

Group Movements of White-Beaked Dolphins (*Lagenorhynchus albirostris*) near Halifax, Canada

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Abstract

Movement patterns of animals are important in understanding their role in the environment (e.g., foraging, residency) and may provide insight into an animal's life history and social structure. Movement is particularly important for animals where resources are highly temporally and spatially variable such as in the marine environment. Groups of white-beaked dolphins (*Lagenorhynchus albirostris*) were tracked at sea near Halifax, Nova Scotia, Canada, during the early summer months from 2003 to 2005. Twelve groups were followed for 20 min or more, and GPS positions of the research vessel when within approximately 10 m of the dolphins were used to determine group movements. For each group, movements were quantified by determining the straight-line bearing, swim speed, and directional deviation (the degree of deviation from straight-line travel). Spearman's correlations were calculated between these variables and day, time, mean water depth, bathymetric variability, dolphin group size, and number of young dolphins in the group. Significant negative correlations were found between bathymetric variability and swim speed ($r_s = -0.839$, $p = 0.001$) and between bathymetric variability and directional deviation ($r_s = -0.608$, $p = 0.036$). A significant positive relationship was found between directional deviation and mean water depth ($r_s = 0.755$, $p = 0.005$). This indicates a tendency for dolphin groups to vary their direction of travel more frequently in areas with lower bathymetric variation and deeper water and to increase their swim speed in areas of lower bathymetric variation. A significant positive relationship was also found between group size and swim speed ($r_s = 0.880$, $p < 0.001$). A possible explanation is that these dolphins are altering their movement patterns and group size in relation to foraging activities.

Key Words: movement, white-beaked dolphin, *Lagenorhynchus albirostris*, cetacean, depth, bathymetry, group size

Introduction

Animals move for a variety of reasons such as foraging, avoiding predators, socializing, and searching for mating opportunities (Turchin, 1998). The details of movement are important for the understanding of various aspects of animal ecology, behaviour, and biology. The monitoring of long-range movement patterns has provided insight into the ecology and conservation of a variety of mobile species (e.g., Austin et al., 2004; Harris et al., 2008; Whitehead et al., 2008). However, information on fine-scale movements can provide information regarding daily activities such as foraging, avoiding predators, and socializing. For example, plains zebra (*Equus burchelli*) avoided grassland areas where lions (*Panthera leo*) had been recently sighted and moved faster with sharper turns when in grassland areas at night (Fischhoff et al., 2007). The movement of goats (*Capra hircus*) became more sinuous in areas of high food density, which increased foraging efficiency (de Knecht et al., 2007). However, elk (*Cervus elaphus*) did not slow down their movements in areas of preferred forage but, instead, visited preferred areas more frequently (Anderson et al., 2008).

Cetaceans move extensively on a variety of scales—from the seasonal, basin-scale migrations of some baleen whales (e.g., Swartz, 1986) to short temporal scale, local movements over minutes and meters observed in all species (e.g., Bailey & Thompson, 2006). These animals live in an environment where foraging is temporally and spatially heterogeneous (Horwood & Cushing, 1978; Steele, 1985), and there is a lack of adequate cover from predators (Norris & Døhl, 1980). In addition, cetaceans have relatively low metabolic costs associated with movement (Williams, 1999). Therefore, these animals are expected to be able to

change location relatively quickly and efficiently in response to local conditions (e.g., foraging opportunities).

White-beaked dolphins (*Lagenorhynchus albirostris*) are found throughout the cold temperate regions of the North Atlantic (Lien et al., 2001) and are commonly found in coastal waters near Halifax, Canada, from May to July (Simard et al., 2006). Mean group sizes in the western Atlantic range from approximately 10 (Kinglsey & Reeves, 1998; Simard et al., 2006) to several hundred animals (Lien et al., 2001). White-beaked dolphins forage on a wide variety of fish and invertebrate species (e.g., herring [*Clupea harengus*], cephalopods, benthic invertebrates; Lien et al., 2001). While these animals undergo seasonal movements (e.g., they are not present near Halifax from roughly August through April), the details of these movements are unknown (Lien et al., 2001; Simard et al., 2006). A long-term photo-identification study of the social ecology of this population provides the first opportunity to examine fine temporal and spatial movements in this species.

In this study, the movements of white-beaked dolphin groups were analyzed to investigate three topics: (1) the alongshore and inshore-offshore movements were investigated in relation to the time of day and day of the year; (2) it was determined if differences in group speed and directional deviation (deviation from straight-line travel) were related to each other and to bathymetric variability and depth; and (3) it was determined if differences in speed and directional deviation are a function of group size and presence of young animals. Information on these relationships may be useful in understanding the migratory and foraging patterns of white-beaked dolphins near Halifax.

Materials and Methods

Field work was conducted in the early summer months of 2003 to 2005 (Table 1) near Halifax, Nova Scotia, Canada (Figure 1). Group-follows were conducted in a 4.2-m rigid inflatable boat. Groups were approached from behind or from the side to minimize disturbance, and the vessel was kept within 10 m of the group whenever possible. The speed and direction of the vessel reflected the speed and direction of the groups. Groups were defined as all animals within 10 body lengths chain rule (Smolker et al., 1992). Only groups which did not change composition were used in this analysis. This was done to be certain that the same animals were being followed throughout each encounter. Group size and number of young were estimated every 5 min, and the maxima of those estimates were used for analysis. Young (calves and juveniles) were determined by estimating body length

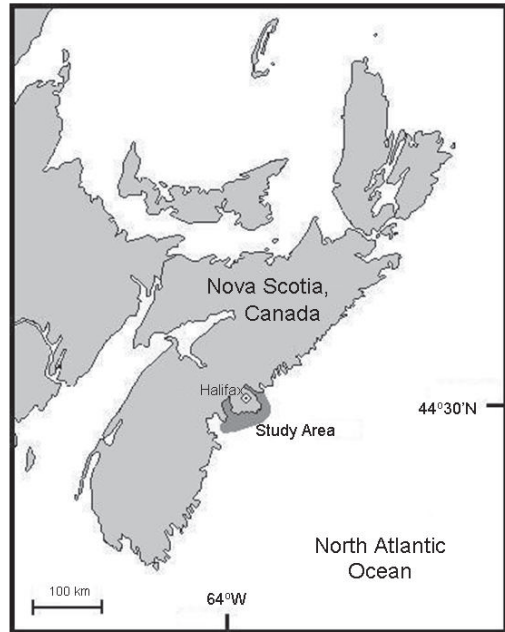


Figure 1. Map of study area for white-beaked dolphins near Halifax, Canada

in relation to adult individuals ($\leq 70\%$ adult body length) (Lien et al., 2001). Photo-identification data were collected throughout encounters when individuals were within approximately 10 m of the boat, and GPS positions (Garmin GPSMAP 76c) were automatically recorded every 60 s.

Movement of each group was plotted using *ArcView GIS*, Version 3.0. The track line for each group was determined using the GPS locations for each photograph taken during the group-follow. Here it was assumed that if a photograph was taken, the boat's GPS location could be used as a proxy of the position of the group. Groups that were followed for less than 20 min and groups with gaps in the GPS track ≥ 10 min were omitted from the analysis. This was done to ensure that the overall movement of the group could be determined (not short-term deviations from an overall direction of travel) and that the GPS track accurately reflected the group movement over consistently fine temporal and spatial scales. During gaps in the photographic record longer than 60 s, it was assumed that the dolphin groups moved in a straight line between consecutive photographs. In the groups used in this analysis, the mean interval between photographs taken was 1 min 36 s (SD 1:15, range = 1 to 9 min, mode = 1), and only 2.7% of intervals were above 5 min (13/482). The mean depth and the overall speed during the encounter were calculated for each group. Depth data were obtained for each dolphin group track

line from an electronic chart (Garmin Blue Chart) as bathymetry data available for use in *ArcView* were sparse resolution only. Speed was calculated as the total distance traveled divided by the time between the first and last positions. The overall direction of travel was the compass bearing (in degrees) between the first and last positions recorded. To relate this to alongshore movements (approximately east-west) and inshore-offshore movements (approximately north-south), the absolute values of the differences between the group bearings and 90° (west-east movement) and 180° (north-south movements) were determined. The directional deviation index was calculated for each group by dividing the total distance traveled by the straight-line distance (*cf.* Jaquet & Whitehead, 1999). Therefore, a high directional deviation value indicated a more meandering track (Figure 2). The contour index was calculated for each group with the following formula (Hui, 1979):

$$\text{Contour Index} = \frac{100(\text{max depth} - \text{min depth})}{\text{max depth}}$$

Therefore, a high contour index indicated higher bathymetric variation.

Spearman's rho correlation tests were conducted to determine relationships between variables: (1) west-east movement, north-south movement, time of day, and day of year; (2) group swim speed, directional deviation, contour index, and

mean water depth; and (3) swim speed, directional deviation, group size, and presence of young.

Results

Twelve groups (out of 32 encounters) were analyzed. Mean group size was 8.4 (SD = 5.18), and 50.0% of groups contained young. The mean swim speed was 1.69 m/s (SD = 0.68), mean directional deviation index was 1.64 (SD = 0.61), and mean water depth was 50.9 m (SE = 5.48) (Table 1).

There was no significant correlation between direction of movement with time of day or day of year. Group swim speed decreased significantly with increasing contour index ($r_s = -0.839$, $p = 0.001$; Table 2). Directional deviation also decreased significantly with increasing contour index ($r_s = -0.608$, $p = 0.036$; Table 2). Directional deviation significantly increased with mean water depth ($r_s = 0.755$, $p = 0.005$; Table 2). Group swim speed also significantly increased with increasing group size ($r_s = 0.880$, $p < 0.001$; Table 3).

Discussion

This study reveals relationships between movements of white-beaked dolphins and environmental parameters. By doing so, it allows further interpretations about the foraging ecology and movement patterns of the species off Nova Scotia.

The mean swim speed for white-beaked dolphins in this study (1.69 m/s) is not unusual for dolphins in the genus *Lagenorhynchus*. For example, dusky

Table 1. Summary of data collected on white-beaked dolphins near Halifax, Canada

Group	Date	Time (h)	Duration of encounter (min)	Group size	Number of young	Speed (m/s)	Directional deviation	Bearing (°)	Contour index	Mean depth (m)	No. GPS positions
654	19/5/03	1118	52	5	2	1.17	1.48	151	8.0	55.2	35
674	22/6/03	1325	29	10	1	1.70	1.33	097	19.2	45.9	10
677	23/6/03	1239	24	3	0	0.74	1.25	324	30.2	19.2	13
694	1/8/03	1014	52	5	1	0.72	1.23	157	28.6	25.9	48
718	20/5/04	1019	22	5	0	1.91	1.68	144	12.2	61.9	9
723	1/6/04	1008	44	12	2	2.56	1.39	262	2.3	54.0	19
736	24/6/04	0747	152	12	0	2.11	1.87	225	3.1	47.3	86
740	24/6/04	1324	33	2	0	1.04	3.41	260	11.2	73.3	18
764	20/6/05	0827	71	12	0	2.20	1.50	153	8.0	45.3	48
768	4/7/05	0942	79	20	1	2.84	2.00	158	0.6	86.0	64
771	8/7/05	0928	65	10	1	1.72	1.30	077	5.6	61.7	55
773	8/7/05	1058	28	5	0	1.53	1.21	105	25.1	34.8	40
Mean	--	--	54	8.4	0.7	1.69	1.64	--	12.8	50.9	37
SD	--	--	36.20	5.18	0.22	0.68	0.61	--	10.43	--	24.28
SE	--	--	--	--	--	--	--	--	--	5.48	--

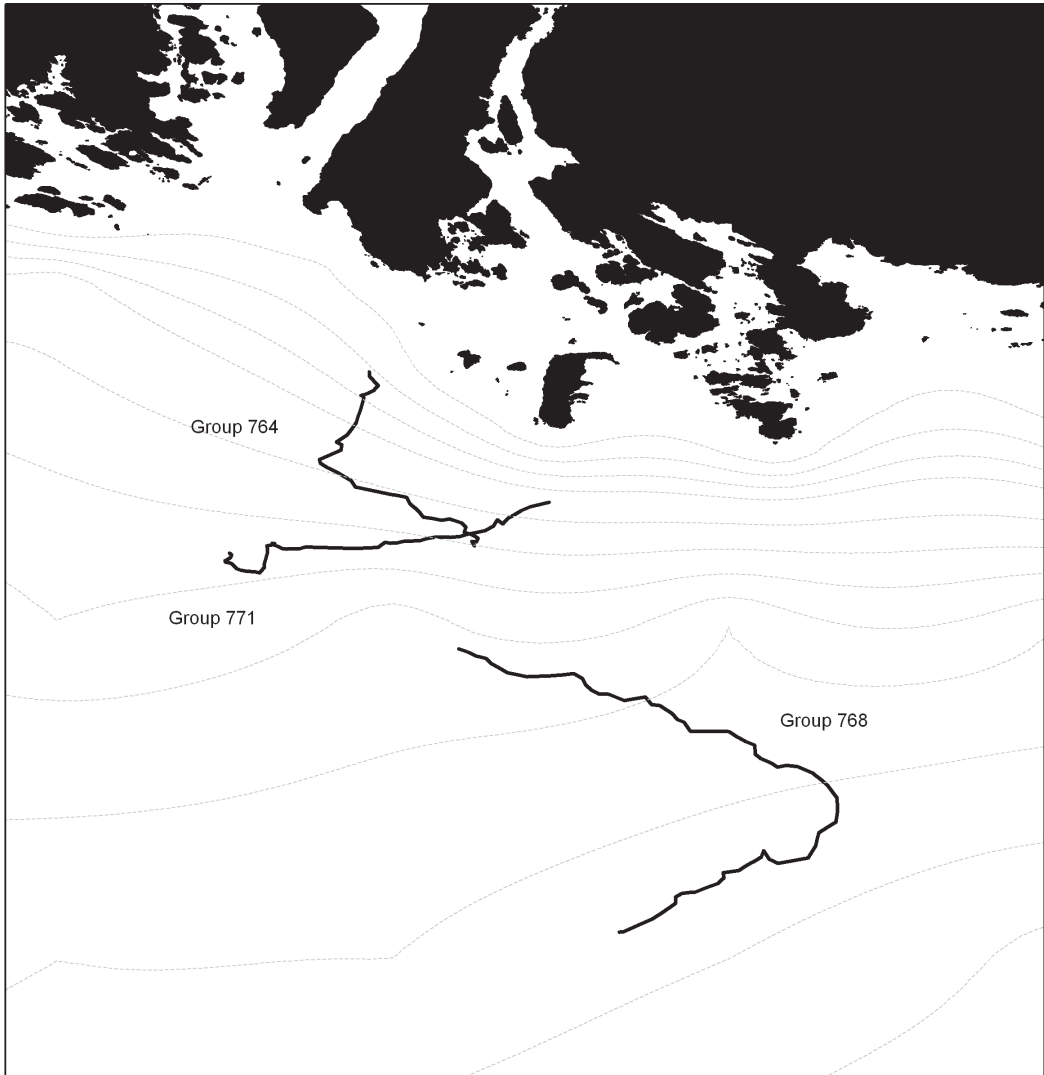


Figure 2. Examples of white-beaked dolphin group movement tracks showing low (Group 771), moderate (Group 764), and high (Group 768) levels of directional deviation; dotted lines represent 10-m bathymetric contours.

dolphins (*L. obscurus*) had a mean swim speed of 2.1 m/s in Golfo San José, Argentina (Würsig & Würsig, 1980) and mean swim speed ranged from 0.56 m/s to 1.80 m/s in Kaikoura, New Zealand (Yin, 1999). A single Atlantic white-sided dolphin (*L. acutus*) exhibited a min average speed of 1.58 m/s over a 6-d period after rehabilitation and release based on satellite tracking (Mate et al., 1994). These speeds are typical for several other genera and species of dolphins as well (Fish & Hui, 1991).

Variations in Direction with Time of Day

There were no significant relationships between time of day and either alongshore (west-east) or inshore-offshore (north-south) directions; therefore, there is no evidence for horizontal diel movement patterns. If movements are a reflection of foraging in this area, this may indicate a less ecologically diverse ecosystem and a more homogeneous prey field. Such diel movements have been observed in several dolphin species, and are often attributed to foraging. For example, dusky dolphins in Kaikoura, New Zealand, exhibited diel movement patterns; the dolphins move offshore late in the day to a deep submarine canyon to feed on organ-

Table 2. Correlations between group swim speed and directional deviation index of white-beaked dolphins near Halifax, Canada, relative to each other and to contour index and mean water depth

	Contour index	Mean water depth	Speed
Speed	$r_s = -0.839$ ($p = 0.001$)**	$r_s = 0.455$ ($p = 0.138$)	--
Directional deviation	$r_s = -0.608$ ($p = 0.036$)*	$r_s = 0.755$ ($p = 0.005$)**	$r_s = 0.476$ ($p = 0.118$)

* = $p < 0.05$; ** = $p < 0.01$

Table 3. Correlations between group swim speed and directional deviation index of white-beaked dolphins near Halifax, Canada, relative to group size and number of young in group

	Group size	Number of young
Speed	$r_s = 0.880$ ($p < 0.001$)**	$r_s = 0.122$ ($p = 0.705$)
Directional deviation	$r_s = 0.259$ ($p = 0.417$)	$r_s = -0.153$ ($p = 0.636$)

* = $p < 0.05$; ** = $p < 0.01$

isms in the deep scattering layer, returning during the day to shallower waters to rest and socialize (Würsig et al., 1997). A similar pattern of movement is observed in Hawaiian spinner dolphins (*Stenella longirostris*). These dolphins move to deep water to take advantage of the vertical migration of deep scattering layer organisms and spend the day resting and socializing in shallow water bays (Benoit-Bird & Au, 2003). These areas have very high levels of bathymetric variation, while this study area is characterized by a broad continental shelf and comparatively little bathymetric relief (max depth in this study area is approximately 100 m). Although the diet of white-beaked dolphins near Halifax is unknown, stomach content analysis from other areas indicate that these dolphins feed on a variety of pelagic and demersal fish, cephalopods, and benthic invertebrates typically found in shallow waters (Lien et al., 2001).

White-beaked dolphins are thought to have seasonal migrations; however, these migrations are not well understood (Lien et al., 2001; Simard et al., 2006). Since day of the year had no significant relationship with direction of movement (west-east and north-south), these results do not indicate a consistent seasonal movement pattern. However, since the longest group-follow lasted 2 h 32 min, it is likely that the observed movement patterns reflect daily activities (e.g., foraging or socializing) rather than sustained migration. Unlike many baleen whales which fast during migration and tend toward straight-line travel while migrating (Mate et al., 1998; Zerbine et al., 2006), smaller odontocetes presumably forage throughout seasonal movements and, therefore, show a greater variation in short-term movement patterns (e.g., Mate et al., 2005).

Variations in Movements with Bathymetric Variability and Water Depth

Significant negative correlations indicated that these white-beaked dolphins swam at higher speeds and deviated from straight-line travel more frequently in areas of low bathymetric variability. As most bathymetric variability in this study area is found closer to shore, it can also be interpreted that dolphins swim faster and deviate more from straight-line travel in offshore areas. This is supported by a positive relationship between directional deviation and water depth—dolphin groups were more likely to deviate from straight-line travel in deeper water.

Würsig & Würsig (1980) found that dusky dolphins in Golfo San José, Argentina, swam at increased speeds in deeper water, and they also found that swim speeds increased during surface feeding events. Bottlenose dolphins (*Tursiops truncatus*) in Moray Firth, Scotland, appear to engage in “intensive search behaviour” (p. 463) involving larger turning angles, which are thought to be for foraging purposes (Bailey & Thompson, 2006). Similarly, brief accelerations and changes in direction were often observed during bottlenose dolphin foraging in Sarasota Bay, Florida (Nowacek, 2002). Zig-zag swimming patterns have been correlated with successful foraging in both sperm whales (*Physeter macrocephalus*; Jaquet & Whitehead, 1999) and right whales (*Eubalaena glacialis*; Mayo & Marx, 1990). While surface feeding events were rarely observed with the white-beaked dolphins in this study area (pers. obs.), results may indicate that these dolphins were foraging further from shore, where increased swim speeds and a decreased tendency for straight-line travel were observed. Foraging behaviours have often been characterized by frequent direction changes and slower movement speeds in dolphins (e.g., bottlenose dolphins; Bailey & Thompson,

2006) as well as terrestrial herbivores (de Knegt et al., 2007). Therefore, the faster speeds and increased directional changes for white-beaked dolphins in offshore waters cannot necessarily be attributed to foraging activity, although they may represent an aspect of search behaviour for patchy food resources.

Variations in Movements with Group Size and Number of Young

As has been found for dusky dolphins in both Golfo San José, Argentina (Würsig & Würsig, 1980), and in Kaikoura, New Zealand (Yin, 1999), white-beaked dolphins traveled faster when in larger groups. The larger groups in Argentina also took part in surface feeding more frequently, however, an activity which also increased group swim speed (Würsig & Würsig, 1980). Therefore, it is possible that white-beaked dolphins in this study area forage in larger groups, further from shore, and facilitate foraging through increased swim speed and increased deviation from straight-line travel.

The presence of young has no significant effect on either speed or directional deviation of groups. This is despite the fact that neonatal and first-year calves are often seen in the study area (Simard et al., 2006). Yin (1999) also found that the presence of calves did not affect group speed of dusky dolphins in Kaikoura, New Zealand. A previous study near Halifax (Simard et al., 2006) found that the proportion of white-beaked dolphins with calves and juveniles was far lower (35.4%). It is possible that by restricting the dataset to group-follows of 20 min or more, calves were more likely to be detected, and the percentage of groups with calves was underestimated in Simard et al.

In this study, we show that the movement of free-ranging white-beaked dolphins can be associated with both environmental parameters (depth and bathymetry) and biological parameters (group size). These correlations can provide a basis for understanding how these animals use their environment. Further studies are necessary to fully understand the foraging ecology of this species in this area (e.g., stable isotope and signature fatty acid analysis to study the specific diet of these dolphins). Reports of this species in the Bay of Fundy and other areas south of Halifax are rare, although Atlantic white-sided dolphins are common (pers. obs.). If the Halifax area does represent the southern limit to their range, these individuals could be naturally more susceptible to changes in their environment as has been suggested for Scottish waters (MacLeod et al., 2005). Therefore, understanding the biology and behaviour of white-beaked dolphins off Halifax is of great importance for their conservation.

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