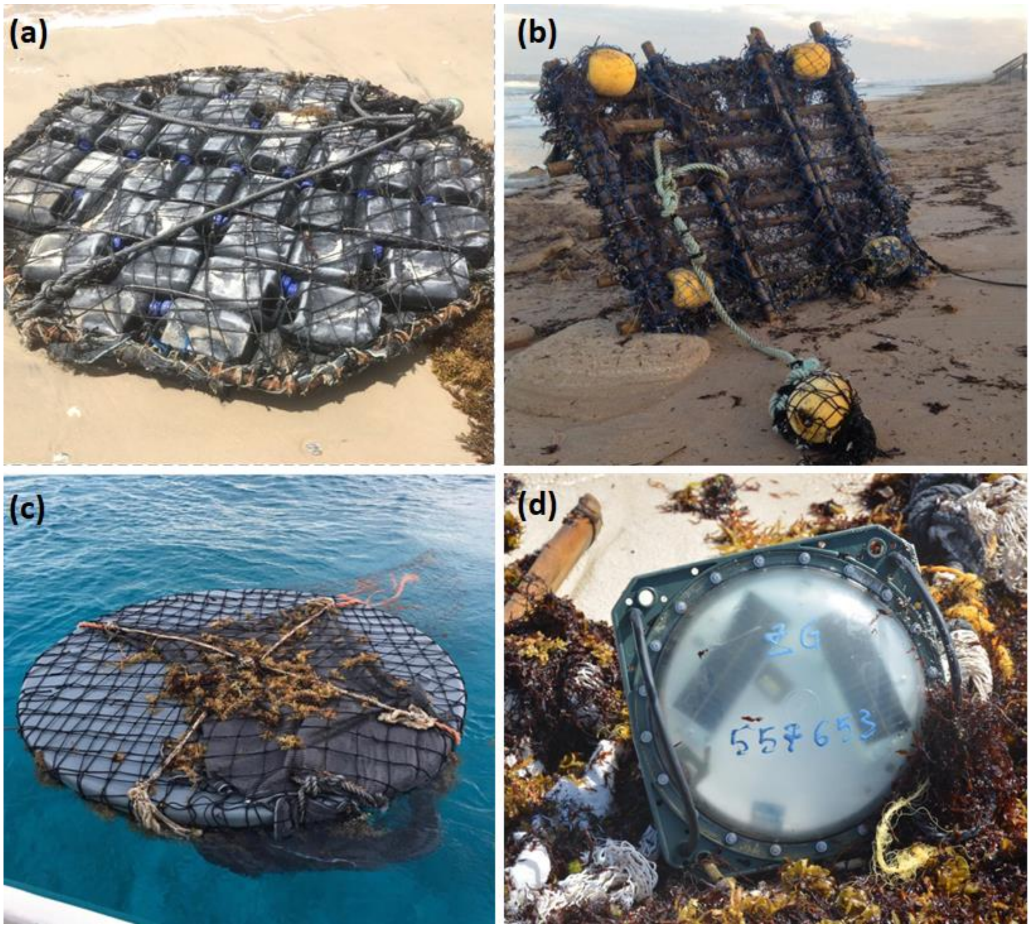


Figure 7. Photographic examples of common FAD components. The typical construction of an octagonal dFAD platform composed of 5L oil containers. Photo courtesy of Kelli Ann Briggs (a). A square bamboo dFAD platform wrapped in non-compliant net cover, photo courtesy of Thomas Pitchford (b). A Zunibal Zunfloat™ with a shadecloth and non-compliant net cover, photo courtesy of John Chamberlain (c). A Marine Instruments M3i+ satellite-linked beacon buoy with post-manufacturing markings stating "ZG 557653" in blue paint marker, photo courtesy of Raven Hoflund (d).

Results

Abundance and distribution of reported FADs

A total of 267 stranded FADs have been reported since 1999, all in various physical conditions throughout the wider Caribbean region and North Atlantic Ocean (Fig. 8). Reports have been made from 29 countries around the Atlantic Ocean, with the majority of reports originating in the United States (US; n = 145, 54.3% of total reports). Sixty-one dFADs (22.8%) were reported as beaching on US State or National Park beaches, in Marine Protected Areas under the management of any nation, or other conservation and protected regions where fishing was restricted, if not banned. This number reflects the percentage of FADs reported in protected regions excluding reports ($n_{excluded} = 27$) that provided only a country as a location of reference (e.g., "Bahamas", or "Bermuda"). There was no significant difference in the number of dFADs reported during the Atlantic hurricane season (June 1st-November 30th; $\chi^2 = 0.25397$, df = 1, p = 0.6143), consistent with the findings of Imzilen et al. (2021). A total of 130 dFADs were reported to the CFTP in the months of December through May, while 122 were reported during hurricane season, and 15 dFADs were excluded from this analysis because the find date was not reported. The number of reports made to the CFTP differed significantly in months that the project was publicized in newspapers, online magazines, Facebook articles, and flyers, and in those months where there was no known publicity ($\chi^2 = 23.375$, df = 1, $p < 0.001$).

Composition of Reported dFADs

As reports began to accumulate, patterns in raft construction became evident. The first model of platform reported (initially reported in 1999), consisted of hand-made rectangular or square rafts made of bamboo lashed together with rope. Manufactured Zunfloat™ FAD rafts were the next model to appear, initially reported in October 2017, roughly one year after first appearing on the market, and similar rafts produced by J.J Chicolino Co. were first reported in May 2019. Homemade FAD platforms have been increasing in frequency with the appearance of rafts composed of dozens of 5 L plastic jugs and containers, wrapped in netting within octagonal or square frames of PVC or metal pipes since March 2017 (Fig. 9). There are significant differences in the number of dFADs of different construction materials ($\chi^2 = 320.06$, df = 7, $p < 0.001$). A total of 70 complete FADs were reported, consisting of both buoy and raft, while 114 individual buoys and 83 lone rafts have been reported. Of these FADs, 63 can be tentatively attributed to a specific flag state and vessel. These FADs bore legible post-manufacture markings on the dome that explicitly stated the vessels name or an alphanumeric code that was traceable via vessel registries. The beaching location of all reports categorized by dFAD platform material was subsequently mapped (Fig. 10).

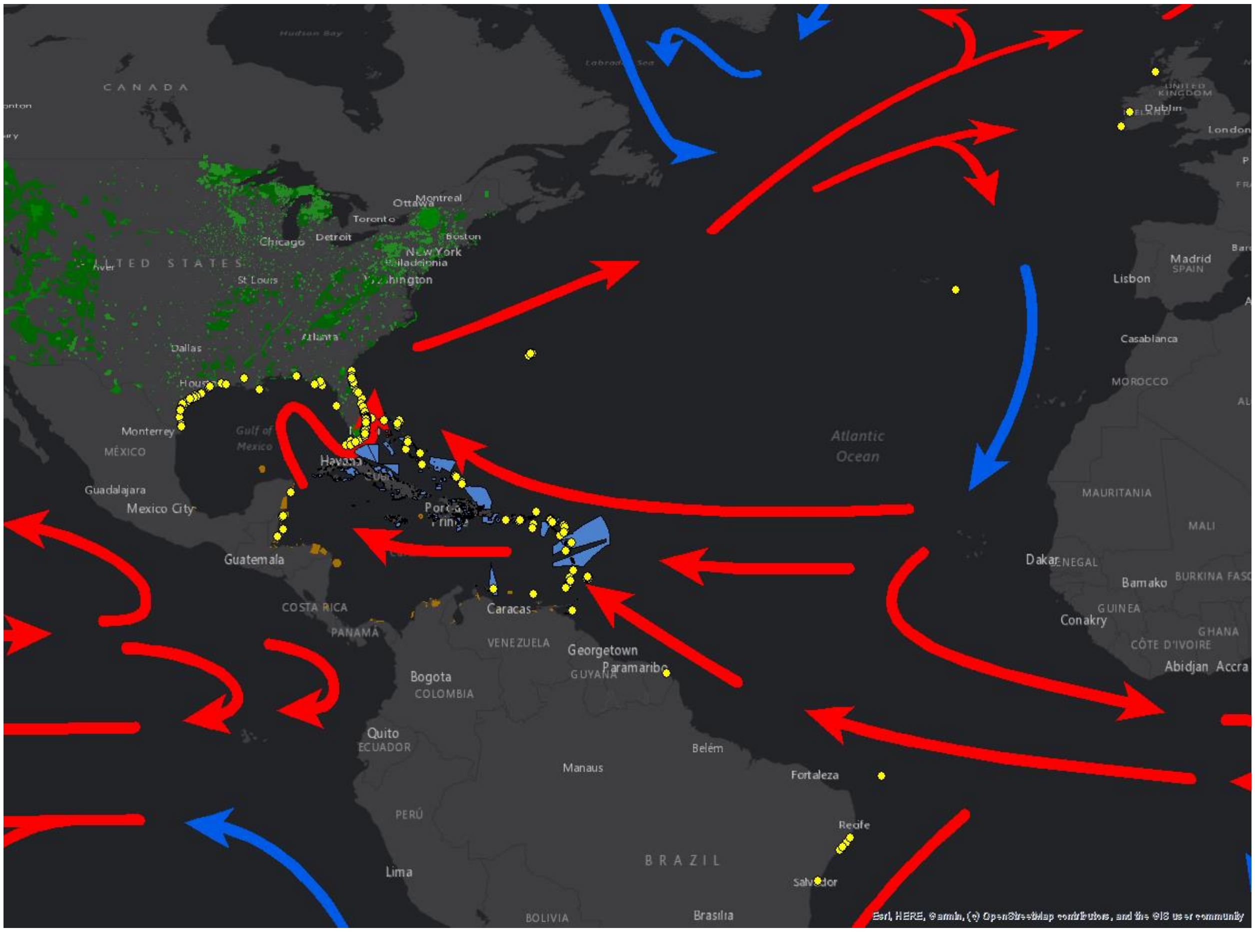
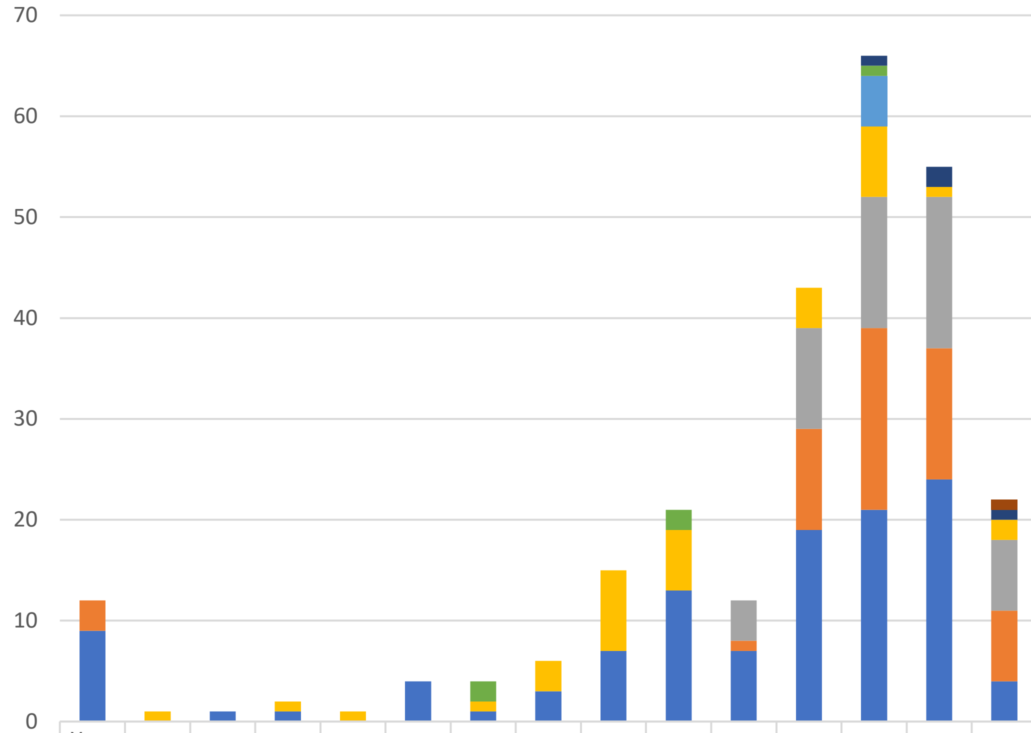


Figure 8. A visual comparison of all beaching locations of FADs reported to the Caribbean FAD Tracking Project from 1999-2021 and United States State Parks and National Parks, Marine Protected Areas, and other designated conservation areas. Yellow dots represent beached FADs, green polygons represent United States parks, and orange and blue polygons represent Caribbean Marine Protected Areas and other conservation regions. Prevailing surface currents in the world's oceans are included. Map made with ArcGIS ArcMap 10.8.



	Year Unknown	1999	2008	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
PVC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
JJ Chicolino Co.	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1
Unspecified	0	0	0	0	0	0	2	0	0	2	0	0	1	0	0
aFAD	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Bamboo	0	1	0	1	1	0	1	3	8	6	0	4	7	1	2
Jugs	0	0	0	0	0	0	0	0	0	0	4	10	13	15	7
Zunibal	3	0	0	0	0	0	0	0	0	0	1	10	18	13	7
Lone Buoy	9	0	1	1	0	4	1	3	7	13	7	19	21	24	4

Figure 9. The number of rafts found annually that were reported to the Caribbean FAD Tracking Project, categorized by raft type. Raft type was determined by reference to reports and affiliated photographs. It should be noted that both find date and report date were included in dFAD reports made to the CFTP, and this figure is a representation of find date, as many FADs were reported some time after discovery. Additionally, due to the timing and nature of this study, 2021 is an incomplete year, and the data cover the period of January 1- May 31, 2021.

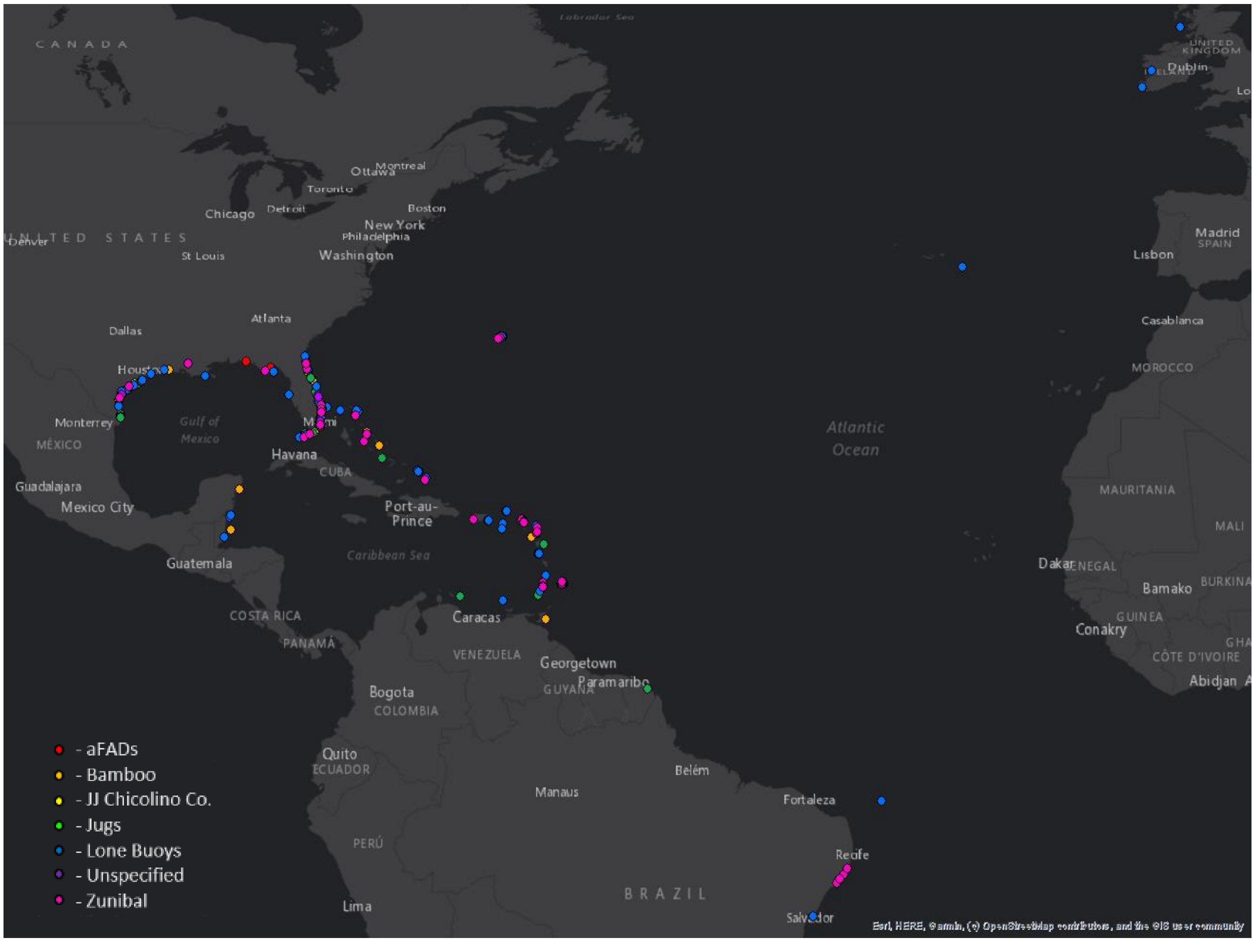


Figure 10. The reported stranding locations and composition of all dFADs reported to the Caribbean FAD Tracking Project in the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico dating from May 1999 to May 2021. Composition of FADs was determined by reference to reports and photographs. Reports were made by the public to the Caribbean FAD Tracking Project's Facebook and email accounts or collected by keyword searches on various websites. Map made with ArcGIS ArcMap 10.8.

A total of 52 Zunfloats™ were reported, as were four rafts manufactured by J.J. Chicolino SL. Of the 92 homemade rafts, 35 were composed of bamboo, 51 were composed of plastic oil jugs or containers within an octagonal frame of PVC piping or metal, five anchored FADs of PVC pipes with curtains made of plastic tarp and burlap draped below were reported, as was one FAD composed of PVC and shadecloth, while five additional FADs were of unspecified construction methods (Fig. 11). Two Zunibal Zunfloats™ were reported to the Caribbean FAD Tracking Project in a severely weathered condition, with photographs depicting both platforms broken into dozens of smaller fragments. Two deceased green sea turtles (*Chelonia mydas*) were reported entangled in the netting of a dFAD found on the coast of Padre Island, Texas in June of 2019, and a third sea turtle (unidentified species) was reported beside a satellite-linked beacon buoy in Grande Isle, Louisiana in August of 2020. The number of lone buoys, manufactured rafts (both JJ Chicolino Co. and Zunibal), and homemade rafts composed of bamboo and plastic jugs have changed significantly since 1999, while the number of anchored FADs, rafts of unspecified make, and PVC dFAD rafts did not differ significantly from 1999 to 2021 (Table 2).

Compliance of Reported FADs with ICCAT Rec. 19-02

Of the 153 reports of dFAD rafts received by the Caribbean FAD Tracking Project, 124 had associated photographs. The images submitted to the CFTP were used to determine the construction methods and materials of the dFADs. Thirty-five of the 153 rafts were made of bamboo, while the remaining 118 were composed of various plastics and synthetic materials. Fifty-five FADs were wrapped or covered in large diameter netting, a non-compliant material as of 2015, and 19 FADs had a net aggregator that hung below the platform when suspended in the water column. In total, 59 (47.58%) of the photographed dFAD rafts were not compliant with ICCAT Recommendation 19-02 regarding the use of non-entangling materials in FAD construction. It is worth noting that some dFADs may have been deployed prior to the establishment of ICCAT Recommendations that restrict the use of entangling materials. There were significant differences in the number of dFAD rafts of different levels of compliance ($\chi^2 = 45.933$, df = 2, $p < 0.001$). The majority of reported FAD rafts were compliant (n = 90, 58.82%), while 41.18% (n = 63) were non-compliant with ICCAT Rec. 19-02 specifications.

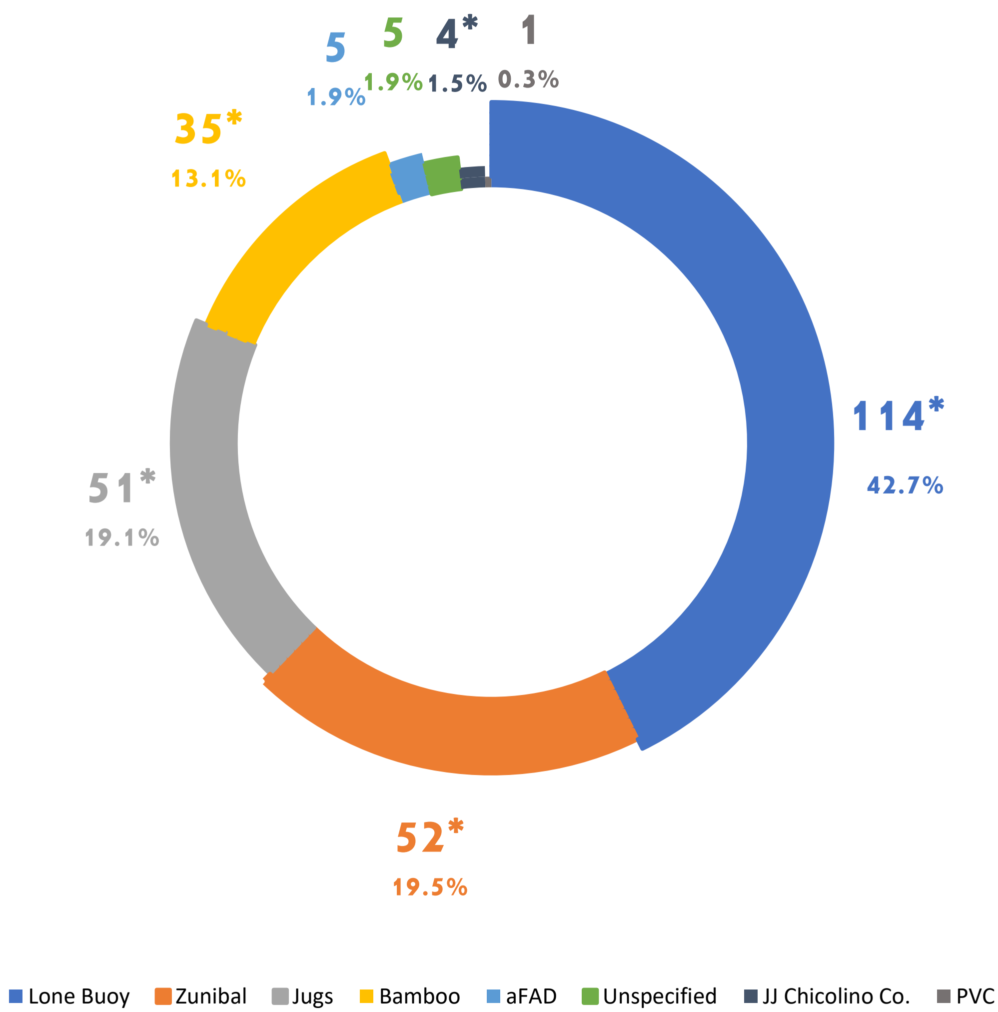


Figure 11. The construction of FAD platforms reported to the Caribbean FAD Tracking Project from 1999-2021 by category. Lone buoys were reported without a raft of any composition affiliated. Handmade dFAD platforms are typically made of either bamboo tied together with ropes or plastic jugs contained within an octagonal frame of PVC pipes wrapped in netting or shade cloth. Zunibal and JJ Chicolino SL platforms are manufactured plastic discs created for use in dFAD fishing, while anchored FADs (aFADs) are designed to anchor to the ocean floor and lack a satellite linked beacon buoy. Composition was determined by reference to reports and associated photographs. Asterix (*) indicates significance, meaning that the number of dFADs composed of that material changed significantly over time.

Table 2. The significance of the number of FADs that are composed of various construction materials (response variables; the number of Lone Buoys, Zunibal floats, Plastic Jug floats, Bamboo floats, aFADs, floats of unspecified make, JJ. Chicolino Co. floats, and PVC floats) over time (explanatory variable), determined by one-way MANOVA tests in RStudio (Version 4.0.3; RStudio Team 2020). The construction materials of FADs were determined by reference to reports and photographs. P values that are less than 0.05 are considered statistically significant. Asterix (*) indicates significance, meaning that the number of dFADs composed of that material changed significantly over time.

dFAD Material	***p* value**
Lone Buoy	7.615e-05*
Zunibal	0.001688*
Plastic Jugs	0.000342*
Bamboo	0.00418*
aFAD	0.1806
Unspecified	0.1618
JJ Chicolino Co	0.007041*
PVC	0.09793

A total of 184 satellite-linked beacon buoys have been reported to the Caribbean FAD Tracking Project, 131 of which were photographed. Seventy-nine had a legible marking on the buoy's dome, 23 buoy's markings were partially legible (likely as a result of weathering and exposure), and 10 were totally illegible. The remaining eight bore no post-manufacture unique identifying marks (Fig. 12). The method with which buoys were marked varied. A total of 105 buoys were marked with an unspecified type of paint or paint markers, only 74 (70.48%) of which were legible. One buoy had the name of the deploying vessel and the buoy's serial number etched into the dome's surface and showed very little indication of weathering, while six were marked with permanent marker, of which four (66%) were legible.

Six satellite-linked buoys were not sufficiently photographed to discern the presence of post-manufacture marking and were thus excluded from any statistical analyses. Fifty-five (41.98%) of the photographed buoys that had a unique post-manufacture identifying mark were marked with the serial number of the buoy, while 66 buoys (50.38%) were non-compliant regarding ICCAT Recommendation 19-02's guidance on buoy marking, and 10 buoys (7.63%) were not photographed well enough to determine whether or not the buoy was properly marked, or the buoys was too damaged to determine compliance. Twenty-five of the photographed, marked buoys clearly bore the deploying vessel's name. Thirty-nine of the buoys were marked with an alphanumeric series that was not consistent with either the name of the vessel or the serial number of the buoy. Researchers believe that these codes represent pertinent information such as the vessel registration number of FAD number, but this is uncertain. In total, 119 (61.03% of all dFADs reported to the Caribbean FAD Tracking Project) were non-compliant with regard to ICCAT Rec. 19-02. The compliance of dFADs and their affiliated components in the Atlantic has changed significantly over time. Compliant dFADs, non-compliant dFADs and dFADs of uncertain compliance all differed over the course of this 22-year observation period (Table 3). The number of FADs reported varies by region (United States, Caribbean, Central America, South America, Mid-Atlantic, and Europe) ($\chi^2 = 420.26$, df = 5, $p < 0.001$).

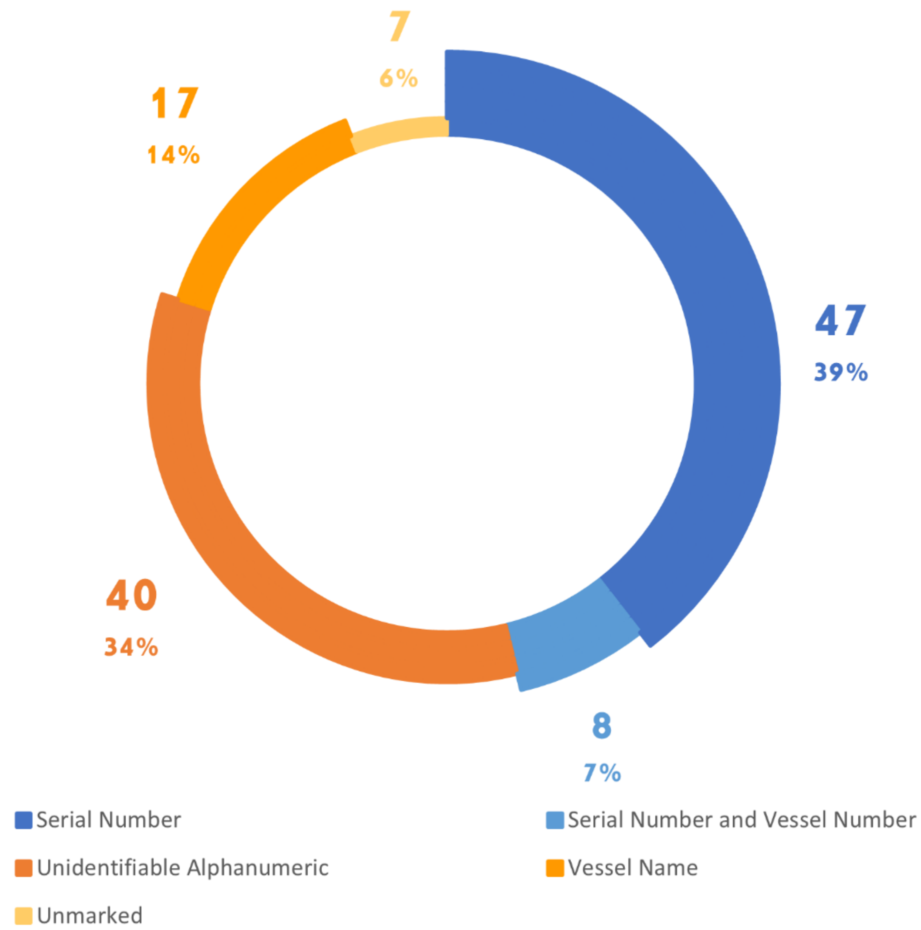


Figure 12. A visualization of all photographed post-manufacture buoy marking by category reported to the Caribbean FAD Tracking project. Blue denotes compliant buoys (e.g., those with a serial number present), while shades of orange represent non-compliant buoys (e.g., those with indecipherable alphanumeric code, solely the deploying vessel name, those unmarked, and those that were not sufficiently photographed. Post-manufacture markings were documented based on reports and affiliated photographs.

Table 3. The significance of the number of dFADs of various levels of compliance (response variables; the number of compliant FADs, non-compliant FADs, and FADs of indeterminable "uncertain" compliance) over time (explanatory variable), analyzed by one-way MANOVA tests in R(4.0.3). Compliance of FADs was determined by reference to reports and photographs. The number of compliant, non-compliant and "uncertain" FADs was significantly different, increasing from 2017 to 2018, and from 2018 to 2019, (p = 0.04196, and p = 0.000553, respectively). Asterix (*) indicates significance, meaning that the number of dFADs of that level of compliance changed significantly over time.

Compliance Category	***p* value**
Compliant	0.0005808*
Non-compliant	5.294e-05*
Uncertain Compliance	0.01037*

Discussion

Trends of dFAD use in the Tropical Atlantic

Over the course of the past decade, it has become evident with trends in dFAD use and beaching events that current FAD management efforts are insufficient to fully mitigate the stranding of dFADs on coastlines around the Atlantic Ocean and Greater Caribbean region. Since its establishment in May of 2019, the Caribbean FAD Tracking Project has accumulated 267 individual reports of lost or abandoned dFADs in the Greater Caribbean region. It is thought that a minimum of 81,000-121,000 dFADs are deployed annually worldwide (Gershman et al. 2016), a figure that is likely growing exponentially every year as many dFADs are not recovered on an annual basis. Escalle et al. (2018) found that approximately 10% of dFADs are recovered at sea or nearshore by either the deploying vessel, or another entity. Minimum estimates suggest that at least 18,000 dFADs are deployed annually in the Atlantic Ocean (Escalle et al. 2021). Maufroy et al. (2015) estimated that approximately 10% of all dFAD deployment in the Atlantic Ocean resulted in a beaching event, while Imzilen et al. (2021) found that 19-22% of deployed dFADs deployed over the course of a decade beached.

The combination of these estimates suggests that a minimum of 1,800-3,960 dFADs were abandoned and beached annually in the Atlantic Ocean alone, with global totals surpassing 26,500 dFADs beaching annually. If the period of data collection is considered to be May 2019-May 2021, an average of 133.5 dFADs were reported annually, and these estimates suggest that the reports made to the Caribbean FAD Tracking Project annually represent a fraction (3.37-7.42%) of the total number of annually beached ALDFG dFADs in the Atlantic Ocean and greater Caribbean region. If the data collection is considered to begin in 2015 with Tom Pitchford's keyword searches, then an average of 44.5 dFADs were reported annually over the course of 6 years, meaning that the reported dFADs account for only 1.12-2.47% of annually beached dFADs in the Atlantic Ocean.

Distribution of beached dFADs

Though the use of drifting FADs has been commonplace in commercial fishing efforts in the Atlantic Ocean for nearly five decades, there has not been an attempt to quantify and describe reports of stranded dFADs in the basin, though several studies have modeled the theoretical distribution and quantity of abandoned and lost dFADs in the Atlantic (Maufroy et al. 2015) or qualified beaching events based on GPS buoy data (Imzilen et al. 2021). Of the total number of FADs reported to the CFTP, 32% did not have an affiliated beacon buoy at the time of reporting. This statistic, combined with the total number of 2,283 FADs beached in the Atlantic Ocean observed by Imzilen et al. (2021) could result in an additional 710 FADs may have been unaccounted for if the percentage of buoys that are severed from their affiliated dFAD is consistent. The reports made to the CFTP span the North Atlantic Ocean, from Brazil to Scotland. Ninety-two reports were made from Caribbean countries, five from Central America, and 10 reports were made from South America. Nine dFADs were reported from the Mid-Atlantic region (e.g., Bermuda and the Azores), and fewer still from Europe, similar to the findings of Maufroy et al. (2015), stating that reports of dFADs would be made from the Eastern coasts of South America and the Caribbean, with outliers on the West coast of European nations.

A total of 145 dFADs were reported in the United States, with the majority reported in Florida (n = 102, 70.34%). Sixty-one dFADs (22.8% of all reports) were located in U.S. State and National Parks, and in other foreign nations, including MPAs and other designated conservation areas. As previously stated, this figure is likely an underestimate, as many reports did not include an exact find location (n = 127, or 47.57%), and an approximate location was determined by geographic descriptions provided in the report including, but not limited to, the names of beaches, bays, small towns, and residential addresses. It is likely that these dFADs were initially deployed in the Gulf of Guinea, consistent with the findings of Maufroy et al. (2015, 2017) and Imzilen et al. (2021), and were subsequently beached further along in their drift path, but without comprehensive and accessible identification measures such as post manufacture marking, and greater t-RFMO transparency, we cannot confirm these trajectories.

Composition of Reported dFADs

Commercial fishing, like many other industries, has adapted over time to increase efficiency and decrease expenses. Of the reports made to the CFTP, eighty-three (31.09%) did not have an affiliated beacon buoy, as opposed to 40% of dFADs in Balderson and Martin’s 2015 study. Those reports that included drifting FAD platforms were initially constructed of bamboo, palm fronds, and other detritus as their commercial use became popularized in the 1980s. Plastic floats such as Zunibal Zunfloats™ and 5L oil containers are buoyant in seawater unless physically compromised, with a greater lifespan allowing the continued reuse of synthetic FAD platforms. The use of homemade dFAD rafts composed of plastic jugs and containers, as well as manufactured dFAD rafts by the company Zunibal appeared in our reports in 2017, with their numbers increasing significantly since their commercial introduction (Table 2).

Compliance of Reported dFADs with ICCAT Rec. 19-02

Knowledge of the shortcomings and limitations of current dFAD management efforts are recognized by t-RFMOs, but few adaptations or additional enforcement efforts have been implemented in recent years. For the purpose of the statistical analyses of this study, reports of drifting FADs that did not contain sufficient information or clear photographic documentation of FAD construction and marking were categorized as "Uncertain", and were disregarded. Drifting FADs were qualified as "non-compliant" if the floating platform did not meet current construction requirements regarding the presence of netting, and/or if the affiliated satellite-beacon buoy was not marked according to ICCAT Rec. 19-02 marking schemes. The reports made to the Caribbean FAD Tracking Project document a lack of compliance with mandatory regulations regarding dFAD construction (ICCAT Rec. 19-02) and their beaching locations can be examined in Figure 13. Fifty-nine photographed dFAD rafts (47.58%) were non-compliant regarding the use of non-entangling materials. Less than one-third of all dFAD rafts were composed of the encouraged biodegradable materials (28.22%). Of these, 14 were non-compliant and were covered in large stretch diameter netting or possessed an aggregator made of netting.

As previously stated, the prevalence of synthetic materials could be the result of greater numbers of synthetic dFADs rafts being deployed, or a result of these platforms being more robust and maintaining buoyancy longer than rafts composed of organic materials such as bamboo or palm fronds, allowing them to drift far enough to eventually beach. Half of the reported photographed satellite-linked beacon buoys (n = 66, 50.38%) were non-compliant in their markings, lacking a serial number inscribed on the buoy's surface. In total, over half (n = 119, 61.03%) of the 195 photographed dFADs reported to the CFTP were non-compliant with ICCAT Rec. 19-02. An additional 20 dFADs were determined to be non-compliant based on finder reports but were not photographed to confirm these claims and were thus not included in statistical analyses.

The lack of compliance with ICCAT Rec. 19-02 may be attributed to fishers disregarding dFAD construction and marking requirements, or a may be the result of the introduction of new mandatory policies after deployment, thus rendering the dFAD non-compliant. There is the possibility that vessels that are already operating illegally may be deploying non-compliant FADs as the likelihood that they can be traced back to them is minimal. Due to the nature of illegal, unreported, and unregulated (IUU) fishing, it would be difficult to confirm this without onboard observer efforts and increased CPC enforcement of recommendations and penalties for infractions. Although minimum time at sea can be estimated based on the presence and size of gooseneck barnacles (*Lepas anatifera;* Magni et al. 2015), due to the lack of photographic evidence and physical samples, this calculation was not possible. A bar graph of all reports made to the CFTP dating from May 1999 to May 2021 depicts the trend of increasing numbers of dFADs of all levels of compliance over time (Fig. 14). The number of non-compliant dFADs was consistently greater than that of compliant dFADs, with the exceptions of 2012, 2016 and 2017, when the number of compliant and non-compliant FADs reported were equivalent (2012; n = 1, 2016; n = 8, 2017; n = 5) (Table 3).

As previously noted, enforcement of ICCAT recommendations is primarily the responsibilities of individual CPCs. Since its establishment in 1966, ICCAT has occasionally referred to the need to "encourage non-Contracting Parties, Entities or Fishing Entities… to abide by these measures" first stated in 1995 (ICCAT Rec. 94-02). ICCAT has not provided guidelines to CPCs and non-CPCs as to how best to enforce these mandatory recommendations, creating an environment that promotes the lack of compliance observed in this study. The observed failure of compliance may be unintentional and resulting from the abandonment or loss of a FAD and the subsequent change in mandatory ICCAT recommendations. Non-compliant FADs may be intentionally deployed without regard to t-RFMO legislation, though without transparency from CPCs and t-RFMOs regarding dFAD ownership, deployment, loss, and deactivation, this is difficult to distinguish. There are few penalties in place for CPCs that fail to enforce these recommendations, and very little accountability from the level of an individual or vessel to that of CPCs or the ICCAT Commission. This lack of accountability and transparency is emphasized by the majority of reported ALDFG dFADs in ICCAT's convention area being non-compliant with regard to ICCAT Rec. 19-02.

We recognize that there are numerous inherent biases due to the crowd-sourced nature of our sampling. The initial "reports" that were collected by Thomas Pitchford were made via keyword searches on search engines and social media platforms. Internet searches are influenced by previous searches, and access to reports may be limited by user account privacy settings, meaning it is likely that reports were published online that we do not have access to. The flyer and emails that were distributed soliciting reports from citizen scientists were only provided in English with no translations made available, thus excluding individuals who could not read or speak English and did not have the ability to translate such materials. Additionally, these materials were distributed to a small group of organizations that the Caribbean FAD Tracking Project was aware of, with limited efforts to contact groups or individuals that were not directly affiliated with the project. Online reports also require that the person who found the raft be knowledgeable enough to use identifying terminology that is accessible through keyword searches. All reports made directly to the Caribbean FAD Tracking Project were made via email or to our Facebook page. First-hand reports require that the person who recovered the dFAD be aware what a dFAD is, and what they may look like, as well as know of the Caribbean FAD Tracking Project and how to make a report to us. The FADs that were reported include only those that were durable enough or were at sea for a short enough period of time that they did not succumb to weathering, theft, or sinking. The majority of dFADs reported to the Caribbean FAD Tracking Project were beached, thus excluding abandoned, lost, or otherwise discarded dFADs that had not yet made it to shore.

Despite these biases, these data provide a minimum number of truly beached FADs in the Atlantic Ocean, a preliminary geographic distribution region, and substantiates the findings of the modelling studies of Maufroy et al. (2015) and Imzilen et al. (2021), as well as those of other dFAD studies. Maufroy et al. (2015) determined that some beaching events occurred along the north coast of South America, but this study did not consider outliers in the Caribbean region. Imzilen et al. (2021) also identified beaching events on the east coast of South America, as well as Caribbean nations and the southern United States of America, similar to the reported beaching locations of reported dFADs. Maufroy et al. (2015) concluded that dFADs that drifted west of 30° W (west of the Azores and Cape Verde) were “unlikely to be recovered by purse seiners” due to their distance from fishing grounds. This is supported by the reported beaching locations of this study, with 1.5% (n = 4) of all reported dFADs beached east of 30° W. This study also confirmed the findings of Imzilen et al. (2021) with regard to the effect of the Atlantic hurricane season on the number of annual beaching events. There was no significant difference in the number of beaching events in the Atlantic during hurricane season and the dry season (χ^2 =

0.25397, df = 1, p = 0.6143), although 15 beaching events were excluded from analyses due to uncertainty of the find date at the time of reporting. The number of dFADs reported to the CFTP without an affiliated satellite-linked buoy (n = 83, 31.09%) was comparable to that of Balderson et al. (2015) in the Seychelles, where ~40% of all dFADs were without a buoy at the time of observation. The dFADs reported to the CFTP were primarily constructed of synthetic materials, n = 108 (75.52%) (referring to raft construction material, and excluding aFADs and rafts of unspecified design), while similarly, in the Indian Ocean, "more than 70% of FADs encountered were made of synthetic material" (Zudaire et al. 2018).

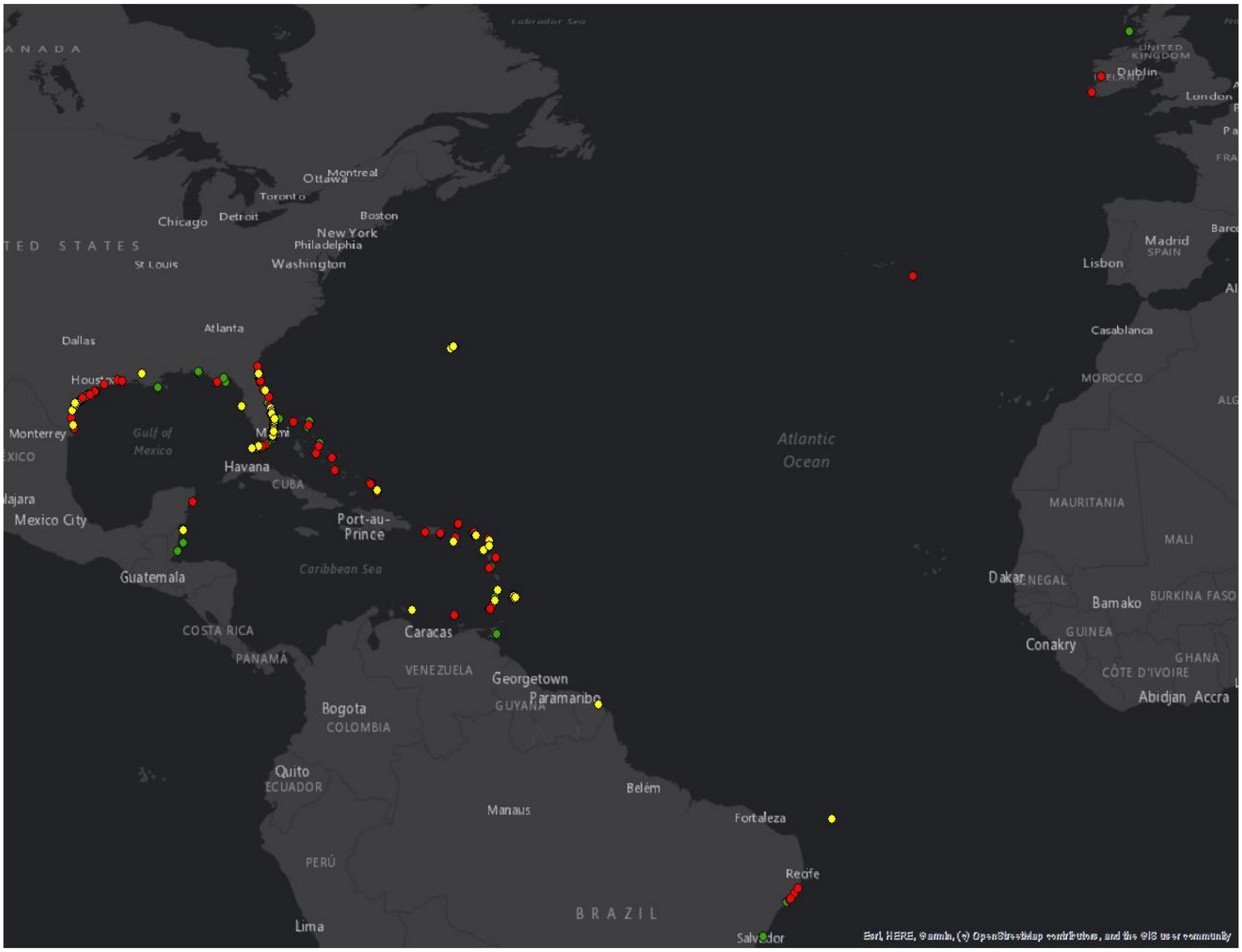


Figure 13. The reported stranding locations, and affiliated level of compliance (regarding ICCAT Rec. 19-02) of all dFADs reported to the Caribbean FAD Tracking Project in the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico dating from 1999 to 2021. Compliance was determined by reference to reports and photographs. Red dots represent non-compliant FADs, yellow dots stand for FADs of uncertain compliance, and green dots correlate with compliant FADs. Reports were made by the public to the Caribbean FAD Tracking Project's Facebook and email accounts or collected by keyword searches on various websites. Map made with ArcGIS ArcMap 10.8.

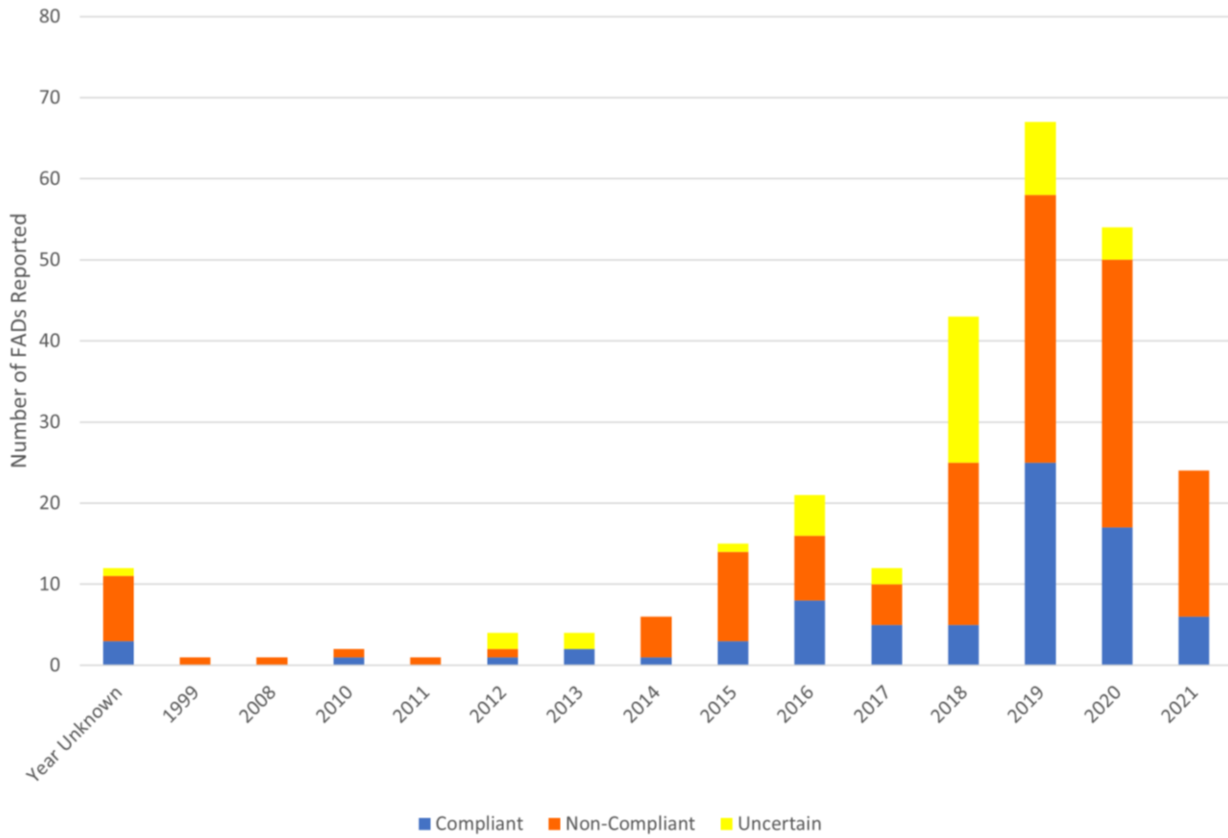


Figure 14. The number of reports received per year by the Caribbean FAD Tracking Project by all methods of communication (Email, Facebook, personal communication), categorized by compliance with mandatory ICCAT Rec. 19-02. Compliance was determined by reference to reports and associated photographs.

The documentation of abandoned and beached dFADs in the western North Atlantic Ocean by the CFTP has illustrated the gap in enforcement and adherence with ICCAT Recommendation 19-02. The use of non-compliant and non-recommended construction methods and materials, as well as the prolific number of "lost and abandoned" dFADs suggests a substantial gap in ICCAT intentions and CPC and vessel follow-through. IATTC has developed and implemented a simple methodology for buoy marking and identification, while IOTC has publicized the goal of creating a comprehensive marking scheme for all active instrumental buoys. Despite these developments by other t-RFMOs, ICCAT recommendations regarding dFAD construction and identification markings are simple and not as specific, allowing flexibility in interpretation by deploying vessels, and penalizing CPCs. The utilization of the Kobe Process could prove to be beneficial in implementing a global dFAD buoy identification system or a reporting center for the loss of dFADs.

There is limited industry transparency or accountability within the tropical tuna purse seine industry. Restricted access to pertinent records such as those of FAD deployment, visit and losses, FAD ownership, and drift path prevents a full understanding of the total number of dFADs in an ocean, as well as allowing the proliferation of IUU fishing with limited penalization for infractions. A comprehensive marking scheme that included more than the buoy's serial number would likely increase accountability as ownership would be more easily attributed, therefore leading to better FAD recovery, diminished losses, and greater compliance with RFMO recommendations as accountability would improve. The ownership of FADs is difficult to determine without access to ICCAT registration records, as the mandatory post manufacture markings do not include information such as vessel name, IMO or MMSI (Maritime Mobile Service Identity), both of which are unique vessel identification numbers. As it stands, identifying the drift path and time at sea of a dFAD is nearly impossible without access to deployment and visit records, and the ownership of dFADs cannot be determined through ICCAT specified post-manufacture markings. Additionally, without deployment dates, it is nearly impossible to determine what mandatory t-RFMO recommendations were in place at the time, and whether dFADs were non-compliant at the time of deployment or if they aged out of compliance after they entered the water. Access to such materials is not made public through ICCAT, therefore limiting understanding of deployment patterns and their relation to eventual recovery or beaching. By involving the other t-RFMOS in such management efforts, the

Caribbean FAD Tracking Project may begin to document greater compliance with such recommendations as the use of non-entangling materials and unique buoy identification codes in dFAD construction.

Conclusion

This study addresses the gaps in knowledge regarding the intricacies of drifting FADs as ALDFG in the northern Atlantic Ocean, including beaching locations, construction materials, and compliance with mandatory t-RFMO regulations. We have concluded that of the total 267 drifting FADs reported, 22.8% stranded in protected regions in North and South America, where commercial fishing is restricted or prohibited entirely. The majority of reported dFADs were reported on United States coastlines (n =145, 54.3%) and on the east coasts of 17 Caribbean nations (n = 92, 34.46%), with outliers in Central America, South America, the Middle Atlantic, and the west coast of Europe. Reported beaching events substantiated the findings of Maufroy et al. (2015) and Imzilen et al. (2021) with regard to beaching locations in the Atlantic Ocean west of 30° W, and a lack of seasonal variation in the number of beaching events resulting from the Atlantic hurricane season. The composition of reported FADs ranged from simple, hand-made anchored FADs to FAD platforms containing over 40 5L oil containers wrapped in shadecloth and netting within a PVC frame. The majority of FADs were made primarily of durable, synthetic materials (n = 113, 73.86%), 52.21% of which were non-compliant with the specifications of ICCAT Rec. 19-02. A total of 139 (52.06%) dFADs (including lone buoys, lone FAD platforms, and "full FADs") were non-compliant with ICCAT Rec. 19-02.

Accordingly, further research surveying the distribution of beached dFADs is needed. Furthermore, solicitation of reports in Spanish and French, in addition to English, would be beneficial in reaching individuals that did not have access to the original materials due to a language barrier. The composition, construction methods, and marking schemes of such FADs are relevant to a multitude of environmental impacts that ALDFG dFADs impose on their surroundings, including megafauna and benthic entanglement, introduction of macro and microplastics, navigational hazards and socioeconomic costs. There have been countless suggestions over the past several decades as to how best to mitigate the effects of dFADs, and many of the arguments come down to ownership and accountability. The implementation of a comprehensive marking scheme could begin address this issue, but better understanding of how dFADs are currently marked is necessary to determine best practices. Further research is also needed to determine the types of incentives that would increase CPC and vessel compliance with regulations. The widespread distribution of ALDFG dFADs in the North Atlantic, in conjunction with the understanding that dFAD use and subsequent abandonment is increasing annually creates a dismaying image of prolific wildlife entanglement and habitat damage. By understanding the nuances of dFAD composition and compliance with RFMO regulations, the development of effective mitigation efforts may be possible, serving to curb this widespread threat to biodiversity and marine environments.

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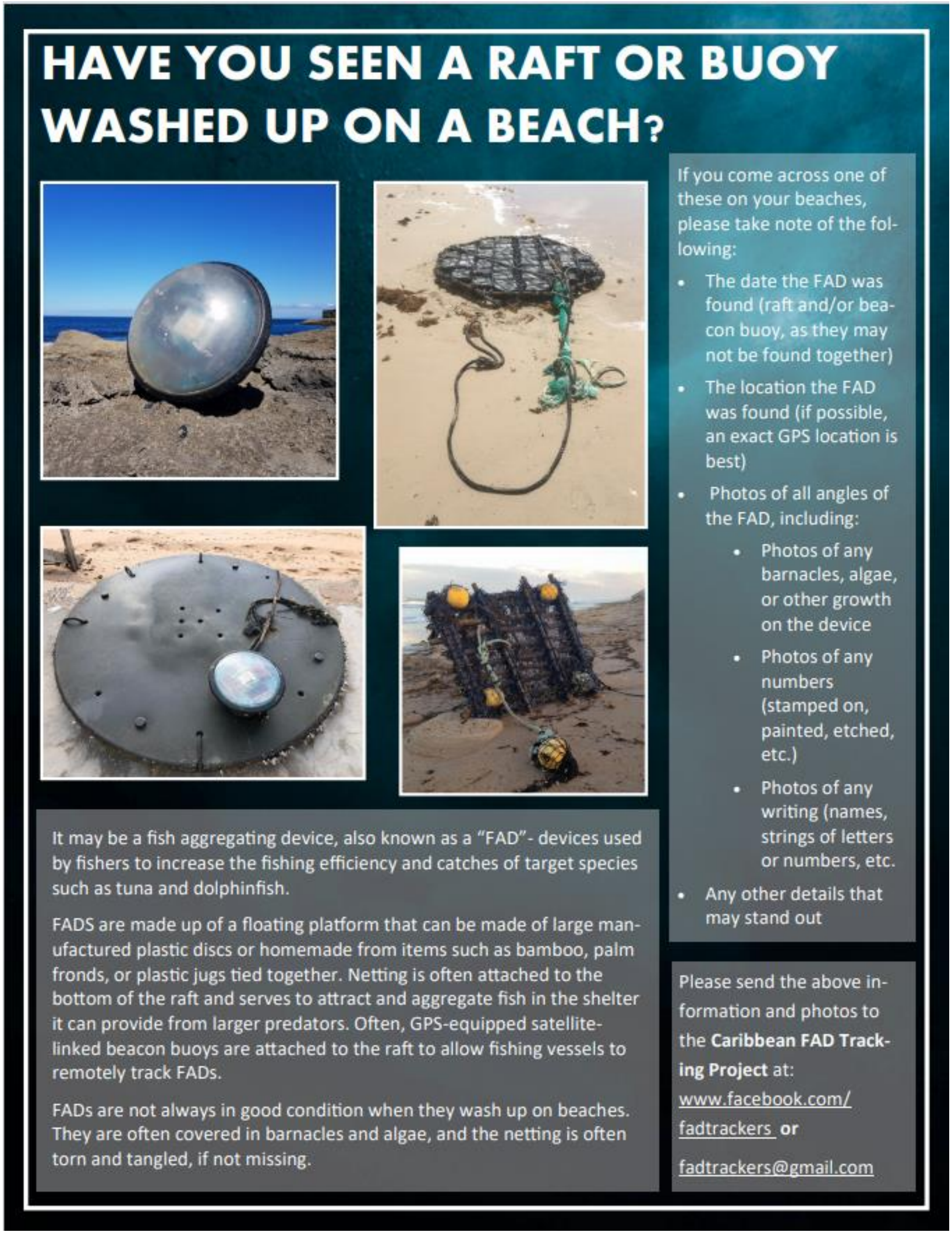
Appendix I

Caribbean FAD Tracking Project Flyer



Appendix II

Initial Email Contacts

The Barbados Sea Turtle Project, University of the West Indies Cave Hill Campus, WIDECAST Affiliate

Broward County Sea Turtle Conservation Program, Broward County, Florida

Fisheries Department, Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives, St. Lucia

Florida Chiefs Beach Patrol Association, FL

Foreign Affairs, National Oceanic and Atmospheric Administration (NOAA), Silver Spring Maryland

Gumbo Limbo Nature Center, Boca Raton, FL

Loggerhead Marine Life Center, Juno Beach, FL

Miami-Dade County Office of Parks, Recreation and Open Spaces, Miami-Dade County, FL

MOTE Marine Laboratory and Aquarium, Sarasota, FL

The Rosenstiel School of Marine and Atmospheric Science ListServ, Miami, FL

Sea Turtle Conservancy, Gainesville, FL

Sea Turtle Oversight Protection, Broward County, FL

Sea Turtle Program, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL

The Wider Caribbean Sea Turtle Conservation Network (WIDECAST), Godfrey, Illinois, serving 40 countries and territories in the Wider Caribbean Region

Appendix III

Publicity featuring the Caribbean FAD Tracking Project

Date	**Publication**
May 31, 2019	Caribbean FAD Tracking Facebook Page Launched
June 2019	Caribbean FAD Tracking Project Flyers distributed (Appendix I)
February 28, 2020	Santa Rosa’s Press Gazette
February 28, 2020	Jacksonville.com
February 28, 2020	The Ledger
February 28, 2020	TCPalm.com
February 28, 2020	The St. Augustine Record
February 28, 2020	Daily Commercial
February 28, 2020	The Daytona Beach News-Journal
February 28, 2020	Panama City News Herald
February 28, 2020	USA Today
February 28, 2020	The Destin Log
February 28, 2020	The Crestview Bulletin
February 28, 2020	The Walton Sun
February 28, 2020	Ocala StarBanner
February 28, 2020	Nfwdailynews.com
March 1, 2020	The Gainesville Sun
March 1, 2020	The El Paso Times
March 1, 2020	The Daytona Beach News-Journal
March 1, 2020	The Palm Beach Post
March 1, 2020	The Herald Tribune

March 2, 2020	Southern Living
May 4, 2020	Palm Beach Daily News
May 4, 2020	Miami Herald (Link no longer available)
May 4, 2020	The Walton Sun
May 4, 2020	The Gadsden Times
May 4, 2020	The St. Augustine Record
May 5, 2020	UPI.com
May 6, 2020	Florida Conservation Coalition News Brief
May 29, 2020	Florida Fish and Wildlife Conservation Commission via Facebook
July 25, 2020	Jacksonville.com
October 24, 2020	Gumbo Limbo Nature Center via Facebook
November 19, 2020	United Nation’s Environmental Programme’s 2021 Action Plan for the Conservation of Marine Mammals (MMAP) in the Wider Caribbean: A Scientific and Technical Analysis
December 19, 2020	Wild Cumberland via Facebook