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REVIEW

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A citizen science approach to enhance dolphinfish (*Coryphaena hippurus*) data collection to improve species management

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Abstract
Public integration in scientific research is fundamental to the conservation and enhancement of marine fisheries. A comprehensive review of the world's largest international citizen science capture–mark–recapture program (Dolphinfish Research Program (DRP)) for dolphinfish (*Coryphaena hippurus*) was completed to catalogue 16 years of conventional tagging data and angler participation from 2002 to 2017. Data showed at least 1313 captains, 1332 vessels and more than 3285 fishing mates from around the world participated in the tag and release of 23,232 dolphinfish. Of those fish, 571 were recaptured and 19 horizontal movement categories were used to reveal detailed descriptions of movements of dolphinfish in the wild. Our review identified science-based outcomes and established future research and outreach direction with the public. The combination of new studies, strategies and initiatives identified through this review will help advance our understanding of dolphinfish and provide the necessary data to ensure the long-term conservation of this critically important offshore fish species.

KEYWORDS
capture–mark–recapture program, citizen science, dolphinfish, recreational fisheries

1 | INTRODUCTION

Data collection on fish species to study life history (e.g. growth and reproduction), movements (e.g. local and regional) and population dynamics (e.g. mortality, population structure and stock size) is challenging due to numerous factors including access to fish habitat, weather and field conditions, cost, time commitment from personnel and capture success (Gillanders et al., 2001; Hilborn & Walters, 1992; Metcalfe & Craig, 2012). To alleviate these challenges, scientists began to engage fishers to assist in data collection, primarily through the act of mark and recapture, a practice dating back to the mid-17th century (Metcalfe et al., 2006). In the late 19th century, conventional tagging programmes began for marine fishes with broad distributions (e.g. halibut, cod, etc.; Muscik & Bonfil, 2005). In the mid-20th century, these efforts were expanded to oceanic scales with large-scale conventional tagging of sharks and tuna (McFarlane et al., 1990; Stevens, 2000; Wilson, 1953). Nowadays, numerous tagging programs across the globe engage the public in conventional tagging and data collection on groups of marine fishes including those dominated by recreational fishers, such as billfish (Ortiz et al., 2003), sharks (Musick & Bonfil, 2005) and tuna (Stokesbury et al., 2011).

Tagging data are used by many stakeholders, including government agencies, inter-governmental organisations (e.g. regional fishery management organisations), universities, non-profits and fishery consulting firms to address fisheries research questions to inform management decisions (Fromentin, 2002; Rudershausen et al., 2019). While tagging programs initially focused on data collection to examine fish distribution, movements, growth and mortality (Mather et al., 1995), the advent of pop-up satellite archival transmitters (PSATs) and other electronic tag instruments (e.g. acoustic and archival tags) permitted more comprehensive data collection and analyses of habitat use, activity patterns, geolocation and post-release mortality (Merten et al., 2016; Stokesbury et al., 2011). Past tagging of commercially important species (e.g. tuna, swordfish, salmon) were largely driven by governmental agencies to support institutional mandates with large budgets to work over large spatial scales. At present, many tagging programs for both commercially and recreationally important species are driven by non-governmental organisations, outside governmental agencies' purview, but supporting and expanding their mission by engaging the public in fisheries data collection. Here, we define the public as stakeholders that engage with governmental or non-governmental organisations to collect fisheries data through the act of mark and recapture of fish.

Public engagement in citizen science programs is on the rise across many different disciplines (e.g. humanities, social science and epidemiology, etc.) (De Moor et al., 2019; Kullenberg Kasperowski, 2016), including fisheries and ocean conservation (Andrews et al., 2019; Fulton et al., 2018), which has the potential to affect the efficacy of conventional and satellite tagging programs to achieve research and management outcomes. One of those programs is the Dolphinfish Research Program™ (DRP), an international citizen science tagging program for dolphinfish (*Coryphaena hippurus*) formed and intended to gather life-history information, such as growth rates, movement rates, discard mortality and foraging behaviour, that are needed to aid in protecting dolphinfish from overfishing. Additionally, the DRP seeks to educate and inform the public about movement and biology of the species from results of the tagging program. Since its inception in 2002, the DRP has expanded to become the world's largest tagging program focused on gathering data with the public on dolphinfish movements, occurrence, habitat use and other life-history traits in the wild (e.g. Farrell et al., 2014; Merten et al., 2014c; Merten & Rodriquez-Ferrer, 2014; Rudershausen et al., 2019). This program was the first major concerted effort to incorporate the public to tag this species. As a result, due primarily to early advertising in major sport fishing magazine outlets, the program became the public's contact to tag dolphinfish. This led to the largest geographical area of anglers tagging (and reporting recoveries) for the species to one program. Through the years, other programs have started to tag dolphinfish with the public. Gray Fishtag Research™ started in 2012 as a multi-species tagging program in which anglers tagged and released many different species, including dolphinfish. Research institutes, such as the University of Miami and North Carolina State University, have also included the public in various aspects of their tagging research on dolphinfish.

The dolphinfish is a highly esteemed game and food fish species (Lynch et al., 2018; MRIP, 2020). Dolphinfish grow to more than 40 kg (Perrichon et al., 2019), occur in large schools in open ocean waters (Oxenford, 1999), readily strike bait (Rudershausen et al., 2012, 2019), put on aerial acrobatics in its fight, is brightly coloured, and is a highly traded seafood commodity (MSA, 2016). These traits make it one of the world's most highly sought pelagic fish species, with total recreational fish landings on the rise in the United States (MRIP, 2020), globally (Cooke & Cowx, 2004) and specifically for dolphinfish since the 1990s (Freire et al., 2020). Directed commercial landings are also significant, with additional indirect harvest in purse seine (Hall & Roman, 2013) and longline (Lynch et al., 2018) fisheries. Attributes such as an early age of maturation (Perrichon et al., 2019), high reproductive capacity, fast growth, large size at maturity and short lifespan (Schwenke & Buckel, 2007) suggest dolphinfish can sustain high rates of exploitation if managed properly. Indeed, dolphinfish are subject to increasing commercial harvest in large fisheries (e.g. Taiwan, Peru, Ecuador) (Aires-da-Silva et al., 2016; Kleisner, 2008), increasing demand in major seafood markets (e.g. China, United States and European Union) (MSA, 2016), increasing popularity of offshore angling (Cooke & Cowx, 2006), including sport fishing tournaments that land the species (Pérez & Roman, 2005), and high discard mortality (Rudershausen et al., 2019). Yet, despite its advantageous life-history characteristics, abundance has decreased in Atlantic fisheries (Lynch et al., 2018). Given its economic importance, this points to an urgent need for conservation and management measures to protect this species, but as of yet these are generally lacking. In the Atlantic Ocean, the species has not been the subject of an official stock assessment or management strategy evaluation, analyses that could balance trade-offs amid competing management objectives and outcomes for the Atlantic stock. This situation is partly due to the perception that dolphinfish stocks are resistant to overfishing, and partly due to an underappreciation of its multinational distribution, which fragments effort on data collection and management. Given the large recreational component of the dolphinfish fishery, a citizen-science approach is one way to institute both opportunistic and structured research initiatives to increase the amount of data collected that could lead to rational management approaches to ensure long-term conservation of this species. The dolphinfish's wide distribution, ease of catch, proximity to the coastline in comfortable marine settings, and popularity make it a model species to engage the public in collecting biological and fishing activity data, including health and mortality of released fish, age estimates and growth rates, local and regional movement connectivity and stock structure, all information that is useful for dolphinfish management. However, given that most dolphinfish are caught for consumption, collecting enough information on the species through a tagging program is challenging.

Our goal was to review conventional and satellite dolphinfish tagging data acquired through citizen tagging efforts for the DRP in specific geographical regions, as an example of stakeholder involvement in fishery research to support management. Results were used to describe the status of dolphinfish data collection throughout its range in the western central Atlantic Ocean including the Caribbean Sea (WCA), prioritise new objectives to improve and enhance future data collection and to identify methods to improve data collection techniques and ways to further engage the public in this research.

2 | MATERIALS AND METHODS

2.1 | Tagging practices

Hallprint® PDAT nylon dart tags (Hallprint, South Australia, Australia) with an individually numbered external 15.2 cm yellow or orange polyethylene streamer were implanted in the dorsal musculature posterior of the operculum below the base of the dorsal fin. Microwave Telemetry Inc., popup satellite archival transmitters (PSAT PTT-100 standard (180 d) and high-rate x-tag models (30 d) Microwave Telemetry Inc., Columbia, MD, USA) and Wildlife Computers Inc., first- and second-generation mark-report tags were deployed on fish greater than 90 cm. Attachment of these devices to all dolphinfish followed methods used by Merten et al. (2014c). Anglers were provided with literature on conventional tagging best practices and online videos to educate them about proper methods to tag dolphinfish with conventional tags. All satellite tags were deployed with the public under supervision of DRP scientists.

2.2 | DRP data acquisition, management and processing

Hard copy data records (tag release cards, tag release field logs, recapture reports, letters from anglers), digital files (Microsoft Excel.xls; Microsoft Word.doc; Portable Document Format.pdf) and media reports (monthly newsletters, newspaper and magazine articles, letters from fishing clubs), were reviewed for accuracy and completeness before input into a cloud-based relational database (Google Bigquery). Original digital tagging release and recapture files did not contain all data fields on tag release cards, tag release field logs and recapture reports (i.e. angler information, release condition and tagging zone data). Therefore, new data fields were created for input into the database. In addition, both the total number of tags distributed to anglers as well as angler residency information by U.S. zip code were compiled according to locations where tags were shipped based on tag kit requests. For the latter, this information served as the basis for participation in the DRP and for feedback on program operations through an online survey (Appendix 1). Tagging activity represented the second level of participation. Third- and fourth-level participation were estimated based on names of anglers reported on tag logs who were involved in the tagging process at sea and anglers who contacted the DRP to report a recapture. Angler residency information by zip code, state and country and original GPS coordinates reported on tag release and recapture files were mapped using ArcGIS ArcMap v10.6.1. Where necessary, GPS coordinates were corrected for inconsistencies between reported and archived coordinates. The database was corrected when inconsistent with original handwritten documents. If the location in the database did not match the original documents, that record was removed from the tagging location dataset. Lastly, fork lengths (in inches) of tagged fish were checked for accuracy between original handwritten documents and lengths recorded in the database. As for location coordinates, the dataset was corrected when inconsistent with original handwritten documents. If a fork length in the dataset did not match the original document, that fork length was removed from the record in the dataset. For analyses, fork lengths were rounded down to the nearest half-inch and converted to centimetres.

2.3 | Tagging zones

Major tagging zones for the DRP defined based on where most fish were released included nine zones along the U.S. East Coast (U.S. EC) (based on latitude), the Bahamas (BA), tropical Western Atlantic (TA) (north of the Greater Antilles) and the Caribbean Sea (CS) (Lesser Antilles and south of Greater Antilles) (Merten et al., 2014a). Other zones included the Western and Eastern Tropical Pacific. Recorded tag and recapture sites depended on angler reports (i.e. fishery dependent), so movement categories established between sites represented fishery-dependent movements. All recorded recapture data were grouped relative to dolphinfish movement among and between these tagging zones. These categories established a basis to compile, compare and contrast future recaptures that varied among states based on each recovery's days at liberty (DAL) and the location of each tag and recovery site. Fishery independent movements from pop-up satellite archival transmitters (PSATs), which represented dolphinfish movements independent of the distribution of fishing effort, were not partitioned into movement categories due to a small sample size (n = 26). All location data were spatially plotted as the frequency of DAL from fishery-dependent movements and number of tag deployments by individual tagger. In addition, average annual resident recreational angler populations were compiled by geographical region from 2002 to 2016 for assessment against total resident angler tag kit recipients for the DRP based on angler zip codes. These geographical regions, acquired from the National Marine Fisheries Service included: Gulf of Mexico (GOM) (Texas, Louisiana, Mississippi, Alabama, West Florida); South Atlantic Bight (SAB) (East Florida, Georgia, South Carolina, North Carolina and Mid-Atlantic Bight (MAB) (Virginia, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts and New Hampshire)[1]. Data for New England states (except Maine and Vermont) were grouped with the MAB because angler tagging activity in the DRP occurred south of Cape Cod along the U.S. EC. Additional descriptive statistics for recaptures included the longest straight-line conventional tag movements.

2.4 | Previous DRP publications

Subsets of DRP data used in previous scientific publications were categorised by assessing the methods of each manuscript to verify what data were used (i.e. years, count and type of data (releases, recoveries, tag type, mortality)) and the manuscript research topic (Table 1). Then, science-based accomplishments through these publications were assessed with respect to how these works contributed towards addressing the DRP's original objectives established in 2002.

[1] https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-economics-united-states accessed 3/30/2020.

TABLE 1 Dolphinfish Research Program (DRP) manuscript topic, year published, data years, examples and type from 2002 to 2017

Manuscript topic	Year published	Data years	Data (# of examples)	Data type
U.S. E.C. movements	2014	2002–2011	306	U.S. E.C. recoveries
Bahamas movements	2014	2004–2012	1188/33	Bahamas releases/recoveries
Vertical habitat use	2014	2006–2011	6	WCA satellite transmitters
Oceanographical preferences	2014	2002–2007	8111	U.S. E.C. releases
Predator–prey interactions	2014	2013	In situ observation	In water film post tagging
WCA population structure	2015	2004–2012	15	International recoveries
NE Caribbean Sea movements	2016	2008–2014	742 / 22	NE Caribbean Sea releases/recaptures
Discard mortality	2019	2002–2017	3773	WCA release health

Abbreviations: NE Caribbean Sea, Northeastern Caribbean Sea; U.S. E.C, United States East Coast; WCA, Western Central Atlantic Ocean.

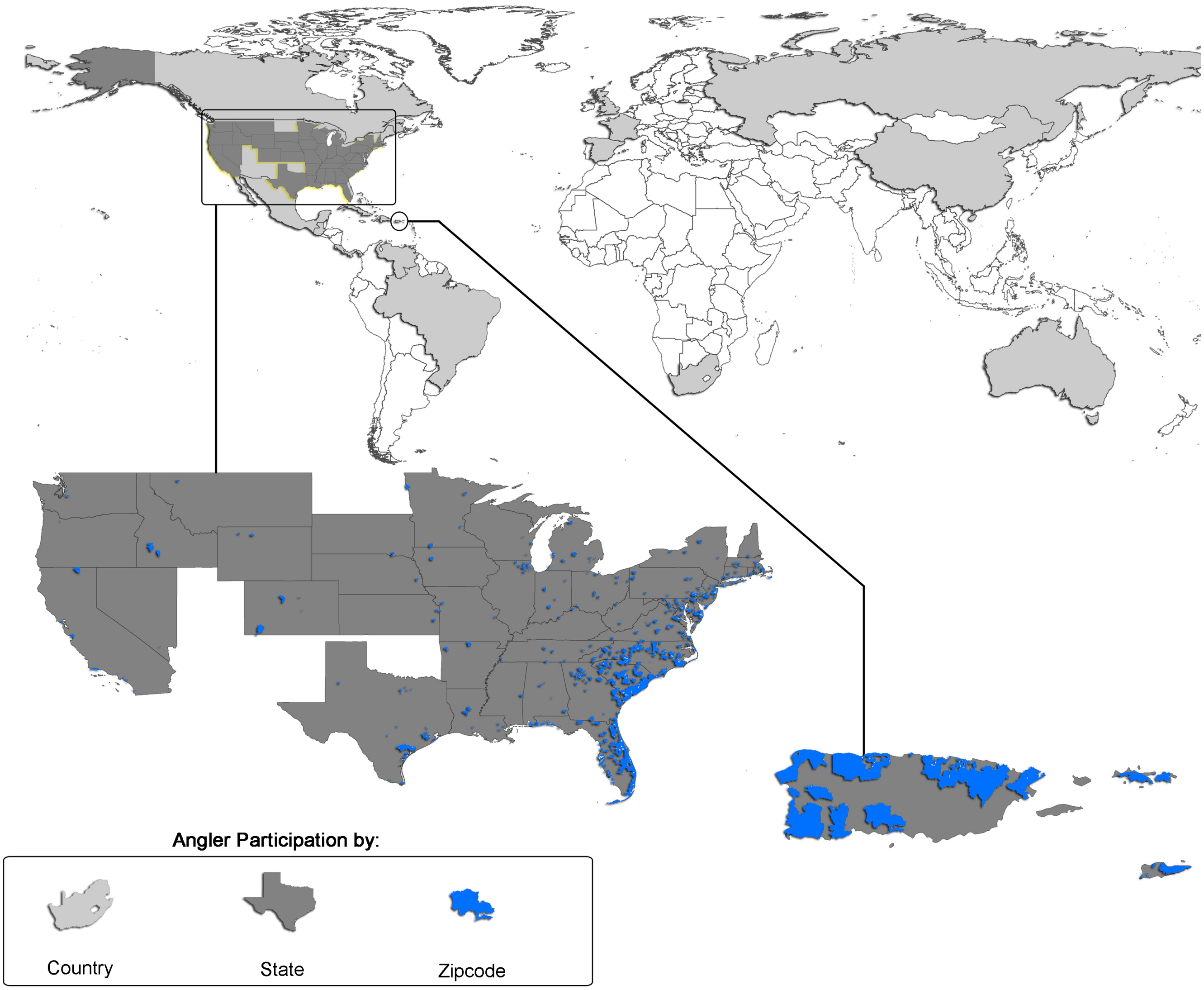

FIGURE 1 Dolphinfish Research Program angler participation by U.S. zip code, state and country from 2002 to 2017

3 | RESULTS

3.1 | DRP tagging data

From January 1, 2002, until December 31, 2017, 37,707 tags were distributed to 3023 anglers, including 1313 captains, 1332 vessels and 3285 additional anglers from 25 countries and 43 states (Figure 1), who tagged and released 23,232 dolphinfish. Most releases were off the U.S. EC (87.12%), followed by the Bahamas (5.54%), Tropical Atlantic and Caribbean Sea (5.16%), Gulf of Mexico (2.00%), Western Tropical Pacific (0.15%) and Eastern Tropical Pacific (0.09%) (Table 2; Figure 2). Only 2.2% (n = 516) of tag releases contained unusable

TABLE 2 Dolphinfish Research Program (DRP) tag deployments by tagging zone and geographical area from 2002 to 2017

Zone	Tag deployments	% Total	% total	Geographical area	Anglers DRP	Anglers FEUS (thousands)
FL1 – Key West to Islamorada, FL	8783	37.80	68.99	SAB	2565	2664.86
FL2 – Key Largo to Jupiter, FL	6451	27.76				
FL3 – Jupiter to Cape Canaveral, FL	796	3.43				
SAB1 – Savannah, GA, to Charleston, SC	557	2.40	13.76			
SAB2 – Charleston, SC and northern SC	2640	11.36				
NC1 – Wilmington to Hatteras Bight, NC	536	2.31	3.1			
NC2 – Hatteras Bight and northern NC	184	0.79				
MAB1- Virginia to Maryland	110	0.47	1.22	MAB	274	3748.8[a]
MAB2 – Maryland to Massachusetts	174	0.75				
Bahamas	1286	5.54	12.93	International	NA	NA
Caribbean Sea	1196	5.15			117	NA
Gulf of Mexico	465	2.00			67	2107.26
China	34	0.15			NA	NA
Eastern Tropical Pacific Ocean	20	0.09			NA	NA
Total	23,232				3023	

Note: Total resident angler tag kit recipients for the DRP and average annual angler resident population by geographic area were provided from the National Marine Fisheries Service Fisheries Economics of the United States (FEUS) technical memorandum.

Abbreviation: NA, not applicable.

[a]Average includes resident anglers from New Hampshire, Massachusetts, Rhode Island and Connecticut.

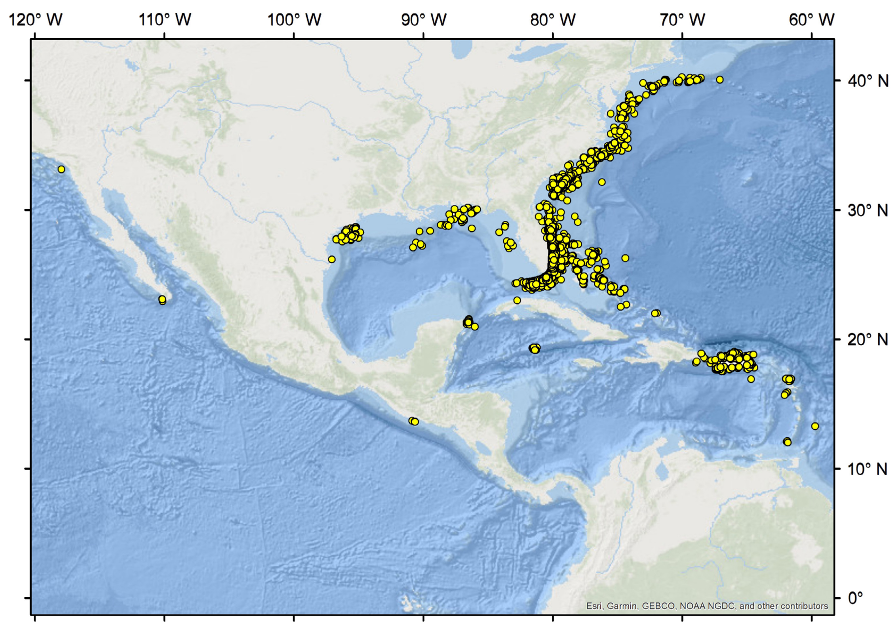

FIGURE 2 Spatial distribution of dolphinfish tag deployments from 2002 to 2017 in the Dolphinfish Research Program

geographical coordinates. In total, 5022 outings were documented with at least one tag deployment. Annual numbers of tag deployments ranged from 448 in the first year of the program to 2409 in 2007 (mean ± standard deviation; 1422.43 ± 483.01). Daily tagging activity per vessel ranged from 1 to 123 dolphinfish tagged and released (4.6 ± 7.88).

Annual tagging participation ranged from 54 to 117 vessels (89.31 ± 19.02). More than half (53.94%) of all vessels only participated for 1 year, with 46.05% participating more than 2 years. Of those that participated more than 2 years, 11.56% participated for at least 5 years and 2.28% greater than 10 years. Of 17 vessels that accounted for 51% of all recorded releases, all but two were based in Florida, one was based in Charleston, SC and one was based in San Juan, Puerto Rico. The cumulative number of individual tag deployments ranged from 1 to 2658 (32.22 ± 156.46) (Figure 3) and total participation was highest in the South Atlantic Bight. During 2002–2017, 15 different fishing teams deployed 26 satellite transmitters on dolphinfish (Appendix 2).

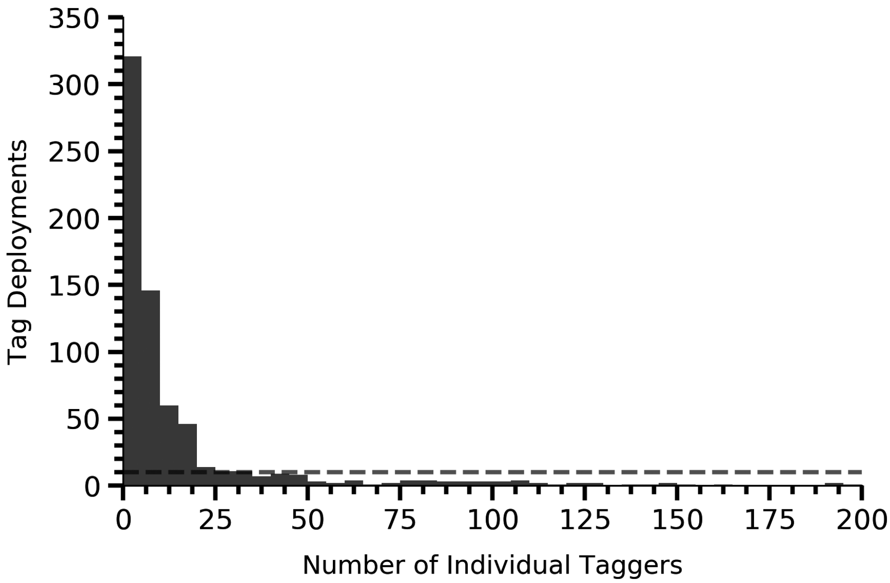

FIGURE 3 Frequency of dolphinfish tag deployments by individual tagger for the Dolphinfish Research Program from 2002 to 2017. The grey dotted line represents the number of tags ($n = 10$) included in a basic tagging kit distributed by the program

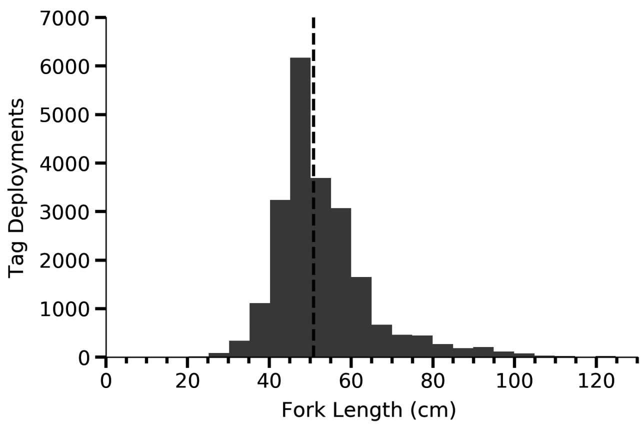

FIGURE 4 Frequency of dolphinfish tag deployments by fork length (inches) for the Dolphinfish Research Program from 2002 to 2017. The black dotted line represents the 20" minimum size set by the South Atlantic Fisheries Management Council

Dolphinfish tagged and released ranged from 15 to 139 centimetres fork length (52.07 ± 12.57 cm FL). The most frequent 5-cm size class of fish tagged and released was 45 cm ($n = 3812$) followed by 55 cm ($n = 2377$) then 50 cm ($n = 2227$). The length-frequency distribution was skewed towards smaller sizes (Figure 4).

Of fish tagged, 571 anglers reported recaptures (39–139 cm FL) and only 28 (4.9%) failed to report the release date ($n = 9$; 1.5%) or contained erroneous release ($n = 3$; 0.52%) or recapture ($n = 16$; 2.8%) locations. Days at liberty (DAL) ($n = 562$) ranged from less than 1 day to 557 days. Most recaptures (71.8%) were less than 40 days after release (Figure 5). Of those, more than half ($n = 232$) were less than 7 DAL. Overall, 26.8% of recaptures occurred between zero and 3 DAL. Days at liberty were slightly bimodal in distribution. Longer term recaptures, between 201 and 280 DAL, were 4.8% ($n = 27$) of recaptures.

Straight-line movements of dolphinfish from all recoveries and satellite tag deployments were concentrated along the U.S. EC with broad movements observed throughout the WCA to the Azores, Lesser and Greater Antilles, southern and western Caribbean Sea (Figure 6). Northward movements within Florida represented the largest category (41.3%) of straight-line movements, followed by northward inter-state movements (25.3%) along the U.S. EC (Table 3; Appendix 3). Short-term Florida revisits constituted the third most frequent (6.1%) movement category with one short-term revisit to the Mid-Atlantic Bight (MAB) and two to the South Atlantic Bight (SAB). Annual revisits of fish recaptured within 1 year after tagging along the U.S. EC were 1.2% of all recaptures. When combined, 14% of movements were associated with the Bahamas, Tropical Atlantic or Caribbean Sea. Southward movements along Florida's east coast occurred 17 times (2.9%) over the period examined. The fastest straight-line movement from Florida was 8 days to South Carolina, 7 days to North Carolina and 10 days to the MAB. On average (mean), dolphinfish moved along the entire U.S. EC (Florida to the MAB) in 44 days.

The longest straight-line movement between a conventional tag and recapture site was 3993 km for a fish tagged off Charleston, South Carolina and recovered 241 days later off the Azores. The median straight-line distance between tag and recapture sites was 179 km with 75% of movements less than 570 km (mean ± SD: 426 ± 625 km).

3.2 | Previous DRP publications

Subsets of the data reviewed in this paper were published previously in detailed examinations of dolphinfish movements along the U.S. East Coast (Merten et al., 2014) and in the Bahamas (Merten et al., 2014), adult male vertical habitat use acquired through PSATs (Merten et al., 2014), predator–prey interactions (Merten et al., 2014d), species oceanographical preferences (Ferrel et al., 2014), stock structure (Merten et al., 2015), regional connectivity with the Caribbean Sea (Merten et al., 2016) and discard mortality (Rudershausen et al., 2019) (Table 1). Science-based accomplishments through these publications, including defining movement rates, routes, pathways and

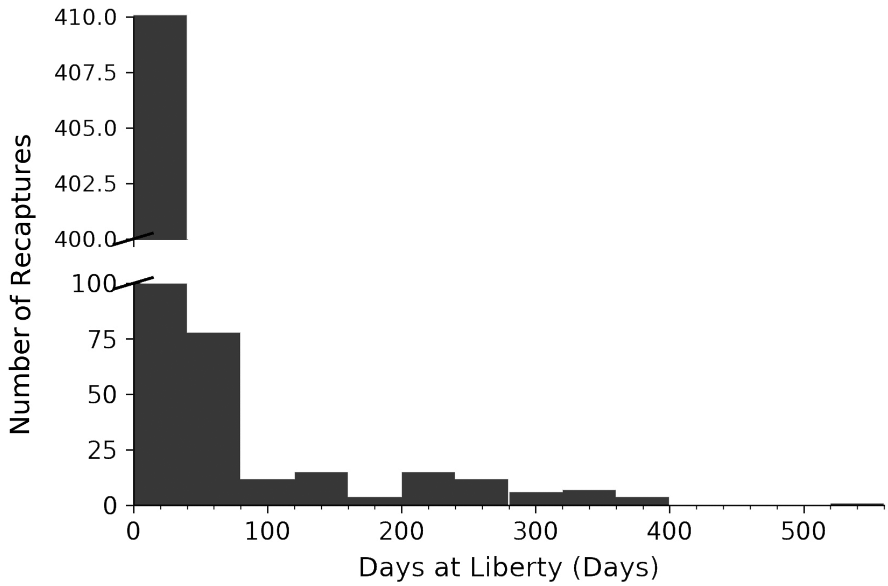

FIGURE 5 Frequency of dolphinfish recapture events by days at liberty (DAL) for the Dolphinfish Research Program from 2002 to 2017

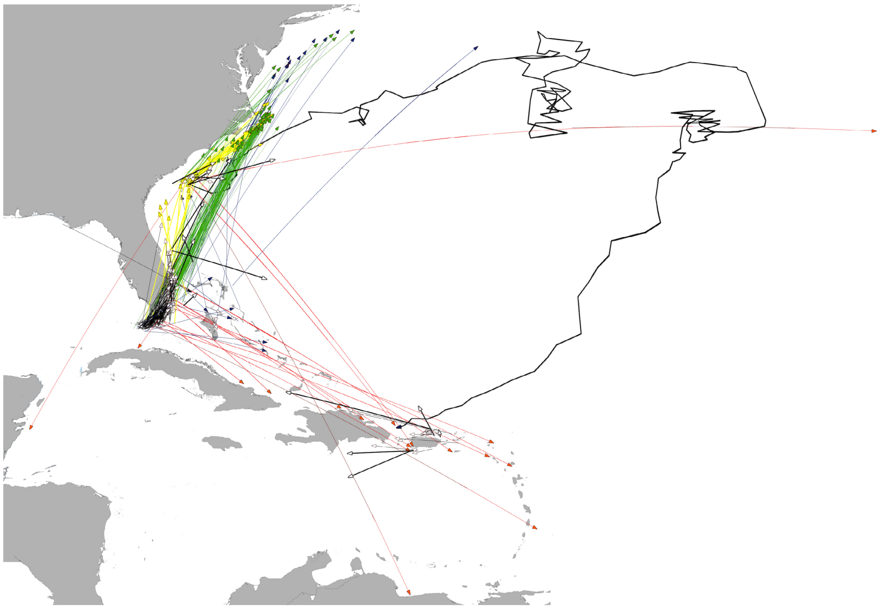

FIGURE 6 Straight-line conventional mark and recapture and satellite tag movements (straight-line (thick black arrow) and geolocation track) generated from the involvement of volunteer anglers in the Dolphinfish Research Program from 2002 to 2017

occurrence are referenced with respect to how these works contributed towards the DRP's original objectives (Table 4). Lastly, key milestones achieved through angler participation and program advancement, including the evolution of the Dolphinfish Research Program in terms of funding structure and program name by year, vessel and organisational milestones by date or year, tagging milestones by date or year, research theories by year and topics of publications by year are presented in a timeline in Figure 7.

4 | DISCUSSION

Results of the first 16 years of the DRP revealed detailed life history and movement pattern information among geographical regions for dolphinfish in the Western Central Atlantic Ocean. This review provides a baseline for future comparison as the DRP expands data collection and angler participation throughout the region and acquires more information for fisheries managers tasked with managing the WCA stock.

5 | REGIONAL CONVENTIONAL AND SATELLITE TAGGING DATA

5.1 | United States East Coast

5.1.1 | Florida straits

Most conventional tag deployments and subsequent conventional tag recoveries were from Key West to Cape Canaveral, Florida (Table 2; Appendix 3 Panel A), and most movements were of short duration (<40 DAL) within the Florida Straits. This is due in part to more tag-kit recipients and tagging activity by participating anglers fishing off east Florida in spring and summer and a higher number of

TABLE 3 Fishery-dependent dolphinfish movement categories and established definitions generated by recaptures with days at liberty (n = 562) from 2002 to 2017

Movement categories	Description	Examples (#)	App. I
FL Instate	Tagged and recovered off FL EC with DAL <60 and recovery site north of release site.	236	B
FL Short-term Revisit	Tagged and recovered off FL EC with DAL >60.	37	ND
SC Instate	Tagged and recovered off SC with DAL <90.	17	F
SAB Short-term Revisit	Tagged north of FL and recovered south of its release site with DAL >120.	2	ND
NC Instate	Tagged and recovered off NC with DAL <60.	11	ND
MAB in region	Tagged and recovered in the MAB with DAL <60.	6	ND
MAB Short-term Revisit	Tagged in the MAB and recovered south of its release site with DAL >120.	1	ND
GOM in region	Tagged and recovered in the GOM with DAL <60.	1	ND
Inter-State Movements	Tagged off one EC state and recovered off another EC state north of its release site.	145	C-E,G,H
FL to SAB Annual Revisit	Tagged off FL and recovered in the SAB in a year subsequent to when it was tagged.	7	ND
U.S. EC Dispersal	Tagged on the EC and recovered in the high seas, foreign or U.S. territorial waters.	14	I
BA to U.S EC	Tagged within the BA and recovered along the EC.	10	K
U.S. EC to BA	Tagged on U.S. EC and recovered in the BA	9	L
BA Instate	Tagged and recovered in the BA	26	J
U.S TA Instate North Coast	Tagged and recovered in the U.S. TA north of PR or the USVIs.	14	M
U.S CS Instate South Coast	Tagged and recovered in the U.S. CS south of PR or the USVIs.	5	M
U.S. TA or CS to BA or U.S. EC	Tagged in the U.S. TA or CS and recovered in the BA or along the U.S. EC.	3	ND
GOM to U.S. EC or BAH	Tagged in the GOM and recovered along the U.S. EC or BA	1	ND
EC Southerly Movement	Tagged along the U.S. EC and recovered south of its release site with DAL <30.	17	ND

Abbreviations: BA, Bahamas; CS, Caribbean Sea; DAL, Days at Liberty; EC, United States East Coast; FL, Florida; GOM, Gulf of Mexico; MAB, Mid-Atlantic Bight; NC, North Carolina; ND, not depicted; Ref, in Appendix 1 (App. I); SAB, South Atlantic Bight; SC, South Carolina; TA, Tropical Atlantic.

resident recreational anglers and overall greater fishing effort than in other U.S. states (NMFS, 2008, 2018). Florida anglers generated the greatest number of releases and recaptures and 15 of them accounted for nearly half of the conventional tagging data (Figure 3). Previous studies of citizen science have documented that most volunteers contribute little, while relatively few contribute the most (Ponciano et al., 2014; Sauermann & Franzoni, 2015). As a result of this participation, however, detailed information was obtained on northerly movements through the Florida Straits and along the U.S. EC, inter-state movements and connections with the Bahamas and Caribbean Sea. Knowledge gaps that remain that could be partially addressed using DRP data or addressed through program expansion are the following:

- Determine what proportion of the annual seasonal abundance comes from the three major routes dolphinfish take into Florida's waters: (1) Loop Current and Straits of Florida via the Yucatan Channel (western Caribbean Sea), (2) Old Bahamas Channel (north of Cuba) and (3) the Bahamian escarpment (northeast of the Bahamas) (Merten et al., 2016).
- Increase tagging activity in fall and winter to quantify movements when sea surface temperatures decline, the trajectory of the Florida Current changes and the formation of winter coastal countercurrents (Lee et al., 1991).
- Gather detailed recreational tournament length and weight and logbook data (from charter and recreational captains) to examine how changes in current flow or other oceanographical or harvest factors could contribute to high or low pulses of fish.

Investigating these dynamics could reveal insights into why many participants in the DRP claim the size and number of dolphinfish in Florida's waters has been declining over recent years (SAFMC public comment board)[2].

5.1.2 | South Atlantic Bight (SAB)

Data collected within the SAB were the second highest by region. However, only 12 inter-state recaptures connected Florida dolphinfish with the SAB and the first was not until the 8th year of the program despite thousands of fish being tagged and released off Florida. A notable decrease in recreational fishing effort in the

[2]https://safmc.net/public-comments/.

TABLE 4 Original scientific objectives of the Dolphinfish Research Program (DRP) and specific reference documenting evidence of science-based outcomes in scientific literature published using DRP data

		Status and priorities by region				
Original objectives	**References**	**U.S East Coast**	**Mid-Atlantic Bight**	**Gulf of Mexico**	**Caribbean Sea**	**Eastern PO**
Identify spring and fall migration routes	Merten et al. (2014a), Merten et al. (2014b), Farrell et al. (2014)	IC; Fall & Winter	IC; climate change	UNK	IC; Cayman Islands	IC; climate change
Document international range	Merten et al. (2014b), Merten et al. (2014d), Merten et al. (2015)	IC; Azores	UNK	UNK	IC; GOM	UNK
Identify recreational fishing grounds	Farrell et al. (2014)	IC; MAB	IC; SNE	IC	IC; DR	UNK
Define temporal and spatial occurrence	Farrell et al. (2014), Merten et al. (2016), Rudershausen et al. (2019)	IC: MAB	UNK	UNK	IC; LA	UNK
Identify winter grounds for U.S. dolphinfish	Merten et al. (2014b)	PC; AC	UNK	UNK	PC; SS	UNK
Identify routes dolphinfish use to enter U.S. waters	Merten et al. (2016)	PC; AC	PC; GS	UNK	PC; AP	UNK
Collect data to define critical habitat	Merten et al. (2014c), Merten et al. (2014d), Merten et al. (2015)	PC; GD	UNK	UNK	IC; GD; Outside USC	UNK
Define relevance of *Sargassum*	Merten et al. (2014a), Farrell et al. (2014)	PC; *Sargassum* events	IC	IC	IC; *Sargassum* events	N/A
Collective time-sensitive depth and temperature data	Merten et al. (2014c)	IC; SAB & MAB	UNK	UNK	IC; Outside USC	UNK
New objectives		Florida Straits	Participation	Participation	mFADs	southern Panama

Note: Status (Partially Complete: PC; Incomplete: IC; UNK; Unknown) and priorities (e.g. key word(s) describing priority topic(s) or locations) are included by region. MAB, Mid-Atlantic Bight; SNE, southern New England; DR, Dominican Republic; LA, Lesser Antilles; AC, Antilles Current; SS, Sargasso Sea; GS, Gulf Stream; AP, Anegada Passage; USC, United States Caribbean Sea; mFADs, moored fish aggregating device; GD, Gender differences; N/A, not applicable).

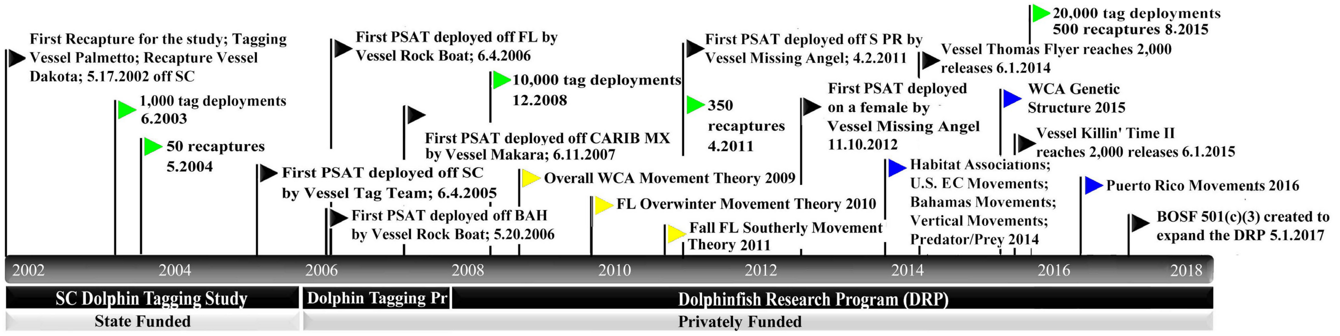

FIGURE 7 Timeline that details the evolution of the Dolphinfish Research Program in terms of funding structure and program name by year, vessel and organisational milestones by date or year (black triangles), tagging milestones by date or year (green), research theories by year (yellow) and topics of publications by year (blue). BA, Bahamas; BOSF, Beyond Our Shores Foundation; CARIB MX, Yucatán Mexico; FL, Florida; PSAT, pop-up satellite archival transmitter; S PR, south coast Puerto Rico; SC, South Carolina; U.S. EC, United States East Coast; USVIs, United States Virgin Islands; WCA, western central Atlantic

SAB, compared to Florida (Lovell et al., 2013; NMFS, 2018), can lead to a subsequent decrease in both the number of recaptures and apparent inter-state movements to the SAB. This decline in SAB data is further illustrated by an increase in recorded recapture and inter-state movements to North Carolina ($n = 66$) and the MAB ($n = 13$). Moreover, two movements from the eastern and central BA to the SAB and seven Florida to SAB annual revisits suggest that the Antilles Current may be a major supply route for SAB dolphinfish fisheries. Therefore, knowledge gaps that could be partially addressed utilising DRP data or through program expansion include the following:

- Determine the major route taken by dolphinfish into SAB fisheries and how it varies throughout the year.
- Determine how currents or other factors (e.g. productivity, water temperature or habitat (surface *Sargassum* or depth distribution of prey)) change dolphinfish dispersal rates.

Additional horizontal and vertical movement data collected from key recreational fishing grounds between Edisto Banks (32.05791 × −79.40736) and Winyah Scarp (32.7716 × −78.40516), and off northern Florida, could reveal why many participants claim the length of dolphinfish occurrence in the SAB has been declining in recent years (SAFMC public comment board)[3].

5.1.3 | Mid-Atlantic Bight (MAB)

Dolphinfish movements within the MAB were minimal due partly to low first- (i.e. 274 kit recipients) and second-level participation (i.e. 1.22% of total releases), although 20 inter-state movements connected MAB dolphinfish with lower latitudes along the U.S. EC. Aside from this observation, several questions about the MAB can be addressed using tagging data:

- Identify recreational fishing grounds and stock fishing pressure
- Determine horizontal and vertical habitat use
- Investigate range expansion due to climate change and connectivity with the central Atlantic, CS and lower latitudes of the U.S. EC.

For the latter, the recapture of a dolphinfish by an industrial long-liner south of the Azores in 2005 and an 180-day track of a satellite-tagged adult male from South Carolina to the CS in 2014 illustrated the long-distance movement capability of this species (Merten et al., 2016). Additionally, the recapture showed commercial fishing mortality of this species in the central Atlantic while the estimated geolocation track showed the high amount of time this species remained in the central Atlantic (Merten et al., 2016). An increase in dolphinfish tagging activity off the MAB can lend more insights into these events and whether they represent a previously unstudied pattern. Lastly, off southern New England, a large area of the Rhode Island Sound and Nantucket Shoals has been leased to offshore wind energy companies[4] to construct and deploy wind turbines beginning in 2022. An increase in dolphinfish tagging data before and after construction could lead to information on how dolphinfish, and subsequent recreational fishing activity, is affected by such activity.

5.1.4 | The Bahamas, Tropical Atlantic and the Caribbean Sea

Tagging and movements were extensive in relation to the Bahamas (BA), tropical Atlantic Ocean (TA) and Caribbean Sea (CS). Collectively, dolphinfish moved to these locations at low abundance or were absent off the U.S. EC (Merten et al., 2016). In the Bahamas, most anglers tagged and released fish within the Tongue of the Ocean east of Andros Island and, given the complex geomorphology of the Bahamian archipelago, including deep basins

[3]https://safmc.net/public-comments/.

[4]https://www.boem.gov/renewable-energy/state-activities/massachusetts-activities accessed 1/14/2020.

separated by extensive shallow shelf areas, movement routes and retention patterns were highly variable within the archipelago (Merten et al., 2014b). In the future, the proximity of the BA and TA to the Antilles Current, outside of the Bahamian archipelago adjacent to the Sargasso Sea, urges studies to determine the extent to which the Antilles Current serves as a supply route for U.S. EC, SAB and North Carolina dolphinfish fisheries during the spring, if the Sargasso Sea serves as a winter ground for the species, and the spatial-temporal dynamics of fishing mortality (i.e. direct or incidental catch) in this region.

In the TA, most data collection was along the north coasts of Puerto Rico and the United States Virgin Islands (USVIs). In the CS, data collection was mostly off St. Johns, USVIs and the southwestern coast of Puerto Rico. In general, dolphinfish predominately moved westward and slower north of the islands (Merten et al., 2016). In addition, the Mona Passage, which connects the TA with the CS, was omnidirectional with respect to dolphinfish movements, yet depth and habitat use within the passage and region were largely undocumented. However, over the period reviewed, most DRP satellite tags were deployed in these locations, which represent a future source of information about dolphinfish habitat use. Data acquired from these tags for male and female dolphinfish remain to be analysed, but can lead to a better understanding of whether sexes differ in daily vertical movement and how dolphinfish vertical movement varies among other WCA regions. Lastly, dolphinfish connectivity between the northeastern, southern and the western CS remains unknown and represents a key research focus moving forward to better establish regional connectivity, pathways and routes, to begin to assess stock inputs and removals on different spatial and temporal scales.

5.2 | Future public engagement and data collection strategy

Survey participants indicated a need to explore the use of a web-based application for data submission. In January 2018, the DRP transitioned to use of a cloud-based relational database to centralise data storage, link data sources and ensure data quality. Using this new system, the DRP can now scale up data collection and ultimately participation and explore the use of an APP for data submission. In addition, this type of system could be useful to help maintain active participation of volunteers by linking tagging data to an online mapping system that illustrates results in near-real time. In 2019, the DRP initiated the first version of such a feature (www.dolphintagging.com/map), which can serve as the start of an online tagging profile for DRP participants, something survey respondents supported.

Respondents indicated interest to initiate other data collection initiatives, including gathering catch length and weight, overall fishing trip harvest and fishing effort data. With the advent of reliable, durable and solar-powered self-contained GPS devices for vessel monitoring, initiatives to help gather tagging, catch and effort data with the public can take citizen science data collection for offshore fisheries to unprecedented levels. As a pilot test of this, since 2016, the DRP has deployed these devices on 50 different vessels throughout the WCA and has collected data on 4286 trips (unpublished DRP). Coupling fishing trip and tagging data collection can further expand available data into other areas, such as catch-per-unit-effort, to ensure sustainable management of offshore fish species into the future.

International participation was mostly undertaken by fishermen that travelled abroad from the U.S. with tagging kits. The DRP expanded angler participation to the Caribbean Sea in 2008, an area that offers a unique opportunity to engage recreational and charter fishermen, and thousands of small-scale artisanal anglers that target dolphinfish and therefore depend the most on conservation of wild stocks. Focus areas include the Lesser Antilles, Dominican Republic, Haiti and Cuba. The challenge is to first identify artisanal anglers in those locations that are willing to tag and release small dolphinfish and also to incentivise their annual participation. The high number of anglers in the Caribbean Sea and year-round presence of dolphinfish could combine to rival the amount of data generated from Florida-based recreational anglers.

6 | EMERGING ISSUES

6.1 | Fish aggregating devices (FADs)

Within the last decade, use of recreational moored fish aggregating devices (mFADs) increased dramatically in the Dominican Republic (e.g. Casa de Campo and Punta Cana), where they commonly overlapped with established artisanal FAD sites (Bareuther, 2016; Wilson et al., 2020). In addition, within the last several years, Puerto Rico and the USVIs have initiated new open-access mFAD programs, following the Hawaiian model (Holland & Jaffe, 2000), which led to a re-emergence of recreational FAD use and increased multi-sector overlap at these sites (Merten et al., 2018). The emergence of mFADs in waters around Puerto Rico and the USVIs introduced a priority to investigate dolphinfish behaviour and fishery dynamics (e.g. dolphinfish landings and catch) at these structures working with recreational, charter and small-scale commercial fishermen. Off Puerto Rico, a dolphinfish remained at an mFAD for 4 days, while north of the USVIs, several dolphinfish remained at submerged and surface mFADs for weeks (unpublished DRP). In 2019, a geolocating satellite tag deployed on a dolphinfish south of Puerto Rico was recaptured at a private mFAD off the Dominican Republic 56 days later (unpublished DRP). The recapture event became known because the satellite transmitter pinged from a marina and then a town. After revision of the tag recovery survey in 2018 to assess whether recovered fish were captured at mFADs, what remains to be determined is both the number of future recoveries at these structures and if recaptures increase with the use of mFADs in the region. During 2018, of 28 recoveries (26.9% of 2018's total) reported in the TA and CS, 19 (73.1%) were at mFADs (unpublished DRP). Despite the apparent biases and several assumptions that mFAD recoveries pose, at the broadest level, reported recoveries at mFADs document public and private FAD use throughout the region, information that is needed.

6.2 | Sargassum

The DRP provided essential data and research results in certain international regions of the WCA (e.g. BA, U.S. TA and CS) but gaps remain for the broader tropical Atlantic and Caribbean Sea where similar research questions exist for other dolphinfish stocks in other oceans (e.g. Pacific and Mediterranean stocks) (Díaz-Jaimes et al., 2010). Features near the tropical Atlantic that merit future research include the Sargasso Sea (~ 20-40^{O}N, 80-20^{O}W) (i.e. northeast of the Bahamas and south of Bermuda), named for the prevalence of holopelagic brown algae *Sargassum fluitans* and *S. natans*, and the Anegada Passage. The former is thought to serve as unique habitat for dolphinfish (Farrel et al., 2014) and both species serve as pathways for fish to move into U.S. exclusive economic zones and the northeastern Caribbean Sea (Merten et al., 2016). In addition, the Sargasso Sea is thought to have been affected by an unusually strong and negative North Atlantic Oscillation in 2010 that induced massive quantities of *Sargassum* to be transported throughout the tropical Atlantic eventually circulating to the Caribbean Sea and Gulf Stream (Johns et al., 2020). Effects of these massive habitat features on the distribution and abundance of dolphinfish remain unknown, along with effects of new localised blooms of *Sargassum*, given its expanded geographical range (Johns et al., 2020), on dolphinfish recruitment, movement and fishing activity. While the Sargasso Sea and Anegada Passage are both isolated from most recreational and small-scale artisanal anglers, large-scale commercial fishing activity is prevalent in both areas. According to a multi-decadal time series of U.S. commercial longline activity in the western central Atlantic, longline fishing was higher near and within the Anegada Passage than most other regions in the Caribbean Sea (Lynch et al., 2018). In addition, focal areas of activity in the Sargasso Sea included areas northeast of the Bahamas and south of Bermuda, areas of essential habitat for dolphinfish (Lynch et al., 2018). To quantify the importance of these areas to dolphinfish and if changes in *Sargassum* distribution and abundance affect this species, multi-day research cruises should be conducted to document presence of each life history stage, movement and abundance. Directed research cruises in these locations, combined with increased international participation from recreational and small-scale artisanal anglers, could provide robust, spatially comprehensive data collection programs necessary to assess population status of this species in the WCA.

7 | CONCLUSION

A more comprehensive approach to management of dolphinfish, whether adapted to the social and economic situation of specific locations (i.e. in island states), or with conservation and management measures harmonised across jurisdictions, is needed. The impact of a lack of collaboration among resource jurisdictions is illustrated by the experience in the eastern Pacific Ocean (EPO), where the Inter-American Tropical Tuna Commission (IATTC) undertook an exploratory stock assessment for the Peruvian and Ecuadorian dolphinfish fishery to obtain preliminary stock reference points and baseline information (Aires-da-Silva et al., 2016). As in the WCA, the study found little to no data on catch and catch rates, and no data from other countries throughout the EPO, all of which prevented the development of a conventional stock assessment. To assess the population status of this species in the WCA, robust, spatially comprehensive data collection programs are needed. Given the attributes that make dolphinfish a model species to engage the public in collecting data, incorporating a non-traditional approach (i.e. use of catch and effort with individual anglers) in addition to or as a substitute for conventional approaches (i.e. using catch and effort from commercial fleets and directed research cruises) for data collection seems appropriate and may be more cost-effective.

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CONFLICT OF INTEREST

The author(s) has/have no competing interests to declare.

AUTHORS' CONTRIBUTIONS

WM and DH performed the measurements, WM and DH were involved in planning and supervised the work, WM, DH, and RA, processed the experimental data. WM performed the analysis, drafted the manuscript and designed the figures. WM and RA aided in interpreting the results and worked on the manuscript. All authors, including CG, JL, and EB discussed the results and commented on the manuscript and revisions.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. A public map will be published on dolphintagging.com/map.

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SUPPORTING INFORMATION

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