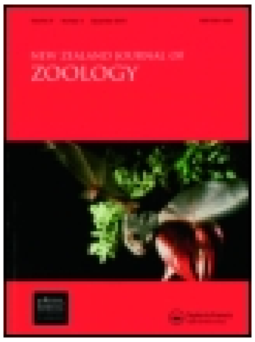

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E. L. Beatson & S. O'shea

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Stomach contents of long-finned pilot whales, *Globicephala melas*, mass-stranded on Farewell Spit, Golden Bay in 2005 and 2008

E. L. BEATSON
S. O'SHEA
School of Applied Sciences & Earth and Oceanic Sciences Research Institute
Auckland University of Technology
Private Bag 92006
Auckland 1142, New Zealand
emma.beatson@aut.ac.nz

Abstract New data are reported on the diet of the long-finned pilot whale, *Globicephala melas*, based on stomach contents recovered from whales involved in a mass stranding on Farewell Spit, Golden Bay, South Island, on 23 January 2008. The stomachs of 11 whales were examined, from which identifiable prey remains were recovered from six, four females and two males (3.1–5.4 m in length). Prey remains comprised exclusively cephalopod beaks (1–46 beaks per whale), attributed to two genera in two orders: arrow squid, *Nototodarus* spp. (Teuthoidea: Ommastrephidae), and common octopus, *Pinnoctopus cordiformis* (Octopoda: Octopodidae). The stomachs of eight whales were infested with parasitic nematodes, with two ulcerated; the stomachs of five whales did not contain any prey remains. These data complement and are comparable to the only other information available for this species from this region, reported from whales mass-stranded at this same location in December 2005. Lower beak rostral length versus mantle length and biomass regression equations for *Nototodarus* spp. are reviewed, highlighting the importance of the use of species-specific regression equations for reconstructing both cephalopod mantle length and biomass from lower beak remains in dietary studies.

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Keywords Cephalopoda; diet; Farewell Spit; *Globicephala melas*; long-finned pilot whale; mass stranding; New Zealand; *Nototodarus*

INTRODUCTION

Cetaceans strand frequently along New Zealand coasts; from April 2005 to March 2008 some 1061 individuals attributed to 22 species came ashore in 273 separate stranding events (The New Zealand Whale Stranding Database (NZWSDB), Museum of New Zealand Te Papa Tongarewa, Wellington). Of these stranded cetaceans, pilot whales are by far the most frequent mass-stranding species, accounting for 773 individuals (73%) stranded in this time period (NZWSDB). Despite the substantial opportunity strandings have provided in terms of understanding the biology and ecology of cetacean populations in New Zealand waters, the diet of long-finned pilot whales, *Globicephala melas*, has been only recently reported (Beatson et al. 2007a,b). Of approximately 30 odontocete species occurring in New Zealand waters, the diets of only three others have been described: sperm whale, *Physeter macrocephalus* (Gaskin & Cawthorn 1967; Clarke & MacLeod 1982; Clarke & Roper 1998; Gomez-Villota 2007); pygmy sperm whale, *Kogia breviceps* (Beatson 2007); and common dolphin, *Delphinus* sp. (Meynier et al. 2008).

Dietary studies are of considerable importance, as prey species of toothed whales are extensively exploited in New Zealand waters (commercial fish and cephalopods), and the techniques with which these fisheries resources are exploited (nets), and the intensity with which this equipment is deployed threaten to damage the egg masses of some 78 of 86 species of squid in New Zealand waters (O'Shea et al. 2004). Apparent shifts in the diet of sperm whales in New Zealand have occurred since the 1960s, an earlier time when commercially exploited fish species (orange roughy, hoki, ling, etc.) comprised 37% by weight in the diet of sperm whales (Gaskin & Cawthorn 1967) to the present, a time during

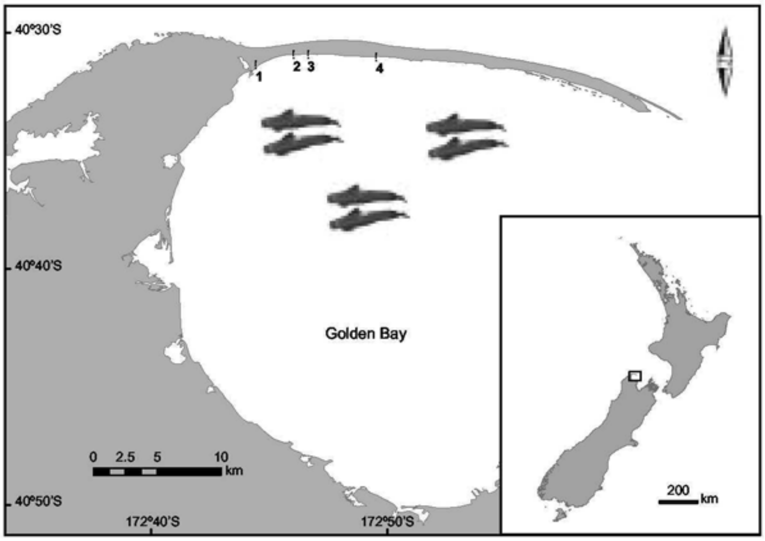

Fig. 1 Location of long-finned pilot whale 2005 and 2008 mass strandings, Farewell Spit, Golden Bay. 1, Site of 2005 and 2008 live strandings; 2, site of 2008 live stranding and single dead whale; 3, group of nine dead whales from 2008 stranding; 4, single dead whale from 2008 stranding.

which no fish species has been recovered from the stomachs of any of 16 recently stranded individuals (Gomez-Villota 2007). No historical information is available for the diet of other whale species in New Zealand waters.

Stomach contents recovered from a subset of 124 long-finned pilot whales that stranded on Farewell Spit, Golden Bay in December 2005 provided the first dietary information for this species from New Zealand waters (Beatson et al. 2007a; Fig. 1). Additional information on the diet of the long-finned pilot whale, from one site of recurring mass stranding (with more than 20 events recorded from this region since 1978 (NZWSDB)), Golden Bay, is presented here. Earlier reported results and conclusions of Beatson et al. 2007a are also re-evaluated in this communication with an investigation of the accuracy of *Nototodarus* spp. regression equations used to describe the relationships between lower rostral length (LRL) and mantle length (ML) and LRL and biomass of ingested prey.

MATERIALS AND METHODS

Thirty-four long-finned pilot whales stranded on Farewell Spit, Golden Bay, on 23 January 2008; of these 20 were successfully refloated and 14 died *in situ* (Department of Conservation, unpubl. data; Fig. 1). Morphometric data and stomach contents were collected from 11 of these whales, following the protocols of Geraci & Lounsbury (1993); three additional whales were unable to be accessed due to the remote location of the carcasses. Animals were classified into the age groupings of calf, juvenile, or adult, based on total body length measurements used by Beatson et al. (2007a). Gender, body length and maturity classification for each of the animals examined in 2005 and 2008 are provided in Table 1.

All stomach chambers were examined for gross pathology *in situ*. Stomach contents were recovered in entirety, frozen, and freighted to Auckland University of Technology. For analysis they were thawed, rinsed through a 1.0 mm sieve, and sorted. When present, parasites were collected and preserved in 70% ethanol. Cephalopod remains were fixed in a 5% buffered formalin solution, then preserved in 70% ethanol. Cephalopod lower beaks were identified to the lowest possible taxon with the aid of Auckland University of Technology's reference collection of beaks extracted from entire, identified squid and octopus from New Zealand waters. Prey species composition was determined for the five whales from the 2005 stranding, and the six whales from the 2008 stranding. Because of the small sample size, no detailed investigation of potential dietary differences between age, sex, or reproductive category within stranding event groups was undertaken.

Cephalopod prey size

The mantle length and biomass of live prey at ingestion for the squid component of the diet was estimated from the rostral length of lower beaks (LRL), and compared and contrasted with a combination of novel regression equations and those of Clarke (1986) and Jackson & McKinnon (1996). For octopus, the hood length of lower beaks (LHL) was used for mantle length and biomass estimation using regression equations constructed by Lu & Ickeringill (2002). Measurements of LRL or LHL were taken with digital calipers, or (for very small beaks) with a micrometer under a binocular microscope.

The total number of individuals of each cephalopod species present in a stomach was estimated as the number of upper or lower beaks (whichever was higher). The relative importance of prey items was quantified by: (1) frequency of occurrence (FO), defined as the proportion of six stomachs that contained a particular prey species, regardless of mass or abundance; (2) proportion of numerical abundance (%Num), the percentage of the total number of prey items recovered from all stomachs represented by a particular prey category; (3) proportion of reconstructed prey mass (%Mass), the percentage of reconstructed mass of prey recovered from all stomachs represented by a particular prey category; and (4) index of relative importance (IRI) (*sensu* Pinkas et al. 1971), which combines the above three methods and is calculated following the formula: IRI = FO × (%Num + %Mass).

This paper presents both the 2005 and 2008 prey size estimates using species-specific regression equations for the two *Nototodarus* species that occur in New Zealand waters (*N. gouldi*, present study; *N. sloanii*, Jackson & McKinnon (1996)). In this study, 83 specimens of New Zealand *N. gouldi*, ML 117–357 mm and wet weight 35–1514 g, were investigated using Microsoft Excel software to generate species-specific regression equations. These novel regression equations were then compared with previously published regressions for what was referred to as *Nototodarus* (New Zealand east coast) and *Nototodarus* (New Zealand west coast) by Clarke (1986) and *Nototodarus sloanii* (Jackson & McKinnon 1996). To assess any potential differences in prey size (both length and mass) between pilot whales involved in the 2005 and 2008 strandings, independent *t*-tests were performed using SPSS 15.0 statistical software.

Table 1 Biological data of stomachs examined from 10 *Globicephala melas* stranded at Farewell Spit on 21 December 2005, and 11 *G. melas* stranded at Farewell Spit on 23 January 2008.

Code	Sex	Length (cm)	Maturity	Comments
Nov 2005				
GM01/05	M	490	Adult	Stomach parasites present
GM02/05	M	570	Adult	Empty stomach, stomach parasites present
GM03/05	M	200	Calf	Empty stomach
GM04/05	M	510	Adult	Empty stomach, stomach parasites present
GM05/05	F	250	Calf	
GM06/05	F	320	Juvenile	
GM07/05	F	320	Juvenile	Empty stomach
GM08/05	M	530	Adult	
GM09/05	F	420	Adult	Empty stomach, stomach parasites present
GM10/05	F	380	Juvenile	Stomach parasites present
Jan 2008				
GM27/08	M	190	Calf	Empty stomach
GM28/08	M	470	Adult	Empty stomach, stomach parasites present
GM29/08	F	410	Adult	Stomach parasites present, stomach ulceration
GM30/08	F	440	Adult	Stomach parasites present
GM31/08	F	270	Juvenile	Empty stomach
GM32/08	F	310	Juvenile	Stomach parasites present
GM33/08	M	420	Juvenile	Stomach parasites present
GM34/08	M	250	Juvenile	Empty stomach
GM35/08	F	430	Adult	Stomach parasites present
GM36/08	M	500	Adult	Empty stomach, stomach parasites present
GM37/08	M	540	Adult	Stomach parasites present, stomach ulceration

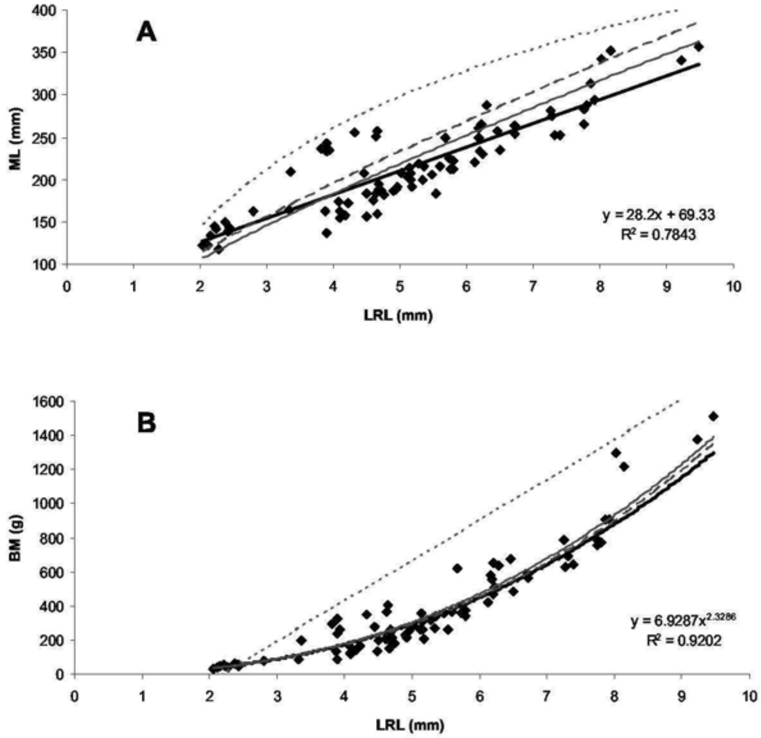

Fig. 2 Regression lines of lower rostral length (LRL) against **A**, mantle length and **B**, biomass for *Nototodarus* spp. Solid thick line *N. gouldi* regression, this study; solid thin line *Nototodarus* "west coast" regression, Clarke (1986); dashed line *Nototodarus* "east coast" regression, Clarke (1986); dotted line *N. sloanii* regression, Jackson & McKinnon (1996). *y* and R^2 equations correspond to *N. gouldi* regression, this study.

Fig. 3 (*below*) Combined reconstructed mantle length (**A**,**C**) and biomass (**B**,**D**) of cephalopods in the diet of *Globicephala melas* stranded on Farewell Spit, expressed in percent by number. Light bars represent 2005 data (n = 55); dark bars represent 2008 data (n = 93). *Nototodarus gouldi* regression equations (present study) were used to construct A,B; *N. sloanii* regressions (Jackson & McKinnon 1996) were used construct C,D.

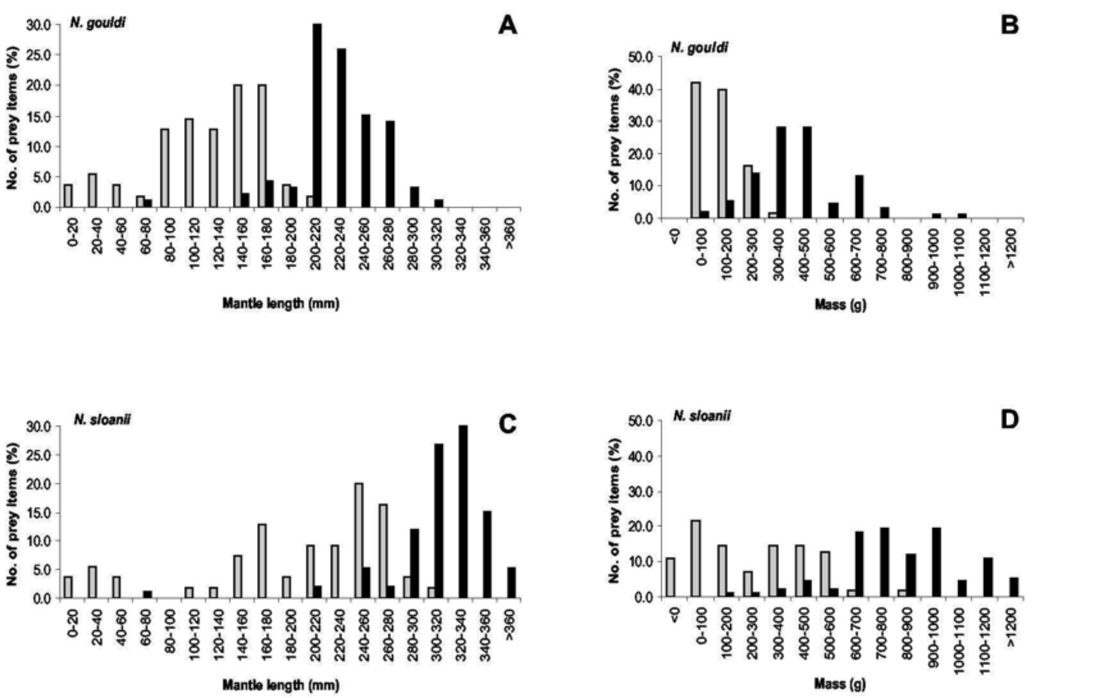

Fig. 4 Ulcerated forestomach of an adult female *Globicephala melas* (GM29/08) infested with nematode parasites (presumably *Anisakis* spp.). Scale bar = 5 cm.

Estimation of food consumption

Data on pilot whale size and the estimated biomass of cephalopods recovered from stomach contents were used to derive crude estimates of daily food consumption. Our calculations follow the Innes et al. (1987) estimations of ingestion rate as an allometric function of body weight for cetaceans, $IB = 0.123M^{0.80}$, where M = body weight in kg, and IB = ingestion rate in kg/day. Body weight (W, kg) of each whale was estimated from body length (L, cm) using Lockyer's (1993) regression equation: $W = 0.023L^{2.501}$. Although derived from a large sample of pilot whales (662) from the Faroe Islands these data may not be representative of Southern Hemisphere pilot whales, however, this remains the best available regression. This information on daily food consumption was used to estimate the number of days of feeding represented by the beaks recovered from each stomach.

RESULTS

Altogether, 21 stomachs were examined from the 2005 and 2008 strandings combined, with 11 stomachs found to contain identifiable prey remains: five from 2005 and six from 2008. Prey remains comprised 153 lower and 127 upper cephalopod beaks belonging to two genera of cephalopods: arrow squid, *Nototodarus* spp. (Teuthoidea: Ommastrephidae) and octopus, *Pinnoctopus cordiformis* (Octopoda: Octopodidae) (Tables 3, 4). *Nototodarus* spp. were present in all stomachs with prey remains, while *P. cordiformis* were present in 60% of those that contained prey remains in 2005 and 20% in 2008. Nematode parasites, presumably *Anisakis* sp., were found in 13 stomachs; two of the whales infested with nematodes also displayed ulceration of the stomach lining (Table 1; Fig. 4).

Cephalopod prey size

Details of all regression equations describing the relationships of LRL/LHL versus ML, and LRL/LHL versus BM, calculated and compared in this investigation are summarised in Table 2. A comparison of the species-specific *Nototodarus gouldi* regression of LRL versus ML calculated in this study with the regression lines provided by Clarke (1986) reveal that for LRL >4 mm, *N. gouldi* mantle length is overestimated by the regressions for *Nototodarus* "New Zealand east coast" and "New Zealand west coast" (Fig. 2A), although comparison of regressions of LRL against biomass differ little (Fig. 2B). The regressions of both Clarke (1986) and the present study differ considerably from the *N. sloanii* regression equations of Jackson & McKinnon (1996) (Fig. 2A,B). Both *N. gouldi* and *N. sloanii* can occur off the coast of central New Zealand (Smith et al. 1987), and the two species cannot be reliably differentiated on the basis of beak morphology. No information exists on the distribution of the pilot whales involved in the strandings nor where they may have foraged prior to stranding, therefore, we were unable to ascertain which species of *Nototodarus* the beaks examined in this study were derived from. Consequently, size of prey at ingestion has been calculated

Table 2 Equations describing the relationships between beak length (LRL/LHL) and mantle length (ML) and biomass (BM) for *Nototodarus* spp. LRL, Lower rostral length; LHL, hood length of lower beaks.

Species	Author	Relationship	*n*	Equation	r^2
Nototodarus spp. "NZ west coast"	Clarke (1986)	LRL versus ML	407	$\ln ML = 4.11 + 0.793 \ln LRL$	0.89
Nototodarus spp. "NZ west coast"	Clarke (1986)	LRL versus BM	403	$\ln BM = 1.91 + 2.37 \ln LRL$	0.91
Nototodarus spp. "NZ east coast"	Clarke (1986)	LRL versus ML	1145	$\ln ML = 4.18 + 0.788 \ln LRL$	0.94
Nototodarus spp. "NZ east coast"	Clarke (1986)	LRL versus BM	1131	$\ln BM = 1.79 + 2.41 \ln LRL$	0.95
Nototodarus sloanii	Jackson & McKinnon (1996)	LRL versus ML	170	$ML = 168.83 \ln LRL + 25.52$	0.90
Nototodarus sloanii	Jackson & McKinnon (1996)	LRL versus BM	170	$BM = 236.10\ LRL - 512.99$	0.90
Nototodarus gouldi	This study	LRL versus ML	83	$ML = 28.20\ LRL + 69.33$	0.78
Nototodarus gouldi	This study	LRL versus BM	83	$BM = 6.93\ LRL^{2.33}$	0.92
Pinnoctopus cordiformis (= *Octopus maorum*)	Lu & Ickeringill (2002)	LHL versus ML	17	$ML = -43.69 + 29.18\ LHL$	0.74
Pinnoctopus cordiformis (= *Octopus maorum*)	Lu & Ickeringill (2002)	LHL versus BM	12	$BM = 2.14 + 2.50 \ln LHL$	0.91

Table 3 Composition of cephalopods in the stomach contents of 10 *Globicephala melas* stranded at Farewell Spit on 21 December 2005, and 11 *G. melas* stranded at Farewell Spit on 23 January 2008. FO, Frequency of occurrence; %N, percentage by number; M, total reconstructed biomass (kg); %M, percentage by reconstructed biomass; IRI, index of relative importance. M and %M calculated using the equation describing the relationship between LRL and biomass for *N. gouldi* (this study). Asterisk denotes value unable to be calculated (recovered upper beaks only).

Species in diet												Total	FO	%N	M	%M	IRI
2005	GM01	GM02	GM03	GM04	GM05	GM06	GM07	GM08	GM09	GM10							
Ommastrephidae																	
Nototodarus spp.	1				3	33		6		13		56	1	87.5	6.4	91.4	178.9
Octopodidae																	
Pinnoctopus cordiformis	4							2		2		8	0.6	12.5	0.6	8.6	12.6
Total upper cephalopod beaks	4	0	0	0	3	31	0	1	0	15		54					
Total lower cephalopod beaks	5	0	0	0	2	33	0	8	0	11		59					
Reconstructed biomass of prey (kg)	0.6	0	0	0	0.3	3.6	0	1.4	0	1		6.9					
2008	GM27	GM28	GM29	GM30	GM31	GM32	GM33	GM34	GM35	GM36	GM37						
Ommastrephidae																	
Nototodarus spp.			1	4		5	39		46		1	96	1	98.0	38.5	99.2	197.2
Octopodidae																	
Pinnoctopus cordiformis											2	2	0.2	2.0	0.3	0.8	0.5
Total upper cephalopod beaks	0	0	1	4	0	2	31	0	33	0	2	73					
Total lower cephalopod beaks	0	0	0	2	0	5	39	0	46	0	2	94					
Reconstructed biomass of prey (kg)	0	0	*	0.6	0	1.7	14.4	0	21.8	0	0.3	38.8					

Table 4 Composition of cephalopods in the stomach contents of 10 *Globicephala melas* stranded at Farewell Spit on 21 December 2005, and 11 *G. melas* stranded at Farewell Spit on 23 January 2008. FO, Frequency of occurrence; %N, percentage by number; M, total reconstructed biomass (kg); %M, percentage by reconstructed biomass; IRI, index of relative importance. M and %M calculated using the equation describing the relationship between LRL and biomass for *N. sloanii* (Jackson & McKinnon 1996). Asterisk denotes value unable to be calculated (recovered upper beaks only).

Species in diet												Total	FO	%N	M	%M	IRI
2005	GM01	GM02	GM03	GM04	GM05	GM06	GM07	GM08	GM09	GM10							
Ommastrephidae																	
Nototodarus spp.	1				3	33		6		13		56	1	87.5	13.7	95.1	182.6
Octopodidae																	
Pinnoctopus cordiformis	4							2		2		8	0.6	12.5	0.6	4.2	10.0
Total upper cephalopod beaks	4	0	0	0	3	31	0	1	0	15		54					
Total lower cephalopod beaks	5	0	0	0	2	33	0	8	0	11		59					
Reconstructed biomass of prey (kg)	0.8	0	0	0	0.6	8.1	0	3.1	0	1.8		14.4					
2008	GM27	GM28	GM29	GM30	GM31	GM32	GM33	GM34	GM35	GM36	GM37						
Ommastrephidae																	
Nototodarus spp.			1	4		5	39		46		1	96	1	98.0	76.9	99.6	197.6
Octopodidae																	
Pinnoctopus cordiformis											2	2	0.2	2.0	0.3	0.4	0.4
Total upper cephalopod beaks	0	0	1	4	0	2	31	0	33	0	2	73					
Total lower cephalopod beaks	0	0	0	2	0	5	39	0	46	0	2	94					
Reconstructed biomass of prey (kg)	0	0	*	1.4	0	3.8	29.3	0	42.4	0	0.3	77.2					

using species-specific regressions for both species of *Nototodarus* (i.e., Jackson & McKinnon 1996; this study).

Nototodarus spp. accounted for 87.5 and 98% by number of the total cephalopod prey ingested by whales involved in the 2005 and 2008 strandings respectively; the few remaining cephalopod remains were attributed to *Pinnoctopus cordiformis* (Tables 3, 4); *P. cordiformis* beaks recovered from the 2005 stranding ranged from 1.9 to 2.9 mm in lower hood length. Using the *P. cordiformis* LHL versus ML and LHL versus BM regression equations (Lu & Ickeringill 2002), *P. cordiformis* estimated mantle lengths ranged from 13 to 42 mm, and estimated biomass ranged from 44 to 125 g. The single *P. cordiformis* beak recovered from the 2008 stranding was considerably larger at 4.2 mm LHL, 79 mm estimated ML, and 307 g estimated biomass.

The *Nototodarus* beaks recovered from both the 2005 and 2008 strandings ranged from 1.7 to 8.5 mm in lower rostral length. Using the *Nototodarus gouldi* LRL versus ML and LRL versus BM regression equations (present study), *Nototodarus* estimated mantle lengths ranged from 76 to 309 mm and constituted 91.4 and 99.2% by reconstructed mass of prey ingested by whales involved in the 2005 and 2008 strandings respectively (Table 3). Approximately 80% of the total prey items from the 2005 stranding were estimated to be of mantle length between 80 and 180 mm (mean 124.0 ± 6.4 mm), whereas those from the 2008 stranding were significantly larger ($P < 0.01$), with over 80% estimated between 200 and 280 mm (mean 228.7 ± 3.4 mm) (Fig. 3A). Prey items from the 2005 stranding are also estimated to weigh significantly less than those from 2008 ($P < 0.01$), with over 80% of 2005 items having reconstructed biomass under 200 g (mean 125.1 ± 10.0 g) compared to over 80% between 200 and 700 g for the 2008 prey items (mean 418.0 ± 17.4 g) (Fig. 3B). The estimated total biomass of prey found in the stomachs ranged from 0.3 kg to 21.8 kg (median 1.2 kg) (Table 3).

Using the *Nototodarus sloanii* LRL versus ML and LRL versus BM regression

Table 5 Size, estimated daily food requirements (based on the calculations of Innes et al. 1987), and stomach contents of *Globicephala melas* stranded at Farewell Spit. Asterisk denotes total for all prey species combined, inclusive *Pinnoctopus cordiformis*. *Nototodarus gouldi* and *N. sloanii* refer to the regression equation used for *Nototodarus* spp. calculations.

Code	Length (cm)	Estimated weight (kg)	Daily food requirements (kg)	Estimated prey weight in sample (kg), *N. gouldi**	Estimated prey weight in sample (kg), *N. sloanii**	Proportion of daily food requirement present, *N. gouldi**	Proportion of daily food requirement present, *N. sloanii**
Nov 2005							
GM01/05	490	1230	36.46	0.60	0.80	0.02	0.02
GM02/05	570	1795	49.34	0.00	0.00	0.00	0.00
GM03/05	200	131	6.07	0.00	0.00	0.00	0.00
GM04/05	510	1359	39.50	0.00	0.00	0.00	0.00
GM05/05	250	229	9.49	0.30	0.60	0.03	0.06
GM06/05	320	424	15.55	3.60	8.10	0.23	0.52
GM07/05	320	424	15.55	0.00	0.00	0.00	0.00
GM08/05	530	1497	42.66	1.40	3.10	0.03	0.07
GM09/05	420	837	26.78	0.00	0.00	0.00	0.00
GM10/05	380	651	21.92	1.00	1.80	0.05	0.08
Jan 2008							
GM27/08	190	115	5.48	0.00	0.00	0.00	0.00
GM28/08	470	1108	33.54	0.00	0.00	0.00	0.00
GM29/08	410	788	25.52	0.00	0.00	0.00	0.00
GM30/08	440	940	29.40	0.60	1.40	0.02	0.05
GM31/08	270	277	11.07	0.00	0.00	0.00	0.00
GM32/08	310	391	14.59	1.70	3.80	0.12	0.26
GM33/08	420	837	26.78	14.40	29.30	0.54	1.09
GM34/08	250	229	9.49	0.00	0.00	0.00	0.00
GM35/08	430	887	28.08	21.80	42.40	0.78	1.51
GM36/08	500	1294	37.97	0.00	0.00	0.00	0.00
GM37/08	540	1568	44.29	0.30	0.30	0.01	0.01

equations (Jackson & McKinnon 1996), estimated mantle lengths of *Nototodarus* ranged from 110 to 387 mm, and constituted 95.1 and 99.6% by reconstructed mass of prey ingested by whales involved in the 2005 and 2008 strandings respectively (Table 4). Approximately 80% of the total prey individuals from the 2005 stranding were estimated between 140 and 300 mm mantle length (mean 198.8 ± 10.7 mm), whereas those from the 2008 stranding were significantly larger ($P < 0.01$), with approximately 80% estimated at greater than 300 mm mantle length (mean 314.3 ± 4.1 mm) (Fig. 3C). Approximately 80% of 2005 items have a reconstructed biomass under 500 g (including 10% negative values, mean 256.4 ± 29.0 g), significantly less ($P < 0.01$) than the 90% of 2008 prey items estimated to be heavier than 500 g (mean 829.2 ± 25.2 mm) (Fig. 3D). The estimated total biomass of the prey found in the stomachs ranged from 0.3 to 42.4 kg (median 1.6 kg) (Table 4).

Estimation of food consumption

The mean estimated weight of the pilot whales stranded at Golden Bay during the study period was 810 (±112) kg. The estimated average weight of food required daily per pilot whale was 25 (±3) kg. The amount of food represented by prey remains recovered from the stomachs ranged from 0.01 to 0.78 (median c. 0.04) of the daily requirement when using the *Nototodarus gouldi* regressions, and 0.01 to 1.51 (median c. 0.08) of the daily food requirement when using the *Nototodarus sloanii* regressions (Table 5).

DISCUSSION

The stomach contents of long-finned pilot whales from the 2008 mass-stranding comprised exclusively cephalopods, primarily arrow squid (*Nototodarus* spp.), and secondarily octopus (*Pinnoctopus cordiformis*) (Table 2). These findings are consistent with earlier accounts from this area (Beatson 2007a; Table 2). Based on the known life histories of both *Nototodarus* spp. and *Pinnoctopus cordiformis*, Beatson et al. (2007a) suggested that long-finned pilot whales stranded in the vicinity of Golden Bay had previously been foraging both near the surface of the water column and on the sea bed, most likely at depths shallower than 150 m. The same would appear true for those whales involved in the 2008 stranding and is relatively consistent with, albeit somewhat shallower than, the foraging behaviour of long-finned pilot whales reported elsewhere. For example, Gannon (1995) suggested that long-finned pilot whales off the east coast of the United States foraged at 70–165 m in depth, while Desportes & Mouritsen (1993) suggested that around the Faroe Islands this species feeds at depths between 100 and 500 m. Time-depth recorders deployed on long-finned pilot whales in the Ligurian Sea have recorded foraging dives of between 72 and 648 m (Baird et al. 2002).

Cephalopod prey size

The most noteworthy difference in the diets of whales from the two Golden Bay stranding events is that prey items recovered from the stomachs of whales involved in the 2008 mass stranding were estimated to be larger, i.e., both longer and heavier ($P < 0.01$), than those from the 2005 stranding (Fig. 3A–D). This variability in prey size could be related to the size of prey available at the time, rather than prey-size selection of pilot whales, as trends in arrow squid size, growth and maturity have been reported to vary considerably between sites, seasons and years (Jackson et al. 2003). The *Nototodarus* prey-size composition in both 2005 and 2008 is consistent with that reported for the most important prey item in the diet of long-finned pilot whales along the United States mid-Atlantic coast, i.e., *Loligo pealei*, with estimated mantle length between 100 and 300 mm (Gannon et al. 1997).

It must be emphasised that the use of LRL regressions for *Nototodarus* beaks recovered from the stomachs of predators could produce inaccurate mantle length and biomass estimates depending on which species of *Nototodarus* was ingested. It is evidenced from the plotted LRL-mantle length, and LRL-biomass regressions (Fig. 2A,B) that both the length and weight of *N. sloanii* is greater than that of *N. gouldi* for a given LRL measurement. Given that the *Nototodarus* beaks examined in this study could have been either *N. sloanii* or *N. gouldi* (or a combination of both), it is possible that the use of *N. sloanii* regressions has overestimated, while *N. gouldi* regressions has possibly underestimated the size of arrow squid ingested.

Estimation of food consumption

An estimator of pilot whale food intake was given by Sergeant (1969) based on the heart:body weight ratio, which approximates a tenth of the feeding rate. This formula has been widely used in the marine mammal literature and indicates a daily consumption of about 40 kg for a 1000 kg whale. However, more recently, Innes et al. (1986) have discredited this theory; Innes et al. (1987) estimate ingestion rate as an allometric function of body weight, and using this calculation a 1000 kg whale would consume around 31 kg of food daily. Using the Innes (1987) calculation, the amount of food represented by prey remains recovered from the stomachs examined in this study did not meet the daily requirement of any whale calculated from the *Nototodarus gouldi* regressions, and only two whales surpassed the daily food requirements calculated from the *Nototodarus sloanii* regressions (Table 5). However, it was not possible to examine the whole gastric system, and more material may have been present. Such calculations are often extrapolated to derive estimates of total cephalopod consumption by a population (Santos et al. 1999). Such estimates cannot be calculated for pilot whales in New Zealand waters, or even the Southern Hemisphere for that matter, since no population estimates are available.

Both species of *Nototodarus,* collectively termed arrow squid, have been commercially targeted by large, multi-national jig and trawl fleets within New Zealand's 200 nautical mile Exclusive Economic Zone (EEZ) since the early 1970s (Uozumi & Forch 1995). The total catch of arrow squid in the 2005–06 fishing season was 72 418 t, 66 574 t taken by trawl, of which 49 149 t was taken from from the SQU1T fishery (New Zealand Ministry of Fisheries 2007); the SQU1T fishery includes most of the New Zealand EEZ, with the exception of the southern and Kermadec Islands, and represents two-thirds of the total catch since 2000. Catch and effort data from the SQU1T fishery show that the arrow squid catch occurs between December and May, with peak harvest from January to April (New Zealand Ministry of Fisheries 2007). Pilot whales in the Northern Hemisphere have been observed to migrate seasonally, apparently in response to changes in prey distribution and water temperature, with inshore movements documented over summer, and offshore beyond the continental shelf in winter (Zachariassen 1993). Nothing is known of pilot whale abundance or seasonal movements within New Zealand waters. Given the intensity of the squid fishery within the New Zealand EEZ, and the importance of arrow squid to the diet of pilot whales, the relationship between the two warrants further investigation.

Stomach ulceration

Post-mortem pathology is another area that could provide further insights on the health of marine mammals in New Zealand waters. Stomach ulceration was observed in two of the recently stranded pilot whales. Ulceration and inflammation of the stomach can be attributed to parasitic and non-parasitic causes. Most reports of ulceration in marine mammals directly associate the ulcers with parasitism by nematodes (Motta et al. 2008). Parasite-induced ulcers are typically shallow and have the anterior end of the worm embedded in the ulcer bed, although in some cases there may be numerous adult and larval nematode parasites free within the lumen (Geraci & St Aubin 1987). In this study, of the eight pilot whales involved in the 2008 mass stranding that had parasitic infection by nematodes, two individuals displayed gastric ulceration with visible parasites embedded in the ulcerous regions (Fig. 4). Further pathological investigation would be required to identify the association of nematodes with ulcer development. As suggested by Schoroeder & Wegeforth (1935), it is possible that the nematodes may only have invaded existing ulcers, further exacerbating the host reaction.

Recent isolation of *Heliobacter* sp. from gastric mucosa of dolphin carcasses suggests an infectious etiology for gastric ulcers in marine mammals (Harper et al. 2000). Other proposed causes of gastric ulcers include starvation, stress, and trauma (Sweeney & Ridgway 1975; Duignan et al. 2003). Geraci & Lounsbury (1993) suggest that an excess of undiluted acid can produce ulcers in all stomach chambers (particularly the first), as the condition is often seen in emaciated cetaceans. Neither of the pilot whales observed by the authors to display stomach ulcers showed obvious signs of emaciation. The stomachs were not completely empty, indicating that the whales were likely to have eaten within a few days prior to stranding. However, with the total prey remains found in one stomach attributed to a single cephalopod, and the other attributed to three individuals with a combined reconstructed biomass of 300 g, it appears that neither whale was satiated prior to stranding.

Limitations of the study

This study has several limitations related to both sampling and stomach content analysis that must be considered. Samples were taken opportunistically from a minimum of 10 whales that died as a result of a single mass-stranding event in each year and are not necessarily representative of all animals involved in the stranding, or the population as a whole. Biases of dietary studies based on stomach content analysis of stranded cetaceans are well known and have been addressed earlier (Beatson et al. 2007a; see Pierce & Boyle 1991 for a review). Strandings can be biased towards sick animals, whose diet may not be representative of healthy individuals within the population. In the case of a pilot whale mass-stranding, it is unlikely that all animals involved are sick, however, events leading up to the stranding could have disrupted typical foraging behaviour. As strandings likely represent animals using inshore waters before death, neritic prey is likely to be overestimated in their diet. The importance of hard-part remains such as cephalopod beaks is also likely to be overestimated as they are able to withstand digestion for longer periods than softer or more easily digested items such as cephalopod flesh and fish remains.

The constraints of the dietary data presented are acknowledged. Nevertheless, given the inherent difficulties in studying the feeding ecology of oceanic cetaceans, the general lack of knowledge of the biology of whales in New Zealand waters, and the complete lack of any temporal information on diet for any species, ongoing research monitoring diet is of value. Compared with the short-term record of diet provided by stomach contents, diet information from stable isotope analyses reflects the average composition of food resources that have been assimilated over periods of days to months, depending on rates of tissue turnover (Tieszen 1978; Kirsch et al. 1998, 2000). Research involving combined use of stomach content analysis, together with carbon and nitrogen isotope measurements of marine mammal tissues, is recommended to gain further insights on trophic relationships and feeding ecology, including spatial use of habitat and temporal shifts in diet.

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