

Diet of adult and immature North Norwegian Black Guillemots *Cepphus grylle*

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Abstract

In this first study of full-grown Black Guillemot *Cepphus grylle* diet in the Norwegian mainland, 62 of 63 birds caught incidentally in Lumpfish *Cyclopterus lumpus* gillnets in the north of the country in April–June 2012 and 2013 contained food remains in their stomachs. Fourteen prey taxa were identified and crustaceans were present in 90% of the stomachs containing food, with squat lobsters (sub-order Anamura) being most common (in 79%). Rock Gunnel *Pholis gunnellus* was present in 17 (27%) of the samples. The only other prey types found in more than 20% of the samples were sculpins (Cottoidei, probably Cottidae and Agonidae, in 13 samples = 21%) and remains of caridean shrimps (in 13 samples). There were no differences in the frequencies of taxa in the diets of immature and adult birds or between males and females.

Introduction

Seabirds are integral components of marine ecosystems and good indicators of changes in the marine environment (e.g. Furness & Monaghan 1987; Furness & Camphuysen 1997). For example, seabird data, including diet, give early indications of fluctuations in fish stocks and oceanographic conditions (Montevecchi 1993; Frederiksen *et al.* 2004). Conventional studies of seabird diet are often carried out during the breeding season when birds are at the nest and easiest to sample in a non-destructive manner. As a result, overall documentation of food preferences for a given species tends to be biased in space and time, often with a paucity of data from outside the breeding season when birds are not restricted to feeding close to the nest site. Samples collected during the breeding season may consist of prey remains in stomachs of birds collected at sea, food brought to chicks or undigested remains in pellets or faeces. Collecting birds at sea is, of course, possible at any time of year, but most practical when birds are concentrated in predictable areas

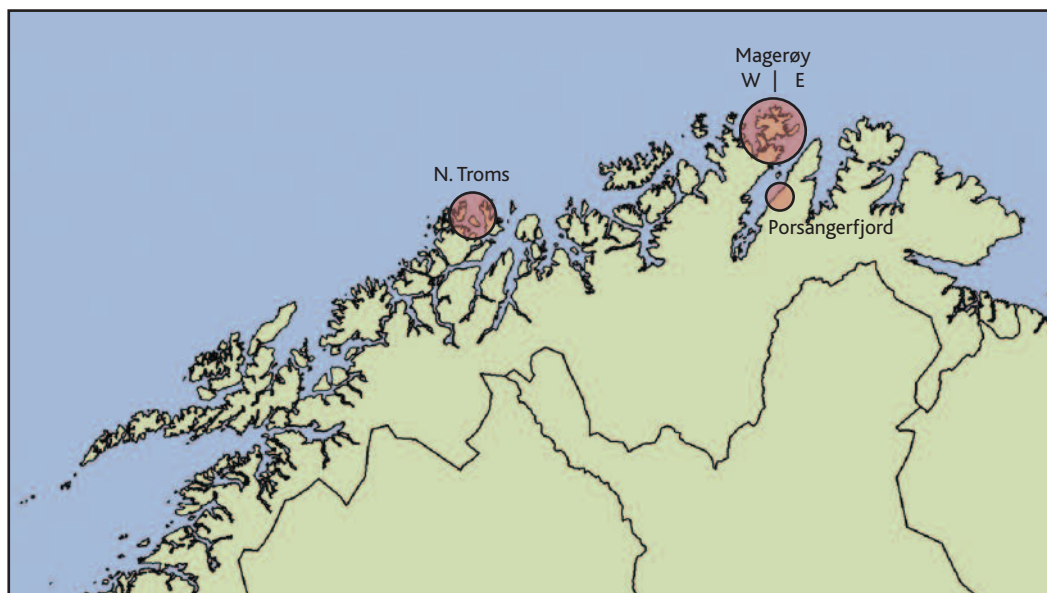


Figure 1. Map showing the areas where Black Guillemots *Cephus grylle* examined in this study were caught in Lumpfish gillnets in North Norway from late April to mid June in 2012 and 2013.

such as on or near the breeding site. Due to ethical considerations and the fact that the method rarely achieves a representative picture of the spatial and temporal variation in diet, the direct killing of birds as a sampling tool for diet studies alone is, however, discouraged (Barrett *et al.* 2007). Alternative sources such as birds accidentally killed in fisheries, oil spills or wrecks are, instead, preferred. Biochemical methods such as stable isotope or fatty acid analyses have allowed us to explore further adult diet non-destructively. They have certain advantages, such as integrating diet composition over space and time, and new methods such as the use of environmental DNA (eDNA) are constantly under development. These must, however, be considered as important supplements to, rather than replacements of, traditional studies of ingested prey (Bearhop *et al.* 2001; Karnovsky *et al.* 2012).

Of the millions of auks (Alcidae) that breed in the North Atlantic, the Black Guillemot (or Tystie) *Cephus grylle* is among the least studied, probably because of its habit of breeding along coastlines at widely dispersed, sheltered, but often very difficult to access nest sites. In addition, their distribution is biased towards the (high) Arctic (Gaston & Jones 1998). As a result, diet studies are scarce. In the Arctic, they feed both inshore and offshore, among ice floes and along the ice edge where they forage both on the sea bottom down to c. 30 m or dive under the ice to catch ice-associated (sympagic) crustaceans and fish (e.g. Mehlum & Gabrielsen 1993; Divoky *et al.* 2015). In subarctic and boreal regions, Black Guillemots feed on a wide variety of fish and invertebrates caught in the water column and on the seafloor. They usually forage within a few kilometres of the coast, often around rocky islands and over submerged reefs in sheltered waters with strong tidal currents and frequently among kelp (Laminariales; Gaston & Jones 1998).

In Norway, about 5,000 pairs of Black Guillemot breed on Svalbard and about 35,000 pairs on the mainland, nearly all north of the Stad Peninsula (62°11.7'N, 5°5.9'E), i.e. along the coasts of the Norwegian and Barents Seas. The Norwegian population constitutes 9–13% of the North Atlantic (and hence nearly the World) population of 260,000–410,000 pairs (Mitchell *et al.* 2004; Barrett *et al.* 2006; Fauchald *et al.* 2015a). Because of an evident decline in numbers, the species is 'Red Listed' as *Vulnerable* on the Norwegian mainland (Barrett *et al.* 2006; Kålås *et al.* 2015).

While predation by feral American Mink *Neovison vison* has been a significant cause of the Black Guillemot population decline in Norway, drowning in fishing nets, especially those set for Lumpfish *Cyclopterus lumpus* is possibly an important contributor, especially in the north of the country (Barrett & Anker-Nilssen 1997; Fangel *et al.* 2015). A reversal of the population decline requires effective management based on knowledge of extrinsic and intrinsic factors that affect Black Guillemot population dynamics, including improved knowledge of diet preferences (Fauchald *et al.* 2015b). Few studies, however, have addressed the diet of Black Guillemots in Norwegian waters. Chick diet has been documented in three colonies on the mainland (Larsen *et al.* 1989; Larsen & Sæter 1989; Larsen 1990; Barrett & Anker-Nilssen 1997; Anker-Nilssen 2010) and three studies have documented summer diet of adults on Svalbard (Hartley & Fisher 1936; Lønne & Gabrielsen 1992; Mehlum & Gabrielsen 1993). This study is the first to address the diet of full-grown Black Guillemots on the Norwegian coast.

Methods

The study is based on stomach samples of birds caught as incidental bycatch in gillnets set at 7–20 m depth by fishing vessels participating in a survey of seabird bycatch in the North Norwegian Lumpfish fishery (Fangel *et al.* 2015). Forty-three birds were caught between 13 May and 16 June 2012 and 20 between 29 April and 29 May 2013, i.e. all within the pre-laying or incubation period for the species (Barrett & Anker-Nilssen 1997). They were caught in two main regions that are c. 250 km apart: northern Troms (N = 12) and around Magerøy, Finnmark (N = 49; Figure 1). In the initial analysis, the latter region was further divided into two, Western Magerøy (N = 16) and Eastern Magerøy (N = 33), west and east of the North Cape respectively (Figure 1). The remaining two birds were caught in Porsangerfjord, immediately south of Magerøy.

Each bird was labelled with details of date, position, gear type and depth, and was deep-frozen whole on return to the fishing port. In the laboratory the birds were thawed, weighed and measured, and then opened to remove the intestine and to visually determine body condition and sex using standard procedures (Camphuysen 2007). Their age (adult or immature) was determined by plumage, degree of maturation (size) of gonads, and presence/absence (size) of bursa Fabricii (Camphuysen & van Franeker 2007).

Figure 2 (overleaf). Lumpfish, Troms, North Norway, 29 May 2013. © Kirstin Fangel.



On removal from the body, the stomach and foregut were opened and the contents washed with water into a petri dish where the species composition was determined under a binocular microscope (64–400 x magnification). Semi-digested remains of fish were further digested in a saturated solution of the biological washing powder ®Bio-tex (at 50°C for 24 h) and the remaining otoliths and skeletal fragments identified using otolith and vertebrate keys (Härkönen 1986; Watt *et al.* 1997) and our own reference collection. Each taxon was noted as present or absent, and no attempt was made to quantify relative abundances. All samples are stored at Tromsø University Museum.

The length and breadth of complete carapaces of squat lobsters (sub-order Anamura) were roughly measured using a ruler. Otoliths were measured using a calibrated graticule in the eyepiece of the microscope and fish lengths were calculated from otolith length/fish length relationships (Sawyer [1967] for Rock Gunnel *Pholis gunnellus* and Breiby [1985] for Norway Pout *Trisopterus esmarkii*).

To assess differences in diet between different groupings of Black Guillemots, niche breaths and overlaps were calculated following De Cáceres *et al.* (2011) using the statistical software R v. 3.2.3 with the package 'indicspecies' (R Development Core Team 2016). Following De Cáceres *et al.* (2011), Rao's quadratic entropy (Rao 1982) was adopted for niche breath, with 0 being the minimum niche breath when a single resource is used and 1 the maximum when distinct resources are used. Niche overlap, on a scale from 0 (no resources used in common between the two groups) to 1 (complete overlap in resource use) was compared between age groups (adult and immature), sexes, areas (Troms and W. and E. Magerøy, excluding the one sample from Porsangerfjord), years (2012 and 2013) and body conditions. Possible differences in occurrence between the (partly-pooled) diet categories 'Galathea', 'other crustaceans', 'gastropods + nereids', '*Pholis gunnellus*' and 'other fish' were tested using a χ^2 test in Minitab 15 statistical software. An ANOVA with Tukey post-hoc test was used to test spatial differences in body condition using the SPSS statistical software v. 23.0 (IBM Corp. 2015).

Results

There was little evidence of sexual dimorphism in adult body measurements with only bill depth (gonys) being slightly larger in males (Table 1). Bill depth and wing length, but no other body measurement of adult birds were slightly larger than those of immature birds (Table 2). All birds were in 'moderate to good' body condition (overall index 4–7 on a scale of 0–9; Camphuysen 2007), but the condition varied with site (ANOVA, $F_{2,56} = 12.62$, $P < 0.001$; Table 3). While there was no evident difference between birds from W. and E. Magerøy (Tukey post-hoc test, $P = 0.552$), birds from Troms had a significantly higher condition index than those from the two other sites ($P = 0.002$ and $P < 0.001$, respectively).

Sixty-two of the 63 samples contained food items. Fourteen taxa were identified, including six crustaceans, three gastropods, one polychaete and four fish. Two samples contained unidentified crabs and two others unidentified fish remains.

Table 1. Means of body measurements (all in mm, except mass in g) of adult female and male Black Guillemots *Cephus grylle* killed in fishing nets in North Norway in late April to mid June 2012 and 2013.

	Female			Male			2-sample t-test	
	Mean	SE	N	Mean	SE	N	t	p
Head + bill	81.6	1.0	20	83.7	0.3	20	-1.96	0.06
Culmen	32.3	0.3	20	32.3	0.2	27	-0.08	0.94
Gonys	8.3	0.1	21	8.9	0.1	28	-4.72	< 0.001
Tarsus	33.1	0.3	21	33.3	0.2	29	-0.32	0.75
Wing	166.8	1.0	21	168.4	0.8	29	-1.27	0.21
Mass	509.0	10.1	21	512.3	10.9	26	-0.22	0.82

Table 2. Means of body measurements (all in mm, except mass in g) of adult and immature Black Guillemots *Cephus grylle* (both sexes) killed in fishing nets in North Norway in late April to mid June 2012 and 2013.

	Adult			Immature			2-sample t-test	
	Mean	SE	N	Mean	SE	N	t	p
Head + bill	82.8	0.5	45	83.2	0.5	12	0.59	0.56
Culmen	32.3	0.2	47	32.0	0.4	13	-0.70	0.49
Gonys	8.7	0.1	49	8.0	0.1	13	-4.97	<0.001
Tarsus	33.2	0.2	50	33.0	0.4	13	-0.54	0.60
Wing	167.7	0.6	50	163.1	1.5	13	-2.82	0.01
Mass	510.8	7.4	47	521.2	9.3	13	0.87	0.39

Remains of crustaceans were present in 56 (90.3%), remains of fish in 29 (46.8%), gastropods in six (9.7%) and jaws of *Nereis* sp. polychaetes in three (4.8%) of the 62 samples (Table 4). Squat lobsters (probably *Galathea strigosa*) comprised the commonest prey type, being found in 49 (79.0%) samples. Rock Gunnel was the second commonest found in 17 (27.4%) of the samples. The only other prey types to be found in more than 20% of the samples were sculpins (Cottoidei, probably Cottidae and Agonidae, in 13 samples = 21.0%) and remains of caridean shrimps (also in 13 samples).

The initial niche breadth and diet overlap analyses suggested very small differences in diet between the two age groups, sexes, regions, years and body conditions (Table 5). This was confirmed by χ^2 tests finding no statistical difference in the diet composition of adults (N = 50) and immatures (N = 15) ($\chi^2_4 = 3.49$, P = 0.479), between adult males (N = 29) and females (N = 21) ($\chi^2_4 = 4.42$, P = 0.352) or between birds with body condition indices < 6 (N = 30) and ≥ 6 (N = 28) ($\chi^2_4 = 1.33$, P = 0.856). Nor were there any apparent differences in diet composition of birds caught in W. and E. Magerøy ($\chi^2_4 = 2.47$, P = 0.651) or those caught in Troms and W. + E. Magerøy combined ($\chi^2_4 = 0.50$, P = 0.973).

The approximate carapace size of the squat lobsters in the samples was 15 × 10 mm, while the mean (\pm SE) length of Rock Gunnels was 108 \pm 8.3 mm (N = 9, range = 80–142 mm) and of Norway Pout was 123 \pm 5.2 mm (N = 16, range 9–161 mm).

Table 3. Mean body condition indices (Camphuysen 2007) of Black Guillemots *Cephus grylle* killed in fishing nets in three regions of North Norway in late April to mid June 2012 and 2013.

	Troms			W. Magerøy			E. Magerøy		
	Mean	SE	N	Mean	SE	N	Mean	SE	N
Subcutaneous fat	2.33	0.14	12	1.50	0.18	16	1.70	0.13	33
Intestinal fat	1.83	0.11	12	1.60	0.13	15	1.68	0.08	31
Pectoral muscle	2.08	0.08	12	1.94	0.06	16	2.03	0.05	33
Overall index	6.25	0.25	12	5.00	0.26	15	5.35	0.19	31

Table 4. Frequency of various food item remains in stomachs of Black Guillemots *Cephus grylle* caught in gillnets in North Norway, in late April to mid June 2012 and 2013. NT = North Troms, WM = Western Magerøy, EM = Eastern Magerøy, Pf = Porsangerfjord.

Region	Total	NT	WM	EM	Pf
N	62	12	16	33	1
No. of samples containing					
Crustacea	56	11	15	30	1
<i>Galathea</i> sp.	49	10	15	24	1
Caridea	13	1	1	11	0
Isopoda	1	0	0	1	0
<i>Pagurus</i> sp.	3	0	1	0	0
<i>Carcinus maenas</i>	1	0	1	2	0
<i>Hyas</i> sp.	6	1	2	3	0
Unidentified crab	2	0	0	2	0
Gastropoda	6	2	0	4	1
<i>Lacuna</i> sp.	5	2	0	3	1
<i>Littorina</i> sp.?	1	0	0	1	0
Neogastropoda	1	0	0	1	0
Nereidae	4	0	2	2	0
Fish	29	5	6	18	0
Cottidae	13	0	3	10	0
Gadid	5	0	1	4	0
<i>Trisopterus esmarkii</i>	3	0	0	3	0
<i>Pholis gunnellus</i>	17	1	4	12	0
<i>Clupea harengus</i>	1	0	0	1	0
Unidentified fish	2	1	0	1	0

Discussion

The stomachs of the Black Guillemots caught in this study contained mainly crustaceans (squat lobsters and caridean shrimps) and fish (Rock Gunnel and Cottoidei) and no remains of soft-bodied prey. Although preferable to shooting birds, one drawback of using birds caught as bycatch is that digestion will have continued for some time after drowning, thus increasing the chances of not detecting or understanding easily digested prey. The lack of the possibility to fix samples immediately after death will, however, have been partly offset by the cold water in this area (5–6 °C in May - <http://www.seatemperature.org>) rapidly cooling the carcasses. In addition to further underrepresentation of soft-bodied prey due

Table 5. Diet niche breadth and overlap indices among Black Guillemots *Cephus grylle* killed in fishing nets in North Norway in late April to mid June 2012 and 2013.

	Niche breadth	95% CI	Overlap	95% CI
Adult	0.402	0.375–0.423	0.939	0.925–0.964
Immatures	0.371	0.250–0.416		
Female	0.376	0.323–0.411	0.919	0.875–0.972
Male	0.408	0.377–0.433		
Troms	0.262	0.076–0.359	0.878	0.825–0.951
Magerøya	0.410	0.388–0.429		
2012	0.413	0.392–0.433	0.875	0.819–0.949
2013	0.314	0.212–0.379		
Body condition < 6	0.396	0.363–0.418	0.984	0.967–0.999
Body condition ≥ 6	0.399	0.343–0.429		

to differential digestion rates, there is also the possibility that some hard parts, e.g. polychaete jaws, may be retained in stomachs for a month or longer (e.g. van Heezik & Seddon 1989). These factors preclude detailed quantification of diet composition. A second bias may arise as a result of all the samples being of birds caught in Lumpfish gillnets that were set in shallow waters in the Lumpfish spawning grounds that consist of bedrock and/or boulders (Goulet *et al.* 1986). There is evidence that Black Guillemots may have individual preferences for either prey or feeding area (Cairns 1981; T. Anker-Nilssen, pers. obs.) and thus the results here may reflect individual Black Guillemots that sought out that one biotope. How representative their diet was for all birds in the region is therefore unknown.

The mean body mass of adult birds in our bycatch sample (510.8 g) was 31.7% higher than that of chick-feeding birds at Røst (387.9 g, N = 70), 425 km SW of the Troms sample site (Barrett & Anker-Nilssen 1997). As the other body measurements were almost identical to those on Røst (head+bill +0.5%, culmen -0.6%, gonys ±0.0%, wing +0.2%), this suggests the birds had a good level of body reserves early in the breeding season, even if the drowned birds were lightly waterlogged when weighed. This is further corroborated by the 'moderate to good' body condition indices of the dissected birds. An optimal body condition early in the season has previously been documented for the Black Guillemot as well as other seabird species, e.g. Atlantic Puffin *Fratercula arctica* and Black-legged Kittiwake *Rissa tridactyla* (Asbirk 1979; Barrett *et al.* 1985), but see Belopol'skii (1961) who recorded maximum mass among Black Guillemots in June. That there is no sexual dimorphism in Black Guillemots except in bill depth (Gaston & Jones 1998) was corroborated in this study and, as such, the lack of difference in the diet between the sexes was expected (see Mancini *et al.* 2013).

In mainland Europe, adult Black Guillemot diet is often composed mainly of fish such as blennies and sculpins, but may also include crustaceans, molluscs and annelids (Ewins 1990; Gaston & Jones 1998). It is also more varied than that of their chicks,

a characteristic common among seabirds that feed their chicks one high-quality fish at a time (single-prey loaders, e.g. Wilson *et al.* 2004; McLeay *et al.* 2009). When self-feeding, adults are typically opportunistic with differences in diet between regions and habitats reflecting the abundance and availability of prey (Cairns 1987; Ewins 1987, 1990). The results of our study were no exception with a much higher frequency of low-trophic organisms recorded in the adult diet compared to the high frequency (> 99%) of fish recorded in chick diet elsewhere in North Norway (Barrett & Anker-Nilssen 1997). There were otherwise far lower frequencies of gastropods than e.g. at Shetland (Ewins 1990), of polychaetes than at Iceland (Petersen 1981) and of sandeels than in the Faroes or Iceland (Petersen 1981; Ólafsdóttir 2002). A winter and pre-breeding diet consisting of items collected opportunistically from a lower trophic level than those collected later in the year during the breeding season, when the birds are constrained to return frequently to the colony, is common among seabirds (Shealer 2002). It may also be partly a reflection of littoral fish seeking deeper waters and/or being less active when the sea is cold (Sawyer 1967; Gibson 1969) and thus possibly becoming less available to seabirds.

The frequency of squat lobsters recorded here was higher than that recorded in any other study. Squat lobsters are abundant and diverse, small benthic crustaceans with a worldwide distribution (Poore *et al.* 2011). *Galathea strigosa*, the species most likely to occur in the Black Guillemot diet, is widespread in rocky subtidal waters along the coasts of Europe from the Canary Islands to the North Cape. In 2014–2016, *G. strigosa* was the dominating crustacean brought to Black Guillemot chicks at Røst, Lofoten, but it was never recorded in the previous 24 years (1990–2013) when hermit crab (super-family Paguroidea) was always the most common invertebrate prey (T. Anker-Nilssen, unpubl. data). In each of all these years, however, most crustaceans were delivered by single birds, suggesting these few individuals had an atypical diet or habitat specialization.

The distribution of *G. strigosa* is restricted to rocky areas, often among small stones and cobbles but also on kelp holdfasts where, being primarily active at night, they avoid predators by hiding inside or near shelters during daylight hours (de Grave & Turner 1997; Pallas *et al.* 2006). As such, although auks are generally accepted as being visual foragers with exceptionally good vision (Gaston & Jones 1998), one would expect a low frequency of squat lobsters in the diet of daylight-feeding Black Guillemots. In northern Europe, however, the frequency of squat lobsters seems to increase with latitude, even if darkness is brief in summer. They occurred in > 20% of 58 stomachs containing prey collected in spring in Shetland and in 40% of 53 and 68% of 30 adults shot during the summer in the Faeroes in 1995–1997 and 2002 respectively (Ewins 1990; Dam 1998; Ólafsdóttir 2002). In Troms and Finnmark, late May to late July is a period of continuous daylight, such that squat lobsters cannot emerge from their hiding places under the cover of darkness to forage. As such, the chances of them being seen and caught in the region will be higher than at more southerly latitudes and may explain the high frequency (79%) of capture found in this study. Furthermore, the kelp beds in North Norway have been heavily grazed by sea urchins over the last decades

(Sivertsen 2006) and recent field observations have suggested that squat lobsters are abundant in these barren areas (T. Pedersen, pers. comm.). It is a mystery why they were not found at all in the diet of Black Guillemots in Icelandic waters (Petersen 1981) where daylight is also plentiful in the summer months.

A squat lobster carapace length of 15 mm as found in this study is well under the maturity length of 34.6 mm for *G. strigosa*, supporting the hypothesis that shallow waters are important nursery areas for this species (Pallas *et al.* 2006). Compared to energy-rich fish that are common in Black Guillemot diet, such as sandeels or Rock Gunnel, squat lobsters are relatively low in energy (17–20 kJ g⁻¹ ash-free dry mass \equiv c. 3 kJ g⁻¹ wet mass, [Steimle & Terranova 1988; Company & Sardà 1998]). Their high frequency in the diet in this study might thus be a reflection of their abundance and predictability in the region rather than their nutritive value, and also of the rocky substrate on which Lumpfish nets are set. Why no sandeels were registered in this study, but were a common prey for adult Black Guillemots in Iceland, the Faeroes and Shetland (Petersen 1981; Ewins 1990; Dam 1998; Ólafsdóttir 2002) may be a result of sandy habitats being unsuitable for Lumpfish spawning (Goulet *et al.* 1986). Furthermore, sandeels that might be in nearby waters generally remain buried in the substrate until later in the summer (Soleim 1945).

While Rock Gunnel is often (up to 70% of items recorded) fed to Black Guillemot chicks through most of its distribution range in the North Atlantic, between France and Cape Kanin and round Iceland (www.fishbase.org), it is less common as food for adults (Gaston & Jones 1998). In the Faeroes, it was not found in 53 samples in summer 1996 and in only 6% of 30 samples in summer 2002 (Dam 1998; Ólafsdóttir 2002). In Shetland and Iceland, however, it was found in quantities similar to those in this study: in 28% of 32 Shetland samples in summer 1982–1985 (Ewins 1990) and in 37% of 38 shot birds and 19% of 31 birds drowned in Lumpfish nets in Iceland (Petersen 1981). Unless adult Black Guillemots actively select for this energy-rich fish (c. 6 kJ g⁻¹ wet mass [Dunn 1975]), the presence of Rock Gunnel in 31% of the present samples suggests that although approaching the north-eastern limit of its distribution, Rock Gunnel is still plentiful in northernmost Norway. Further east, however, on the Russian Kola Peninsula, it only made up 5% of the Black Guillemot chick diet (Belopol'skii 1961). Sculpins that were found in 21% of our samples are also relatively energy-rich fish (c. 4–6 kJ g⁻¹ wet mass [Wiens & Scott 1975; Anthony *et al.* 2000]) and are readily available in shallow, coastal waters.

At Røst, North Norway, Black Guillemots fed their chicks Rock Gunnel with a mean length of 150.9 mm (SD = 2.4 mm) and on Iceland with a mean length of 140 mm (SD = 0.02 mm) (Petersen 1981; Barrett & Anker-Nilssen 1997). These were much larger than those found in this study (108 mm), possibly as a result of adults actively seeking out large fish to bring to their chicks, thereby increasing the energy return rate for their foraging trip, a strategy common for single-prey loaders.

Our results indicate no statistical differences in diet between adults and immatures, sexes, regions, years and body condition states. The opportunistic feeding habit of seabirds outside the breeding season is also well illustrated here. Bearing in mind that as all birds were collected in shallow waters on a rocky substrate, in a short time window and along a very limited stretch of coastline, more studies of non-breeding Black Guillemot diets are needed before more representative conclusions can be drawn on their prey preferences along the Norwegian coast.

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