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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

around the world.

In the south, western, and central Pacific, the South Pacific Regional Fisheries Management Organization (SPRFMO) and the Western and Central Pacific Fisheries Commission (WCPFC) do not mention wahoo in their annual reports, but the National Oceanic Atmospheric Administration (NOAA) through coordination with the Western Pacific Regional Fishery Management Council (WPRFMC) includes wahoo under their Fishery Ecosystem Plan for Pacific Pelagic Fisheries of the Western Pacific Region (WPRFMC 2009, 2023; WCPFC 2022; SPRFMO 2023). In the eastern Pacific Ocean, NOAA in coordination with the Pacific Coast Fishery Management Council (PCFMC) includes wahoo as a monitored species under their Fishery Management Plan for U. S. West Coast Fisheries for Highly Migratory Species, but there are no wahoo-specific management measures included in the plan. In the eastern tropical Pacific Ocean (ETP), the Inter-American Tropical Tuna Commission (IATTC), with the Instituto Nacional de Pesca of Mexico, conducted a tag and release project for wahoo, but little data were acquired to better understand movement, dispersion rates, distributions, and behavior (IATTC 2010). This information would be useful for management and conservation purposes but has not led to any new management measures in the ETP (IATTC 2010).

In the Atlantic Ocean, the International Commission for the Conservation of Atlantic Tunas (ICCAT) does not include wahoo as a priority species but through the years, ICCAT member states have engaged in wahoo growth, maturity, and movement research. However, results have not contributed toward a better understanding of Atlantic wahoo stock status or health (ICCAT 2022). In state and federal waters along the U. S. east coast, NOAA through coordination with the South Atlantic Fishery Management Council (SAFMC) includes wahoo in the Dolphin-Wahoo Fishery Management Plan which allocates annual catch limits for wahoo between recreational (e.g., 97.55% of ACL) and commercial sectors (2.45% of ACL) and sets commercial fishing trip (e.g., 500 pounds mixed weight trip limit), a recreational bag (e.g., two per person per trip), and other regulations including permitting and logbook requirements (commercial and for-hire), commercial sale provisions (trip ticket and electronic reporting requirements for seafood dealers), prohibition on for-hire and recreational bag limit sales, and gear prohibitions (e.g., use of surface and pelagic longline gear for wahoo is prohibited within any time or area closures in the Atlantic Coast).

In the United States Caribbean Sea, until recently, the Caribbean Fishery Management Council (CFMC) did not actively manage wahoo in federal waters but rather coordinated with state agencies on bag and possession limits taken from state waters (CFMC 2024). However, recently the CFMC through three island-based fishery management plans (e.g., Puerto Rico, St. Thomas, St. John, and St. Croix) considered changes to bag, possession, and minimum size standards for wahoo to ensure adequate protection against over-exploitation.

Lastly, the Gulf of Mexico Fishery Management Council expressed interest to potentially implement management and conservation measures for wahoo, but the process to enact such improvements has not begun because wahoo remains unmanaged in federal Gulf of America waters. Despite these U. S.-based management plans and interest, very little effort has been allocated to wahoo governance by country-specific or regional fishery management bodies throughout the western central Atlantic Ocean, yet the species represents a seafood and recreational commodity of increasing importance.

The exploitation status of wahoo throughout its global range is unknown (FAO 2022). In the WCA, mandatory catch data reporting requirements does not exist for all nation-states and there is very little verification of the accuracy of reported commercial, recreational, and artisanal wahoo catches (FAO 2022). Improving our knowledge of wahoo exploitation patterns, catch and sector trends, and seasonal catch patterns can aid regional fishery managers in determining what level of precautionary management should be implemented to ensure yield and stock conservation. In addition, an effort to describe international catch patterns can help identify knowledge gaps as well as prioritize research to better understand the biology and ecology of the species in the region.

In Merten et al. (2022), a thorough analysis of international fisheries for dolphinfish was conducted to identify exploitation patterns and species knowledge gaps in the WCA. Here, we replicate the procedure but for wahoo, a species that serves a similar ecological role in marine food webs and is a highly sought-after seafood commodity and game fish species throughout WCA jurisdictions.

TABLE 1. Nation groupings used in wahoo catch analysis. Catch data was provided by the Food and Agricultural Organization (FAO) from 1950 to 2021. Country names are included, in reverse hierarchical format, for nations reporting catch to the FAO for more than 30 years, between 10 to 29 years, and from 1 to 9 years. Nations not reporting wahoo to 2021 are included at the bottom.

Grouping	Catch
Group 1: Nations Reporting > 30 years	Aruba, Venezuela, Bermuda, Netherlands Antilles, Grenada, St. Vincent and Grenadines, Barbados, Dominica, St. Lucia
Group 2: Nations 10–29 years	Dominican Republic, Trinidad and Tobago, U.S.A, PR, USVI, St. Kitts and Nevis, Spain
Group 3: Nations 1–9 years	Martinique, Guadeloupe, Suriname, Mexico, Panama, France, BVI, Columbia, Belize
Nations Not Reporting	Anguilla, Antigua and Barbuda, Bahamas, Bonaire, Cayman Islands, Costa Rica, Cuba, Curaçao, French Guiana, Turks and Caicos Isl., Saba and Sint Eustatius, Sint Maarten, Nicaragua, Guyana, Haiti, Honduras, Jamaica, Montserrat

MATERIALS AND METHODS

Context

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 WCA. For this study, Food and Agriculture (FAO) wahoo landings in the WCA were analyzed for nations from 1950 to 2021, and catch was grouped between the amount of years nations had been reporting their catch (Table 1). A custom query was used with the FAO FishStatJ database to acquire wahoo landings for countries reporting to the FAO from 1950 to 2021 with the following parameters: **Unit** = Tonnes; **FAO Major Fishing area** = "Atlantic, Western Central"; **ASFIS Species**: Wahoo.

Three groupings were appropriate given the greater differences among nations when reporting began to the FAO (Table 1). Nations reporting for the greatest years (n = 9) were compared to all the nations that began reporting sporadically since 1950 (n = 15). Lastly, each group was then analyzed separately to examine which nations had important national wahoo fisheries through time.

Management and conservation measures

The WCA contains 43 jurisdictions, from Brazil to Canada (Fig. 1). We documented stock trends and enacted fishery management, and conservation measures, in the WCA from 1970 to 2021 from local governing fishery management agencies for each jurisdiction, and from the Caribbean Regional Fishery Mechanism (CRFM), and we structured that information into a timeline. 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 2021) reports from ICCAT.

Commercial catch in the WCA

Catch data were acquired and grouped for all nations reporting landings to the FAO, from 1950 to 2021 using the FAO FishStatJ 4.03.06, and arranged using three equivalent 24-year periods: 1950–1973 (oldest period), 1974–1997 (mid-period), and 1998–2021 (latest period). The analysis of pelagic longline commercial fishing effort used in Merten et al. (2022) was used here for comparisons, but not extended, given the lack of additional years added to the time-series.

To examine temporal wahoo catch trends, five-year averages of landings for wahoo were binned and compared using a regression model for 1990–1994 (Time Average 1) and 2016–2020 (Time Average 2). 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 for Microsoft 365 MSO (Version 2404).

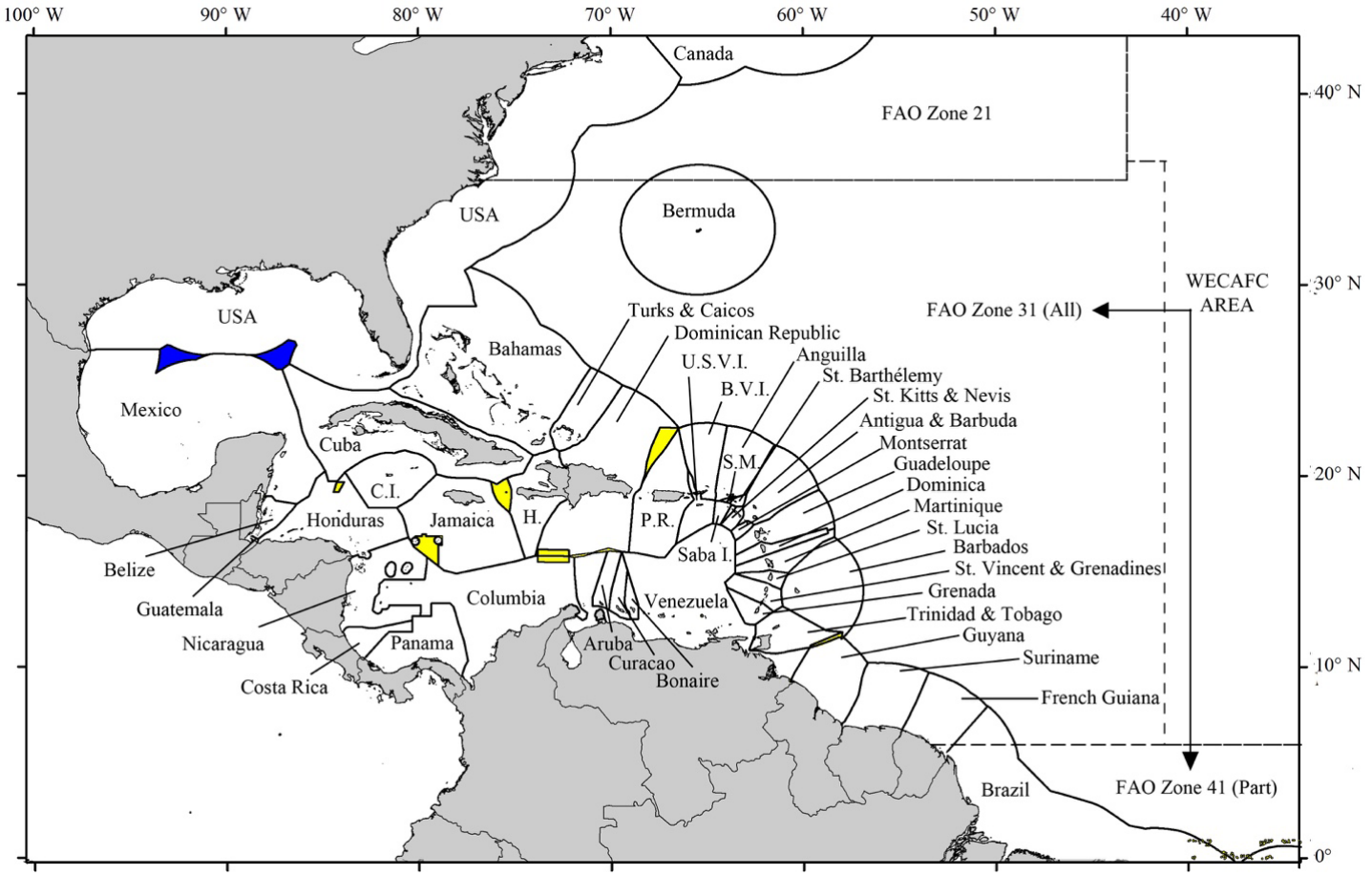

FIGURE 1. Exclusive economic zones in the Western Central Atlantic and FAO zones 31 and 41. C.I. = Cayman Islands; H. =Haiti; Saba I. =Saba Island; S. M. = Saint Maarten; Blue = high seas areas in the Gulf of Mexico; Yellow = disputed or joint jurisdictions.

The Sea Around Us (SAU; http://www.seaaroundus.org/) global catch reconstruction of commercial and recreational fisheries for wahoo was acquired for each exclusive economic zone (EEZ) for all jurisdictions in the WCA from the entire dataset (1950–2019) (Pauly et al. 2020). The wahoo reconstructed industrial catch category was compared to the FAO catch category. For wahoo, 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. Lastly, gear types used to target wahoo in the WCA were assessed from the SAU database.

Recreational catch in the WCA

Recreational wahoo landings in the WCA were assessed in three ways. First, total annual landings, from 1993 to 2021, were acquired from the National Oceanic Atmospheric Administration's (NOAA) Marine Recreational Information Program (MRIP) for all U. S. Atlantic recreational sectors. NOAA's MRIP did not operate in the United States Virgin Islands (USVI) or Puerto Rico (PR) during that time. Total reconstructed U. S. recreational catch (United States East Coast); U. S. Gulf of Mexico (US GOM); and Puerto Rico was acquired from the SAU (1950–2019) and compared to the NOAA MRIP catch (excluding the USVI and PR) using a correlation analysis in Microsoft Excel. Second, reconstructed wahoo specific recreational landings in the final year (2019) of the SAU dataset was acquired for each nation in the WCA and compared to the total amount of landings estimated per nation by the SAU for that year. Third, recreational fishing trends (i.e., began, increasing, decreasing, unknown, not applicable) were assessed from the FAO's country profile database (http://www.fao.org/fishery/countryprofiles/search/en) 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

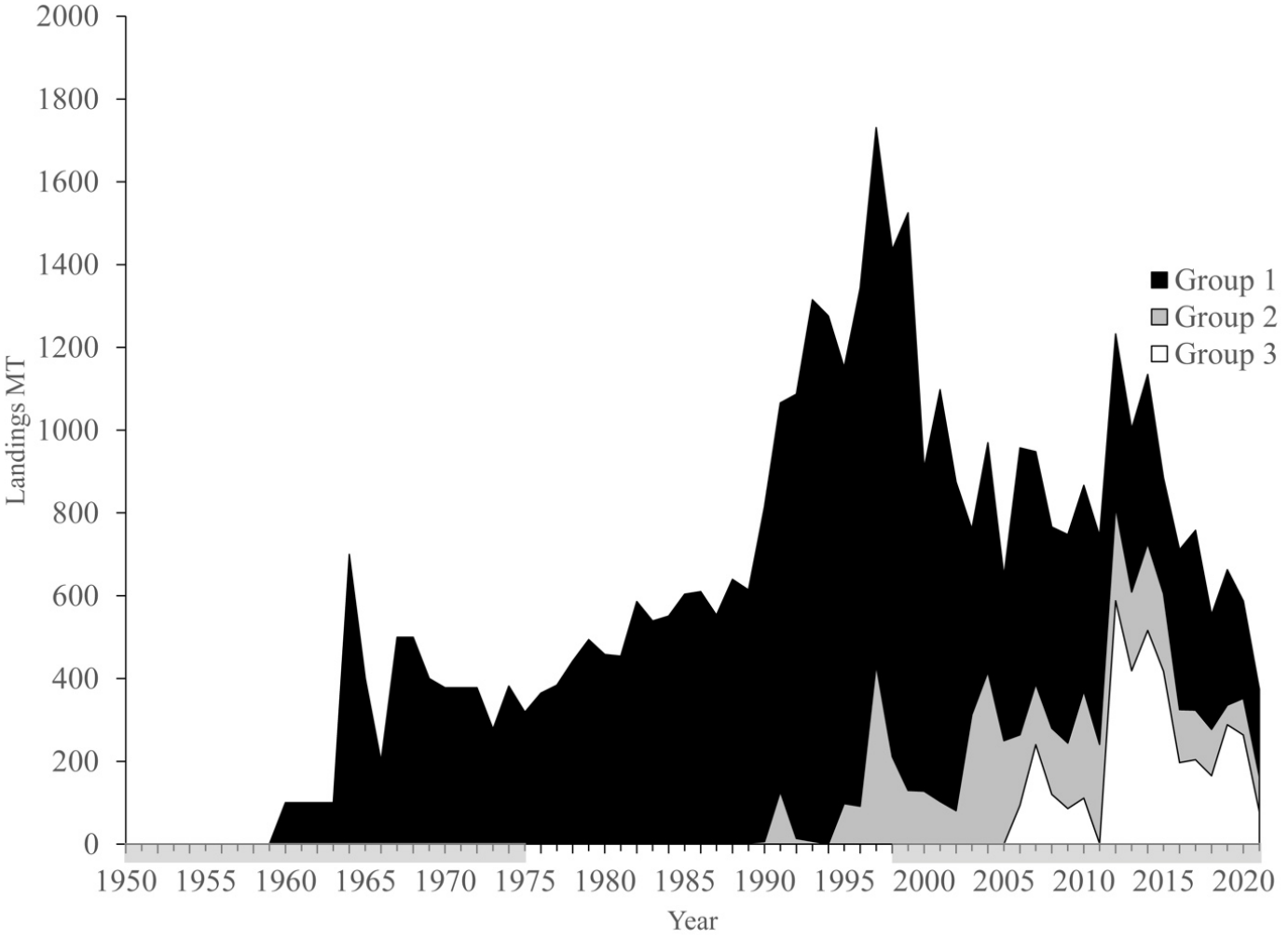

FIGURE 2. Commercial wahoo landings (metric tons) for groups one (nations reporting >30 years), two (nations reporting 10–29 years), and three (for nations reporting <9 years) from 1960 to 2021. The light grey shading denotes the 24-year periods as specified in the text.

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).

Comparison to dolphinfish

Wahoo catch patterns were compared to dolphinfish catch patterns to compare and contrast trends over the time period analyzed in Merten et al. (2022) (1950–2018).

RESULTS

Management and conservation measures

Outside of United States EEZ, only Mexico and the Bahamas have management or conservation measures enacted for wahoo (Table 2). The SAFMC formed the Dolphin-Wahoo FMP in 2003 which has undergone several revisions, and the current measures include a total allowable catch for recreational and commercial sectors as well as daily vessel and bag limits for the species (Table 2).

Commercial catch

There were significant differences in the amount of wahoo catch reported over the periods (Regression; $P < 0.05$) (Fig. 2). Reported landings increased nearly fivefold since 1950 in the WCA, from 188 (SD ± 213) metric tons (MT) in the oldest period to 881 (267) in the latest period. Reported commercial catch peaked in 1997 (1,781 MT) followed by another peak in 2012 (1,232) (Fig. 2). Since 1994, between nation groups, after accounting for autoregressive dependence, there were significant differences in landings between groups (Regression; $P < 0.05$). Initially, first reporting nations

TABLE 2. Discussion of trend and major conservation response to the state of wahoo 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. Wahoo 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. ↓ = decline, declined, decreased, decreasing; exp. = exploited or exploitation; +exp. = overexploitation; BZ = Brazilian (or Brazil).

Time Period	Wahoo
1970-79'	1970-79': Not mentioned FAO Zone 31
1980-89'	1980-89': Not mentioned FAO Zone 31
1990-99'	1990-96': Not mentioned FAO Zone 31; NOM-017-PESC-1994 established 50-mile sport fishing zone in Mexico for pelagics including wahoo. 1997-99': 185.5 metric tons primarily of wahoo and yellowfin tuna in UK-Bermuda,
2000-09'	2000-02': Not mentioned FAO Zone 31, 2002: Majority of fish caught in UK was wahoo and yellowfin tuna, the BMRD has regional research programs directed at wahoo (tagging, species age and growth population genetics), the US develops a Fishery Management Plan for dolphinfish and wahoo fisheries, 2003-04': UK caught 155 t of tuna-like species with majority being wahoo and yellowfin tuna, CRFM examined wahoo data from Caribbean CARICOM countries, new length to weight conversions for wahoo in the North West Atlantic were presented, Mexico bycatch from tuna directed fishing included a lot of wahoo, 2005-07': Tuna-like species landings ↓from 162 t to 24 t in the UK with majority of them being wahoo and yellowfin tuna, CRFM Secretariat examined and analyzed data from wahoo, CRFM undertook assessments of wahoo within the southern Caribbean, 2008-09': Not mentioned FAO Zone 3; Ministry of Agriculture and Marine Resources in the Bahamas established 18 pelagic fish daily limit.
2010-18'	2010-11': New information regarding the reproductive biology of wahoo in the Saint Peter and Saint Paul archipelago of BZ was submitted to the Group, wahoo was reported as bycatch species of the BZ longline fishery and BZ artisanal beach seine fishery, BZ catch of wahoo and other tuna-like species was 52,014.97 t (live weight), 2012: BZ catch of tunas and tuna-like species (like wahoo) was 45,180 t (live weight) representing a decrease of more than 13% if compared with the catches of 2011, 2013: BZ catch of tunas and tuna-like fish (like wahoo) was 18,370.5 t (live weight) representing a ↓of about 27,000 t from 2012, some artisanal fisheries and the sport fishery in Cape Verde wahoo were caught, catches in Mauritania amounted to 1,663 t and essentially comprised wahoo, 2014: BZ catch of tunas and tuna-like fish (like wahoo) was 39,296.4 t (live weight) representing a small ↓from 2013, some artisanal fisheries and the sport fishery in Cabo Verde caught wahoo, SCRS recommends that CPCs assess wahoo as a high priority species and extend the species description chapter for wahoo, 2015-17': BZ catch of tunas and tuna-like fish (like wahoo) was 32,833.5 t (live weight) representing a ↓from 2014 when 39,296.4 t were landed, as of 15 September 2016 more than 1,200 tunas (and a few wahoo) have been tagged, the biological sampling will be extended for 2017 to include wahoo to update and further improve growth and maturity parameters, estimated costs for wahoo for 2017 under the ICCAT SMTYP are 7,500 euros, the Group thought it would be better for AOTTP to focus on wahoo and little tunny, the ICCAT Atlantic Tuna Tropical Tagging Program has a plan to tag wahoo in the Western Atlantic, literature suggests that wahoo appear to comprise a single circumglobal population with little genetic differentiation between oceans, as of writing 801 and 23 little tunny and wahoo have been tagged, as of 2017 BZ catch of tunas and tuna-like fish (like wahoo) was 54,450.63 t (live weight), slightly higher than catches recorded in 2016, total catch of ICCAT species in St Helena in 2017 was 316 t which principally comprised of wahoo and others, In Bermuda the total catch of ICCAT species was 142 t which mainly comprised of wahoo and blackfin tuna, 2018-20': Within ICCAT AOTTP 4,556 little tunny and 131 wahoo have been tagged and released at sea in 2 years since the project began but only one wahoo was recaptured at the St Peter and St Paul Islands off BZ, 129 wahoo have been tagged in BZ, BZ catch in 2018 of tunas and tuna-like species (like wahoo) was 50,435.1 t (live weight) presenting a decrease of 7.3% in relation to the catches in 2017, wahoo size at first maturity varies between 92 and 110 cm, SMTYP continued the collecting of biological samples aiming growth, maturity and stock structure on wahoo and other species, 2021-22': Caribbean Fishery Management Council begins process to manage dolphin and wahoo in U.S. Caribbean Sea waters through Amendment 3 of their pelagic fishery management plan.

represented the majority of submitted landings (group 1: 645 (SD ± 366 MT); group 2: 170 (99); group 3: 135 (173). However, since 2014, when groups 2 and 3 were combined (n = 15), landings surpassed first reporting nations (n = 9) and there were no significant differences in reported landings (319 (82) vs. 388 (183)) ($P = 0.35$).

Reconstructed commercial wahoo landings tracked reported landings (Correlation = 0.74), and reconstructed landings were only greater 30% of the period. The distribution of these, however, were not random over time (Fig. 2). Since 2012, the reconstructed wahoo catch was higher (up to 2.1 times, or 746 MT). Consequently, the reconstructed wahoo catch was 43.4% higher than reported catch from 2012 (T-Test: $P < 0.05$; 574.64 ± 71.11 MT versus 1,016.05 ± 211.59 MT). When SAU artisanal and subsistence sectors were included, reconstructed wahoo landings better tracked FAO reported landings (Correlation = 0.88), but reconstructed catch was higher in every year except 1964 and up to a maximum of 5.5 times higher in 2005 (FAO 730 MT versus SAU (artisanal, industrial, and subsistence) 4,059.32)). However, there are a total of 18 nations that do not report wahoo landings to the FAO (Table 1). Wahoo catch reconstruction data (commercial, subsistence, and artisanal) was estimated for 13 of those nations. When those nations were combined with the rest of nations that report data, the 1997 peak, for example, was estimated to be 3,692.61 MT (Fig. 3), more than double the FAO estimate.

Recreational catch

The reconstructed recreational catch for the WCA was less correlated when compared to the MRIP data (Correlation = 0.74) with the SAU recreational total being higher in every year when comparisons were available to the MRIP data. For the last year of the reconstructed landings dataset (2019), within the WCA, the US represented the largest component of recreational catch (52%; 1,058.74 MT) as well as the largest landing sector by two-fold (Fig. 2; Table 3). For the U.S, wahoo landings were estimated to be 99.64% recreational. The Bahamas, the second largest recreational sector in the region constituted 31.97% (639.32 MT) (Table 3) of the WCA reconstructed catch. The third largest recreational sector was Aruba (4.6% of total recreational catch or 93.47 MT) (Table 3). When combined with reported FAO commercial landings for 2019, the total direct wahoo catch was 3,547.56 MT, of which 57% was estimated to be recreational. For several nations (n = 6; Table 3), the recreational catch was estimated to be 100%. Reconstructed recreational catch was estimated for 13 nations also reporting commercial wahoo landings to the FAO and 13 for nations which do not report commercial landings (Table 3).

For U. S. MRIP data, recreational landings peaked in 2016 at 2,659.27 tons, a year which coincided as the highest regional landings (3,234.83 tons) when combined with FAO commercial data. In that year, the U.S. recreational sector represented 78% of the total regional landings. Reconstructed recreational landings peaked in 1981 (3,522.69 tons) but were the second highest in 2016 (3,464.67 tons) (Fig. 3; Table 3).

Catch in the Western Central Atlantic Ocean

For all SAU sectors (recreational, artisanal, subsistence, and commercial) combined, 2004 was the highest in estimated reconstructed catch at 6,398.88 tons with 48% estimated as artisanal catch (3,071.46 tons). Recreational was the second highest proportion of the SAU reconstructed catch at 38% or (2,479.06 tons) (Fig. 3). For the last year of catch reconstruction data (2019), 21 nations reported commercial records to the FAO. By comparison, 10 nations had catch reconstruction data estimates higher than FAO estimates; 11 nations had FAO estimates higher than SAU estimates (Fig. 4),

Fishing effort for Wahoo

By gear type, recreational fishing gear (i.e., hook and line) was the highest (29.88%) identified gear used to target wahoo over the entire SAU catch reconstruction data set. The second highest gear segment was "un-

TABLE 3. [Following page] Average commercial landings (metric tons) for wahoo in the wider Caribbean region (Zone 31) between two time periods for countries (arranged alphabetically) reporting wahoo to the FAO. The trend for each category is presented as follows: trend began (S), decreased (-), or increased (+) in amount. For recreational fleets, 2018 wahoo specific landings, percent wahoo 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). NR = not reporting during that period. n/a = not applicable. Neg. = negligible. Fleet letters: R = recreational; A = artisanal; C = commercial. WAH = Wahoo specific landings.

Country	Fleet	Average Wahoo Landings			Recreational Fleet		
		1990-94 (MT)	2016-20 (MT)	Trend	2018 WAH TC (MT)	% Total Or Total (MT)	Trend
Countries reporting wahoo landings to the FAO							
Aruba	RC	15.4	8.68	-	94	100%	+
Barbados	RAC	13.4	1.76	-	5.47	0.79%	+
Belize	AC	NR	NR	S	n/r	n/r	
Bermuda	RAC	13.16	15.96	+	193.8	29.2%	+
British Virgin Islands	RAC	NR	NR	S	26.9	100%	+
Colombia	AC	NR	1.11	S	17.7	0%	-
Dominica	AC	10.32	1.04	-	52.43	0%	-
Dominican Republic	RAC	1.75	0.1	-	35.05	100%	+
Grenada	RAC	9.4	7.13	-	0.05	100%	+
Guadeloupe	C			S	n/r	n/r	
Martinique	AC			S	7.3	0%	-
Mexico	AC	NR	2.9	S	32.32	0%	+
Panama	C	NR	29.83	S	43.9	0%	-
Puerto Rico	C			S	n/r	n/r	
St. Kitts/Nevis	RAC	NR	2.04	S	60.9	0.44%	+
St. Lucia	RAC	21.8	21.18	-	76.68	0.37%	+
St. Vincent & Grenadines	RAC	6.52	11.03	+	26.9	0.14%	+
Suriname	C	NR	28.1		135.7	0%	+
Trinidad & Tobago	RC	11.9	1.46	-	45.83	100%	+
US Virgin Islands	RAC	NR	1.79	S	27.73	85.57%	+
USA	RAC	NR	4.72	S	477.04	91.74%	+
Venezuela	AC	73.8	11.5	-	192.64	0%	+
Countries not reporting wahoo landings to the FAO							
Anguilla	RAC				6.23	56.9%	+
Antigua and Barbuda	C				n/a	n/a	-
Bahamas	RC				639.32	100%	+
Bonaire	RC				37.19	0%	+
Cayman Islands	RC				n/r	n/r	+
Costa Rica	C				n/a	n/a	
Cuba	C				n/a	n/a	
Curacao	RC				128.72	0.53%	+
French Guiana	C				n/a	n/r	
Guinea	C				n/a	n/a	-
Guyana	C				n/a	n/a	-
Haiti	AC				616.98	0%	-
Honduras	RAC				34.91	86.01%	+
Jamaica	RAC				17.57	7.93%	+
Montserrat	R				0.05	0%	-
Nicaragua	C				n/a	n/a	
Saba & Sint Eustatius	R				1.8	14.54%	+
St Barthelemy	AC				12.5	n/r	
Sint Maarten	AC				2.08	94.6%	+
Turks & Caicos	RAC				23.73	76.46%	+

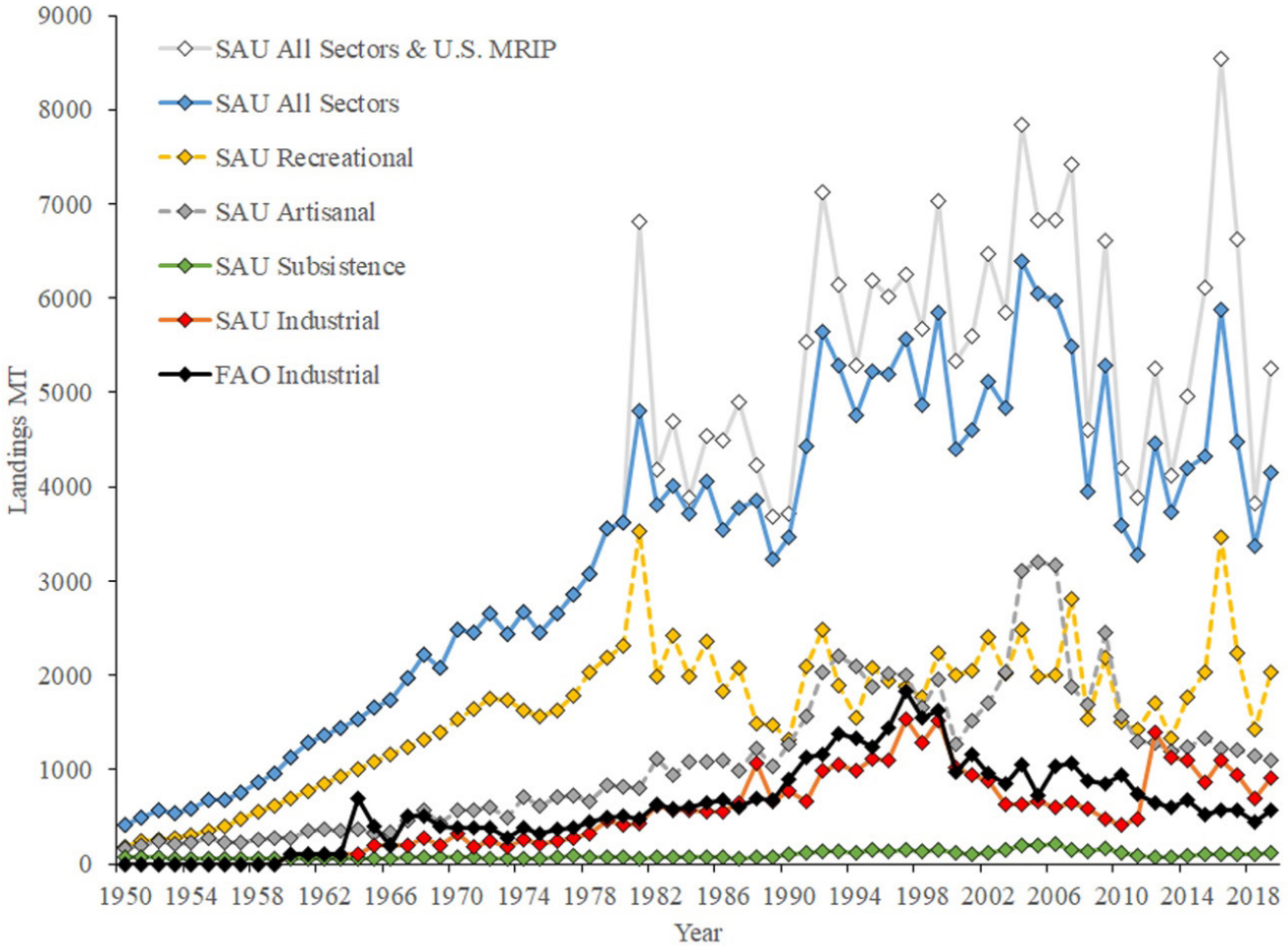

FIGURE 3. Reconstructed Sea Around Us (SAU) wahoo landings by sector, Food and Agriculture Organization (FAO) industrial wahoo landings, and United States Marine Recreational Information Program (U.S. MRIP) wahoo landings from 1950 to 2019.

known class" (18.05%), followed by small-scale lines (12.66%), small-scale longline (10.15%), small-scale gillnets (9.24%), and longlines (8.19%) (Fig. 5). Since 1994, there was a decrease in wahoo caught on recreational gear (21.78%) and small-scale lines (10.60%), but an increase in wahoo caught in unknown class (19.14%), small-scale longline (13.44%), small-scale gillnet (12.10%), and longline (8.46%) (Fig. 5).

Catch comparison to dolphinfish in the WCA

In total, there are 18 nations not reporting dolphinfish or wahoo to the FAO (Table 1). Four countries are reporting FAO wahoo landings but not dolphinfish including: Aruba, Colombia, Panama, and Spain. In addition, four countries are reporting FAO dolphinfish landings but not wahoo which include: Antigua and Barbuda, Belize, Costa Rica, and Cuba. For wahoo, nine nations had FAO landings decrease through time with only two increase (Bermuda & St. Vincent and Grenadines) (Table 3). For dolphinfish, seven nations had landings decrease through time with only two increases (Dominican Republic (DR) and Venezuela). However, for both species, thirteen nations started to report species-specific FAO landings toward the end of the monitoring period, therefore, trends between time average 1 (1990–1994) and 2 (2016–2020) were not possible.

Dolphinfish are caught at much greater quantities than wahoo, with commercial dolphinfish landings reaching a peak at 6,085 MT in 2013 but only 1,232 MT in 2012 for wahoo. For both species, reported landings declined through the end of the monitoring periods. According to SAU catch reconstruction data, the percentage of recreational catch of overall catch is similar be-

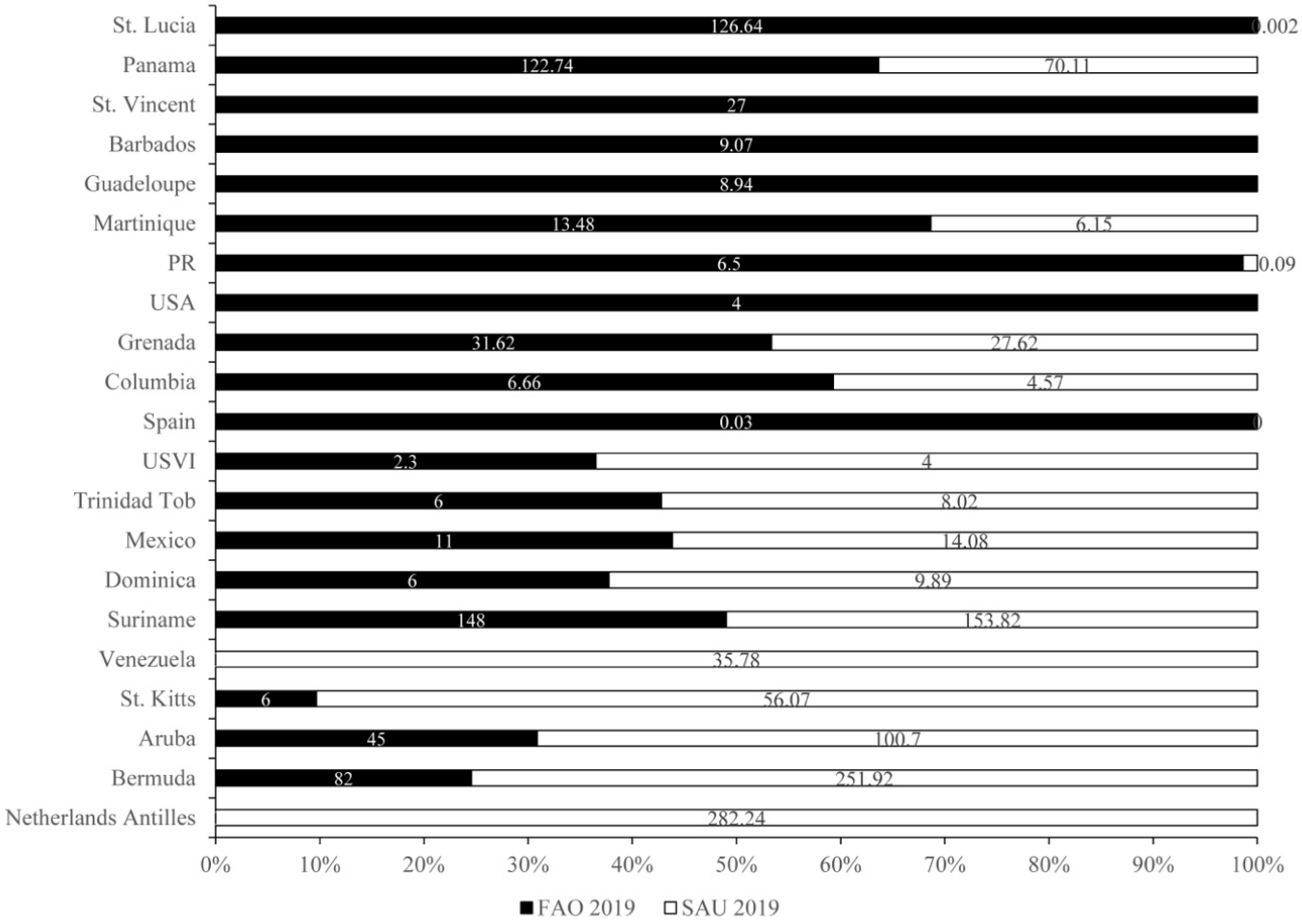

FIGURE 4. Percent reconstructed Sea Around Us (SAU) commercial wahoo landings versus reported Food and Agriculture Organization (FAO) industrial landings by nation for the last estimated year of landings in the SAU database (2019). The values within the bars represent the reported or estimated value of landings in metric tons.

tween wahoo (57% of 2019 total catch) and dolphinfish (62% of 2016 total catch; Merten et al. 2022). However, in terms of absolute numbers, dolphinfish recreational catch (8,847 MT) is more than four times the estimated wahoo recreational catch (2,022 MT) in the region. On a per nation basis, however, Aruba, Bermuda, Panama, and Spain report more landings for wahoo, for both commercial and recreational sectors, than dolphinfish.

In terms of management, besides the United States east coast (Florida to Maine), U. S. Caribbean Sea (Puerto Rico and the United States Virgin Islands (USVI)), Bahamas, and Mexico, no other nations have instituted management measures for dolphinfish or wahoo in the WCA. For U.S. dolphinfish and wahoo management, the South Atlantic Fishery Management Council has managed both species with similar management approaches (i.e., ACL, sector allocation, trip and bag limits) with the exception of the 20" minimum size for dolphinfish from eastern Florida to South Carolina.

DISCUSSION

Fishing effort and catch trends for wahoo within the WCA increased dramatically over the period examined yet the true level of effort and catch remains highly uncertain. Our work provided the first comprehensive analysis of the dynamics of the international wahoo fisheries throughout the Caribbean Sea and the WCA.

Management and conservation measures

Protections for wahoo within the United States have remained unchanged for decades (SAFMC 2002). Recently, however, there was a proposed rule considered by NOAA fisheries that would implement new management measures in the U.S. Caribbean Sea. Specifically,

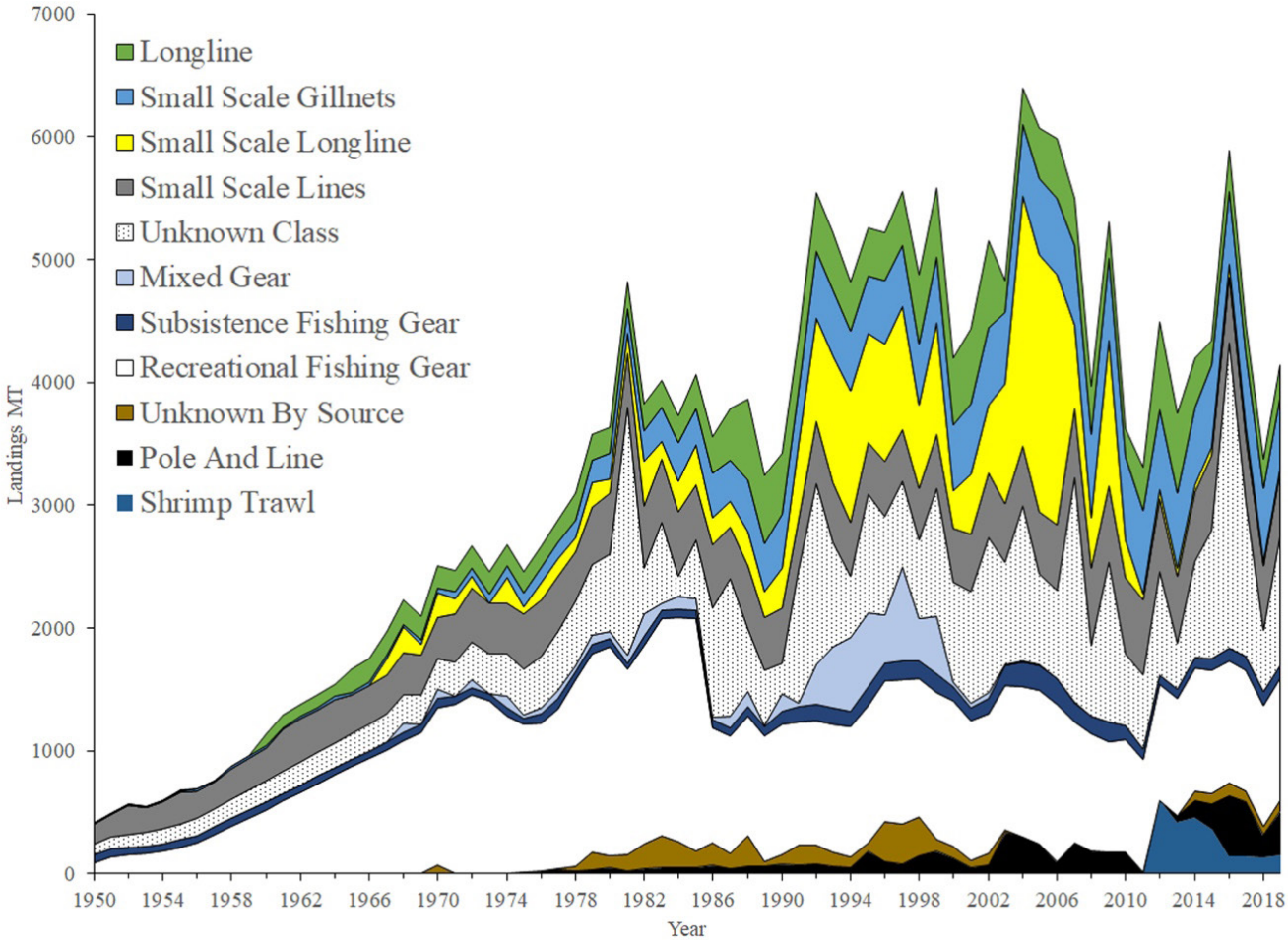

FIGURE 5. Estimated Sea Around Us (SAU) wahoo landings in metric tons by gear type from 1950 to 2019.

the Caribbean Fishery Management Council worked to update Amendment 3 to the Fishery Management Plans for Puerto Rico, St. Croix, and St. Thomas and St. John (Federal Register 2024). If enacted, the rule would establish a 32" minimum size for wahoo within federal waters of the U. S. Caribbean Sea as well as establish differences in vessel and daily bag limits between the islands. For federal waters around Puerto Rico, this rule would establish a recreational bag and possession limit of five wahoo per person per day, not to exceed 10 wahoo per vessel per day, whichever is less. For federal waters around St. Croix, St. Thomas, and St. John the rule would establish a recreational bag and possession limit of two wahoo per person per day, not to exceed 10 wahoo per vessel per day, whichever is less. These measures were proposed to ensure wahoo have adequate time to mature and reproduce and to take a precautionary approach to management to protect against overfishing.

Outside of the United States in the WCA, there are few protections in place to ensure the conservation and management of wahoo. Aside from the Bahamas, which has a recreational limit of 18 pelagic fish per vessel per day (i.e., any combination of dolphinfish, wahoo, tuna, or kingfish), the Caribbean EEZ of Mexico is the only other jurisdiction to have a conservation measure for wahoo; within 50 miles of the coastline wahoo is strictly a recreational species. However, for Mexico's EEZ, estimates suggest illegal fishing accounts for up to 56% of the country's national seafood production which means wahoo, and other high value seafood species (e.g., dolphinfish, tuna, billfish), are likely captured within the 50-mile recreational zone and sold to markets, resorts, and/or restaurants (Environmental Defense Fund 2013). While gathering proof of these transactions is challenging, and even more so sufficient evidence to adequately document the extent of illegal sales of any finfish species, a volunteer participant of the Dolphinfish Research Program (https://dolphintagging.com/) in Mexico's Atlantic EEZ did provide evidence that wahoo and dolphinfish caught within the 50-mile limit are sold to resorts (Personal Communi-

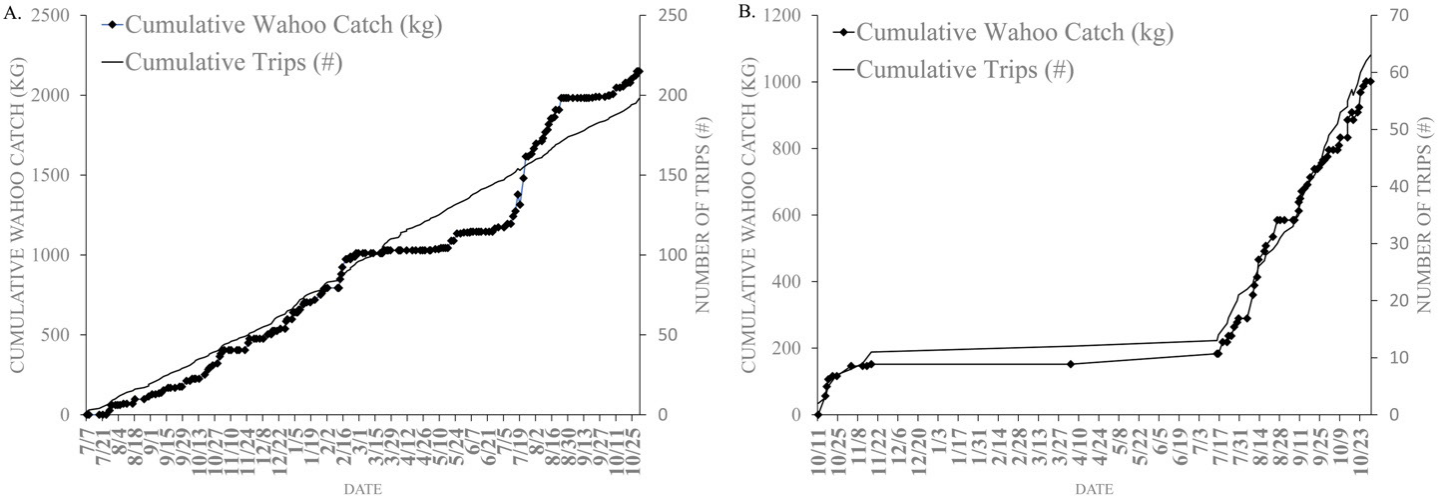

FIGURE 6. Cumulative wahoo landings (kilograms) and cumulative number of trips for boat 1 (Appendix 1) and boat 2 (Appendix 2) monitored south of the Dominican Republic from July 7, 2023 through October 2024.

cation Beyond Our Shores Foundation). Furthermore, the IUU Fishing Risk Index ranks Mexico's Atlantic EEZ as the number one Caribbean, Central American, and West Atlantic nation for IUU fishing (Macfadyen and Hosch 2023), a ranking that likely subjects wahoo to illegal harvest and sale within the protected zone. Similar to Mexico's EEZ, Bahamian waters are rife with IUU fishing, with estimates of one third of marine catch harvested illegally (https://marine.wildaid.org/united-to-protect-sustainable-fisheries-and-marine-resources-in-the-bahamas/) and little enforcement, data collection, and monitoring of sport or commercial fisheries (Elliott 2018). The Bahamas is also a renowned location to catch wahoo, where the main season spans five months (https://www.bahamas.com/plan-your-trip/fishing/fishing-faq), and the topography, bathymetry, and oceanography favor many key zones, which overlap with identified IUU hotspot zones, including near Cay Sal Bank, west of Bimini, and northeast of the Abacos. All of these are recreational hotspot zones where as many as 50 U.S. recreational vessels per day enter to fish and eventually return to the states (Burgess et al. 2016) with most of that catch undocumented or vetted relative to Bahamian or United States fishing laws.

Commercial catch

Commercial wahoo catch has been on the rise throughout the WCA, but the total extent of commercial landings is unknown. In addition, given the incomplete or lack of data collection programs to adequately monitor wahoo catch throughout the region, landings are substantial underestimates. In order to investigate catch under-reporting, beginning in July of 2023, the Beyond Our Shores Foundation initiated a volunteer pelagic and coastal catch monitoring study with commercial anglers along the south coast of the DR and since that time two vessels have collectively landed 3.15 tons of wahoo between coastal and offshore locations in just over a year while targeting dolphinfish (Fig. 6; Appendix 1). When compared to the 2022 FAO DR wahoo landings amount, these vessels would constitute 63% percent of the reported landings, and in recent years (i.e., 2016 onward) commercial wahoo landings were extremely low, even zero in 2018 and 2019 (years when BOSF monitored vessels were active but data was not collected). The most recent FAO DR wahoo landings (i.e., 2022) was still low (5 MT). Based on presentations observed through the Western Central Atlantic Fishery Commission's Fish Aggregating Device working group, the DR Government estimated that there were 2,600 offshore fishing entities (i.e., anglers and fishing associations) that target dolphinfish. The vessels monitored to date have embarked on 261 outings in 15 months targeting dolphinfish and wahoo was caught during 49% of those outings, which suggests that wahoo is still a substantial fishery in DR but this is not reflected in the FAO data. Furthermore, when compared to the entire region's commercial catch for data analyzed in this study (i.e., 2021), those vessels catch represented 0.73% of reported landings, a large proportion for just two vessels, which suggests the commercial catch as recorded across the region is drastically

underestimated. This stresses the need to immediately improve data collection on wahoo throughout WCA jurisdictions, which could be facilitated by the International Commission for the Conservation of Atlantic Tunas (ICCAT) or Western Central Atlantic Fishery Commission (WECAFC).

Sea Around Us (SAU) reconstructed commercial catch estimates were substantially higher than FAO commercial catch estimates since 2012, but lack reliable estimates for 19 nations in the region. Those nations include: Anguilla (UK), Antigua & Barbuda, Bahamas, Belize, British Virgin Islands (UK), Cayman Islands (UK), Costa Rica (Caribbean), Cuba, Dominican Republic, Guadeloupe (France), Haiti, Honduras (Caribbean), Jamaica, Montserrat (UK), Nicaragua (Caribbean), St. Barthelemy (France), St. Martin (France), Turks & Caicos Islands (UK), and the USVI. Since 2012, industrial catch reconstruction for wahoo amounted to 6.45 MTs for all those nations combined, indicating that substantial progress needs to be made collecting fishery statistics in these nations. In addition, given the significant increase in percent difference between SAU and FAO landings when artisanal and subsistence landings are included in the catch reconstruction data, there is an urgent need to establish basic catch data collection processes in those nations to allow for a better understanding of total stock removals and fishing pressure. As shown in the example above, volunteer data collection efforts can be established to acquire basic catch statistics that can be used to improve our regional understanding of catch for species such as wahoo. When compared to the SAU DR reconstructed artisanal catch, the two vessels monitored above represent a higher catch recorded in the last SAU year for DR (2017; 1.87 MT), which further emphasizes the need for improvements to wahoo data collection. In a recent WECAFC working group on flying fish and dolphinfish, member nations moved to elevate wahoo from the Data Collection Reference Framework (DCRF) Group 2 species to Group 1 Main Reference Species in the WECAFC list of aquatic species to improve data collection and contribute to strengthened management of the species based on its importance in the region and the working group's interest in collaborating with ICCAT on data collection.

Recreational catch

The U.S. East Coast and Gulf of Mexico fishery dominated the region in terms of recreational wahoo catch, twice as high as the next highest landing nation (the Bahamas). However, the U.S. wahoo landings, which are assessable via NOAA's MRIP, do not incorporate wahoo landings in Puerto Rico given MRIPs inactivity in the territory. According to SAU's reconstructed recreational wahoo catch, from 2018 to 2019, only 0.14 MTs were estimated as landed in Puerto Rico. Based on ongoing catch and effort research by the Beyond Our Shores Foundation, in 2018, 133 wahoo were landed by 20 vessels monitored around the island, a far higher value than that estimated by the SAU. Combine this discrepancy with the lack of data from the USVI and the U. S. dominance in wahoo catch is likely much higher regionally, which supports the need for better management and data collection, on the species.

More than half of the estimated total wahoo catch, in the most recent SAU year, was from the recreational sector, a value that is only likely to grow. While recreational landings peaked in 2016, a year which coincided with the highest regional landings when combined with FAO commercial data, offshore recreational fishing activity has risen throughout the region, although at an unknown rate, and suggests that new peaks in wahoo landings could be obtained. According to the Organization of Eastern Caribbean States Commission (OECS), there has been intentional development of the recreational fisheries sector as an activity for tourists visiting the Caribbean Sea to engage in recreational fishing on private or chartered vessels or during fishing tournaments. However, attempts to collect data on this sector at a regional level have been limited, and spatial characterization of recreational activity has been lacking (OECS 2020).

According to All at Sea (https://www.allatsea.net/2023-fishing-tournaments-in-the-bahamas-and-caribbean-a-year-round-guide-and-qualifying-events-for-the-offshore-world-championships/), in 2023 alone, 9 nations throughout the region hosted large sportfishing tournaments in which wahoo were caught, yet it is unknown whether detailed catch from these events was recorded. When compared to the analysis of this study, only 2 of the 9 nations reported FAO wahoo landings and all lack public access to recreational landings data or data collection processes in the first place. A requirement to host an offshore fishing tournament should be to collect vessel data on landings for species such as

wahoo so scientists and managers can focus management and conservation on sustaining the populations that drive the tourism activity.

Fishing effort for wahoo

According to the SAU dataset, recreational fishing gear was the highest individual gear used to target wahoo throughout the region. However, what remains to be understood is how recreational fishing power and effort, which expresses the efficiency by which vessels have the potential to catch wahoo (i.e., catchability), has changed over the past few decades. According to Palomares and Pauly (2019), catchability has increased dramatically, yet information on how this has affected catchability for species such as wahoo is lacking (Engelhard 2016). In particular, studies on how hook and line gear has advanced over the last few decades, for example, rod and reel materials, weights, and speeds, as well as lure type and ability to attract wahoo, and other pelagic fish species, are absent in the literature. Furthermore, significant advances have occurred in sonar as well as bathymetric imagery, which allows anglers to more readily target wahoo at bottom features, along contours, banks, and oceanic fronts (i.e., convergent zones, upwellings, and temperature discontinuities), the species' preferred habitat (Franks et al. 2008; Theisen and Baldwin 2012), yet studies on how this has changed for recreational fisheries are not available. Without adequate information on gear and technology used within the recreational fishery (Thurstan et al. 2018), as well as advances in catchability, it will not be possible to use wahoo recreational landings as an index of abundance to assess the population status of the species.

Catch comparison to dolphinfish in the WCA

For both species, there is high uncertainty on total regional landings due to the lack of FAO landings from fifteen nations not reporting dolphinfish or wahoo and the lack of recreational landings for the vast majority of the jurisdictions. Interestingly, there are nations that report wahoo landings but not dolphinfish landings, and vice-versa, suggesting differences in abundance and/or importance of those species to those nations. This point is further emphasized for locations where wahoo (Bermuda & St. Vincent and Grenadines) and dolphinfish (Dominican Republic and Venezuela) landings increased. Lastly, several nations started to report landings toward the end of each study, which indicates an increase in data available on landings. This is a positive step forward, but not necessarily an increase in importance of fisheries due to the lack of historical data.

Dolphinfish are caught in much greater quantities than wahoo, but reported landings declined for both species through the end of the study periods. In addition, in terms of catch percentage by sector, recreational catch was similar between wahoo and dolphinfish, which further emphasizes the need for management of recreational fisheries targeting both species throughout the region.

CONCLUSION

This study showed extensive evidence of increased wahoo stock pressure and population status uncertainty. Given the growth of the wahoo fishery throughout the WCA, and the lack of pervasive fishery management measures, while stock decline has not been modeled like dolphinfish (Lynch et al. 2018; Damiano et al. 2024), anecdotal decline has been suggested by regional fishery stakeholders in the U.S. Caribbean Sea but elsewhere (e.g., U. S. east coast south Atlantic region; https://safmc.net/documents/dw_a1b_wahoof-rp_202311-v2-pdf/) there seems to be an increase in wahoo abundance and availability to the fishery, and it does not appear that increased effort to harvest them has negatively affected their abundance. As such, key points based on this analysis are included below:

- Increases in commercial catch has been recorded but 18 nations still do not report wahoo 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.
- Advances in recreational fishing power and effort have occurred, yet are unquantified, with increased catchability likely for wahoo.
- While dolphinfish is landed in higher quantities based on reported landings, wahoo is landed in nations that lack dolphinfish landings suggesting difference in abundance or fishery value for those nations.
- Management (i.e., new conservation measures (trip and bag limits, minimum sizes) for wahoo has remained unchanged for the past two decades in the United States East Coast fishery and limited in scope elsewhere.

- New management measures (i.e., changes in trip and bag limits, implement minimum sizes) for wahoo have been proposed for the U.S. Caribbean Sea to implement precautionary measures to ensure the long-term conservation of the WCA population.

While advances in U. S. recreational management are warranted given the importance of the recreational wahoo fishery, until there is similar action in international locations, stock decline is likely to continue. In a recent international meeting held by WECAFC, it was determined that given their limited capacity, focus was to remain on other higher priority species but nations were encouraged to pursue improvements in data collection for wahoo. It was also suggested that WECAFC should ask ICCAT to consider the assessment and management of wahoo, with an understanding that WECAFC members would provide the requisite data, yet ICCAT has never formally attempted to manage the species despite the species registered as an ICCAT priority species. To increase data collection, reporting, and knowledge of wahoo fisheries throughout the region, due to the lack of international action, public-private partnerships should be explored and implemented to ensure long-term management and conservation of the WCA wahoo population.

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APPENDIX 1. Image archive of daily wahoo catch reports associated with boat 1 monitored for fishing activity south of the Dominican Republic.


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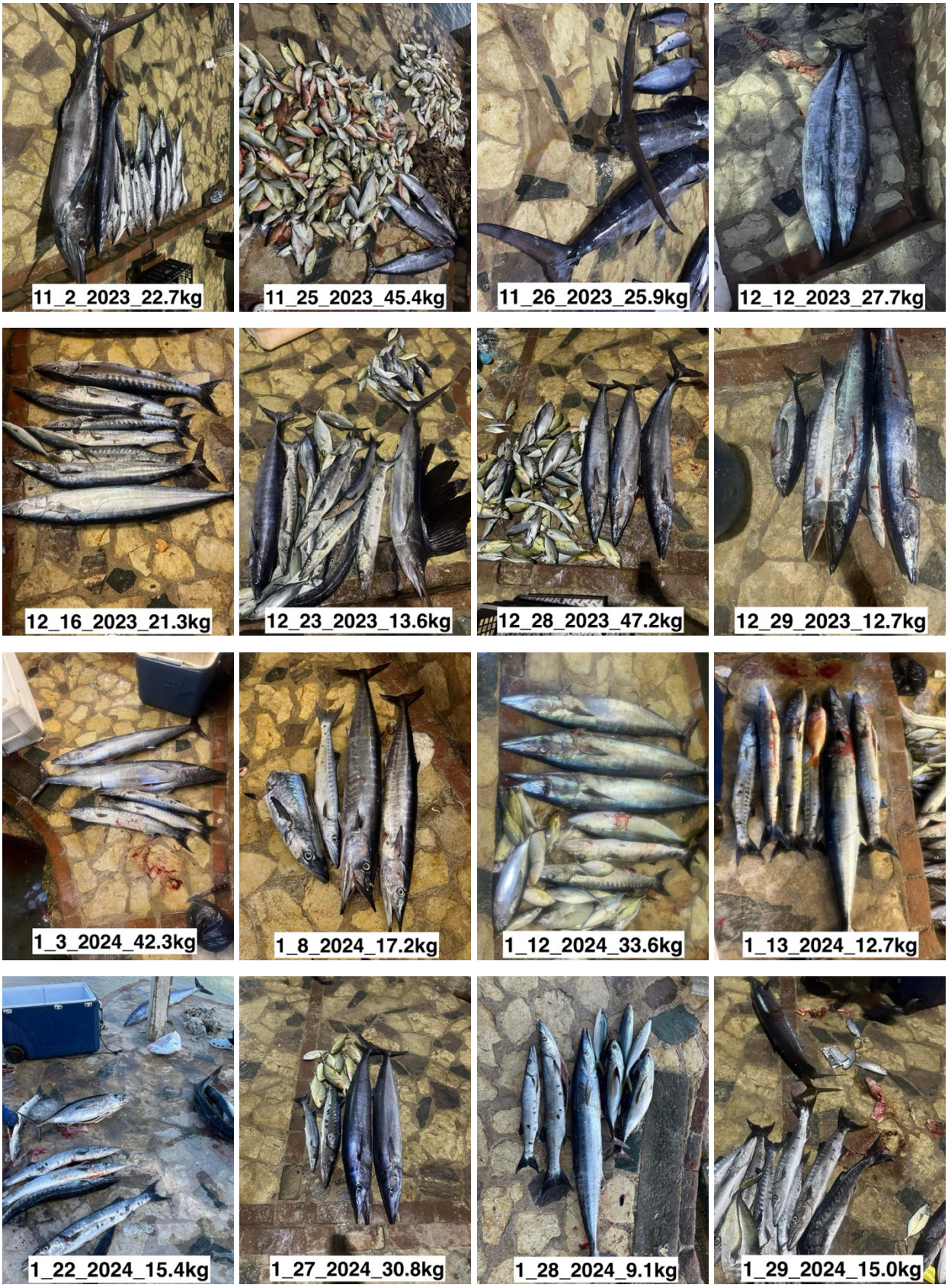
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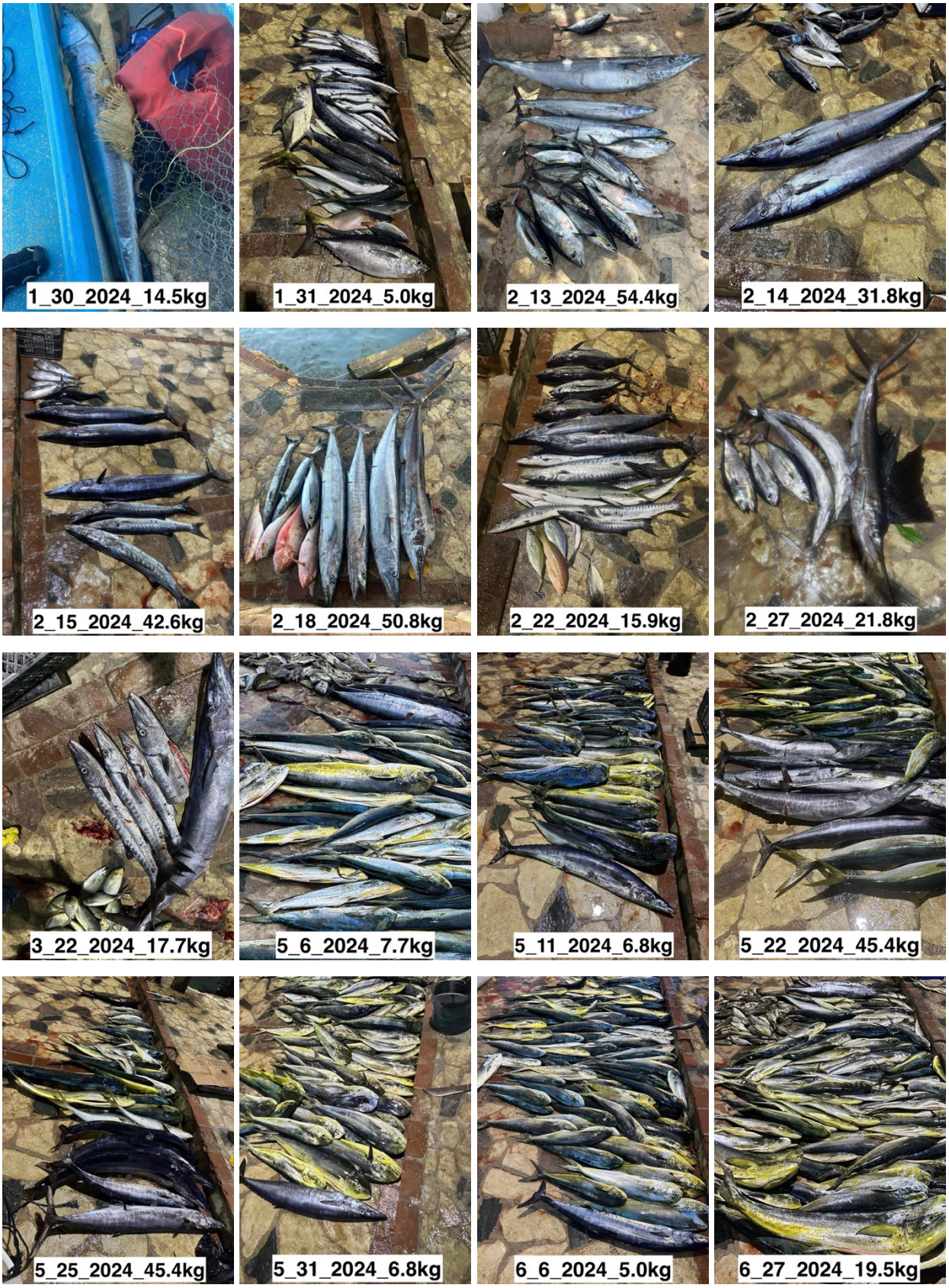
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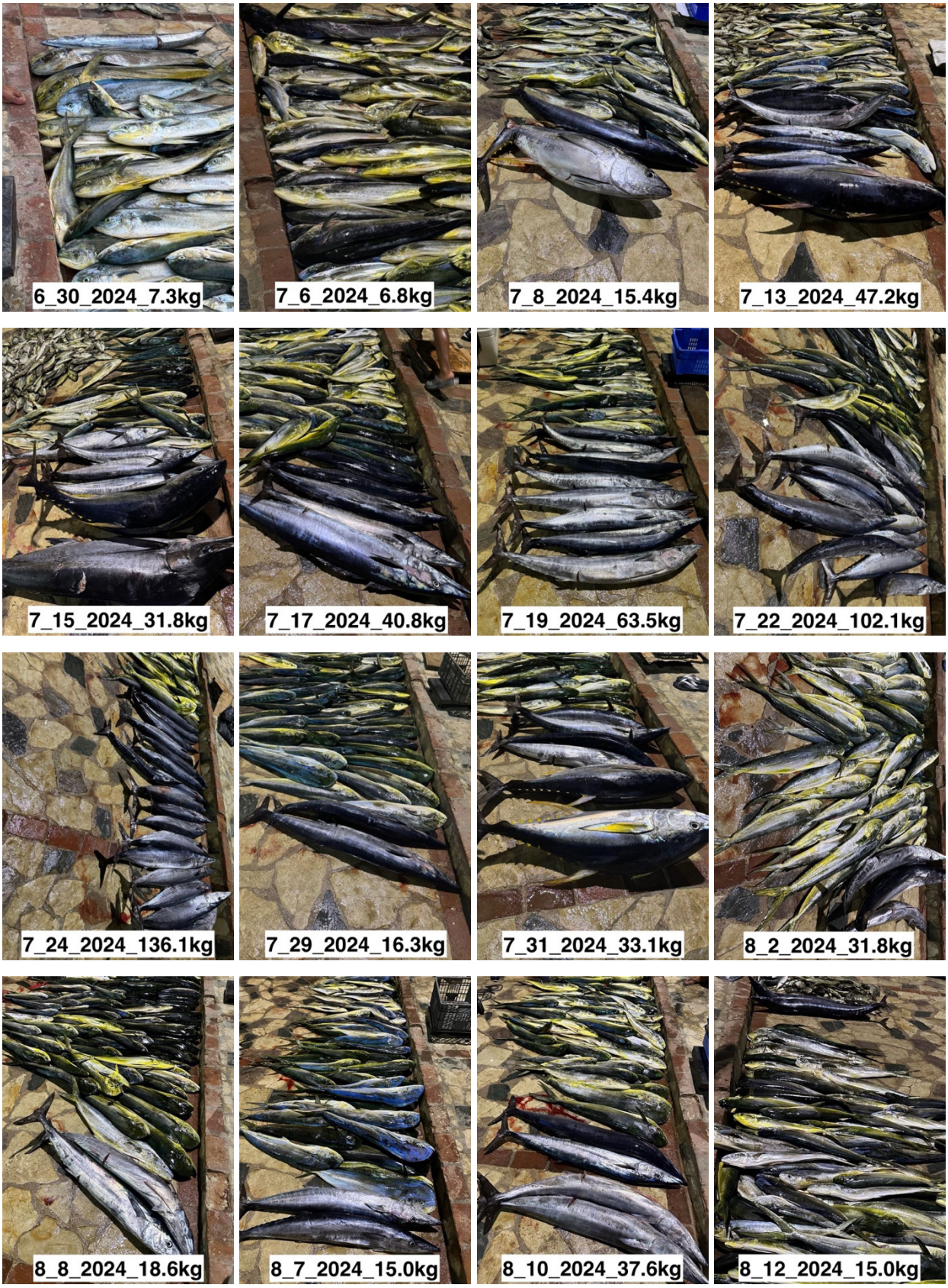
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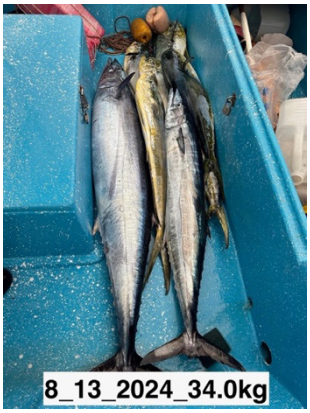
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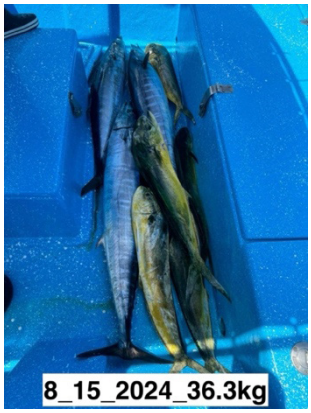
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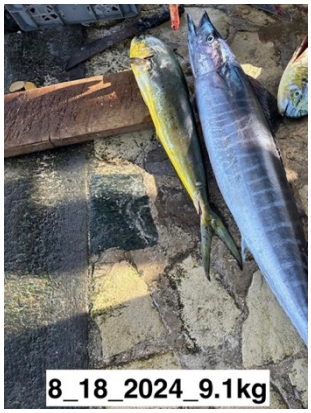
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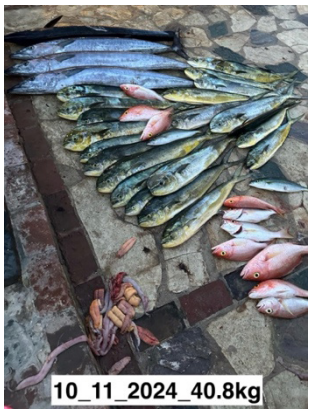
9_23_2024_5.4kg


10_4_2024_7.7kg


10_8_2024_9.1kg

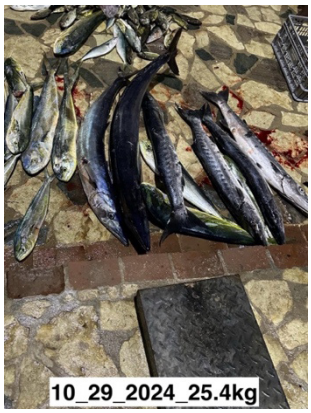

10_11_2024_40.8kg


10_17_2024_6.8kg

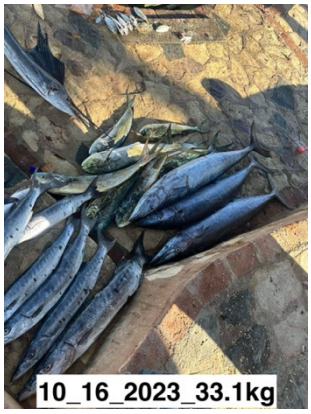

10_19_2024_23.6kg


10_24_2024_21.8kg


10_28_2024_24.0kg


10_29_2024_25.4kg

APPENDIX 2. Image archive of daily wahoo catch reports associated with boat 2 monitored for fishing activity south of the Dominican Republic. Boat 2 does not fish more than six miles offshore.

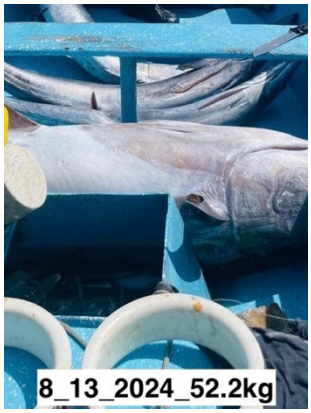


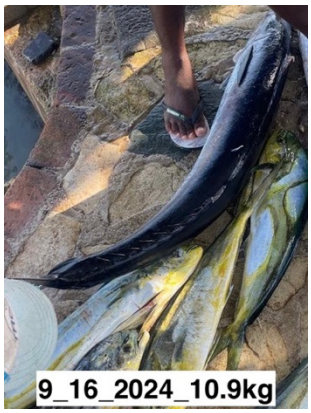
No Image Provided in Report

10_21_2023_9.5kg

No Image Provided in Report

8_9_2024_70.8kg





No Image Provided in Report

9_18_2024_22.2kg

No Image Provided in Report

9_24_2024_4.5kg


9_27_2024_8.6kg


9_30_2024_10.4kg


10_1_2024_20.0kg


10_8_2024_13.6kg


10_9_2024_23.6kg


10_14_2024_53.1kg


10_17_2024_22.7kg


10_22_2024_15.4kg


10_23_2024_44.5kg


10_25_2024_18.6kg


10_27_2024_14.5kg