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Stomach contents of mass-stranded short-finned pilot whales (*Globicephala macrorhynchus*) from North Carolina

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ABSTRACT

We examined the stomach contents of 27 short-finned pilot whales (*Globicephala macrorhynchus)* that mass stranded on the North Carolina coast on 15 January 2005. Eleven whales had prey parts in their forestomachs. We used frequency of occurrence and numerical abundance to assess the relative importance of prey. *Brachioteuthis riisei* (numerical abundance 28%), an oceanic species, was the most important cephalopod prey, but *Taonius pavo* (12%) and *Histioteuthis reversa* (9%) also represented a substantial part of the diet. A large number of otoliths belonging to the fish *Scopelogadus beanii* were present (25%). These results differ from reports of the stomach contents of short-finned pilot whales from the Pacific coast in which neritic species dominate the diet. Our findings also suggest that there is a considerable difference between the diet of short- and long-finned pilot whales (*Globicephala melas*) in the western North Atlantic. The latter feed predominantly on the long-finned squid (*Loligo pealei*) whereas the former feed on deep-water species. Our results indicate the whales fed primarily off the continental shelf prior to stranding.

Key words: stomach contents, *Globicephala macrorhynchus*, short-finned pilot whale, food habits, feeding ecology, diet, cephalopod, stranding.

The abundance and size of pilot whales (*Globicephala* spp.) suggest that they are important predators in the continental shelf ecosystem of eastern North America

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(Kenney *et al*. 1997). Within this region, there is substantial information on the diet of long-finned pilot whales (*Globicephala melas*), which feed predominantly on neritic cephalopods (Sergeant and Fisher 1957; Sergeant 1962; Mercer 1975; Waring *et al*. 1990; Overholtz and Waring 1991; Gannon 1997*a*, *b*). In contrast, the diet of short-finned pilot whales (*Globicephala macrorhynchus*) is poorly known in the northwestern Atlantic Ocean.

The short-finned pilot whale occurs in tropical and subtropical waters worldwide (Leatherwood and Reeves 1983). Their diet has been studied in the Pacific and northeastern Atlantic (Seagars and Henderson 1985, Sinclair 1992, Kubodera and Miyazaki 1993, Hernandez-Garcia and Martin 1994, Bustamante *et al*. 2003), but not in the western North Atlantic. Previous studies (*i.e.*, Seagars and Henderson 1985, Sinclair 1992) have described the stomach contents of short-finned pilot whales from California as comprised almost entirely of the cephalopod *Loligo opalescens*. Hernandez-Garcia and Martin (1994) presented preliminary results of two whales from the Canary Islands and identified the importance of cranchiid squid in the whales' diet. Kubodera and Miyazaki (1993) identified ommastrephids and octopods as the most common prey in the diet of 25 short-finned pilot whales caught off Ayukwa, Ojika Peninsula, Japan. More recently, Bustamante *et al*. (2003) identified four species of ommastrephid squid, seven species of histioteuthid squid, and *Moroteuthis* sp. from the stomachs of two short-finned pilot whales stranded in New Caledonia. In addition, they identified six species of fish belonging to the families Bathyclupeidae and Clorophthalmidae.

Samples of pilot whale stomach contents are typically obtained from the carcasses of stranded or bycaught animals. The stomach contents of stranded cetaceans may exhibit biases toward near-shore prey items (Clarke 1986*b*), but they can provide important information on the diet and foraging behavior of the species (Gannon *et al*. 1997*b*, Santos *et al*. 2001*a*).

In this paper we examine the stomach contents of 27 short-finned pilot whales that mass stranded along the North Carolina coast on 15 January 2005 (Fig. 1). Our main objective is to describe the diet of the whales from this event, which has been the subject of much controversy due to its co-occurrence with tactical mid-frequency sonar operations by the U.S. Navy. We hope to shed light on the circumstances surrounding the stranding and, in particular, to document where the animals last fed prior to stranding.

METHODS

Sample Collection

A full description of the stranding event is provided in Hohn *et al*. (2006). Forestomachs were collected from 27 pilot whales that mass stranded on Bodie Island, North Carolina (a total of 33 pilot whales stranded during this event, but 6 carcasses washed out to sea before the stomachs were collected). The whales were first discovered on 15 January 2005 (Table 1, Fig. 1). After the esophagus and duodenum were ligatured, the stomachs were removed and transported to the NOAA-NMFS Laboratory in Beaufort, North Carolina, where they were stored frozen. The 27 stomachs were later thawed, opened, and the contents examined for the presence of prey. Stomach contents were passed through a metal sieve with a mesh diameter of 1.0 mm to isolate hard parts. Cephalopod beaks were placed in 70% ethanol for long-term storage; otoliths were stored dry.

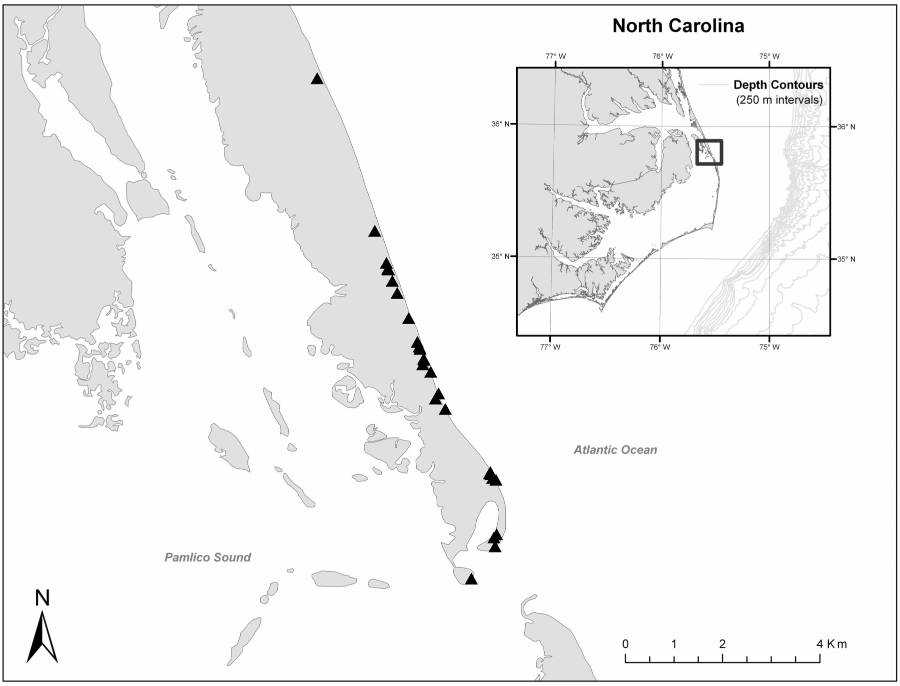

Figure 1. Stranding locations (▲) for short-finned pilot whales. Whales were found along the North Carolina coast on 15–16 January 2005.

Prey Identification

The stomachs contained no fleshy remains or fish bones; hence, we used only cephalopod lower beaks and teleost sagittal otoliths as diagnostic structures in prey identification. Prey items were identified using Clarke (1986*b*) and through comparisons with a beak reference collection of one of the authors (NBB). Thirteen beaks were not positively identified with this collection and were sent to the National Marine Mammal Laboratory for further examination. Fish otoliths were identified at the Woods Hole Oceanographic Institution. Lower beaks and otoliths were identified to the lowest possible taxonomic unit. Two cephalopod beaks were not identified because they were severely damaged and did not have distinguishable characteristics. Most of the otoliths were eroded to the extent that differentiating between left and right otoliths was unfeasible.

Prey Importance Analysis

The relative importance of short-finned pilot whale prey was assessed by two methods: frequency of occurrence and numerical abundance. Frequency of occurrence was calculated as the proportion of stomachs that contained a particular prey species (Hyslop 1980). Percent numerical abundance was calculated by dividing the number of prey from each species in a stomach by the total number of prey present in that stomach. This value was then averaged across the entire sample of stomachs. Only

Table 1. Collection data for short-finned pilot whales included in food habits analyses (Hohn *et al*. 2006). Data for all specimens were collected on 15 January 2005.

Field ID	Sex	Length (cm)	Latitude (°N), Longitude (°W)	Reproductive state
RT102	F	387	35.79, 75.54	Mature
RT105	F	375	35.84, 75.56	Mature
RT106	F	364	35.84, 75.56	Pregnant
RT107	F	357	35.84, 75.56	Mature
RT12	F	210	35.83, 75.56	Immature
RT22	F	360	35.82, 75.55	Mature
RT24	F	330	35.78, 75.53	Pregnant
RT50	F	380	35.83, 75.56	Pregnant
RT54	F	275	35.82, 75.55	Immature
RT59	F	383	35.83, 75.56	Mature
RT67	F	212	35.79, 75.54	Immature
RT71[a]	M	156	35.78, 75.53	Calf

[a]RT71 contained no prey hard parts but contained sea grass and algae described in the results.

whales containing prey hard parts were included in the calculations, resulting in a sample size of 11.

The number of cephalopod prey was estimated from the number of lower beaks; the number of fish prey was estimated by counting the number of otoliths in an individual stomach, dividing by two, and rounding up to the nearest whole number. Unidentified beaks were pooled and included in frequency of occurrence and numerical abundance calculations.

Additionally, we calculated reconstructed mass and estimated length of prey species for which regression equations were available (obtained from Clarke 1986*a*). These equations use cephalopod lower beak rostral length for the calculations, which we measured with digital calipers. None of the beaks used for the measurement calculations were eroded to the degree that measuring was impractical.

Results

Of the 27 forestomachs, only 11 contained prey hard parts (cephalopod beaks and fish otoliths; Table 2). We identified prey species representing nine cephalopod families, and one fish species (Table 2). We found no fleshy remains in any of the forestomachs. Our findings, regardless of which measure of prey importance was used, indicate that the common arm squid (*Brachioteuthis riisei*) was the most important prey for the short-finned pilot whales. *B. riisei* represented 28% of the numerical abundance and 64% of the frequency of occurrence. It was the dominant prey species in 36% of the stomachs examined (Table 2, Fig. 2). Estimated mantle lengths (MLs) of this squid ranged between 65 and 95 mm (Table 3). *Histioteuthis reversa*, *Taonius pavo*, and *Chiroteuthis* spp. also represented a substantial part of the short-finned pilot whale diet (Table 2, Fig. 2). Reconstructed mass of these species suggest that *H. reversa*, *B. riisei*, and *T. pavo* were important components of prey biomass. The single largest prey item (of species for which predictive equations were available) was a *T. pavo* with

Table 2. Total number of specimens, percent numerical abundance and frequency of occurrence (FO), with relative ranks (#), and total reconstructed mass for prey species present in the stomachs of 11 (of 27 examined) short-finned pilot whales stranded on the North Carolina coast. The Field ID of the whale where the prey species was found is included.

Species name	Number of specimens	Numerical abundance %	Numerical abundance #	Frequency of occurrence %	Frequency of occurrence #	Total reconstructed mass (g)	Field ID
Fishes							
Melamphaidae							
Scopelogadus beanii	67	25	2	36	3		RT22, RT59, RT105, RT106
Cephalopods							
Cranchiidae							
Taonius pavo	8	12	3	27	4	11	RT59, RT105, RT107
Liocranchia reinhardti	1	<1	10	9	6	1	RT54
Unidentified	5	2	8	9	6		RT59
Chiroteuthidae							
Chiroteuthis spp.	5	6	6	27	4	6	RT12, RT50, RT54
Enoploteuthidae							
Abralia/Abraliopsis	5	4	7	18	5		RT12, RT54
Unidentified	2	2	8	9	6		RT12
Mastigoteuthidae							
Mastigoteuthis sp.	2	1	9	18	5	3	RT54, RT105
Loliginidae							
Loligo sp.	16	8	5	18	5		RT54, RT67
Histioteuthidae							
Histioteuthis reversa	11	9	4	45	2	15	RT22, RT50, RT54, RT59, RT105
Histioteuthis arcturi	2	1	9	9	6		RT59
Brachioteuthidae							
Brachioteuthis riisei	16	28	1	64	1	13	RT12, RT50, RT54, RT59, RT67, RT102
Lepidoteuthidae							
Lepidoteuthis grimaldii	2	1	9	18	5		RT54, RT67
Ommastrephidae	1	<1	10	9	6	6	RT59
Unknown squid	3	2	8	18	5		RT12, RT54
Total	146						

an ML of 393 mm (Table 3). *Loligo* sp., a neritic cephalopod, was present in large numbers, but the specimens were very small and their frequency of occurrence value was only 18% (Table 2, Fig. 2). We found three beaks that could not be identified to family (2% of numerical abundance) (Fig. 2).

In addition to the cephalopod beaks, we found otoliths from the melamphaid, *Scopelogadus beanii*, in the forestomachs of three whales (Table 2, Fig. 2). This fish was

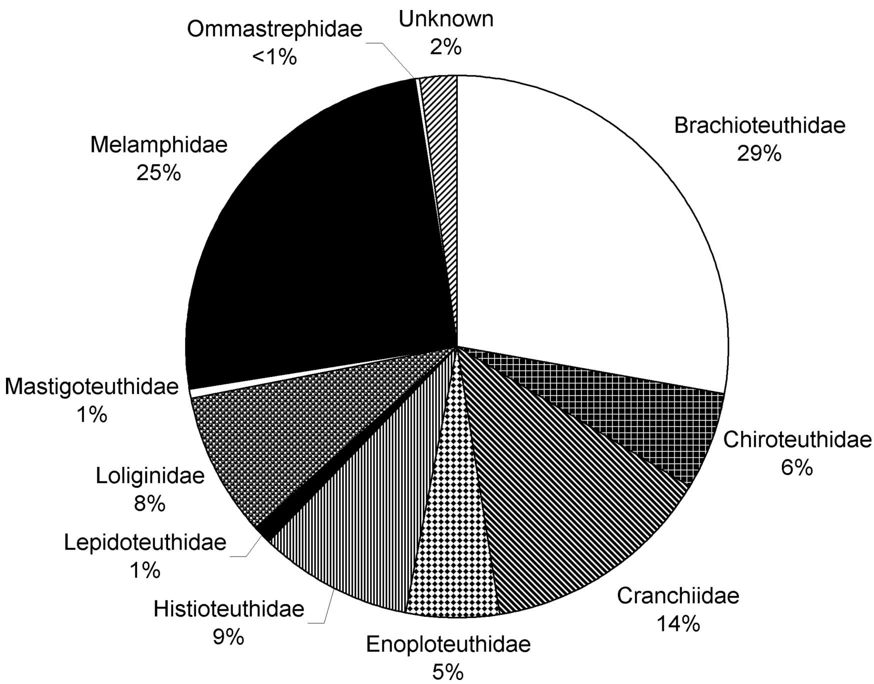

Figure 2. Proportion of numerical abundance (%Num) for prey families present in the stomachs of short-finned pilot whales stranded on the North Carolina coast.

also an important component of the diet, contributing 25% in numerical abundance and 36% in frequency of occurrence. This fish was the dominant prey species in 28% of the stomachs. However, these otoliths were small, implying that the contribution of teleost prey to total biomass of prey was low. A regression equation was not available to estimate the size of this prey item, but *S. beanii* is known to grow to be 8.4–12.2 cm standard length (SL) at maturity (Maul 1986).

Two of the female specimens, RT54 and RT59, contained the greatest diversity of prey species in their stomachs (Fig. 3). RT105, a 375-cm female, contained the most prey, including hard parts of 62 *Scopelogadus beanii* (Table 1, 2; Fig. 3). RT71, a calf, contained two species of seagrass in its stomach: *Syringodium filiforme* and *Thalassia testudinum*, and one species of brown macroalgae, *Sargassum* sp.

Discussion

The most striking aspects of our results are the low total prey count and relatively high diversity of prey species. Our findings differ from previous published accounts of both short-finned and long-finned pilot whale food habits. Compared to previous studies, the short-finned pilot whales investigated here had fewer prey items in their stomachs. The predominant prey species found here have not been recorded previously as a significant part of this predator's diet.

The short-finned pilot whale stomachs examined in this study contained relatively few prey hard parts. Seagars and Henderson (1995) found 99 lower beaks in a

Table 3. Summary of short-finned pilot whale prey species with the highest numerical abundances. Regression equations were used to estimate mantle length (ML) when available: mantle length in mm (L) and weight in grams (W) of pilot whale prey items from lower rostral length (LRL).

Species name	Regression equations	Range of estimated lengths (mm)	Habitat/biology
Scopelogadus beanii	Not available	Not available	Bathypelagic; adult depth range: 800–1,000 m. (Maul 1986).
Brachioteuthis riisei	$L = -16.31 + 20.18LRL$ $\ln W = 0.55 + 1.41\ln LRL$ (Clarke 1986a)	65–95 ML	Diel vertical migration depth range: 150–1,000 m (Roper and Young 1975).
Histioteuthis reversa[a]	$L = -13.6 + 22.21LRL$ $\ln W = 1.594 + 2.31\ln LRL$ (Clarke 1986a)	31–53 ML	Diel vertical migration (Roper and Young 1975).
Loligo sp.[b]			Neritic. Occur in waters of the coastal margins and continental shelf. Some species migrate in shore to spawn during the summer months (Summers 1969).
Taonius pavo[c]	$L = -12.3 + 61.43LRL$ $\ln W = 0.786 + 2.19\ln LRL$ (Clarke 1986a)	197–393 ML	Vertical distribution: >600–700 m. Do not exhibit strong vertical migration (Roper and Young 1975).

[a]Regressions are available for the family Histioteuthidae, but not for the species *Histioteuthis reversa*.

[b]Regressions are available for *Loligo* spp. (Clarke 1986*a*, Gannon *et al*. 1997*b*); however, our samples were very small and existing equations have not been tested with very small specimens.

[c]Regressions are available for the subfamily Taoniinae, but not for the species *Taonius pavo*.

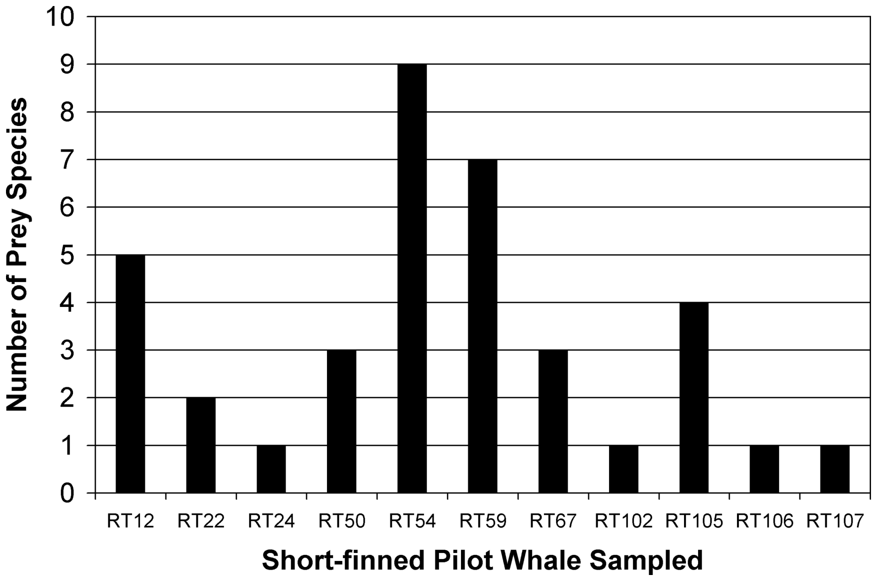

Figure 3. Number of prey species found in the stomachs of 11 short-finned pilot whales (stomachs of 16 other whales contained no prey hard parts).

single animal and Hernandez-Garcia and Martin (1994) found a total of 313 lower cephalopod beaks in a single whale stomach. We found only 79 lower beaks in a total of 11 stomachs. No fleshy, partly undigested remains were found in the North Carolina stomachs. Both of these findings, along with previous data that show that prey hard parts may remain in a cetacean stomach for at least eight days (Walker *et al*. 1996), indicate that the whales had not eaten recently before stranding. This is also supported by the fact that the majority of whales had empty stomachs.

There is also a considerable difference between our results and findings from the US Pacific, northeastern Atlantic, and Japanese coasts. Although differences in prey species composition between the present investigation and previous studies are expected due to differences in location, one might expect to find ecological similarities among prey types of different geographic regions. Our findings differ from results on the U.S. Pacific coast, which indicate that the neritic cephalopod, *Loligo* sp., is the dominant prey of short-finned pilot whales. Sinclair (1992) found that *Loligo opalescens* comprised about 95% of all food items found in four stranded short-finned pilot whales. Seagars and Henderson (1985) also found *L. opalescens* to be the dominant prey species. *Loligo* sp. was present in the North Carolina pilot whales, but they appeared to be small individuals and their FO value was low suggesting that this genus does not account for a substantial proportion of northwestern Atlantic short-finned pilot whale prey biomass. Short-finned pilot whales in our study fed primarily on oceanic species. Hernandez-Garcia and Martin (1994) found the diet of short-finned pilot whales from the northeastern Atlantic to be composed mostly of cranchiid squid; however, cranchiid squid composed only 14% of numerical abundance in our study. There is also a considerable difference between our results and findings from the Japanese coast. Although ommastrephids (large and muscular cephalopods) comprised a large part of the diet of short-finned pilot whales from Japanese water (Kubodera and Miyazaki 1993), they comprised <1% of the prey in this study. *G. macrorhynchus* in our study fed primarily on the small species, *B. riisei*. Due to the small sample sizes of these studies, geographical variation, and limited information on prey distributions, it is difficult to elaborate further on the similarities and differences between studies.

There are important differences between the diet of short- and long-finned pilot whales (*Globicephala melas*) in the western North Atlantic. The distribution of the short-finned pilot whale and long-finned pilot whale overlap between 38°N (the northern limit of *G. macrorhynchus*) and 35°30′N (the southern limit of *G. melas*) (Leatherwood and Reeves 1983). Due to their morphological and ecological similarities, one might expect these animals to consume similar prey. In the northwest Atlantic, long-finned pilot whales feed predominantly on long-finned squid (*Loligo pealei*) (Gannon *et al*. 1997*a*, *b*) and exhibit seasonal movements that correspond with the migration pattern of this prey species (Payne and Heinemann 1993). *L. pealei* spend the winter months offshore, aggregated at depths of 100–200 m, and move inshore to spawning and feeding areas during late spring through fall (Roper *et al*. 1984). Our findings do not suggest that *Loligo* is an important prey species for short-finned pilot whales. Consequently, one would not expect northwestern Atlantic *G. macrorhynchus* to show seasonal movement corresponding with *Loligo* migration.

The contents of the pilot whale stomachs examined here suggest that these animals fed offshore of the continental shelf prior to stranding (the continental shelf is relatively narrow in this region, Fig. 1). *B. riisei* is found in the north Atlantic and central Pacific Ocean. It is an oceanic species residing in water as deep as 3,000 m (Roper *et al*. 1984), but it has been found to aggregate at depths of about 800 m (Roper and Vecchione 1996; Table 4). This species has been recorded as prey of long-finned pilot whales and southern bottlenose whales (*Hyperoodon planifrons*) from Tierra del Fuego, Argentina (Clarke and Goodall 1994), as well as Cuvier's beaked whales (*Ziphius cavirostris*) and pygmy sperm whales (*Kogia breviceps*) from the Northeast Atlantic (Santos *et al*. 2001*b*, 2006). They were also consumed by two dwarf sperm whales (*K. sima*) that stranded in the same time and location as the whales from this study.[2] *S. beanii* is a bathypelagic species found at depths between 800 and 1,000 m (Maul 1986). The majority of the remaining prey species are also oceanic (Table 3). Our results indicate that short-finned pilot whales dive to great depths to obtain species such as *S. beanii*. However, many of the prey species, including *B. riisei*, and *T. pavo*, exhibit diel vertical migrations, making it difficult to speculate about the depths at which the whales fed most commonly. Our observations of the diet of stranded animals may not be representative of the northwestern Atlantic short-finned pilot whale population. The stomach contents of stranded marine mammals are often biased toward coastal prey (Clarke 1986*b*) or low-quality food that does not typically form part of the diet. The first of these potential limitations does not seem to apply here, as most prey were deep-water species. However, the consumption of *Loligo* sp. could have occurred when the whales were close to the shore. The second limitation may be of greater importance in this study, because many of the prey found in the stomachs were small bodied. *Brachioteuthis riisei*, for example, does not grow to be more than 15cm in ML (Roper and Vecchione 1996). To meet their caloric demands, short-finned pilot

[2]Unpublished data from V. J. Mintzer, Duke University Marine Laboratory, 135 Duke Marine Lab Road, Beaufort, NC 28516, May 2006.

whales would have to consume large numbers of these small squids, but we did not find large numbers of beaks in the stomachs. However, we do not know the digestion or egestion rates of cephalopods in cetacean stomachs or the energetic value of the prominent prey species, so it is difficult to interpret these observations fully. It is also important to note that some of the whales could have regurgitated consumed materials prior to stranding. There is no information on regurgitation rates of wild odontocetes, but if it did occur, our results may be biased to prey hard parts that would be more likely to be retained in the folds of the stomach.

Pilot whale mass strandings are not uncommon and appear to be a natural occurrence in most cases. *G. macrorhynchus* mass strandings occurred four times in North Carolina between 1992 and 2005 (Hohn *et al*. 2006). Investigations overseen by the National Marine Fisheries Service for the January 2005 stranding did not determine a definitive cause of stranding. Gas emboli, diagnosed in sonar-related stranding events of beaked whales (Jepson *et al*. 2003), were not found in any of the whales. However, the stranding was associated in time and space with sonar activity and shares characteristics with other sonar-related mass strandings: that is, all animals stranded alive, several different cetaceans species stranded, and no common disease was found among the whales (Hohn *et al*. 2006).

The circumstances surrounding these strandings have been controversial because of assertions that naval sonar was responsible. The U.S. Navy conducted tactical mid-frequency sonar operations off the coast of North Carolina between 12 and 14 January 2006. The live stranding of three species within a 2-d period was unique in North Carolina and qualified as an unusual mortality event (Hohn *et al*. 2006). Nevertheless, natural factors may have played a role. Notable changes in wind direction and speed occurred the week of the stranding (9–17 January 2005). Changes from upwelling to downwelling favorable conditions were consistent with circumstances that have been correlated with previous strandings (Hohn *et al*. 2006, Walker *et al*. 2005).

Pilot whales have been known to interact with the pelagic longline fishery, mid-Atlantic bottom trawl fishery, North Atlantic bottom and mid-water trawl, and mid-Atlantic coastal gillnet fisheries (Waring *et al.* 2002). It is important to note that seven of the stranded whales had healed scars around their jaws, indicating past interactions with hook-and-line fisheries (Hohn *et al*. 2006). However, the most numerous prey species found in the stomachs are not commonly caught by or used as bait in fisheries off North Carolina. *Illex* spp. and *Loligo* spp. are the two squids targeted in Northwest Atlantic fisheries (Pritchard 2005) and these species accounted for only 0% and 8% of the numerical abundance of the prey found in our study. Although the scars suggest that some of the stranded whales engaged in depredation of catch or scavenging of bait, the healed condition of the scars, the lack of *Illex* squid and the small proportion of *Loligo* in the stomachs suggest that the stranded whales did not interact with fisheries recently before stranding.

Our findings indicate that the pilot whales last fed mostly off the continental shelf prior to stranding, where they consumed a variety of cephalopod prey and one species of teleost prey. Despite the low prey count and lack of fleshy remains, the whales were in good body condition and not emaciated (Hohn *et al.* 2006), so it is unlikely that the animals had gone for a substantial period without feeding. There is little information on the digestion and egestion rates of cephalopod and teleost prey in cetaceans, so it is impossible to accurately estimate how long a period elapsed between the last feeding bout and the stranding event.

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