Ecological Indicators 84 (2018) 319–336

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Consequences of drift and carcass decomposition for estimating sea turtle mortality hotspots

Bianca S. Santos[a,*], David M. Kaplan[a], Marjorie A.M. Friedrichs[a], Susan G. Barco[b], Katherine L. Mansfield[c], James P. Manning[d]

[a] *Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA 23062, United States*
[b] *Virginia Aquarium & Marine Science Center, Virginia Beach, VA 23451, United States*
[c] *University of Central Florida, Biology Department, Orlando, FL 32816, United States*
[d] *National Oceanic Atmospheric Administration, Northeast Fisheries Science Center, Woods Hole, MA 02543, United States*

ARTICLE INFO

Keywords:
Sea turtle strandings
Sea turtle mortality
Chesapeake bay
Carcass decomposition
Drift leeway
Drift simulations
Endangered species
Conservation

ABSTRACT

Sea turtle strandings provide important mortality information, yet knowledge of turtle carcass at-sea drift and decomposition characteristics are needed to better understand and manage where these mortalities occur. We used empirical sea turtle carcass decomposition and drift experiments in the Chesapeake Bay, Virginia, USA to estimate probable carcass oceanic drift times and quantify the impact of direct wind forcing on carcass drift. Based on the time period during which free-floating turtle carcasses tethered nearshore were buoyant, we determined that oceanic drift duration of turtle carcasses was highly dependent on water temperature and varied from 2 to 15 days during typical late spring to early fall Bay water conditions. The importance of direct wind forcing for turtle carcass drift was assessed based on track divergence rates from multiple simultaneous deployments of three types of surface drifters: bucket drifters, artificial turtles and turtle carcass drifters. Turtle drift along-wind leeway was found to vary from 1 to 4% of wind speed, representing an added drift velocity of approximately 0.03–0.1 m/s for typical Bay wind conditions. This is comparable to current speeds in the Bay (0.1–0.2 m/s), suggesting wind is important for carcass drift. Estimated carcass drift parameters were integrated into a Chesapeake Bay oceanographic drift model to predict carcass drift to terrestrial stranding locations. Increased drift duration (e.g., due to low temperatures) increases mean distance between expected mortality events and stranding locations, as well as decreases overall likelihood of retention in the Bay. Probable mortality hotspots for the peak month of strandings (June) were identified off coastal southeastern Virginia and within the lower Bay, including the Bay mouth and lower James River. Overall, results support that sea turtle drift time is quite variable, and varies greatly depending on water and air temperature as well as oceanic conditions. Knowledge of these parameters will improve our ability to interpret stranding events around the globe.

1. Introduction

Coastal strandings of deceased sea turtles provide a unique opportunity to study drivers of mortality in the world's threatened and endangered sea turtle populations (Epperly et al., 1996, Hart et al., 2006). However, interpreting coastal strandings of dead sea turtles can be challenging for a number of reasons. Level of turtle carcass decomposition and/or lack of visible injuries often make determining the cause of mortality impossible. Furthermore, although stranding events provide a general time period and region of mortality, they do not provide a specific space-time location for mortality events that can be directly related to potential causal factors (e.g., human activities, environmental conditions, etc.). Management guidelines have highlighted the need to better understand landfall patterns of stranded sea turtles to infer possible causes of mortality from mortality locations (Turtle Expert Working Group, 1998).

Sea turtle carcasses typically sink upon death, until the accumulation of decomposition gases causes the body to bloat and float to the surface (Epperly et al., 1996). At this point, the body is partially submerged and acts as a drifting object. The drift of a deceased sea turtle from death at-sea to a terrestrial stranding location depends on physical forces, namely the direction and intensity of local currents and winds (Epperly et al., 1996, Hart et al., 2006). Forecast models integrating these physical forcing mechanisms can be used to predict the trajectories of drifting objects, including deceased sea turtles. However, the drift characteristics of turtle carcasses, such as the

* Corresponding author.
E-mail addresses: bsantos@vims.edu (B.S. Santos), dmk@vims.edu (D.M. Kaplan), marjy@vims.edu (M.A.M. Friedrichs), sgbarco@virginiaaquarium.com (S.G. Barco), kate.mansfield@ucf.edu (K.L. Mansfield), james.manning@noaa.gov (J.P. Manning).

http://dx.doi.org/10.1016/j.ecolind.2017.08.064
Received 5 June 2017; Received in revised form 25 August 2017; Accepted 29 August 2017
Available online 25 September 2017
1470-160X/

impact of direct wind forcing on carcass movements and the period of time carcasses are positively buoyant and, therefore, capable of significant horizontal movements at the ocean surface, are poorly understood. Careful interpretation of stranding observations based on detailed knowledge of these carcass drift parameters is necessary to better identify probable space-time coordinates of mortality events.

The Chesapeake Bay (Bay) and its surrounding coastal waters are critical forging and developmental habitat for the approximately 5000 to 20,000 sea turtles (primarily juveniles) who use Bay waters seasonally (Musick and Limpus 1997, Coles 1999, Mansfield et al., 2009). However, a significant number of sea turtle strandings are recorded on local beaches each year. Approximately 100–300 sea turtles are found stranded on Virginia's coastline, of which the vast majority are deceased (Mansfield 2006, Swingle et al., 2015). Despite a number of management efforts aimed at reducing turtle mortality, hundreds of turtles continue to wash up every year (National Marine Fisheries Service, 2006, Dealteris and Silva 2007, Swingle et al., 2015). Furthermore, as most fatalities potentially go unobserved due to low likelihood of landfall and carcass decomposition, these stranding events may considerably underestimate total at-sea mortality (Murphy and Hopkins-Murphy, 1989, Epperly et al., 1996). With all sea turtles within U.S. waters classified as threatened or endangered (National Research Council, 1990), there is a pressing need to understand stranding events and identify sources of mortality to ensure population recovery.

Here we address two key uncertainties when estimating mortality locations using stranding data and oceanographic drift simulations: (1) the probable amount of time dead turtles drift before stranding on shore, and (2) the correction to pure oceanic drift needed to account for direct wind forcing on turtle carcasses floating at the surface. A critical factor influencing oceanic drift times is the decomposition rate of carcasses, which controls both how long the carcass will remain buoyant and what decomposition state it will be in when it strands. Carcass decomposition studies are needed to relate the level of decomposition of observed stranded turtles to probable water drift times; however, very limited research on carcass decomposition has been conducted on sea turtles. Higgins et al. (1995) observed the complete decay of two Kemp's ridleys to occur within 4-12 days; however, one turtle yielded unreliable results due to inconsistencies in sampling protocol between treatments. Furthermore, this study's subtropical location in the Gulf of Mexico may not be representative of the more temperate conditions in our region, the Chesapeake Bay. Intermittent observations noted in Bellmund et al. (1987) of five dead turtles entangled in a pound net in the Chesapeake Bay suggests total decay to occur on a much longer time scale, upwards of 5 weeks, yet detailed information on oceanographic conditions, time of year, or turtle sizes are not presented in the study. The discrepancies in decomposition results, limited ocean temperature range, and small sample sizes highlight the need for controlled field studies relating carcass condition to probable drift time over a range of environmental conditions.

In addition, whereas ocean circulation models are often available to assess the impact of currents, little is known about the impact of direct wind forcing on the surface transport of turtle carcasses. An object's movement through water caused by surface winds is referred to as it's leeway (Allen and Plourde, 1999, Breivik et al., 2011). The impact of winds on drifting objects is generally assessed in terms of leeway coefficients representing the fraction of the wind speed that must be added to the along-wind and cross-wind current components to accurately simulate drift patterns (Allen, 2005). Field experiments to determine leeway coefficients have been carried out to assess drift characteristics of a variety of objects, such as watercrafts and human bodies, primarily for the purposes of search and rescue operations (Allen and Plourde, 1999, Breivik et al., 2011). Some studies have investigated the drift of animal carcasses in relation to likelihood of carcass landfall (Degange et al., 1994), but few provide specific estimates of carcass leeway parameters (Bibby and Lloyd, 1977, Bibby, 1981). Nero et al. (2013) evaluated turtle carcass leeway from the track of a single tagged moribund turtle, providing the sole estimate of sea turtle wind-induced drift in the literature. There is a noted need to combine experimentally obtained drifter data with oceanographic models to better understand how oceanic conditions affect the flow of carcasses at sea (Hart et al., 2006, Nero et al., 2013, Koch et al., 2013). To address this data gap, we carried out field drift experiments to better estimate the impact of winds on turtle carcass drift patterns (specifically, the along-wind and cross-wind leeway coefficients).

Results from both the decomposition study and the carcass drift experiments were used to parametrize a carcass drift model and provide initial estimates of probable mortality locations from deceased sea turtle strandings data for coastal areas in the Chesapeake Bay. Collectively, the outcomes of this study enhances our ability to infer locations of mortality from stranding events in the Bay, as well as elsewhere around the globe.

2. Materials and methods

For simplicity in this study, we will use the term "stranding" to refer to the final beached location of a deceased sea turtle. Though stranding datasets often also include data on sick or injured sea turtles that are alive, simulation of the movements of these individuals is greatly complicated by their potential for active swimming, and, therefore, we focus exclusively on deceased individuals.

2.1. Decomposition study

When stranded turtles are found on the beach (which generally occurs within 12 h of stranding in populated areas), carcass condition is assessed on a condition code scale from 1 (freshly deceased; we are excluding alive code 0 strandings) to 5 (bones) as per the National Oceanographic and Atmospheric Administration's Sea Turtle Stranding Salvage Network (STSSN) stranding report forms and guidelines (http://www.sefsc.noaa.gov/species/turtles/strandings.htm) (Table 1). We conducted carcass decomposition experiments to relate condition codes to probable post-mortem in-water times for a variety of environmental conditions. The decomposition rate of eight juvenile sea turtles, including two loggerheads (*Caretta caretta*), two Kemp's ridleys (*Lepidochelys kempii*) and four greens (*Chelonia mydas*), ranging in size from 26.3 to 68.0 cm straight carapace length notch to tip and 2.38–36.5 kg in mass, were assessed during the summers of 2015 and 2016. Carcasses were supplied by the Virginia Aquarium & Marine Science Center Stranding Response Program (VAQS) and Maryland's Department of

Table 1
Summary of condition code criteria. Descriptions are compiled from observations noted during the sea turtle decomposition study and the National Oceanographic and Atmospheric Administration's Sea Turtle Stranding Salvage Network stranding report forms and guidelines (http://www.sefsc.noaa.gov/species/turtles/strandings.htm).

Condition Code	Carcass State	Criteria
0	Alive	
1	Fresh dead	No odor, scutes and skin intact, no bloating, turtle may still be in rigor
2	Moderately decomposed	Mild to strong odor, slightly to very bloated, body mostly intact with skin and scutes only beginning to peel, some small cuts/scratches, internal organs still distinguishable
3	Severely decomposed	Carcass deflated, strong to no odor, moderate to significant amount of skin peeling, internal organs beginning to liquefy, hard to distinguish individual organs, large abrasions on body cavity
5	Skeleton, bones only	Carapace and plastron no longer held together, any soft tissue remains are minimal and unidentifiable, bones are clean or have minimal attached tissues