

**ANALYSIS OF NORTH ATLANTIC RIGHT WHALE
SWIMMING BEHAVIOR DURING BOTTOM
FORAGING EVENTS TO ASSESS
ENTANGLEMENT RISK**

by

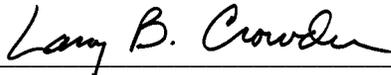
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ABSTRACT

The western North Atlantic right whale, *Eubalaena glacialis*, is critically endangered throughout its range. With approximately 300 individuals remaining, this population suffers significant impacts from entanglement in commercial fishing gear that are impeding the species' ability to recover from historic hunting pressures. The purpose of this study was to evaluate the circumstances surrounding serious entanglements. Data collected from foraging right whales tagged in 2001 and 2002 were analyzed to identify behavior(s) that may increase the risk of entanglement in certain types of gear at certain depths. Results suggest that foraging right whales display 'risky' behaviors that may increase their chances of becoming entangled, including swimming at depths where floating loops of line from bottom-fixed gear extend into the water column, and increased rolling behavior through vertical line during the ascent and descent portions of the dive cycle. This work could contribute to current conservation efforts on behalf of the whale by informing the design of more 'whale-friendly' fishing gear, as well as help managers determine more effective mitigation strategies to reduce the risk that fishing gear poses to right whales.

TABLE OF CONTENTS

ABSTRACT.....	1
ACKNOWLEDGEMENTS.....	3
INTRODUCTION.....	4
<i>Purpose and Objectives.....</i>	4
<i>Overview: Status of Right Whales.....</i>	5
<i>Entanglements.....</i>	6
<i>Research.....</i>	12
METHODS.....	15
<i>DTAGs and Data Collection.....</i>	15
<i>Data Analysis.....</i>	16
RESULTS.....	18
<i>Tag Data.....</i>	18
<i>Proximity to Bottom.....</i>	19
<i>Rolling Behavior.....</i>	21
DISCUSSION.....	22
<i>Fishing Gear and Proximity to Bottom.....</i>	23
<i>Fishing Gear and Rolling Behavior.....</i>	24
<i>New Gear Modifications.....</i>	25
<i>Conclusions.....</i>	26
<i>Future Work.....</i>	27
LITERATURE CITED.....	30
FIGURES.....	33
<i>Figure 1: Example of a dive profile.....</i>	33
<i>Figure 2: Proximity to bottom, RW213b.....</i>	33
<i>Figure 3: Proximity to bottom, RW220.....</i>	34
<i>Figure 4: Proximity to bottom, RW233.....</i>	34
<i>Figure 5: Example of a ‘typical’ roll profile.....</i>	35
<i>Figure 6: Roll variation within individual.....</i>	35
<i>Figure 7: Roll variation between individuals.....</i>	36
<i>Figure 8: Examples of non-stereotyped roll behavior.....</i>	37
<i>Figure 9: Questions of scale.....</i>	38
<i>Figure 10: Lobster pot/trap gear.....</i>	39
<i>Figure 11: Gillnet gear.....</i>	39

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Introduction

PURPOSE & OBJECTIVES

The purpose of this study is to provide researchers with information on the foraging behaviors of individuals within the highly endangered population of western North Atlantic right whales (*Eubalaena glacialis*) found off the east coast of the U.S. and Canada. In addition, this project provides resource managers with insight into those behaviors which are likely to present challenges to their goal of reducing injury and mortality from entanglement in commercial fishing gear.

First, I present the preliminary results of a recent and on-going study on right whale foraging ecology and dive behavior, a subject of some of the most important scientific research addressing entanglement problems. My project represents the first attempt to provide a detailed characterization of right whale locomotor behaviors using an extremely dense data set recorded by innovative digital tags. While this particular project is not yet complete, it is intended that these results will point out potentially ‘risky’ behaviors to researchers interested in analyzing these data in more detail.

Second, this project brings together the most current data available on the status of the population with information on the regulations that are designed to reduce serious injury and mortality from entanglement in commercial fishing gear. In this study, I investigate the potential effectiveness of current and proposed gear modifications by comparing the locomotor behaviors of right whales during bottom foraging events to specific characteristics of the portions of bottom-set fishing gear believed to be most dangerous. This examination should assist managers in their efforts to select more appropriate mitigation strategies for the reduction of entanglement risk.

In summary, the objectives of this study are:

- (1) to investigate the swimming behavior of right whales during bottom foraging events; and
- (2) to show how some of these behaviors may increase entanglement risk in certain parts of gear, at certain depths.

OVERVIEW

Since the establishment of international protections for large whales during the middle of the last century, many populations are recovering from historic whaling and the prospect for most species appears good (Clapham *et al.* 1999). In contrast, the North Atlantic right whale remains critically endangered throughout its range, and continues to experience low abundance and high anthropogenic mortality (Clapham *et al.* 1999, NMFS 2003, 2005). Recent estimates indicate that the eastern North Atlantic population is nearly extinct (Brownell *et al.* 1999, Clapham *et al.* 1999), and the western North Atlantic population numbers only about 300 individuals (NMFS 2005).

The western North Atlantic right whale is distributed adjacent to a highly developed coastline, making it more vulnerable to human activities than many other whale species (Clapham *et al.* 1999). Principal among these threats are ship strikes and entanglements in fishing gear, which together are responsible for a vast majority of right whale anthropogenic mortality (Clapham *et al.* 1999, IWC 1999, Knowlton and Kraus 2001, Laist *et al.* 2001). Interestingly, however, other large whale species with similar distributions are doing comparatively well. Fin whales, for example, do not seem to be as susceptible to entanglements and ship strikes as right whales, even though they forage

near the same areas (Waring *et al.* 2003, NMFS 2005). Similarly, humpback whales are recovering, even though they are frequently entangled (Palsbøll *et al.* 1997, Smith *et al.* 1999, Robbins and Mattilla 2000). In contrast, recent evidence indicates that the western North Atlantic right whale population is declining despite almost seven decades of protection, and whale biologists predict that under the status quo, the species will go extinct within the next 200 years (Caswell *et al.* 1999). Further conservation and management action is urgently required to reduce the frequency of ship collisions and entanglements, and thus allow this population to begin to recover (Caswell *et al.* 1999, Knowlton and Kraus 2001, NMFS 2003).

Under the Marine Mammal Protection Act of 1972, management of the North Atlantic right whale falls within the jurisdiction of the National Marine Fisheries Service (NMFS) (16 USC 1631 *et seq.*). In addition, this species is afforded protection under the Endangered Species Act of 1973 (16 USC 1531 *et seq.*). Under the ESA, NMFS is mandated to conserve the right whale and must undertake actions to prevent further decline of the population, facilitate its recovery, and safeguard the quality of its habitat. As part of this mandate, NMFS must ensure that fishing operations authorized by the agency do not jeopardize the species' continued existence.

ENTANGLEMENTS

Between 1970 and 1999, approximately 6% of all known right whale deaths were due to entanglement in commercial fishing gear (Caswell *et al.* 1999, NMFS 2000). More than half the population bear scars from interactions with fishing gear, and, more importantly, the average rate of serious injuries caused by entanglements has been

increasing in recent years (Knowlton *et al.* 2002). Today, entanglement causes from 10% to upwards of 30% of all deaths (Knowlton and Kraus 2001, Johnson 2005).

Whale entanglements can involve multiple body parts, including the rostrum (upper jaw), flipper bases and tail stock, but line in the mouth is the most frequent type of serious injury (Knowlton and Kraus 2001, Johnson *et al.* 2005). Mouth entanglements are also believed to be the most lethal, as they compromise the animal's ability to feed (Knowlton *et al.* 2002).

Many different types of gear can be involved in entanglements, but it is believed that right whales most commonly become entangled in bottom-set gear marked by surface floats, particularly gillnet and lobster pot/trap gear (Clapham *et al.* 2003, Johnson *et al.* 2005). In the few cases where managers have been able to identify the type of gear involved in entanglement, lobster pot and gillnet line are most frequently implicated (Knowlton and Kraus 2001, Clapham *et al.* 2003, Johnson *et al.* 2005). Floating line is hypothesized to be the most common part of fishing gear involved in right whale entanglements, prompting NMFS to propose that fishing line in the water column presents the highest risk to the animals (NMFS 2003). Current management measures, therefore, aim to reduce the amount of vertical line in the water column.

To address the problem of entanglements, NMFS established the Atlantic Large Whale Take Reduction Team in 1996 pursuant to section 118(f)(1) of the 1994 Amendments to the MMPA, which charges the agency with the development and implementation of a Take Reduction Plan (ALWTRP, or Plan). The goal of the Plan is to reduce take to a level less than the Potential Biological Removal level within six months of its implementation, and the Plan is continually adjusted to further reduce the

probability of entanglement. The Potential Biological Removal (PBR) level is defined under the MMPA as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock annually while allowing that stock to reach or maintain its optimal sustainable population (OSP) level.⁽¹⁾ Researchers believe the population is well below OSP, and as such the PBR has been set to zero (Waring *et al.* 2003). For this reason, the loss of even a single individual, and particularly a reproductive female, is considered detrimental to this population.

Currently, five commercial fisheries in particular are believed to be most often involved in entanglements along the Atlantic coast: the Northeast/Mid-Atlantic American lobster trap/pot fishery, the Northeast sink gillnet fishery, the Southeast Atlantic gillnet fishery, the Southeastern U.S. Atlantic shark gillnet fishery, and the Mid-Atlantic coastal gillnet fishery (NMFS 2005). As a result, the ALWTRP is intended to reduce incidental bycatch of right whales in these fisheries through recommendations on education, management and enforcement.

Under the Plan, fishers are subject to a combination of two types of restrictions on their activities: gear modifications and time-area closures. Gear modifications can be temporary or permanent, fishery-specific or universal, and are designed to reduce the severity of entanglement. Time-area closures entail removal of gear from the water when whales are present, and include critical habitat areas (CHAs), and area management zones (Seasonal Area Management zones (SAMs) and Dynamic Area Management zones (DAMs)). Closures are designed to reduce the chances of entanglement.

⁽¹⁾ Parameters used to calculate OSP and PBR are defined in the MMPA (16 USC 1362(9)).

Temporary Gear Modifications. Temporary modifications are imposed in area closures (described below), and are fishery-specific. They include the use of sinking or neutrally buoyant line only (*i.e.*, no floating line), the use of only one buoy line for a minimum number of traps or net string, and the incorporation of ‘weak links’ into specific parts of the gear. The first two modifications are designed to reduce the amount of vertical line in the water column, which NMFS suspects poses the highest entanglement risk to large whales. The last modification is meant to make the surface buoy and bottom set gear easily separable from the rest of the line should a whale encounter any part of the gear, thus reducing the severity of, or preventing, the entanglement.

Universal Gear Requirements. In addition to fishery-specific modifications imposed under the area closures, a set of Universal Requirements are in effect year-round for all lobster pot/trap fisheries and anchored gillnet fisheries. They are always required in addition to the temporary regulations imposed by time-area closures: no buoy line floating at the surface; no wet storage of gear (all gear must be hauled out of the water at least once every thirty days); and fishermen are encouraged, but not required, to maintain knot-free buoy lines.

Critical Habitat. The establishment of critical habitat areas (CHAs) is required under the Section 7 of the ESA, and for right whales these areas include the Cape Cod Bay and Great South Channel CHAs in the north, and the Southeast U.S. CHA in the south. Under the Take Reduction Plan, some fisheries are required to remove gear from some of

the CHAs seasonally, while others can continue to fish in these areas year-round using ‘Low Risk’ gear.

Seasonal Area Management. SAMs are imposed in areas outside critical habitat that support predictable aggregations of right whales, and have specific boundaries and pre-designated closing and opening dates. The current SAM program incorporates two zones: SAM West, which is in effect from March 1 through April 30, and SAM East, which is in effect from May 1 through July 31. Fishers have the options of either removing their gear from the SAM zones during the designated times, or continuing to fish within the zones using gear modified to qualify as ‘Low Risk’ (NMFS 2003).

Dynamic Area Management. DAMs occur in areas without predictable aggregations of right whales, and entail temporary restrictions set off by a ‘trigger event.’ If three or more whales are sighted within a 75 nm² area such that the density is equal to or greater than 0.04 right whales per square nm, that area plus an additional 15 nm buffer around it are designated a DAM for 15 days. DAM zones affect lobster trap/pot and gillnet fishers using areas north of 40°00’ N. Similar to SAM zones, fishers have the option of removing their gear altogether from the DAM zones during the designated times, or continuing to fish within the zones using gear modified to qualify as ‘Low Risk’ (NMFS 2003). Modifications are similar to those imposed on fishers using SAM zones, with some minor differences.

Despite the implementation of regulations created under the ALWTRP, estimates suggest that about 10 percent of the population of western North Atlantic right whales still experience an interaction with commercial fishing gear every year, and that rates of entanglements may actually be increasing (Knowlton *et al.* 2002). The numbers of right whales involved in entanglements were not carefully monitored prior to the implementation of regulations in 1997, so it is difficult to say how successful the regulations have been in reducing interactions with gear (A. Johnson, personal communication; T. Johnson, personal communication). Since 1997, NMFS has frequently adjusted regulations under the ALWTRP to further reduce the risk posed to right whales by commercial fishing gear; it is not yet known, however, whether or not the regulations are having the desired effects due to the very recent establishment of the newest set of rules in early 2004 (A. Johnson, personal communication).

In addition to affecting whales, regulations implemented under the Plan affect fishers. In theory, the reduction of large whale entanglements in fishing gear would indirectly benefit fishers by also reducing loss of or damage to gear; because encounter rates are so low, however, the average benefit to an individual fisher is likely negligible. In contrast, the costs associated with compliance with gear modification or removal requirements are well-documented. For example, NMFS (2005) estimates that approximately 5100 additional vessels will be affected by the newest set of regulations slated to go into effect in the summer of 2005. The costs imposed on the fishing industry will equal approximately \$14.2 million, although the cost to individual fishers is predicted to vary by fishery (NMFS 2005).

Fishers regulated under the Plan will also experience social consequences to restrictions on their activities. For example, the ratio of the cost of compliance to average vessel revenues will force some fishers out of business (NMFS 2005). For others it will mean increased numbers of days at sea, fishing in areas further from home, or a switch to another fishery (NMFS 2005).

However, the question remains as to whether current regulations are actually reducing the frequency or severity of right whale entanglements. Managers are not sure if they are, in fact, targeting the most dangerous parts of gear, or if they are doing so effectively. As such, the question posed here is: will the new gear restrictions reduce right whales entanglements to the point where the western North Atlantic population can begin to recover?

This project aims to address this question by examining the behavior of right whales while swimming at depth, where interactions with bottom-set gear likely occur. For mitigation strategies to be effective, we need to understand the circumstances surrounding entanglement, which means not only understanding the activities of fishers and their gear, but also of the whales themselves.

***RESEARCH: ANALYSIS OF NORTH ATLANTIC RIGHT WHALE SWIMMING BEHAVIOR
DURING BOTTOM FORAGING EVENTS TO ASSESS ENTANGLEMENT RISK.***

Understanding the fundamental characteristics of the right whale's ecology and life history that make it most susceptible to human-caused mortality is critical to understanding how to best manage and protect the species. Thus, in addition to recommendations on how to directly reduce the threat of serious injury to right whales

from entanglements, the Take Reduction Plan contains non-regulatory measures promoting gear research, as well as basic biological research, to fill in important informational gaps for this species.

One important area of research investigates how right whales utilize the water column, including their foraging ecology and diving behavior. Because of the frequency and severity of mouth entanglements, researchers are particularly interested in understanding foraging behavior at depths where right whales are most likely interacting with bottom-set gear. Therefore, several studies have been conducted in the Bay of Fundy, an important summer feeding ground for western North Atlantic right whales.

The Bay is located in Canadian waters just north of Maine, and whales here filter-feed at depth where their prey aggregate. Plankton layers in the Bay of Fundy form just above the bottom mixed layer, the thickness of which is dependent on the rate of flow over the bottom, which changes throughout the tidal cycle (Baumgartner *et al.* 2003a, Baumgartner *et al.* 2003b, Baumgartner and Mate, 2003). This variation could easily lead to layers of *Calanus*—the major prey source for North Atlantic right whales—being only 10's of cm off the bottom.

Furthermore, current work in Cape Cod Bay has found dense plankton layers ≤ 30 cm above the bottom (C. Mayo, personal communication). If a whale is foraging at or near one of these layers, it may turn upside down and swim through the layer, as evidenced by the mud on the heads of surfacing whales, callosity impressions on the bottom, and dorsally mounted tags returning full of mud. While swimming in this orientation, the whale could theoretically get closer to the bottom based on the size and morphology of the head and jaws (M. Moore, personal communication). The whale,

however, could also be rendered more susceptible to sinking versus neutrally buoyant line in this orientation, as evidenced by the high numbers of animals catching line in the mouth.

Therefore, the purpose of this project was to evaluate the behaviors of right whales that may increase their risk of entanglement in certain gear types at certain depths. Specifically, I used data collected with multi-sensor digital acoustic tags, or DTAGs, (Nowacek *et al.* 2001, Johnson and Tyack 2003) to analyze fine-scale motor behavior during foraging dives in an effort to identify behavior(s) that may cause right whales to be disproportionately susceptible to entanglement. I had two main objectives toward accomplishing this goal:

1. To analyze locomotor behaviors of right whales during foraging dives, including proximity to the bottom, and the orientation parameters pitch, roll and heading throughout the dive cycle;
2. To compare their behaviors to certain characteristics of bottom-set fishing gear that may increase the chances of entanglement.

In addition, I compare the swimming behaviors to gear modifications proposed in a Draft Environmental Impact Statement released by NMFS in March of 2005. In other words, can I show from my understanding of right whale foraging movements gained through this study, that these new regulations will effectively target the most dangerous parts of fishing gear?

This is an on-going project that is not yet complete. In previous experiments, acoustic data from DTAGs were used to evaluate risk factors involved in collisions between ships and right whales (Nowacek *et al.* 2004). These studies have shown that

right whales foraging in the Bay of Fundy have stereotypic dive patterns, with some minor differences between individuals. However, there has been no detailed examination of the orientation behaviors recorded by the tag, and as such, this project represents a first attempt at identifying potentially ‘risky’ foraging behavior from the data. Through preliminary analyses of right whale foraging behaviors, I hope to show researchers which areas of the data represent instances where the whales may be increasing their chances of entanglement at certain portions of the dive cycle. Subsequent analyses can then focus on examining these specific behaviors in more detail, and, ideally, contribute to current conservation efforts on behalf of the whale by informing the design of fishing gear that may reduce the chances of entanglement.

Methods

DTAGS & DATA COLLECTION

In the summers of 2001 and 2002, researchers from the Woods Hole Oceanographic Institution attached multi-sensor digital acoustic recording tags (DTAGs) with suction cups to free-swimming whales in the Bay of Fundy, Canada, using the methodology developed by Nowacek *et al.* (2001). DTAGs are small, light-weight, and non-invasive, and are designed to release from the animals in less than 24 hours. They contain a low-power digital signal processor that continuously records behavioral data throughout the dive cycle. The tags record acoustic information at sampling rates of 16 kHz or 32 kHz, immediately synchronized with the sensor measurements acceleration, magnetic field, and pressure; from these measurements, changes in the orientation and

depth of the tagged animals were calculated (Nowacek *et al.* 2001, Johnson and Tyack 2003). Finally, the tag contains a VHF beacon that enables researchers to track each surfacing of tagged animals as well as locate and recover tags after detachment.

DATA ANALYSIS

The high frequency sampling rate of the DTAG allowed for an examination of fine-scale changes in locomotor behavior throughout the dive cycle for each tagged whale. Profiles showing depth, pitch, roll and heading were plotted using Matlab (Student Version 6.5 and Professional Version 7.0) software. These profiles were plotted together to compare differences in the orientation parameters simultaneously throughout the dive cycle. All data were expressed in degrees.

Orientation was expressed in terms of the Euler angles pitch, roll and heading, with reference to the fixed Earth frame (Johnson and Tyack 2003). These parameters describe the main axes of rotation passing through any body, around which that body can pivot. Measurements were corrected for the position of the tag on the whale before they were used to calculate orientation parameters.

In this analysis, a positive pitch refers to a nose-upward tilt, such as during the ascent phase of a dive cycle, and vice-versa. Similarly, a positive roll represents a roll to the right, and a negative roll, a roll to the left. Heading was adjusted to follow the compass convention, with, for example, zero degrees representing a northward track, 90 degrees an eastern track, etc.

To investigate the circumstances surrounding entanglements, right whale behaviors (as characterized by the profiles) were compared to characteristics of fishing gear types most often implicated in entanglements. Characteristics included height from the bottom, floating loops of ground and anchor line, and vertical buoy line connecting the surface system to bottom-set gear—parts of the gear hypothesized to be conducive to entanglement. Specifically for this project, only depth and roll were examined as changes in these two parameters seem most likely to place whales at the greatest risk of more serious entanglement. Whales increase their chances of encountering gear while foraging at depths where gear is set, and rolling behavior would likely increase the severity of an entanglement by ‘wrapping’ the whales in gear. All parameters will be analyzed in future studies.

Depth profiles were examined to determine the whales’ proximity to the bottom while foraging, where managers believe whales may be interacting with gear. It is possible to calculate depth from bathymetric data using latitude/longitude coordinates of the whales throughout the tagging event; unfortunately, the WHOI team was only able to record coordinates during the initial tagging, and opportunistically whenever the whales were resighted as they surfaced between dives. For this reason, only an estimation of proximity to bottom was possible for a limited number of whales.

Using geospatial software ArcView 9.0, depths were extracted by overlaying any coordinates recorded by the WHOI team with a georeferenced, 15 arc-second resolution bathymetric raster file of the Bay of Fundy provided by the U.S. Geological Survey. Estimations of proximity were calculated by extrapolating a line to connect depths extracted from the bathymetry file. Only those whales with coordinates recorded for a

series of at least two dives were used (*i.e.*, it wasn't possible to extrapolate a line indicating depth for whales with only one recording).

Roll profiles were examined to determine portions of the dive cycle when right whales have the potential to increase the severity of their entanglements. Theoretically, a whale that has encountered gear will become more 'wrapped up' in the line while rolling around than a whale that proceeds to swim more or less 'straight.' Recognizing portions of the dive cycle when whales predictably increase their rolling behavior should help identify sections of fishing gear most likely to be involved in entanglement.

Results

The Woods Hole team tagged 14 North Atlantic right whales: 5 in 2001, and 9 in 2002 (Table 1). Due to the small sample size, tag data from both years were combined. In total, tags recorded over 46 hours of dive behavior, for a total of approximately 175 dives. Mean number of dives recorded per whale was 12.5 (maximum = 23, minimum = 4), and 3.3 hours (maximum = 5.5, minimum = 1.0).

As in previous studies (*e.g.*, Nowacek *et al.* 2001, Baumgartner and Mate 2003), tagged whales displayed individualized, stereotyped patterns in large-scale behavior throughout the dive cycle (Fig. 1). Examples of stereotyped behavior included duration of the dive, amount of time spent at each portion of the dive cycle, and foraging depth. Smaller-scale changes in swimming behavior, however, were not so uniform. In this study, small-scale changes in roll varied throughout the dive cycle within and between individuals. In addition, stereotyped, 'predictable' roll behaviors were more

characteristic of whales with few dives recorded—as number of dives recorded increased, so did variability in fine-scale behavior.

PROXIMITY TO BOTTOM

Estimates of depth from bathymetric data indicate that right whales can sometimes forage very close to the bottom. Dive profiles from four whales met the criteria for estimation of proximity to bottom while foraging: RW213b, RW220, RW 232 and RW233. RW232 was eliminated due to a possible misrecording of the time of tag deployment or recovery. Of the remaining three, estimates of proximity varied.

Table 1. Number of hours and dives recorded for each whale tagged in the Bay of Fundy in 2001 and 2002.

	RW#	No. Hours	No. Dives
2001			
	207	5.48	20
	214	1.36	6
	221	1.71	8
	227	4.04	16
	241	2.66	11
2002			
	213b	1.51	7
	213g	5.13	20
	220	1.03	4
	221	7.91	20
	222	1.73	7
	229	4.30	23
	232	4.23	13
	233	1.80	8
	236	3.50	12
	Sum	46.37	175
	Mean	3.31	12.5

Two positional coordinates were recorded for whale 213b, one at the initial time of tagging, and again when the tag fell off the animal after the seventh dive (Fig. 2). Using depth extracted from the bathymetric file, 213b's first dive came to within 10's of centimeters from the bottom, while the last dive was probably 100m above the bottom. Looking closer at the profile, it is clear that 213b displays v-shaped, or 'exploratory' behavior (Baumgartner and Mate 2003) during the first 3 dives, hovers around 80m at the end of the third dive, and then returns to between this depth and 110m on subsequent dives. From here, dives are u-shaped (Baumgartner and Mate 2003), and 213b swims between these depths consistently. It is likely that the whale located a *Calanus* layer between these depths, and that time spent at depth thereafter represents bouts of foraging.

Two sets of coordinates were recorded for RW220 (Fig. 3). Similar to RW232, who was eliminated from analysis, time was inaccurately recorded for this sample; however, because RW220 foraged at a consistent depth along its entire track, and bottom depth varied by only a few meters, it is not necessary to pick out specific dives to still be able to estimate proximity to bottom. It is clear that this whale foraged approximately 30 meters from bottom during each of its four dives, or only about one-third as far above bottom as RW213b.

Figure 4 shows the extrapolation of bottom depth drawn for right whale 233, for whom coordinates were recorded while the whale was surfaced just prior to each of three consecutive dives, the most for any of our whales. From this line it is clear that bottom depth increased with each dive, and that RW233 is approaching this depth while foraging. In contrast to the other two whales, 233 was likely foraging right along the bottom.

While bottom topography in the area where right whales were tagged is relatively flat with little variation (Woodley and Gaskin 1996), extrapolated lines are still oversimplifications of true bottom depth, as depths can vary by 10s of meters in the distance likely covered during one dive cycle. These lines are only meant to convey the point that proximity to bottom during foraging varied both between and within whales, from relatively close to relatively far.

ROLL BEHAVIOR

Right whales in this study tended to roll more during the ascent and descent portions of the dive cycle than while at the surface or foraging at depth (Fig. 5). Most whales displayed stereotypic, patternized roll behavior, although with some differences within (Fig. 6) and between individuals (Fig. 7). A few whales displayed nonstereotyped behavior, with rolls occurring at different portions of the dive cycle along the length of the track (Fig. 8). Again, whales with greater numbers of recorded dives showed more variability in their roll behavior than whales with fewer dives (Fig. 9).

While rolling was more likely during ascent and descent, a few whales did show some roll behavior while foraging at depth (*e.g.*, Fig. 5, 7B, 8A). Therefore, these larger rolls at depth, while not characteristic of most of the dive cycle for most whales, did occur with some frequency during the few hours of recorded dive behaviors.

Discussion

For reasons that are still unclear, western North Atlantic right whales are more susceptible to entanglement in commercial fishing gear than other large whale species with similar distributions (Clapham *et al.* 1999). Fin whales, for example, do not seem to suffer from entanglements to the degree that right whales do, though they forage in similar areas (Waring *et al.* 2003, NMFS 2005). Because the same gear is present in the habitat of both species, differences in the whales' behaviors are likely contributing to the discrepancy in their susceptibilities to entanglement. For example, fin whales and right whales are believed to forage at different depths, above substrates with different topographic reliefs (Woodley and Gaskin 1996), which could be one causal factor. Understanding right whale swimming behaviors in these areas is therefore important to determining the circumstances surrounding entanglements. In particular, identifying behaviors that put the animals most at risk of entanglement in certain parts of gear at certain depths can help managers determine more effective mitigation strategies.

Bottom-set gear is most often implicated in entanglements, and floating loops of line, in particular, are believed to be the most dangerous components of this gear (Clapham *et al.* 2003, Johnson *et al.* 2005, NMFS 2005). The data presented here suggest that right whales display behaviors that could potentially increase their risk of encountering these portions of the gear. 'Risky' behaviors included swimming at depths where floating loops of line extend into the water column, and increased rolling behavior at specific segments of the dive cycle.

PROXIMITY TO BOTTOM

Prior to this study, only indirect evidence existed that right whales can forage along the bottom. Baumgartner and Mate (2003) demonstrated that *Calanus* will aggregate in discrete layers near the mixed-bottom layer, sometimes only 10s of centimeters from the bottom. In this study, foraging right whales were shown to swim at various depths, sometimes close to the bottom, and other times far from the floor. Right whale #233 consistently foraged right against the bottom, and during an ‘exploratory’ dive (Baumgartner and Mate 2003), right whale #213b probed the water all the way to the floor. These examples show that right whales can and do forage in close proximity to the bottom.

Of risk to bottom-foraging whales are bottom-set gear, particularly lobster pot/trap (Fig. 11) and gillnet gear (Fig. 12). Lobster fishers often use floating loops of groundline to connect their traps because sinking line is prone to chafing or becoming tangled on rocks (Johnson 2005). These loops can extend up to 6 meters above the bottom, well within the range of a right whale foraging at depth (A. Johnson, personal communication).

Similarly, floating loops of anchorline connecting gillnet panels to anchors can hover in the water column 2 to 4 meters above the bottom (A. Johnson, personal communication). In addition, the panels themselves can rest along the bottom, extending approximately 2 meters into the water column, or float up to 4 meters above the bottom (A. Johnson). Fishers in the Bay of Fundy will typically string together 3 panels⁽³⁾, each

⁽³⁾ The number of panels is highly dependent on the target species and soak-time. Most strings of groundfish gillnets in the Bay of Fundy are comprised of only 3 nets (A. Read, personal communication). In other areas, more nets are common; for example, fishers using gillnets in New England waters commonly use 15 to 20 panels (A. Johnson, personal communication).

about 90 meters long, and composed of nearly invisible monofilaments (Johnson 2005). For a typical set, then, the entire 540 m² of net string theoretically poses a risk to whales foraging at depth.

ROLLING BEHAVIOR

Whales tagged in this study were capable of rolling (defined as ‘deviation from straight’) to varying degrees, but tended to do so more during the ascent and descent portions of the dive cycle than while at the surface or during foraging. While some rolling did occur during bottom foraging, even the largest rolls were always below a 90° deviation from straight, and most were below 50°. In other words, whales did not appear to actually ‘roll’ in the conventional 360° visualization of the term; rather, foraging whales tended to rock from side to side, in phase with fluke strokes. Similarly, while tagged whales tended to display the largest deviations from straight while descending or ascending, they did not appear to ever complete a 360° roll or series of rolls during these portions of the dive cycle. The only true ‘rolls’ displayed by any of our whales were from RW221 (Fig. 9B), who completed at least 3 rolls while at the surface after the second dive. Rolling at the surface was not typical for this whale or others, however.

From these data, it is not clear that the whales’ natural roll behaviors *per se* are conducive to entanglements. However, I suggest that if there is any risk of entanglement extending from roll behavior, that it is during the ascent and descent portions of the dive cycle. This would put these whales most at risk of entanglement from vertical line extending through the water column, which is in agreement with views held by the National Marine Fisheries Service (2003, 2005). The main source of vertical line is buoy

line extending from marker buoys at the surface down to bottom-set gear. Figure 11A shows individual lobster pots each marked with their own buoys, which puts a lot more vertical line in the water than the system shown in Figure 11B, where a single buoy is used to mark a series of traps. Whales encountering these gear components while rolling are more likely to become ‘wrapped up’ in gear, increasing the severity of entanglement.

GEAR MODIFICATIONS

In March of 2005, NMFS released a Draft Environmental Impact Statement for Amending the Atlantic Large Whale Take Reduction Plan (DEIS), which centers around broad-based gear modifications. The modifications apply to bottom-set gear used by most lobster pot/trap and gillnet fisheries operating along the east coast, and are similar to those described in the Introduction, with some small differences. Overall, the regulations aim to further remove floating and vertical line by requiring the use of sinking groundline in addition to already-required sinking buoy line, and to include more weak links with reduced breaking strengths.

The sinking groundline requirement appears promising for the reduction of mouth entanglements, which are believed to be the most common and the most dangerous. In contrast, the potential effectiveness of splicing weak links into more portions of gear is questionable for reducing mouth entanglements. However, I am not suggesting that weak links are not a good idea, as any technology designed to make gear more yielding to whales is worth trying. Weak links will probably be more useful in reducing the severity of entanglements, rather than preventing them in the first place.

To offset the cost to fishers in complying with regulations on their gear, NMFS (2005) also proposes the phasing out of SAMs and DAMs, and the imposition of gear modifications on a seasonal, rather than a year-round, basis. This would allow fishers to keep more gear in the water, for more days of the year. This arrangement assumes that gear modifications will be effective in preventing entanglements, precluding the necessity of gear removal. This is a large assumption, but fishers complain that the current arrangement of gear removal is ineffective at reducing or preventing entanglements because it encourages them to set their traps right outside area closures, effectively creating a fence of gear around the whales (Johnson 2005). In addition, fishers generally cannot remove large gear sets from DAM zones in a reasonable amount of time, forcing most to leave their traps inside during area closures. Also, there is a large lag-time between when the threshold number of whales is sighted and the actual implementation of a DAM, further limiting the effectiveness of this strategy. Acknowledging the limitations of area management zones, NMFS opts to make the gear more ‘whale-friendly.’

CONCLUSIONS

The findings described here verify what researchers and managers already suspected, which is that right whales are foraging at depths where floating loops from bottom-set gear extend above the bottom. In addition, this study shows that right whales tend to roll more dramatically at depths where they are likely to encounter buoy line, suggesting that vertical line in the water column is also dangerous.

Based on the characterization of right whale foraging behavior as determined in this study, proposed gear modifications aimed at reducing entanglements seem to be targeting the most dangerous parts of bottom-set gear. Because the effectiveness of these modifications is unknown, however, removal of gear from the water is still the only sure way to prevent entanglements. Obviously this would entail large economic and social costs to fishers, which would need to be weighed against the benefits society as a whole receives from this species' continued existence.

The results of this study are preliminary only, and clearly more detailed work needs to be done with these data to accurately characterize right whale swimming behaviors. Many assumptions went into interpretations of the data, including that of simple bottom topography when estimating depth, the assumption of representativeness of our sample to reality, and the assigning of biological significance to trends without statistical testing. While these assumptions place limitations on the application of any conclusions drawn from this study, the project still represents a good starting point for those wishing to analyze these behaviors in more detail.

FUTURE STUDIES

Clearly these data have potential for additional, more sophisticated analyses. Researchers continuing on in this line of work will be interested in understanding more about the orientation behavior of foraging right whales, including better estimates of proximity to bottom, and quantification of roll behavior. In addition, we need to know more about the pitch and heading behaviors of these whales, and to compare these quantified behaviors between foraging and non-foraging events.

The biggest challenge to quantification of these behaviors was the lack of geospatial data throughout the duration of the tagging. With positional data, a whale's track could be displayed using GIS applications, and depth along the entire track extrapolated from a georeferenced bathymetry file. At the very least, coordinates for the whales while surfaced between each dive would serve to verify tracks determined by more indirect means. This could be done by calculating the course of a whale using heading and distance data. To calculate distance, fluke stroke rates would be measured from pitch data, which would then be used to estimate speed using the regression equation for cetaceans determined by F. Fish (personal communication)⁽⁴⁾. For my project, we were not able to have GIS software automatically plot these measurements from, for example, an uploaded database table; with thousands of sample points recorded per track, however, manual entry is not a viable option if we want the tracks to be accurate.

In addition to plotting tracks, it would have been interesting to be able to visualize the swimming behaviors of the whales using animation software. The GeoZui3D program developed by researchers at the University of New Hampshire represents the most likely candidate for this kind of visualization. Unfortunately GeoZui is not designed to allow users to enter their own data into the program without the assistance of programmers. Currently, David Wiley of the National Oceanic and Atmospheric Administration is working with the creators of GeoZui to develop the program for visualization of humpback whale movements, also gathered from DTAGs, but on an experimental basis only (D. Wiley, personal communication).

⁽⁴⁾ F. Fish calculated this regression equation using data from his 1998 study, and two other studies: Bose and Lien 1989; and Videler and Kamermans 1985.

Researchers will continue with the tagging project in the Bay of Fundy in the summer of 2005, and ideally, data collected would include more positional information. If it is not possible to record position continuously, coordinates between dives would still be very useful for later processing. Also, more accurate records of timing of deployment and recovery of tags would improve analysis techniques for future studies.

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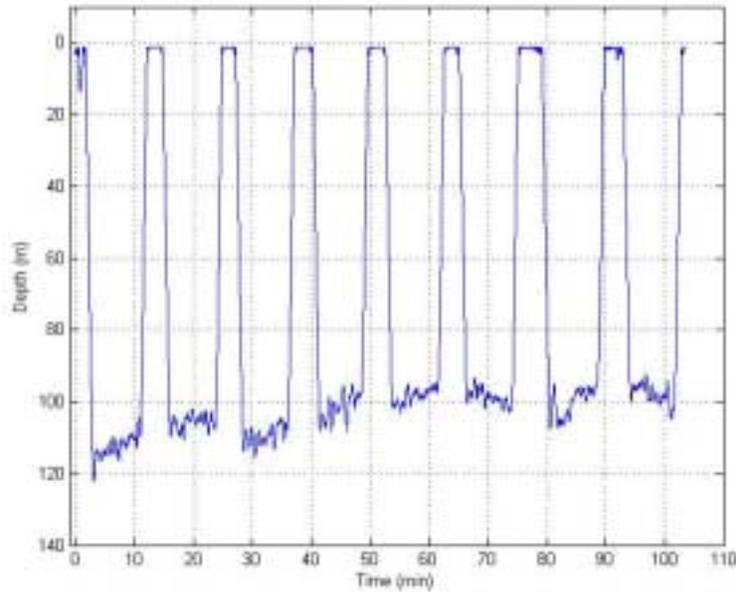


Figure 1. Example of a dive profile, taken from RW221. Positions along the top represent time spent at the surface, while positions along the bottom represent bouts of foraging at depth. Note the stereotyped patterns.

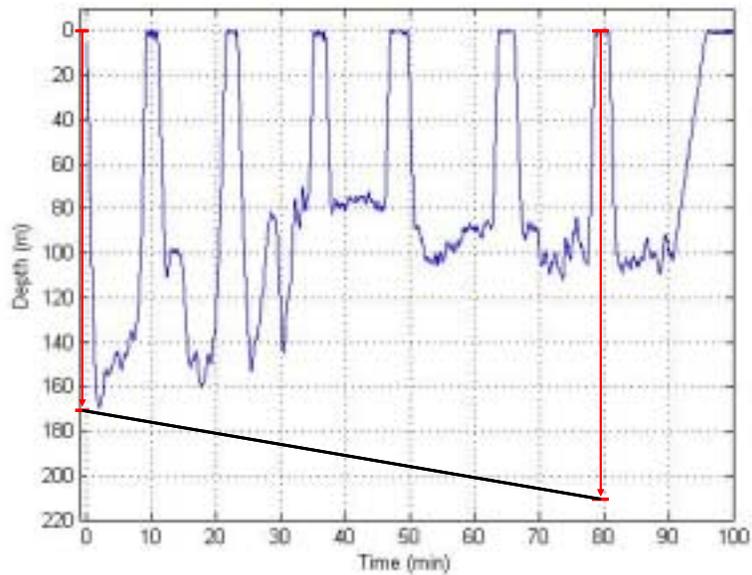


Figure 2. Extrapolated line showing estimation of bottom depth and proximity to bottom for RW213b (black line) Red lines indicate positions where coordinates were recorded, and corresponding depth measurements extracted from a bathymetry file of the Bay of Fundy.

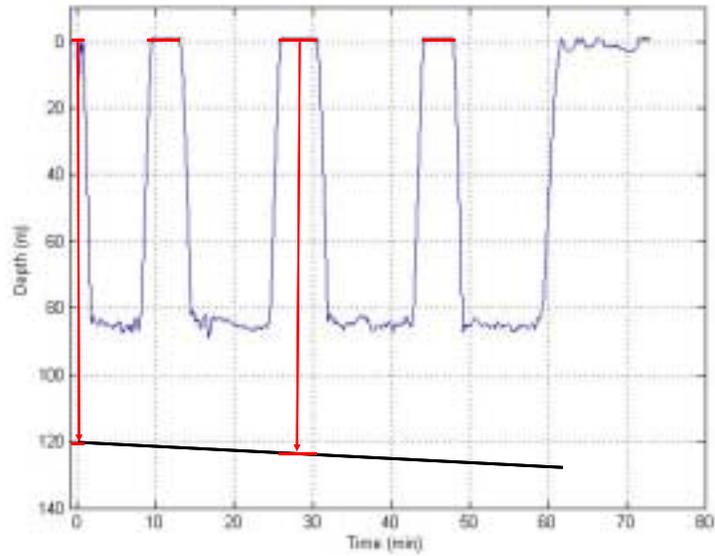


Figure 3. Extrapolated line showing estimation of bottom depth and proximity to bottom for RW220 (black line) Red lines indicate positions where coordinates were recorded, and corresponding depth measurements extracted from a bathymetry file of the Bay of Fundy.

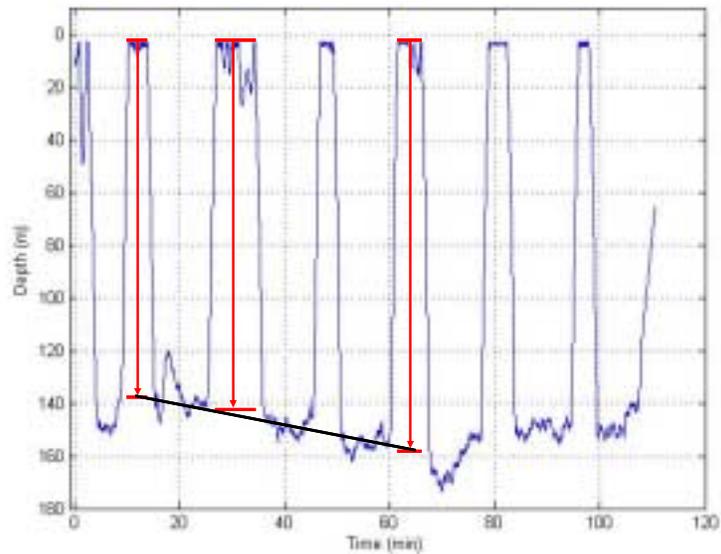


Figure 4. Extrapolated line showing estimation of bottom depth and proximity to bottom for RW233 (black line) Red lines indicate positions where coordinates were recorded, and corresponding depth measurements extracted from a bathymetry file of the Bay of Fundy.

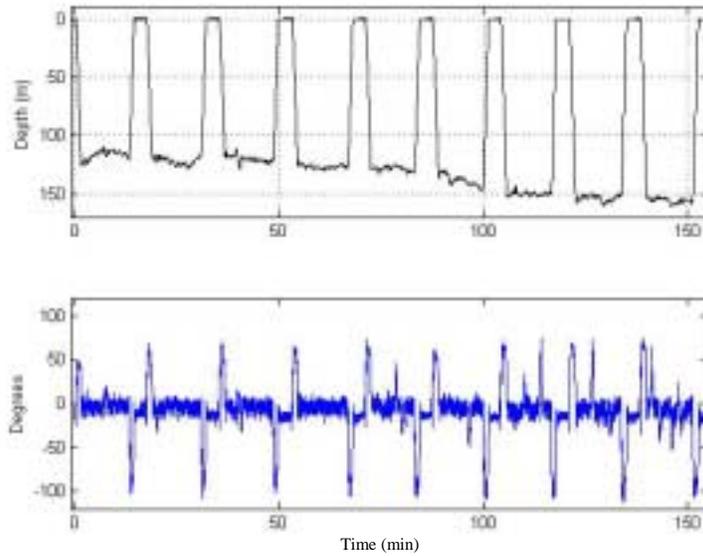


Figure 5. Example of a ‘typical’ roll profile (blue), in line with its corresponding dive profile (black), taken from RW207. Positive peaks represent a roll to the right, and vice-versa. Note the regular pattern of large changes in roll orientation during ascent and descent portions of the dive cycle, and relatively small oscillations around zero while foraging.

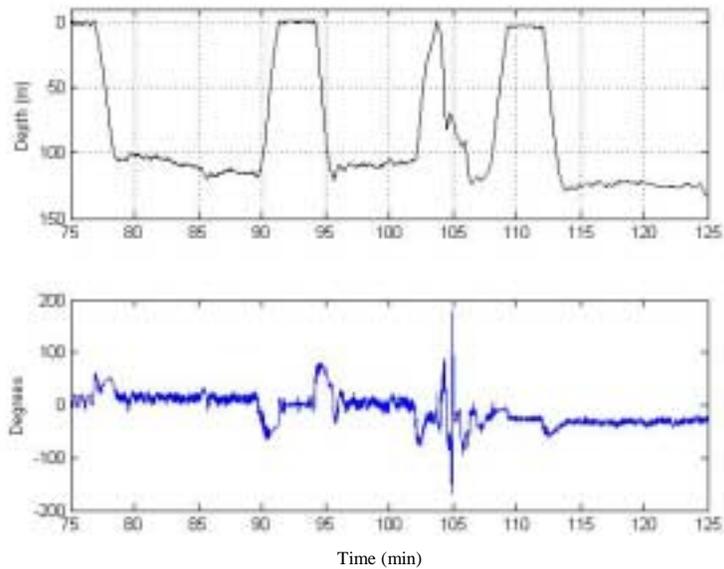


Figure 6. Variation within individual: Close-up of the roll profile from RW232. Note the irregularity in roll behavior (blue), without the more typical patternized behaviors during specific portions of the dive cycle.

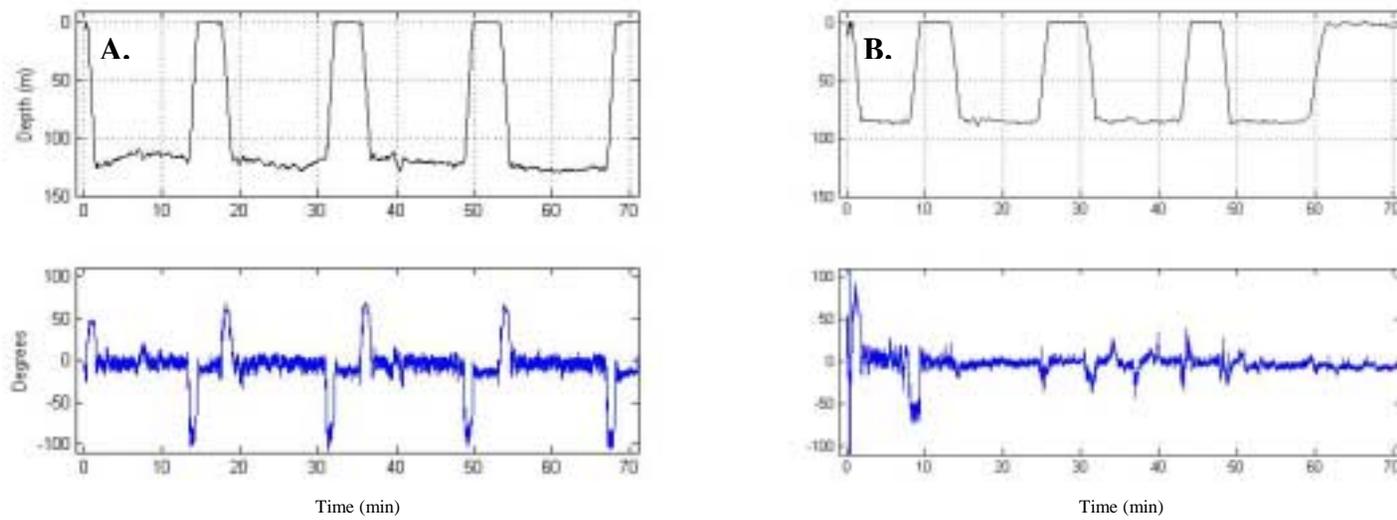


Figure 7. Variation between individuals: Comparison of the roll profiles of RW207, showing predictable, large rolls during ascent and descent; vs. B. RW220, showing erratic, relatively small rolls throughout the dive cycle.

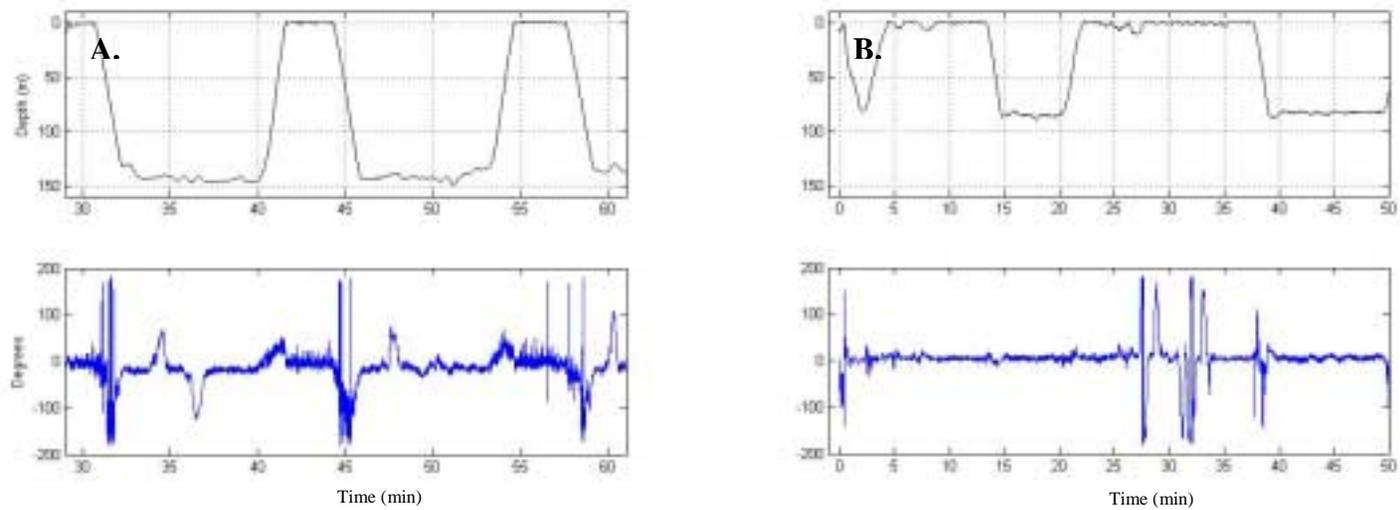


Figure 8. Examples of non-stereotyped behavior. A. Roll profile from RW214, showing large rolls at depth; B. Roll profile from RW221 (2002), showing large rolls at the surface.

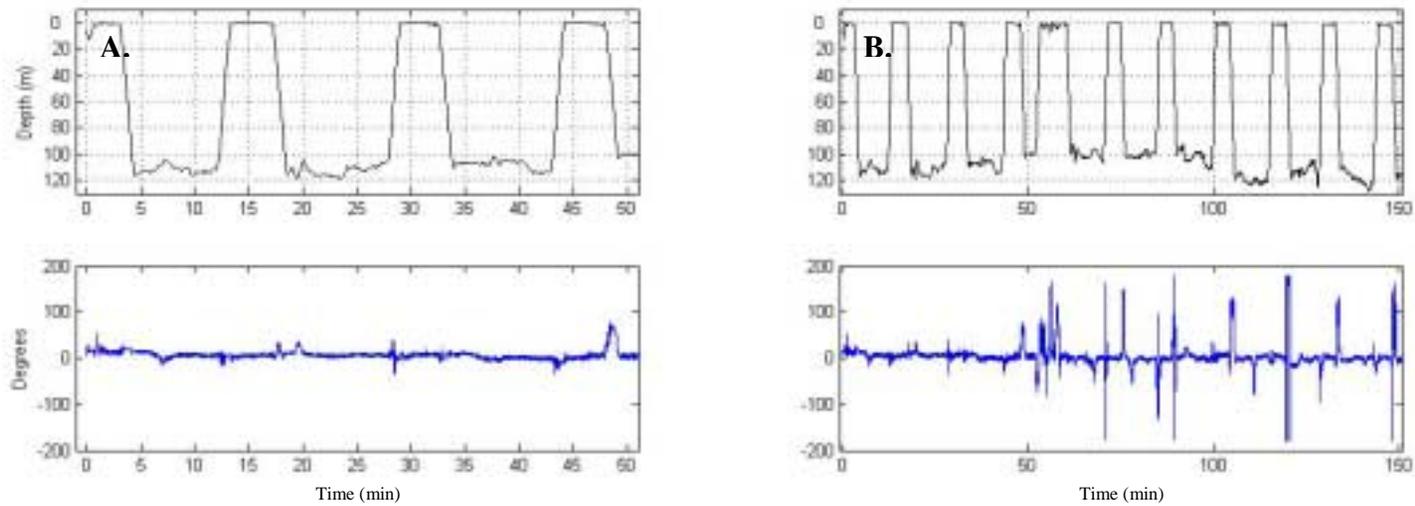


Figure 9. Questions of scale: A. Close-up of the first 4 dives of RW241, showing ‘predictable’ roll behavior, with only small rolling occurring. B. Zoom-out of 10 dives of the same whale, showing roll behavior actually varies along the entire track. Both small and large rolls occur mostly during ascent and descent.

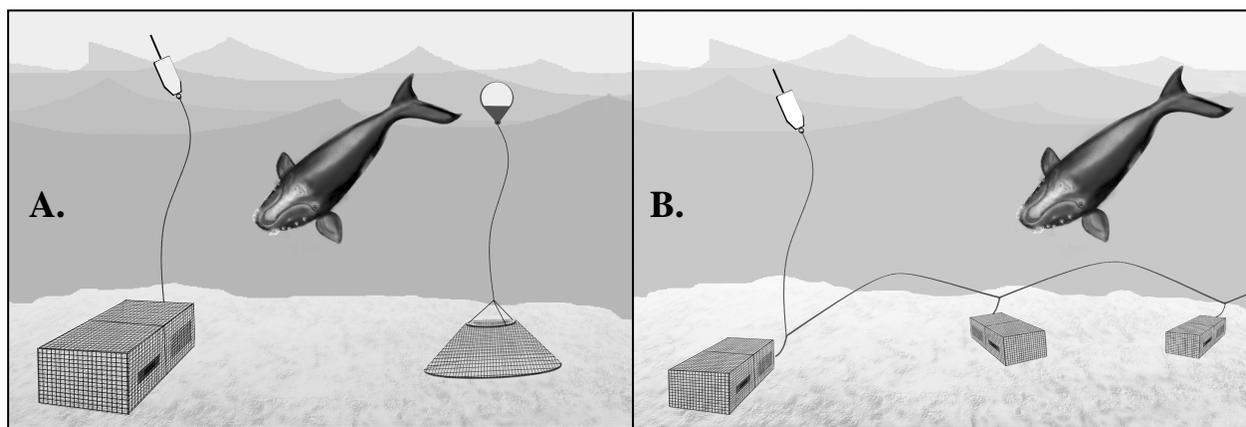


Figure 10. Lobster pot/trap gear showing A. single traps, each marked by their own buoy; and B. a series of traps marked by only one surface buoy. Note the floating loops of groundline connecting traps. Illustrations by Tora Johnson.

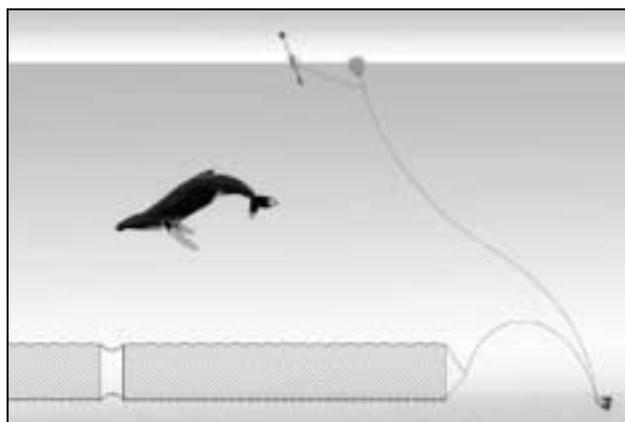


Figure 11. Gillnet gear. Note the floating loops of line connecting panels to each other and to the anchor. Illustration from the Center for Coastal Studies.