Biological Conservation 144 (2011) 2202–2212

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Modeling loggerhead sea turtle (*Caretta caretta*) interactions with US Mid-Atlantic bottom trawl gear for fish and scallops, 2005–2008

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ARTICLE INFO

Article history:
Received 6 January 2011
Received in revised form 10 May 2011
Accepted 18 May 2011

Keywords:
Bycatch
Unobservable fisheries interactions
Generalized additive model
Turtle excluder device
Mitigation

ABSTRACT

Interactions between sea turtles and northwestern Atlantic trawl fisheries are of global concern, and the National Marine Fisheries Service is considering expanding bycatch reduction regulations, including deployment of turtle excluder devices (TEDs). To inform bycatch mitigation strategies, the number of loggerhead sea turtle (*Caretta caretta*) interactions was estimated for US Mid-Atlantic bottom trawl fisheries for fish and scallops. A generalized additive model of interactions was developed using 1994–2008 Northeast Fisheries Observer Program data from trawl fisheries that were not required to deploy TEDs. Predicted loggerhead interaction rates were applied to 2005–2008 commercial fishing data to estimate the number of interactions for the trawl fleet. For trawl fisheries in which TEDs were required, an experimentally-determined TED exclusion rate (97%) was applied to estimate the number of loggerheads that were excluded by TEDs. Latitude, depth, and sea surface temperature (SST) were associated with the interaction rate. Average annual interactions for 2005–2008 were estimated at 292 (CV 0.13, 95% CI 221–369) loggerheads, with an additional 61 (CV 0.17, 95% CI 41–83) excluded by TEDs. The interaction rate was highest south of latitude 37°N in waters <50 m deep with SST >15 °C; interaction magnitude in terms of adult equivalents was highest at latitude 37–39°N, depth <50 m, and SST >15 °C. Predicted average annual loggerhead interactions decreased compared to 1996–2004, likely due to decreased commercial fishing effort in high-interaction areas. Additional sea turtle conservation measures can be informed by the high-interaction-rate and -magnitude areas identified through this analysis.

1. Introduction

Interactions between sea turtles and northwestern Atlantic trawl fisheries are of global concern (NMFS and USFWS, 2008; Wallace et al., 2010). Trawl fisheries that are conducted in the Northwestern Atlantic Ocean are of particular interest because of their proximity to one of the largest loggerhead sea turtle (*Caretta caretta*) nesting aggregations in the world (TEWG, 2009). Loggerheads are listed as threatened under the US Endangered Species Act (ESA) and are globally endangered according to the International Union for Conservation of Nature (www.iucnredlist.org). Estimated average annual interactions numbered 616 loggerheads in US Mid-Atlantic bottom otter trawl gear for 1996–2004 (Murray, 2008) and 136 loggerheads in scallop trawl gear for 2004–2005 (Murray, 2007).

Trawl fisheries interactions are possible threats to loggerhead population recovery (NMFS and USFWS, 2008). Recovery for slowly maturing species such as loggerheads depends heavily on large juvenile and adult survival because turtles with a high reproductive value contribute most to population growth (Crowder et al., 1994). Loggerheads in mature life stages are generally distributed in the neritic zone, after spending the first few years of life in pelagic zones (TEWG, 2009). Trawl fisheries operate mainly in the neritic zone and overlap with these reproductively valuable individuals, although some large juveniles remain partly or fully oceanic and routinely interact with pelagic longline fisheries as well (Lewison and Crowder, 2007; McClellan and Read, 2007).

Currently, the only US bottom trawl fisheries that are affected by sea turtle conservation regulations are the southern shrimp (Penaeid) and summer flounder (*Paralichthys dentatus*) fisheries. A gear modification called a turtle excluder device (TED) has been required in shrimp trawls in certain times and areas since 1987 (NMFS, 1987), and in most shrimp trawls south of the Virginia/North Carolina border since December 1994 (NMFS, 1992b). Certified TEDs are designed to prevent sea turtles that have entered the trawl net from being captured in the cod end, or bag, of the trawl gear. A metal grid blocks the turtle's progress farther into the net and directs it toward an escape opening (Fig. 1). Since January 1996, TEDs have also been required in summer flounder trawls between Cape Charles, Virginia (37°05′N latitude) and the North Carolina/South Carolina border (33°35′N)—designated the Summer

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0006-3207/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2011.05.012

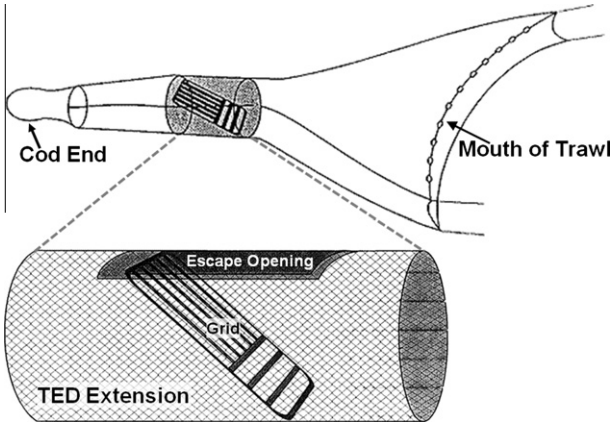

Fig. 1. Turtle excluder device (TED) in bottom otter trawl gear.

Flounder Fishery-Sea Turtle Protection Area—with an exemption from 15 January to 15 March for trawlers north of Oregon Inlet, North Carolina (35°46.1′N) (NMFS, 1996) (Fig. 2a). Prior to this regulation, TEDs were required year round in summer flounder trawls south of Cape Charles through temporary or interim regulations dating back to November 1992 (NMFS, 1992a,c, 1993a–c). TEDs or tow-time restrictions in summer flounder trawls were required by North Carolina state regulations as early as 1990.

For several Mid-Atlantic trawl fisheries, the National Marine Fisheries Service (NMFS) is considering implementing new sea turtle conservation regulations, which could include (1) increasing the size of the TED escape opening required in the summer flounder fishery; (2) requiring the use of TEDs in the flynet, whelk (Melongenidae), calico scallop (*Argopecten gibbus*), and Mid-Atlantic sea scallop (*Placopecten magellanicus*) trawl fisheries; and (3) moving the current northern boundary of the Summer Flounder Fishery-Sea Turtle Protection Area from Cape Charles, Virginia, farther north (NMFS, 2007, 2009).

This paper presents loggerhead sea turtle interaction information that can ultimately be used to evaluate bycatch mitigation strategies for US Mid-Atlantic bottom trawl fisheries for fish and scallops. Further, the present analysis attempts to quantify some portion of gear interactions that do not result in incidental capture. Under the ESA, sea turtle interactions, or "takes," encompass not only captures, but all interactions with the fishing gear. Gear interactions that are typically estimated as bycatch are those that would be detected under standard fisheries observer protocols (i.e., captures and surface interactions). These interactions are herewith referred to as "observable" (Fig. 3). Interactions taking place below the surface or away from the vessel's view would not be detected by fisheries observers, and thus, are "unobservable." For some portion of unobservable interactions, additional information is available that allows interaction rates to be estimated (e.g., a gear modification such as a TED may prevent capture of the animal, and we can estimate the exclusion rate). Other unobservable interactions remain unquantified (e.g., an animal could be struck by, hooked by, or entangled in fishing gear but break free or escape before the gear is retrieved).

The present study (a) uses a generalized additive model (GAM) of observed interactions for 1994–2008 in order to identify environmental factors or fishing traits that are associated with loggerhead interactions, (b) applies predicted interaction rates to 2005–2008 commercial fishing effort to estimate observable interactions, and attempts to quantify unobservable interactions in which turtles passed through TEDs at depth, (c) identifies localized regions with high interaction rates, high interaction magnitudes, or high trawl fishing effort, and (d) presents observable interaction estimates in terms of adult equivalents, which is the metric most informative of population-level impacts (Haas, 2010).

2. Methods

2.1. Analysis extent

The study area was the US Mid-Atlantic, which was delineated from Georges Bank and the Gulf of Maine along NMFS statistical areas (Fig. 2a) following Orphanides and Magnusson's (2007) management- and ecosystem-based definition of trawl fishing regions (although Orphanides and Magnusson's Southern New England regions were considered as part of the Mid-Atlantic). The analysis encompassed only the Mid-Atlantic because a single observed loggerhead interaction occurred in the Gulf of Maine/Georges Bank (Fig. 2a and b), providing too little information to support a robust model-based analysis for that area. Similarly, too few interactions were observed with non-loggerhead sea turtle species (Fig. 2c) to support estimates for those species.

Northeast Fisheries Observer Program (NEFOP) data for 1994–2008 were used for modeling the observable loggerhead

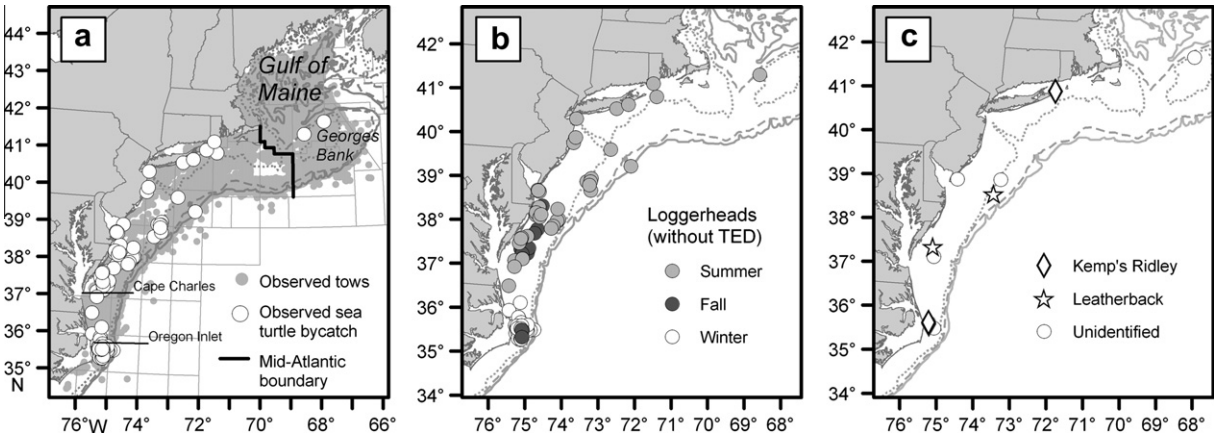

Fig. 2. (a) Observed bottom trawls for fish and scallops and observed sea turtle bycatch, June 1994–December 2008. The extent of the Mid-Atlantic (thick black line) is delineated along statistical areas (thin gray lines). (b) Loggerhead bycatch in non-TED trawls by season: spring (16 April–15 May, none observed); summer (16 May–31 October, $n = 44$); fall (1 November–30 November, $n = 13$); winter (1 December–15 April, $n = 55$). (c) Non-loggerhead bycatch. The 50 m (dotted), 100 m (dashed) and 200 m (solid) depth contours are shown.