

New records of the ragged-tooth shark, *Odontaspis ferox*, from the western North Atlantic Ocean, with a summary of regional occurrences

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ABSTRACT

Four new records of the ragged-tooth shark, (*Odontaspis ferox*, *i.e.* smalltooth sand tiger) are reported from recreational and commercial fisheries in the western North Atlantic Ocean. Two specimens of unknown sex were caught in the recreational swordfish (*Xiphias gladius*) fishery in the northern Gulf of Mexico (~225 and ~250 cm total length (TL)), a mature male was caught in the South Atlantic Bight (~200 cm TL) by an angler targeting barrelfish (*Hyperoglyphe perciformis*); and another mature male was caught in the Sargasso Sea off Bermuda (~275 cm TL) by a commercial fisher targeting Atlantic wreckfish (*Polyprion americanus*). All four specimens were incidentally caught on rod-and-reel and released alive. The Gulf of Mexico and South Atlantic Bight specimens reported herein contribute to the limited number of ragged-tooth shark interactions in these regions, while the observation in Bermuda is the first documented record for this locality.

INTRODUCTION

Deep-water fisheries greatly developed globally in the mid-20th century (Roberts 2002; Morato *et al.* 2006), exposing deep-water fauna to persistent anthropogenic influences (da Ros *et al.* 2019). As these fisheries expanded, so too did the interaction with new or obscure species, some of which now support prominent fisheries (*e.g.* orange roughy, *Hoplostethus atlanticus*; Atlantic wreckfish, *Polyprion americanus*; toothfish, *Dissostichus eleginoides*; alfonsino, *Beryx decadactylus*); while others (*e.g.* goblin shark, *Mitsukurina owstoni*; coelacanths, *Latimeria* sp.) largely remain uncommon observations (Sedberry *et al.* 1999; Koslow *et al.* 2000; Parsons *et al.* 2002; Clark 2009; Iwata *et al.* 2019). As global fisheries continue to move into deeper waters it will be paramount to understand the impacts on the species encountered, especially those with K-

selected life history characteristics such as chondrichthyans (Simpfendorfer and Kyne 2009). As such, examinations of first records, range expansions, and new observations of species that are not commonly encountered can provide meaningful biological and ecological data.

The ragged-tooth shark (*Odontaspis ferox*, *i.e.* smalltooth sand tiger) is considered a circumglobal species inhabiting subtropical and tropical marine waters and is often associated with continental and insular shelves (Compagno 1984; Cortés *et al.* 2012; Ebert and Stehmann 2013). Despite the expansive range, there are infrequent reports of ragged-tooth sharks, and most are isolated observations, typically from disparate geographic regions (*e.g.*, Compagno 1984; Fergusson *et al.* 2008; Barcelos *et al.* 2018; Richardson *et al.* 2019). Reports from Canary Island divers and the New Zealand commercial fishery indicate this species inhabits depths as shallow as 1 m and as deep as 928 m (Fergusson *et al.* 2008; Francis and Lyon 2012; Barría *et al.* 2018). However, the ragged-tooth shark is not often encountered in shallow depths limiting the number of overall interactions, which in part contributes to an IUCN Red List precautionary assessment of ‘Vulnerable’ (Graham *et al.* 2016). The maximum recorded size of an encountered ragged-tooth shark is 520 cm total length (TL) and was documented from a female caught at Walvis Ridge in the open waters of the southeastern Atlantic Ocean (Kukuev and Batal'yabts 2019).

The life history of the ragged-tooth shark has only been briefly assessed due to the limited number of specimens examined. Currently, no information is available for age and growth, but a cursory description of reproduction was compiled by Ferguson *et al.* (2008) from existing literature. Ferguson *et al.* (2008) estimated size-at-maturity to be between 300 - 350 and 200 - 250 cm TL for females and males, respectively, and embryo size-at-parturition to be near 100 cm TL. This estimate is further corroborated by a 101 cm TL female reported from Taiwanese waters that exhibited a vitelline scar, indicating recent pupping (Hsu *et al.* 2013).

There have been no documented observations of gravid females. Although baseline biological data are being collected, numerous critical information gaps still exist that necessitate continued reporting of unique isolated observations. As such, the records reported herein contribute to the growing body of literature and summarize observations of ragged-tooth sharks in the western North Atlantic Ocean.

METHODS AND RESULTS

GULF OF MEXICO (GOM)

The recreational charter, *Intensity Offshore Outfitters* (Venice, Louisiana, United States), was targeting swordfish, *Xiphias gladius*, in the north central Gulf of Mexico within the Bureau of Ocean Energy Management (BOEM) lease block MC109 on August 12th, 2019 (Fig. 1; GOM 1). Anglers were aboard the F/V *Renegade* and were following typical daytime deep-drop swordfish fishing techniques popular in the region, using Atlantic bonito (*Sarda sarda*) belly strips as bait. Fishing occurred approximately 30 m off the bottom in water depths ranging between 450 and 490 m. The shark was hooked and fought for approximately 90 minutes. Once alongside the boat, the captain estimated the total length to be 225 cm and weight to be 115 kg. The shark was photographed and released alive. Upon release, the shark exhibited very strong swimming and did not behave as if exhausted from the interaction.

A second specimen from the Gulf of Mexico was caught by the recreational charter *Paradise Outfitters* (Venice, Louisiana, United States) in BOEM lease block MC 401 on July 21st, 2020 (Fig. 1.; GOM 2). The charter was targeting swordfish, following common daytime methods. Squid was used as bait and the gear was fished 30 m off the bottom in 457 m of water.

Once brought boat-side, a short video was taken of the shark and TL was estimated to be 250 cm. Weight was estimated to be 96 kg following Fergusson *et al.* (2008) $TW = (2.166 \times 10^{-6}) TL^{3.189}$. The shark was released alive.

SARGASSO SEA (SAR)

The commercial fishing vessel, *Fine Tuna* (Bermuda), was targeting Atlantic wreckfish off the east coast of Bermuda on August 19th, 2020 (Fig. 1; SAR1). The fisher was using vertical line techniques to target deep-water fishes baited with Atlantic mackerel (*Scomber scombrus*). The gear was deployed on the bottom in a water depth of 731 m. The shark was foul hooked in the first dorsal fin and brought alongside the vessel. The fisher estimated length to be 275 cm TL prior to the shark being released alive. Photographs taken verified the shark was a male, likely mature, as the claspers extended well past the pelvic fins (Fig 2). Weight was estimated to be 130 kg following Fergusson *et al.* (2008).

SOUTH ATLANTIC BIGHT (SAB)

A private recreational vessel was targeting barrelfish (*Hyperoglyphe perciformis*) off the east coast of Florida in May of 2020 (Fig. 1; SAB 1). The angler was fishing a deep-water bottom rigging for reef fish, baited with whole squid, and fished on the bottom in a water depth of 305 m. The shark was hooked and fought for approximately 30 minutes prior to being brought boat side. The angler estimated the total length to be 200 cm prior to releasing the shark alive. The shark was determined to be a mature male from photographs based on the aforementioned criterion (Fig 2). Weight was estimated to be 47 kg following Fergusson *et al.* (2008).

IDENTIFICATION

Identification of each new record was conducted based upon the photographs and/or videos taken during each interaction (GOM 1, SAR 1, and SAB 1, Fig. 2; GOM 2, see supplementary material). The presence of a long snout and noticeably larger first dorsal fin compared to the second, as well as placement of the first dorsal fin over the pectoral fin inner margin distinguishes these sharks as the genus *Odontaspis* instead of *Carcharias* (Compagno 2002). Of the two extant species of *Odontaspis*, the lighter grey/grey-brown coloration, smaller eye relative to body size, and the nearly equilateral triangular shape and lack of white-tip on the first dorsal fin distinguishes these sharks as the ragged-tooth shark (*Odontaspis ferox*) instead of the bigeye sand tiger (*O. noronhai*; Compagno 2002; Castro 2011). Dentition was not examined due to the resolution of the photographs and videos.

DISCUSSION

Over the last three decades, 17 ragged-tooth sharks have been reported from the western North Atlantic Ocean, including those reported in the current study (Fig. 1, Table 1). Previous studies have documented interactions and collected opportunistic data (*e.g.* length, weight, sex) from the South Atlantic Bight ($n = 9$; Sheehan 1998, Gilmore 2007; Ross and Quattrini 2007, Castro 2011), the Caribbean Sea ($n = 2$; Anquila *et al.* 2016, Travares *et al.* 2019), and the Gulf of Mexico ($n = 2$; Bonfil 1995, Sulak *et al.* 2007). There have also been two additional reports, one from the Gulf of Mexico and another from Cuba; however, there is uncertainty around the confirmation of these reports, as discussed below.

A single tooth (FMNH 35592) identified as *O. ferox* resides in the Field Museum in Chicago, Illinois, United States donated in 1938 by Stuart Springer during his tenure at Bass

Biological Laboratory. However, recent photographic examination of FMNH 35592 denotes the tooth is more consistent with the tooth morphology of *Carcharias* instead of *Odontaspis* (G Phillips, Mississippi Museum of Natural Science, pers comm). Although anecdotal, documentation for FMNH 35592 indicates the collection location, year, and specimen length corresponds closely with the work of Springer in 1938 as he describes two sand tiger sharks (recorded as *Odontaspis littoralis*) being examined from Englewood, Florida, United States (Springer 1938). Further examination of this tooth would be necessary to accurately confirm species of origin, which could potentially be achieved through genetic analysis.

The record from Cuban waters is presented in the English version of Ecology of Marine Fishes of Cuba (Claro and Parenti 2001) which lists the ragged-tooth shark as ‘recorded’ and notes the source as personal communication from L. Espinosa; however, the original Spanish version (Claro 1994) does not include this species. Despite extensive efforts, the authors could not substantiate the observation reported in the text. Subsequent communication with researchers and literature searches did not provide any other anecdotal or published records of ragged-tooth sharks from Cuban waters. At this time, supporting evidence is necessary to determine the validity of this potential record.

The two new reports from the Gulf of Mexico represent the first observations of ragged-tooth sharks in the region in over 15 years. Historically, the first record from the Gulf of Mexico occurred in 1989 off Campeche Bank, Mexico (Bonfil 1995) and was landed by a commercial red snapper (*Lutjanus campechanus*) fisher. The second record occurred in 2004 at BOEM lease block VK 826, United States, during a *Lophelia* reef study (Sulak *et al.* 2007). This sighting was based on a Johnson-Sea-Link (JSL) submersible video recording. Both prior Gulf of Mexico records were female sharks, 366 cm TL and 300 - 400 cm TL respectively (Bonfil 1995; Sulak *et*

al. 2007), which corresponds with an appropriate size, 300-350 cm TL (Fergusson *et al.* 2008) to assume they had reached maturity. Unfortunately, the sex of the two new Gulf of Mexico specimens reported herein could not be determined from the photographs or videos, and as such, maturity could not be inferred.

The recent observation of a mature male ragged-tooth shark, from the Miami Terrace region of the South Atlantic Bight, is one of several reports from this area over the last three decades. Initial records from this region were attributed to a sole recreational angler, R. Shatman, fishing between Miami, Florida, United States and Bimini, Bahamas (Castro, 2011). One of these reports was of a male ragged-tooth shark that was subsequently examined by J. Castro and R.G. Gilmore. During this examination, presumed mating scars were documented and although mating scars are not typically associated with males, Gilmore (1993) noted similar mating scars are commonly found on male sand tiger sharks (*Carcharias taurus*). This examination prompted a directed JSL camera expedition in the late 1990s within this region to document mating populations of ragged-tooth sharks (Gilmore 2007), but ultimately did not identify any additional specimens. Several years later, two females were captured on JSL video during a deep-sea coral expedition conducting mapping and characterization of the ecosystem off the coast of Florida, United States (Gilmore 2007). Similar to the previously encountered male, both females were noted to have fresh mating scars. For the new interactions reported herein, the presence or absence of mating scars could not be determined due to the photographic/video resolution. However, the historic observations as well as the two new records show that the South Atlantic Bight is being used by mature sharks and potentially lends credence to the hypothesized mating populations within these waters.

The observation reported from the Sargasso Sea is the first record from the waters surrounding Bermuda and is the deepest known capture of the ragged-tooth shark in the North Atlantic Ocean to date. Previous deep-water studies on the eastern boundary of Bermuda also noted that *Lophelia* reefs (Freiwald *et al.* 2021) are within close proximity of the capture site, which corresponds with new and historical observations of ragged-tooth sharks from the South Atlantic Bight and northern Gulf of Mexico. Further, the record from Bermuda also corresponds with previous reports that indicate that this species is often associated with steeply shelved islands (Fergusson *et al.* 2008). Future studies within the western North Atlantic Ocean should investigate both deep-water coral reefs and insular slope regions in an effort to further describe preferred habitat for ragged-tooth sharks.

A commonality among these new records is that each interaction occurred in deep waters (> 300 m). Historically, recreational anglers targeting swordfish in the northern Gulf of Mexico, fished at night in depths less than 100 m. With the growing popularity of daytime fishing methods, anglers are now fishing in water greater than 400 m. Anglers employed this method in order to target the depths corresponding with the known diel migrations of swordfish (e.g. Lerner *et al.* 2013). In the South Atlantic Bight, recreational anglers are targeting swordfish at depth, but also other benthopelagic fishes such as barrelfish, which have a known depth range of 200 - 400 m (Suca and Llopiz 2017). Lastly, in Bermuda the commercial fishery expanded into deeper water during the 1970s and 1980s when populations of shallow reef fishes were in decline. Fishers instead started targeting snappers and groupers in depths of 215 - 325 m and incidentally caught the first Atlantic wreckfish within this region (Sedberry *et al.* 1999). Development of the Atlantic wreckfish fishery off Bermuda expanded commercial efforts into even deeper waters ranging from 360 - 684 m (Sedberry *et al.* 1999). As the fisheries in the Gulf of Mexico, South

Atlantic Bight, and Sargasso Sea off Bermuda expanded into deeper water, they also coincidentally overlapped with the known depth range of the ragged-tooth shark (Fergusson *et al.* 2008). As these established and new fisheries continue to expand, interactions with the ragged-tooth shark will likely increase, highlighting the importance of fishery dependent observations to provide better insight into the distribution of this species in the western North Atlantic Ocean. As such, it is paramount that stakeholder collaborations continue to be fostered so that future observations can be properly documented from this region.

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TABLES

Table 1. Recorded observations of the ragged-tooth shark, *Odontaspis ferox*, from the western North Atlantic Ocean. (SAR = Sargasso Sea, SAB = South Atlantic Bight, GOM = Gulf of Mexico, CAR = Caribbean, Rec. = Recreational, JSL = Johnson-Sea-Link submersible, Com. = Commercial, Mass values denoted with * were estimated following Fergusson *et al.* (2008) $TW = (2.166 * 10^{-6}) TL^{3.189}$).

Region	Location	Year	Sex	TL (cm)	Mass (kg)	Depth (m)	Collection	Source
SAR	Bermuda	2020	M	~275	130*	731	Com. Fisher	Current Study
SAB	South Cat Cay, Bahamas	1992	M	314	191	365-655	Rec. Angler	Castro 2011
SAB	South Cat Cay, Bahamas	1993	M	309	165	365-655	Rec. Angler	Castro 2011
SAB	Cape Hatteras, NC, USA	1994	F	340	~250	173	Bottom Trawl	Sheehan 1998
SAB	Jacksonville, FL, USA	2004	-	250	96*	573	JSL Video	Ross & Quattrini 2007
SAB	Blake Plateau, USA	2005	M	200	47*	627	JSL Video	Ross & Quattrini 2007
SAB	Miami Terrace, USA	2005	F	-	-	310	JSL Video	Gilmore 2007
SAB	Miami Terrace, USA	2005	F	-	-	310	JSL Video	Gilmore 2007
SAB	Salvo, NC, USA	2016	F	237	81*	109-120	Bottom Trawl	VIMS 35382
SAB	Bahamas	-	M	-	-	365-655	Rec. Angler	Castro 2011
SAB	Miami Terrace, USA	2020	M	~200	47*	305	Rec. Angler	Current Study
GOM	Cayo Nuevo, Mexico	1989	F	366	289	130	Com. Fisher	Bonfil 1995
GOM	Viosca Knoll 826, USA	2004	F	300-400	170-430*	454	JSL Video	Sulak <i>et al.</i> 2007
GOM	MC 109, USA	2019	-	~225	~115	457-487	Rec. Angler	Current Study
GOM	MC 401, USA	2020	-	~250	87*	~457	Rec. Angler	Current Study
CAR	Colombia	2014	F	212	90	-	Artisanal Longline	Anguila <i>et al.</i> 2016
CAR	Cape Codera, Venezuela	2018	-	180	30	80	Artisanal Gillnet	Tavares <i>et al.</i> 2019

FIGURES

Fig 1.

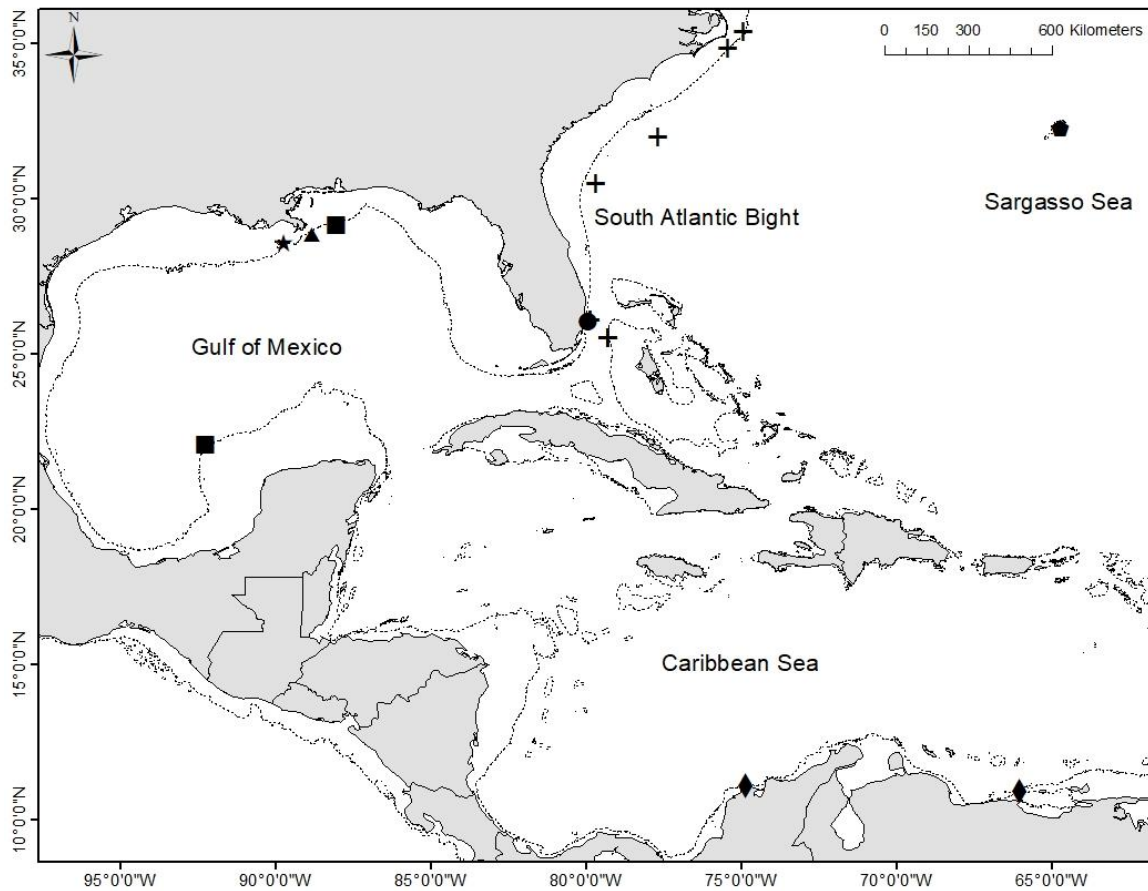


Fig 1. New records of the ragged-tooth shark, *Odontaspis ferox*, from the Gulf of Mexico, BOEM lease block MC 109 (▲; GOM 1) and lease block MC 401 (★; GOM 2), South Atlantic Bight (●; SAB 1), and Bermuda (◆; SAR 1). Historical observations from the western North Atlantic Ocean include two from the Gulf of Mexico (■; *i.e.* Bonfil 1995, Sulak *et al.* 2007), nine from the South Atlantic Bight (+; *i.e.* Sheehan 1998, Gilmore 2007, Ross and Quattrini 2007, Castro 2011, VIMS 35382), and two from the Caribbean Sea (◆; *i.e.* Anguila *et al.* 2016, Tavares *et al.* 2019). The dashed black line indicates the 200 m bathymetric contour.

Fig 2.

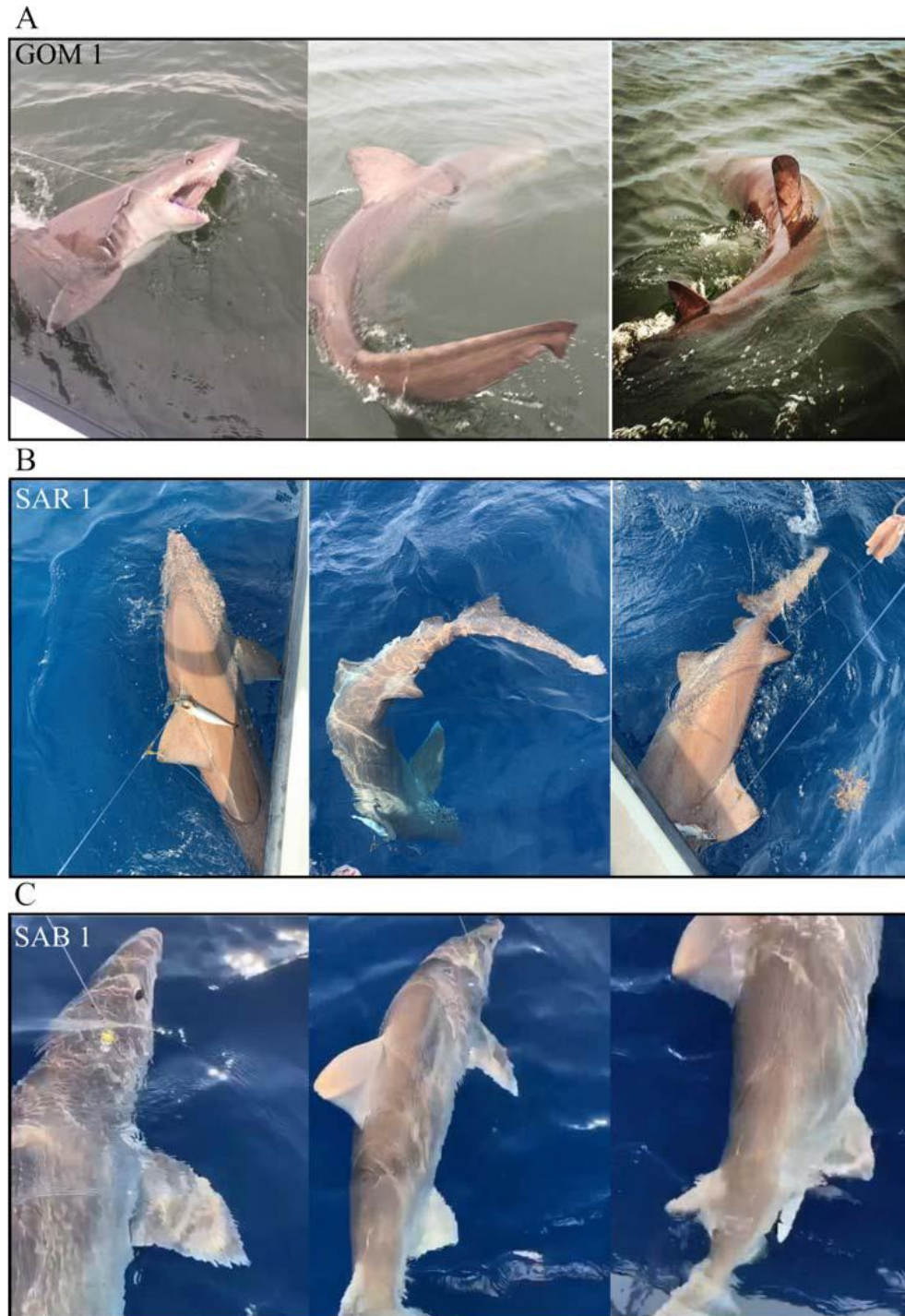


Fig 2. Photographs documenting three new records of the ragged-tooth shark, *Odontaspis ferox*, in the western North Atlantic Ocean. Captures occurred in the (A) north central Gulf of Mexico (GOM 1), (B) Sargasso Sea (SAR 1), and (C) South Atlantic Bight (SAB 1).

SUPPLEMENTARY MATERIAL

Video documenting one new record of the ragged-tooth shark, *Odontaspis ferox*, in the western North Atlantic Ocean. Capture occurred in the north central Gulf of Mexico (GOM 2).