MASS–LENGTH RELATIONSHIPS AND ENERGY CONTENT OF FISHES AND INVERTEBRATES DELIVERED TO NESTLING THICK-BILLED MURRES *URIA LOMVIA* IN THE CANADIAN ARCTIC, 1981–2007

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SUMMARY

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We summarize data relating to the length and mass of prey items delivered by Thick-billed Murres *Uria lomvia* to nestlings, or otherwise deposited on breeding ledges, at a number of colonies in Nunavut, Canada. These data are augmented from specimens taken by divers in the Nuvuk Islands area of northeastern Hudson Bay. Together, these records allowed us to develop predictive equations for estimating mass from length for the fishes *Stichaeus punctatus, Mallotus villosus, Leptoclinus maculatus, Gymnelus* spp., *Eumesogrammus praecisus, Ammodytes* spp., all Cottidae, *Triglops* spp., *Liparis* spp., and all squid (*Gonatus* spp.) over the range of sizes typically delivered to murre nestlings. We also provide energy content on a dry weight and wet weight basis for several of these fishes and invertebrates. In addition, we list all prey species delivered to nestling Thick-billed Murres in the Hudson Strait and northern Hudson Bay regions over the past three decades.

Key words: Thick-billed Murre, *Uria lomvia,* Nunavut, diet, mass–length, *Stichaeus, Mallotus, Leptoclinus, Gymnelus, Eumesogrammus, Ammodytes, Cottidae, Triglops, Liparis,* squid

INTRODUCTION

The Thick-billed Murre *Uria lomvia* is the most abundant seabird breeding in the eastern Canadian Arctic (Brown *et al.* 1975, Gaston 1991, Gaston & Hipfner 2000), with large populations in Ungava Bay, Hudson Strait, northern Hudson Bay, Davis Strait, Baffin Bay and adjacent waters, and as far west as Prince Leopold Island in Barrow Strait. Consequently, its range covers most of the marine water types found in Nunavut.

Thick-billed Murres dive to more than 140 m depth (Croll *et al.* 1992, Elliott *et al.* 2007), feeding on large zooplankton and small fish (less than 30 cm, Gaston & Hipfner 2000). They deliver food to their nestlings carried in the bill, with usually only one item (fish, squid or crustacean) carried at a time. (Sometimes several small items may be carried.) Consequently, most of the food delivered to nestlings is whole or near-whole when delivered at the colony. Some birds bring fish before their egg has hatched, others deliver fish after chicks have fledged or disappeared, and some non-breeders or failed breeders also bring fish. Although some of these "extraneous" fish are eaten, some are deposited on the cliffs, along with fish intended for chicks, which for various reasons, are not eaten.

In the course of studies at several Thick-billed Murre colonies in Nunavut, Canada, we retrieved a large number of food items from cliff ledges soon after they had been deposited. Because Thick-billed Murres defecate copiously on their breeding ledges, any food item that is unsullied by defecation is likely to have been delivered only a short time before (within one to two hours). In addition, most prey items delivered come from within 45 minutes' flying time of the colony (Woo 2002, Elliott *et al.* 2008). Consequently, items retrieved from breeding ledges in clean condition have probably been dead for less than three hours. We used such specimens to derive length–mass relationships.

Substantial research has been conducted on the diet of murres, based on observations and identifications of prey items being delivered to nestlings (Pearson 1968, Gaston 1985a, Harris & Wanless 1985, Birkhead & Nettleship 1987, Swann *et al.* 1991, Hatchwell *et al.* 1992, Bryant *et al.* 1999, Gaston *et al.* 2003). In some cases, observers have estimated the size of individual prey items, usually based on a comparison with the length of the bird's bill (Gaston 1985a, Birkhead & Nettleship 1987). To translate these observations into mass (a more useful measure of the nutrition supplied to the chick), knowledge of the length–mass relationship is required for each species or species group.

For Thick-billed Murre nestling diet items, such relationships have been published previously by Gaston (1985b, 1987). Similar relationships for the prey of Black Guillemots *Cepphus grylle* were given by Cairns (1987). The present paper compiles an improved set of relationships based on a larger sample collected over the period 1980–2007. It also includes details of length and mass for specimens for observations in which sample sizes were insufficient to derive meaningful relationships, should other investigators be able to expand those samples in future, and provides a complete listing of diet items identified for Thick-billed Murres at the colonies studied.

It must be kept in mind that not all of these fish would have been suitable for nestlings. In some cases, their unsuitability may have been the reason we obtained them. For example, a disproportionate number of these items were very large fish found next to very small chicks, presumably because the meal was too large for the chick to swallow. Gaston & Nettleship (1981) found that prey items obtained from ledges were significantly larger than those estimated from adult bill length during direct observations or those collected using throat ties that prevent the nestling from swallowing. Consequently, these data are not suitable for deriving any information on the size of food items actually eaten by chicks.

All of the fish included here were obtained inside of the ecozones described by Coad & Reist (2004), mostly in the Hudson Strait ecozone.

METHODS

Voucher specimens of prey items were collected incidentally during studies of Thick-billed Murres, often during chick-banding, at three breeding colonies: Coats Island (62°57′N, 82°00′W) during 1984–2006, Digges Island (62°33′N, 77°50′W) during 1980–1982 and Hantsch Island (61°55′N, 65°00′W) in 1982 (Fig. 1). In addition, many benthic fishes taken by Thick-billed Murres were collected by divers searching for Black Guillemot prey during 1981–1983 at Nuvuk Islands (62°23′N, 78°50′W). Details of length–mass relationships among the Nuvuk Islands specimens were presented

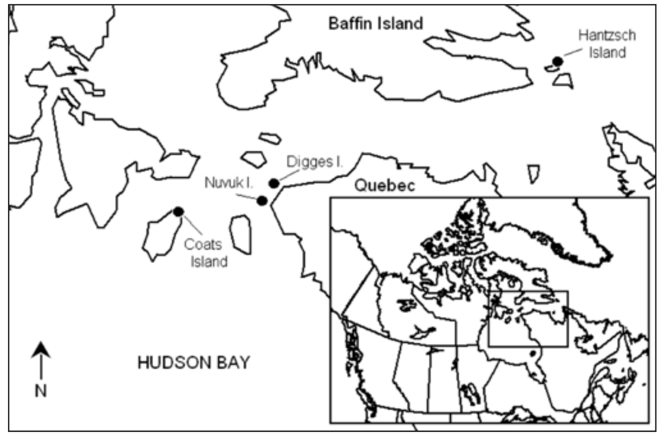

Fig. 1. Map of Nunavut, Canada, showing the position of localities mentioned in the text.

TABLE 1
Coefficients and exponents for mass–length[a] relationships of Thick-billed Murre *Uria lomvia* prey species

Species/group	Locality	Coefficient	Exponent	R^2	N
Stichaeus punctatus	All Canadian Arctic	4.89	3.12	0.98	100
	Coats Island	5.20	2.37	0.67	18
	Nuvuk Islands	5.03	2.22	0.98	82
Mallotus villosus	Coats Island	4.21	3.74	0.85	187
	All Canadian Arctic	4.18	3.77	0.85	196
Leptoclinus maculatus	Coats Island	3.04	2.16	0.87	70
Gymnelus spp.	All Canadian Arctic	2.83	3.06	0.96	116
	Coats Island	2.89	2.76	0.82	58
	Nuvuk Islands	3.09	3.30	0.98	58
Eumesogrammus praecisus	All Canadian Arctic	6.70	3.29	0.96	109
	Coats Island	6.45	3.00	0.83	42
	Nuvuk Islands	7.18	3.36	0.99	62
Boreogadus saida	All Canadian Arctic	6.24	2.98	0.86	354
	Coats Island	6.40	2.93	0.84	307
	Digges Island	5.69	3.13	0.92	43
Ammodytes spp.	All Canadian Arctic	2.26	2.86	0.79	87
	Coats Island	2.35	2.74	0.55	66
	Digges Island	2.20	2.77	0.76	21
All sculpins	All Canadian Arctic	7.37	2.57	0.87	252
Triglops spp.	All Canadian Arctic	6.48	2.96	0.81	113
Myoxocephalus spp.	All Canadian Arctic	9.54	2.64	0.96	10
Gymnocanthus spp.	All Canadian Arctic	11.11	4.03	0.92	17
Liparis spp.	All Canadian Arctic	0.50	3.73	0.86	22
Gonatus spp.	All Canadian Arctic	0.16	1.62	0.81	11

[a] Length is measured in decimetres (one tenth of a metre) to avoid small coefficients.

by Cairns (1987), but are included here to make all information available from a single source.

Identification was made as accurately as possible in the field using Leim & Scott (1968) and Hunter *et al.* (1984). If identity was in doubt, the specimen was sent to the Canadian Museum of Nature for confirmation. Length was measured from the snout to the base of the fork (fork length) or from snout to the tip of the caudal fin (total length) by arranging the specimen as straight as possible along a ruler accurate to ± 1 mm. For species with pointed caudal fins, these two measurements are identical. In other cases, only fork length was used for regression analyses. Specimens were weighed using an electronic scale accurate to ± 0.1 g. Items reported as “dried,” “slightly dried” or otherwise incomplete were excluded from analyses. Mass–length regressions were calculated by selecting the Power regression option in Microsoft Excel 98. Regression coefficients and parameters were automatically output by the program. All means are given ± standard deviation. As an aid to future workers, all data are available in downloadable form as an appendix to this paper (www.marineornithology.org/PDF/36_1/Elliot-appendix.xls).

During 2006 and 2007, fresh fish were measured and then washed and frozen. In the laboratory, each frozen fish was freeze-dried for 36 hours in a Labconco freeze drier. The freeze-dried samples were weighed before homogenization in a blade coffee grinder. Pellets were then prepared (0.3–0.6 g) using a Parr pellet press. If the prey item was large enough, two or three pellets were made so that energy density values could be averaged, and variation among pellets assessed. For prey items of less than 0.3 g (dry weight), samples were combined to ensure a minimum weight of 0.3 g. The pellets were dried at 55°C for 24 hours, weighed to the nearest 0.0001 g and combusted in a Parr adiabatic calorimeter, which was calibrated using a benzoic acid standard. Standard corrections for residual acid and fuse wire burning were incorporated as outlined in the Parr Operating Instructions.

RESULTS

All power regression results are given in Table 1.

Fish

Arctic Cod Boreogadus saida *(Gadidae)*
Arctic Cod made up about 50% of the items delivered at Coats and Digges islands (Gaston *et al.* 1985, 2003), and 342 specimens were included in our regression (Fig. 2). Total length was an average of 3.85 mm longer than fork length, giving a regression output of

$$\text{Mass} = 133.6\ 10^{-6}\cdot\text{Length}^{2.33}\ (R^2 = 0.396,\ n = 45),$$

in which Length is total length. Energy density, at 22 kJ/g dry weight, was high (Table 2), which is consistent with the pelagic, lipid-rich lifestyle reported for this species. Our values for energy content were higher than those reported by Lawson *et al.* (1998) for Labrador (4.4 kJ/g wet weight)and Ball *et al.* (2007) for the eastern Beaufort Sea (1.2 kJ/g wet weight, 16.6 kJ/g dry weight; based on a single 112-mm specimen), but lower than those reported by Cairns (1984) for western Hudson Strait (26.5 kJ/g dry weight) and by Weslawski *et al.* (1994) for Svalbard (24.2 kJ/g dry weight).

Atlantic Poacher Leptagonus decagonus *(Agonidae)*
Six Atlantic Poacher specimens were collected at Coats Island: 7 August 1992 (140 mm, 10.3 g), 28 July (140 mm, 5.5 g), 28 July (130 mm, 5.2 g), 29 July (152 mm, 10.4 g), 30 July (137 mm, 8.9 g) and 8 August (137 mm, 9.3 g) 2006; and 1 August (151 mm, 11.3 g) and 3 Aug (142 mm, 8.1g; 139 mm, 8.2g) 2007. This species was not reported in the Foxe Basin ecoregion by Coad & Reist (2004). Energy density was low (Table 2), which is consistent with the benthic ecology reported for this species.

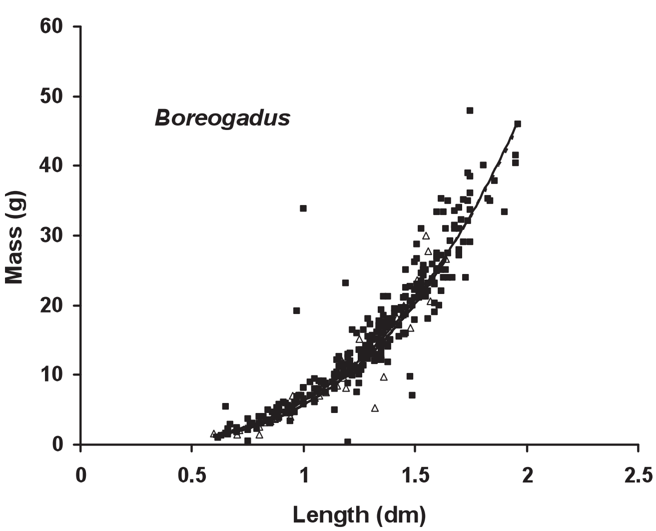

Fig. 2. Fork length versus mass for *Boreogadus saida* collected in the Canadian Arctic (n = 342). Dashed line represents Digges Island (open triangles); dotted line represents Coats Island (filled squares).

TABLE 2
Energy content (wet and dry weight) of Thick-billed Murre *Uria lomvia* nestling diet determined by bomb calorimetry

Species/group	Wet weight energy (kJ/g)	N	Dry weight energy (kJ/g)	N
Stichaeus punctatus	4.11±0.08	5	18.29±0.49	6
Mallotus villosus	4.90±0.16	17	23.47±0.46	18
Leptoclinus maculatus	4.97±0.17	6	21.59±0.49	7
Gymnelus spp.	4.09±0.24	7	18.80±0.53	7
Eumesogrammus praecisus	3.22±0.38	3	18.18±0.39	4
Boreogadus saida	4.70±0.19	16	21.99±0.45	17
Ammodytes spp.	5.06±0.11	8	23.39±0.54	8
Triglops spp.	4.33±0.21	16	21.00±0.45	18
Leptagonus decagonus	3.51±0.31	5	18.40±0.46	6
Gonatus fabricii	3.48±1.49	2	17.00±3.75	2
Decapods	3.48±0.45	2	18.30±0.41	2
Parathemisto libellula	4.18±0.41	2	21.56±0.50	2

Arctic Shanny Stichaeus punctatus *(Stichaeidae)*
Many Arctic Shanny specimens were collected at Nuvuk Islands, off northern Quebec, in 1981–1983, with a smaller number collected at Coats Island (Fig. 3). Based on the regression from Bonavista Bay, Newfoundland and Labrador (Keats *et al.* 1993), most of the Coats Island specimens were over 5 years of age; those collected from the Nuvuk Islands were mostly younger. Energy density was low (18.3 kJ/g dry weight, Table 2), and similar to the value of 18.7 kJ/g reported by Anthony *et al.* 2000) for Gulf of Alaska. That finding is consistent with the benthic ecology of the family (Leim & Scott 1968), although a higher figure was reported by Cairns (1984) for western Hudson Strait (22.4 kJ/g).

Banded Gunnel Pholis fasciata *(Pholidae)*
Seven Banded Gunnel specimens were collected at Coats Island: 10 August 1984 (122 mm, 4 g), 10 August 1985 (5.1 g), 13 August (239 mm, 36.2 g) and 21 August (approximately 225 mm, 23.8 g) 1998, 2004 (no date or details recorded), 1 August 2005 (265 mm, 54.2 g), and 26 July 2006 (182 mm, 16.4 g). The last five specimens were likely too large to be swallowed by chicks.

Capelin Mallotus villosus *(Osmeridae)*
Most Capelin specimens were collected at Coats Island (n = 233, Fig. 4), with a few collected at Digges Island (n = 13, Fig. 4). Total length was an average of 3.8 mm longer than fork length, giving a regression output of

$$\text{Mass} = 0.80\,10^{-6}\cdot\text{Length(mm)}^{3.35}\ (R^2 = 0.99,\ n = 13),$$

where Length is total length. Carscadden and Frank (2002) provided year-by-year regressions for somatic mass (Fulton K; somatic mass = total mass – gonadal mass) against total length of Capelin collected off Newfoundland. Averaged over all years, the regressions were

Mass $= 2.04\,10^{-6}\cdot\text{Length(mm)}^{3.46}$ (males), and Mass $= 2.71\,10^{-6}\cdot\text{Length(mm)}^{3.18}$ (females) [range in coefficients: $1.66\,10^{-6} - 7.01\,10^{-6}$ (females), and $0.32\,10^{-6} - 7.21\,10^{-6}$ (males); range in exponents: 3.02 – 3.32 (females), and 2.88–4.00 (males)].

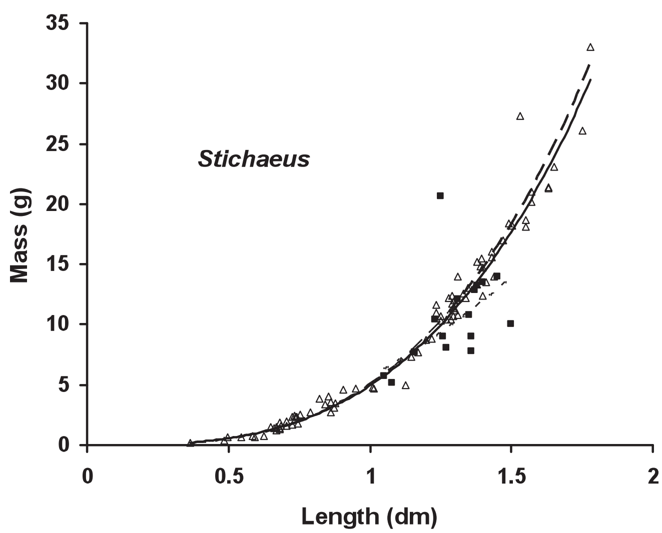

Fig. 3. Fork length versus mass for *Stichaeus punctatus* collected in the Canadian Arctic (n = 99). Dashed line represents Nuvuk Islands (open triangles); dotted line represents Coats Island (filled squares).

Hence, the exponent was not significantly different between the two data sets. However, the exponent for the larger data set of fork length–mass (Fig. 4) is larger than that for females in any year, suggesting that Capelin collected at Coats Island may primarily be males. Furthermore, Capelin from Coats Island were significantly lighter than Capelin from Newfoundland, even though Newfoundland Capelin were measured without gonads. Energy density was high (4.9 kJ/g wet weight, Table 2), which is consistent with the pelagic and lipid-rich nature of this prey item and with the observation that many of the fish collected in 2006 and 2007 were gravid. Nonetheless, our energy density was well below that reported by Lawson *et al.* (1998) for the northwest Atlantic (8.4 kJ/g wet weight), although those authors reported that their value was derived from two specimens that differed widely in energy density. Anthony *et al.* 2000) reported lower values in the northeast Pacific (4.45 kJ/g wet weight).

Daubed Shanny Leptoclinus maculatus *(Stichaeidae)*
All Daubed Shanny specimens were collected at Coats (Fig. 5) except for two specimens from Digges Island on 11 August 1981 (90 mm, 2.5 g) and 17 August 1981 (no readings). Energy content

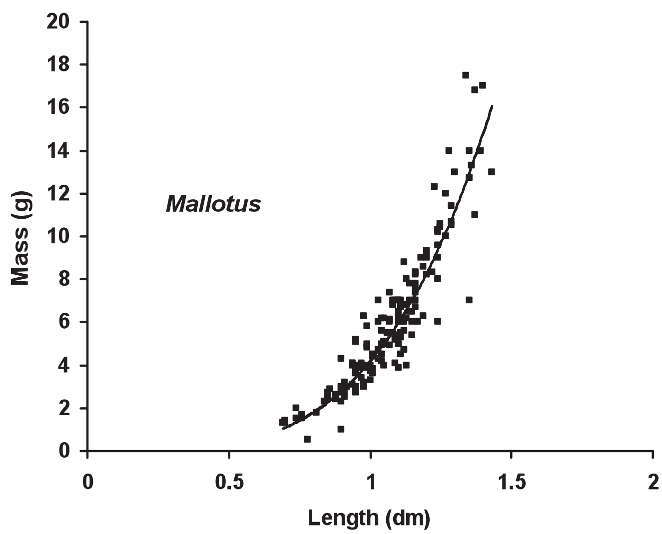

Fig. 4. Fork length versus mass for *Mallotus villosus* collected in the Canadian Arctic (n = 176). Dotted line represents Coats Island.

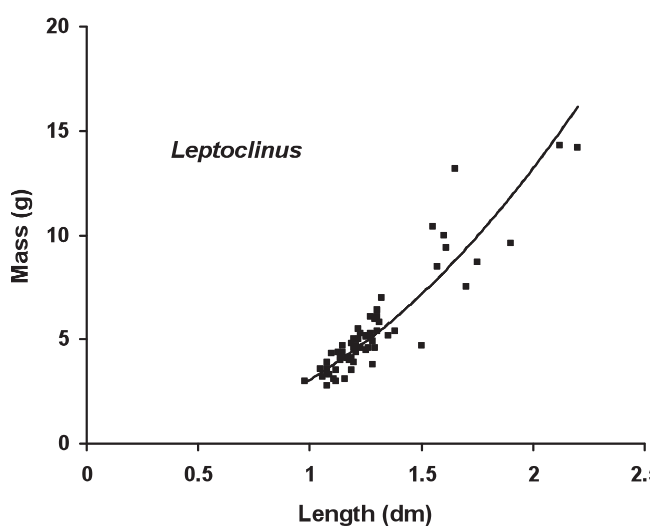

Fig. 5. Fork length versus mass for *Leptoclinus maculatus* collected at Coats Island.

was intermediate between benthic and pelagic prey items (5.0 kJ/g wet weight, Table 2), which is consistent with this prey item usually being found either as a benthic dweller or in pelagic schools (Piepenburg *et al.* 1996, Elliott *et al.* 2008). Our energy density was below that reported by Lawson *et al.* (1998) for the northwest Atlantic (5.9 kJ/g wet weight), but similar to the 4.8 kJ/g reported by Anthony *et al.* (2000) from the Gulf of Alaska.

Fish Doctor Gymnelus sp. *(Zoarcidae)*
All Fish Doctor identifications before 2002 were of *Gymnelus viridis* (n = 18). However, specimens taken at Coats 5 August 2002 (170 mm, 12.9 g) and 4 August 2006 (219 mm, 32.1 g) were identified as *Gymnelus retrodorsalis. G. retrodorsalis* closely matched the mass–length relationship developed for *Gymnelus* (Fig. 6) which, presumably, were primarily from *G. viridis.* In 2004–2007, when all *Gymnelus* collected were identified, nine *Gymnelus* were identified as *G. viridis* and one as *G. retrodorsalis.* Energy density was similar to other benthic prey items on a dry-weight basis (18.8 kJ/g), but was the highest of the benthic prey items on a wet-weight basis (4.1 kJ/g, Table 2).

Fourlined Snake Blenny Eumesogrammus praecisus *(Stichaeidae)*
Most of our Fourlined Snake Blenny specimens were collected at Coats Island or at the Nuvuk Islands (Fig. 7). Energy content was the lowest, on a wet-weight basis, of any of the prey items examined (3.2 kJ/g, Table 2), which is consistent with this prey item being a benthic, lipid-poor species.

Glacier Lanternfish Benthosema glaciale *(Myctophidae)*
Two Glacier Lanternfish specimens were collected at Hantzsch Island on 7 August 1992 (63 mm, 2 g) and 19 August 1982 (55 mm, 2 g). Another two unidentified myctophids were collected at Hantzsch Island on 10 Auust 1982 (60 mm, 1 g) and 19 August 1982 (66 mm, 3 g)

Greenland Halibut Reinhardtius hippoglossoides *(Pleuronectidae)*
All flatfish were identified as Greenland Halibut, including four specimens from Digges Island, five from Hantzsch Island and a single specimen from Coats Island (1996). All were delivered in August. The average size across the Canadian Arctic was 107 mm and 7.1 g (n = 10).

Lumpsucker Eumicrotremus spp. *(Cyclopteridae)*
Single specimens of Lumpsucker *Eumicrotremus spinosus* (68 mm, 8.8 g) and *E. derjugini* (85 mm, 20 g) were collected at Digges Island on 6 August and 18 August 1981, respectively. Specimens of *Eumicrotremus* were also collected at Coats Island on 8 August 1985, 10 August 1988, 17 August 1990, 3 August 1993, 30 August 1995 and 5 August 1998 (identified as *E. derjugini*). It is noteworthy that all collections occurred in August. *Eumicrotremus* specimens averaged 75 mm and 12 g (n = 8).

Sand Lance (Europe, Sand-Eel) Ammodytes spp. *(Ammodytidae)*
Most Sand-Eels were not identified to species. Both individuals identified to species at Coats Island were *Ammodytes hexapterus* (23, 25 July 1986); both individuals identified to species at Digges Island were *A. dubius* (14 August 1980). Both individuals identified as *A. dubius* were small (78 mm, 1.1 g; 108 mm, 2.9 g); both individuals identified as *A. hexapterus* were relatively large (190 mm, 12.5 g; 150 mm, 5.2 g). In general, *Ammodytes* collected at Coats Island weighed more than those collected at Digges Island (Coats: 6.5 ± 0.5 g; Digges: 2.6 ± 0.4 g; $t = 5.80$, df = 27, $P < 0.0001$) and were longer (Coats: 139 ± 2 mm; Digges: 100 ± 5 mm; $t = 6.94$, df = 27, $P < 0.0001$). However, there was no difference in the mass–length relationship between the two regions (ANCOVA: $P > 0.5$, Fig. 8). The only specimen collected from Hantzsch Island was similar to the *Ammodytes* from Coats (165 mm, 11.1 g). A gravid Sand-Eel (128 mm, 5.6 g) was found at Coats Island on 28 July 1998. Mass–length relationships were strongly influenced by a single, possibly erroneous, datum (166 mm, 32 g), and we present a regression analysis that excludes this data point. On a wet-weight basis, Sand-Eels had the highest energy density of any prey item (5.1 kJ/g, Table 2), which is consistent with its status as a lipid-rich prey item found regularly in the water column. Energy density of *Ammodytes* varies with the season, with peak values of about 21 kJ/g dry weight or 5–6 kJ/g wet weight (Hislop *et al.* 1991,

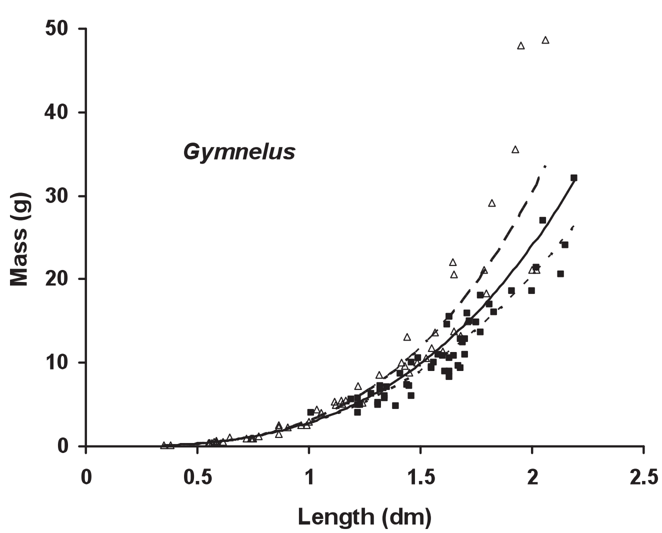

Fig. 6. Fork length versus mass for *Gymnelus* spp. collected in the Canadian Arctic (n = 123). Dashed line represents Nuvuk Island (open triangles); dotted line represents Coats Island (filled squares).

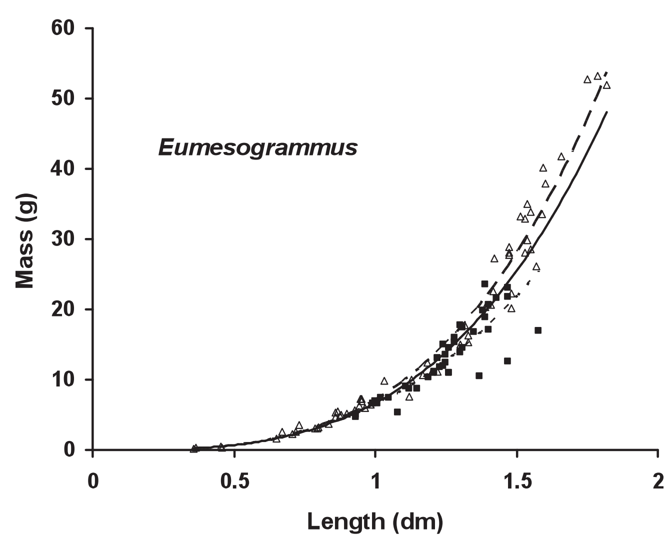

Fig. 7. Fork length versus mass for *Eumesogrammus praecisus* collected in the Canadian Arctic (n = 109). Dashed line represents Nuvuk Island (open triangles); dotted line represents Coats Island (filled squares).

Mårtensson *et al.* 1996, Van Pelt *et al.* 1997, Robards *et al.* 1999). For example, our value was above that reported by Lawson *et al.* (1998; 4.4 kJ/g wet weight) in the northwest Atlantic. Anthony *et al.* (2000) reported values in the northeast Pacific (5.4 kJ/g wet weight) that were similar to ours.

Sculpins (Cottidae)

The sculpin genera dealt with here are all more similar to one another in appearance than they are to other fish genera (with the possible exception of the rare *Leptagonus*), having broad heads; broad, spreading pectoral fins; and narrow, rather stiff, tails. Gaston (1985a) did not distinguish among the genera, but our recent experience suggests that the genera are often distinguishable by sight, at least into two groups: *Triglops* spp. and *Myoxocephalus, Icelus* and *Gymnocanthus* spp. Coincidentally, the two groups have significantly different mass–length relationships.

A single *Icelus spatula* was collected at Coats, 8 August 1984. *Myoxocephalus* constituted 13 of 140 (9%) sculpin that were identified to genus at Coats Island and all of the sculpin that were identified to genus at Nuvuk Islands. At Coats Island, seven *Myoxocephalus* were identified as *M. scorpius,* four as *M. scorpioides* (31 July and 3 and 26 August 1998 and 28 July 2006) and one as *M. aeneus* (5 August 2002). *Gymnocanthus* constituted 10 of 140 (7%) sculpin identified to genus at Coats Island. All *Gymnocanthus* were classified as *G. tricuspis. Triglops* constituted 117 of 140 (84%) sculpin identified to genus at Coats and all of the sculpin identified to genus at Digges and Hantzsch islands. *T. pingeli* constituted 38 of 47 (81%) *Triglops* identified at Coats Island and *T. murrayi* constituted the remainder (19%). *T. nybelini* constituted 4 of 5 (80%) of *Triglops* at Hantzsch Island and 6 of 8 (75%) at Digges Island, with single specimens of *T. pingeli* collected at each of Digges and Hantzsch islands and a single specimen of *T. murrayi* collected at Digges Island. Gravid *Triglops* were found at Coats Island on 9 August 1995 and 4 August 1996. Gravid sculpin (unidentified) were found on 5 August 1995 and 29 July 2003.

The length–mass relationships differed significantly between *Triglops* and non-*Triglops* species (ANCOVA: $F = 18.1$; Fig. 9). However, there was no significant difference in the relationships within each *Triglops* species or between any of the other three genera (ANCOVA: $P > 0.5$). Nonetheless, the mass–length relationship developed for all sculpins in general explains a high percentage of the variability (Fig. 9). Sculpin (*Triglops* spp. only) had intermediate energy density (4.3 kJ/g wet weight, Table 2), which is consistent with this prey item occurring both in the water column and on the ocean floor (Atkinson & Percy 1992, Elliott *et al.* 2008).

Slender Eelblenny lumpenus fabricii *(Stichaeidae)*

Single Slender Eelblenny specimens were reported at Digges Island on 14 August 1980 (5.4 g) and 31 July 1982 (172 mm, 6.9 g) and at Coats Island on 8 August 1984 (154 mm, 9 g).

Snailfish Liparis sp. *(Cyclopteridae)*

The *Liparis* genus was recorded primarily from the Nuvuk Islands, although there were two records of *Liparis fabricii* at Hantzsch Island on 29 July 1982 (58 mm, 4 g) and 1 August 1982. There were also records of *Liparis* spp. at Hantzsch Island on 22 August 1982 (85 mm, 10 g) and at Digges Island during 1981 (no date; 110 mm). Note that *Liparis* from Digges and Hantzsch islands are much heavier than those from Nuvuk (Fig. 10), suggesting that they may have been a different species.

Stout Eelblenny Anisarchus medius *(Stichaeidae)*

A Stout Eelblenny single specimen was collected at Digges Island on 12 August 1980 (88 mm, 1.4 g).

Invertebrates

Crustacea

Decapods (shrimp) averaged 76 mm and 4.35 g (n = 7); amphipods averaged 39.1 mm and 0.3 g. Four species of shrimps were identified: four specimens of *Lebbeus groenlandicus* collected at Digges Island on 6 August 1980 and at Coats Island on 28 July

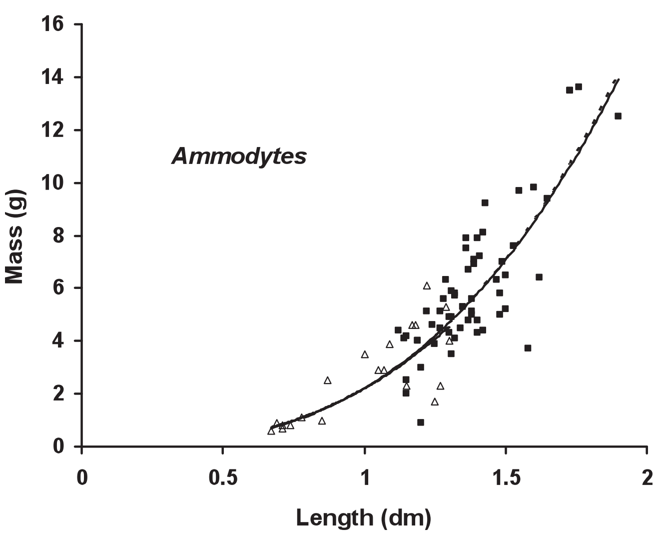

Fig. 8. Fork length versus mass for *Ammodytes* spp. collected from the Canadian Arctic. Dashed line represents Digges Island (open triangles); dotted line represents Coats Island (filled squares). An outlier of 166 mm and 30.2 g was removed from the analysis.

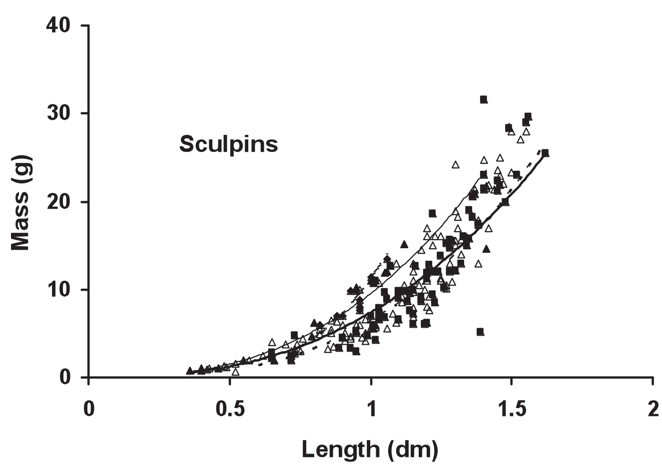

Fig. 9. Fork length versus mass for sculpins collected in the Canadian Arctic (n = 230): *Triglops* spp. (dotted line, filled squares); *Myoxocephalus* spp. (dashed line, filled triangles); *Gymnocanthus* spp. (thin solid line, filled diamond); other unidentified sculpins (open triangles).

2006, 1 August 2007 (two specimens: 2.9 g and 4.8 g); two specimens of *Argis dentata* collected at Coats Island on 28 July 1998 (9.1 g) and 1 August 2007 (9.6 g); and single specimens of *Sclerocrangon boreas* (74 mm, 3.5 g) at Coats Island on 15 August 1998 and *Pandalus montagui* at Coats Island on 14 July 2006. Shrimp with suspected egg masses were collected at Coats Island on 5 August 1996 and 16 July 2006. The only amphipod identified was a *Parathemisto libellula* collected at Coats Island on 10 August 1985. Sight identifications suggest that most of crustacea delivered at Coats Island were *Parathemisto libellula.* These crustacea had relatively low energy densities (Table 2). *Parathemisto libellula* was reported having the lowest energy density (13.7 kJ/g dry weight) of any Arctic invertebrate sampled in Spitzbergen (Wotowicz & Szaniawska 1986), but was similar to our value in another study from Svalbard (16.7 kJ/g dry weight, Weslawski *et al.* 1994). Shrimp also had low energy densities (14–17 kJ/g dry weight) in Svalbard (Weslawski *et al.* 1994).

Polychaetes

A polychaete identified as *Nereis* sp., but not confirmed by the museum, was collected at Coats Island on 7 August 1989 (124 mm, 1.3 g).

Squid Gonatus *spp.*

Individual squid formally identified at Coats Island (3 August 1996) and Digges (24 August 1982) islands belonged to the genus *Gonatus* (no species identified). The average weight was 5.5 g and length 84 mm (Fig. 11). Squid had relatively low energy densities (Table 2); Lawson *et al.* (1998) reported much higher energy densities (6.9 kJ/g wet weight) in the northwestern Atlantic.

DISCUSSION

During 24 years of collections at Coats Island we identified 16 genera of fish representing 11 families, five genera of crustacea, one squid and one annelid delivered to chicks. One additional genus was found at Hantzsch Island (*Benthosema*), one at Digges Island (*Anisarchus*) and one at both Digges and Hantzsch islands (*Liparis*). Because of very unequal sampling, the diversity of different sites cannot be compared. We identified 26 species altogether, but critical species determinations were carried out on only a small sample of the total collection, and so some additional species may not have been detected.

The lack of representation of certain genera and species is surprising. We identified no gadids other than *Boreogadus,* despite *Gadus ogac* being common in the vicinity of both the Coats and Digges island colonies (AJG pers. obs.). Likewise, the genus *Lycodes,* represented in the Canadian Arctic by several species of benthic fishes, was not identified in any sample. Although *Myoxocephalus* sculpins of about 150–200 mm length were common in shallow waters adjacent to the Coats Island colony, all specimens of this genus but one recovered from the colony were less than 100 mm in length. These apparent instances of selection may relate either to the unpalatability, or otherwise unsuitability of the species concerned, or to aspects of their behaviour or ecology that make them unavailable to murres during the period of their development when they might represent suitable nestling food.

We were able to derive usable mass–length regressions for 11 species or genera. However, the R^2 values in some cases rely heavily on a small number of atypically large specimens. The accuracy of these formulas when used to derive mass over the typical range of prey size delivered may be somewhat lower than are indicated here. There is also the question of the accuracy with which length can be estimated in the field, which needs to be tested separately for each sampling site to take account of local conditions. Despite these caveats, the variation in exponents among species means that the application of an empirically derived formula is likely to be more accurate than the simple assumption, sometimes adopted, that mass is proportional to length cubed.

Energy densities were generally high for pelagic prey items, which require high lipid concentrations for buoyancy in the water column, and generally low for benthic prey items (Table 2). Exceptions were *Triglops* sculpins and Daubed Shanny, which were intermediate. These prey items have been previously reported to occur in pelagic as well as benthic habitats (Atkinson & Percy 1992, Elliott *et al.* 2008). Fish Doctors had intermediate energy density on a wet-weight basis, but a low energy density on a dry-weight basis. That finding may reflect drying during transit (deflating measured mass values), because Fish Doctors are usually obtained far from the colony (Montevecchi & Piatt 1987, Elliott *et al.* 2008).

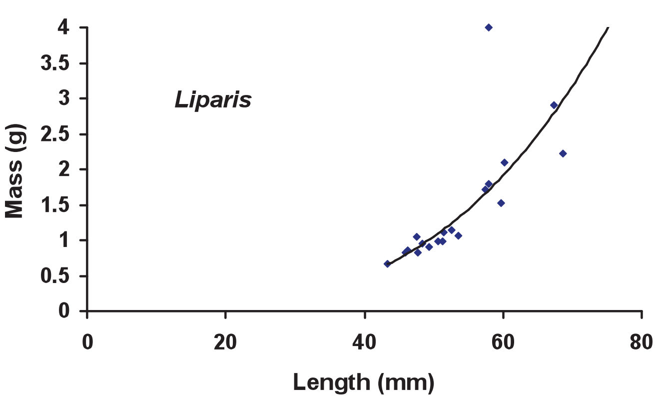

Fig. 10. Fork length versus mass for *Liparis* collected in the Canadian Arctic (n = 22).

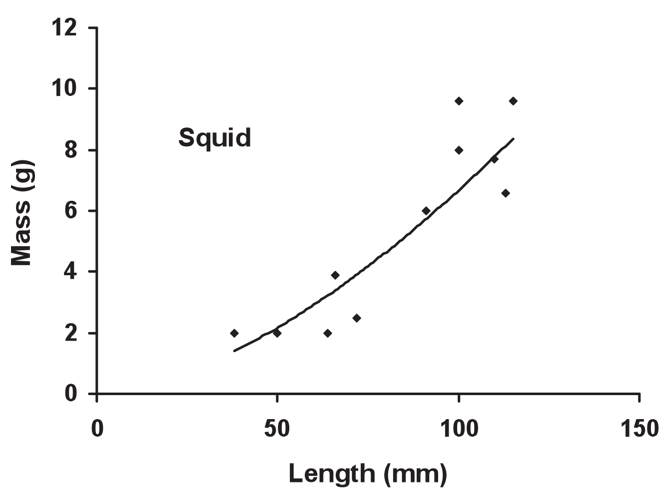

Fig. 11. Total length versus mass for squid collected in the Canadian Arctic (n = 11).

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REFERENCES

ANTHONY, J.A., ROBY, D.D. & TURCO, K.R. 2000. Lipid content and energy density of forage fishes from the northern Gulf of Alaska. *Journal of Experimental Marine Biology and Ecology* 248: 53–78.

ATKINSON, E.G. & PERCY, J.A. 1992. Diet comparison among demersal fish from the Canadian Arctic. *Polar Biology* 11: 567–573.

BALL, J.R., ESLER, D. & SCHMUTZ, J.A. 2007. Proximate composition, energetic value, and relative abundance of prey fish from inshore eastern Bering Sea: implications for piscivorous predators. *Polar Biology* 30: 699–708.

BIRKHEAD,T.R. & NETTLESHIP, D.N. 1987. Ecological relationships between Common Murres, *Uria aalge,* and Thick-billed Murres, *Uria lomvia,* at the Gannet Islands, Labrador. III. Feeding ecology of the young. *Canadian Journal of Zoology* 65: 1638–1649.

BROWN, R.G.B., NETTLESHIP, D.N., GERMAIN, P., TULL, C.E. & DAVIS, T. 1975. Atlas of seabirds of eastern Canada. Ottawa: Canadian Wildlife Service. 220 pp.

BRYANT, R., JONES, I.L. & HIPFNER, J.M. 1999. Responses to changes in prey availability by Common Murres and Thick-billed Murres at the Gannet Islands, Labrador. *Canadian Journal of Zoology* 77: 1278–1287.

CAIRNS, D.K. 1984. The foraging ecology of the Black Guillemot. Final report on contract no. 24SU.KN107–2-4203. Ottawa: Canadian Wildlife Service. 186 pp.

CAIRNS, D.K. 1987. The ecology and energetics of chick provisioning by Black Guillemots. *Condor* 89: 627–635.

CARSCADDEN, J.E. & FRANK, K.T. 2002. Temporal variability in the condition factors of Newfoundland Capelin (*Mallotus villosus*) during the past two decades. *ICES Journal of Marine Science* 59: 950–958.

COAD, B.W. & REIST, J.D. 2004. Annotated list of the Arctic marine fishes of Canada. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2674. Winnipeg, MB: Department of Fisheries and Oceans. 112 pp.

CROLL, D., GASTON, A.J., BURGER, A.E. & KENNOFF, D. 1992. Foraging strategy and physiological adaptation for diving in Thick-billed Murres. *Ecology* 73: 344–356.

ELLIOTT, K.H., DAVOREN, G.K. & GASTON, A.J. 2007. Influence of buoyancy and drag on the dive behaviour of an arctic seabird, the Thick-billed Murre. *Canadian Journal of Zoology* 85: 352–361.

ELLIOTT, K.H., WOO, K., GASTON, A.J., BENVENUTI, S., DALL'ANTONIA, L. & DAVOREN, G.K. 2008. Seabird foraging behaviour indicates prey type. *Marine Ecology Progress Series* 354: 289–303.

GASTON, A.J. 1985a. The diet of Thick-billed Murre chicks in the eastern Canadian arctic. *Auk* 102: 727–734.

GASTON, A.J. 1985b. Energy invested in reproduction by Thick-billed Murres (*Uria lomvia*). *Auk* 102: 447–458.

GASTON, A.J. 1987. Length and weight of fish delivered by Thick-billed Murres to their chicks at Digges, Coburg and Coats islands. *Canadian Wildlife Service Technical Reports* 5: 1–12.

GASTON, A.J. 1991. The seabirds of Hudson Bay, Hudson Strait and adjacent waters. In: Croxall, J. (Ed). Supplement to the status and conservation of the world's seabirds. Technical. Report No. 11. Cambridge: International Council for Bird Preservation. pp. 7–16.

GASTON, A.J. & HIPFNER, J.M. 2000. Thick-billed Murre (*Uria lomvia*). In: Poole, A. & Gill, F. (Eds). The Birds of North America, No. 497. Philadelphia, PA: The Birds of North America. 32 pp.

GASTON, A.J. & NETTLESHIP, D.N. 1981. Thick-billed Murres of Prince Leopold Island. Monograph 6. Ottawa: Canadian Wildlife Service. 351 pp.

GASTON, A.J., CAIRNS, D.K., ELLIOT, R.D. & NOBLE, D.G. 1985. A natural history of Digges Sound. *Canadian Wildlife Service Report Series* 46: 1–63.

GASTON, A.J., WOO, K. & HIPFNER, J.M. 2003. Trends in forage fish populations in northern Hudson Bay since 1981, as determined from the diet of nestling Thick-billed Murres *Uria lomvia. Arctic* 56: 227–233.

HARRIS, M.P. & WANLESS, S. 1985. Fish fed to young Guillemots *Uria aalge,* and used in displays on the Isle of May, Scotland. *Journal of Zoology, London* 207: 441–458.

HATCHWELL, B.J., BIRKHEAD, T.R., GOODBURN, S.F., PERRINS, J.M. & JONES, S.E. 1992. Chick diets and food intake of nestling Common Guillemots *Uria aalge*: an inter-colony comparison. *Seabird* 14: 15–20.

HISLOP, J.R.G., HARRIS, M.P. & SMITH, J.G.M. 1991. Variation in the calorific value and total energy content of the Lesser Sandeel (*Ammodytes marinus*) and other fish preyed on by seabirds. *Journal of Zoology, London* 224: 501–517.

HUNTER, J.G., LEACH, S.T., MCALLISTER, D.E. & STEIGERWALD, M.B. 1984. A distributional atlas of the records of marine fishes of Arctic Canada in the National Museum of Canada and Arctic Biological Station. *Syllogeus* 52. 35 pp.

KEATS, D.W., STEELE, D.H., GREEN, J.M. & MARTEL, G.M. 1993. Diet and population size of the Arctic Shanny, *Stichaeus punctatus* (Pisces: Stichaeidae), at sites in eastern Newfoundland and the eastern Arctic. *Biological Fisheries* 37:173–180.

LAWSON, J.W., MAGALHAES, A.M. & MILLER, E.H. 1998. Important prey species of marine predators in the northwest Atlantic: proximate composition and energy density. *Marine Ecology Progress Series* 164: 13–20.

LEIM, A.H. & SCOTT, W.B. 1968. Fishes of the Atlantic coast of Canada. Ottawa: Fisheries Research Board of Canada. 485 pp.

MÅRTENSSON, P., LAGER GOTAAS, A.R., NORDAY, E.S. & BLIX, A.S. 1996. Seasonal changes in the energy density of prey of northeast Atlantic seals and whales. *Marine Mammal Science* 12: 635–640.

MONTEVECCHI, W.A. & PIATT, J.F. 1987. Dehydration effects on the energy determination of seabird prey. *Canadian Journal of Zoology* 65:2822–2824.

PEARSON, T.H. 1968. The feeding biology of sea-bird species breeding on the Farne Islands, Northumberland. *Journal of Animal Ecology* 37: 521–552.

PIEPENBURG, D., VON DORRIEN, C.F., SCHMID, M.K., CHERNOVA, N.V., NEVELOV, A.V., GUTT, J., RACHOR, E. & SALDANHA, L. 1996. Megabenthic communities in the waters around Svalbard. *Polar Biology* 16: 431–446.

ROBARDS, M.D., ANTHONY, J., ROSE, G.A. & PIATT, J.F. 1999. Changes in proximate composition and somatic energy content for Pacific Sand Lance (*Ammodytes hexapterus*) from Kachemak Bay, Alaska, relative to maturity and season. *Journal of Experimental Marine Biology and Ecology* 242: 245–258.

SWANN, R.L., HARRIS, M.P. & AITON, D.G. 1991. The diet of some young seabirds at Canna, 1981–1990. *Seabird* 13: 54–58.

VAN PELT, T.I., PIATT, J.F., LANCE, B.K. & ROBY, D.D. 1997. Proximate composition and energy density of some north Pacific forage fishes. *Comparative Biochemistry and Physiology* 118A: 1393–1398.

WESLAWSKI, J.M., RYG, M., SMITH, T.G. & ORITSLAND, N.A. 1994. Diet of Ringed Seals (*Phoca hispida*) in a Fjord of West Svalbard. *Arctic* 47: 109–114.

WOO, K. 2002. Foraging ecology of the Thick-billed Murre: patterns of prey location and selection [MSc thesis]. Ottawa: University of Ottawa. 117 pp.

WOTOWICZ, M. & SZANIAWSKA, A. 1986. Calorific value, lipid content and radioactivity of common species from Hornsund, Southwest Spitsbergen. *Polar Research* 4: 79–84.

Fish delivered to Thick-billed Murre nestlings at Coats Island. Left column, from the top: *Mallotus*, *Triglops*, *Triglops* (gravid), *Gymnelus*, *Boreogadus*; right column: *Stichaeus*, *Eumesogrammus*, *Leptoclinus*, *Ammodytes*. Photo by Kerry Woo.