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Increased longline bait predation by northern fulmars (*Fulmarus glacialis*) around the Faroe Islands during the breeding season

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Abstract

Seabird bycatch is common in longline fisheries and detrimental to some seabird populations. Simultaneously, the loss of longline bait to seabirds may pose a considerable economic loss to fishermen. Here, we study northern fulmars (*Fulmarus glacialis*), bycaught in longline fisheries close to the Faroe Islands between 2004 and 2021. Biological data on age and sex and the quantity of bait in the stomachs was assessed. Males were over-represented in the bycatch sample, as were adult birds, likely caused by sex- and age-specific foraging segregation. Overall, 71% of 820 fulmars contained bait, on average 2 items per bird (range: 0–17 items). No difference in the average number of bait items was detected between males and females or between adult and non-adult birds. During the breeding season, however, adults contained significantly more bait in their stomach than outside the breeding season. No such effect was found for non-adult birds. Together with a lower body condition during the breeding season, this may indicate higher food requirements by breeding birds, potentially increasing entanglement risks. Regular loss of bait reduces fishing efficiency, likely resulting in economic loss. Reducing seabird bycatch may therefore benefit fishermen as well as seabird populations.

Keywords: seabird-fishery interaction; bycatch; demersal longline fisheries; entanglement; plastic monitoring; seabird conservation

Introduction

Seabirds are interacting with fishing activities worldwide (Montevecchi 2001). The bycatch of seabirds during fishing operations is regarded as one of the most negative consequences (Dias et al. 2019). This problem was first acknowledged in the 1980s (Brothers et al. 1999). Dias et al. (2019) estimate that 100 out of all 359 seabird species are affected by bycatch. Compared to other fisheries, longlining has been described as a relatively low-impact fishing technique. As target species show species- and age-specific differences in habitat choice, longlines can be deployed in specific areas, or a specific type or size of bait can be chosen to select for certain fish (Brothers et al. 1999). In addition, longlining is described as generally non-destructive to bottom structures (Dunn and Steel 2001). However, although considered as low impact on fish communities and (benthic) habitat, longline bycatch is estimated to annually affect between 160 000 and 320 000 birds on a global scale (Anderson et al. 2011).

While targeting longline bait is a high-risk foraging approach for seabirds, it is also a predictable resource and is often combined with additional food availability from discards and offal by the same vessel (Montevecchi 2001). The bait on longline hooks is often taken by seabirds during setting operations. The lines with baited hooks float on the surface for a short period of time, depending on vessel speed and tension of the line, weights used, and the turbulence caused by the propeller (Brothers et al. 1999). Once the lines sink, they get out of the reach of non-diving seabirds. However, if hooked, struggling seabirds themselves can decelerate the sinking speed, attracting even more birds (Barnes et al. 1997). Bycatch in longline fisheries is affected by many biological and environmental factors. Species, age, breeding status, and sex as well as seabird density are thought to be the main drivers of risk (Bugoni et al. 2011, Gianuca et al. 2017). However, season, weather, fishing intensity as well as gear type and hooks or bait used, may also influence the risk of seabirds getting entangled in active fishing gear (Clay et al. 2019).

Since recognizing bycatch as a risk to seabird populations, efforts were made to reduce seabird mortality in longline fisheries. Melvin et al. (2023) summarize the several requirements that suitable mitigation measures have to meet. Most importantly, seabird bycatch has to be reduced significantly. However, at the same time, fishery operations should not be hampered when setting or hauling lines, resulting in similar fishing efficiency. The most common mitigation measures that have been recommended by ACAP (2021) include fishing gear adaptations (e.g. bird-scaring lines, underwater setting, weighted lines, hook design), operational adaptations (offal discard bans, dyed bait), or management options (spatial or temporal closures). These bycatch mitigation measures, in particular when applied in combination, can significantly reduce seabird bycatch. Examples have been recently summarized by Melvin et al. (2023) and show that seabird bycatch in longline fisheries can be successfully reduced.

The northern fulmar (*Fulmarus glacialis;* hereafter fulmar) is a common seabird occurring in the North Atlantic, North Pacific, and throughout the Arctic Ocean. Fulmars reach maturity at around 9 years of age (Ollason and Dunnet 1978). They are generalists and opportunistic predators, foraging on or near the sea surface on fish, squid, crustaceans, jellyfish, floating carcasses of mammals and birds, as well as on offal and discards from fisheries (e.g. Camphuysen and Van Franeker 1996, Garthe et al. 2004, Danielsen et al. 2010, Mallory et al. 2010). The proportion on which fulmars depend on fishery as a source of food is debated and likely depends on location, season, and fishing pressure (Camphuysen and Garthe 1997, Phillips et al. 1999). Nevertheless, it is evident that fulmars attend fishing vessels regularly at day and night (Dupuis et al. 2021), and in some cases the distribution of fulmars has been linked directly to fishery activities (Darby et al. 2021). Consequently, the fulmar is a species likely affected by longline bycatch within its distributional range (e.g. Dunn and Steel 2001, Løkkeborg and Robertson 2002, Fangel et al. 2015, Colston-Nepali et al. 2020, Northridge et al. 2020). All recent population estimates in the North Atlantic have detected a serious decline in fulmar numbers, e.g. in the Canadian Arctic (Mallory et al. 2020), on Iceland (Garðarsson et al. 2011), in Norway (incl. Svalbard; Anker-Nilssen et al. 2021), in colonies in the UK and Ireland (Cordes et al. 2015, Burnell 2023), and for the small German fulmar breeding population (Dierschke et al. 2022b). The reasons for the recent decline remain unclear and may involve a range of factors, but the effects of fishery and bycatch have been identified as one of the potential drivers (e.g. Dunn and Steel 2001, Miles et al. 2020, Burnell 2023) and therefore additional information on seabird fishery interaction is considered valuable (Dierschke et al. 2022a).

For this article, bycaught fulmars from the Faroe Islands were studied. Fulmars are bycaught during demersal longline operations, taking place close to the Faroe Islands. They mainly target large individuals of different Gadoid species, but also redfish (*Sebastes* spp.) or flatfish (Danielsen and Agnarsson 2018). The local fulmar population is currently estimated to consist of 600 000 breeding pairs; however, also here, a decrease of 20%–30% from 1990 to 2010 was observed (Hammer et al. 2014). Fulmars hooked in longlines, were collected non-structurally by fishermen. Therefore a proper analysis of bycatch rates and seasonal and temporal changes is not feasible. However, within the given sample, differences in age and sex can be evaluated and related to, e.g. breeding season and mechanism of entanglement in longlines. Details on sex and age within bycaught fulmars can help identifying major threats of longline bycatch to the local fulmar population (Fangel et al. 2016). The stomach contents of these fulmars were analysed, including the quantity and mass of bait items in the stomachs. As the collected birds were initially intended for plastic monitoring (Van Franeker et al. 2011, Van Franeker et al. 2021), we evaluated if this sampling technique is suitable for that purpose. The quantity of bait lost to predating fulmars is relevant for estimating the effect that fulmars may have on the fishing efficiency (Gandini and Frere 2011). The repeated loss of bait to seabirds can lead to negative economic consequences for the fishing industry (Sánchez and Belda 2003).

Materials and methods

Fulmars, bycaught in local longline fisheries, were voluntarily collected by Faroese fishermen. The original purpose of this sample was the analysis of ingested plastic by fulmars in Faroese waters, these results are presented elsewhere (e.g. Van Franeker et al. 2011, Van Franeker 2012). For the current study, bait data were available for 820 fulmars. These birds were collected between 2004 and 2021, covering all seasons. Fulmars were collected incidentally; therefore, no total bycatch rates can be inferred from these data. The distribution of collected fulmars by year and month is shown in Table 1. Most fulmars (97.6%) were collected within 100 km from the closest shore of the Faroe Islands; the maximum distance was six birds caught 219 km off the Faroese coast.

Birds were dissected according to Van Franeker (2004). In short, biometric data were collected, such as bill, head, tarsus, and wing length. Details on moult, colour phase, external pollution, and injuries were noted. The type of entanglement was defined as either 'internal' (hooked in e.g. bill, throat, or stomach), 'external' (hooked in wing, leg, or elsewhere), or 'unclear' (no hook/damage visible). The condition of the birds was determined by inspecting breast muscle, subcutaneous and intestinal fat, in combination scoring from 0 (very emaciated) to 9 (very good condition). The sex was assigned based on the presence of either testes or ovary. Age categories range from juveniles, second-year birds, and immatures to breeding adults. Juvenile birds have a large *Bursa of Fabricius* and have uniform fresh coverts and secondaries on the wings. During the second-year, the Bursa disappears, and from this age onwards, moulting of the secondaries and coverts occur, creating a pattern of feathers of different generations. Immature fulmars do not have a Bursa anymore but ovary, oviduct, and testes are not fully developed. Adult birds have fully developed ovaries, oviducts, and testes. See Van Franeker (2004) or OSPAR (2015) for details and drawings. The stomachs (proventriculus and gizzard) were extracted and stored at −20°C for later analysis. Stomachs were opened and contents were rinsed on a 1 mm mesh sieve, according to Van Franeker (2004) and Provencher et al. (2019). Visible chunks of bait in the proventriculus were collected and described (for examples see Supplementary Photos S1–S8). No identifiable bait items were found in the gizzard. Bait was identified by clear cuts through tissue and bones of the bait animals, and bait type was defined as either fish, squid, whelk, or 'other'. Most fish bait on the Faroe Islands consists of pieces of Atlantic mackerel (*Scomber scombrus)*, imported Pacific saury (*Cololabis saira*), and Atlantic herring (*Clupea harengus*). Squid bait is often imported from South America, but the species were unknown. For whelk bait, the common whelk (*Buccinum undatum)* is used. Bait items were counted, and in addition, the wet mass per bait type (in gramme) was weighed for 518 of the 820 birds.

To test for differences between sample proportions, the 2-sample z-test was applied, as recommended by Van Franeker et al. (2021) at http://epitools.ausvet.com.au/content.php?page=z-test-2. The non-parametric Mann–Whitney U test was used to evaluate differences in numbers of bait between sex, age, season and breeding status.

In relation to trends over time, we separated our samples for actively breeding fulmars and those adults that were not breeding actively. Active breeders were identified for the months June, July, and August, when internal and external

Table 1. Number of northern fulmars available for this study, split by month and year.

Month/year	1	2	3	4	5	6	7	8	9	10	11	12	Total
2004	3	8	23	8	1								**43**
2005	2	11	5	40	14	6	48	13	26	59		13	**237**
2006	47												**47**
2007													**0**
2008	6	40											**46**
2009			38										**38**
2010										11	0		**11**
2011		6			83	14	35				1		**139**
2012	21	14						33					**68**
2013													**0**
2014											12		**12**
2015	7			15				30					**52**
2016			21										**21**
2017			33								25		**58**
2018			15	15									**30**
2019													**0**
2020													**0**
2021					2	16							**18**
Total	**86**	**79**	**135**	**78**	**100**	**36**	**83**	**76**	**26**	**70**	**38**	**13**	**820**

Within the sampling period from 2004 to 2021, a total of 820 fulmars were studied.

data showed them to be adult and judged to be certainly or likely incubating an egg or raising a chick at the time of collection. This was done by assessing the presence of a brood patch, morphometrics of sexual organs, and delayed moult of primary feathers. To test for a potential trend in bait ingestion over years, we applied GLMM analyses (Generalized Linear Mixed Model) using Poisson distribution and link function logarithm (Genstat 22nd Edition). With the individually ingested number of bait items, as response variate, we tested for the mixed effect of year and breeding status (actively breeding at the time of collection or not).

Ethical statement

No fulmar was specifically killed for this study. On the Faroe Islands, fulmars are not protected. No permits are involved in the fishing and there are no regulations on what to do with longline bycatch. Fulmar longline bycatch is used for plastic research with the approval of the Faroese Food and Environmental Agency (e.g. Umhvorvistovan document 1 800 440–1, dated 23 May 2018; Van Franeker 2012).

Results

For this study, 820 fulmars were available. Of these birds, 18 individuals (2.2%) belonged to the coloured plumage phase, indicating that part of the fulmars foraging around the Faroe Islands has a high Arctic origin. Of all birds, 71% had at least one bait item in their stomach (Table 2). For 371 birds (45%), the type of entanglement was described as internal, 245 birds (30%) were entangled externally, seven birds (1%) showed signs of both internal and external entanglement, and 197 birds (24%) showed no detectable signs of entanglement. The sample consisted of significantly more males than females ($P < 0.0001$; Table 3). All age classes were represented in our sample, but the great majority consisted of adult birds ($n = 595$; 73%), followed by immatures from over 2 years to breeding adult age ($n = 137$; 17%), and finally 27 second-year birds (3%) and 61 juveniles (7%).

When comparing the proportion of adult birds with non-adults (juvenile to immature), a significant difference was detected ($P < 0.0001$; Table 3). Most birds (72.2%) were in good body condition (Condition Index ≥ 7), 27.6% were in moderate condition (Condition Index 4–6), and only two birds were in poor condition (Condition Index 3 or lower; Table 3).

Bait ingestion

A total of 1538 bait items was identified, the majority consisted of fish (67%), followed by squid (27%) and whelk (6%). Only one bait item was identified as 'other' (crab bait). On average, all birds combined (including those without bait present) contained 1.88 bait items (Table 2; Fig. 1) with an average wet mass of 19.1 g per bird (mass available for 518 fulmars). Due to varying bait size, wetness, and grade of digestion, the mass of each identified bait item was highly variable (on average 6.4 g, but ranging from < 0.1 to 36 g), and therefore all following analyses were based on bait numbers. Examples of bait in varying sizes and states of digestion are shown in the Supplementary Photos S1–S8. The maximum number of ingested bait items was 17 pieces, six birds had ten or more bait items in their stomach (Fig. 1). All of these six birds were males, and all were adults except for a single second-year bird.

While the two birds in poor condition did not contain any bait, the moderate condition birds ingested on average 2.13 bait items. Birds in good condition were found to have significantly fewer bait items on average in their stomachs (1.82 items; $P = 0.0002$) than those in a moderate condition (Table 3; Supplementary Fig. S1 and Table 1). When considering the type of entanglement, no differences were found in average bait numbers between birds that got entangled internally (e.g. in the bill), externally (e.g. around the wing), and birds of which the entanglement type was unknown (Table 3).

Females and males did not show significant differences in either frequency of occurrence (%FO) of ingested bait or the average number of bait (Table 3). There was no significant difference between adult and non-adult birds in terms of frequency of occurrence or average number of bait (Table 3). Bait ingestion was not correlated to the type of entanglement: Birds with zero bait had the same ratio of external, internal, or unknown entanglement (30%, 47%, and 24%) as did birds with

Table 2. Details of northern fulmars available for this study.

	All birds combined			
	Sample size (n)	Bait %FO	Average number of bait ± se	
All birds	820	71%	1.88	± 0.07

Given are the sample size, the frequency of occurrence of ingested bait (bait %FO) and the average number of bait items ± standard error, calculated over all 820 available fulmars.

Table 3. Overview of bait ingestion details by northern fulmars of different characteristics.

Groups	Sample size (n)	%FO	Average number of bait ± se		Test results
Sex					
Female	284	67	1.85	± 0.11	% male/female birds $P < 0.0001$
Male	536	72	1.89	± 0.09	%FO male/female $P = 0.3679$
					Average n bait $P = 0.919$
Age					
Juvenile (JU)	61	79	1.93	± 0.20	
2nd year (2Y)	27	74	1.74	± 0.43	
Immature (IM)	137	62	1.53	± 0.15	
Non-adults (JU, 2Y, IM) combined	225	68	1.67	± 0.12	% adult/non-adult birds $P < 0.0001$
Adult	595	72	1.95	± 0.09	%FO adult/non-adult $P = 0.2605$
					Average n bait $P = 0.129$
Body condition					
Poor (0–3)	2	0	0		
Moderate (4–6)	226	76	2.10	± 0.12	% mod./good birds $P < 0.0001$
Good (7–9)	592	69	1.80	± 0.09	%FO mod./good $P = 0.0487$
					Average n bait $P = 0.0002$
Entanglement type					
Internal	372[a]	70	1.93	± 0.12	Average n bait Int/Ext/Unk $P > 0.05$
External	246[a]	72	1.87	± 0.12	
Unknown	196	71	1.82	± 0.13	

[a]7 birds were found to be entangled both internally and externally and were excluded from this analysis. Given are the sample size, the frequency of occurrence (birds with bait; %FO) and the average number of bait ± standard error. Birds are divided by sex, age, body condition, and type of entanglement. Test results detecting potential significant differences between groups are summarized.

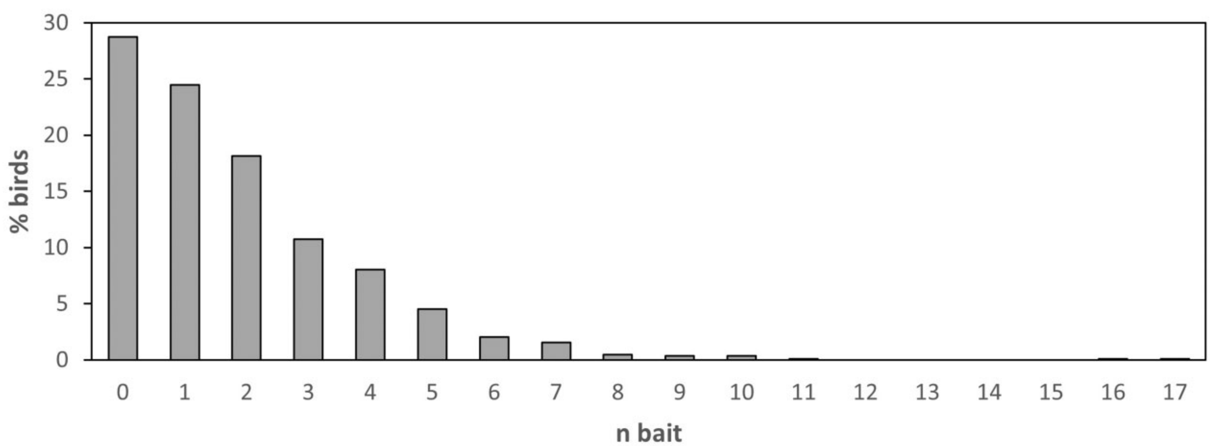

Figure 1. Proportions of northern fulmars ($n = 820$) with a certain amount of bait items in their stomach. In these fulmars, the number of bait items ranged from 0 to 17.

one or more bait items (31%, 45%, and 24%, respectively; see Supplementary Fig. S2 and Table 2).

When comparing the monthly averages of the number of bait items, it appeared that higher numbers of bait were detected during summer compared to the rest of the year, as shown in Fig. 2 (tabulated data provided in Supplementary Table S3). When restricting the analyses to adult fulmars, bait numbers were significantly higher ($P < 0.001$) during the chick-rearing period in July and August (average 2.53 bait items) than outside this period (average 1.77 bait items; see Table 4 and Fig. 3). The same is true when including the month June, when fulmars incubate their egg ($P < 0.001$). As not all adults may be active breeders at the time of bycatch (e.g. failed breeders), the analysis was repeated using only actively breeding birds. Results confirmed that in the full June to August period, actively breeding fulmars had on average 2.75 bait items in the stomach, whereas non-breeding individuals had a significant lower 1.92 bait items ($P = 0.011$; Supplementary Table S3).

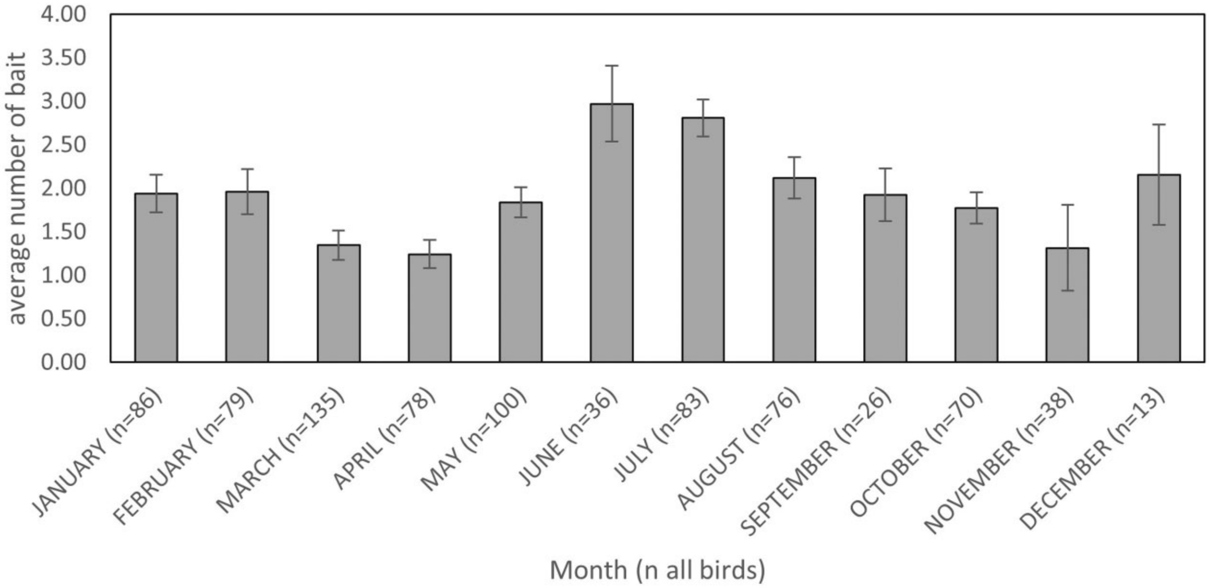

Figure 2. Average number of bait ± standard error ingested by 820 northern fulmars divided per month. Numbers in parentheses indicate the number of birds available for each month.

Table 4. Monthly figures for bait ingested by adult northern fulmars (n = 595).

	Adult birds											
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
n birds	62	58	83	68	75	28	80	67	10	31	24	9
Bait %FO	79	66	63	62	75	93	89	69	90	81	46	67
Average *n* bait	2.00	1.93	1.40	1.32	1.80	3.11	2.85	2.15	2.30	1.81	1.33	1.78
± se	0.25	0.32	0.24	0.18	0.21	0.50	0.21	0.26	0.63	0.28	0.68	0.57

Given are the sample size, the frequency of occurrence (bait %FO) and the average number of bait ± standard error.

For non-adult birds, the test resulted in a non-significant difference between the breeding and non-breeding periods. On average, non-adult birds had ingested 1.8 bait pieces during the chick-rearing period in July and August and similarly 1.7 bait pieces throughout the remaining year (Fig. 3; Supplementary Table S3).

The average number of bait items varied strongly per year (Supplementary Table S4) and initially suggested a significantly long-term decreasing trend in the number of bait items in the stomachs (simple linear regression over the full sample of 820 birds: $P = 0.011$). However, since we observed that breeding status had a strong effect on the quantity of ingested bait (see Supplementary Fig. S3), we analysed the data by a GLMM approach with year and breeding status as covariates. Both covariates, year and breeding status, were significantly contributing to a decreasing trend. However, the effect of YEAR (F prob 0.014) was overshadowed by that of breeding status (F prob < 0.001). When actively breeding birds were excluded, simple linear regression no longer showed a significant year effect (662 birds, $P = 0.079$).

Discussion

Within this study it was not possible to obtain data on total bycatch rates of fulmars in Faroese longline fisheries. However, after three fishing trips with onboard observers on Faroese longline vessels, preliminary data indicate that ~9500 fulmars may be caught annually, with an observed peak in June (Danielsen 2022). Data from other regions, such as the UK suggest a range of 2000–9000 fulmars longline bycatch fatalities in British waters (Northridge et al. 2020). In Norway, fulmars are estimated to comprise 99% of the longline bycatch (Dunn and Steel 2001) and to have an entanglement rate of 0.24 birds per trip (Fangel et al. 2016). The now-available data from the Faroe Islands, however, still allows a closer analysis of sex and age ratio's within bycaught fulmars and relevant information on the efficiency of these birds predating on bait from longline hooks.

Catch rate biases

Within the available dataset, male birds were more commonly bycaught than female fulmars. Sex bias towards male seabirds has been found in the majority of the available bycatch studies [summarized by Gianuca et al. (2017)]. The sex composition of live fulmars following Faroese fishing vessels is unknown. For fulmars from surrounding North Atlantic colonies, however, Darby et al. (2023) found two times more males than females attending different types of fishing vessels. Also in the South Atlantic, Bugoni et al. (2011) showed that in different albatross and petrel species, males were more commonly observed around fishing vessels than females. While in many studies it was hypothesized that this bias may be caused by larger body proportions or a more dominant behaviour by males, other studies suggest that sex-specific foraging segregation within seabird species may

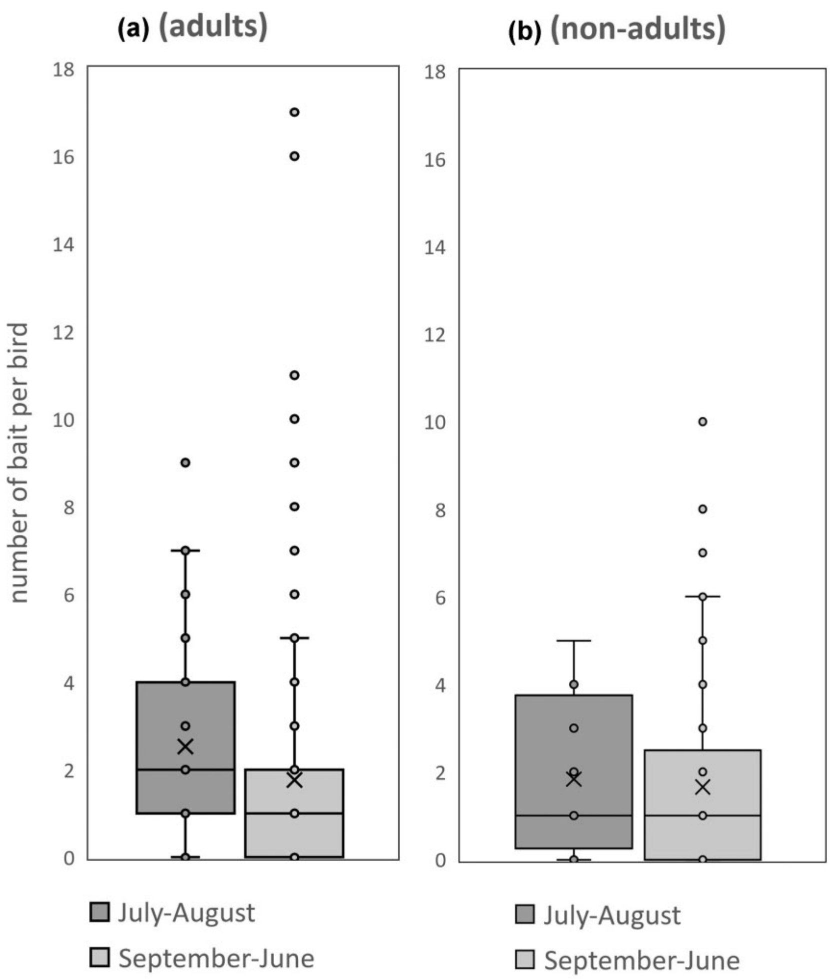

Figure 3. Number of longline bait items ingested by northern fulmars from the Faroe Islands. The uptake of bait is compared between the chick-rearing period (July and August) and the remaining year (September-June). The left panel (a) shows adult birds ($n = 595$), the right panel (b) non-adult birds ($n = 225$). Data points (circles) show the number of bait for each bird. Please note that most fulmars had similar numbers of bait in their stomachs; thus, data points mostly overlap (for details see Supplementary Table S3). Within the boxes, 50% of the birds are included. The mean number of bait is shown by the x symbol, and the median value by the horizontal line inside the boxes. Whiskers include 1.5 times the interquartile range.

explain the higher bycatch of males (such as summarized by Gianuca et al. (2017)). In our study, most birds were caught within 100 km of the Faroese coast, which may explain the higher number of male fulmars caught. For example, the proportion of male birds was particularly high in May (82% of 100 birds; see Supplementary Fig. S4). In May, both males and females leave the nesting sites for the pre-laying exodus (MacDonald 1977b); however, males remain closer to the colony and visit their nest site more regularly, than females (Danielsen and Bengtson 2009, Edwards et al. 2016). During incubation and chick-rearing, both partners seem to have similar foraging range and duration, as shown by Edwards (2015). But, during the non-breeding season, fulmars show sex-dependent range differences with males remaining more central place foragers during autumn and winter (Quinn 2014).

Within our sample there was a strong bias towards adult fulmars. This may be caused by bycatch locations close to the colonies, as younger birds spend their time further away from colonies than breeding birds (e.g. Weimerskirch et al. 1985). Fulmars are known to spend their first years widely dispersed (Macdonald 1977a) and to return to their colony around four to five years after fledging, as prospecting breeders (Hatch and Nettleship 1998; Mallory et al. 2012). The age distribution of the North Atlantic fulmar population is not known; however, for close southern relatives modelling data suggests a distribution of ~50% adults, 25% immatures, and 15% juveniles (Carneiro et al. 2020). In Norwegian longline fisheries, the bycatch rate of fulmars was similarly distributed between adult and non-adult birds in May and June; however, during the chick-rearing months July and August, 81.4% of the bycaught fulmars were adults (Fangel et al. 2016). The authors argue that the bias could be caused by the influx of failed breeders from other regions or the dispersal of immature birds in the late breeding period, while active breeders are limited by central-place foraging constraints. The removal of mainly adult birds by longline fisheries is of conservation concern for a long-living and slowly reproducing species as the fulmar. Baetscher et al. (2022) suggest that the removal affects the breeding success for the current breeding season, as well as for upcoming years, as fulmars are largely monogamous seabirds and may lose successful breeding opportunities by having to establish new pair bonds (e.g. Ollason and Dunnet 1978, Hatch 1987). Quinn (2014) also suggests that older breeders (age based on ringing data) remain closer

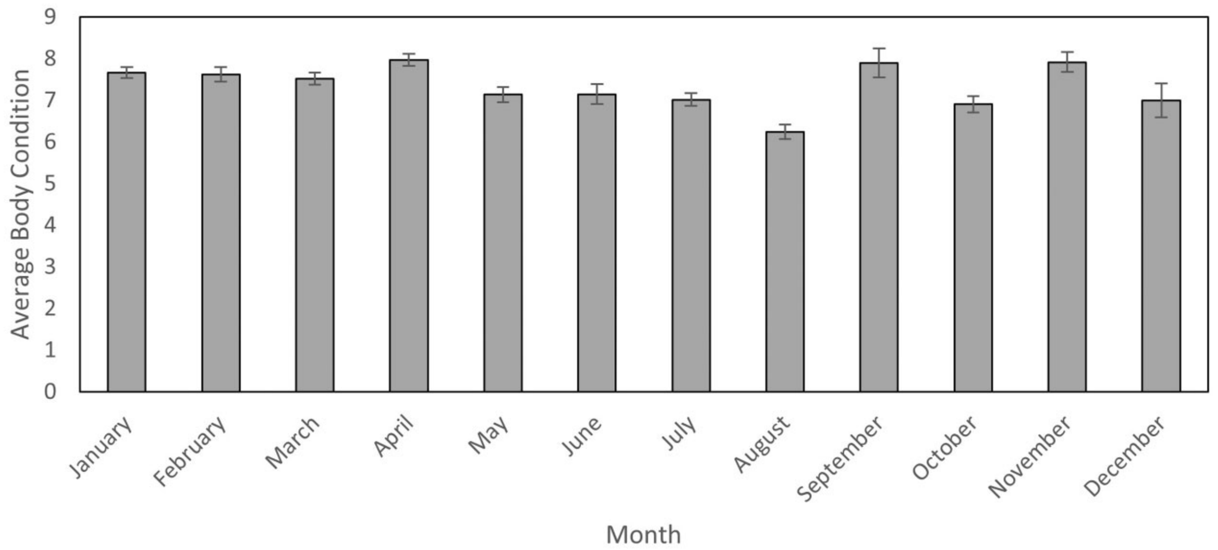

Figure 4. Average body condition in 595 adult fulmars for each month of the year with standard error. Body condition ranges from 0 (very emaciated) to 9 (very good condition).

to the colony. Since experienced adult breeders have higher breeding success rates (Ollason and Dunnet 1978) losing such birds to longline fisheries will increase the vulnerability of the bird population.

Bait ingestion

Neither sex nor age influenced the average number of the bait in fulmar stomachs when considering the entire sample. Each bycaught fulmar had on average two pieces of bait ingested. As the proportions of different types of bait used by fishermen are not known, no conclusions can be drawn on whether fulmars prefer a certain type of bait, such as fish or squid. Although males dominated the highest maximum amounts of bait in stomachs (all six birds with ten or more bait items were males), the overall lack of differences between males and females in terms of average number of bait indicates that boldness by males (as argued in many studies; Gianuca et al. (2017)), may not cause the increased mortality of males in longline fisheries. However, the high numbers of bait in many of the fulmars indicate high specialization of food acquirement from longline fishing vessels in individual birds. The number of bait only represents a snapshot of time, as soft fish tissue and, in particular, bait, already chopped to small pieces, may be digested within hours (Hilton et al. 2000). Following longline vessels year-round, these fulmars must be stealing a considerable quantity of bait throughout their lifetime before eventually getting entangled. The only other study quantifying bait in stomachs recorded an average of 4 bait items in 166 albatrosses and petrels bycaught in the South Atlantic, and the maximum number of bait found in one bird was 6 bait items (Gandini and Frere 2011), thus much less compared to the maximum of 17 items found in one fulmar from the current study. Gandini and Frere (2011) did not specify the season in which the birds were caught. However, our data indicate that season influences the uptake of bait.

A higher average number of bait was found in adult fulmars during the incubation and chick-rearing periods. During the chick-rearing period, food requirements are high, and the time for foraging trips is limited. Because of this, adult fulmars may take higher risks when stealing bait from longline fishing vessels, also indicated by the preliminary data of Danielsen (2022) with most birds bycaught in June. While the data of Fangel et al. (2016) indicate good body condition of their sampled fulmars throughout the breeding season, our data show, that the body condition in adult birds is significantly lower during the chick-rearing period ($n = 147$; average Condition Index 6.7) than throughout the rest of the year ($n = 448$; average Condition Index 7.5; Mann–Whitney U test; $P < 0.001$), as can be seen in Fig. 4 (for details see: Supplementary Table S1). Decreased body condition during the breeding season was also found in bycaught fulmars from the North Pacific (Beck et al. 2020). This further supports the idea that fulmars that are feeding chicks with increasing energy demands, while simultaneously depending on potentially suboptimal foraging grounds closer to the colonies (Hatch 1990, Phillips et al. 2017), may be desperate to find food and consequently take higher risks at seemingly easily acquired food sources behind fishing vessels.

Implications for plastic monitoring

Partial regurgitation of stomach contents can be observed regularly in birds when caught by shooting or handheld nets. It was unclear if regurgitation also occurs when birds are pulled under water after being entangled in longlines. Retrieving the stomach content as complete as possible is relevant for plastic ingestion studies to ensure comparability. Fulmars from longline bycatch have been recommended as suitable bioindicators for plastic pollution (Provencher et al. 2019, Lusher et al. 2022, Savoca et al. 2022) and have already been previously used by e.g. Mallory (2008), Van Franeker et al. (2011), Kühn and Van Franeker (2012), Herzke et al. (2016), and Snæþórsson (2023). The fact that the majority (71%) of 820 longline victims had remains of bait in their proventricular stomach strongly indicates that regurgitation at the moment of entanglement is uncommon. This study substantiates that fulmars caught in longline fisheries can be used as reliable bioindicators for plastic ingestion.

Economic loss

In some fisheries, stolen bait and consequently reduced fishing efficiency have caused entire fishing trips to be unprofitable (Sánchez and Belda 2003). Løkkeborg (1998) predicted that up to 70% of the longline bait can be lost to seabirds in Norway. Gandini and Frere (2011) estimated, based on bait found in Procellariiform seabird species from the South Atlantic, that the financial loss of longline bait may cost the industry 1.5 to 2 million US dollars over a period of ten years. For 20 longline vessels from the Russian Pacific, Artyukhin et al. (2006) estimated a financial loss of at least 630 000 in 2003 and 840 000 US dollars in 2004. Although the predation rates by fulmars on the Faroe Islands are not known, it appears that fishermen may lose considerable income through reduced fishing efficiency caused by seabirds predating on longline baits. Different scenarios were proposed by Kühn (2016), where economic loss could range from a few hundred Danish Krones, when <100 birds follow the ship, and fishing efficiency is as low as 10% (10% of the hooks catch a fish), up to almost 90 000 Danish Krones per fishing trip in a worst-case scenario with 1000 birds following the ship and an assumed fishing efficiency of 100%. It is clear that financial damage is unavoidable as long as seabirds are able to steal considerable amounts of bait. Since this problem affects both seabirds and fishermen, several mitigation measures have been successfully applied to decrease the bycatch of seabirds in longline fisheries on a global scale (Melvin et al. 2023). Currently, no mitigation measures to reduce seabird bycatch are required on the Faroe Islands. General mitigation measures such as bird-scaring lines, offal restrictions, or weighted lines have shown good results in demersal longline fishing operations elsewhere (Melvin et al. 2023) and could be implemented on the Faroe at relatively low costs (Kühn 2016). In addition, avoiding longline fishing in the vicinity of colonies during the chick-rearing months would be beneficial for seabird conservation. Diurnal closures (e.g. night-setting) may be less suitable as fulmars attend fishing vessels at night as well as during the day (Dupuis et al. 2021). In addition, the high latitude location of the Faroe Islands imply long polar days and nights; therefore, diurnal closures are not feasible during summer and winter. Attention should be given to the interaction between discarding offal from longline vessels and setting the lines, as the simultaneous occurrence of these activities increases the attraction of fulmars to the vessels (Votier et al. 2023).

Most importantly, Avery et al. (2017) estimate that catch efficiency of fish can be increased by 9% when applying mitigation measures and simultaneously reduce unintended seabird bycatch by almost 90%, resulting in a win-win situation for both fisherman, and seabird populations. Weighing financial loss from reduced fishing efficiency against the costs of mitigation measures, it will be beneficial to any longline fishing industry as well as the seabird populations that are involved.

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Author contributions

Conceptualization: JAF, SKU; Data curation: JAF, SKU; Resources: JAF, JKJ, BO, JD, P-JS; Methodology: JAF, SKU; Writing Original draft: SKU; Writing—review & editing: all authors.

Supplementary data

Supplementary data is available at *ICES Journal of Marine Science* online.

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Data availability

The data underlying this article are available in the article and in its online supplementary material.

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Supplementary Material to:

Increased longline bait predation by northern fulmars (*Fulmarus glacialis*) around the Faroe Islands during the breeding season

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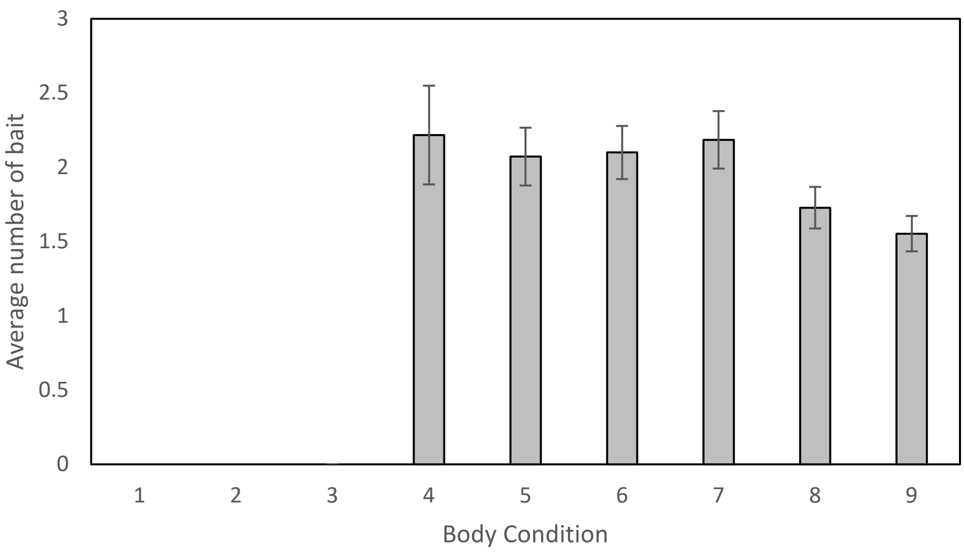
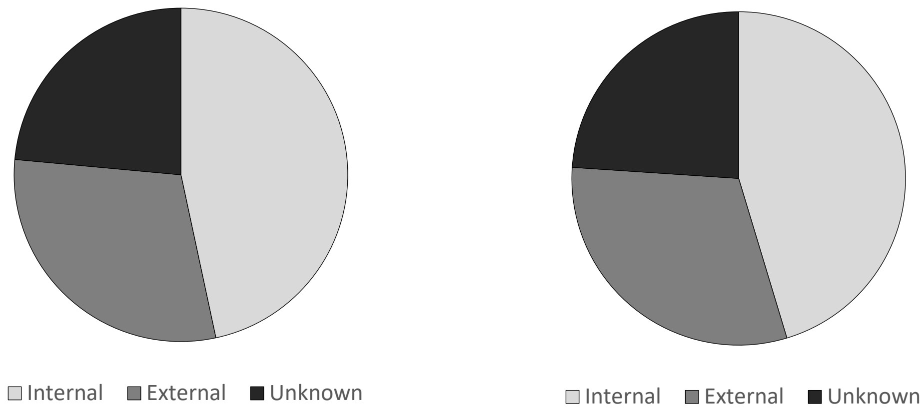


Supplement Figure 1. Uptake of longline bait by all northern fulmars grouped by Body Condition. The Body Condition is the sum of three scores, calculated by inspecting development of the breast muscle and the abundance of subcutaneous fat and intestinal fat (Van Franeker 2004). Scores for each category are designated from 0 (absent) to 3 (well developed/abundant). Therefore the total score ranges from 0 (very emaciated; poor condition) to 9 (very good condition). Underlaying data are presented in Supplement Table 1.

Supplement Table 1. Body Condition of fulmars caught as bycatch in longline fisheries. Given are the sample size, the Frequency of Occurrence (Bait %FO) and the average number of bait ±standard error are given. In addition data has been divided for adult and non-adult fulmars. For a description of the Body Condition scores, see header Supplement Figure 1.

Body Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
All birds									
n birds	0	0	2	23	83	120	173	195	224
Bait %FO			0	78	73	78	75	69	65
avg n bait			0	2.22	2.07	2.10	2.18	1.73	1.55
±se			0	0.33	0.19	0.18	0.19	0.14	0.12
All adults									
n birds	0	0	1	15	59	95	128	154	143
Bait %FO			0	87	73	80	74	72	65
avg n bait			0	2.53	2.14	2.18	2.27	1.86	1.50
±se			0	0.42	0.25	0.21	0.24	0.17	0.14
All non-adults									
n birds	0	0	1	8	24	25	45	41	81
Bait %FO			0	63	75	72	78	59	65
avg n bait			0	1.63	1.92	1.80	1.93	1.24	1.64
±se			0	0.50	0.29	0.35	0.28	0.22	0.22



Supplement Figure 2. Proportion of birds with signs of either internal, external entanglement or where the type of entanglement was unknown. ***Left****: Fulmars with 0 bait items in their stomach.* ***Right****: Fulmars with 1 or more bait items ingested. Figures are based on the numbers of birds per category shown in Supplement Table 2.*

Supplement Table 2. Number of birds with signs of either internal, external entanglement or where the type of entanglement was unknown. Data is grouped for birds with no bait and birds with at least one bait item.

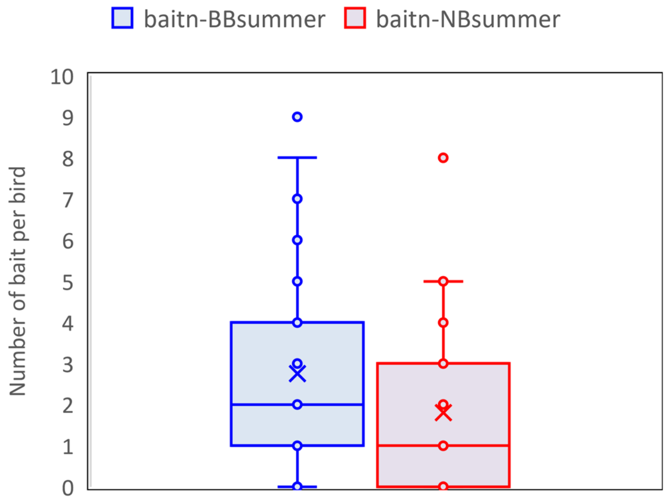
	Internal	External	Unknown
0 bait (left)	111	71	56
≥1 bait (right)	267	181	141

Supplement Table 3. Monthly amount of bait ingested by all available northern fulmars (n=820) split per age group. 'All non-adults' include juvenile, 2nd year and immature fulmars. Given are the sample size, the Frequency of Occurrence (Bait %FO) and the average number of bait ±standard error.

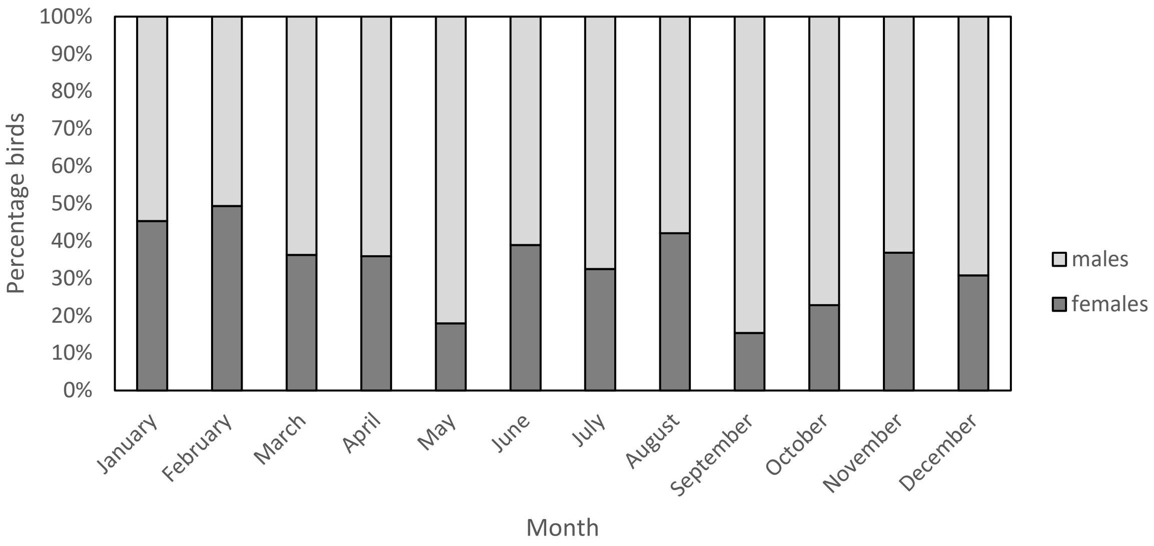
Month	***1***	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All birds												
n birds	86	79	135	78	100	36	83	76	26	70	38	13
Bait %FO	74	67	6	59	76	89	88	7	88	79	47	77
avg n bait	1.94	1.96	1.35	1.24	1.84	2.97	2.81	2.12	1.92	1.77	1.32	2.15
±se	0.22	0.26	0.17	0.16	0.17	0.43	0.21	0.24	0.3	0.18	0.49	0.58
All adults												
n birds	62	58	83	68	75	28	80	67	10	31	24	9
Bait %FO	79	66	63	62	75	93	89	69	90	81	46	67
avg n bait	2.00	1.93	1.40	1.32	1.80	3.11	2.85	2.15	2.30	1.81	1.33	1.78
±se	0.25	0.32	0.24	0.18	0.21	0.50	0.21	0.26	0.63	0.28	0.68	0.57
All non-adults												
n birds	24	21	52	10	25	8	3	9	16	39	14	4
Bait %FO	63	71	56	40	80	75	67	78	88	77	50	100
avg n bait	1.79	2.05	1.27	0.70	1.96	2.50	1.67	1.89	1.69	1.74	1.29	3.00
±se	0.45	0.44	0.21	0.33	0.30	0.93	1.20	0.59	0.30	0.24	0.70	1.41

Supplement Table 4. Yearly variation of bait ingestion by northern fulmars. Given are the sample size, the Frequency of Occurrence of ingested bait (Bait %FO) and the average number of bait items ± standard error.

YEAR	n birds	Bait %FO	Average number of bait ± se	
2004	43	74	0.93	± 0.11
2005	237	80	2.14	± 0.12
2006	47	70	1.40	± 0.20
2007	0			
2008	46	72	2.33	± 0.36
2009	38	74	1.74	± 0.25
2010	11	100	2.27	± 0.38
2011	139	83	2.39	± 0.18
2012	68	72	2.43	± 0.29
2013	0			
2014	12	50	0.83	± 0.34
2015	52	54	1.25	± 0.22
2016	21	48	1.33	± 0.80
2017	58	50	1.43	± 0.35
2018	30	20	0.27	± 0.11
2019	0			
2020	0			
2021	18	83	2.00	± 0.38



Supplement Figure 3. Different bait predation of active breeders (BBsummer) versus non-breeders (NBsummer) in summer.



Supplement Figure 4. Proportions of bycaught male and female fulmars per month. The Table below provides the underlaying data for this figure and in addition, the Frequency of Occurrence (Bait %FO) and the average number of bait ±standard error specified for male and female fulmars each. For underlaying data please see Supplement Table 5, and for combined data Supplement Table 3.

Supplement Table 5. Number of bycaught male and female fulmars per month. The Table provides the number of birds, the Frequency of Occurrence (Bait %FO) and the average number of bait ±standard error specified for male and female fulmars each.

Month	**1**	**2**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
FEMALE											
n birds	39	39	49	28	18	14	27	32	4	16	14	4
Bait %FO	0.64	0.72	0.67	0.54	0.78	0.86	0.93	0.63	1	0.63	0.43	1
avg n bait	1.92	2.28	1.47	1.25	1.44	2.79	3.22	1.63	1.25	1.19	0.71	4.25
±se	0.35	0.36	0.22	0.31	0.28	0.74	0.32	0.3	0.25	0.31	0.3	0.95
MALE											
n birds	47	40	86	50	82	22	56	44	22	54	24	9
Bait %FO	0.83	0.63	0.56	0.62	0.76	0.91	0.86	0.75	0.86	0.83	0.5	0.67
avg n bait	1.96	1.65	1.28	1.24	1.93	3.09	2.61	2.48	2.05	1.94	1.67	1.22
±se	0.28	0.37	0.23	0.18	0.2	0.55	0.27	0.34	0.35	0.21	0.76	0.46

Supplement Photos: The following photographs show a variety of bait encountered in stomachs of bycaught northern fulmars from Faroese waters. All pictures were taken by J.A. van Franeker.

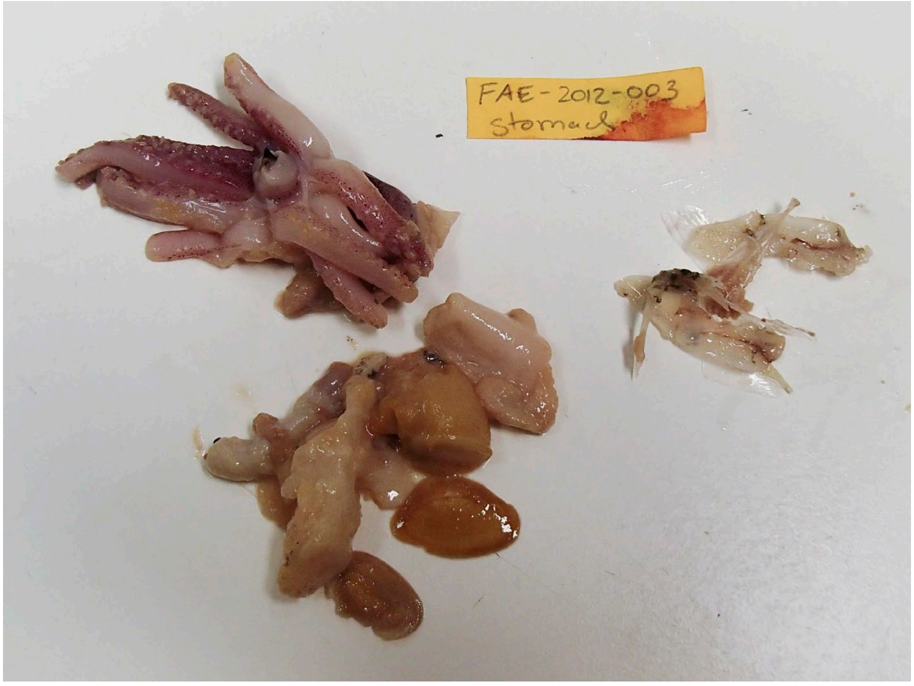
Supplement Photo 1. This picture shows bait of fish (top) and whelk (Bottom left). Please note the clearly cut fish vertebrae. The flesh is already digested. The bottom right items are remains of the natural diet of fulmars.

Supplement Photo 2. Fish bait, the left bit is slightly more digested than the right one. Both show clear cuts identifying them as bait used in longline fishing operations.

Supplement Photo 3. One clearly cut pieces of fish bait. Other items depicted were categorized as natural food (and a feather likely ingested during preening).

Supplement Photo 4. Bait is depicted in the bottom left of this picture. Varying states of digestion were observed, from fish with still large amounts of flesh present to clean vertebrae. In addition natural food and remains of a local newspaper were found, indicating foraging of this fulmar close to the Faroe Islands.

Supplement Photo 5. Fully digested fish bait items. The remaining vertebrae pieces show clear cuts in the size common for longline bait.



Supplement Photo 6. Squid bait (top left) where also clear cuts through flesh were noted. On the bottom whelk bait is shown, already partly digested. Remains on the right are likely natural prey items.

Supplement Photo 7. A piece of squid bait with the 'parrot beak'-like jaws well visible.

Supplement Photo 8. Partly digested chunks of whelk bait. Clear cuts in the flesh are visible. On the bottom, the snail opercula are shown. These items resist the digestion process much longer than the soft tissue.