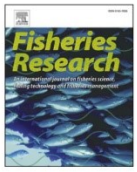
Fisheries Research 293 (2026) 107621

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres



Growth estimates from integrated analysis of tag-recapture and direct aging data for dolphinfish (*Coryphaena hippurus*)

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ARTICLE INFO

Keywords:
Dolphinfish
Age
Growth
Tag-recapture
Otolith
Length-increment
Age-at-length

ABSTRACT

The combination of age-at-length and tag-recapture data allowed for an integrated growth model to be explored for dolphinfish. Dolphinfish tag-recapture events (n = 266) were distributed throughout the Western Central Atlantic and Eastern Tropical Pacific Ocean and otolith data (n = 124) were obtained from a study conducted in Puerto Rico. Age-at-length and length-increment data, when integrated, led to lower growth parameters for the Gompertz and Richards growth models. The estimated asymptotic size ($L\infty$) for the different models varied between 130 and 136 cm (fork length (FL)) fit to only the otolith data and 128–147 cm FL when integrated with tag-recapture data. Maximum estimated age obtained through the length-increment model was 2.28 years. Predicted maximum longevity was 4 years. Nominal daily growth rates versus size at release and sex indicated a two-stage growth process up to 67 cm FL when growth rates steadily declined from peaks (female: 0.30 cm FL/day; male: 0.37 cm FL/d). When gender specific growth estimates were combined with tag-recapture events with indeterminate sex, nominal growth rates smoothed but still indicated a two-stage growth process for young fish. Overall, integrated nominal daily growth rate was 0.368 cm FL/day. For a species that has yet to have a stock assessment in the Atlantic Ocean, and routine assessments in the Pacific Ocean, this work can be used to contribute to better management advice for this important resource as growth assumptions have a great impact on stock assessment results and derived management quantities.

1. Introduction

Age and growth of individual fish are fundamental biological attributes incorporated into fisheries stock assessment models used in developing population-scale management and conservation guidance (Maunder et al., 2018; Aires-da-Silva, 2015). Age and growth rates for pelagic fish species are derived through the use of scales, otoliths, vertebral centra and spines (i.e., direct aging), length-composition, and tag-recapture data (i.e., length-increment aging), or an integration of those methods, to more accurately represent fish growth and how it changes with age. In both the Multifan-CL (Fournier et al., 1998) and the stock synthesis (Methot and Wetzel, 2013) stock assessment models commonly applied to tropical tunas, length-based age-structured data are used to better estimate the mean length-at-age and variation of length-at-age, which when combined with length composition data of the assessed stock, can have an impact on fishing mortality and biomass estimates. In the case of bluefin (*Thunnus thynnus*) and yellowfin tuna (*T. albacares*), length-increment data helped to improve growth models (Shuford et al., 2007), identify growth rate shifts within populations (Hearn and Polacheck, 2003), and reform tuna fishery management (Hearn and Polacheck, 2003; Shuford et al., 2007; Gunn et al., 2008). For sailfish (*Istiophorus platypterus*), length-increment data helped establish stronger growth parameter estimates (Ehrhardt et al., 2006) as well as raise longevity estimates (Ortiz et al., 2003). In the case of dolphinfish (*Coryphaena hippurus*), a highly migratory pelagic fish distributed worldwide in tropical and subtropical waters, growth estimates from the integration of direct aging and length-increment data have not been utilized in stock assessments or to improve species management and conservation.

An exploratory stock assessment (Aires-da-Silva et al., 2016) and complementary management strategy evaluation (MSE) (Valero et al., 2016) led by the Inter-American Tropical Tuna Commission (IATTC) on dolphinfish in the southeastern Pacific Ocean concluded that the stock synthesis method was a promising tool for conducting stock assessments of the species but tagging data were needed to provide independent estimates of fishing mortality, natural mortality, and allow integration of direct aging and length-increment data to improve age and growth estimates. In the Atlantic Ocean, a stock assessment on the species has

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https://doi.org/10.1016/j.fishres.2025.107621
Received 11 July 2025; Received in revised form 1 December 2025; Accepted 2 December 2025

Caribbean Journal of Science (2025), 55: pp. 127–150.
ISSN 0008-6452

Condition of the International Fisheries of Wahoo (*Acanthocybium solandri*) in the Western Central Atlantic Ocean

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Abstract—**We conducted a scientific literature review and a comprehensive analysis of data based on international fisheries of wahoo (*Acanthocybium solandri)* to determine catch trends and data gaps among jurisdictions in the Western Central Atlantic Ocean (WCA). This is the first regional catch review for wahoo in the WCA. Based on FAO catch records from 1950 to 2021, reported commercial landings increased nearly fivefold, but 18 nations still do not report commercial wahoo landings to the FAO, yet are known to catch the species. When recreational landings were combined with reported commercial landings for 2019, total direct wahoo catch was 3,547 metric tons, of which 57% was estimated to be recreational. When compared to dolphinfish catch, wahoo was nearly four times lower for the region, but several nations report more substantial wahoo fisheries than dolphinfish fisheries. Despite the importance of the recreational wahoo sector throughout the region, artisanal landings are estimated to be higher according to catch reconstruction data. Similar to dolphinfish, the presence of fish aggregating devices (FADs) in different parts of the WCA, as well as environmental processes (e.g., Sargassum blooms), lead to the presumption that higher amounts of juvenile wahoo may be caught throughout the region, and anecdotal evidence of stock decline has been suggested. Results stress the immediate need for WCA nations to adopt a precautionary approach for proper fishery management of wahoo throughout the WCA, to increase spawning biomass thus strengthening a foundation of long-term overall stock health and conservation.**

The wahoo (*Acanthocybium solandri* (Cuvier and Valenciennes, 1831), Scombridae) is a pelagic, mid-trophic level species, reaching up to 210 cm in fork-length and nearly 100 kg in weight (Collette and Nauen 1983; Garber et al. 2005). Wahoo have been aged to approximately 5–6 years (Oxenford et al. 2003), and occur in tropical and subtropical temperate waters globally. In the Western Central Atlantic (WCA), wahoo occur from the northeast coast of Brazil to the northeast coast of the United States (Collette and Nauen 1983; Oxenford et al. 2003). Globally, wahoo are considered to have two distinct lineages with minor crossover between the Pacific and Atlantic populations (Garber et al. 2005). In the WCA, genetic studies have found that there is a single population (Oxenford et al. 2003). Wahoo are targeted by commercial, recreational, and subsistence fisheries on global and regional scales where they occur (Oxenford et al. 2003), and represent an important target species during fishing tournaments in regions where recreational fisheries are established (Alio 2012).

Regional fisheries management organizations (RFMOs) through international agreements between member states lead fisheries governance for highly migratory species (HMS). Management policies and regulations set forth by RFMOs structure species-specific seasonal and annual landings limits, area closures, and size and gear restrictions for participating member states within each jurisdiction (Merten et al. 2022). For wahoo, expansive fishery governance with RFMOs has not occurred despite the species importance to countries

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SPECIAL ISSUE ARTICLE OPEN ACCESS

Integration of Multiple Data Types to Document Spatial Effort in a Recreational Fishery for Highly Migratory Species in Relation to Offshore Wind Development

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Received: 2 April 2024 | **Revised:** 10 January 2025 | **Accepted:** 23 January 2025

Funding: This work was supported by the State of Maine Department of Marine Resources and the National Oceanic and Atmospheric Administration.

Keywords: billfish | fishing effort | recreational fishing | renewable energy | sharks | tagging | tunas

ABSTRACT

The expansion of offshore wind interests in US waters has raised concern over potential adverse impacts to fisheries activity and productivity. Yet evidence-based platforms for assessing those impacts are lacking for many recreational fisheries. We demonstrate how data from a federal fishery survey (Large Pelagics Intercept Survey [LPIS]), cooperative tagging programs, and the direct survey of recreational fishermen can be used to characterize the spatial extent of baseline (pre-construction) effort in a recreational fishery that targets highly migratory fishes (HMS) in US territorial waters of the Atlantic, Gulf of Mexico, and Caribbean. To document the location of effort, LPIS catch data and tag, release, and recapture (CTR) records from four cooperative tagging programs were independently aggregated onto a grid of offshore wind lease blocks. An online survey of recreational fishermen was also executed to assess the spatial extent of effort in relation to a Draft Call Area (DCA) in the Gulf of Maine region. Collectively, the LPIS and CTR data described widespread recreational fishing effort for HMS, including within and around the majority of existing and planned offshore wind lease areas. Responses to the online survey revealed more widespread effort within the Gulf of Maine DCA than both the LPIS and CTR data, but some respondents may have overrepresented true levels of fishing effort. Our results demonstrate the need for multiple data types to comprehensively assess offshore wind impacts on the recreational HMS fishery and to inform marine spatial planning in regions into which offshore wind energy development may be expanded.

1 | Introduction

Growing concerns over adverse impacts of climate change have initiated global expansion of renewable energy technologies (Olabi and Abdelkareem 2022). In the United States (US), policies established under the Federal Sustainability Plan have set aggressive goals for reducing carbon emissions and initiated, among other things, plans to develop 30 GW of offshore wind capacity in US waters by 2030. To begin to meet these goals, large portions of ocean off the US east coast and in the Gulf of Mexico have been sited and/or leased for offshore wind farm development, and there is intent for further development in many regions. Although rooted in the desire to mitigate climate change, plans for such rapid and widespread

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Fishery Bulletin
established in 1881 -a-

Spencer F. Baird
First U.S. Commissioner of Fisheries and founder of Fishery Bulletin

Spatiotemporal dynamics of dolphinfish (*Coryphaena hippurus*) in the western Atlantic Ocean

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Abstract—Dolphinfish (*Coryphaena hippurus*) are caught throughout the western Atlantic Ocean over varying spatial and temporal scales. Prior attempts to quantify the population dynamics of dolphinfish in this region have been inhibited by an inability to model the spatiotemporal dynamics of this stock. We fit a seasonal vector autoregressive spatiotemporal (VAST) model to quantify the spatiotemporal dynamics of western Atlantic dolphinfish, to estimate standardized relative indices of abundance during 1986–2022 at regional scales, and to estimate changes in spatial distribution. The magnitude of abundance was greatest during spring and summer in northern spatial strata and was comparable over seasons in southern spatial strata. Abundance of dolphinfish appeared to be stable during 1986–2018 and then declined during 2019–2022. This trend occurred in all regions, except for in Atlantic waters from Cape Hatteras, North Carolina, to the southern border of Georgia, where abundance remained stable during 2019–2022. No shift in the distribution of the population was detected, but regional patterns of abundance provide insight into changes in the timing of availability. This study resulted in the first standardized index of relative abundance to capture the spatiotemporal dynamics of western Atlantic dolphinfish. These results have increased our understanding of the population dynamics of this species in this region and should prove useful in future attempts to manage the population at different spatial and temporal scales.

Manuscript submitted 21 August 2023.
Manuscript accepted 18 March 2024.
Fish. Bull. 122:35–43 (2024).
Online publication date: 3 April 2024
doi: 10.7755/FB.122.1-2.3

The dolphinfish (*Coryphaena hippurus*) is a mid-level trophic predator and migratory, cosmopolitan species of pelagic fish that is found throughout tropical and subtropical regions (Palko et al., 1982; Luckhurst, 2017; Moltó et al., 2020). The stock structure of dolphinfish caught in the western Atlantic Ocean, specifically in the southern extent of Food and Agriculture Organization of the United Nations (FAO) major fishing area 21 (the northwestern Atlantic Ocean) and FAO major fishing area 31 (the western Central Atlantic Ocean), is not precisely known (Damiano, 2023). Using analyses of size composition in catches over space, life history traits, and allelic frequencies, Oxenford and Hunte (1986) found evidence of a northern and southern stock in the western Central Atlantic Ocean and hypothesized that there are 2 unique seasonal migration patterns. The northern stock migration has been defined by seasonal movements into waters of Puerto Rico during late fall and early winter, movement along the Greater Antilles and Bahamas and into Florida waters during the spring, then into waters of the eastern United States during late spring and summer, and finally outward toward Bermuda during late summer (Oxenford and Hunte, 1986; Oxenford, 1999).

Tagging experiments conducted by Merton et al. (2014a, 2014b, 2016) revealed further complexity in the stock connectivity between dolphinfish caught along the eastern United States, in the Caribbean Islands, and in the Caribbean Sea, expanding the northeastern circuit to include coastal waters along the northeastern United States, and dolphinfish caught along an additional pathway to waters in Florida from the Caribbean Sea and through the Straits of Florida (Damiano, 2023). The connectivity between populations

Caribbean Journal of Science (2025), 55: pp. 127–150.
ISSN 0008-6452

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Caribbean Journal of Science (2023), 53: pp. 336–352.
ISSN 0008-6452

Increase in Dolphinfish (*Coryphaena hippurus*) Fishing Success Off the North Coast of Puerto Rico during Hurricane *Leslie*

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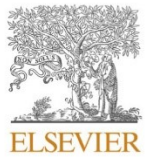
Abstract—**Documenting how storms and environmental variability affect the population dynamics, trends, and abundance of dolphinfish (*Coryphaena hippurus*) on short temporal scales is important for improving dolphinfish resource monitoring, conservation, and management. Here, a multifaceted technique was used to document an abrupt increase in fishing success among small-scale fishing sectors off the north coast of Puerto Rico during the 2018 Hurricane *Leslie* event. Seven datasets were used to document this event, and each provided substantiating information, but the combination of vessel catch and effort and seven-day averages of floating-algae density (FD), derived from the satellite-based alternative floating algae index (AFAI) imagery, present the newest technique to monitor dolphinfish fishing success on short and near-real time scales. Results revealed vessel effort and FD co-occurrence, with several vessel tracks within FD coverage of .01%-0.4%. Catch records from outings confirmed landings of dolphinfish from *Sargassum* and during the episode, 87% of total dolphinfish catch occurred at *Sargassum* habitat, with the remaining associated with nearby fish aggregating devices (FADs). Scuba visual census and fish tracking provided additional evidence of dolphinfish abundance and movements associated with *Sargassum* and nearby FADs. The combination of these methods provided a new technique to support insight into documenting changes in fishing success for dolphinfish, a key pelagic fishery. Expanding the spatiotemporal coverage of these methods could lead to the underpinnings of robust dolphinfish (and other pelagic fish, e.g., tuna and billfish) resource monitoring, improving data collection, and enhansing regulatory and data reporting compliance among small-scale fisheries.**

Weather systems have been found to cause economic loss due to equipment destruction (Buck 2005; Solis et al. 2013) and loss of time at sea (Agar et al. 2020) to commercial and recreational fisheries throughout the world. Hurricanes can be particularly disruptive by destroying maritime infrastructure (e.g., entire fleets, docks, marinas, boat ramps, and ports) (Ingles 2008) leading to a decrease in revenue generated by fisheries where storm impacts occur. For example, the commercial grouper industry in the Gulf of Mexico experienced an estimated $927,000 USD immediate loss of revenue between 2005 and 2009 due to hurricanes (Solis et al. 2013). In Puerto Rico and the U.S. Virgin Islands, Hurricanes *Irma* and *Maria* caused an estimated loss of $17.8 USD million, excluding post-harvest impacts, to small-scale fisheries (SSFs: recreational, charter, and artisanal) around Puerto Rico (Agar et al. 2020).

Coastal marine animals and habitats (e.g., salt marshes, mangroves, coral reefs) can also suffer impacts from large flooding events that cause excessive

Marine Policy 143 (2022) 105189



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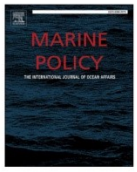
Marine Policy

journal homepage: www.elsevier.com/locate/marpol



Full length article

Condition of the international fisheries, catch and effort trends, and fishery data gaps for dolphinfish (*Coryphaena hippurus*) from 1950 to 2018 in the Western Central Atlantic Ocean

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ARTICLE INFO

Keywords:
International fisheries
Dolphinfish
Catch and effort
Precautionary management

ABSTRACT

We conducted a scientific literature review, and a comprehensive analysis based on international fisheries databases, for dolphinfish (*Coryphaena hippurus*) from the Western Central Atlantic Ocean (WCA) from 1950 to 2018. This analysis updated the dolphinfish catch and efforts trends in comparison to those calculated in Mahon (1999), the first regional catch review for the species that was conducted with data from the 1950s through the mid-1990s. Results showed that the commercial pelagic longline effort doubled within, and quadrupled outside, of national jurisdictions. Commercial landings increased nearly three-fold, but 23 nations still do not report explicit dolphinfish landings to the FAO yet are known to catch dolphinfish. In the WCA, the US Atlantic recreational fishery represents the largest reporting sector by two-fold. When combined with reported commercial landings for 2016, total direct dolphinfish catch was 14,110 metric tons, of which 62 % was estimated to be recreational catch. Since the first regional fishery analysis of dolphinfish, the uncertainty of the status of the fishery has increased with several nations reporting higher landings of unidentified marine fish species. Also, new burgeoning social (e.g., FAD programs) and environmental processes (e.g., *Sargassum* blooms) lead to the presumption that higher amounts of juvenile dolphinfish are caught throughout the region. First reports of consequential amounts of dolphinfish bycatch have been documented in the pelagic longline fisheries, as well as the first modeled and anecdotal evidence of stock decline has been suggested. Results stress the immediate need for WCA nations to adopt a precautionary approach for proper fishery management of dolphinfish throughout the WCA, not only to increase spawning biomass but also for overall stock health and its conservation.

1. Introduction

Fisheries governance for highly migratory species (HMS) is led by regional fisheries management organizations (RFMOs) through international agreements between participating member states [33]. Management policies and regulations set forth by RFMOs structure species specific seasonal and annual landings limits, area closures, and size and gear restrictions for participating member states within each jurisdiction. For dolphinfish (*Coryphaena hippurus*), a circum-tropical HMS [29], of significant economic [32] and cultural value [30], expansive fishery governance at the RFMOs has not occurred.

In the Eastern Pacific Ocean (EPO), dolphinfish is caught incidentally in the tuna purse-seine fishery [52], with the latter regulated by the Inter-American Tropical Tuna Commission (IATTC). While management of dolphinfish is not a priority for the IATTC, the Antigua Convention that established the Commission (i.e., IATTC) set a responsibility to implement measures to avoid, reduce, and minimize impacts on bycatch species (i.e., dolphinfish). Therefore, over the last several years, dolphinfish was under two Commission-led studies to determine impacts on its fishery and recommend appropriate conservation measures if necessary. Focusing on the Ecuadorian and Peruvian artisanal directed dolphinfish fishery, with additional data inputs from bycatch (tuna

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https://doi.org/10.1016/j.marpol.2022.105189
Received 3 March 2022; Received in revised form 19 June 2022; Accepted 24 June 2022

Received: 24 September 2021 | Revised: 4 April 2022 | Accepted: 5 April 2022

DOI: 10.1111/fme.12555

Fisheries Management and Ecology WILEY

REVIEW

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

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Funding information
American Fishing Tackle Company; Perry and Neblett, P.A; Dennis G Punches Charitable Foundation; Guy Harvey Ocean Foundation; Beyond Our Shores Foundation; Grady-White Boats; Sirius XM Marine

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

Perle *et al. Anim Biotelemetry* (2020) 8:30
https://doi.org/10.1186/s40317-020-00217-9

Animal Biotelemetry

RESEARCH Open Access

Dolphinfish movements in the Eastern Pacific Ocean of Mexico using conventional and electronic tags

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Abstract

Background: The dolphinfish, *Coryphaena hippurus*, is a fast-swimming, predatory fish exhibiting relatively fast growth and early maturation among marine teleosts. It is an important, potentially renewable resource throughout its global subtropical-to-tropical range. Understanding the ecology of this wide-ranging fish is critical to proper fisheries management, but studies have historically depended heavily upon aggregated catch data reported by fisheries. This study uses tagging data to explore finer scale dolphinfish movements in two subregions of the Eastern Pacific Ocean (EPO)—the west coasts of Baja California Peninsula (WBC) and Oaxaca (OAX), Mexico.

Results: Adult dolphinfish (fork length 66–129 cm) were tagged with conventional ($n = 132$ tags) and electronic tags ($n = 30$ tags, miniPAT) between 2010 and 2014. Recapture rate of conventional tags was 4.5% with a maximum days of liberty of 141 days (mean = 56 d); 20 electronic tags reported but all did so prior to programmed release dates, with days at liberty ranging from 4 to 62 (mean = 24 d). Fish remained within the region they were tagged except for six fish tagged in WBC and one in OAX. Latitudinal (WBC) and longitudinal (OAX) extensions of observed fish movements (determined via a novel analytical approach) increased with days at liberty. Despite occasional deep dives (max 262 m), fish remained surface oriented with short excursions below the isothermal layer but larger OAX fish (fork length [103 cm, 120 cm]) inhabiting warmer waters (sea surface temperatures (SST) > ~ 26 °C) spent more time below the isothermal layer than smaller fish (fork length [90 cm, 112 cm]) inhabiting colder WBC surface waters (SST > ~ 22 °C).

Conclusions: This study reveals movements of dolphinfish that infer regional differences in thermal habitat utilization and displacement over time. This inference evokes questions important to fisheries management regarding the three-dimensional extent of the dolphinfish's realized thermal niche, its population structure, and the spatiotemporal connectivity of its habitats within the multinational EPO. With improved tag retention, longer deployments should capture increasing displacements along observed axes (N/S vs. E/W); the orientation of seasonal displacement axes suggest longer-distance movements would provide opportunities for reproductive mixing via trans-national migrations.

Keywords: Dolphinfish, Electronic tagging, Marine, Movement ecology, Migration, Tracking, WC-GPE3, Eastern Pacific Ocean, Fisheries

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Background

The common dolphinfish (*Coryphaena hippurus*) is an epipelagic predatory fish inhabiting tropical and subtropical waters in all oceans [1]. Globally, dolphinfish

North American Journal of Fisheries Management

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10348

ARTICLE

Estimating Discard Mortality for Dolphinfish in a Recreational Hook-and-Line Fishery

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Abstract

Minimum length limits are used to manage Dolphinfish *Coryphaena hippurus* in the U.S. South Atlantic, but rates of discard mortality are unknown for this fishery and others throughout the species' worldwide range. We estimated discard mortality for Dolphinfish in the U.S. South Atlantic, Caribbean, and Gulf of Mexico recreational hook-and-line fishery by using conventional tag–recapture data. Overall, 4,648 Dolphinfish were tagged in these areas between 2002 and 2018 through the efforts of cooperating (fishery-dependent) taggers as well as research scientists who employed gear types and fishing styles representative of the recreational fishery for this species. The condition of each tagged and released fish was classified as good or poor depending on hook trauma, bleeding, and postrelease swimming behavior. Numbers of tagged and recaptured fish in each release condition were used to estimate condition-specific discard mortality by fitting a relative risk model. The model assumption of 100% survival of fish in good condition was scaled downward by using numbers of dying fish in good condition from tank holding and satellite tagging experiments. An overall median rate of discard mortality (0.248; 95% credible interval = 0.053–0.389) for the fishery was estimated by summing the products of each condition-specific mortality rate and the proportion released in each condition. Given relatively high discard mortality rates (>20%), the results suggest that alternative management strategies (e.g., mandatory retention of hook-traumatized individuals contributing to a bag limit, regardless of size), educating fishers on the use of alternative gear types (e.g., circle hooks), modifying fishing practices (e.g., trolling with heavy drags to reduce rates of deep hooking), or a combination thereof may be more effective solutions than minimum size or bag limits to control the rates of fishing mortality for Dolphinfish.

Recreational harvest represents an increasingly greater proportion of the take in a variety of fisheries around the world (Cooke and Cowx 2004, 2007). Along with a global increase in recreational landings (Cooke and Schramm 2007), the number of dead discards in recreational fisheries has also increased (Davis 2002). Discarding in recreational

*Corresponding author: pjruders@ncsu.edu
Received January 11, 2019; accepted August 9, 2019

ARTICLE IN PRESS

Marine Policy xxx (xxxx) xxxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Prioritizing global genetic capacity building assistance to implement CITES shark and ray listings

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ARTICLE INFO

Keywords:
CITES
Genetic capacity building
Shark and ray conservation
Shark international trade
Traceability
Fisheries

ABSTRACT

The global demand for shark and ray products has fuelled a lucrative international trade, driving large population declines as a consequence. This high-volume trade exceeds the capacity of nations to monitor their trade and enforce international trade regulations, leaving them susceptible to international trade sanctions. Here, a multi-criteria decision analysis was used to examine global trade levels and regulatory controls associated with the world's shark and ray trade to prioritize international genetic capacity building assistance to implement the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II shark and ray listings. A total of 76 nations were identified as priority nations to collaborate in a genetic implementation program. Improving the capacity of nations to detect CITES Appendix II shark and rays bound for international markets using a genetic program can aid as an additional tool to enhance trade-monitoring and enforcement efforts to improve the conservation and management of commercially important and threatened shark and ray populations.

1. Introduction

The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) is a major international agreement between governments that bans the international trade of species that are threatened with extinction and affected by trade (Appendix I), and regulates the international trade of species that may become threatened with extinction unless trade is subject to strict regulations to avoid utilization that is incompatible with their survival (i.e., Appendix II [1,2]). Since 1973, CITES has listed over 35,000 wild species with the vast majority listed under Appendix II.

Since 2001, twelve shark species as well as all rays in the genus *Mobula* have been listed in Appendix II (*Cetorhinus maximus* [2001], *Rhincodon typus* [2001], *Carcharodon carcharias* [2004], *Lamna nasus* [2013], *Carcharinus longimanus* [2013], *Sphyrna lewini* [2013], *S. mokarran* [2013], *S. zygaena* [2013], *Mobula birostris* [2013], *M. alfredi* [2013], *C. falciformis* [2016], *Alopias superciliosus* [2016], *A. pelagicus* [2016], *A. vulpinus* [2016], *Mobula* spp. [2016]). CITES has become a key policy tool to ensure the legal and sustainable trade of these species [1], and there is momentum by parties to list more elasmobranchs under Appendix II, with 20 species being listed in the last six years. However, recent evidence suggests low compliance and reporting by CITES parties, possibly due to a lack of capacity to monitor and enforce these new shark trade regulations [3]. Moreover, the reporting, monitoring and enforcement requirements continue to increase as new CITES regulations become effective where nations are now required to identify the movement of shark products by species. For example, silky shark (*C. falciformis*), the second most common shark species in trade, was listed to Appendix II in October 2017, requiring nations to gather silky shark-specific landings and trade data, despite the lack of capacity to effectively do so [3].

Accurate species-specific data of landings and traded products is urgently needed to enforce CITES shark and ray listings to allow better quantification of catch and trade trends, and to provide more robust stock assessments, which are essential for sustainable fisheries management [4]. In order to improve enforcement at different governance levels, visual identification techniques (e.g., fin comparisons, morphometrics, distinguishable features) have been traditionally used to identify sharks and rays to species level when handled (e.g., dead or alive; [5], but these methods are often difficult to use when identifying sharks that have been landed without their fins attached, headless, or processed [5]. As a result, genetic techniques (e.g., DNA barcoding,

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https://doi.org/10.1016/j.marpol.2019.103544
Received 28 July 2018; Received in revised form 22 March 2019; Accepted 10 May 2019

Scientia Marina 82(2)
June 2018, 000-000, Barcelona (Spain)
ISSN-L: 0214-8358
https://doi.org/10.3989/scimar.04730.09A

Use of video monitoring to quantify spatial and temporal patterns in fishing activity across sectors at moored fish aggregating devices off Puerto Rico

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Summary: A key challenge in small-scale fisheries that use moored fish aggregating devices (mFADs) is the ability to accurately quantify multi-sector fishing activity through fishery-independent methods. Here, we present a novel fishery-independent assessment of multi-sector fishing activity associated with a newly developed open access mFAD programme off San Juan, Puerto Rico. We identified three fishing sectors (recreational, charter and commercial) and 158 individual fishing vessels that routinely operated in the vicinity of the mFADs. The results indicate that daytime fishing activity varied by time of day, day of week, location and sector. During fishing tournaments, the data revealed that fishing activity increased threefold; across monitoring periods, for-hire charter vessels were the most consistent day-to-day user segment, and recreational activity peaked on weekends. Our study represents a new technique for rapidly identifying and detecting multi-sector fishing activity near mFADs and highlights the potential to gather comparable data wherever mFADs are deployed. The results are used to discuss how this technique can be used to assess the performance of mFADs to identify sector overlap and guide management in determining deployment patterns and facilitate the design of cost-effective surveys to estimate mFAD vessel activity, and potentially catch, of mFAD-associated species.

Keywords: fish aggregating devices; fishery-independent survey; video monitoring; small-scale fisheries; recreational fisheries; Caribbean Sea.

Uso de video para cuantificar los patrones espacio-temporales de la actividad pesquera de los distintos sectores en los Sistemas de Agregadores de Peces de Puerto Rico

Resumen: Un reto crucial en las pesquerías artesanales que utilizan los sistemas de agregadores de peces fijos (mFAD, por sus siglas en inglés) es el poder cuantificar con certeza la actividad pesquera multisectorial a través de métodos independientes de la pesca. En este estudio presentamos un innovador análisis independiente de la pesca para la actividad de pesca multisectorial asociada a los nuevos mFAD establecidos en Puerto Rico. Se identificaron 3 sectores pesqueros (recreacional, de alquiler y comercial) y 158 embarcaciones que rutinariamente pescaban alrededor de los mFAD. Los resultados muestran que la actividad pesquera diurna variaba por hora del día, día de la semana, lugar y sector. Durante torneos de pesca la actividad pesquera se triplicó, a lo largo de los periodos evaluados los botes de alquiler mostraron mayor consistencia por día y la actividad recreativa aumentó durante el fin de semana. Nuestro estudio plantea una nueva técnica para identificar rápidamente y detectar actividad multisectorial pesquera cerca de los mFAD y resalta el potencial de tomar datos comparables en otros lugares donde se coloquen los mFAD. Los resultados se utilizan para discutir cómo esta técnica puede ser utilizada para evaluar la ejecutoria de los mFAD, identificar solape de uso por varios sectores y guiar las decisiones en cuanto a los patrones para colocar los mFAD y facilitar el diseño de estudios costo efectivos para estimar la actividad de embarcaciones y el potencial de captura de peces alrededor de los mFAD.

Palabras clave: sistemas de agregadores de peces; estudios independientes de pesca; evaluaciones utilizando video; pesquería artesanal; pesquería recreativa; mar Caribe.

Citation/Como citar este artículo: Merten W., Rivera R., Appeldoorn R., Serrano K., Collazo O., Jimenez N. 2018. Use of video monitoring to quantify spatial and temporal patterns in fishing activity across sectors at moored fish aggregating devices off Puerto Rico. Sci. Mar. 82(2): 000-000. https://doi.org/10.3989/scimar.04730.09A

Fisheries Research 151 (2014) 114–121

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Movements of dolphinfish (*Coryphaena hippurus*) along the U.S. east coast as determined through mark and recapture data

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ARTICLE INFO

Article history:
Received 23 March 2013
Received in revised form 23 October 2013
Accepted 28 October 2013

Keywords:
Dolphinfish
Movements
Migrations
Connectivity
U.S. east coast
Mark-recapture

ABSTRACT

Conventional mark and recapture ($n = 306$ recaptures) and satellite monitoring data ($n = 6$ transmitters) were used to examine small and large scale dispersal and movement patterns of dolphinfish (*Coryphaena hippurus*) along the U.S. east coast. Movement rates were dependent upon region, latitude, and distance from shore released. Movements from Florida to the South-Atlantic Bight (SAB) (44.67 ± 39.53 km/d) and Florida to northeastern North Carolina (MAB) (44.62 ± 15.31 km/d) had the highest observed rates, while movements within the SAB were the slowest (11.80 ± 27.94 km/d). Regional movement headings varied with latitude, with dolphinfish released from Florida Keys to Central Florida displaying the most directional variability, with 3.5% conducting southerly movements. The majority of the southerly movements occurred during fall. The maximum straightline dispersal rate was 238.25 km/d and the greatest displacement distance was 1915 km observed in 51 days between the Florida Keys and Long Island, New York. Understanding the movements of dolphinfish along the U.S. east coast is the first step toward better predicting seasonal and annual stock abundances by state and elucidating state-to-state stock connectivity. On a larger scale, identifying movement patterns along the east coast is a pre-requisite to describing the spatial and temporal movement patterns to other regions such as the Bahamas and Caribbean Sea.

1. Introduction

Dolphinfish, *Coryphaena hippurus* Linnaeus, 1758, is a highly migratory circum-tropical species (Oxenford, 1999; Hammond, 2008) of significant commercial and recreational importance (Oxenford and Hunte, 1986; Rodríguez-Ferrer et al., 2004). However, there is a lack of information on the movements and migrations of dolphinfish along the U.S. east coast necessary for appropriate stock-based management (Mahon and Oxenford, 1999). Understanding these factors is critically important for both fishers and managers to be able to predict the distribution and occurrence of dolphinfish throughout the year, enhance resource allocation, and conduct more applicable stock assessments.

Along the U.S. east coast, dolphinfish are distributed from George's Bank, off New England, south to Key West, Florida (Beardsley, 1967). Throughout this range, dolphinfish abundances are seasonally variable. Off Florida, abundances increase during April and peak from May to June; in the South Atlantic Bight (SAB), dolphinfish begin to increase during May and peak in abundance during June and July (Oxenford and Hunte, 1986). In the Mid-Atlantic Bight (MAB), abundances begin increasing in June and peak from July to August (Oxenford and Hunte, 1986). Despite knowledge of these patterns, movements connecting successive peaks in abundance in differing regions are lacking and are needed to describe the spatial and temporal extent necessary for regional management (Oxenford and Hunte, 1986).

Past movements of dolphinfish were largely inferred through compiling size and abundance observations at geographically separated locations by time of year (Oxenford and Hunte, 1986; Rivera and Appeldoorn, 2000). However, observations such as these do not uncover regional connectivity patterns, movement pathways, distances covered, and movement rates that dolphinfish actually exhibit while moving along the U.S. east coast. A mark and recapture study conducted in 1991 along the U.S. east coast resulted in 60 marked dolphinfish and only 4 recaptures, which offered little insight into their movements and migrations (Personal Comm. Donald Hammond). From 2002 until 2005, the South Carolina Department of Natural Resources (SCDNR) initiated a larger scale mark and recapture study along the U.S. east coast, which resulted in 4922 marked and released dolphinfish and 125 reported recaptures. These data were the first to show a northerly movement trend along the U.S. east coast from Florida to the MAB and movement rates and patterns between tagging regions (Hammond, 1998). Since 2006, the Dolphinfish Research Program, which started after

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0165-7836/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fishres.2013.10.021

Bull Mar Sci. 90(3):849–864. 2014
http://dx.doi.org/10.5343/bms.2013.1078

research paper

Spatial differentiation of dolphinfish (*Coryphaena hippurus*) movements relative to the Bahamian archipelago

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ABSTRACT.—Dolphinfish [*n* = 1188; 35–152.5 cm FL; mean: 73.78 (SD 16.58) cm FL] movements relative to The Bahamas were examined using conventional plastic dart tags (PDTs) and single point pop-up satellite archival tags (*n* = 2; 107.5 and 120 cm); these movements were compared to surface drifter tracks (*n* = 144) in the region from 2004 to 2012. The overall recapture rate for dolphinfish released within The Bahamas was 2.7% (*n* = 33) for fish that ranged in size from 45 to 122.5 cm FL [81.87 (SD 21.84) cm FL]. Days at liberty (DAL) averaged 23.03 (SD 20.60) d (range 0–77 d) and movement speeds (range 0–19.93 km d^{-1}) and headings were dependent upon the location of tagging. Linear displacements ranged from 0 to 1903.16 km. Movements within The Bahamas were to the south in the Tongue of the Ocean, Northeast Providence Channel, and Exuma Sound, ranging from 4 to 23 DAL. However, the majority of dolphinfish released in the Tongue of the Ocean showed little net dispersal (<1 km) after 5–77 DAL. Emigration from The Bahamas occurred most frequently for fish released north of Great Abaco and Eleuthera Islands; fish were recaptured from near Cape Canaveral, Florida, to southeast of George's Bank after 14–58 DAL. Recapture patterns when compared to drifter tracks suggest dolphinfish migrate in a circuit around the western central Atlantic to The Bahamas, but paths can vary widely in temporal and spatial scale. These observations are potentially key for understanding inter-regional dolphinfish movements and stock structure between exclusive economic zones in the western central Atlantic and Caribbean Sea.

Date Submitted: 14 October, 2013.
Date Accepted: 30 January, 2014.
Available Online: 28 April, 2014.

The dolphinfish (*Coryphaena hippurus* Linnaeus, 1758) is an epipelagic, highly migratory species distributed throughout the world's subtropical and tropical oceans (Oxenford and Hunte 1986, Ditty et al. 1994, Hammond 1998). Recent work on global phylogeography and population structure suggests a widely distributed and closely related genetic structure with greatest divergence found within the Mediterranean Sea (Díaz et al. 2010). Studies on age and growth observed dolphinfish to be fast-growing, early-to-mature, short-lived pelagic predators with high rates of annual natural and fishing mortality (Oxenford 1999). Morphological and physiological characteristics such as sexual dimorphism, tendency to school, and fast burst swimming (Oxenford

Fisheries Research 151 (2014) 177–190

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Dolphinfish (*Coryphaena hippurus*) distribution in relation to biophysical ocean conditions in the northwest Atlantic☆

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ARTICLE INFO

Article history:
Received 21 August 2013
Received in revised form
20 November 2013
Accepted 27 November 2013

Keywords:
Species distribution modeling
Zero-inflated negative binomial
Dolphinfish
Sargassum
Habitat
Fisheries oceanography

ABSTRACT

We analyzed temporal and spatial catch per unit effort (CPUE) of dolphinfish (*Coryphaena hippurus*) along the U.S. east coast using pelagic longline logbook data (1999–2007). A zero-inflated negative binomial model was fit using a variety of oceanographic variables to better understand distribution and abundance. The two most important dynamic oceanographic variables were sea surface temperature and chlorophyll-*a* concentration. We also used catch and release locations of dolphinfish caught by recreational fishermen (2002–2007) to compare conditions between datasets and for model evaluation. Dolphinfish CPUE was highest at 22–25 °C with a peak at 24 °C for the longline dataset, while recreational dolphinfish were caught in waters >19 °C with peak catches occurring at 27 °C. Dolphinfish CPUE was highest when chlorophyll-*a* concentration was <0.2 mg m^{-3}, and the majority of recreational dolphinfish were captured in waters <0.1 mg m^{-3} with a peak at 0.02 mg m^{-3}. We also found that a majority (73.26%) of recreational dolphinfish were caught in association with *Sargassum spp.*, and larger dolphinfish (>82.3 cm FL) are caught more frequently outside of the floating mats.

1. Introduction

Dolphinfish (*Coryphaena hippurus*) inhabit the tropical and subtropical waters of the world, where they are sought in commercial and recreational fisheries. Their distribution is generally limited by the 20° isotherm (Palko et al., 1982) and their local catch rate and abundance are influenced by inter-annual and seasonal temperature changes (Kleisner, 2009; Kraul, 1999; Norton, 1999; Zúñiga Flores et al., 2008). Along the east coast of the United States, archival tags revealed dolphinfish can tolerate temperatures as low as 16 °C, and they prefer surface waters (0–10 m) between 27.2 °C and 28.9 °C (Hammond, 2008). Recently, Kleisner (2009) found that the seasonal abundance of dolphinfish along the east coast of the United States and Gulf of Mexico is heavily influenced by sea surface temperature and distance to temperature fronts.

While the seasonal ingress of dolphinfish off the U.S. east coast is correlated to temperature, it is also influenced by a voracious appetite to sustain their rapid growth rate (Palko et al., 1982; Schwenke, 2005). Prey items include a wide variety of perciformes, tetradontiformes, cephalopods, crustaceans, and juvenile conspecifics (Gibbs et al., 1959; Shcherbachev, 1973). Additionally, the western north Atlantic provides a unique habitat for dolphinfish due to an abundance of *Sargassum spp.* (hereafter '*Sargassum*') production within and adjacent to the Sargasso Sea (Carpenter and Cox, 1974; McGillicuddy et al., 1998). The presence of dolphinfish around *Sargassum* has been well documented (Casazza and Ross, 2008; Moser et al., 1998; Oxenford, 1999; Rooker et al., 2006; Ross, 2004), and the relationship is generally characterized by the floating mats providing habitat for prey items and physical shelter from predators.

High growth rate, early maturity, and high fecundity have enabled sustained high exploitation rates of dolphinfish during recent decades. The fisheries for dolphinfish along the U.S. east coast include recreational and commercial fishing, but is traditionally dominated by the recreational sector (SAFMC, 2003). The estimated recreational landings data show that along the U.S. Atlantic coast approximately 3600 m (~1.3 million individuals) of

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0165-7836/$ – see front matter © 2014 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fishres.2013.11.014

Mar Biol (2014) 161:1823–1834
DOI 10.1007/s00227-014-2464-0

ORIGINAL PAPER

Diel vertical movements of adult male dolphinfish (*Coryphaena hippurus*) in the western central Atlantic as determined by use of pop-up satellite archival transmitters

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Received: 4 February 2014 / Accepted: 14 May 2014 / Published online: 7 June 2014

Abstract The vertical movements of six adult male dolphinfish (*Coryphaena hippurus*) (95–120 cm estimated fork length), caught using standard sportfishing methods, were investigated using high-rate single-point pop-up satellite archival transmitters from 2005 to 2011 in the western central Atlantic. Data revealed a diel activity pattern within the mixed surface layer with dives below the thermocline suggesting temperature is not a barrier to vertical movements for short periods of time. Dolphinfish were tracked for periods of 4.96–30.24 day ($\Sigma = 83.37$ day), reaching depths >200 m, and in temperatures ranging from 16.20 to 30.87 °C. The six tags allowed comprehensive vertical movement analyses by time of day, duration at depth, and based on vertical movement patterns. The longest (>60 min), deepest (>30 m), and most extensive vertical movement patterns occurred during night rather than day, with the most time spent near the surface during the day. Dolphinfish spent 66 % of their time in the surface layer (0–9.9 m) and only one individual spent 8 % of the monitoring period diving >8 °C from the maximum surface temperatures recorded while tracked. Two tags were analyzed based on lunar phase and revealed contrasting relationships between vertical movements during new and full phases. Our results suggest dolphinfish vertically shift between surface and at-depth feeding strategies to exploit aggregating epipelagic and mesopelagic prey items leading to predictable diel vertical movements.

Communicated by D. Righton.

Electronic supplementary material The online version of this article (doi:10.1007/s00227-014-2464-0) contains supplementary material, which is available to authorized users.

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Introduction

The dolphinfish (*Coryphaena hippurus*) is a large pelagic predator of significant economic importance to commercial and sportfishing industries and artisanal fisheries worldwide (Oxenford and Hunte 1986). In the western central Atlantic, dolphinfish are known to school and associate with drifting objects such as holopelagic algae (*Sargassum* spp.) and flotsam (Hemphill 2005) from George's Bank to Rio de Janiero, Brazil (Oxenford and Hunte 1983). Throughout this range, dolphinfish undertake long-distance movements at times exceeding 1,000 km along the US east coast (Merten et al. 2014a) and to the Caribbean Sea (Merten et al. 2014b).

Dolphinfish, like wahoo and marlin, are generally observed along continental shelf breaks, deep seamounts, or open ocean temperature and current fronts (Oxenford et al. 2003; Hemphill 2005; Farrell et al. 2014). In recent years, the innovation of compact electronic tags and pop-up satellite transmitters (PSATs) has led to a profusion of depth and temperature distribution data of many pelagic species relative to these features with the exception of dolphinfish. Theisen and Baldwin (2012) used PSATs to document the depth and temperature distribution of wahoo (*Acanthocybium solandri*) to depths >200 m and in

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Genetic structure and dispersal capabilities of dolphinfish (*Coryphaena hippurus*) in the western central Atlantic

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Abstract—The dolphinfish (*Coryphaena hippurus*) is of major recreational and commercial importance, and landings have increased in recent years around Puerto Rico, throughout the Caribbean Sea, and along the U.S. East Coast, yet its genetic structure among these localities is uncertain. A portion of the mitochondrial nicotinamide adenine dinucleotide (NADH) dehydrogenase subunit 1 (ND1; 1288 base pairs) gene was used at 2 spatial scales to investigate the population structure of dolphinfish. In a comparison of 183 specimens of dolphinfish between the northern and southern coasts of Puerto Rico over 4 consecutive years (2010–2013), no genetic differentiation was detected (Φ_{ST}= −0.002, P=0.640). On a broader scale, patterns of genetic variation of ND1 were compared for samples collected throughout the western central Atlantic from Florida, South Carolina, North Carolina (southeastern United States; N=90); Puerto Rico (northeastern Caribbean Sea; N=183); Barbados, Dominica, and Trinidad and Tobago (eastern Caribbean Sea; N=43); and the central North Atlantic in the Azores Islands (N=8), and 199 haplotypes were identified from all of the regions combined. Analysis of all samples (N=324) revealed shallow genetic structure (Φ_{ST}=0.009, P=0.023), but pairwise regional comparisons did not, indicating low population differentiation of dolphinfish throughout the western central Atlantic.

Manuscript submitted 26 May 2014.
Manuscript accepted 28 July 2015.
Fish. Bull. 113:419–429 (2015).
Online publication date: 14 August 2015.
doi: 10.7755/FB.113.4.5

The combination of tagging and genetic approaches (e.g., DNA sequencing and microsatellite analyses) has led to significant improvements in characterizing the stock and population structure of marine pelagic fishes, in interpreting biomass dynamic models, in generating stock-recruitment curves, and in conducting cohort analyses (Graves, 1998; Reiss et al., 2009). Specifically, tag and genetic data can be used to estimate regional biomass exchange and define stocks demographically; this information is useful in the stock assessment process (Waples et al., 2008). Alternatively, tag or genetic data have allowed scientists to refine assessment models and facilitate a more precise allocation of management effort. Therefore, this combination of approaches provides more realistic estimates of immigration, emigration, mortality (natural and anthropogenic), and the extent of population mixing, all of which are informative in assessment models (Hilborn and Walters, 1992).

The results of these models provide fishery managers with information necessary to adjust fishing effort, set size limits and quotas, identify seasonal hot spots and essential fish habitat (e.g., *Sargassum*), and protect spawning stocks to safeguard recruitment and future landings (Allendorf et al., 1987), although the applicability of management measures can vary depending on effective population size (i.e., small versus large). Nevertheless, tag and genetic data are increasingly used to manage highly migratory fish stocks because they provide better estimates of spatiotemporal population differentiation and effective population sizes (Hauser and Carvalho, 2008)

Fisheries Research 175 (2016) 24–34

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Movement dynamics of dolphinfish (*Coryphaena hippurus*) in the northeastern Caribbean Sea: Evidence of seasonal re-entry into domestic and international fisheries throughout the western central Atlantic

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ARTICLE INFO

Article history:
Received 1 February 2015
Received in revised form 26 May 2015
Accepted 18 October 2015

Keywords:
Dolphinfish
Fisheries management
Migration
Mark-recapture

ABSTRACT

Distinct spatial variation and fisheries exchange routes for dolphinfish (*Coryphaena hippurus*) were resolved relative to the northeastern Caribbean Sea and U.S. east coast using conventional ($n = 742$; mean ± SD cm FL: 70.5 ± 15.2 cm FL) and pop-up satellite archival tags ($n = 7$; 117.6 ± 11.7 cm FL) from 2008 to 2014. All dolphinfish released in the northeastern Caribbean Sea moved westward (274.42° ± 21.06°), but slower in the tropical Atlantic than Caribbean Sea, with a maximum straight-line distance recorded between San Juan, Puerto Rico, and Charleston, South Carolina (1917.49 km); an 180-day geolocation track was obtained connecting the South Atlantic Bight to the northern limits of the Mona Passage. Two recaptures occurred within the Mona Passage from San Juan, Puerto Rico, and St. John, United States Virgin Islands, providing the first evidence that dolphinfish may cross the Greater Antilles island chain between the Atlantic Ocean and Caribbean Sea in both directions during their migration. To investigate this further, fish movements were compared to surface drifter tracks ($n = 196$) in the region. Entry of drifters into the Caribbean Sea from the Atlantic Ocean occurred through the northern Lesser Antilles, the Anegada Passage, and the Mona Passage; both passages were observed to be an entry and exit. Results suggest domestic and international fisheries exchanges occur annually between the United States and Caribbean island nations (Antigua and Barbuda, Anguilla, St. Kitts, United States Virgin Islands, Puerto Rico, Hispaniola, The Bahamas, Cuba, Bermuda), with return migration directed towards the Yucatan Channel/Loop Current (south of the Greater Antilles) or Straits of Florida/Gulf Stream (north). Understanding dolphinfish movements and regional connectivity among exclusive economic zones of northern Caribbean islands and the United States is critical for accurate assessments of fishing mortality, spawning biomass and stock health, and given the regional connectivity, management must be consistent between jurisdictions.

1. Introduction

Dolphinfish is a mid-trophic level pelagic fish of significant importance to artisanal, recreational, and commercial fisheries throughout the world's tropical and subtropical oceans (Parker et al., 2006). Mahon (1999) provided a comprehensive review of direct and indirect fishing effort for dolphinfish in the western central Atlantic from 1950 to 1995 and reported that overall, fishing pressure and landings (from artisanal, small and large-scale commercial, and recreational) increased throughout the time-period. Due to an increase in recreational fishing participation (Parker et al., 2006) and commercial operations (Mahon, 1999; South Atlantic Fishery Management Council, 2003), the trend for higher fishing pressure and landings continues (Parker et al., 2006).

In the United States (i.e., Atlantic coast, Gulf of Mexico, and Puerto Rico/U.S. Virgin Islands), recreational landings increased from 1.8 million to 4.5–6.3 million kg/yr from 1980 to 2005, and commercial landings increased from 272,700 to 636,363 kg/yr from 1955 to 2005 (Parker et al., 2006). In the northeastern Caribbean Sea around Puerto Rico, landings for artisanal, recreational, and commercial operations was estimated at 305,000 kg/yr in 1979

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http://dx.doi.org/10.1016/j.fishres.2015.10.021
0165-7836/

Caribbean Journal of Science, Vol. 48, No. 1, 59-62, 2014

First stranding and sighting of the false killer whale (*Pseudorca crassidens*) off Puerto Rico

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Abstract.– Despite years of collecting anecdotal and scientific information of cetaceans around Puerto Rico, the false killer whale (*Pseudorca crassidens*), was never reported. Here, we report the first stranding and sighting event to take place in Puerto Rico in January, and March 2013, respectively. Both events took place along the south coast of Puerto Rico. During the sighting, cooperative prey sharing tactics were observed when two animals appeared to attack a common dolphinfish (*Coryphaena hippurus*).

Keywords.–*Pseudorca crassidens*, northeast Caribbean Sea, feeding behavior

The false killer whale (*Pseudorca crassidens*, Owen 1846) occurs in all tropical and warm temperate oceans of the world (Baird 2009). In the Caribbean Sea, sightings have been documented in Colombian waters to the northeast of Providencia Island (Pardo et al. 2009), near Aruba (Luksenbury 2011, 2013), off St. John, Cuba, St. Vincent, and Tobago (Magnucci-Giannoni 1989). Other sightings have been reported from Venezuela (Bolaños and Bohier 1996) and near St. Vincent and the Grenadines (Mignucci-Giannoni 1989). Strandings have been reported from Antigua (Gricks 1994) and Colombia (Pardo et al. 2009). Until now, no

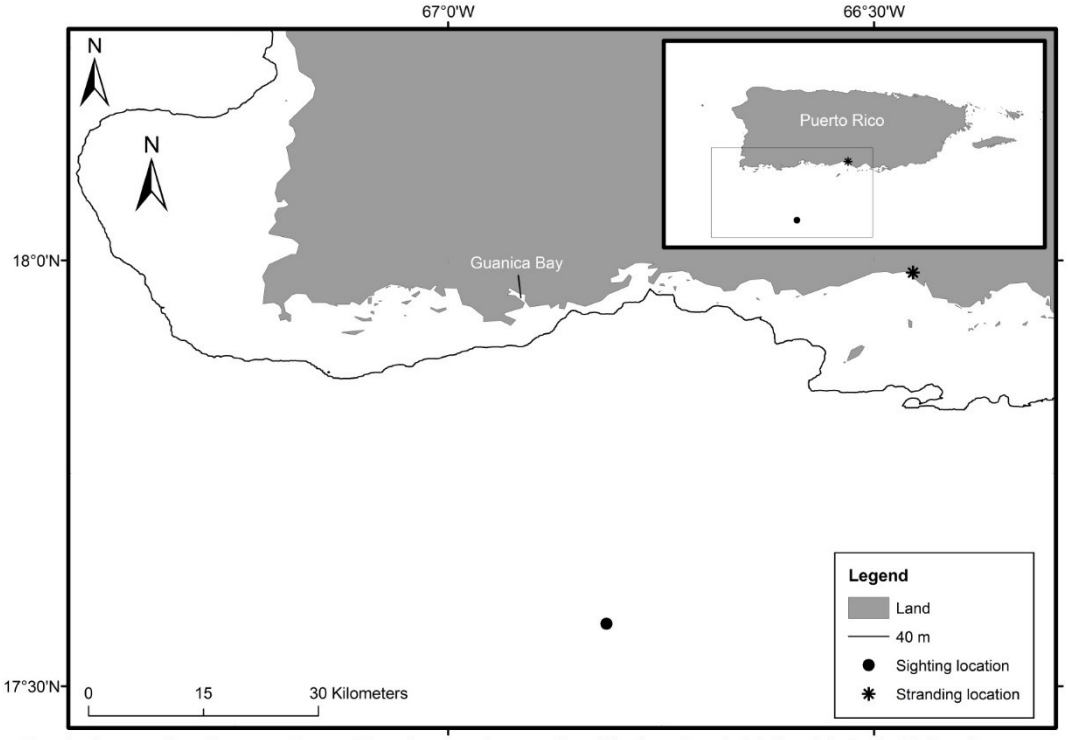

Fig. 1. A map of southwestern Puerto Rico showing the stranding (black star) and sighting (black circle) locations.