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Short communication

# Interpreting the spatio-temporal patterns of sea turtle strandings: Going with the flow

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ABSTRACT

Knowledge of the spatial and temporal distribution of specific mortality sources is crucial for management of species that are vulnerable to human interactions. Beachcast carcasses represent an unknown fraction of at-sea mortalities. While a variety of physical (e.g., water temperature) and biological (e.g., decomposition) factors as well as the distribution of animals and their mortality sources likely affect the probability of carcass stranding, physical oceanography plays a major role in where and when carcasses strand. Here, we evaluate the influence of nearshore physical oceanographic and wind regimes on sea turtle strandings to decipher seasonal trends and make qualitative predictions about stranding patterns along oceanfront beaches. We use results from oceanic drift-bottle experiments to check our predictions and provide an upper limit on stranding proportions. We compare predicted current regimes from a 3D physical oceanographic model to spatial and temporal locations of both sea turtle carcass strandings and drift bottle landfalls. Drift bottle return rates suggest an upper limit for the proportion of sea turtle carcasses that strand (about 20%). In the South Atlantic Bight, seasonal development of along-shelf flow coincides with increased numbers of strandings of both turtles and drift bottles in late spring and early summer. The model also predicts net offshore flow of surface waters during winter – the season with the fewest relative strandings. The drift bottle data provide a reasonable upper bound on how likely carcasses are to reach land from points offshore and bound the general timeframe for stranding post-mortem (< two weeks). Our findings suggest that marine turtle strandings follow a seasonal regime predictable from physical oceanography and mimicked by drift bottle experiments. Managers can use these findings to reevaluate incidental strandings limits and fishery takes for both nearshore and offshore mortality sources.



## 1. Introduction

Estimating mortality is an important component of demographic analyses, having added consequence for long-lived, threatened and endangered vertebrate species with delayed maturity (Crowder et al., 1994; Crouse, 1999). However, calculating mortality rates and assigning cause of death are particularly challenging for stranded marine animals because of their dynamic, aquatic environment. Previously, analyses of carcass landfall patterns have been performed for marine

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mammals (Piatt and Ford, 1996; Garshelis, 1997; McLellan et al., 2002), seabirds (Bibby and Lloyd, 1977; Hyrenbach et al., 2001), and sea turtles (Murphy and Hopkins-Murphy, 1989; Epperly et al., 1996). Still, despite widespread collection and investigation of sea turtle strandings data for over 25 years (Sea Turtle Stranding and Salvage Network), there is no clear way to interpret trends in sea turtle stranding numbers. Sea turtle populations are imperiled worldwide, and our work corroborates the recommendations of the Turtle Expert Working Group (1998) to investigate landfall patterns of stranded turtles.

The majority of sea turtle strandings involve individuals that died at sea due to natural or anthropogenic causes such as encounters with fishing gear (NRC, 1990); however, most carcasses show no evidence of cause of death (Sis and Landry, 1992; Turtle Expert Working Group, 1998). Because carcasses decompose while entrained in currents and eddies, the number of recorded sea turtle strandings likely represents a minimum estimate of mortality (Murphy and Hopkins-Murphy, 1989; Epperly et al., 1996). However, the relationship between turtle mortality at sea and observed strandings on shore is still poorly understood. Here, we use turtle and drift bottle data sets to decipher trends in strandings to reveal new insights into the probable locations of mortality sources and the probability of stranding as a function of spatial location. We evaluate nearshore transport of turtle carcasses relying on strandings data (recorded from 1995 to 1999 along the North Carolina (NC) coast) in conjunction with a physical oceanographic model (Werner et al., 1999). We assess these results in the context of extensive drift bottle release experiments conducted in the 1960s and 1970s (Harrison et al., 1967; Bumpus, 1973). Moreover, we develop reasonable bounds for the numbers of turtles that may be dead at sea based on beach strandings within our study area, as well as the general timeframe for and probability of carcass stranding events.

Discerning seasonality of stranding patterns and how the number of turtles stranded on the beach is related to the number of carcasses at sea will help sea turtle managers develop more accurate estimates of mortality rates. This research provides the first attempt to identify seasons when turtles are, and are not, likely to strand. It also provides the first evidence to sea turtle managers that incidental stranding limits (ISLs) need to be recalculated on a seasonal basis, in light of oceanographic conditions. Such information could then be applied in fisheries management to create more accurate time and area closures for fisheries with historic bycatch of sea turtles.

Although coastal water circulation tends to be local and hence difficult to predict primarily due to shoreline geography and bathymetry (S. Lozier, personal communication), recent advances in coastal current modeling made by Werner et al. (1999) allowed us to predict near-shore surface currents in the South Atlantic Bight (SAB). In our analysis, we compare turtle stranding patterns to modeled currents; the inference derived from the model helps to clarify the relationship between at-sea turtle mortality and on-shore turtle strandings.

Population biology and physical oceanography have, until recently, been scientific fields with little crossover. Our goal in this paper is to examine how oceanographic and wind conditions potentially affect the flow of carcasses at sea, in hopes that we may be better able to interpret perceived trends in strandings numbers, not only for sea turtles, but also for other marine animals. This paper provides a starting point for more robust analyses and demonstrates that stranding research requires knowledge of a species' distribution as well as an understanding of seasonal physio-oceanic processes.

### 1.1. *Case study: NC sea turtle strandings*

Loggerhead (*Caretta caretta*) and Kemp's ridley (*Lepidochelys kempii*) sea turtles are typically the most common species to strand on ocean-facing beaches in NC. Among the five marine turtle species that reside in or migrate through US coastal waters, *C. caretta* and *L. kempii* are classified under the US Endangered Species Act as threatened and endangered, respectively (NRC, 1990). Despite their current regulatory status, NC Loggerheads are part of the "northern" subpopulation that is declining (NMFS, 2001). Incidental death via shrimp trawling has been cited as the most important source of anthropogenic mortality for sea turtles in US waters (NRC, 1990), but scientists have yet to quantify whether turtle strandings in one region are influenced by local fishing effort in another.

Ideally, attempts to investigate stranding patterns should account for factors that affect the initiation and duration of carcass buoyancy (e.g., turtle size, carcass decomposition rate, water temperature, and presence of scavengers) and the probability of carcass landfall (e.g., direction, intensity, and seasonality of prevailing winds, surface and near-bottom current regimes, lunar tides, and the spatial proximity of mortality sources to shore) (NRC, 1990; Crowder et al., 1995; Epperly et al., 1996; Lewison et al., 2003). However, this information is not always available or known. Oceanic conditions that produce nearshore currents could facilitate the stranding of drifting turtle carcasses (Crowder et al., 1995), and hence partially explain the increased number of strandings observed during certain seasons in the northwestern Atlantic (e.g., spring; Amos, 1989). Similarly, winter wind regimes may initiate net offshore flow in shelf waters, thus precluding or reducing carcass landfall (Epperly et al., 1995a). This paper represents the first published attempt to integrate physical oceanography with sea turtle strandings data to examine the possible forcing effect of nearshore marine processes and dynamics.

## 2. Materials and methods

By combining several novel yet complementary data sets (Table 1), we took a multi-faceted approach to understand and interpret patterns in sea turtle strandings.

### 2.1. *Marine turtle stranding data*

We obtained sea turtle stranding records from 1995 to 1999 for NC, sorted it by month, and filtered the spatially referenced data to include strandings only occurring on ocean-facing beaches. Through $\chi^2$ analyses (Steel et al., 1997), we tested the null hypothesis of uniform stranding distributions within two cuspate bays, Raleigh Bay and Onslow Bay, during May and June, the months when the highest cumulative number