Marine Policy 143 (2022) 105189

Contents lists available at ScienceDirect

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

purse-seine fishery), Aires-da-Silva et al. [2] conducted a stock assessment, while Valero et al. [45] implemented a management strategy evaluation. Both studies were exploratory and contributed to the understanding of the population dynamics and history of exploitation of dolphinfish in the EPO, but stock status remains unknown because no reference points (target or limit) were previously quantified [2]. These studies also highlighted the need for strengthening data collection programs throughout the EPO to obtain more information on catch statistics, including recreational catch, and estimates of likely unreported catches. These data are necessary for a region-wide conventional assessment and to evaluate which management strategies will maximize yield without jeopardizing the dolphinfish spawning biomass [45].

In the Atlantic Ocean, the largest governing RFMO (i.e., International Commission for the Conservation of Atlantic Tunas (ICCAT)) has neither conducted a sub-regional, or international stock assessment, nor established any exploratory study on dolphinfish despite high levels of its incidental catch in the ICCAT HMS longline fisheries [23]. Within the ICCAT's catch and effort data collection, dolphinfish is labeled as "other fishes" under commercial bycatch, a designation that labels this fish as un-recognized under the convention agreement as a priority species. This designation effectively removes any ICCAT priority to determine the impact on the Atlantic dolphinfish stock, leads to lower quality data collection on both indirect and direct dolphinfish fisheries throughout the region, and eliminates the opportunity to seek conservation measures if necessary.

In the Western Central Atlantic (WCA), Prager [36] conducted an exploratory dolphinfish assessment for the southeastern United States and Gulf of Mexico, while Mahon and Oxenford [28] completed a precautionary assessment for dolphinfish for a portion of the Caribbean Sea. Despite these subregional assessments, the Western Central Atlantic Fisheries Commission (WECAFC), the largest fisheries commission in the WCA, has not formally assessed the dolphinfish fishery despite the importance of this fish to both commercial and recreational fisheries among its member states. Such a need was identified in the mid-1990′s and discussed in several Caribbean Regional Fishery Mechanism (CRFM) meetings thereafter [4,10]; (CRFM 2010); however, the lack of a formal assessment may be due in part to the lack of any statutory management authority among member states throughout WECAFC's region. Like IATTC in the Pacific, WECAFC has some member states with adequate to robust data collection, but many member states remain unable to procure even basic catch statistics, thereby creating uncertainly on the status of the dolphinfish fishery throughout the WCA and inadequate data standardization to allow for regional comparisons.

The United States (US) has the most robust fishery management framework for dolphinfish in the WCA [39]. In 2003, the South Atlantic Fisheries Management Council (SAFMC) began the Dolphin Wahoo Fisheries Management Plan (FMP) for the US Atlantic coast, from Florida to Maine, which established license and permit requirements, catch quotas by sector, bag and vessel limits, and regional size limits (i.e., first for Florida Atlantic coast) for dolphinfish [39]. In 2004, the Puerto Rico Department of Natural and Environmental Resources established a bag (5 per person) and vessel limit (20 per vessel), which increased in 2010 to 10 per person and 30 per vessel [53,54]. In 2012, SAFMC amended their FMP to expand a 20″ minimum size to include South Carolina [40]. Currently, the SAFMC is amending its FMP along the US Atlantic Coast, which began in March 2016 in reaction to the commercial annual catch limit (ACL) being met and the subsequent harvest closure that occurred on June 30, 2015. In addition, revised recreational landings data from the Marine Recreational Information Program (MRIP) were included to improve harvest estimates to establish a new acceptable biological catch (ABC) level and management for the stock. Throughout public hearings, anecdotal views on the state of the condition of the dolphinfish fishery were voiced from several hundred anglers in Florida stressing the need to implement stringent conservation measures due to changes in the fishery, which many anglers feel are rooted in both domestic and international issues.

Outside the US waters in the WCA, there have not been any concurrent or parallel management approaches for dolphinfish. Many of its biological attributes, such as an early age of maturation [50], high reproductive capacity, fast growth, large size at maturity and short lifespan [51] suggest it can sustain considerable rates of exploitation, if the population is managed properly. Yet, despite its advantageous life-history characteristics, a decrease in its relative abundance has been documented in Atlantic fisheries [23], and as the oceans warm, dolphinfish may expand their geographic range toward higher latitudes [38] in the WCA, which lack protections for juveniles or mechanisms to prevent overfishing.

A concern prevails about juvenile dolphinfish caught near fish aggregating devices (FADs) in the Caribbean, as well as their potential catch in association with the drastic increase of episodic pulses of *Sargassum* in the region [20]. Due to the lack of data on dolphinfish catch and effort trends for many nations throughout the region, these issues are amplified [7]. Therefore, as a first step toward addressing these issues, it is necessary to establish a clear picture on the history of international dolphinfish exploitation throughout the WCA and how catch trends, or the lack thereof, prevail among fishing sectors and jurisdictions throughout the WCA, and also determine as best as possible what is being caught.

The aim of this work is to provide a comprehensive update on the condition of international dolphinfish (*Coryphaena hippurus*) fisheries, catch and effort trends, and data gaps among jurisdictions from 1950 to 2018 throughout the WCA. Results update trends established by Mahon's [27] first regional review, which covered up to the mid-1990 s, and identify changes in landings, pinpoint strengths and weakness among data collection programs, and discuss which agencies bear the greatest capacity to enhance regional international fisheries management to ensure a sustainable fishery into the future.

2. Materials and methods

2.1. Context

We conducted a scientific literature review, and a comprehensive analysis of data based on international fisheries of dolphinfish (*Corphaena hippurus*), to determine catch and effort trends, and data gaps among jurisdictions in the WCA from 1950 to 2018 (Fig. 1). The framework for this review followed that by Mahon [26] and Mahon [27]. For our study, we first compared catch and effort analyses between "First Reporting Nations", nations reporting catch and effort to the FAO, and ICCAT, respectively, for the longest period. This procedure was similar to that followed by Mahon [26,27], but in our work an additional group, named "All Others", was included to identify catch and fishing effort from all other nations that were not reporting in the past (Table 1). Each group was then analyzed separately to examine which nations have important national dolphinfish fisheries. Fleet names referenced in the text follow ICCAT fleet codes and names identified in Table 1.

2.2. Management and conservation measures

The WCA contains 43 jurisdictions, from Brazil to Canada (Fig. 1). We documented the stock trends and enacted fishery management, and conservation measures, in the WCA from 1970 to 2018 from local governing fishery management agencies for each jurisdiction, and from the CRFM [5,6,8,9,11], and we structured that information into a timeline. Blackfin (*Thunnus atlanticus*) and yellowfin (*T. albacares*) tuna as well as blue marlin (*Makaira nigricans*) were added to the timeline to compare the history of stock trends and fishery management policies for these species to trends and policies implemented for dolphinfish in the WCA. Information to compile the timeline was collected from the biennial (from 1970 through 1993) and Standing Committee on Research and Statistics (SCRS) (from 1994 to 2018) reports from ICCAT. Jurisdictions were identified and mapped using ArcGIS online maritime boundaries

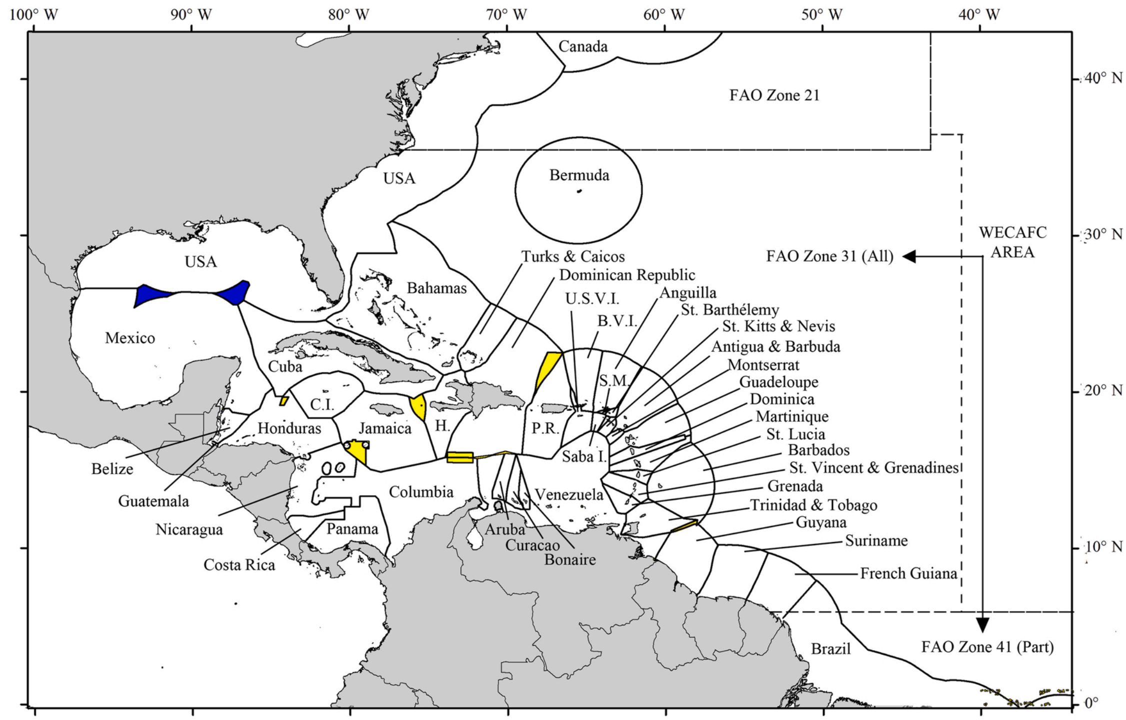

Fig. 1. Exclusive economic zones in the Western Central Atlantic and FAO zones 31 and 41. C.I.= Cayman Islands; H.=Haiti; Saba I.=Saba Island; S.M.=Saint Maarten; Blue= high seas areas in the Gulf of Mexico; Yellow=disputed or joint jurisdictions.

geodatabase version 11.[1]

2.3. Catch and effort in the WCA

2.3.1. Longline effort for large pelagics

Effort data (i.e., number of hooks set during longline operations by 5 × 5 spatial grid), as published in Mahon [26], were updated through 2018. To accomplish this, the longline fishing activity in FAO zones 31 and 41, from ICCAT Task II data, were collected from 1956 to 2018, stored, and binned by nation using Google Bigquery. Annual summed effort data were plotted using ArcMAP v 10.7.1 and divided into effort inside or outside the area of national exclusive economic zones (EEZs) (herein jurisdictions). Exploratory analysis revealed temporal dependence among effort variables. Thus, we fitted regression models with autoregressive order 1 errors. Moreover, when fitting effort across years, the variance increased over time. Therefore, the logarithm of effort was used. Effort data and the following sections on catch, were all analyzed using R version 4.1.1 and results were plotted using Microsoft Excel version 2016 and graphically enhanced using Photoshop CS4. Nations labeled in the plot followed Mahon [26]. To examine trends in fishing effort, data were arranged into three equivalent periods of 21 years and named as follows: 1956–1976 (oldest period), 1977–1997 (mid-period), 1998–2018 (latest period). A regression model was fitted to analyze effort by period. The alpha level used in all regression models was 0.05. A final regression model was fitted to compare fishing effort between the two nation groups (First Reporting, All Others), with data from each nation, pooled over 1988–2018, the period for which all nations were reporting effort.

2.3.2. Commercial catch

Catch data were acquired and grouped for all nations reporting landings to the FAO, from 1950 to 2018 using the FAO FishStatJ 4.1.0, and arranged similarly to effort data using three equivalent 23-year periods: 1950–1972 (oldest period), 1973–1995 (mid-period), 1996–2018 (latest period). An exploratory analysis revealed similar temporal dependence among most catch variables as observed with effort. Thus, we followed the same statistical methods as outlined above.

For nations not specifically reporting dolphinfish catch (n = 23) to the FAO but may have landings of dolphinfish embedded within mixed groupings of unidentified marine fishes (UIM), unidentified tuna-like fishes (UIT), and unidentified pelagic fishes (UIP) reported to the FAO, data were acquired back to 1950. For the UIM, UIT, and UIP groupings, regression models were fitted but no temporal dependence was found. To examine trends since Mahon [27], five-year averages of landings for dolphinfish, UIM, UIT, and UIP from nations reporting and not reporting dolphinfish were binned and compared using a regression model between 1990 and 1994 (Time Average 1) and 2014–2018 (Time Average 2). In addition, landings data for tuna and tuna-like species for nations reporting and not reporting dolphinfish were acquired to examine coastal and offshore pelagic fishery catch trends among and within those groups (Appendix 2 for FishStatJ query). A regression model was used to compare landings between and within groups among the periods mentioned above. Then, pairwise comparisons between groups and periods were conducted using a two-sample t-test assuming equal variances. The alpha level used in all t-tests was 0.05 and run using Microsoft Excel 2016.

In Mahon [27], only one landings dataset from the FAO was available for the analysis. Recently, the Sea Around Us[2] (SAU) conducted a global catch reconstruction of many commercial and recreational fisheries, including dolphinfish, UIM, and UIP categories of landings. Therefore, reconstructed dolphinfish, UIM, and UIP catch data was collected from the SAU [34][48] for each EEZ for all jurisdictions in the WCA from the entire dataset (1950–2016). Each reconstructed catch category was compared to the analogous FAO category, except UIP, which was compared to the FAO's unidentified tuna-like species because the UIP category was not used by any of the nation's reporting catch in the WCA.

[1] https://www.marineregions.org/sources.php.

[2] http://www.seaaroundus.org/.

Table 1
Nation groupings used in catch and effort analysis. For effort, the International Commission for the Conservation of Atlantic Tunas (ICCAT) fleet codes and fleet names are provided for the first reporting nations (dating back to 1956) and all other nations reporting Task II effort since [27]. For dolphinfish catch provided to the Food and Agricultural Organization (FAO), country names are included for first reporting nations, all others, and nations not reporting dolphinfish since [27] to 2018.

Grouping	Effort		Catch
	ICCAT Fleet Code	ICCAT Fleet Name in Text	
First Reporting Nations	BRA, TAI, CUB, JPN, KOR, USA, VEN	Brazil, Chinese Taipei, Cuba, Japan, Korea Republic, USA, Venezuela	Barbados, Dominican Republic, Grenada, Guadeloupe, Martinique, Mexico, St. Lucia, USA
All Others Reporting	BLZ, BLZ-ES, BLZ-GH, BLZ-JP, BLZ-TT, BLZ-UY, BRB, CAN, CHN, EU. ESP-ES-SWO, MEX, MIX. KR+PA, PAN, PHL, TTO-TT-TRINID, UK. BMU, UK.TCA-USA, URY, URY-JP, VCT, VUT	Belize, Belize (España), Belize (Ghana), Belize (Japan), Belize (Trinidad and Tobago), Belize Uruguay, Barbados, Canada, China, EU.España Target SWO, Mexico, Korea + Panama, Panama, Philippines, Trinidad, UK. Bermuda, UK Turks and Caicos-(USA), Uruguay, Uruguay (Japan), St. Vincent and Grenadines, Vanuatu	Antigua and Barbuda, Belize, Bermuda, BVI, Costa Rica, Cuba, Dominica, France, Puerto Rico, St. Kitts/Nevis, St. Vincent, Suriname, Trinidad and Tobago, USVI, Venezuela
Nations Not Reporting Effort to ICCAT or Dolphinfish Catch		Aruba, Bahamas, Cayman Islands, Columbia-Caribbean, French Guiana, Guinea, Guatemala-Caribbean, Guyana, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Nicaragua-Caribbean, Spain, St. Barthelemy, St. Martin	Aruba, Bahamas, Cayman Islands, Columbia, French Guiana, Guinea, Guatemala, Guyana, Haiti, Honduras, Jamaica, Japan, Montserrat, Netherlands Antilles, Nicaragua-Caribbean, Panama-Caribbean, Korea, Spain, St. Barthelemy, St. Martin, Turks and Caicos, United Kingdom

For dolphinfish, nations with reconstructed and FAO catch data were compared and plotted using Microsoft Excel. A paired two-sample t-test was run for each comparison as well as a correlation analysis using Microsoft Excel 2016.

2.3.3. *Recreational catch*

Recreational dolphinfish landings in the WCA were assessed in three ways. First, total annual landings, from 1993 to 2018, were acquired from the National Oceanic Atmospheric Administration's (NOAA) Marine Recreational Information Program (MRIP) for all US Atlantic recreational sectors. NOAA's MRIP did not operate in the United States Virgin Islands (USVIs) during that time. Total reconstructed US recreational catch (United States East Coast); US Gulf of Mexico (US GOM); and Puerto Rico) was acquired from the SAU and compared to the same time as the NOAA MRIP catch (excluding the USVIs) using a correlation analysis in Microsoft Excel 2016. Second, reconstructed dolphinfish specific recreational landings in the final year (2016) of the SAU dataset was acquired for each nation in the WCA and compared to the total amount of reconstructed recreational landings per nation for that year. If dolphinfish specific estimates were not available, the total amount of recreational landings was indicated. Third, recreational fishing trends (i.e., began, increasing, decreasing, unknown, not applicable) were assessed from the FAO's country profile database[3] as well as country-specific catch reconstruction working papers from the SAU. Trends were categorized based on text included in either of those sources that indicated recreational fishing effort: (1) began; (2) represented a certain total catch percent or proportion of effort (labeled as an increase); (3) decreased due to socio-economic factors; (4) was not mentioned (unknown); or (5) not labeled as a fishing sector (not applicable).

3. Results

3.1. *Management and conservation measures*

Management and enacted conservation measures for dolphinfish emerged after 2000 but prevailed fragmented throughout the WCA (Table 2). When compared to ICCAT managed species, there was a lack of detail regarding the dolphinfish stock status, which has never been formally assessed, unlike blue marlin and yellowfin tuna, which have been assessed 6 and 7 times, respectively, since the mid-1990 s (Table 2).

3.2. *Catch and effort in the Western Central Atlantic Ocean*

3.2.1. *Longline effort for large pelagics*

There were significant differences in longline fishing effort between the periods within and outside jurisdictions (Regression; $P < 0.05$) (Fig. 2). Inside jurisdictions, it doubled from the oldest period with a mean of 158,285 (SD ± 112,561 hooks x 1000) to 340,705 (168,656) in the latest period, while outside jurisdictions, it quadrupled from the oldest period 247,409 (176,466) to 1,018,767 (301,784) in the latest period. For effort outside jurisdictions, from 1988 to 2018 when additional nations started to report effort to the FAO (within the group "All Others"), these nations constituted a comparable proportion of recorded effort versus nations active before Mahon's study (within the group "First Reporting Nations") (Regression; $P = 0.015$). Since 2010, the top ten nations comprising the greatest longline effort outside jurisdictions, by ICCAT fleet name, included St. Vincent and Grenadines, followed by Chinese Taipei, USA, Spain targeting swordfish, Vanuatu, Venezuela, Trinidad, Belize (Trinidad & Tobago), Japan, and Korea. For effort within jurisdictions from 1994 to 2018, All Others constituted a comparable proportion of recorded effort versus first reporting nations (ANOVA; $P = 0.881$). Since 2010, only 12 nations recorded longline effort within their jurisdictions. From greatest to least effort the fleet names were: USA, Mexico, Venezuela, St. Vincent and Grenadines, Japan, Trinidad and Tobago, Chinese Taipei, Belize, Korea, Belize (Trinidad and Tobago), Vanuatu, Turks and Caikos (USA). A total of 17 nations did not report WCA effort to ICCAT but have jurisdictions within the study region where dolphinfish occur seasonally.

3.2.2. *Commercial catch*

There were significant differences in the amount of dolphinfish catch reported over the periods (Regression; $P < 0.05$) (Fig. 3). Reported landings increased nearly threefold since 1950 in the WCA, from 1493 (SD ± 321) metric tons (MT) in the oldest period to 4393 (1034) MT in the latest period. Since 1994 by nation groups, after accounting for autoregressive dependence, there were no significant differences (Regression: $P = 0.35$) in landings between nation groups. Initially, however, first reporting nations represented the majority of submitted landings (1470 (1528) versus 2823 (2815) MT). Since 2010, All Other nations (n = 14) had surpassed first reporting nations (n = 8) in

[3] http://www.fao.org/fishery/countryprofiles/search/en.

Table 2
Discussion of trend and major conservation response to the state of yellowfin tuna, blue marlin, and blackfin tuna stocks in the Atlantic Ocean as depicted from the history of International Commission for the Conservation of Atlantic Tunas (ICCAT) biennial and Standing Committee on Research and Statistics (SCRS) reports. Dolphinfish conservation measures and stock status were examined relative to reports from the Caribbean Regional Fisheries Mechanism (CRFM) and countries within the Western Central Atlantic (WCA) Ocean. ↓ = declined, decreased, decreasing; SA = stock assessment; exp. = exploited or exploitation; +exp. = overexploitation; MS = minimum size (for yellowfin tuna MS = 3.2 kg); OFD = overfished; OFG: overfishing; U.S. EC = United States East Coast; BZ = Brazil; DR = Dominican Republic; FL = Florida; GA = Georgia; SC = South Carolina; PR = Puerto Rico; BAH = Bahamas; N/A = not applicable; ACL = annual catch limit TC: total catch; PLL = Pelagic longline; PS: Purse seine; FE = fishing effort; BUM: blue marlin; WHM: white marlin; YFT = yellowfin tuna; BET = bigeye tuna; EEZ = exclusive economic zone; PWG: pelagic fisheries working group; CFF = Caribbean Fisheries Forum.

Time Period	Dolphinfish	Yellowfin Tuna	Blue Marlin	Blackfin Tuna
1970–79′	1970–79′: Not mentioned	1970–73′: ↓ trend, Marked & serious ↓, Increase in capture size proposed, SA 71, Stocks fully exp.; 1974–76′: Seriously reduce the TC in future years, 3.2 kg minimum size; 1976′–79′: MS, ↓ trend, heavily exp., ’	1970–76′: Not Mentioned; 1977′–79′: Stocks rapidly dropped, has been OFD	1970–73′: Not mentioned; 1974–76′: Substantial catches; 1977–79′: Major catches: BZ and DR, Smallest catch of all tuna spp.
1980–89′	1980–89′: Not mentioned	1980–83′: Abundance ↓ steadily; Stock heavily exp., MS, ↓ trend, high levels of exp., Continuous ↓, Fully exp.; 1984–86′: Slight ↓, Moderate ↓in abundance, ↓of estimated biomass, MS, Intensive exp., Moderate ↓in the mean abundance of the stock, Intensive & Strong exp.; 1987–89′: Intensive exp., MS, Slight ↓, catches ↓, very low adult biomass, ↓in catch rates, ↓in spawning biomass 87′–88′; Moderate exp., +exp. observed from 80′–83 stated 89′	1980–86′: ↓trend, Continual ↓, Some +exp., Continual & substantial ↓; 1987–89′: Slight ↓, Some +exp.	1980–83′: Should be monitored, Directed fisheries exist in WCA; 1984–86′: Sampling for size by U.S; 1987–89′: Not mentioned
1990–99′	1990–93′: Not mentioned, 1994–96′: Eastern Caribbean assessment by PWG in CRFM considered stable 1997–99′: 18 dolphinfish pp/day St. Lucia	1990–93′: Near full exp., MS, +exp., Close to full exp., Biomass ↓since 89′, Close or slightly above full exp., High rates of exp., Heavy exp. on spawning stock; 1994–96′: Approximately fully exp., MS Close to maximum exp., Stock is fully exp., ↓, SA 94′; Close to full exp., Spawning biomass ↓, [Rec. 93–04]; 1997–1999: SA 97′, Close to full exp., MS, U.S. Atlantic Tunas Conservation Act, Exp., SA 98′, 97′–99′	1990–93′: Generally ↓, ↓ in stock biomass, At least fully exp., Likely +exp., Continued ↓of estimated biomass, SA 92′; 1994–96′: ↓ in stock biomass; Likely +exp., At least fully exp, Considered +exp., Decline in stock biomass, No ICCAT regulations, SA 96′, Continue to ↓in stock status; 1997–99′: +exp., No ICCAT regulations, Considered +exp.	1990–96′: Not mentioned; 1997–99′: CARICOM tag program 97′–98′
2000–09′	2000–03′: SCDNR Tagging Program 2004–06′: Dolphin FMP U.S. EC; 20″ MS FL & GA; 60 per vessel 10 pp/d; 2004 PR, 20 per vessel 5 pp/d ; 2007–09′: Mexico Article 68 07′, Selected for assessment at CRFM meeting in conjunction with CFF	2000–03′: MS, [Rec. 93–04], [Rec. 99–01], SA 00′, SA 03′; 2004–06′: Steady decline in overall Atlantic catches from 01′ to 04′, Lowest level since 1984, MS repealed in 06′; 2007–09′: [Rec. 99–01] Note: This measure was replaced, ↓ trend in TC, SA 08′, OFG not occurring, Reduction in overall Atlantic Catches, [Rec. 99–01] although this measure was intended to reduce the catches of juvenile BET, impacts are expected on all tropical tunas, Showed some improvement between 03′ & 08′,	2000–03′: SA 96′, Reduce marlin landings by 25 % from 96′ levels., In 96′, OFG occurring for 3 Decades, Reduce PLL & PS landings to 50 % of 99′ levels, In 99′, ↓14 % from 96′ level, OFG still occurring in 00′, SA 00′; 2004–06′: Reduce PLL & PS landings to 50 % of 96′ or 99′ levels, whichever is greater, SA 00′; Catches continued to ↓through 04′, ↓ in Abundance, SA 06′, May Be Stabilizing; 2007–2009′: Catches continued to ↓through 04′, Trends for 01′–04′ suggest that the ↓in abundance may have slowed or halted, SA 06′, Reduce PLL & PS landings to 50 % of 96′ or 99′ levels, whichever is greater	2000–09′: Mentioned but NSD
2010–18′	2010–13′ PR: 30 per vessel 10 pp/d, 20″ MS expanded to SC, 2 fish pp/d Mexico 2014–16′: Prohibit U.S. for-hire bag limit sales, Filets from BAH enter U.S., large amounts of juvenile dolphinfish caught in association with sargassum events CRFM, dolphinfish included in ICCAT mandate but there is not a formal code to facilitate statistical reporting, U.S. PLL closed 2017–18′: 4000 lb U.S. commercial trip limit once 75 % ACL reached, Stock concern Florida and South Carolina = smaller size, less big fish, seasonal changes	2010–13′: SA 08′, Reduction in overall Atlantic catches, Showed some improvement between 03′ & 08′, [Rec. 93–04], SA 2011, ↓in stock levels over last several years, Estimated OFD in 2010, [Rec. 93–04], Estimated 26 % chance that not OFD & OFG was not occurring in 2010, Estimated OFD in 2010, Specific limits of number of PLL &/or PS Boats for a number of fleets, limits on numbers of fishing vessels less than the average of 91′ & 92′, Specific limits of PLL Boats: China (45), Chinese Taipei (75), Philippines (10), Korea (16), PS: Panama (3). Reduction small YFT landed; 2014–16′: SA 2011, Estimated to be OFD in 10′, SA 2016, OFD;	2010–13: Catches ↓ through 04′, Trends for 01′–04′ suggest that the ↓ in abundance may have slowed or halted, SA 06′, SA 11′, ↓ Trend, Catches ↓through 09′, OFD & undergoing OFG, Stock below BMSY, Reduce PLL & PS landings to 50 % of 96′ or 99′ levels, whichever is greater, Catches ↓ in 09′, Stock will continue to ↓ further, All BUM brought to PLL & PS vessels alive shall be released in a manner that maximizes their survival, Stock Below BMSY, Catches ↓ In 09′, OFD & undergoing OFG, Continued ↓ trend, If the recent catch levels of BUM (3358 T in 10′) are not substantially reduced, the stock will continue to ↓ further; 2014–16′: SA 11′, OFD, OFG, ↓ trend in	2010–18′: Mentioned but NSD 2014: Concern regarding blackfin tuna reproduction at or around FADs and the harvesting of juveniles of the species CRFM

(*continued on next page*)

Table 2 (*continued*)

Time Period	Dolphinfish	Yellowfin Tuna	Blue Marlin	Blackfin Tuna
		2016–18′: SA 2016, OFD, One of the most exp. fish species, ↓ trend in average weight, OFD	biomass partially stabilized, Stock will continue to ↓ further, ↓ through 09′, OFD, OFG, Continued ↓trend; 2017–18′: Plan to rebuild stock; OFD SA 18′; Catches greater than TACs	

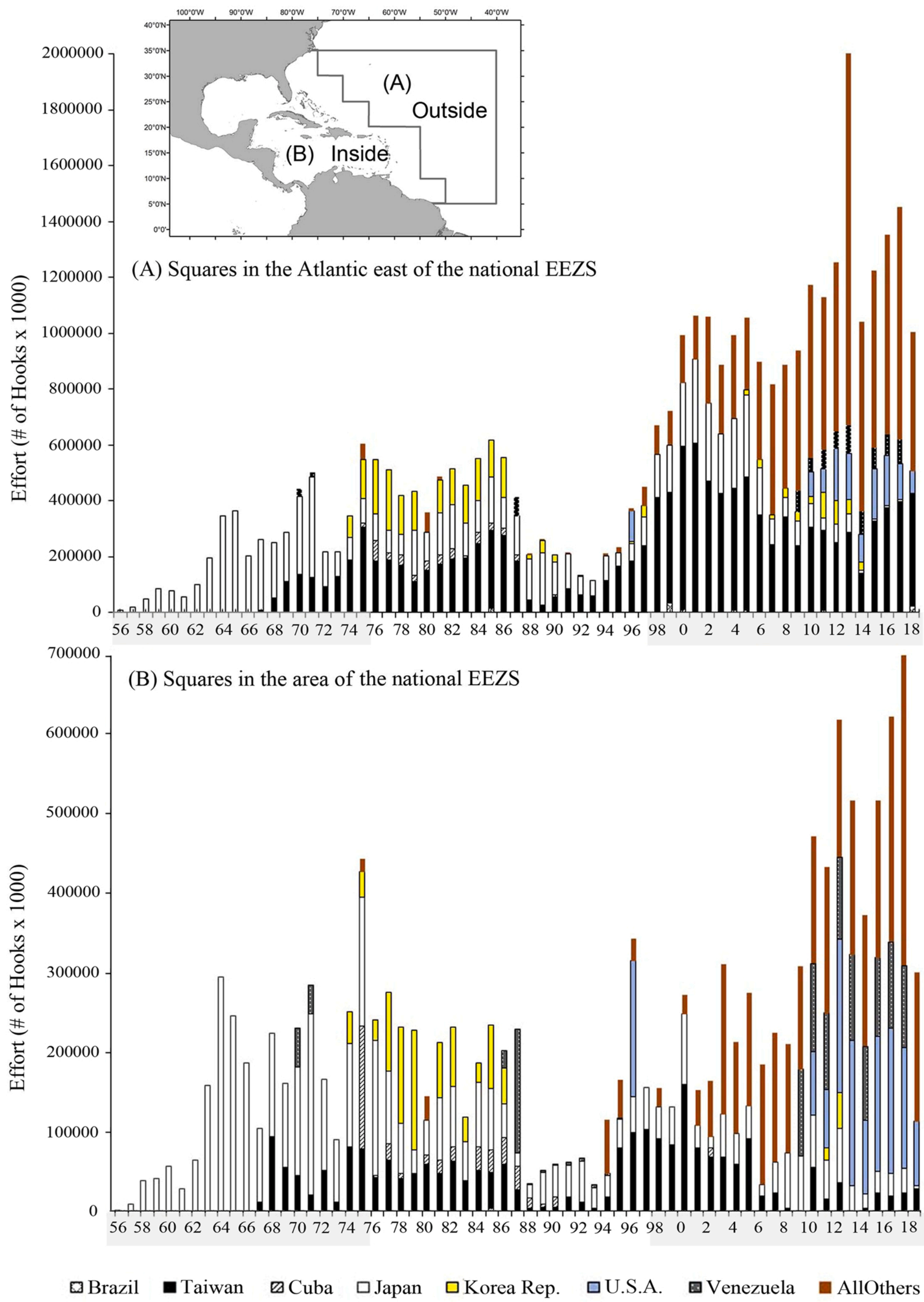

Fig. 2. Pelagic longline effort (number of hooks x 1000) by first reporting nations and the group “All Others” for areas outside (A) and (B) inside jurisdictions from 1956 to 2018. The light grey shading denotes the 21-year periods as specified in text.

landings (2939 (845) versus 2159 (3340) MT). Of the first reporting nations, only the Dominican Republic (DR) (average landings increased 85 MT), Venezuela (average landings increased 569 MT), and France (landings have only been reported since 2009 but were among the highest in the region: 1084 (592) MT) reported increases in landings. Since 2010, the ten nations that reported the most landings to the FAO

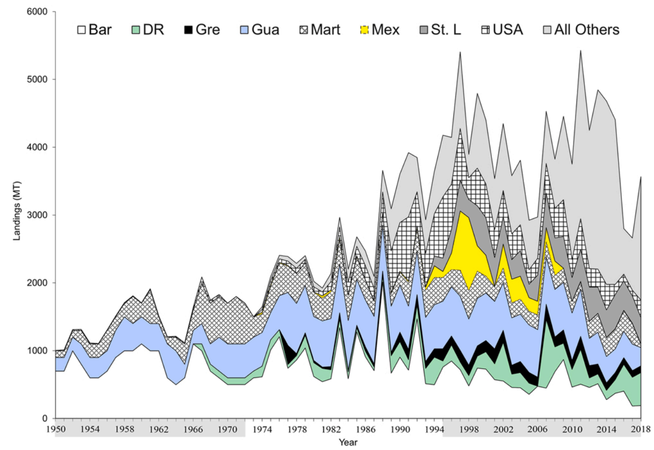

Fig. 3. Commercial dolphinfish landings (metric tons) for first reporting nations and the group "All Others" from 1950 to 2018. The light grey shading denotes the 23-year periods as specified in the text.

from greatest to least were: Venezuela, France, Guadeloupe, St. Lucia, Barbados, DR, US, Martinique, Dominica, and Suriname. These latter nations accounted for 88 %−93 % of FAO landings, with the lowest percentage recorded in the most recent year (2018). A total of 23 nations did not report explicit dolphinfish landings to the FAO but are known to catch dolphinfish.

For UIM landings for nations that report dolphinfish landings, there were no significant differences (Regression: $P = 0.22$) in average UIM reported between time average 1 and time average 2 even though average UIM landings decreased over 71 % (11,909 to 3231 MT) (Table 3). Only Barbados, DR, and Trinidad and Tobago recorded an increase in the average landings of UIM. In terms of UIT landings among reporting nations, Barbados, Costa Rica, St. Kitts/Nevis, Suriname, and the USVI recorded increases. For nations not reporting dolphinfish landings, there were no significant differences (Regression; $P = 0.76$) in average UIM reported landings between time average 1 and time average 2 (Table 3) even though UIM landings decreased by 22 % (3411 to 2664 MT). However, Haiti, Jamaica, the Cayman Islands, Panama, St. Barthelemy, St. Martin, and Turks and Caicos recorded an increase in UIM between time average 1 and 2. Haitian landings increased four-fold (3476 to 15,130 MT), while the Cayman Islands and Jamaica landings increased 48 % (1456 to 2761 MT) and 40 % (7120 to 11,753 MT), respectively. Nicaragua reported the same average UIM between both periods, and Guatemala and Guyana had a decrease in UIM but an increase in UIT. Colombia showed an increase in UIM and a decrease in UIT. Republic of Korea did not report any dolphinfish landings, UIM, or UIT (Table 3), despite having effort within the region.

Over the entire period (1950–2018), there were significant differences in the amount of oceanic pelagic landings between non-reporting and reporting nations (Regression: $P < 0.05$; 34,722 (20,086) versus 26,022 (18,194). However, pairwise comparisons between periods revealed significant differences initially (T-Test: $P < 0.05$; 31,703.04 $\pm$ 31,120.68 MT versus 6768.69 $\pm$ 2593.23 MT (oldest period)), followed by a non-significant difference ($P = 0.13$; 41,107.78 $\pm$ 13,570.97 MT versus 35,727.7 MT $\pm$ 19,190.34 MT (mid-period)), then a significant difference ($P < 0.05$; 31,357.04 $\pm$ 5515.75 MT versus 35,569.96 $\pm$ 8180.51 MT (latest period)) as reporting nations surpassed non-reporting nations in landings through time. For coastal pelagic landings, reporting nations have remained between five to seven times higher than non-reporting nations over the entire period but both groups have increased (Fig. 4).

Reconstructed commercial dolphinfish landings tracked reported landings (Correlation = 0.74), but reconstructed landings were greater in 55% of the period. The distribution of these, however, were not random over time (Fig. 5a). From 2000–2016, apart from three years, the reconstructed dolphinfish catch was higher (up to 2.3 times or 2634 MT). Consequently, the reconstructed dolphinfish catch was 39.4% higher than reported catch from 2000 through 2016 and 18% higher over the entire period (*T*-Test: $P < 0.05$; 1648.62 $\pm$ 954.40 MT versus 1482.44 $\pm$ 766.41 MT). For reconstructed UIM landings, estimates were higher in every year except three when compared to the FAO estimates with a maximum of 2.7 times or 323,530.92 MT higher in 2015 (Correlation = 0.72). On average, reconstructed UIM estimates were 76% higher over the entire period. Lastly, reconstructed UIP landings were higher in every year except four when compared to FAO UIT estimates and on average 4.6 times higher than reported landings. However, trends were not strongly correlated (Correlation = 0.49).

3.2.3. *Recreational catch*

The reconstructed recreational catch for the US (East Coast, US GOM, and Puerto Rico) was highly correlated when compared to the MRIP data (Correlation = 0.93) with the SAU recreational total being only 3% higher than the MRIP estimate over the period. For the last year of the reconstructed landings dataset (2016), within the WCA, the US represented that largest component of recreational catch (85%) as well as the largest landing sector by two-fold (Fig. 5 subpanel A). Puerto Rico, the second largest recreational sector in the region constitutes 6.9% of the US Atlantic Ocean recreational catch. The third largest recreational sector is The Bahamas (5.6% or total recreational catch or 475 MT) (Table 3). When combined with reported commercial landings for 2016, the total direct dolphinfish catch was 14,270 MT, of which 62% was estimated to be recreational. For some nations, the recreational catch was estimated to be up to 30% (Honduras) of the total. Reconstructed recreational catch was estimated for 11 nations also reporting commercial dolphinfish landings to the FAO and 9 nations which do not report commercial landings (Table 3).

When reconstructed recreational catch was compared to the 2016 FAO commercial landings by nation, twelve nations and territories showed higher recreational landings. The top five were the US, The Bahamas, Aruba, British Virgin Islands, and Trinidad and Tobago. Estimated 2016 recreational landings among nations that make up the Greater Antilles (The Bahamas, Turks and Caicos, DR, Puerto Rico, USV. I, B.V.I) were estimated at 1100 MT (Table 3).

4. Discussion

Large pelagic fishing effort and catch trends for dolphinfish within the WCA increased, shifted, and revealed a continuing uncertainty on the total catch and effort imparted upon the dolphinfish stock. Our work reiterated points made by Mahon [27], more than two decades ago, but also provided additional information to offer a comprehensive update of the dynamics of the international dolphinfish fisheries throughout the Caribbean Sea and the WCA.

4.1. *Longline effort for large pelagics*

Large pelagic longline fishing effort substantially increased outside of jurisdictions over the entire period. While the main targets are swordfish (*Xiphias gladius*), yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna, dolphinfish (*Coryphaena hippurus*) represents a substantial amount of bycatch in the US longline fleet (USLL) [23]. This fleet directs effort over a wide range of habitats within the WCA but focuses largely within the US GOM and along the US East Coast. Gear modifications, logbooks and observer requirements have evolved for the USLL to require the use of large (16/0 size) corrodible circle hooks, limits on the length of the mainline, and full logbook and observer coverage of sets and landed target species [46], distinguishing the USLL as one of the most highly regulated and monitored fisheries in the region. Despite these advances in bycatch reduction, and data monitoring for the USLL fleet, a greater selectivity toward larger fish exists [46], which translates to large dolphinfish caught as bycatch (personal

Table 3
Average commercial landings (metric tons) for dolphinfish in the wider Caribbean region (Zone 31 and 41) between two time periods for countries (arranged alphabetically) reporting dolphinfish to the FAO. Unidentified commercial landings of fishes that could include dolphinfish are shown for all countries in three categories and presented in alphabetical order: unidentified marine fishes (# italics), and unidentified tuna-like fishes (# underlined). The trend for each category is presented as follows: trend began (S), decreased (-), or increased (+) in amount. A ^{X} for the unidentified landings indicates the same value was reported over the period. For recreational fleets, 2016 dolphinfish specific landings, percent dolphinfish of total recreational catch or total recreational catch, and sector trend is provided from the Sea Around Us or Marine Recreational Information Program (United States and Puerto Rico). This table was modified following [27]. NR = not reporting during that period. n/a = not applicable. Neg. = negligible. Fleet letters: R = recreational; A = artisanal; C = commercial. ^{DOL} = Dolphinfish specific landings.

Country	Fleet	Dolphinfish Landings			Unidentified Landings				Recreational Fleet		
		1990–94 (MT)	2014–18 (MT)	Trend	1990–94 (MT)	2014–18 (MT)	Trend UIM	Trend UIT	2016 DOL TC (MT)	% Total Or Total (MT)	Trend
Countries reporting dolphinfish landings to the FAO											
Antigua and Barbuda	RAC	*NR*	29.4	S	*820;* 2^{X}	*187;* 24	–	+	0	216	+
Barbados	RAC	820.6	286.4	–	*65;* 128	*230*	+	–	.01^{DOL}	1 %	+
Belize	RC	*NR*	1.8	S	*274*	*119*	–		n/r	n/r	+
Bermuda	RAC	*NR*	4	S	*119*	*4*	–	n/a	n/r	n/r	+
Brazil	RAC	*NR*	1333	S	*0*	*0*	n/a	n/a	n/r	neg.	+
British Virgin Islands	RAC	5	1	–	*392;* 20^{X}	*770*^{X}	+	–	29^{DOL}	25 %	+
Costa Rica	RAC	*NR*	75.6	S	*65;* 2	*28;* 141	–	+	n/r	neg.	+
Cuba	RAC	*NR*	19	S	*22096*	*5583*	–	n/a	n/r	neg.	+
Dominica	RAC	*NR*	239.2	S	*549*	*156*	–	n/a	n/r	neg.	S
Dominican Republic	RAC	242	327.2	+	*1077*; 113	*1498*	+	–	39^{DOL}	25 %	+
Grenada	RAC	135	103.2	–	*354*	*34*	–	n/a	.15^{DOL}	8 %	+
Guadeloupe	RAC	656	260	–	*5555*	*2028*	–	n/a	n/r	.01	+
Martinique	RAC	333	45	–	*2487*	*227*	–	n/a	n/r	.03	+
Mexico	RAC	59	7	–	*142578*	*13106*	–	–	n/r	3800	+
Puerto Rico	RAC	*NR*	38.2	S	*499*; 79	*104;* 1	–	–	517^{DOL}	43 %	+
St. Lucia	RAC	*NR*	428	S	*609*; 44	*425;* 19	–	–	.70^{DOL}	9 %	+
St. Kitts/Nevis	RAC	*NR*	53.6	S	*254*	*44;* 9	–	+	.28^{DOL}	25 %	+
St. Vincent/ Grenadines	RAC	*NR*	57	S	*1125*	*9*	–	n/a	.08^{DOL}	8 %	+
Suriname	AC	*NR*	147.6	S	*9010*	*32,154*	+	n/a	n/a	n/a	n/a
Trinidad & Tobago	RC	*NR*	12	S	*2773*; 2334	*6078;* 369	+	–	111^{DOL}	9 %	+
USA	RC	657	176	–	*26245*; 93	*1753;* 8	–	–	7448^{DOL}	3 %	+
U.S.V.I	RAC	*NR*	24	Began	*723*	*19;* 4	–	+	22^{DOL}	24 %	+
Venezuela	RC	657	1226.2	+	*32436*; 487	*1760*; 41	–	–	0	0	–
Countries not reporting dolphinfish landings to the FAO											
Aruba	RA				*232*	*48*	–	n/a	109^{DOL}	13 %	+
Bahamas	RA				442	*12*	–	n/a	475^{DOL}	8 %	+
Cayman Islands	R				*122*	*125*^{X}	–	n/a	.05^{DOL}	.2 %	+
Columbia	R				*1456*; 909	*2761*; 7	+	–	n/r	n/r	UNK
French Guiana	R				*3401*	*52*	–	n/a	n/r	n/r	UNK
Guinea	UNK				0	0	n/a	n/a	n/r	n/r	UNK
Guatemala	R				*102*	*80;* 54	–	+	n/r	n/r	UNK
Guyana	R				*35969*	*16291*; 86	–	+	n/r	n/r	UNK
Haiti	RA				*3476*	*15130*^{X}	+	n/a	n/r	n/r	UNK
Honduras	RAC				*500*	*410*	–	n/a	21^{DOL}	30 %	+
Jamaica	RAC				*7120*	*11753*	+	n/a	1^{DOL}	17 %	+
Japan	C				*6*	*3*^{X}	–	n/a	n/a	n/a	n/a
Montserrat	RAC				*69*	*32*	–	n/a	n/r	n/r	UNK
Netherlands Antilles[I]	RA				*566*	0	–	n/a	12^{DOL}	9 %	+
Nicaragua	R				*203*	*203*	same	n/a	n/r	n/r	UNK
Panama	R				*628*	*833*	+	n/a	n/r	n/r	UNK
Korea	C				0	0	n/a	n/a	n/a	n/a	n/a
Spain	RAC				0	*6*	+	n/a	n/a	n/a	n/a
St. Barthélemy	R				0	*100*^{X}	+	n/a	6^{DOL}	20 %	+
St. Martin	R				0	*90*^{X}	+	n/a	21^{DOL}	20 %	+
Turks and Caicos	R				*287*	*30*^{X}	–	n/a	18^{DOL}	10 %	+

communication NMFS). However, given most of the longline effort outside jurisdictions within the WCA exists from distant water fleets (e.g., Chinese Taipei, Spain, Vanuatu, Japan, and Korea) [12,42][16], fleets which may lack bycatch reduction strategies, their bycatch for dolphinfish could be greater than the USLL. This scenario could represent additional pressure on the region's stock. In addition, it is unknown whether distant water fleets maintain the same data collection and observer requirements for fishing operations, which adds to the inability to quantify the spatio-temporal bycatch on the stock, information needed to fully understand the situation. If bycatch of dolphinfish in these fleets is at a similar level as the USLL [23], the amount of bycatch, although currently unknown, should be used by fishery managers in conjunction with effort data to establish appropriate total allowable catch buffers and be reduced from acceptable biological and total allowable catch quotas for fleets directing effort toward dolphinfish within jurisdictions throughout the region.

For effort within jurisdictions, there have been increases for distant water fleets, but the US, Mexico, Venezuela, St. Vincent and Grenadines

Fig. 4. Coastal and oceanic species landings (metric tons) for countries not reporting dolphinfish (upper pane) and countries reporting dolphinfish (bottom pane) from 1950 to 2018. The light grey shading denotes the 23-year periods as specified in the text.

showed the highest effort. The difference in comparison to the past is that some of the effort within jurisdictions now is directed toward dolphinfish. This is a shift likely due to a decrease in other target fish [19], but future research should empirically determine the percent of directed effort per species per jurisdiction. This type of information could help identify which nations have the most directed dolphinfish effort relative to other pelagic fisheries, which should justify the need for better species management. In addition, improved estimates on relative effort by jurisdiction could aid in better determining what the effort is for i.e., landings for local consumption or export.

Fluctuations in dolphinfish seafood price and demand in export markets may also determine how much commercial effort is directed toward dolphinfish per year and what percentage of catch is exported or remains in local markets. These figures could help further justify management to help protect dolphinfish under these aspects of commerce. The presumption across the WCA, however, is most dolphinfish is caught for local consumption, which in places like Puerto Rico has been well documented [25,44]. As a result, scientific research on how export markets impact commercial effort on dolphinfish is needed. Furthermore, natural disasters, pandemics, economic downturns and fuel price variability could also have a broad influence on recreational and commercial efforts, yet evidence of these trends are lacking but remain important to document.

A priority area identified through this work relative to fishing effort is Mexico, which represents the second top nation for effort within jurisdictions, yet landings for dolphinfish are extremely low. By area, Mexico has one of the largest jurisdictions within the region and contains suitable year-round habitat for dolphinfish [14,23]. The indicator of high longline effort within its EEZ introduces a substantial amount of potential pressure on dolphinfish, yet what once was reported as a substantial fishery two decades ago, it has been reported as nearly non-existent nowadays for reasons unknown.

Given the expansion of fishing to encompass seemingly all parts of jurisdictions within the region [41] of various classes of vessels [42],

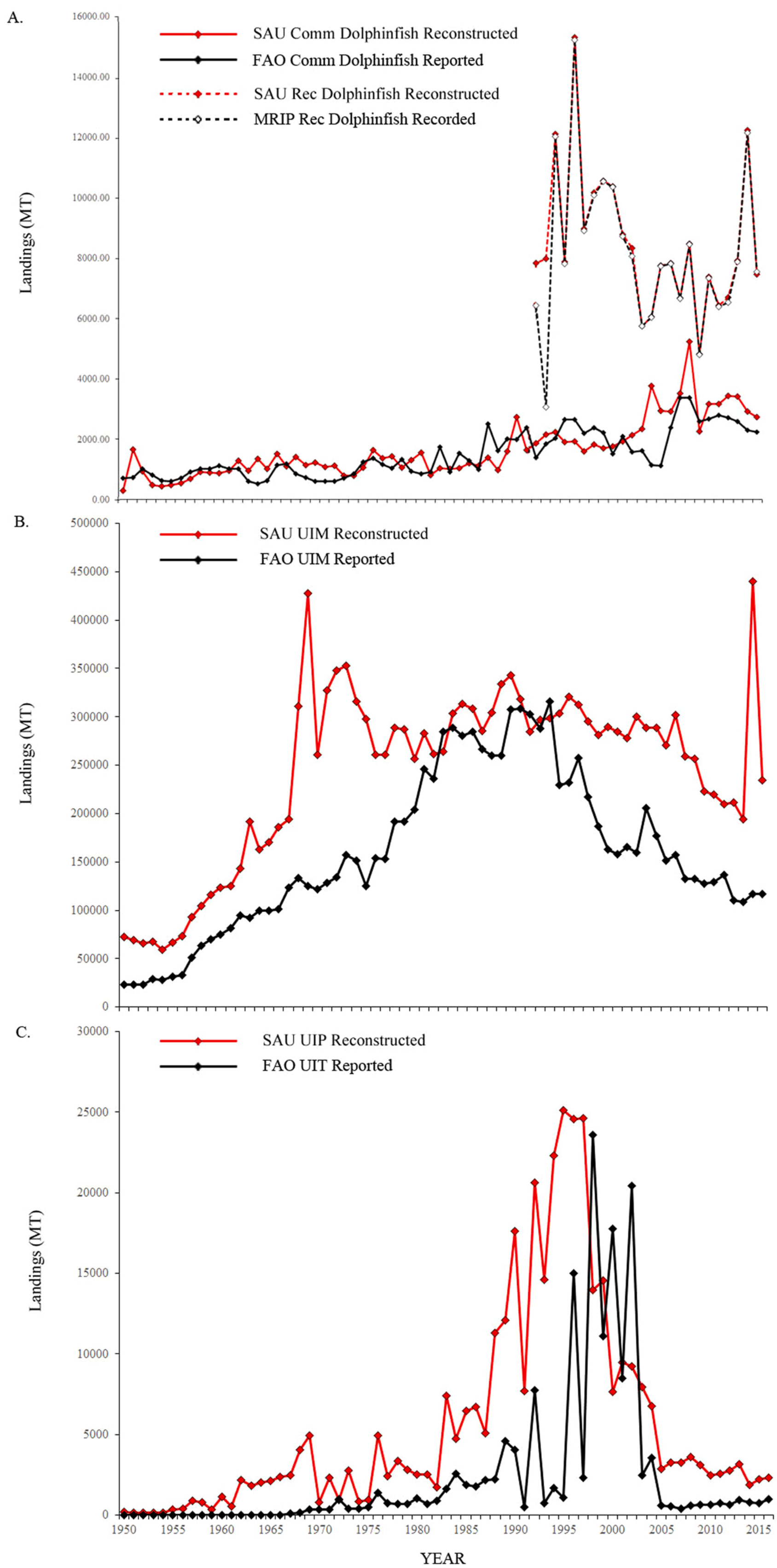

Fig. 5. Comparisons from 1950 to 2016 for (A.) United States FAO commercial dolphinfish landings (metric tons) against the Sea Around Us (SAU) reconstructed dolphinfish landings as well as United States Marine Recreational Information Program (MRIP) recreational landings against SAU reconstructed dolphinfish landings; (B.) reported FAO un-identified marine fish (UIM) landings against SAU UIM reconstructed landings; (C.) reported FAO un-identified tuna-like species (UIT) landings against SAU un-identified pelagic (UIP) species reconstructed landings.

there is a need to better characterize and quantify effort by vessel class, flag state and foreign fishing entity, gear type, and areas within jurisdictions. Pauly and Zeller [35] identified the presence of foreign nation states active in different jurisdictions throughout the WCA, yet total dolphinfish catch, effort, bycatch records, and descriptions of these fishing relationships are lacking. Plus, Chuenpagdee et al. [3] estimated more than 1 million fishers within the Americas and Caribbean region are responsible for nearly 2 million tons of catch through small-scale fisheries. It is still unknown what percentage of the effort to acquire that catch is directed toward dolphinfish, and where this effort is highest and what gear type is used. This stresses the need to increase Information and Communication Technology into small-scale fisheries to increase data collection of catch and effort data throughout the region, like work done in Timor-Leste [43].

Given 17 nations were identified through our work that did not provide within jurisdiction fishing effort to ICCAT in the WCA, it is probable fishing effort has increased more within jurisdictions than we determined. Fishing effort research is hampered by the lack of data from those nations, but if new estimates are obtained, future scientific research should incorporate those effort levels into a similar analysis to compare the spatial and temporal trends throughout the region and through time.

4.2. Commercial catch

Commercial dolphinfish landings reported to the FAO have increased markedly since Mahon [27]. However, annual take may have been high in the past with the rise only due to greater capacity for nations to report species-specific landings through improved data collection programs. One trend suggesting the increase is due to the combination of the development of dolphinfish-specific fisheries and the ability for nations to collect landings data is that the new nations (e.g., “all others”) have surpassed first reporting nations in the amount of dolphinfish landings. However, it is important to note, it is unknown how much of the increase in reported landings can be attributed to improved data collection and expanded reporting, and therefore certain aspects of the dolphinfish commercial catch trends presented may have captured a rise in WCA nations’ ability to report species-specific landings.

Since 2014, in addition to an increase in reported commercial dolphinfish landings from the DR (i.e., a first-reporting nation), Venezuela, and France (i.e., new reporters), these nations have become the region’s top commercial fisheries directed towards dolphinfish in the Greater Antilles, southern Caribbean Sea, and Lesser Antilles, respectively. With the lack of dolphinfish specific landings from 23 nations throughout the region, however, it is unknown how DR, Venezuela, and France compare in terms of percentage of annual and total regional catch. Given the indicators of decline in relative dolphinfish abundance in the region [23] and anecdotal accounts of regional decline from anglers, the urgent need presented by Mahon [27] for improved data collection and reporting requirements for all nations with commercial catch of dolphinfish remains but now under more dire circumstances.

4.3. Recreational catch

The majority of the WCA catch was from the recreational sector, but recreational values for only half of the nations within this region were able to be procured by the Sea Around Us database. One difference from commercial dolphinfish fisheries, is recreational size of capture tends to be smaller (unpublished data Dolphinfish Research Program). Notwithstanding, of the nations where dolphinfish recreational landings and percent total catch were estimated, dolphinfish is clearly an important fishery. Therefore, any decline in its stock size, or health, could impart negative socio-economic consequences for a given nation. Yet only the recreational fishery in the US GOM, Atlantic coast, Puerto Rico and Virgin Islands have bag and vessel limits [39]; [53,54], with protections for juveniles being landed only established within the Florida Straits, Georgia, and South Carolina waters. Given the estimated size of recreational landings among nations that make up the Greater Antilles (e.g., The Bahamas, Turks and Caicos, DR, Puerto Rico, USVI, BVI), plus evidence that dolphinfish move from east to west along this island chain [29], protection for juveniles along this tract may increase yield [45] down current. Alternatively, anecdotal accounts of lower yield within the Florida Straits could be due in part to the lack of juvenile protection from areas that serve as a source for the region of dolphinfish (i.e., north, and south of the Greater Antilles). As it stands, recreational fisheries of the Greater Antilles constitute the same size as the US Mid-Atlantic Bight (MAB) recreational sector, which has been increasing in recent years. When combined, these two regions equate to nearly half the size of the South Atlantic Bight (SAB) and Florida recreational fishery, but have no limits (i.e., minimum sizes) on the harvest of juveniles like the SAB or Florida recreational fishery.

Through a management strategy evaluation of dolphinfish in the southern EPO, Valero et al. [45] showed the spawning biomass of dolphinfish to increase with minimum size limits, and under scenarios of no or moderate discard mortality to increase yield in the fishery. The combination of a lack of minimum size throughout the region for recreational fisheries, plus no requirement on the use of non-offset circle hooks to decrease discard mortality [37] for small fish released or that shake off before being landed, represents a missed opportunity for proper management of this fishery in the WCA. Within the MAB, the use of lobster pots for fishing, and throughout the Greater Antilles the use of fish aggregating devices (FADs), have increased over the past few decades [47] and it remains to be determined what percentage of total recreational catch from these regions represent juveniles. Ultimately, for the region’s top recreational fisheries without any form of protection for juveniles (i.e., MAB and Greater Antilles), fishery managers, whether at the WECAFC, and US Fishery Management Council level, are missing an opportunity to increase spawning biomass and yield, policies which could be enacted on a per island basis (i.e., island-based fishery management plans) or under a statutory agreement among member states in WECAFC.

4.4. Catch uncertainty

Despite advances in data collection and reporting capacity for some nations, uncertainty of total dolphinfish catch within the WCA has prevailed since Mahon [27], a troubling situation for the fishery. FAO landings, when compared to reconstructed catch estimates, were lower in most years but FAO values often represent an underestimate of the catch [35]. In one sense, uncertainty of catch and stock pressure have increased due to an overall increase in recreational fishing directed toward dolphinfish, coupled with inadequate recreational catch and effort records, in the WCA since the 1990s [17]. Evidence of more uncertainty include nations (e.g., Haiti and Jamaica) that recorded an increase of unidentified marine fish species landed, and no dolphinfish reported landings, yet are known to land dolphinfish [18,24]. Furthermore, the size of commercial and recreational landing sectors per ocean basin is largely unknown for Central American nations from Mexico to Panama that straddle the Pacific and Caribbean and GOM basins. In addition, reported landings from France for the region are high yet obscure, as it is unknown what exactly is being reported for this grouping, and where those landings originate.

While coastal pelagic landings have always been high for first reporting nations when compared to non-reporting nations, oceanic pelagic landings rose substantially, which partly could be attributed to non-reporting nations beginning to report landings. For example, in the mid-1990s, several nations began reporting more accurate landings, and thus a component of the rise during this period is attributable to the rollover from non-reporting to reporting nations. Both, oceanic and coastal pelagic landings are high for non-reporting nations, roughly half the level of reporting nations, with the highest interannual variability observed for non-reporting nations and for oceanic pelagic landings.

This could be attributed to the lack of capacity for non-reporting nations to accurately record, submit, and maintain consistent landings records versus fluctuations in actual landings levels and points to the need to build capacity among these nations to eliminate uncertainty with coastal and oceanic pelagic landings.

Given high uncertainty, a precautionary approach to management of dolphinfish fisheries is needed more now than ever [15], but it has largely been ignored in regional attempts to actually manage dolphinfish. For example, despite strong calls by some fishery stakeholders within the US Atlantic recreational fishery to reduce stock pressure and landings, the SAFMC only reduced daily recreational vessel limits by 10% per boat per outing (from 60 to 54 fish per vessel per outing) and did not pursue the introduction of any gear modifications or protections for juveniles in the fishery within their FMP. In the WCA, the US Atlantic recreational fishery represents the largest reporting sector by two-fold; therefore, any management or conservation changes imparted on this sector could lead to one of the most substantial positive outcomes for the dolphinfish stock in the WCA. If managements actions are not pursued, then angler welfare could ultimately be negatively impacted even for those stakeholders against new conservation and management measures for the stock [1]. However, foreign fleets fishing outside of national jurisdictions, which are not obligated to report or maintain dolphinfish landings records, could potentially overshadow any progress made in US recreational management. Therefore, work to better manage and conserve the species needs to be jointly pursued by all landing sectors, and perhaps one of the most substantial first steps would be to make catch and effort reporting of dolphinfish landings mandatory for all ICCAT and WECAFC members in the WCA.

5. Conclusion

This study showed extensive evidence of increased dolphinfish stock pressure and greater uncertainty, despite two-decades of advances in data collection and fishery management policies for higher valued target fish species in the region. Given the growth of the dolphinfish fishery throughout the WCA, and the lack of pervasive fishery management measures, stock decline has been modeled [23] and referenced anecdotally by many separate groups of fishery stakeholders. As such, many of the points made by Mahon [27] remain or are updated below:

- Bycatch is consequential, but the total amount is unknown among Atlantic longline fisheries.
- Increases in commercial catch has been recorded but 23 nations still do not report landings to the FAO.
- Throughout the WCA, landings are primarily recreational, yet an accurate picture of total recreational landings is lacking given low recreational reporting rates.
- New technology is available that can aid data collection and reporting systems to enable nations to record catches to the species level.
- Public-Private partnerships should be explored and implemented to increase data collection and reporting on local and regional scales.

As primary target species have declined [31], commercial effort encounter rates with mid-trophic level species (e.g., dolphinfish) may have increased due to shifts in pelagic fish community and trophic level structure [13], which may have led to higher incidence of bycatch for those species or even directed effort. Given more industrial fishing effort [21] toward lower abundant target species [23], plus the expansion of small-scale fisheries [3], which target mid-trophic level species such as dolphinfish [49], an increase in the importance of mid-trophic level species may have occurred, and in the case for dolphinfish, led to a decrease in stock health, throughout the WCA. As such, management actions are now being made by various state agencies. For example, the Florida Fish and Wildlife Commission, just adopted state regulations that drop the recreational vessel limit from 60 to 30 fish per trip, reduce the bag limit from 10 to 5 per person per trip, and ban the possession of vessel or bag limits by the captain and crew within Atlantic state waters[4] (personal communication March 2022). While this is a great step forward for reducing stock pressure, the same policy has been implemented in Puerto Rico waters since 2004, yet anglers rarely hit that vessel or bag limit and comment that the fishery is still not as healthy as it used to be. In Puerto Rico from 2016 through 2018, vessel catch and effort data collected among charter and recreational vessels (n = 15) in Puerto Rico revealed 93% of trips (n = 785) caught less than 10 dolphinfish per trip (unpublished Beyond Our Shores, Inc.). Unless vessel and bag limits are lowered to the point of reducing the top 10% of daily landing limits, a reduction in stock or recreational fishing pressure on dolphinfish is likely not to be achieved . If a policy is adopted by other nations within the Greater Antilles, within the GOM and MAB, this reduction could alleviate some pressure on the stock and in turn potentially increase spawning biomass and yield. As it stands, there is still an urgent need to improve important data collection on several aspects of dolphinfish fisheries in the WCA, starting with basic landings estimates. Other studies deserving priority are those to improve regional discard mortality estimates, to show the efficacy of catch rates between different gear types (especially in comparison to non-offset circle hooks), to collect catch size composition for small-scale fisheries, especially at FADs, lobster pots, and *Sargassum* mats are needed. Each of these along with improved catch and effort datasets, can help local and regional fishery managers make informed decisions for more effective and tangible management for dolphinfish.

CRediT authorship contribution statement

Wessley Merten: Conceptualization, Methodology, Data curation, Investigation, Formal Analysis, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition; Richard Appeldoorn: Writing – original draft, Writing – review & editing; Abby Grove: Data curation, Investigation; Alfonso Alguiar-Perera: Writing – original draft, Writing – review & editing; Freddy Arocha: Writing – original draft, Writing – review & editing; Roberto Rivera: Formal analysis.

Declaration of Competing Interest

None.

Acknowledgements

This research did not receive any specific grant from funding agencies in the for or not-for-profit sectors but was funded by private financial supporters of the Beyond Our Shores Foundation. We would like to acknowledge the United States South Atlantic and Caribbean Fishery Management Councils for showcasing the need to conduct this work.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.nanoen.2020.105422.

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