A characterisation of common bottlenose dolphin (*Tursiops truncatus*) interactions with the commercial shrimp trawl fishery of South Carolina, USA

Justin T. Greenman[1] and Wayne E. McFee[2]

Contact e-mail: Justin.Greenman@noaa.gov

ABSTRACT

In the United States, interactions between the shrimp trawl fishery and bottlenose dolphins are known to exist; however, the level of mortality is largely unknown, and has not been studied in South Carolina, USA. The current study attempted to determine if interactions between bottlenose dolphins and the South Carolina commercial shrimp trawl fishery pose a significant threat to dolphin populations and if fishery related mortality is underreported. Onboard observations were made during a 25 day (August–December 2010) field study. No dolphin takes occurred during the observational period. These observations focused on direct physical interactions with the gear and depredation behaviours. Additionally, a sub-sample of the shrimp fishery in South Carolina was asked to participate in a mailed survey. The survey included questions related to gear, dolphin observations, and the status of the shrimp fishery. This paper also examines historical dolphin stranding data from the NOAA/CCEHBR MMIS database for signs of shrimp fishery interactions. A three-tiered flow diagram was developed to characterise each stranding case according to the likelihood that mortality resulted from trawler interaction. Field results point to significant dolphin presence around commercial trawlers ($x^2 = 23.406$, $p < 0.001$). Survey results showed 12 unreported incidents of shrimp trawl fishery mortality of dolphins. Finally, stranding records revealed several more cases with signs of possible trawler interaction. The current US National Marine Fisheries Service (NOAA) designation of the fishery as a Category II fishery is correct. Increased observer coverage and improved communication with the fishery on the importance of reporting takes is warranted.

KEYWORDS: COMMON BOTTLENOSE DOLPHIN; FISHERIES; INCIDENTAL CATCHES; TRAWLS; STRANDINGS; CONSERVATION; MANAGEMENT PROCEDURE

INTRODUCTION

Although not previously studied in South Carolina, interactions between bottlenose dolphins (*Tursiops truncatus*) and trawl fisheries are well documented in other parts of the United States and around the world (Fertl and Leatherwood, 1997; Zollett, 2005). Previous research has focused on social structure (e.g. Chilvers and Corkeron, 2001; Fleming, 2004; Scheinin, 2010), feeding behaviours (e.g. Broadhurst, 1998; Corkeron *et al.*, 1990; Gonzalvo *et al.*, 2008; Svane, 2005), and mortality from bycatch (e.g. Dans *et al.*, 2003; Fortuna *et al.*, 2010; Zeeberg *et al.*, 2006). The current study investigated all of these topics to characterise the interaction between trawl fisheries and bottlenose dolphins in South Carolina.

Previous stranding record studies have shown that the crab pot fishery is the most common source of fishery related mortality of dolphins in South Carolina (Burdett *et al.*, 2007; Burdett and McFee, 2004; McFee and Hopkins-Murphy, 2002; McFee and Lipscomb, 2009; Sturgeon, 2010). Burdett and McFee (2004) noted that many dolphins stranded dead without gear attached to the body but still exhibited line wounds. Some of these animals, however, presented wounds that were larger in diameter than crab pot line wounds, raising the suspicion that they were caused by some other source, potentially the shrimp trawl fishery. In addition to direct signs of fishery interaction (e.g. rope or net marks and gear attachment), stranding records can reveal other signs of fishery related mortality. For instance, dolphins that die as a result of entanglement often appear to be robust and otherwise healthy at their time of death, but necropsies can reveal sub-dermal haemorrhaging, froth in the lungs and bronchi, and undigested fish and shrimp in the stomach. Dolphins that die from chronic illness or disease often have difficulty feeding and as a result usually have relatively empty stomachs (Pate and McFee, 2012).

The US shrimp harvest in 2010 exceeded 250 million pounds (about 114,000 tonnes) and yielded over 400 million US dollars in revenue (NMFS, 2011). Although the South Carolina shrimp harvest contributes only a small portion (approximately 0.8% or 2 million pounds per year) of the total US domestic shrimp production, it is the largest and most economically valuable commercial fishery in South Carolina. It averages just over 400 trawl licenses per year, about two-thirds of which are held by residents of South Carolina (Julia Byrd, SCDNR, pers. comm.; SCDNR, 2007). The exact opening and closing dates for this fishery are decided annually by the South Carolina Department of Natural Resources (SCDNR), but the season generally runs from May/June to December/early January. Trawling is restricted to daylight hours and to oceanic and lower sound and bay areas. Most trawling occurs at depths of 5–15m (SCDNR, 2007), but may vary depending on the bottom structure and where shrimp are being found.

Although they range in size and shape, the basic bottom-trawl shrimping set up used in South Carolina involves 1–4 nets towed along the seafloor (Fig. 1). The mouth of each net is stretched apart by two ‘doors’, one attached to either side of the net. In four-net configurations, each side (port and

[1] *The Graduate School, College of Charleston, 66 George Street, Charleston, SC 29424, USA.*
[2] *NOAA/NOS/NCCOS/Center for Coastal Environmental Health and Biomolecular Research, 219 Ft Johnson Rd, Charleston, SC 29412, USA.*

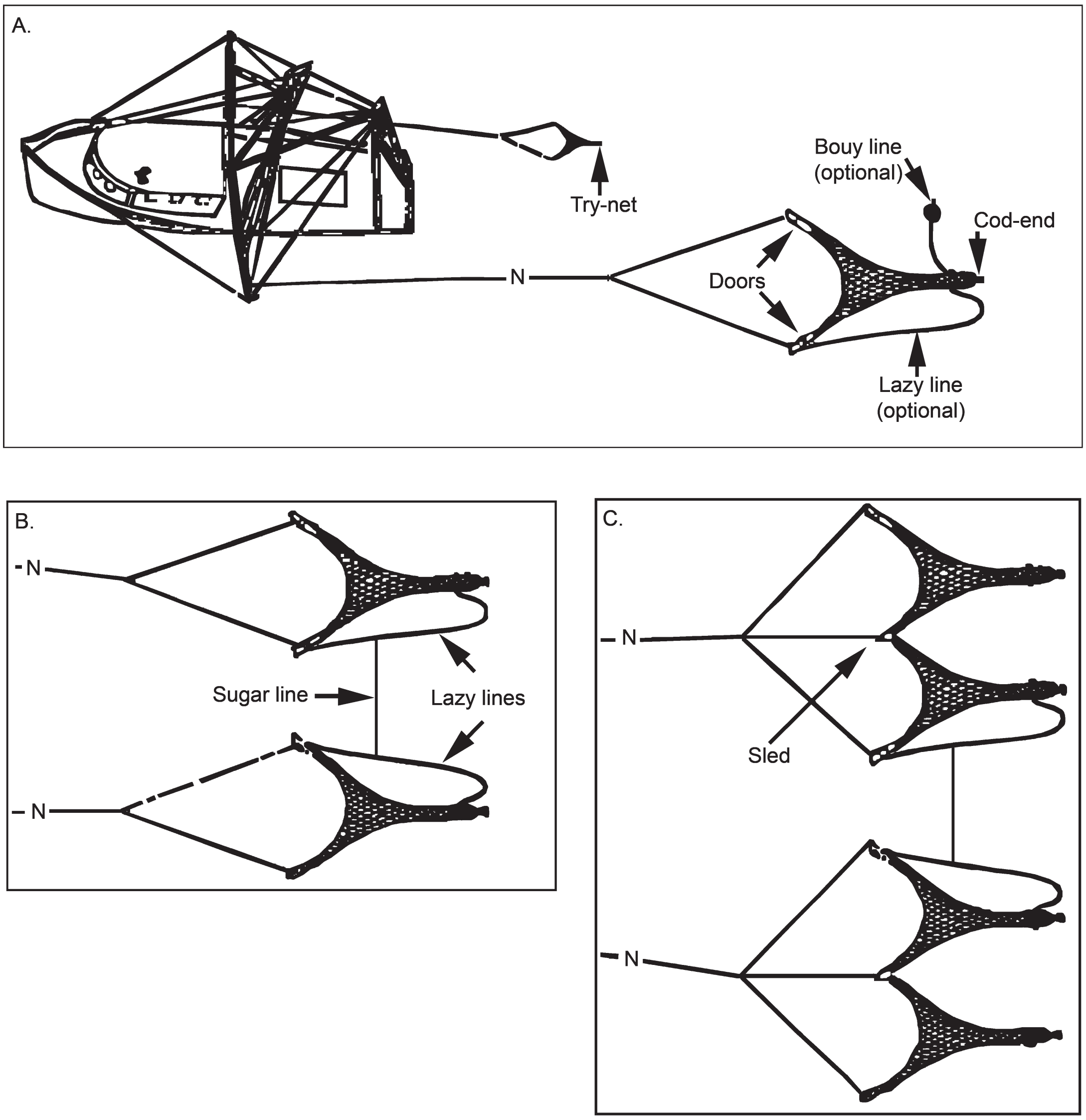

Fig. 1. Three common trawl net configurations. A: Single Net; B: Two-Net; C: Four Net. Modified from: US Bureau of Commercial Fisheries (Kristjonsson, 1967). [Available at: *www.fao.org/docrep/005/ac740t/AC740T05.htm*].

starboard) has two nets. Each pair of nets is connected by a steel 'sled' which is attached between the two nets. A float-line on the top of the net's mouth keeps the net from collapsing vertically. A weighted bottom line keeps the net close to the bottom, while a tickler chain acts to disturb the sediment and force organisms into the net and ultimately to the posterior, or 'cod-end', of the net. Some vessels attach additional mesh and/or chafing gear around the posterior end of the net to protect the cod-end from wear. Attached to most nets is a 'lazy' line which is connected to the door lines and aids in pulling in the nets. When a vessel has more than one lazy line, it may use a 'sugar' line to connect the two lazy lines, allowing both lines to be retrieved at once. Some smaller vessels may also attach an optional buoy line to the net to aid in retrieval. In addition, some trawlers drag a small 'try-net' during the normal tow and retrieve it frequently to assess the shrimp catch.

Each year, in accordance with the US Marine Mammal Protection Act (MMPA) of 1972, the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) produces its annual List of Fisheries (LOF), which classifies the level of incidental serious injury and mortality of marine mammals occurring in each of the nation's fisheries (NOAA, 2011). Classifications are determined using the Potential Biological Removal (PBR) approach, which is used to estimate the number of individuals that may be removed (i.e. serious injury or mortality) from a stock without adversely affecting the optimum sustainable 'population' (OSP) (NOAA, 2011). The concept of OSP is such that it represents a population size that maximises reproductive potential while staying within the constraints of an area's carrying capacity (NOAA, 2011). NOAA currently uses three classes to describe US fisheries based on the percent of PBR a fishery is responsible for taking. Fisheries that are responsible for taking a significant percentage (i.e. >1% of PBR per year over a consecutive five year period) are classified as either Category I (≥50% of PBR) or Category II (between 1% and 50% of PBR). Due to the relatively high incidence of marine mammal mortality, fisheries in these two categories are subject to several regulations meant to monitor and mitigate the likelihood of fishery interactions. In addition, these fisheries are required to accommodate a marine mammal observer onboard their vessel, if NMFS requests one.

Category I and II fisheries are also required to follow any applicable take reduction plans developed by NMFS.

If a fishery is responsible for removing less than 1% of PBR per year over a given five year period, it is classified as a Category III fishery. These fisheries are estimated not to pose a major threat to marine mammal populations and are therefore subject to little regulation. Up until 2010, the Southeastern US Atlantic and Gulf of Mexico shrimp trawl fishery, of which the South Carolina fishery is a member, was classified as a Category III fishery. The 2011 LOF however, reclassified the fishery as a Category II fishery, in part due to two reported shrimp trawl fishery entanglement cases from South Carolina, one that was entangled in a buoy-line attached to the cod end of a net in 2002 and one that was brought up dead in a trawl net in 1998 (NOAA, 2010). In addition, from 2006–2012, the SCDNR research vessel '*Lady Lisa*' caught three dolphins (two in SC, one in North Carolina) in their net during scientific trawling operations.

In South Carolina, coastal dolphins are managed as the South Carolina/Georgia Coastal Stock (SCGCS), (Waring *et al.,* 2012). This stock inhabits the same waters commonly used by shrimp trawlers; therefore it is believed that this stock is the most impacted by the shrimp trawl fishery. The current minimum population estimate for the SCGCS is about 6,300 individuals and it has a PBR of 64 (Waring *et al.*, 2012). Thus, 1% PBR would be 0.64 dolphins and 50% PBR would be 32 dolphins. Therefore, in order to be classified as Category II, the shrimp fishery would have been expected to take a total of between 3.2 and 160 dolphins over a given five year period. South Carolina also experiences seasonal influxes of coastal dolphins from the Southern Migratory Coastal Stock (SMCS) during the spring and fall months. While travelling to and from their coastal fishing grounds, trawlers are also likely to encounter the Charleston Estuarine System Stock (CESS) and the Northern Georgia/Southern South Carolina Estuarine System Stock (NGSSCES).

The overall objective of this study was to characterise and quantify physical gear interactions between dolphins and trawl gear and to determine the impacts of these interactions on bottlenose dolphins in South Carolina. This study sought to: (1) determine if gear configuration and fishing method have a significant effect on dolphin presence, abundance, and behaviour around shrimping vessels; and (2) investigate if commercial shrimp trawl takes in South Carolina are underreported and if mortality has exceeded 1% of PBR per year for any given five-year period.

METHODS

Onboard observations

Onboard observations were conducted aboard four South Carolina commercial shrimp trawl vessels. One based out of Beaufort, one from McClellanville, and two vessels from Charleston, one that primarily trawled north of Charleston Harbor and one that trawled south of the harbor (Fig. 2). Observations were conducted over 25 days from August to December 2010; 16 days were out of Charleston, six out of McClellanville, and three from Beaufort.

Dolphin observations were recorded during each gear-deployment and gear-retrieval as well as every 10 minutes during the tow. Using the 'one-zero' sampling method, the presence or absence of dolphins, mother/calf pairs (M/C), direct physical gear interaction behaviours (Fertl and

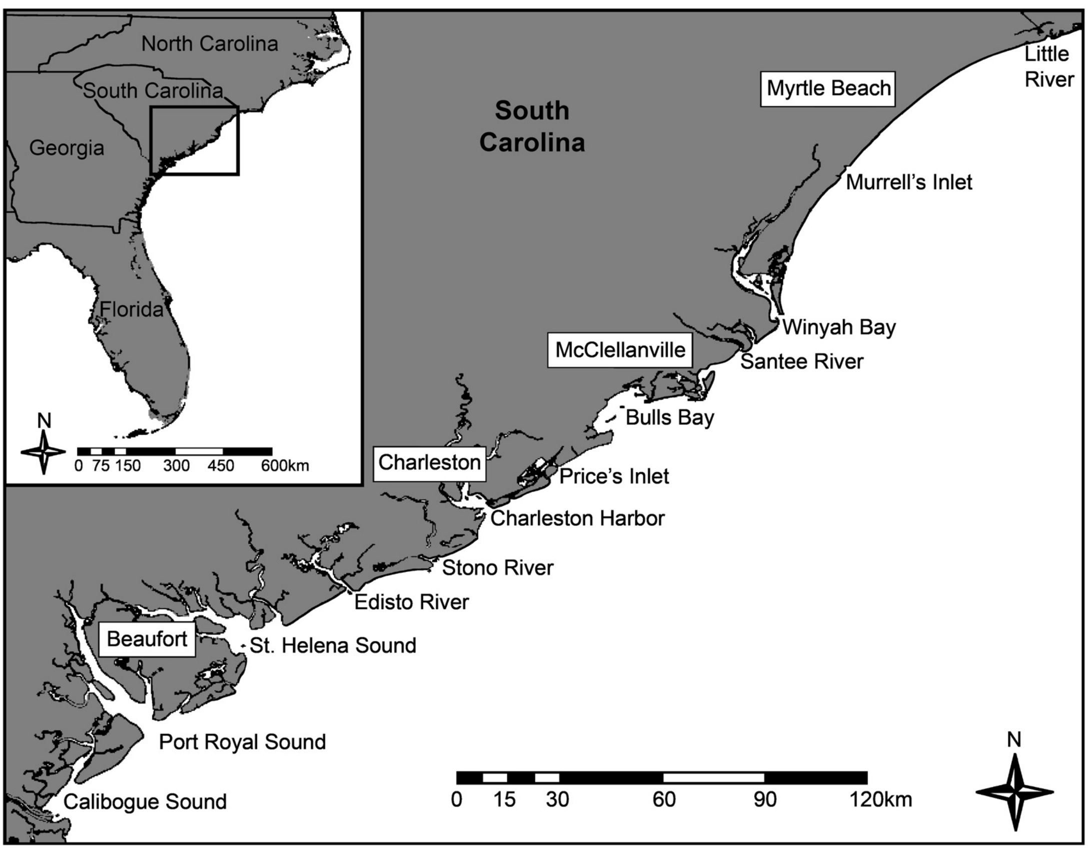

Fig. 2. Map of the study area.

Leatherwood, 1997; Zollett, 2005) and the presence of other trawlers was recorded at each interval (Mann, 1999). All dolphins seen within 100m of the stern of the vessel were considered to be 'present'. The number of dolphins and mother/calf pairs (M/C) present at each interval was estimated. Calves were defined as swimming in echelon position and being 2/3 or less the size of the adult dolphin or those with visible fetal folds (Shane, 1990). Feeding behaviours such as net depredation and eating discards (Fertl and Leatherwood, 1997) were recorded using the *ad libitum* sampling method and therefore the data on these behaviours was anecdotal (Mann, 1999).

The time and locations of each tow were determined using a *Garmin* GPSmap 76 handheld GPS unit (Olathe, Kansas, USA). Photo identification was conducted using a *Canon* EOS-1 Ds Mark II digital camera (Ōta, Tokyo, Japan) with a *Canon* 100–400mm telephoto lens. Photographs of each dolphin's dorsal fin and any direct physical interactions were then entered into *FinBase*, a *Microsoft Access* database, to create a catalog of 'Shrimp Boat Dolphins' (Adams *et al.*, 2006). This database will be used in future research to determine if the dolphins photographed are known individuals of a particular stock and how often individual dolphins engage in trawler interactions.

Shrimp trawler survey

In order to enhance knowledge of dolphin/shrimp trawl fishery interactions, a mail survey questionnaire was created and distributed to a subset (n = 157) of the fishery who had maintained a South Carolina commercial trawler license for at least the last five years consecutively (2007–20l1). The survey questionnaire was organised into three sections: Status of the Fishery; Shrimping Logistics; and Bottlenose Dolphin Observations. Information was obtained using the SCDNR shrimp trawl licensing database. Each fisher was mailed a survey packet that included a cover page, the survey questionnaire, and an empty, postage-paid, pre-addressed envelope to facilitate in the return of the completed survey. In order to protect anonymity, no return address was listed on this empty envelope.

Stranding record data

Bottlenose dolphin stranding records were accessed via the National Ocean Service (NOS), Center for Coastal Environmental Health and Biomolecular Research (CCEHBR), Marine Mammal Information System (MMIS) Database. Using this Microsoft Access database, a query was run for Human Interaction (HI) data. In the database, these records are separated into 'Yes HI', 'No HI', 'Cannot Be Determined' (CBD-HI), or 'Not Available' (N/A). Stranding records that were 'No HI' or 'N/A' were excluded from the dataset. Further, only 'Fishery Interaction' (FI) cases of the 'Yes HI' records were used. Cases in which 'Crab Pot' or 'Monofilament' gear could be identified were removed from the dataset. In addition, only strandings that occurred during the commercial shrimp trawl season for that year were included in the final dataset. All remaining records categorised as 'Yes HI' were included in the final dataset, including four confirmed trawler takes. Any CBD-HI cases which mentioned suspicion of human interaction were also included in the final dataset.

Information gathered from the four confirmed stranding cases, the onboard observation study and the mail survey were used to create a Dolphin/Trawl Fishery Interaction Flow Chart (Fig. 3). The purpose of the flow chart is to provide a tool for marine mammal researchers to use when determining if a dolphin's mortality likely resulted from a shrimp trawl fishery interaction. The chart is divided into three levels: 'Level 1: Gear Attachment', 'Level 2: Gear Wounds', 'Level 3: Post-Mortem Exam'.

In Level 1 if gear attachment is present, researchers are offered a choice of gear type and gear size. Gear size ranges were determined from field measurements, the fisher survey, and data from a previous crab fishery gear tension test (Burdett *et al.*, 2007; Burdett and McFee, 2004). The 16mm to 4mm range provided for line width represents the overlap between the gear types used in the trawl fishery and other South Carolina fisheries, particularly the crabpot fishery. Based on the answers provided by researchers, categories are assigned: 'Confirmed', 'Unconfirmed/Probable', 'Unconfirmed/Possible', 'Cannot Be Determined' (CBD), and 'Other'. A full description of each category can be found in Table 1. Level 2 is focused on gear wounds and is structured almost identically to Level 1, but 'Confirmed' and 'Other' are not included in the list of potential classifications since without the presence of gear, it is impossible to confirm whether or not mortality resulted from interactions with a given fishery. Level 3 focuses on gross pathology data obtained during necropsies, including external observations of body condition and internal examinations of the respiratory system, digestive tract and musculature. This level is meant to be read from left to right and takes an 'all or nothing' approach. If the body condition is robust, researchers continue across the chart until they answer 'No' to one of the options. Only if all of the answers are 'Yes', Unconfirmed/Probable is the potential classification.

Statistical analysis

Statistical analysis was conducted using IBM SPSS statistical software (Armonk, NY, USA). Dolphin presence and gear interaction data collected during onboard observations and all data collected from the survey were categorical. These categorical data were tested using cross tabulation and the Pearson chi-square (x^2) test to determine the statistical significance of the observations. Effects on mean dolphin group size, mean number of M/C pairs, and the mean number of nearby trawlers were analysed using an ANOVA test. For both tests, a 95% confidence interval was used and thus p-values < 0.05 were considered to be statistically significant.

RESULTS

Direct onboard observations

Bottlenose dolphin mortality

No bottlenose dolphin mortality was observed during 25 days of onboard observations. However, physical interactions with the fishery were noted. Rubbing and biting of the lines was seen only during haul-back. These line interactions occurred on 6% (n = 4) of haul-backs. Net interactions were seen on 1% (n = 1) of set-outs and 14% (n = 10) of haul-backs. Since physical gear interactions could

Table 1

Criteria used to classify trawl fishery interaction in South Carolina.

Classification	Criteria
Confirmed trawl fishery interaction	Stranded with gear, reported sighting with gear, freed from gear.
Unconfirmed, probable	Wounds and body condition very similar to confirmed cases (i.e. rope and/or net abrasions, stomach full of common fishery bycatch fish remains, robust body condition, froth in lungs and bronchi).
Unconfirmed, possible	Wounds and body condition similar to confirmed cases. Wounds may have resulted from other fishing practices and may not be characteristic of trawl gear (i.e. puncture wounds, lacerations, rope marks that may be post mortem).
CBD, mutilation	Interaction with trawl fishery could not be determined. Animals showed signs of fishery interaction, but carcass was too heavily mutilated or appendages were lost, preventing complete wound analysis.
Other fishery	Interaction with a fishery other than the trawl fishery. Dolphins stranded with gear attached or evidence of entanglement not congruent with trawl gear (i.e. crab pot gear, monofilament lacerations).

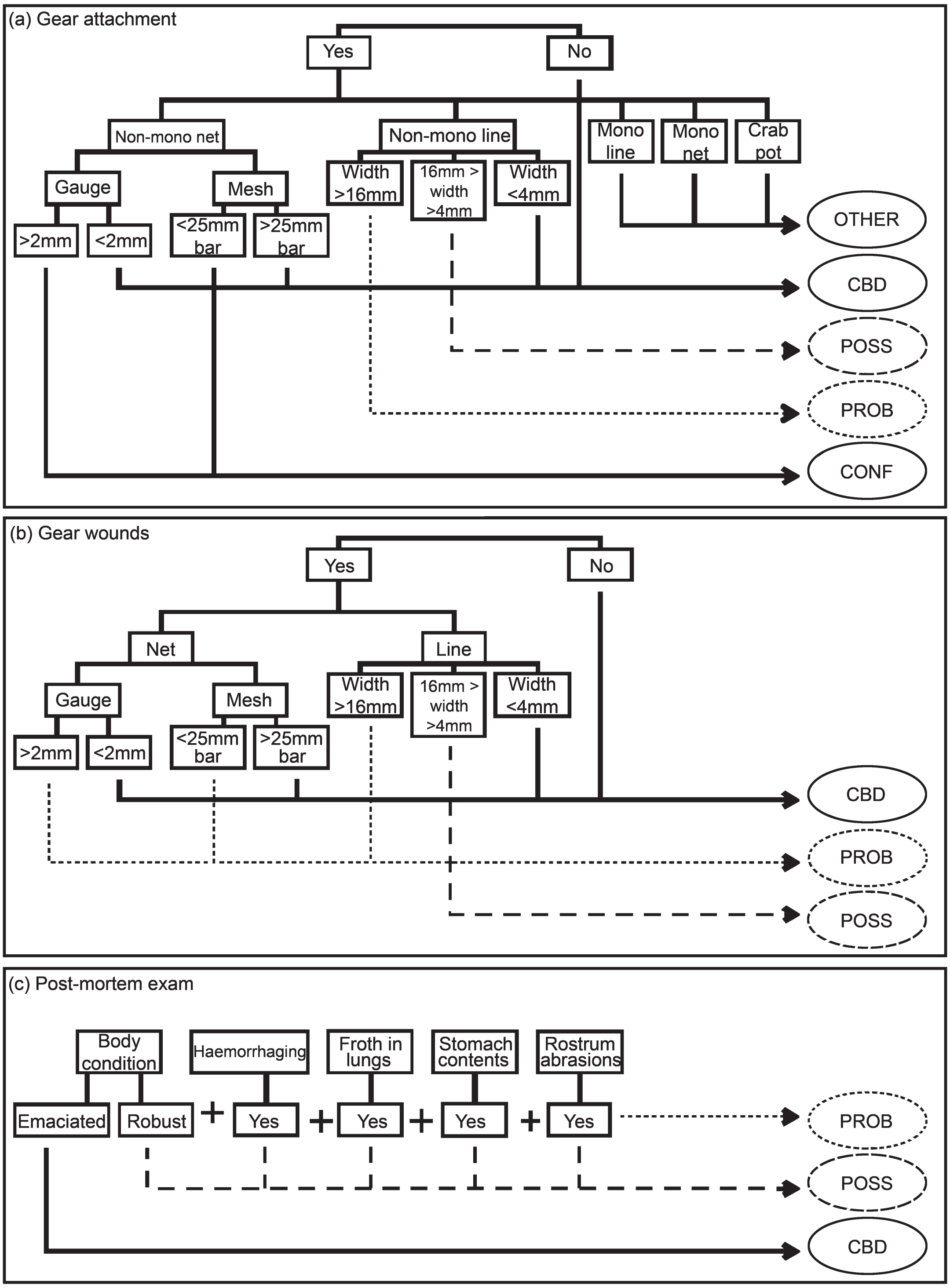

Fig. 3. Dolphin/Trawl Fishery Interaction Flow Chart.

not be observed during towing, this stage was removed from further analysis of gear interactions. Vessels towing four nets (Charleston Harbour North and Charleston Harbour South) had significantly more net interactions than the two-net commercial vessels ($x^2 = 4.394$; $p = 0.036$). When the two Charleston based vessels (Charleston Harbour North and Charleston Harbour South) were compared over their overlapping range, no significant differences in physical gear interactions were observed.

Bottlenose dolphin presence and abundance
From August to December 2010, 1,176 observations were made, including 71 at set-out, 1,034 during towing and 71 at haul-back. Dolphins were present in 69% ($n = 810$) of the total observations. Dolphins were observed significantly more often during towing and at haul-back ($x^2 = 68.613$; $p < 0.001$) than at set-out. When analysed with and without the observations made during the towing stage, Charleston Harbour and Beaufort had significantly higher dolphin presence than the other vessels ($x^2 = 39.630$; $p < 0.001$; $x^2 = 10.281$; $p = 0.016$). The group size over all vessels and all stages ranged from 1 to 40 individuals with a mean of 6.72 ± 5.88 dolphins. When other commercial trawl vessels were seen in nearby waters, dolphin group size had a slightly smaller mean of 5.91 ± 4.98 dolphins. When group size was analysed based on location, Charleston had a mean of 8.38 ± 6.70, which was significantly higher than in Beaufort (5.44 ± 4.805) or McClellanville (4.29 ± 3.148) ($F = 45.835$, $p < 0.001$).

Mother-calf (M/C) pairs were seen in 35% ($n = 281$) of the observations. This includes 28% ($n = 5$) of set-outs, 34% ($n = 250$) during towing, and 46% ($n = 26$) of haul-backs. M/C pairs were seen significantly more often on the vessels towing four nets, both of which were Charleston (Charleston Harbour South and Charleston Harbour North) based vessels ($x^2 = 4.841$; $p < 0.028$). However, when compared over their overlapping range, no significant differences in dolphin presence or M/C presence were seen between these two Charleston based vessels. When M/C pairs were observed, total group size ranged from 2–25, with a mean of 10.19 ± 6.07 dolphins, including a mean of 1.30 ± 0.46 M/C pairs per event.

Indirect observations
Shrimp fishery survey: Gear types
Of the 157 surveys mailed, there were 44 (28%) complete responses. Although respondents were asked a variety of shrimp fishery related questions, only the gear type and dolphin interaction data will be presented here. More than half of the respondents said that they only use a single net. The rest were split between two nets and four nets with some reporting that they have used both two and four net configurations. A majority of respondents (>70%) said they use a lazy-line. Twisted polypropylene and twisted polyester were the most common types of line used, with line widths ranging from 0.5–1 inch. Sugar-line use was less common (57%), but for those that use one, twisted polypropylene and twisted polyester were the most common type of line used and they ranged in width from 0.25–0.75 of an inch. The mesh sizes of nets were much more varied; body-mesh width ranged from 1–2 inches stretched, while bag-mesh size ranged from 0.75–1.75 inches stretched.

The low level of sugar-line use, along with the answers to several of the shrimping logistics questions, suggests that about half of the respondents run small-scale shrimping operations with small trawlers and single, hand-pulled nets. However, when SCDNR licensing data were queried, these small, single net trawlers only made up about 25% of the total fishery (George Steele, SCDNR, pers. comm.). It appears that the demographics of the survey respondents may be skewed towards small-scale and 'recreational' shrimping operations. In contrast, the vessels used in the onboard observations were larger, two to four net, winch-pulled operations.

Shrimp fishery survey: Dolphin interactions
A majority of the respondents said that they saw dolphins eating discarded bycatch on most or every trip. Discarded flounder (*Paralichthys spp*.), cutlass fish (*Trichiurus lepturus*) and Spanish mackerel (*Scomberomorus maculatus*) were specifically mentioned as 'favourites' of the dolphins. Most, (>60%) said that they rarely or never saw dolphins biting, tugging, or rubbing their nets or lines, while the rest reported that they had witnessed dolphins depredating fish or shrimp from their nets and several reported that dolphins have caused damage to their gear.

When asked about incidental takes of bottlenose dolphins, five respondents (11%) said that they had caught a dolphin in their net, including one respondent who caught more than one. In addition, four other respondents said that while they had never caught a dolphin, they had heard of someone catching one. Six respondents (14%), including two that reported net takes, said that they had entangled a dolphin in the lazy line; none more than once. In addition, two respondents said that while they had never entangled a dolphin, they had heard of someone else entangling one in their lazy line. None of the respondents said that they had entangled a dolphin in their sugar line or had ever heard of someone entangling one in their sugar line. A total of nine respondents admitted to dolphin takes in at least one gear type, with several having more than one; the survey revealed at least 12 dolphin takes.

A description of the take was provided in 10 of the 12 cases. In one case the dolphin freed itself from the gear, in four cases the shrimper freed the dolphin from the gear, whilst in five cases the dolphin was dead. Two respondents of the latter commented that the dolphin was decaying and one said that the dolphin died from drowning. Of note is that the net, lazy line and chaffing gear were all implicated in at least one of the dolphin takes. Only two (5%) of the respondents said that they had ever contacted the SCDNR or Marine Mammal Stranding Network (MMSN) about a dolphin take and 10 (26%) said that they had never even heard of the MMSN. There was no significant difference between number of nets a trawler used and whether or not they reported having ever caught a dolphin in their net or lazy line. However, all six line entanglements were reported by shrimpers with home ports in South Carolina.

Stranding record review
An initial database query of bottlenose dolphins that stranded in South Carolina yielded 1,024 total records spanning from

1992–2011. When this dataset was queried for signs of human interaction (HI), it resulted in 105 cases that were determined to be HI, 438 cases in which HI could not be determined (CBD-HI) and 481 cases with no signs of HI. Of the 105 HI cases, 70 had signs of fishery interaction (FI), 15 showed characteristics of a boat strike, 10 had evidence of mutilation and 10 had other signs of HI (e.g. marine debris, died during capture, multiple compounding sources). All HI reports were reviewed to confirm their classification and to look for signs of trawler interactions (TI). In addition, 17 CBD-HI cases with specific comments about HI suspicions were also reviewed. Thus, 122 standings were used for this part of the stranding analysis.

Based on the Dolphin/Trawl Fishery Interaction Flowchart, as described in the Methods, four cases were confirmed as TI, of which two dolphins were taken in the SCDNR SEAMAP scientific survey. In addition, three cases were determined to be Unconfirmed/Probable TI and five cases were determined to be Unconfirmed/Possible TI. A description of the 12 TI confirmed, probable, or possible cases is shown in Table 2. Forty-eight of the remaining cases were attributed to other sources such as boat strike, other fisheries, mutilation and marine debris. However, for over half (n = 64) of the cases reviewed, interactions with the trawl fishery could not be determined.

The 12 confirmed, probable, and possible TI cases were assigned age classes based on McFee and Hopkins-Murphy (2002). None of the TI animals were classified as neonates. However, five of the animals, including one confirmed case and four possible cases were <184 cm and classified as young of the year calves. Two of the confirmed cases, two of the probable cases and one of the possible cases were classified as immature (201–240cm). One probable case was classified as mature (>240cm), while the total length of the last confirmed case was unknown.

DISCUSSION

Direct observations

Bottlenose dolphin mortality

While no bottlenose dolphin takes were observed during onboard observations, dolphins were observed rubbing and biting the nets and using their foreheads and rostrums to manipulate the mesh to gain access to the fish inside (Fig. 4). This type of gear interaction is consistent with previous studies (Broadhurst, 1998; Svane, 2005) and could place them at risk for entanglement. This behaviour was also reported by several of the mail survey respondents who claimed that dolphins damaged their gear by biting holes in the nets. However, it is also suggested that the source of much of this gear damage is from sharks which also feed behind shrimp trawlers (Fertl and Leatherwood, 1997; Zollett, 2005).

The small mesh size used in commercial shrimping makes it unlikely that a dolphin would get its fins or flukes caught in the net. Yet, while picking fish out of the net, it is possible that a dolphin could get its teeth or entire rostrum stuck in the mesh (Fertl, 1994). Broadhurst (1998) theorised that this behaviour does not result in direct bycatch of the dolphins and that the use of chaffing gear could deter dolphins from manipulating the net. However, one respondent in the mail survey reported a dolphin take in which the animal was actually stuck in the chaffing gear.

It is also believed that dolphins can be caught when they enter the mouth of the net to feed (Waring *et al.*, 2012; Zollett, 2005). Changes in speed or direction of a vessel can alter the shape of the mouth and body of the net, reducing or eliminating a dolphin's ability to escape (Zollett, 2005). At the beginning of set-out, the net is relatively shapeless and slow-moving and at haul-back, trawler speed decreases significantly which causes the mouth of the net to collapse (Waring *et al.*, 1990).

It is possible that some of the dolphins trapped during set-out and haul-back are alive when they are caught in the net,

Table 2

Date, location, sex, length, and classification of confirmed, probable, and possible shrimp trawl fishery mortalities in South Carolina (1992–2013).

Field no.	Date	Location	Sex	Length	Classification	Criteria for classification
SC1236	02/08/12	Georgetown Co.	Male	223	Confirmed	SCDNR trawler take.
SC0630	28/07/06	Beaufort Co.	Male	236	Confirmed	SCDNR trawler take.
SC0224	23/08/02	Beaufort Co.	Female	152	Confirmed	Commercial trawler take in float line.
SC9827	28/05/98	Beaufort Co.	–	–	Confirmed	Commercial trawler take in net.
SC0842	10/12/08	Beaufort Co.	Female	185+	Probable	Flukes cut off, stomach full of shrimp and fish, foam in bronchus, rostral abrasions, hatch marks.
SC0236	11/12/02	Charleston Co.	Female	229	Probable	Hatch marks on flippers, foam in bronchi.
SC9835	04/07/98	Charleston Co.	Male	248	Probable	Line marks circumventing body, froth in bronchi, fish in esophagus and stomach, wound to upper right tooth row.
SC1052	28/08/10	Charleston Co.	Male	135	Possible	5mm line wounds through mouth causing dislocation of jaws, also constricting wraps around both pectoral fins and the thoracic region, haemorhagging on head and jaw.
SC0952	25/11/09	Charleston Co.	Male	221	Possible	Wounds consistent with rope entanglement.
SC9826	28/05/98	Charleston Co.	Female	176	Possible	X-marks on left flipper, left fluke cut off, left side of body with line marks running from flipper back, other line marks on body.
SC9726	01/06/97	Charleston Co.	Male	145	Possible	Line marks on right side, abraded rostrum, bloody mouth, partially digested fish in stomach. A leatherback turtle found mutilated, no head or appendages on the same day ~½ mile south of the dolphin stranding.
SC9725	18/05/97	Charleston Co.	Female	113	Possible	Dorsal fin crosshatches, line marks on rostrum 6cm, flukes and peduncle, bruise right ear 7 × 6cm, partially digested fish and shrimp were observed in the forestomach.

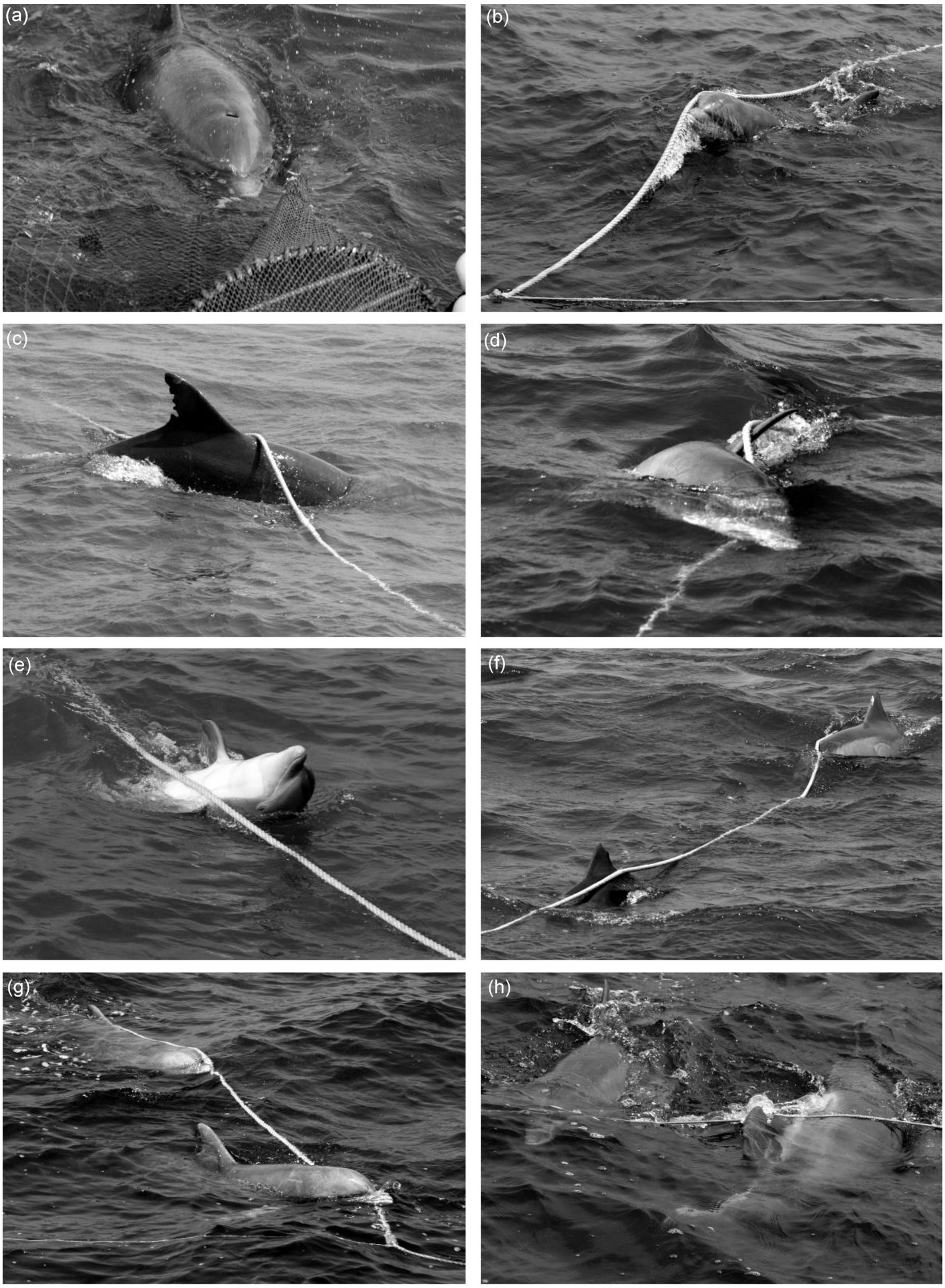

Fig. 4. Individual (a,b,c,d,e) and multiple (f,g,h) dolphins engaging in physical gear interactions with trawl net (a), lazy line (b,c,d,e,f,g), and sugar line (h). Photos by J. Greenman.

but die since tow times can last for multiple hours (Fertl and Leatherwood, 1997). Several necropsies of dolphins caught by trawlers in other areas indicated that the animals had drowned, and that they had experienced traumatic muscle and ligament injuries while struggling to free themselves from the underwater entrapment (Lipscomb, 1996; Northridge, 2003). It is also believed that dolphins found in the nets are rarely alive when caught, but rather that they are dead or dying when they are scooped up in the net (Fertl and Leatherwood, 1997). Mail survey respondents reported that the dolphins they caught were 'long dead' and decaying. In this survey, as seen in previous ones (Fertl, 1994), many respondents insisted that dolphins were too quick or smart to be caught in the net. While this may be true for healthy and experienced adults, sick or injured animals as well as calves and neonates may not be strong enough to swim out of the net. This may account for why calves made up 50% ($n = 6$) of the TI cases.

During both set-out and haul-back, there is a period of time when the lines and nets are sitting slack on the surface of the water making them more likely to entangle. Several studies reported that bottlenose dolphins can drown when they are entangled around the tail stock by hanging lines (Fertl, 1994; McFee *et al.*, 2007). Those animals that do manage to free themselves may still have a serious injury. In rough seas, these lines can move in even more unexpected ways, perhaps increasing the likelihood of entanglement.

During onboard observations, dolphins were observed rubbing and biting the lazy line and sometimes the sugar line (Fig. 4). It appears that dolphins use the line as a 'scratching post'. Dolphins are tactile animals and it is believed that touching plays a large role in dolphin social structure (Dudzinski, 1998). In several cases, multiple dolphins were rubbing on the same line at the same time (Fig. 4). 'Playing' with the lines during haul-back was also reported by Fertl and Leatherwood (1997). While the lazy line is a relatively thick and stiff line, the sugar line is often similar to lines used on crab pots. A study on the movement of this type of line suggests strong currents can cause this line to move in erratic ways, making it more likely to cause entanglement (McFee *et al.*, 2007). In addition to currents, water churned up by the trawler's propeller or by dolphins splashing and engaging in social behaviours could have a similar effect on the lines.

Line types and widths can vary depending on the vessel, especially when individuals make modifications to their gear. One such modification was actually implicated in a South Carolina bottlenose dolphin entanglement in 2002. A small-scale shrimp fisher had attached a 20ft line and buoy to the top of the cod-end to aid in grappling the net. This 9mm diameter line became wrapped twice around the mouth, body and peduncle of the animal. This gear modification may be quite common, since a similar line-buoy modification was observed on two of the commercial vessels in the current study although no direct interaction with this gear was observed. These modifications create difficulties for researchers using gear attachment and gear wound width as a method for identifying trawler interactions, since some of the lines are of the same type and size as those used in the crab pot fishery. If the take had not been reported and instead the buoy line cut, the animal could have washed up on the beach with what would have appeared to be textbook characteristics of a crab pot fishery interaction. This could result in the crab pot fishery being falsely implicated as a possible cause of death.

Several factors have been suggested as having a significant effect on rate of marine mammal fishery interactions and bycatch, including the prevalence of other marine mammals in the fishing area, time of day, tow duration, level of tow in water column, size of net opening, haul-back speed and gear design (Waring *et al.*, 1990). In the present study, both line and net interactions were seen significantly more often during haul-back. In addition, significantly more net interactions were observed on vessels towing four nets than those towing just two nets. This seems logical, since four nets provide more surface area for dolphin interaction than two nets.

Presence and abundance

Bottlenose dolphins, including M/C pairs, were observed associating with trawl vessels along the entire study area and during all stages of trawling. However, dolphins were present at the haul-back more frequently and in larger group sizes than at set-out. Dolphins were also observed following the cod-end during haul-back and depredating on fish protruding from the mesh and other fish that had fallen out of the net. These findings are consistent with the results from several other studies which frequently observed dolphins congregating around the cod-ends at haul-back (Broadhurst, 1998; Corkeron *et al.*, 1990; Fertl, 1994; Svane, 2005). There are several factors that may explain this occurrence. At haul-back the gear and the catch are at the surface, making them more visible to observers than during the tow. Additionally, the haul-back process can be noisy and the sound of the engine and winch may alert nearby dolphins to the food source (Fertl and Leatherwood, 1997; Zollett, 2005). In addition to picking fish out of the net, dolphins fed on catch that washed out of the net during the haul-back process and bycatch discarded during culling. Fertl (1994) also suggested that in addition to foraging, social and sexual interactions between dolphins may play an important role in dolphin movements around shrimp trawlers.

Onboard observations revealed that there were significant differences in dolphin presence based on observation vessel. The Charleston Harbour-North and Beaufort vessels had significantly higher dolphin presence than the other vessels. This is an interesting result, since the Charleston Harbour-North and Beaufort vessels differ not only in where they shrimp but also in how many nets they use. Charleston Harbour-North used four nets and primarily trawled north of Charleston Harbour, while Beaufort used two nets and trawled in St. Helena Sound. Therefore, number of nets and shrimping location do not appear to be good predictors of overall dolphin presence, but M/C pairs were seen significantly more often on both of the four-net, Charleston-based vessels. It is possible that M/C pairs are attracted to four net trawlers because they provide more cod-ends to feed from or because they catch more per tow and thus have more discards. However, it may also be that M/C pairs are drawn to the habitats around Charleston Harbor. Charleston observations also showed a significantly higher mean group size than in McClellanville or Beaufort. Yet, the mean group size for Charleston (8.38 ± 6.70) is much smaller than the mean groups size of 15 observed near shrimp trawlers during previous photo-id studies in Charleston (Speakman *et al.*, 2006). It is possible that this discrepancy is a result of differences in the study methods and sampling season. While the current study was conducted aboard commercial trawlers during the months of August to December and included a large number of observations ($n = 810$), Speakman *et al.* (2006) used a small motorboat during the months of June to November and had a smaller number ($n = 47$) of trawler associated observations.

Indirect observations

The mail survey results clearly showed that dolphin takes in the South Carolina shrimp trawl fishery are underreported. Three of the takes reported in the survey were by fishers that have been trawling for 11–20 years suggesting at least three takes since 1992. The other nine were by fishers with over 20 years of experience. In addition, the 44 respondents of this survey only represent about 10% of the fishery, which has averaged about 433 licenses per year over the last five years. Therefore, it is possible that the total number of dolphins taken in this fishery is much higher.

As stated earlier, it is believed that the South Carolina/Georgia Coastal Stock (SCGCS) has the most overlap with the shrimp trawl fishery. Using this SCGCS assessment (PBR = 64), the two known commercial dolphin takes that occurred in 1998 and 2002 are not enough to meet the NMFS criteria for classification as a Category II fishery (1% PBR <50% PBR). However, the SCGCS also includes the entire Georgia coast and a recent study found that dolphins frequently associated with shrimp trawlers near Savannah, GA (Kovacs and Cox, 2014). If dolphin takes in Georgia occur at a similar rate as in South Carolina, it may provide enough data to confirm its Category II designation. Given that the small subset (n = 44) of shrimper survey respondents admitted to an additional 12 takes, it is still likely that the fishery as a whole has exceeded 1% PBR.

Using the Dolphin/Trawl Fishery Interaction Flowchart (see Methods), the four known takes (two SCDNR and two commercial) were confirmed as trawler interaction (TI) cases. In addition, the flow chart revealed three cases of Unconfirmed/Probable TI and five cases of Unconfirmed/Possible TI. Even if just the probable cases are included, the shrimp trawl fishery has met the Category II criteria for any given five year period from 1994–2012.

SUMMARY

No dolphin takes occurred during the direct onboard observations though it is clear that dolphins increase the likelihood of entanglement by rubbing on lines and nets. The four-net vessels (Charleston Harbour South and Charleston Harbour North) had significantly more net interactions and higher M/C presence. However, these were also the only two vessels based out of Charleston and therefore location may also be a factor in these direct physical gear interactions. Line type and number of lines were too similar to compare between vessels. Fishing method differed very little between the vessels, but was variable depending on the presence of shrimp. When shrimp catch is good, commercial trawlers tend to circle around a specific area while trawling, allowing dolphins more time to interact with the vessel. Tow time was not a significant factor, but the longer the gear sat at the surface between tows, the more likely dolphins were to be observed interacting with it. In conclusion, while gear configuration and fishing method appear to play a role in dolphin presence, abundance, and behaviour around shrimping vessels, these results were not statistically significant.

Only two commercial shrimp fishery dolphin takes were reported to NMFS, SCNDR, or SCMMSN from 1998–2002, yet 12 dolphin takes were reported in the shrimp fisher survey. In addition, the flow chart revealed three cases of Unconfirmed/Probable TI and five cases of Unconfirmed/Possible TI. Based on these data, shrimp trawl related bottlenose dolphin mortality is clearly underreported. Mortality exceeded 1% of the Potential Biological Removal (PBR) annual average for the five-year period of 1998–2002; therefore, in conclusion, the current status of the fishery as Category II is warranted.

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REFERENCES

Adams, J., Speakman, T., Zolman, E. and Schwacke, L.H. 2006. Automating image matching, cataloguing and analysis for photo-identification research. *Aquat. Mamm.* 32(2): 374–84.

Broadhurst, M.K. 1998. Bottlenose dolphins, removing by-catch from prawn-trawl codends during fishing in New South Wales, Australia. *Mar. Fish. Rev.* 60(3): 9–14.

Burdett, L., Adams, J. and McFee, W. 2007. The use of Geographic Information Systems as a forensic tool to Investigate sources of marine mammal entanglement in fisheries. *J. Forensic. Sci.* 52(4): 904–8.

Burdett, L.G. and McFee, W.E. 2004. Bycatch of bottlenose dolphins in South Carolina, USA, and an evaluation of the Atlantic blue crab fishery categorisation. *J. Cetacean Res. Manage.* 6(3): 231–40.

Chilvers, B. and Corkeron, P. 2001. Trawling and bottlenose dolphins' social structure. *Proceedings of the Royal Society* 268: 1901–5.

Corkeron, P.J., Bryden, M.M. and Hedstrom, K.E. 1990. Feeding by bottlenose dolphins in association with trawling operations in Moreton Bay, Australia. pp.329–36. *In*: Leatherwood, S. and Reeves, R.R. (eds). *The Bottlenose Dolphin*. Academic Press, San Diego, California. 653pp.

Dans, S.L., Koen Alfonso, M., Pedraza, S.N. and Crespo, E.A. 2003. Incidental catch of dolphins in trawling fisheries off Patagonia, Argentina: can populations persist? *Ecol. Applications* 13(3): 754–62.

Dudzinski, K. 1998. Contact behavior and signal exchange in Atlantic spotted dolphins. *Aquat. Mamm.* 24(3): 129–42.

Fertl, D. 1994. Occurrence, movements, and behavior of bottlenose dolphins (*Tursiops truncatus*) in association with the shrimp fishery in Galveston Bay, Texas. M.S. Thesis. Texas A&M University, College Station. 134pp.

Fertl, D. and Leatherwood, S. 1997. Cetacean interactions with trawls: a preliminary review. *J. Northwest Atl. Fish. Sci.* 22: 219–48.

Fleming, K. 2004. The social structure, behavior, and occurrence of bottlenose dolphins in relation to shrimp trawlers in Southport, North Carolina. M.S. Thesis. University of North Carolina-Wilmington. 52pp. [Available at: *http://libres.uncg.edu/ir/uncw/f/flemingk2004-1.pdf*].

Fortuna, C.M., Vallini, C., Filidei, E., Ruffino, M., Consalvo, I., Di Muccio, S., Gion, C., Scacco, U., Tarulli, E., Giovanardi, O. and Mazzola, A. 2010. By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy). *Chem. Ecol.* 26: 65–76.

Gonzalvo, J., Valls, M., Cardona, L. and Aguilar, L. 2008. Factors determining the interaction between common bottlenose dolphins and bottom trawlers off the Balearic Archipelago (western Mediterranean Sea). *J. Exp. Mar. Biol. Ecol.* 367: 47–52.

Kovacs, C. and Cox, T. 2014. Quantification of Interactions between Common Bottlenose Dolphins (*Tursiops truncatus*) and a Commercial Shrimp Trawler near Savannah, Georgia. *Aquat. Mamm.* 40(1): 81–94.

Kristjonsson, H. 1967. Technique of finding and catching shrimp in commercial fishing. Proc. FAO World Scientific Conference on the Biology and Culture of Shrimps and Prawns. 12–24. June 1967, Cuidad de Mexico. 69pp.

Lipscomb, T.P. 1996. Pathologic findings in dolphins known to have died from underwater entrapment pp.43–4. *In*: Kuiken, T. (eds). *Diagnosis of By-catch in Cetaceans: Proceedings of the Second ECS Workshop on Cetacean Pathology*. European Cetacean Society, Montpellier, France. European Cetacean Society Newsletter No. 26 – Special Issue. 43pp.

Mann, J. 1999. Behavioral sampling methods for cetaceans: A review and critique. *Mar. Mammal Sci.* 15: 102–22.

McFee, W., Pennington, P., Burdett, L., Powell, J., Schwacke, J. and Dockery, F. 2007. Assessing movements of three buoy line types using DSTmilli loggers: Implications for entanglements of bottlenose dolphins in the crab pot fishery. *NOAA Tech. Memo. NOS-NCCOS* 67: 58.

McFee, W.E. and Hopkins-Murphy, S.R. 2002. Bottlenose dolphin (*Tursiops truncatus*) strandings in South Carolina, 1992–1996. *Fish. Bull.* 100(2): 258–65.

McFee, W.E., Hopkins-Murphy, S.R. and Schwacke, L.H. 2006. Trends in bottlenose dolphin (*Tursiops truncatus*) strandings in South Carolina, USA, 1997–2003: implications for the Southern North Carolina and South Carolina Management Units. *J. Cetacean Res. Manage.* 8(2): 195–201.

McFee, W.E. and Lipscomb, T.P. 2009. Major pathologic findings and probably causes of mortality in bottlenose dolphins stranded in South Carolina from 1993 to 2006. *J. Wildl. Dis.* 45: 575–93.

National Marine Fisheries Service. 2011. Fisheries of the United States – 2010. [Available at: *http://www.st.nmfs.noaa.gov/st1/publications.html*].

National Oceanic and Atmospheric Administration. 2010. List of Fisheries – 2011. 75 Federal Register 215 (8 November 2010): 68468-68504. [Available at: *http://www.nmfs.noaa.gov/pr/interactions/lof*].

National Oceanic and Atmospheric Administration. 2011. List of Fisheries – 2012. 76 Federal Register 229 (29 November 2011): 73912-73953. [Available at: *http://www.nmfs.noaa.gov/pr/interactions/lof*].

Northridge, S. 2003. Reduction of cetacean bycatch in pelagic trawls. Final report to the Department for Environment Food and Rural Affairs and The Joint Nature Conservation Committee. Project MF0733. [Available at: *http://www.eurocbc.org/MF0733_Reduction_of_cetacean_bycatch_in_pelagic_trawls.PDF*].

Pate, M. and McFee, W. 2012. Prey Species of Bottlenose Dolphins (*Tursiops truncatus*) from South Carolina Waters. *Southeast. Nat.* 11(1): 22.

Scheinin, A. 2010. The population of bottlenose dolphins (*Tursiops truncatus*), bottom trawl catch trends and the interaction between the two along the Mediterranean continental shelf of Israel. PhD Thesis, University of Haifa, Israel. 172 pp.

Shane, S.H. 1990. Behavior and ecology of the bottlenose dolphin at Sanibel Island, Florida. pp.245–66. *In*: Leatherwood, S. and Reeves, R.R. (eds). *The Bottlenose Dolphin*. Academic Press, San Diego, Californa. 653pp.

South Carolina Department of Natural Resources. 2007. Status of South Carolina's Coastal Resources: Shrimp Update. [Available at: *http://www.dnr.sc.gov/marine/mrri/pubs/yr2007/shrimp07.pdf*].

Speakman, T., Zolman, E., Adams, J., Defran, R.H., Laska, D., Schwacke, L., Craigie, J. and Fair, P. 2006. Temporal and spatial aspects of bottlenose dolphin occurrence in coastal and esturine waters near Charleston, South Carolina. *NOAA Tech. Mem.* NOS-NCCOS-37: 243pp. [Available from *http://www.scribd.com/doc/7163057/Speakman-Et-Al*].

Sturgeon, N. 2010. Bottlenose dolphins and the Atlantic blue crab fishery: A study of coincidence and interaction in Charleston Harbor, SC. M.S. Thesis. College of Charleston, Charleston, South Carolina. 160pp. [Available at: *http://repository.library.cofc.edu/handle/11249/252*].

Svane, I. 2005. Occurrence of dolphins and seabirds and their consumption of by-catch during prawn trawling in Spencer Gulf, South Australia. *Fish. Res.* 76: 317–27.

Waring, G., Josephson, E., Maze-Foley, K. and Rosel, P. 2012. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2011. 319. NOAA Tech Memo NMFS NE 221. [Available at: *http://www.nmfs.noaa.gov/pr/sars/pdf/ao2012.pdf*].

Waring, G.T., Gerrior, P., Payne, P.M., Parry, B.L. and Nicolas, J.R. 1990. Incidental take of marine mammals in foreign fishery activities off the Northeast United States, 1977–1988. *Fish. Bull.* 88: 347–60.

Zeeberg, J., Corten, A. and Graaf, E. 2006. Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa. *Fish. Res.* 78: 186–95.

Zollett, E. 2005. A review of cetacean bycatch in trawl fisheries. Literature Review Prepared for NOAA's Northeast Fisheries Science Center. Woods Hole, MA. [Available at: *http://www.dfo-mpo.gc.ca/science/coe-cde/cemam/themes/04_zollet-trawl-bycatch-review.pdf*].