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Spatiotemporal patterns of overlap between short-finned pilot whales and the U.S. pelagic longline fishery in the Mid-Atlantic Bight: An assessment to inform the management of fisheries bycatch

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ABSTRACT

Short-finned pilot whales (*Globicephala macrorhynchus*) depredate pelagic longlines along the shelf break of the Mid-Atlantic Bight. The mortality and serious injury of short-finned pilot whales in the U.S. pelagic longline fishery recently exceeded Potential Biological Removal levels defined under the U.S. Marine Mammal Protection Act, and bycatch mitigation techniques developed to date have been unsuccessful. We examine the spatial and temporal characteristics of pilot whale habitat use and longline fishing effort, quantify spatiotemporal patterns of pilot whale bycatch based on environmental factors, and assess the potential for a spatial management approach to mitigate pilot whale bycatch. We assess patterns of overlap and bycatch of pilot whales and longlines by applying Area Under the Curve and Williamson's Spatial Overlap Index analyses to telemetry data from short-finned pilot whales, along with longline fishing effort and Pelagic Observer Program (POP) fisheries observer data from 2014 and 2015. We found that proximity to the 1000 m isobath, season, and sea surface temperature (SST) were important variables influencing pilot whale-longline overlap and POP bycatch rates. Pilot whale density was consistently highest immediately inshore of the 1000 m isobath, but longline effort varied seasonally relative to the 1000 m isobath. Resultant seasonal patterns in pilot whale-longline overlap relative to the 1000 m isobath were strongly and significantly correlated with POP bycatch rates; the highest bycatch rates primarily occurred in fall and winter months, when longline effort shifted inshore near the 1000 m isobath. We observed differences in the distribution of logbook and POP longline sets relative to the 1000 m isobath; POP sets were more dispersed relative to this feature while the overall distribution of longline effort was typically focused at the 1000 m isobath. Since bycatch primarily occurred close to the 1000 m isobath, more bycatch might be observed if the observer effort better reflected the overall distribution of longline effort. In winter months, POP bycatch occurred in cooler waters than most observations of tagged pilot whales, and therefore the relationship between bycatch and SST during winter months requires further exploration. Together, our results suggest that a spatial management approach could be effective in reducing pilot whale bycatch in the pelagic longline fishery, and an improved understanding of the relationships between pilot whale bycatch and dynamic variables might allow high-risk regions for pilot whale bycatch to be further delineated.

1. Background

The incidental bycatch of marine mammals in fishing gear is a major conservation issue that affects marine mammal populations around the world (Gilman et al., 2006; Hamer et al., 2012; Moore et al., 2009; Read et al., 2006; Werner et al., 2015). Globally, reported bycatch rates in longline fisheries have increased in recent years, likely due to both increased monitoring of bycatch and increased fishing effort (Hamer et al., 2012). In some longline fisheries, cetacean bycatch occurs as a result of depredation, the damage or removal of bait or captured fish from fishing gear by marine predators (Rabearisoa et al., 2015). Depredation can provide a meal for foraging cetaceans at relatively low energetic cost, which may encourage individuals to alter their natural foraging patterns (Ashford et al., 1996; Gilman et al., 2006; Hall, 1998; Hamer et al., 2012). Depredation has been observed in many odontocete species (Ashford et al., 1996; Gilman et al., 2006; Hamer et al.,

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2012; Werner et al., 2015), and can increase the risk of entanglement and hook ingestion (Hamer et al., 2012). Marine mammals are long-lived and have low reproductive rates, so increases in mortality rates due to bycatch can adversely affect their demography (Gilman et al., 2006; Read, 2008; Read et al., 2006; Werner et al., 2015).

The overlap between fishing effort and bycaught species can be used to inform the spatial management of bycatch in marine systems, particularly for highly migratory marine megafauna (Forney et al., 2011; McClellan et al., 2009; Wallace et al., 2013). Spatiotemporal patterns of fishing effort and/or the habitat use of bycaught species can be integrated into effective management plans (Becker et al., 2016; Hazen et al., 2016; Howell et al., 2008). Several sources of information can inform this approach, including broad distributional patterns, individual movements, and environmental drivers of the distributions of bycatch species (Forney et al., 2011; Garrison, 2007; Gredzens et al., 2014; Moore et al., 2009). Recent advances in satellite telemetry have significantly advanced our understanding of the habitat use and ecology of marine megafauna (Hart and Hyrenbach, 2009; Joyce et al., 2016; Vaudo et al., 2017). Satellite telemetry is particularly advantageous in the study of highly mobile marine animals (Ropert-Coudert and Wilson, 2005), and has been used to identify spatial components of habitat use (Baird et al., 2012; Baumgartner and Mate, 2005; Block et al., 2011; Eckert, 2006; Hart and Hyrenbach, 2009; Lowry et al., 1998) and to develop effective management strategies for cetacean species (Hart and Hyrenbach, 2009; Hazen et al., 2016; Kindt-Larsen et al., 2016).

Short-finned pilot whales (*Globicephala macrorhynchus*) are deep-diving odontocetes found in tropical and sub-tropical regions that exhibit diverse diets and diving behaviors, but primarily forage on deep-water fish and squid (Mintzer et al., 2008; Perrin et al., 2009; Quick et al., 2017). Although they do not typically feed on the swordfish and tunas targeted by the U.S. pelagic longline fishery in the Mid-Atlantic Bight (MAB), short-finned pilot whales depredate both bait and catch from this fishery (Gilman et al., 2006; McCreary and Poncelet, 2006; Garrison, 2007; Waring et al., 2016). Short-finned pilot whales are managed as a single stock in the Northwest Atlantic from Florida to Massachusetts (Hayes et al., 2017), and bycatch in the pelagic longline fishery is the leading cause of anthropogenic mortality for this stock (Hayes et al., 2017). The U.S. Marine Mammal Protection Act (MMPA) mandates that such mortality for each stock not exceed the Potential Biological Removal (PBR), a biological reference point, to ensure that marine mammal stocks are maintained in a good conservation status. When mortality levels exceed PBR, a Take Reduction Team is formed to identify mitigation strategies. The Pelagic Longline Take Reduction Team (PLTRT) was formed in 2005 when annual bycatch mortality of short-finned pilot whales was approaching PBR (McCreary and Poncelet, 2006; Moore et al., 2009; Waring et al., 2006). Mitigation measures investigated by the PLTRT have included: a shortened mainline length; the use of acoustic deterrents; and the delineation of the Cape Hatteras Special Research Area (CHSRA), which designates a region of increased observer requirements and compliance by fishermen in an area of high by-catch (Waring et al., 2016). Fishing restrictions in place when the current study was conducted included shortened mainline lengths (less than 20 nautical miles), additional observer coverage within the CHSRA, and the display of informational placards on active pelagic longline vessels (US OFR, 2009). However, these mitigation measures have not been successful in decreasing pilot whale bycatch, and bycatch levels for short-finned pilot whales recently exceeded PBR by 21% (Hayes et al., 2017). Thus, there is a critical need to develop new strategies to decrease the mortality of pilot whales in the pelagic longline fishery in the Northwest Atlantic.

Despite relatively high levels of bycatch of short-finned pilot whales, little was known about their seasonal movement patterns in the Northwest Atlantic until recently. At-sea surveys often combine sightings of short-finned and long-finned pilot whales (*G. melas*), because it is difficult to distinguish the two species at sea (Hain et al., 1985; Kenney et al., 1997; Kenney and Winn, 1987; Overholtz and Waring, 1991; Rone and Pace, 2012; Waring, 1993). In the Northwest Atlantic, the northern extent of the range of the short-finned pilot whale range overlaps with the southern extent of long-finned pilot whale habitat between New Jersey and George's Bank (Hayes et al., 2017). Bycatch in the pelagic longline fishery appears to be restricted largely to short-finned pilot whales (Hayes et al., 2017; McCreary and Poncelet, 2006). Recent deployments of satellite-linked transmitters on short-finned pilot whales have provided the first detailed information on their habitat use and movement patterns (Thorne et al., 2017).

To understand whether spatial management approaches could be used to reduce bycatch of pilot whales in the longline fishery, it is first necessary to examine the overlap between whales and the fishery and the influence of environmental variables on this pattern. Thus, our objectives were to: 1) assess spatial overlap between pilot whales and longlines along the northeastern coast of the United States; and 2) examine temporal patterns and environmental drivers of both overlap and observations of pilot whale bycatch.

2. Methods

2.1. Study area and pelagic longline fishery

Most bycatch of pilot whales in the U.S. Atlantic pelagic longline fishery occurs in the MAB and the Northeast Coastal (NEC) regions of the east coast of the United States (Garrison, 2007). The continental shelf in this region is broad (approximately 50–200 km from the shoreline to the edge of the continental shelf), but narrows as one progresses south, and is demarcated by a steep slope at the shelf break. Several submarine canyons occur in the MAB, the largest of which is Hudson Canyon in the New York Bight. We describe the shelf region east of the Hudson Canyon as the Southern New England Shelf (SNE shelf) for the purposes of this study and refer to canyons situated between Norfolk and Washington Canyons as the Mid-Atlantic canyons region (Brooke et al., 2017; Fig. 1). The steep slope at the edge of the continental shelf provides habitat for many marine mammal species, particularly sperm whales (*Physeter macrocephalus*), fin whales (*Balaenoptera physalus*), and short-finned pilot whales (Hain et al., 1985; Kenney et al., 1997; Thorne et al., 2017). Within the MAB, the Cape Hatteras region serves as foraging habitat for several species of marine mammal including short-finned pilot whales, bottlenose dolphins (*Tursiops truncatus*), and Cuvier's beaked whales (*Ziphius cavirostris*) and is also used by many pelagic longline vessels (Garrison, 2007; Hamazaki, 2002; Roberts et al., 2016; Schick et al., 2011; Thorne et al., 2017). In the MAB and NEC, the pelagic longline fishery targets swordfish (*Xiphias gladius*), yellowfin tuna (*Thunnus albacares)*, and bigeye tuna (*Thunnus obesus*), and primarily uses squid and mackerel as bait (Sakagawa et al., 1987; Witzell, 1999). Longline fishermen set gear where target fish species are expected to occur, and longline locations vary spatially and temporally based on factors such as sea surface temperature and the location of eddies (Hsu et al., 2015). Swordfish are typically fished at night with the use of light sticks near hooks, while fishermen targeting tuna usually fish during daylight hours (Sakagawa et al., 1987; Witzell, 1999; Beerkircher et al., 2002). Most bycatch occurs along the shelf break, defined as the region between the 200 m and 2000 m isobaths, between North Carolina and the Gulf of Maine (Garrison, 2007).

2.2. Longline fishing effort and Pelagic Observer Program fisheries bycatch

We used two data sources to examine longline fishing effort: self-reported longline logbook data from fishermen that includes the location and date of every longline set during the study period, as well as details of mainline, gangion, and floatline lengths, and target catch for all longline sets; and longline sets observed by the Pelagic Observer Program (POP), representing a subset of all longlines, that includes detailed information on gear, catch and bycatch in addition to the