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ARTICLE

Observed trends in scavenging by common bottlenose dolphins (*Tursiops truncatus truncatus*) in for-hire fisheries in the eastern U.S. Gulf of Mexico

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Abstract

Interactions between bottlenose dolphin and recreational rod and reel fisheries are a complex issue for resource managers in the United States, which may impact anglers' catch and lead to dangerous situations for scavenging or depredating dolphins. To examine this issue, we analyzed data collected by observers on for-hire fishing vessels off the eastern U.S. Gulf Coast from 2009 to 2020. A generalized additive model indicated number of anglers, number of discarded fish, proximity to shore, prior scavenging events, type of released fish, and area fished were all significant predictors of scavenging by dolphins. The Florida panhandle had the highest odds of scavenging, while scavenging in the Big Bend and Tampa Bay has increased through time. The Florida panhandle is a well-known area for illegal feeding of dolphins, suggesting human behavior may be influencing fisheries interactions. Model outputs indicate that dolphins are primarily cuing on fishing activity rather than number of discards, but are more likely to scavenge discards from the family Lutjanidae (snappers), which comprised 40% of observed discards but 80% of scavenging events. This study highlights factors influencing the frequency of dolphin scavenging events, guiding managers and scientists on additional studies and mitigation measures needed to address this issue.

KEYWORDS

bottlenose dolphins, fishery interactions, Florida, Gulf of Mexico, hook and line fishery, recreational fishery, reef fish, rod and reel fishery, scavenging, *Tursiops truncatus truncatus*

1 | INTRODUCTION

Fisheries interactions with small cetaceans such as common bottlenose dolphins (*Tursiops truncatus truncatus*) generate complex challenges for fisheries and protected species managers globally (Broadhurst, 1998; Brotons et al., 2008; Cox et al., 2003; Noke & Odell, 2002, Werner et al., 2015). In rod and reel fisheries, fisheries interactions can occur when small cetaceans remove captured fish or bait (i.e., depredation), or feed on released live or dead fish (i.e., scavenging) (Perrtree et al., 2014; Powell & Wells, 2011; Zollett & Read, 2006). Both scavenging and depredation have negative consequences for cetaceans and anglers. Small cetaceans have an increased chance of injury or mortality due to entanglement, hooking, or ingestion of gear (Adimey et al., 2014; Christiansen et al., 2016; Read, 2008; Read & Waples, 2010; Tixier et al., 2020; Wallace, 1985; Wells & Scott, 1994; Wells et al., 2008). Small cetaceans are also more likely to be injured by vessel strikes while engaging in fisheries interactions (Christiansen et al., 2016; Donaldson et al., 2010; Wells & Scott, 1997). Fisheries interactions with cetaceans have an economic cost for anglers, who may lose captured fish, purchase additional bait, burn additional fuel to avoid animals, or replace lost or damaged gear (Powell & Wells, 2011; Read, 2008; Tixier et al., 2020).

Frustration stemming from depredation and scavenging can increase the risk of angler retaliation to small cetaceans, causing another source of injury or mortality (i.e., shooting, stabbing; Department of Justice, 2006, 2007; Hayes et al., 2017; Read, 2005; U.S. v. Key, 2009; Vail, 2016; Zollet & Read, 2006).

Fisheries interactions between rod and reel fisheries and bottlenose dolphins are reported as common and increasing occurrences in the eastern U.S. Gulf of Mexico (Cunningham-Smith et al., 2006; Powell et al., 2018; Powell & Wells, 2011; Samuels & Bejder, 2004; Shippee et al., 2017). These interactions are now considered a significant challenge for anglers and resource managers, culminating with the U.S. Congress directing the National Marine Fisheries Service to review the issue (National Marine Fisheries Service [NMFS], 2022b). However, there is limited research on interactions between dolphins and rod and reel fisheries, especially in the Gulf of Mexico (Powell & Wells, 2011; Rechimont et al., 2018; Shippee et al., 2017; Zollett & Read, 2006).

There are several potential reasons for the relatively high rates of reported occurrences of depredation and scavenging by bottlenose dolphins with rod and reel fisheries in the eastern Gulf of Mexico. Overfishing can deplete fish stocks and create competition between fisheries and dolphins (Rechimont et al., 2018). Competition is likely exacerbated by declines in fish populations caused by harmful algal blooms, increased predation by invasive lionfish, climate change, and effects of the 2010 *Deepwater Horizon* oil spill (Coleman & Koenig, 2010; Green et al., 2012; Lewis et al., 2020; Powell & Wells, 2011). Another complex driver of depredation and scavenging, particularly off the Gulf coast of Florida, is the unintentional or intentional feeding of dolphins by humans, including anglers (Christiansen et al., 2016; Donaldson et al., 2010; Powell et al., 2018). Illegal feeding of dolphins (i.e., intentional food provisioning) or unintentional feeding through regulatory discards (i.e., released fish) can lead to depredation and scavenging behaviors by conditioned dolphins associating anglers and boaters with the potential opportunity for food (Christiansen et al., 2016; Donaldson et al., 2010; Powell et al., 2018; Samuels & Bejder, 2004). This conditioned behavior can be passed on to social associates and dependent calves through cultural transmission, thereby quickly spreading depredation and scavenging behaviors and increasing fisheries interactions (Christiansen et al., 2016; Herzing, 2005; Wells, 2003; Whitehead et al., 2004).

In the Gulf of Mexico, recreational rod and reel fisheries include different modes that use similar gear when fishing.

Fishing modes include fishing from either a private vessel, or from vessels in the for-hire sector, which range from small fishing charters for private parties (e.g., six passengers) to large headboats with as many as 70–90 individuals (National Research Council Ocean Studies Board, 2006; Powers & Anson, 2016). Many fish species in the Gulf of Mexico targeted by these fishers are regulated by state and federal fishery managers and have seasonal and size restrictions, and therefore must be discarded during certain seasons or if they are not of legal size. For example, red snapper, *Lutjanus campechanus*, is a coveted species in the Gulf of Mexico, with 3,459 and 2,840 metric tons landed in 2020 by commercial and recreational fishermen, respectively (NMFS, 2021). The recreational red snapper fishing season is open for approximately two to four months per year primarily between late May and early September (exact dates are adjusted annually and vary between states for private anglers), with occasional weekend openings and daily bag limits (Farmer et al., 2020; Powers & Anson, 2016). Recreational fishing trips in the Gulf of Mexico generated at least $2.76 billion in value added impacts and supported approximately 50,000 jobs in 2019, the majority of which are attributed to West Florida (NMFS, 2022a).[1]

[1] These values are based on state-level impact multipliers and do not account for interstate and interregional trading and

To better understand the occurrence of fisheries interactions between bottlenose dolphins and recreational rod and reel fisheries in the eastern Gulf of Mexico, we analyzed a large data set collected by the fisheries dependent monitoring (FDM) observer program operated by the Florida Fish and Wildlife Conservation Commission (FWCC) for for-hire fisheries. The purpose of this data set is to monitor trends in recreational fisheries throughout the state of Florida and understand how management regulations affect harvest and fishers, but it includes information on observed dolphin scavenging events. The objective of this study was to identify predictors of bottlenose dolphin scavenging for for-hire fisheries and where dolphin scavenging events most frequently occur.

2 | MATERIALS AND METHODS

2.1 | Data source

Data manipulation and analysis were completed using R 4.2.2 software (R Core Team, 2023). Our data set consisted of observations recorded by FWCC fisheries observers for the FDM program on for-hire rod and reel fishing trips between June 2009 and March 2020 along the eastern Gulf of Mexico in Florida. Each observation represents a single fish captured by an angler. For every observation, over 50 associated variables are recorded by

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the economic impacts associated with that trading; therefore, they may be considered lower bound estimates.

the observer to provide context for the conditions that gave rise to the fish being caught and released or retained by the angler. Each observation is identified by a reference number created using the date of the trip, a trip number for that date, and a unique station number, indicating where the vessel was fishing. Stations are unique to the trip and organized in chronological order from the beginning of the trip (the first station) to the end of the trip (the last station). At each station, another variable identified the order in which fish are caught. The data set is comprehensive, but there are instances where an observer did not record all fish or related variables on the trip. This was most likely to happen on large headboats, where blocked sightlines, or a large number of anglers, may prevent the observer from maintaining a complete record. Data from the years 2009 and 2020 is incomplete; as noted above, the program began in June 2009 and ended in March 2020, due to the COVID-19 pandemic.

Marine mammal scavenging was recorded as a factor under a variable that describes potential actions following release of a captured fish. This variable was only recorded after discard, so we could only analyze fishery interaction events that happened following release (i.e., scavenging). Depredation from gear by marine mammals was not included because it could not be seen directly or confirmed when it took place under the water, but scavenging was recorded when it was directly observed. The species of marine mammal involved in the observed interaction event was not recorded; however, based on information from the program director (O.A., personal observation), observed interactions were all likely bottlenose dolphins. Furthermore, bottlenose dolphins are the only species reported in this area to engage in scavenging, depredation, and begging behaviors (Balmer et al., 2019; Powell & Wells, 2011; Powell et al., 2018; Samuels & Bejder, 2004). Thus, we assumed that all marine mammal scavenging events in the data set were bottlenose dolphins. We filtered the data to remove records where fish were not discarded, duplicated records, spearfishing records, research trip records, records where Zone of fishing was unspecified, and records where fishing coordinates were located on land.

2.2 | Spatial analysis

We conducted a spatial analysis of dolphin scavenging events using ESRI's ArcGIS Pro software (ESRI Inc., 2021). Using the latitude and longitude coordinates recorded in the fishery observer data set, we computed scavenging events per observed sets within a 10 km square fishnet grid. We examined spatial patterns to identify areas with more frequent observations of bottlenose dolphin scavenging, both annually and across the sampling period (June 2009–March 2020).

2.3 | Model fitting

Covariates considered for evaluation in model fitting are described in Table 1. Fishing areas from the Florida Trip Ticket (Figure 1) were grouped into zones as indicated in Figure 1. The species of captured fish was truncated to taxonomic family to reduce the number of levels for this variable, as more than 200 fish species were recorded. We collapsed these observations to the family level, but were still left with 65 families, many with very few observations. Thus, we only included families with >1,000 observations as factors and combined the remaining 55 families into an “Other” category. Because many observed dolphin scavenging events occurred on the same trip or at the same station, these observations could not be considered independent. To address temporal autocorrelation, we created two binary lag variables to indicate whether a scavenging event had been observed previously at the station or on the trip. Several variables were excluded from the model selection approach due to multicollinearity with other variables (e.g., exclusion of variables with >70% correlation), large percentages of missing values, or preliminary analyses suggesting they were not significant predictors (Table 1).

We evaluated all potential combinations of the included variables in Table 1, including an interaction between Zone and Year, in a generalized additive modeling (GAM) framework using R package "mgcv" (Wood, 2017). We fit 1,008 total binomial models using tensor interaction splines with base spline "ts" with *k* constrained to 6 knots for computational efficiency and to avoid overfitting. We used the residual maximum likelihood method, which is best-suited to unbalanced, multiclassified data and is less prone to under-smoothing and overfitting than alternative approaches (Brown & Kempton, 1994). We ranked all models by AICc using R package "AICcmodavg" (Mazerolle, 2020). All models within two AICc points of each other were compared using ANOVA. Goodness of fit for the final model selected was verified using *gam.check* in R package "mgcv" (Wood, 2017). Odds ratios for model coefficients were generated using *tbl_regression* from R package "gtsummary" (Sjoberg et al., 2021).

3 | RESULTS

3.1 | Data summary

The observer data set contained 323,580 catch records between June 2009 and March 2020. Of these, 239 were duplicates and were removed. After eliminating spearfishing trips, research trips, trips where Zone was unspecified, trips where fishing coordinates were on land, and sets where fish were retained, we were able to evaluate 111,517 valid records of discarded fish, e.g., "released alive," "released dead," and "preyed on by sharks or barracuda (released)." Between June 2009 and March 2020, 9,293 ± 4,162 (mean ± *SD*) discards were observed per year, with the fewest observations (1,154) in the COVID-truncated sampling season of 2020 and the most observations (12,824) in 2019. On average, 28.8 ± 24.8 scavenging events were observed per year. The most scavenging events were observed in 2016 (75). In 2014, no instances of scavenging were recorded; however, observation effort was low (2,466 sets). Few sets were observed in southwest Florida until 2015 (Figure 2) and no scavenging was observed in this Zone.

Almost all (99.7%) discarded fish were released alive. A total of 345 scavenging events were observed. Of these, 276 (80%) were on fish from the family Lutjanidae, and 260 (75%) were on red snapper (*Lutjanus campechanus*). Of the 345 total scavenging events recorded, only one event was on a legal-sized fish, which was a red snapper that had been partially eaten by a shark or barracuda while reeled in.

3.2 | Spatial analysis

Most scavenging events were observed in nearshore environments (<33 km) off the Florida Panhandle, with some additional observations off the Big Bend and Tampa Bay (Figure 3). The highest number of observed scavenging events was off Panama City

Beach in 2016. The highest scavenging events per observed discard sets were off the Big Bend in 2017 and 2019. No scavenging was observed off southwest Florida; however, observational effort in this area was limited prior to 2015.

3.3 | Model fitting

Of the 1,008 models fit, six were within two AICc points of each other (Appendix S1). Four contained the covariate Depth, which had 206 missing values, and two contained Distance from Shore, which had no missing values. We selected the best model from each of these subsets using ANOVA testing, and then selected the best model as that with the greatest sample size and highest adjusted R^2 value. The final selected model was:

Scavenging(0,1) ~ (Year, by = Zone, k = 6, bs = "ts") + (Anglers, k = 6, bs = "ts") + (Discards, k = 6, bs = "ts") + (Distance from Shore, k = 6, bs = "ts") + Zone + Fish Family + Prior Scavenging at Station + Prior Scavenging on Trip

This model explained 24.5% of the deviance in the data as attributable to annual trends by Zone, number of anglers, number of discarded fish, distance from shore, Zone, family of discarded fish, and prior scavenging at the station and on the trip (Table 2, Figure 4). Odds of scavenging were highest in the Florida Panhandle (Zone PH) and Big Bend (Zone BB), followed by

Tampa Bay (Zone TB) (Table 3). Although the odds of scavenging were about half in Tampa Bay (0.47, 95% CI [0.22, 0.99]) relative to the Big Bend, the model indicated an increasing trend in scavenging events through time for both Zones, with a flat trend in the Florida Panhandle and no trend in Zone SWFL, where no scavenging was observed (Figure 4). The probability of observing a scavenging event increased almost linearly with an increasing number of anglers (Figure 4). The relationship between the probability of observing a scavenging event and the number of fish discarded was less clear; scavenging activity was highest with the first few discards, then decreased, then rose again at high levels of discards (Figure 4). A decreasing trend in scavenging events was noted with an increasing distance from shore (Figure 4). The odds of scavenging were significantly higher with prior observations of scavenging at station (10.6, 95% CI [6.96, 16.3] and on the trip (3.89, 95% CI [2.58, 5.87] (Table 3). Although Lutjanidae only represented 40% of discarded fish, they represented 80% of scavenging events. The model noted the highest scavenging on discarded Lutjanidae, followed by Carangidae, then Serranidae (Figure 4). Relative to Balistidae, odds of scavenging on Lutjanidae were 8.09, 95% CI [4.51, 14.5] times higher; odds of scavenging on Carangidae were 6.37, 95% CI [2.91, 14.0] times higher; and odds of scavenging on Serranidae were 3.75, 95% CI [1.72, 8.16] times higher.

4 | DISCUSSION

Our analysis shows that observed dolphin scavenging occurs most frequently in the coastal waters of the Florida Panhandle, but this behavior is now increasing off Florida's Big Bend and in Tampa Bay. Dolphins in the Florida Panhandle engaging in scavenging behaviors (Figure 3) most likely belong to the Gulf of Mexico Northern Coastal stock and the Northern Gulf of Mexico Continental Shelf stock (Hayes et al., 2022). Individual dolphins engaging in scavenging behaviors offshore of the Tampa Bay area and shoreward of the 20 m isobath (Figure 3) most likely belong to the Gulf of Mexico Eastern Coastal Stock (Hayes et al., 2022). Dolphins in the Big Bend Zone contain animals from both the Northern and Eastern Coastal stocks (Hayes et al., 2022). There is no evidence to support that scavenging is occurring because of growing dolphin populations. The Northern Coastal stock experienced an unusual mortality event[2] of unprecedented size and duration from 2010 to 2014, and this stock also is estimated to have experienced a maximum reduction of 50% from the 2010 *Deepwater Horizon* oil spill (DWH MMIQT, 2015; Hayes et al., 2022; Schwacke et al., 2017). The

[2] Under the United States Marine Mammal Protection Act, an unusual mortality event is defined as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response."

Continental Shelf stock was not impacted as severely but was also estimated to decline by a maximum of 3% from the 2010 *Deepwater Horizon* oil spill (DWH MMIQT, 2015). The Eastern Coastal stock was not thought to be impacted by the *Deepwater Horizon* oil spill, but this stock has experienced multiple unusual mortality events in the past two decades (Hayes et al., 2022; Litz et al., 2014).

The odds of observing scavenging were nearly double in the Florida Panhandle and Big Bend relative to Tampa Bay. Notably, our findings link observed bottlenose dolphin scavenging to areas with documented chronic high levels of food provisioning in the Florida Panhandle over the duration of data collection (March 2009–June 2020). Supplemental analysis suggested the model-estimated higher probability of scavenging events closer to shore was driven by the Panhandle and Big Bend Zones (Figure S1). Dolphins inhabiting waters off the Florida panhandle (particularly the Northern Coastal stock) are frequently involved in illegal feeding (Balmer et al., 2019; Powell et al., 2018). Wild dolphins in these coastal areas have been provisioned since at least the 1980s and it is a well-known area for chronic feeding and harassment (NMFS, 1994; Powell et al., 2018; Samuels & Bejder, 2004). Dolphins off Panama City Beach, Florida, are targeted for provisioning and swim-with programs by recreational boaters, fishermen, and tourism ventures (Balmer et al., 2019; Powell et al., 2018; Samuels & Bejder, 2004). This has resulted in a concentrated number of highly conditioned dolphins in this nearshore area and likely explains the significant decreasing trend in scavenging events with increasing distance from shore (Balmer et al., 2019; Christiansen et al., 2016; Donaldson et al., 2010; Powell et al., 2018).

Conditioned dolphins engage in fishery interaction behaviors more often than dolphins that are not fed (Christiansen et al., 2016; Donaldson et al., 2010; Powell et al., 2018). In addition to the illegal provisioning of dolphins that commonly occurs in the eastern Gulf of Mexico, unintentional provisioning of conditioned dolphins sometimes occurs. Anglers must also follow state and federal fishery regulations that require them to release undersized or out-of-season fish near dolphins. This is not illegal, but it can reinforce dolphins' association with fishing boats and feeding opportunities in the same way as when they are illegally provisioned. Any successful provisioning because of unintentional or intentional feeding by rod and reel anglers perpetuates the association between dolphins and fishing gear, thereby reinforcing fishery interaction behaviors. Powell et al.

(2018) witnessed two known conditioned dolphins attempting to depredate captured fish from recreational anglers in Panama City, confirming the linkage between food provisioning and fisheries interactions in this area. Knowledge transfer between conspecifics and the plasticity of foraging behavior by bottlenose dolphins may facilitate the spread of foraging tactics associated with human and fishery interaction behaviors, such as provisioning, depredation, and scavenging, within the Northern Coastal stock and to adjacent populations, including the Eastern Gulf of Mexico Coastal Continental Shelf and Bays, Sounds, and Estuarine stocks (Mann & Sergeant, 2003; Nowacek, 2002; Torres & Read, 2009; Weiss, 2006; Wells, 2003; Whitehead et al., 2004). Although to a lesser extent than the Panhandle, illegal feeding of wild dolphins and unintentional provisioning from released and discarded fish also occurs around Tampa Bay, contributing to the increasing frequency of scavenging in this Zone and by the Eastern Coastal Stock (Christiansen et al. 2016; Cunningham-Smith et al., 2006; Powell & Wells, 2011). No scavenging events were observed in the southwest Florida Zone despite documented illegal feeding, fishery interactions, and retaliation within portions of this area reported though other sources (NMFS, 2022b); however, this Zone had a significantly shorter observed time series (2015–2020; see Figure 2) and accounted for only 10% of the observed sets across all Zones. Furthermore, reports of illegal feeding and fishery interactions between bottlenose dolphins and rod and reel gear primarily occur within the inshore bay waters which were not observed. Continued monitoring of this area for an increase in scavenging, including placing observers on inshore trips, is recommended.

Only 40% of discards were species in the Lutjanidae (snapper) family, but they represented 80% of observed scavenging events, and the odds of a dolphin scavenging on a Lutjanid were eight times higher than on a Balistid (triggerfish), likely indicating a preference for snappers. This is consistent with reports from anglers (J.R.P., personal observation). The 80% value is a minimum observed scavenging frequency because it does not account for the additional fish directly depredated from hooks or fish scavenged at a depth out of the observer's sight. The vast majority (94%) of Lutjanid scavenging events (75% of all scavenging events) were on red snapper, which are highly prized by anglers (Farmer et al., 2020). Red snapper harvest is closely managed by both state and federal regulations[3] that require fish to be discarded if they are smaller than the legal size or caught outside of seasonal

[3] Summary of current regulations as of January 6, 2023, can be accessed at https://gulfcouncil.org/fishing-regulations/red-snapper-lutjanus-campechanus

restrictions, creating frequent opportunities for dolphin scavenging from such regulatory discards. Indeed, all but one scavenging event was on a regulatory discard.

The relationship between number of anglers and number of discards relative to the probability of observing a scavenging event in our analysis (see Figure 3) suggests that dolphins may be more attracted to the amount of fishing activity rather than the number of fish released. Number of anglers and number of discards were not strongly correlated. The linear relationship between scavenging probability and number of anglers may indicate dolphins are cuing on fishing lines and related fishing activity in the water and/or the different sounds of the vessels' engines. Dolphins may also be alerted to the different sounds of low-frequency inboard engines of high-capacity headboats versus the higher frequency sounds of smaller charter boats with outboard engines. In other areas of the southeastern U.S., dolphins have been observed to initiate fishery interactions when a fish is caught and/or gear is hauled and sorted (Cox et al., 2003; Greenman & McFee, 2014; Noke & Odell, 2002; Zollett & Read, 2006). Other studies have documented bottlenose dolphins associating commercial fishing boat activity, including various sounds of differing fishing activity and boat engine sounds, with a food source (Fertl & Leatherwood, 1997; Noke & Odell, 2002). Regardless of what the dolphins are cueing on, it is clear that regulatory discards of snapper are disproportionately impacted. These released fish provide a low-cost foraging opportunity, but bring dolphins closer to boats where injury risk from boat strike and fishing gear entanglement is increased (Christiansen et al., 2016; Donaldson et al., 2010; Wells & Scott, 1997).

Interactions between bottlenose dolphins and gear or catch can become frustrating for anglers, and has led to retaliatory acts resulting in serious injuries and mortalities to dolphins (Department of Justice, 2006, 2007; Shippee et al. 2017; U.S. v. Key, 2009; Vail, 2016). The Department of Justice has prosecuted three fishermen for acts of retaliation against dolphins depredating from hook and line gear in the Gulf of Mexico (Department of Justice, 2006, 2007; U.S. v. Key, 2009). Two cases involved charter boat captains shooting at dolphins with guns; one out of Orange Beach, Alabama, and one out of Panama City, Florida (Department of Justice, 2006, 2007). The third case involved a commercial reef fish fisherman out of Panama City, Florida who was sentenced and convicted for making and throwing pipe bombs at bottlenose dolphins to deter them from his gear in the eastern Gulf of Mexico (U.S. v. Key, 2009; Vail, 2016). Continued fishery interactions in the Florida panhandle and Zones with emerging increases (Big Bend and Tampa Bay) may exacerbate growing frustration by anglers, further highlighting the need for safe mitigation techniques to reduce interaction frequencies.

Safe mitigation techniques are desired by both anglers and resource managers to reduce incidents of human and fisheries interactions and resulting impacts to dolphins and anglers. Currently, avoidance is the best method to reduce dolphin scavenging and depredation behaviors in the Gulf of Mexico although inconvenient and often impractical (Fader et al., 2021; U.S. Federal Register, 2020; Werner et al., 2015). Avoidance involves fishermen voluntarily relocating to a different fishing location where dolphins are not present and is the safest method for preventing death or serious injury to marine mammals (Fader et al., 2021; Werner et al., 2015). Our analysis suggested the odds of continued scavenging are reduced four-fold by moving locations; thus, moving, and potentially waiting or moving a fair distance, might be an effective mitigation technique to reduce scavenging. In addition, scavenging decreased with increased distance from shore, suggesting that fishermen could move further offshore to reduce the probability of scavenging by dolphins. The distances fishermen move to avoid interactions with dolphins varies (with anecdotal reports of up to 25 km) across the Gulf of Mexico. Relocating is particularly challenging for charter vessels and headboats who have paying customers, lose fishing time, and incur increased fuel costs to move the boat to a new location, especially if that location is further from shore (Tixier et al., 2020).

Deterrents and gear modifications have been attempted to reduce marine mammal bycatch and depredation in other fisheries with varying success (Cox et al., 2003; Dawson et al., 2013; Hamer et al., 2015; McPherson, 2011; Shippee et al., 2017; Tixier et al., 2020; Werner et al. 2015; Zollett & Read, 2006; 50 CFR §229.35). Acoustic deterrent devices (also known as pingers) are designed to reduce the risk of entanglement or depredation and scavenging by dissuading dolphins away from areas of active fishing gear. However, Read and Waples (2010) found acoustic devices to be ineffective at reducing bottlenose dolphin depredation in gill nets and saw many instances of depredation in both nets with and without active pingers, including two instances of dolphins entangled while depredating a pinging gillnet. This indicates that dolphins' motivation for obtaining food using a low-cost foraging technique may outweigh the dissuasive effect of the sound stimulus. It may also create a "dinner bell effect" in which bottlenose dolphins use the sound to locate potential foraging opportunities thus increasing depredation and scavenging occurrences rather than deterring them as intended (Cox et al., 2003; Dawson et al., 2013; Read & Waples, 2010). Some anglers in the northern Gulf of Mexico reported trying acoustic devices to deter dolphins from their gear but indicated the devices were not effective at preventing scavenging or depredation. Several anglers have resorted to turning off depth sounders when fishing in areas with high occurrences of dolphin scavenging and depredation behaviors to further reduce potential "dinner bell" effects (J.R.P., personal observation).

Reducing barotrauma in reef fish after capture is another potential means for mitigating dolphin scavenging. Specifically, venting fish to assist in their return to depth by deflating the swim bladder or the use of descending devices so the fish can easily return to depth rather than erratically swimming at the surface (Ayala, 2020; Curtis et al., 2019; Drumhiller et al., 2014; Pulver, 2017; Shippee et al., 2017). However, there are anecdotal reports from anglers suggesting that bottlenose dolphins learn to depredate fish from descending devices over time (J.R.P., personal observation). Preliminary analyses indicated venting was not a predictor for scavenging behavior in this study potentially because discarded fish, regardless of venting status, are disoriented and far from natural cover upon release making them especially susceptible to predators like dolphins.

Gear modifications for rod and reel gear are one promising method of mitigation that has not yet been fully explored as a safe and effective option for long-term use. Gear modifications can be successful at reducing dolphin bycatch associated with depredation in other commercial fisheries (e.g., crab pot/trap gear; Virginia pound net gear; Noke & Odell, 2002; Schaffler et al. 2011; U.S. Federal Register, 2014). A gear modification in the Florida king mackerel commercial troll fishery (hook and line gear) was preliminarily successful at deterring bottlenose dolphins from depredating without reducing catch (Zollett & Read, 2006). Partnerships with private and for-hire anglers to develop and test gear mitigation options for reducing depredation and scavenging are needed to address this issue. This paradigm has been successful to improve other fishing practices (e.g., https://returnemright.org/). Gear modifications often create an additional, upfront economic cost for anglers and so may be initially unpopular but potentially successful over the long run. If anglers recoup upfront costs and modifications prove successful, this mitigation will likely gain support (Dawson et al., 2013; Fader et al., 2021; Hamer et al., 2015; Werner et al., 2015).

Understanding the scope and scale of fishery interactions between bottlenose dolphins and anglers is critical given they result in economic consequences to anglers and increased risk of serious injury or mortality from hooking, entanglement, vessel strikes and retaliatory acts for dolphins. This complex management issue is increasingly challenging based on the long-standing nature of human interactions with bottlenose dolphins coupled with dolphins' highly adaptable behavior and ability to teach behaviors to conspecifics, environmental changes, and the interplay with fishery stock management regulations in the Gulf of Mexico. The results of our study can be used to guide future efforts by resource managers to reduce fisheries interactions between rod and reel anglers and bottlenose dolphins. We provide insights on locations with increased frequency of scavenging and frequently scavenged fish species, as well as scavenging predictors like distance to shore and number of anglers onboard. Future expansions of this work could include data from private anglers or commercial fishermen as well as other regions within the Gulf coast for a holistic view of scavenging in the Gulf of Mexico. Observer coverage in this data set was limited to coastal waters of the eastern Gulf, warranting the expansion of data collection across a finer spatial scale at popular fishing areas inshore in Florida's bay and estuarine waters. Our study focused on scavenging because it was a recorded variable in the observer data set, but determining regional trends for depredation would also advance understanding and mitigation of bottlenose dolphin fishery interactions. Further research and partnerships involving resource managers, anglers, and academia are needed to identify potential deterrent techniques or fishing practice or gear modifications that are successful at safely and effectively mitigating dolphin and fisheries interactions. Overall, our study provides a framework that highlights how data sets collected for fisheries management purposes can also be utilized to provide valuable information for marine mammal conservation and management efforts, which may be useful for addressing fisheries interactions with small cetaceans across the globe.

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TABLE 1 Covariates considered for evaluation in model-fitting.

Variable	Type	Description	Included in model-fitting?
Discards	Numeric	Number of discards at station (incremented by one for each fish released back into the water, dead or alive)	Yes
Anglers	Numeric	Number of anglers on vessel (may include captain and crew)	Yes
Distance from Shore	Numeric	Distance (km) from US shoreline, computed using function *st_distance* from "sf" package in R (Pebesma, 2018)	Yes
Depth	Numeric	Bathymetric depth (m) recorded by observer at station	Yes
Year	Numeric	Year of fishing	Yes
Zone	Factor	Location of fishing (PH: Panhandle; BB: Big Bend; TB: Tampa Bay; SW: Southwest Florida)	Yes
Fish Family	Factor	Grouped fish species into five families (Balistidae, Carangidae, Lutjanidae, Serranidae, and Other)	Yes
Prior Scavenging at Station	Factor	"1" for all discard records after the first scavenging event at station	Yes
Prior Scavenging on Trip	Factor	"1" for all discard records after the first scavenging event on trip	Yes
Fishing Mode	Factor	Anchored fishing, drift fishing, trolling, and holding (e.g., idling)	No; preliminary model-fitting indicated not significant
Bottom Type	Factor	Natural reefs, artificial reefs, flat bottom, and unknown	No; preliminary model-fitting indicated not significant
Venting Type	Factor	"1" for fish vented prior to release	No; preliminary model-fitting indicated not significant; 1685

			incomplete records including 5 during scavenging events
Fork Length	Numeric	Fork length (cm) of released fish	No; preliminary model-fitting suggested not significant; 11,155 incomplete records including 75 during scavenging events
Catch	Numeric	Number of fish caught at station (incremented by one for each fish caught in sequence)	No; failed multicollinearity check with “Discards” (72% correlated)
Release Condition	Factor	Whether fish was alive or dead on release	No; preliminary model-fitting suggested not significant

TABLE 2 Coefficients for best-fitting predictive model.

Parametric coefficients:				
Parameter	**Estimate**	***SE***	***Z***	**Pr(>|*z*|)**
(Intercept)	−8.42E+00	4.37E-01	−19.263	<2.00E-16***
Zone: PH	4.61E-01	3.43E-01	1.344	0.178836
Zone: SW	−4.77E+01	6.58E+05	0	0.999942
Zone: TB	−7.52E-01	3.80E-01	−1.979	0.047814*
Fish Family: Carangidae	1.85E+00	4.00E-01	4.625	3.75E-06***
Fish Family: Lutjanidae	2.09E+00	2.98E-01	7.016	2.28E-12***
Fish Family: Other	3.95E-01	7.88E-01	0.502	0.615774
Fish Family: Serranidae	1.32E+00	3.97E-01	3.33	0.000868***
Prior Scavenging at Station	2.36E+00	2.17E-01	10.913	<2.00E-16***
Prior Scavenging on Trip	1.36E+00	2.10E-01	6.468	9.95E-11***
Approximate significance of smooth terms:				
Term	**Edf**	**Ref. *df***	χ^2	***p***
Year by Zone: BB	1.01E+00	5	13.338	0.000173***
Year by Zone: PH	1.54E-03	5	0	0.757502
Year by Zone: SW	1.95E-12	5	0	1
Year by Zone: TB	9.00E-01	5	6.338	0.007013**
Anglers	1.02E+00	5	43.75	<2.00E-16***
Discards	1.97E+00	5	27.464	7.45E-07***
Distance from Shore	8.56E-01	5	4.736	0.017475*

*p < .05. **p < .01. ***p < .001.

TABLE 3 Odds ratios for model coefficients.

Characteristic	**Odds ratio**	**95% CI**	***p***
Zone			
BB	—	—	
PH	1.59	0.81, 3.11	.2
SW	0.00	0.00, Inf	>.9
TB	0.47	0.22, 0.99	.048
Fish Family			
Balistidae	—	—	
Carangidae	6.37	2.91, 14.0	<.001
Lutjanidae	8.09	4.51, 14.5	<.001
Other	1.48	0.32, 6.95	.6
Serranidae	3.75	1.72, 8.16	<.001
Prior scavenging at			
0	—	—	
1	10.6	6.96, 16.3	<.001
Prior scavenging on trip			
0	—	—	
1	3.89	2.58, 5.87	<.001

FIGURE 1 Florida Fish and Wildlife Conservation Commission (FWCC) Trip Ticket fishing area code map, provided by the Florida FWCC. Area codes were used to examine the relationship between geographic location and bottlenose dolphin scavenging events observed by the fisheries dependent monitoring observer program operated by the Florida FWCC. Each coded area is between latitude and longitude lines. For analysis, areas were grouped into Zones as follows: areas 2–4 coded as southwest Florida (SW), area 5 coded as Tampa Bay (TB); areas 6–7 coded as Big Bend (BB); and areas 8–10 coded as Panhandle (PH).

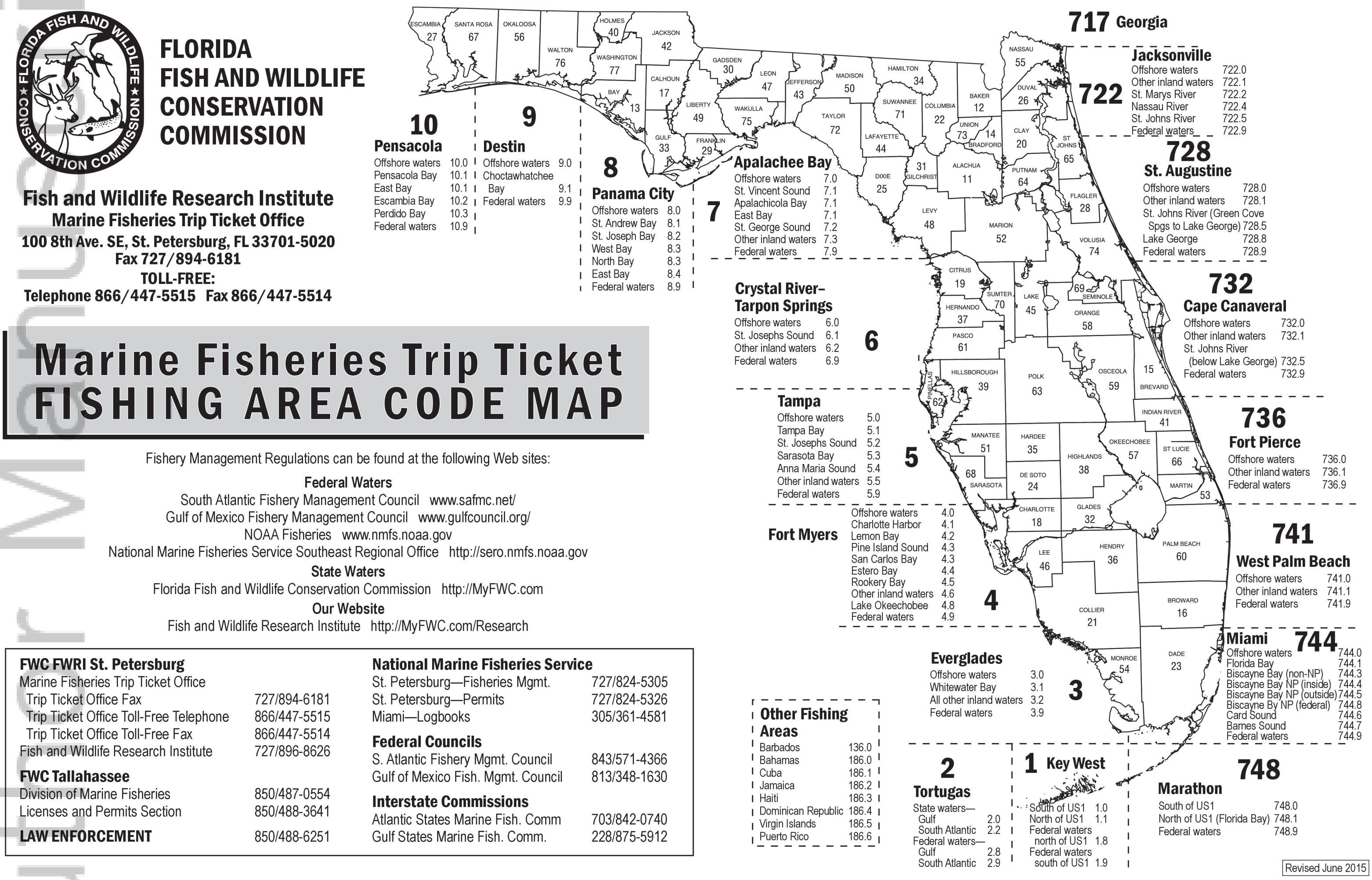
FIGURE 2 Observed discards, by year and Zone on for-hire fishing trips in the eastern U.S. Gulf of Mexico. Zone codes – BB: Big Bend; PH: Florida Panhandle; TB: Tampa Bay; and SW: Southwest Florida.

FIGURE 3 Frequency of scavenging events by bottlenose dolphins relative per observed sets on eastern U.S. Gulf of Mexico for-hire trips June 2009–March 2020. Observed scavenging events and discard sets were counted within a 10 km^2 fishnet grid. Warmer colors indicate a greater frequency of observed scavenging by bottlenose dolphins; white cells denote areas with observation effort but no scavenging events. Coastal bathymetry is shown in grayscale, with light blue line denoting 20 m bathymetric contour used to delineate coastal versus oceanic stocks of bottlenose dolphins. Black polygons denote "Zone" codes used in analysis (BB: Big Bend; PH: Florida Panhandle; TB: Tampa Bay; and SW: Southwest Florida).

FIGURE 4 Predictive covariates for dolphin scavenging. Final selected GAM model smoothed parametric and term plots for covariates predicting dolphin scavenging events on observed for-hire fishing trips in the eastern U.S. Gulf of Mexico (Zone codes denote BB: Big Bend; PH: Florida Panhandle; TB: Tampa Bay; and SW: Southwest Florida).

Appendix S1. Model specifications and AIC.

Figure S1. Predictive covariates for dolphin scavenging. Smoothed parametric and term plots for covariates in the expanded version of the final selected GAM model, incorporating interaction between distance from shore (km) and Zone fished. Model predicts dolphin scavenging events on observed for-hire fishing trips in the eastern U.S. Gulf of Mexico (Zone codes denote BB: Big Bend; PH: Florida Panhandle; TB: Tampa Bay; and SW: Southwest Florida).



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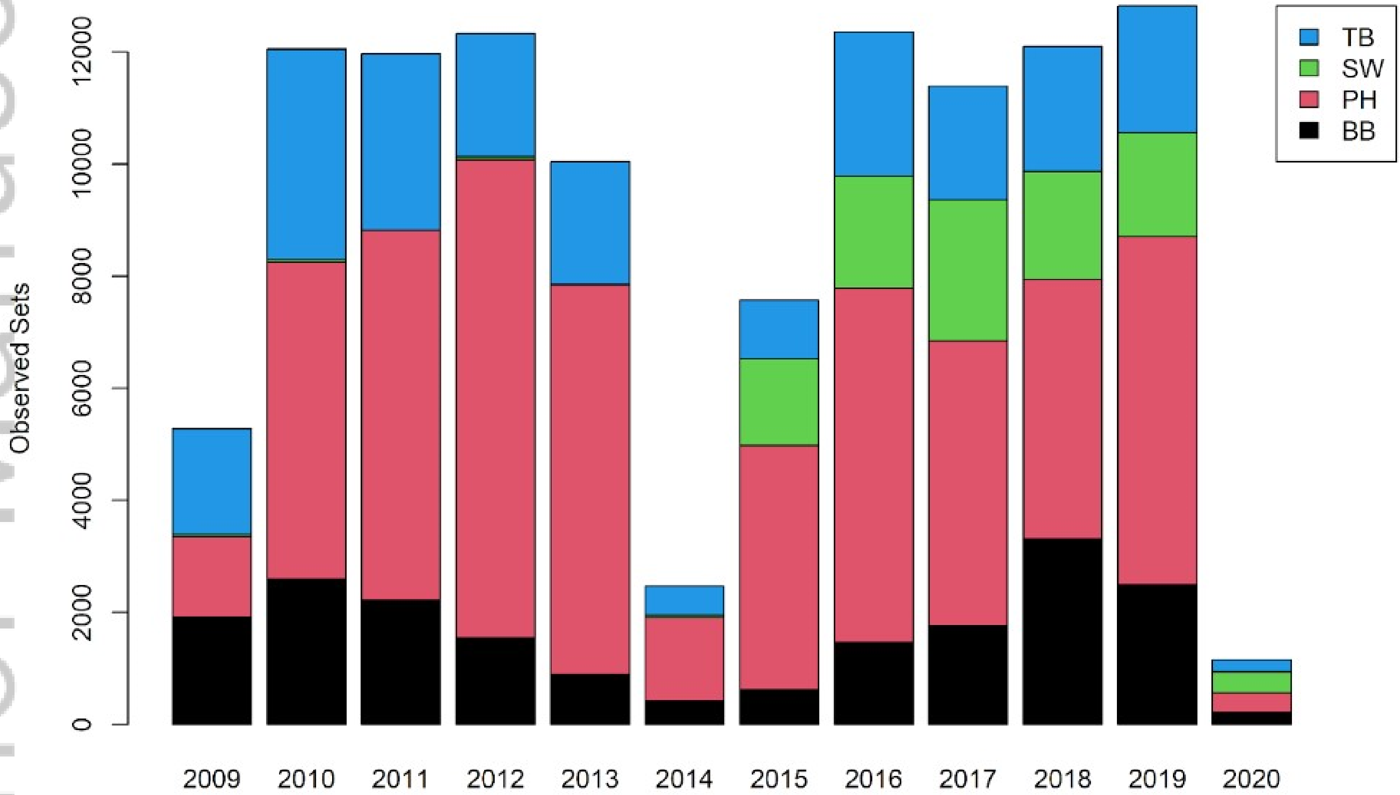

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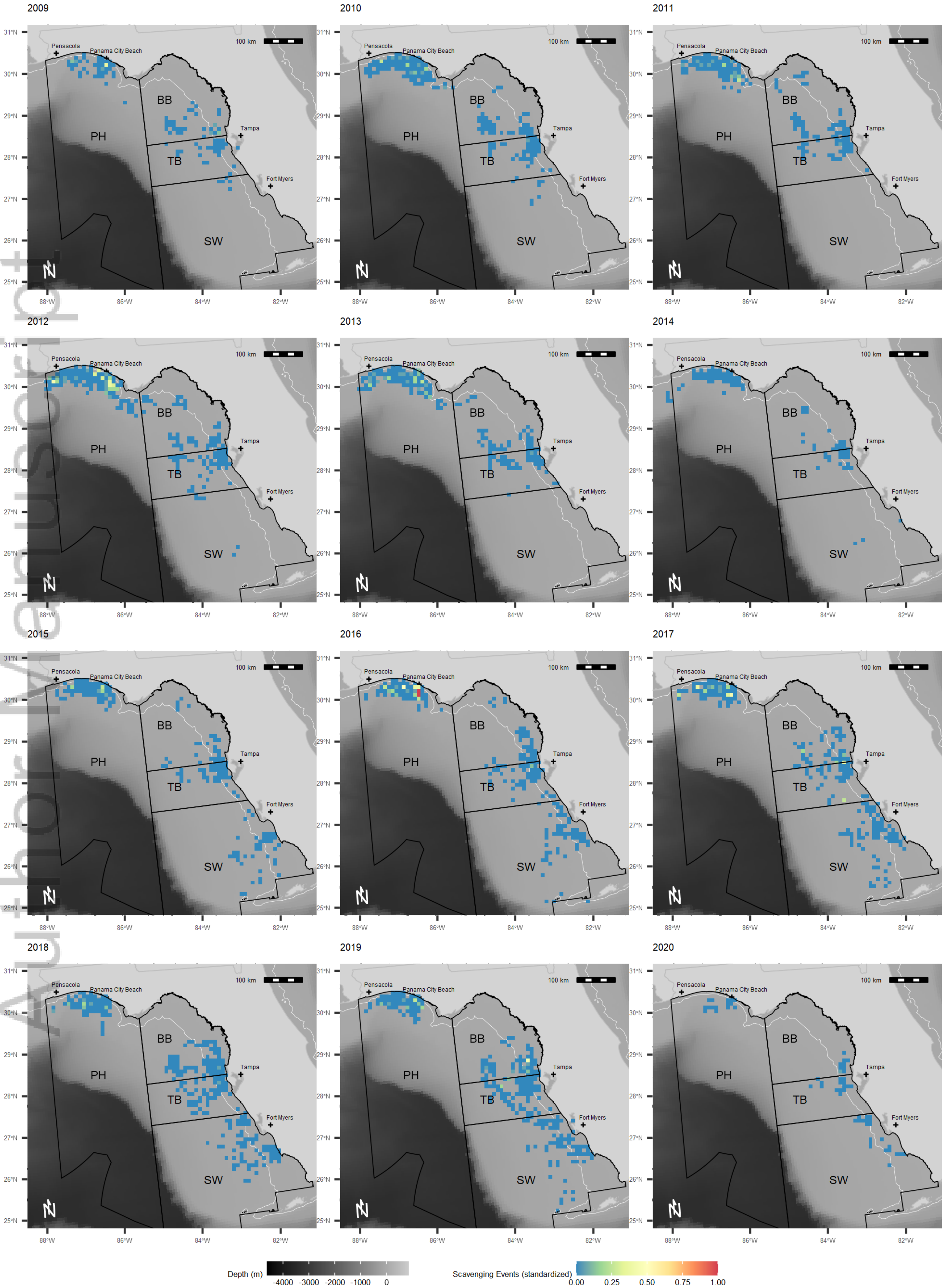
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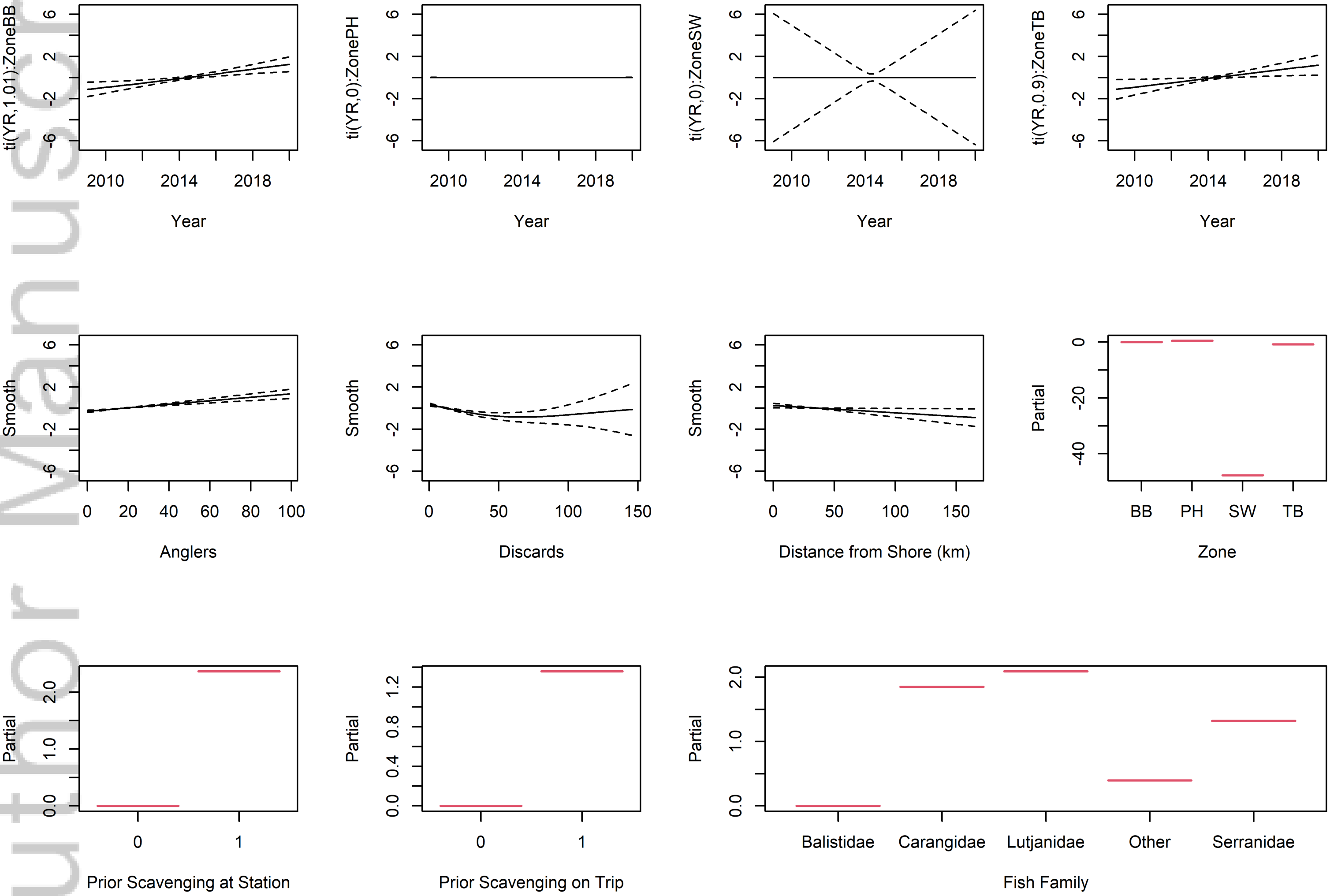
28°N
27°N
26°N
25°N
88°W
86°W
84°W
82°W
Depth (m)
-4000 -3000 -2000 -1000 0
Scavenging Events (standardized)
0.00 0.25 0.50 0.75 1.00



MMS_13030_5351_Fig4.png