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Dangerous dining: surface foraging of North Atlantic right whales increases risk of vessel collisions

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North Atlantic right whales are critically endangered and, despite international protection from whaling, significant numbers die from collisions with ships. Large groups of right whales migrate to the coastal waters of New England during the late winter and early spring to feed in an area with large numbers of vessels. North Atlantic right whales have the largest *per capita* record of vessel strikes of any large whale population in the world. Right whale feeding behaviour in Cape Cod Bay (CCB) probably contributes to risk of collisions with ships. In this study, feeding right whales tagged with archival suction cup tags spent the majority of their time just below the water's surface where they cannot be seen but are shallow enough to be vulnerable to ship strike. Habitat surveys show that large patches of right whale prey are common in the upper 5 m of the water column in CCB during spring. These results indicate that the typical spring-time foraging ecology of right whales may contribute to their high level of mortality from vessel collisions. The results of this study suggest that remote acoustic detection of prey aggregations may be a useful supplement to the management and conservation of right whales.

Keywords: foraging ecology; endangered species; vessel collision; right whale

1. INTRODUCTION

North Atlantic right whales (*Eubalaena glacialis*) are critically endangered and, despite international protection from whaling, significant numbers die from collisions with ships [1]. During the winter and spring, a majority of the remaining population of right whales migrates to New England waters to feed, residing for months in a region also intensively used by coastal and international shipping [2].

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North Atlantic right whales have the largest *per capita* record of vessel strikes of any large whale population in the world [3].

Almost half (45%) of the right whale population was present in Cape Cod Bay (CCB) in the late winter and early spring of 2010 [4]. In the spring, these whales are commonly observed feeding at or just below the water's surface on dense patches of copepods, their preferred zooplankton prey [5]. Right whale feeding behaviour in CCB is probably a contributing factor to collisions with ships. There have been five confirmed right whale deaths owing to ship strike in and around CCB in spring months over the past 30 years [6]. Previous tagging studies of right whales on their summer feeding grounds demonstrated that right whale dive depth closely tracks the peak concentration of their prey [7]. In this study, we combine data on the diving behaviour of feeding right whales with data on the distribution of their prey in the water column in CCB, to assess whether the foraging ecology of right whales leads to increased risk of vessel collisions.

2. MATERIAL AND METHODS

This study was conducted in April of 2009 and 2010, using a combination of a suction cup archival recording tag to document the subsurface behaviour of individual right whales, and direct (net and pump sampling) as well as indirect (acoustic backscatter) sampling methods to quantify and track the distribution of the right whale prey in the bay. Our goal was to measure the time right whales spend at a depth where they are most vulnerable to being struck by a ship.

(a) *Tagging*

An archival recording tag with suction cups (Dtag) [8] was attached to 13 individual North Atlantic right whales in CCB, MA, USA (41°–42° N latitude, 70°–70.5° W longitude) in April 2009 and 2010, for periods of 0.5–4.8 h (mean = 2.2 h, s.d. = 1.47 h). The depth (pressure) sensor of the tags has an accuracy of ±0.5 m. Dive profiles were derived from the pressure sensor data from tagged whales (figure 1).

(b) *Active acoustic prey sampling*

In 2010, a towfish with multiple frequency acoustic echosounders (SIMRAD ES 60 (38, 120 and 200 kHz) and EK 60 (710 kHz)) measured volume backscattering strength in the water column around the tagged whale (electronic supplementary material, figure S1). The system was towed off the starboard beam of the large vessel at a speed of approximately 5 knots at a depth of 0.25 m. Owing to near-field effects of the acoustic echosounders, volume backscatter data were collected from depths of 2.0 m (38 kHz), 1.0 m (120 and 200 kHz) and 0.5 m (710 kHz) to the sea floor. Single beam (38, 200 and 710 kHz) and split beam (120 kHz) systems were used. The ping rate was 0.5 Hz with the system defaults for all other parameters for all systems. CCB has a mean depth of 30 m, so data were averaged into depth bins of 0.25 m for 38, 120 and 200 kHz and 0.05 m for 710 kHz. All echosounders were calibrated in CCB using a 38.1 mm diameter Tungsten carbide sphere.

Scatterers were acoustically identified as being small crustaceans (copepods) when the volume backscatter strength at 710 kHz was more than 10 dB greater than at 38, 120 or 200 kHz, thus eliminating fish and large crustaceans from inclusion in the volume backscatter used to estimate copepod abundance. Such data filtering does not exclude non-biological sources of scattering; however, we do not believe those contributions to be large because the acoustic estimates of copepod distribution and abundance agree strongly with those from the net and pump sampling. A distorted wave born approximation scattering model [9] calculated the target strength (TS) at 710 kHz of a 1.5 mm-long copepod (mean length of copepods sampled in this study) to be −114.6 dB. Volume backscattering strengths (S_v) were converted to numerical density (N) estimates by $S_v = 10\log_{10}(N) + \mathrm{TS}$.

(c) *Net sampling*

Vertical net casts to depths of 1, 5 or 20 m depth were conducted at 10 sites in CCB, using a 0.5 m diameter ring net with 150 µm mesh.

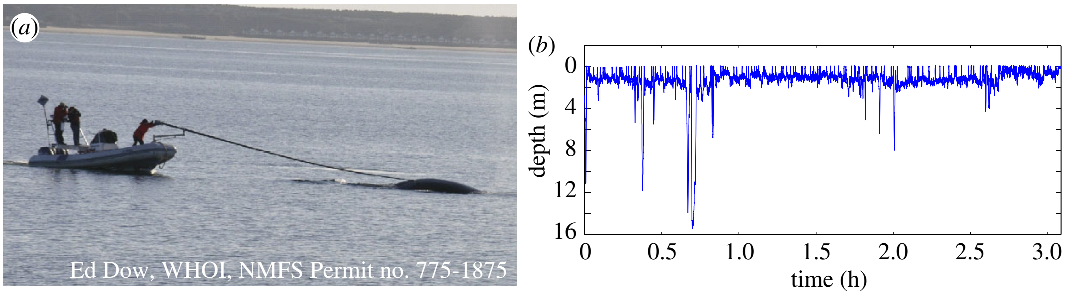

Figure 1. (*a*) Attachment of the suction cup Dtag to the back of a North Atlantic right whale and (*b*) the resulting dive depth profile for this individual whale.

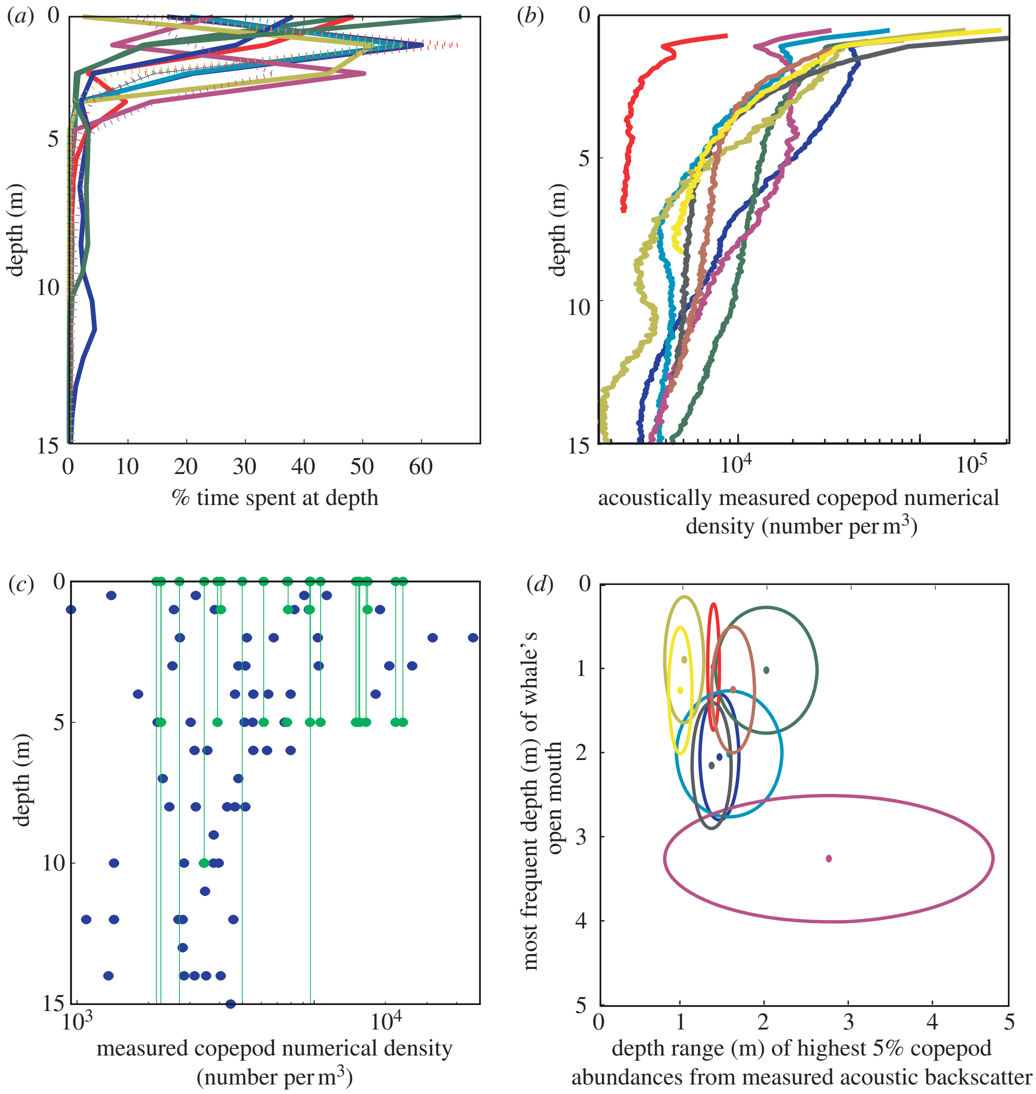

Figure 2. (*a*) Percentage of the total time each tagged whale spent in 1 m depth bins. Dashed lines, 2009 data; solid lines, 2010 data, (*b*) Acoustic backscatter estimates of copepod numerical density by depth from 2010 measured near tagged right whales ($n = 9$), (*c*) net tow (green) and pump sample (blue) measurements of copepod numerical density from 2009 and 2010 measured near tagged or feeding right whales, and (*d*) peak (most frequent) depth of a feeding right whale's open mouth (top of ellipse shows measured tag depth, central point estimates centre of the whale's open mouth, with the estimated 1.5 m mouth gape for a feeding whale) and the depth range of the greatest 5% of copepod abundance in the water column based on acoustic backscatter measurements for whales from 2010. Dive profile and acoustic backscatter measurements are colour-coded to indicate measurements from individual whales.

Sampling sites were within 500 m of tagged right whales. Samples were preserved in 10 per cent buffered formalin solution, with subsamples being identified (to species when possible) and enumerated using compound and dissecting microscopes.

(d) *Pump sampling*

Vertical profiles of zooplankton abundance were sampled within approximately 500 m of the tagged whales. A discrete depth vertical pump [10] was used to filter a known volume of sea water through a

333 μm mesh [11]; all samples were rinsed off the mesh with sea water and preserved with 6–8% buffered formalin. Date, time, location, depth of sample and depth of water column were recorded in a data-logging program for each sample collected. Each vertical profile was therefore made up of discrete depth samples, for which metadata were uniformly collected.

3. RESULTS

The dive data from 13 tagged right whales indicate that the whales spent the majority (mean = 84%, range 62–98%) of their time with their dorsal surface between 0.5 and 2.5 m of the water's surface, making them difficult to see and vulnerable to collisions with vessels of a range of sizes (figure 2*a*). The most abundant zooplankton in the net samples were *Calanus finmarchicus* (C-IV, C-V and adult). *Psuedocalanus newmani* and *Oithona similus* were also present. The daytime distribution of copepods documented by acoustic backscatter data, pump and net sampling identified high concentrations of zooplankton only in the upper 5 m of the water column (figure 2*b*,*c*). Prey sampling around tagged whales found that these surface patches often covered an area greater than several square kilometres and persisted for several hours. Acoustic estimates and pump sampling of the prey field in the surface layers near feeding whales found numerical densities of 10^3–10^5 m^{-3} copepods (and in some regions greater than 10^5 m^{-3}). Previous studies [5] established a feeding threshold of approximately 10^3 m^{-3} copepods for right whales in this habitat. There was a strong relationship between the depth of the centre of a feeding whale's mouth and the mean depth of the top 5 per cent concentration of their prey in the water column (figure 2*d*; $r^2 = 0.44$).

4. DISCUSSION

The diving behaviour of foraging whales observed during this study was markedly different from dive profiles described in other deeper water habitats, and in CCB during times of year when prey aggregate at depth [7]. The stereotyped deep 'flat-bottom' dives described for right whales feeding on deeper prey aggregations [7] were not observed during this study. Instead, most whales stayed at or just below the surface while actively feeding, at a depth that corresponded to the peak concentration of their zooplankton prey.

While in-the-field monitoring and research remain important components of right whale conservation, remote monitoring for right whales can be used to alert managers, and in turn boat operators, of whale presence. Currently, a real-time passive acoustic monitoring (PAM) network of buoys is in place to monitor for right whale vocalizations in Massachusetts waters [12]. However, our data indicate that tagged right whales did not vocalize while actively feeding, leaving whales exposed to the risk of ship strike while they are particularly vulnerable because of their shallow dive pattern. The development of autonomous active acoustic echosounders for remote detection of zooplankton to be moored in feeding habitats may provide an additional way to remotely monitor the influential right whale prey patches, and therefore, may be a key way of predicting the location of right whales [13], their diving behaviour and the risk of ship collision.

This study highlights the importance of documenting endangered species' ecology to the management of anthropogenic risks that hinder population recovery. In this example, the seasonal behaviour of right whale prey makes right whales in CCB particularly vulnerable to collisions with vessels during April. CCB has been dynamically managed for 13 years using aerial right whale surveys, boat-based zooplankton surveys [4] and more recently PAM [14] to alert managers to the presence of right whales in the bay. When feeding right whales aggregate around a surface or subsurface zooplankton resource, dynamic management areas with voluntary speed restrictions are implemented to warn mariners of increased ship strike risk [4]. The results of this study support the management strategy used in CCB, and suggest that remote acoustic detection of prey aggregations may be a useful supplement to the study and management of right whales. More broadly, understanding the typical foraging ecology of threatened or endangered species can lead to better predictions of their distribution, and identify locations and periods of particular vulnerability for negative anthropogenic interactions.

Tag data, photographs, and nearby zooplankton samples were collected under NOAA NMFS Scientific Permit nos. 655-1652-01, 775-1875 and 633-1763 and were approved by the Penn State Institutional Animal Care and Use Committee.

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