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PATHOLOGY OF NORTHERN FULMARS (*FULMARUS GLACIALIS*) AND SHEARWATERS BEACHED ON SABLE ISLAND, NOVA SCOTIA, CANADA

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ABSTRACT: Marine birds are frequently found dead on beaches, either from natural or from anthropogenic causes. Complete necropsies of those carcasses can provide valuable information, particularly for pelagic species, such as Northern Fulmars (*Fulmarus glacialis*) and shearwaters, which come to land only to breed and for which information on diseases that may affect them is, therefore, sparse. Between 2000 and 2012, 315 carcasses of four species of Procellariiformes (173 Northern Fulmars, 89 Great Shearwaters [*Ardenna gravis*], 50 Sooty Shearwaters [*Ardenna grisea*], and three Cory's Shearwaters [*Calonectris diomedea*]) were collected on Sable Island, Nova Scotia, Canada, an isolated island near the edge of the continental shelf. A complete necropsy, including examination for the presence of ingested plastic, was performed on all carcasses. Most (70%) of these birds were immature. The cause of death was undetermined in 22% (n=70) of the birds: 36% (62/173) of the Northern Fulmars, 4% (4/89) of the Great Shearwaters, 6% (3/50) of the Sooty Shearwaters, and 33% (1/3) of the Cory's Shearwaters. Emaciation was considered the primary cause of death in 91% of the remaining 245 birds: 87% (97/111) of the Northern Fulmars, 92% (78/85) of the Great Shearwaters, 100% (47/47) of the Sooty Shearwaters, and 100% (2/2) of the Cory's Shearwaters. Notable primary causes of death other than emaciation included mycobacteriosis and neoplasia in Northern Fulmars and transmural parasitic proventriculitis in Great Shearwaters. For Northern Fulmars, nutritional condition (as determined semiquantitatively) was compared with other parameters. Birds in good nutritional condition had heavier body mass and flight muscle mass than those in poor nutritional condition ($P<0.01$). More adults were in poor nutritional condition than expected by chance (91%; $\chi^2=8.23$, $P<0.01$), whereas only 57% of immature birds were in poor condition. There was no relationship between nutritional condition and sex or mass of ingested plastic. Our study provides information on some previously unsuspected health threats in Procellariiformes.

Key words: Beached birds, Northern Fulmar, nutritional condition, pathology, plastic ingestion, Procellariiformes, Sable Island, shearwater.

INTRODUCTION

Seabirds are frequently found dead on beaches worldwide, and mortality events can involve very large numbers of these birds (Baduini et al. 2001; Haman et al. 2013). Beached-bird necropsies provide important information about diseases, diet, and natural or human-related environmental stressors, including oil spills, entanglement in fishing gear, and plastic ingestion (Roletto et al. 2003; Hamel et al. 2009; Bond et al. 2014). Complete necropsies of beached birds are particularly valuable for pelagic species that only come to land to breed, thus limiting opportunities to identify causes of death. Beached-bird surveys lead to a better understanding of the threats to marine and coastal birds and can identify seasonal and interannual patterns of mortality (Harris et al. 2006).

Sporadically since the 1970s, and continuously since 1993, beached-bird surveys have been conducted on Sable Island, Nova Scotia, Canada, an isolated island in the western North Atlantic, situated near the edge of the Scotian Shelf (Lucas et al. 2012). Surrounding currents cause a large and persistent anti-clockwise gyre roughly centered on the island, which entrains floating materials, including animal carcasses, some of which eventually wash ashore. Although more than 50 species of beached seabirds and waterfowl have been collected on Sable Island since the 1970s, and human-related problems, such as oiling and ingestion of plastic, have been documented (Lucas and MacGregor 2006; Bond et al. 2014), there is no detailed information available on pathologic changes in most of these birds.

One of the most commonly encountered groups of birds collected during beached-bird surveys on Sable Island has been Procellariiformes, including Northern Fulmar (*Fulmarus glacialis*), Great Shearwater (*Ardenna gravis*), Sooty Shearwater (*Ardenna grisea*), and Cory's Shearwater (*Calonectris diomedea*; Lucas et al. 2012). Although none of these species breed in Atlantic Canada, they forage within the waters off Nova Scotia outside of the breeding season, and nonbreeders use these waters year-round (Brown 1986; Huettmann and Diamond 2000; Gjerdrum et al. 2018). Northern Fulmars and shearwaters are susceptible to anthropogenic sources of morbidity and mortality from entanglement in, and ingestion of, human-associated marine debris (Newman et al. 2007), but we know little of other causes of death in these birds.

The primary purpose of our study was to identify pathologic changes in beached carcasses of Northern Fulmars and Great, Sooty and Cory's Shearwaters found on Sable Island. We examined associations between species, sex, age, nutritional condition, pathologic changes, and mass of ingested plastic. Our findings provide pertinent information on some previously unsuspected causes of morbidity and mortality in Procellariiformes.

MATERIALS AND METHODS

Intact carcasses of Northern Fulmars and shearwaters were collected from the Sable Island (43.91°N, 59.91°W) shoreline between July 2000 and January 2012. Carcasses of oiled birds were not included in our study. Most birds were collected during beached-bird surveys, usually conducted every 30–45 days (weather and beach conditions permitting). Additional carcasses were gathered opportunistically (Lucas et al. 2012). The month of collection was recorded, and the seasons defined by seasonal equinoxes and solstices, although the degree of autolysis of many carcasses indicated some delay between the birds' death and their collection. Carcasses were stored frozen in individual plastic bags for variable amounts of time. After thawing, we weighed carcasses (excluding those that were wet, sandy, or incomplete), performed a complete necropsy, and collected and weighed any anthropogenic material found in the proventriculus and gizzard (reported in Bond et al. 2014). In a proportion of the Northern Fulmars, we determined the weight of the left flight muscles (pectoralis, supracoracoid, and coracobrachialis).

We determined sex and age (immature or adult) using the criteria described by van Franeker (2004) and conducted a detailed, external and internal gross examination to identify pathologic changes. Standard ancillary tests, including histopathology, bacteriology, and parasitology, were used where appropriate to determine the cause of death or to further characterize gross lesions; these tests were often unrewarding because many carcasses were extensively autolyzed. For histopathology, tissue samples were fixed in 10%-buffered formalin, dehydrated in graded alcohol and xylene, and embedded in paraffin; 5-µm-thick sections were stained with H&E and, in one case, with Ziehl-Neelsen (acid-fast) stain. For bacteriology, samples were cultured at 35 C in 5% CO_2 on Columbia agar with 5% sheep blood and on MacConkey agar. Bacterial isolates were identified with the Bruker (Billerica, Massachusetts, USA) Microflex LT matrix-assisted laser desorption ionization–time of flight mass spectrometry system with MBT Compass software (version 4.179; Bruker). A presumptive isolate of *Mycobacterium* sp. was sent to the National Reference Centre for Mycobacteriology (National Microbiology Laboratory, Public Health Agency of Canada, Winnipeg, Manitoba, Canada) for confirmation and further identification by amplification and sequencing of the 16S rRNA gene. Grossly visible helminths recovered at necropsy were fixed in hot (63 C) alcohol-formalin–acetic acid and transferred to lactophenol for identification with a dissecting microscope.

We categorized the nutritional condition of each bird into one of five categories by scoring the relative abundance of fat in each of two locations (subcutis and coelomic cavity) on a scale of 0 (completely absent) to 3 (abundant), and the relative size of pectoralis muscles on a scale of 0 (severe atrophy) to 3 (convex) (van Franeker 2004). Birds considered in poor nutritional condition had scores of 0–1 for pectoralis muscle size and for fat in both locations. Birds considered in moderately poor nutritional condition also had a score of 0–1 for pectoralis muscle size, but the score for subcutaneous and coelomic fat was 2 in one or both locations. For birds considered in moderate, moderately good, or good nutritional condition, the score for pectoralis muscle size was 2–3. The score for fat was 1 in either subcutaneous or coelomic location for birds in moderate nutritional condition, 2 in both locations for birds in moderately good nutritional condition, and 3 in one or both locations for birds in good nutritional condition.

For the purpose of analyses, birds considered in poor or moderately poor nutritional condition were classified as *poor nutritional condition*, also referred to as *emaciation*, and birds considered in moderate, moderately good, or good nutritional condition were classified as *good nutritional condition*. Although a poor nutritional condition is usually well defined (little or no discernible fat, marked atrophy of pectoralis muscles) and can, in itself, be a cause of death, the category of *moderate nutritional condition* is more subjective and implies the need to look further for a cause of death besides simple emaciation.

Primary diagnoses (causes of death, including emaciation) were defined as pathologic changes most likely to have started the process that led to the eventual death of the bird. In contrast, secondary diagnoses included pathologic changes that may or may not have contributed to the bird's death but were not considered the initial problem. For example, a bird with a broken wing would have eventually died from emaciation or starvation, but the primary diagnosis was trauma.

Statistical analyses examining the relationship between nutritional condition and other variables were only conducted on Northern Fulmars, for which there were sufficient data. We used analysis of variance and the Tukey post hoc test to determine the validity of our general classification of poor versus good nutritional condition by comparing body masses among the five nutritional categories: good ($n=22$), moderately good ($n=8$), moderate ($n=7$), moderately poor ($n=14$), and poor ($n=50$). Chi-squared tests were used to test for relationships among the explanatory variables of age (adult or immature), sex, and nutritional condition (poor or good; Cochran 1954; Larntz 1978). Generalized linear models with binomial distribution (Venables and Ripley 2002) were used to test for relationships between nutritional condition and body mass, mass of left flight muscles, and mass of ingested plastic, the latter to examine whether that debris might have affected the health of the bird, as suggested in Procellariiformes (Lavers et al. 2014). Only birds in poor nutritional condition with no other pathologic findings (i.e., emaciation as primary diagnosis) and those in good nutritional condition with no identified cause of death were used in the analyses.

Means±SD are reported. Statistical analyses were performed in R software (version 3.5.1; R Core Team 2020) using the *dplyr* (Wickham et al. 2020) and MASS (Venables and Ripley 2002) packages. Statistical significance was determined at $\alpha=0.05$.

RESULTS

We recorded data from 315 carcasses, including 173 Northern Fulmars, 89 Great Shearwaters, 50 Sooty Shearwaters, and three Cory's Shearwaters; 70% (220/315) were immature (Table 1). Of the Northern Fulmars collected, 96% were of the double-light color morph (van Franeker and Luttik 2008). Because of their small sample size, Cory's Shearwaters were not included in any of the analyses. Most carcasses were collected in spring and summer (Table 1). Beach surveys were more frequent and regular during March through October. In late fall and winter, high winds, flooding, and winter beach profiles reduce access to the shoreline and impede searches, thus increasing intervals between surveys (Lucas et al. 2012).

Primary diagnoses were identified for 78% of birds, including 64% of Northern Fulmars, 96% of Great Shearwaters, 94% of Sooty Shearwaters, and 67% of Cory's Shearwaters (Table 2). Most birds showed lesions of emaciation as a primary diagnosis (71%), although that was less common in Northern Fulmars (56%) than it was in Great Shearwaters (88%) or Sooty Shearwaters (94%) ($\chi^2_1=45.86$, $P<0.01$). A primary cause of death other than emaciation was identified only in Northern Fulmars and Great Shearwaters. Among the Northern Fulmars, 36% (62/173) had no determined cause of death (no primary diagnosis), a much higher proportion than in Great and Sooty Shearwaters ($\chi^2_1=42.56$, $P<0.01$). Eight of these 62 fulmars (seven immature, one of unknown age), collected in spring or fall, had discordant scores of nutritional condition, with atrophic pectoralis muscles (score of 1) but abundant fat stores (score of 3) in the subcutis, coelomic cavity, or both. These eight birds were

TABLE 1. Overview of the numbers and corresponding percentages of age, sex, and season collected, for four species of Procellariiformes beached on Sable Island, Nova Scotia, Canada, between 2000 and 2012. Seasons delimited by seasonal equinoxes and solstices (spring, 21 March–20 June; summer, 21 June–21 September; fall, 22 September–21 December; winter, 22 December–20 March).[a]

Species	Total no. collected (%)	Immature, no. (%)			Adult, no. (%)		Age unknown, no. (%)			Season, no. (%)				
		M	F	Unk	M	F	M	F	Unk	Spring	Summer	Fall	Winter	Unk
COSH	3 (1)	—	—	—	1 (33)	2 (67)	—	—	—	2 (67)	—	1 (33)	—	—
SOSH	50 (16)	24 (48)	16 (32)	2 (4)	3 (6)	2 (4)	—	—	3 (6)	32 (64)	18 (36)	—	—	—
GRSH	89 (28)	35 (39)	26 (29)	1 (1)	7 (8)	6 (7)	9 (10)	—	5 (6)	12 (13)	75 (84)	1 (1)	—	1 (1)
NOFU	173 (55)	52 (30)	55 (32)	9 (5)	19 (11)	10 (6)	10 (6)	8 (4)	10 (6)	107 (62)	10 (6)	19 (11)	34 (19)	3 (2)
Total	315 (100)	111 (35)	97 (31)	12 (4)	30 (9)	20 (6)	19 (6)	8 (3)	18 (6)	152 (48)	103 (33)	22 (7)	34 (11)	4 (1)

[a] COSH = Cory's Shearwater (*Calonectris diomedea*); SOSH = Sooty Shearwater (*Ardenna grisea*); GRSH = Great Shearwater (*A. gravis*); NOFU = Northern Fulmar (*Fulmarus glacialis*); M = male; F = female; Unk = unknown; — = not applicable.

TABLE 2. Pathologic changes in 315 Procellariiformes beached on Sable Island, Nova Scotia, Canada, between 2000 and 2012. Percentage of total displayed in brackets.

Pathologic changes	Species,[a] no. (%)				Total all birds (%)
	COSH	SOSH	GRSH	NOFU	
Primary diagnosis, emaciation	2 (67)	47 (94)	78 (88)	97 (56)	224 (71)
Primary diagnosis, other					
Trauma (with or without secondary infection)[b]	—	—	5	4	9
Infection (bacterial or fungal)[c]	—	—	—	5	5
Infection (parasitic)[d]	—	—	2	—	2
Neoplasia[e]	—	—	—	3	3
Metabolic[f]	—	—	—	2	2
Subtotal	—	—	7 (8)	14 (8)	21 (7)
No diagnosis	1 (33)	3 (6)	4 (4)	62 (36)	70 (22)
Total	3	50	89	173	315
Secondary diagnosis					
Infection (parasitic)[g]	—	1	4	6	11
Infection (bacterial or fungal)[h]	—	—	—	2	2
Metabolic[i]	—	1	—	1	2
Trauma[j]	—	—	—	1	1
Congenital anomaly[k]	—	—	—	1	1

[a] COSH = Cory's Shearwater (*Calonectris diomedea*); SOSH = Sooty Shearwater (*Ardenna grisea*); GRSH = Great Shearwater (*A. gravis*); NOFU = Northern Fulmar (*Fulmarus glacialis*); — = not applicable.

[b] Wing fracture, internal hemorrhage, cellulitis secondary to skin laceration, and esophageal perforation by fish bone.

[c] Mycobacteriosis; air sacculitis and pericarditis; septicemia; oophoritis; and orchitis.

[d] Proventricular perforation with secondary coelomitis (nematodes).

[e] Hepatic neoplasm (possibly myeloproliferative disease) and subcutaneous round-cell tumors.

[f] Egg impaction and rectal impaction.

[g] Proventricular ulcer (nematodes), muscular sarcocysts, renal parasitism (trematodes), marked intestinal cestodiasis, and pulmonary nematodiasis.

[h] Focal air sacculitis.

[i] Chronic intracoelomic fat necrosis.

[j] Focal proventriculitis from partial perforation by a fishhook.

[k] Male pseudohermaphroditism (based on gross and microscopic identification of a normal single testicle on the left side and a distinct thin-walled oviduct).

excluded from analyses of nutritional condition. The remaining 54 Northern Fulmars (45 immature, two adult, seven of unknown age) were considered in good nutritional condition. Of the 45 immature birds, 11 were collected in winter, 26 in spring, three in summer, four in fall, and one in an unknown season.

All four Great Shearwaters with no primary diagnosis were considered in good nutritional condition. One of three Sooty Shearwaters with no primary diagnosis was in good nutritional condition; this information was not available for the two other birds.

The general classification of Northern Fulmars into either poor or good nutritional condition was supported by analysis of variance and Tukey post hoc tests comparing body mass between the five nutritional categories. There was no difference in body mass between birds in good and moderately good condition (P=0.99) or moderate condition (P=0.78) or between birds in moderately poor and poor condition (P=0.99); birds in good condition were significantly heavier than those in moderately poor (P=0.01) or poor condition (P=0.01). There was also no difference in body mass between birds in moderately good and moderately poor condition (P=0.18) or poor condition (P=0.053) or between birds in moderate and poor condition (P=0.42). However, as indicated previously, we chose to assign the birds in moderate condition to the general category of good condition because a marginal (rather than poor) nutritional condition implies the need to look further for a cause of death besides simple emaciation.

Nutritional condition (poor or good) was not related to sex (χ^2=0.19, P=0.66) or mass of ingested plastic (P=0.21). Body mass was also not related to mass of ingested plastic (R^2<0.01, P=0.76). Birds in good nutritional condition were significantly heavier (n=37; mean±SD, 748.74±17.03 g) than those in poor condition (n=64; 619.24±124.08 g; P<0.01), and those in good condition had significantly heavier (left) flight muscle mass (n=40; 33.28±5.81 g) than those in poor condition (n=55; 22.97±4.76 g; P<0.01). Nutritional condition was also significantly related to age: adults were in poor condition (21/23; 91%) more often than expected by chance (χ^2=8.23, P<0.01). Only 59/104 immature Northern Fulmars (57%) were in poor nutritional condition.

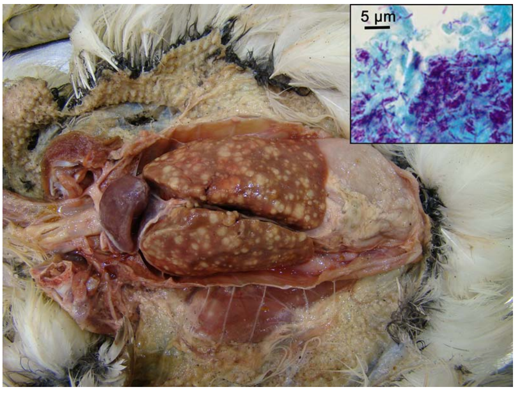

FIGURE 1. Systemic mycobacteriosis caused by *Mycobacterium avium* in an immature Northern Fulmar (*Fulmarus glacialis*). The liver contains many white masses of various sizes. Microscopically, these masses consist of granulomas containing many strongly acid-fast bacterial rods (inset).

Primary causes of death other than emaciation included trauma with or without secondary infection, primary infection (bacterial, fungal, or parasitic), neoplasia, and metabolic (Table 2). Notable secondary diagnoses were identified in 17/315 Northern Fulmars and Great and Sooty Shearwaters (5%; Table 2).

The most notable primary diagnosis was a single case of systemic mycobacteriosis (tuberculosis) in an immature Northern Fulmar, involving a large proportion of its hepatic and splenic parenchyma (Fig. 1). Macroscopically, the liver contained numerous firm, white masses of variable size (1–4 mm in diameter); several of which had necrotic centers. The spleen contained several similar white, albeit less discrete, nodules. Microscopically, a large proportion of the hepatic parenchyma had been replaced with granulomas, which the Ziehl-Neelsen stain showed to contain large numbers of strongly acid-fast bacterial rods (Fig. 1, inset). The spleen contained numerous large, but less discrete, aggregates of macrophages with intracellular acid-fast bacteria. A *Mycobacterium* sp. was isolated from the liver and identified as *Mycobacterium*

FIGURE 2. Very enlarged liver on the right, weighing 137 g, from an emaciated, immature Northern Fulmar (*Fulmarus glacialis*), suspected to be caused by myeloproliferative disease. For comparison, the liver on the left, weighing 15.4 g, is from an emaciated, adult Northern Fulmar. Both organs are very autolyzed, explaining their discoloration and the extensive fragmentation of the unusually soft, enlarged liver.

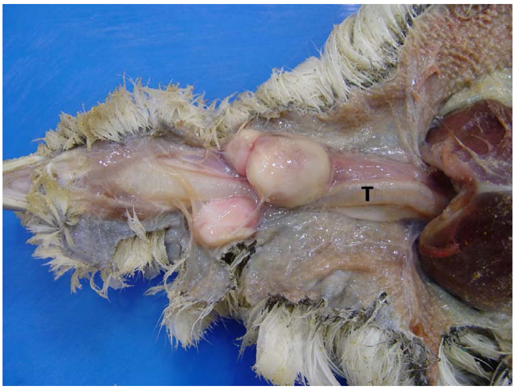

FIGURE 3. Emaciated, adult Northern Fulmar (*Fulmarus glacialis*). Three subcutaneous masses identified microscopically as round-cell tumors are in the midcervical region in close proximity to the trachea (T). These tumors are suspected of having compromised the bird's ability to breathe and/or swallow by compressing the trachea and esophagus, thus affecting its capacity to fly and forage.

avium, either subspecies *avium* or *silvaticum*, but could not be characterized further.

Neoplasms, which are generally rarely observed in free-living animals, were found in three Northern Fulmars. In one emaciated, immature bird, a very enlarged liver occupied most of the coelomic cavity (Fig. 2). Microscopically, hepatic sinusoids were distended, and hepatic cords were compressed by an infiltration of many mononuclear cells, which could not be characterized further because of severe autolysis. The tentative primary diagnosis was myeloproliferative disease. Two emaciated birds (one adult, one immature) had one or a few well-demarcated, subcutaneous masses on their heads or necks (Fig. 3) diagnosed as benign round-cell tumors. Microscopically, these masses were composed of spindle cells within a fine fibrovascular stroma, with, in one bird, some areas suggestive of cartilaginous metaplasia. Although considered benign, rather than malignant, tumors, their number or location was thought to have interfered with the bird's ability to forage in both cases.

Proventricular ulcers, with gross or microscopic evidence of close association with nematodes in three of four cases, were found in three Great Shearwaters and one Sooty Shearwater, all immature birds (Fig. 4). In two of the Great Shearwaters, the ulcer had perforated the proventricular wall, leading to a clinically significant coelomitis; those lesions were, thus, considered primary diagnoses in these two birds. In one case, the nematodes were tentatively identified as *Anisakis* spp.; in the other cases, the parasites were too autolyzed for identification.

FIGURE 4. Emaciated, immature Great Shearwater (*Ardenna gravis*). Focal chronic parasitic proventriculitis characterized by a deep central crater, within which, are anchored several nematodes tentatively identified as *Anisakis* spp. This lesion, interpreted as a secondary diagnosis, was not thought to have contributed to the bird's death.

DISCUSSION

Our study provided a unique opportunity to identify causes of death in some species of Procellariiformes, birds that are largely pelagic, and for which that information is very limited. Although the beached-bird survey program on Sable Island provides long-term data on numbers, seasonal occurrence, and oiling rates for these species (Lucas et al. 2012), to our knowledge, this is the first systematic pathologic investigation of beached seabirds from that island. The Northern Fulmar is an indicator species for the state of the North Sea ecosystem within the current Ecological Quality Objectives (van Franeker 2004; OSPAR Commission 2010); thus, it is beneficial to know common causes of mortality in this species.

Our study also provided an opportunity to explore some aspects of nutritional condition in Northern Fulmars. Birds in good nutritional condition had significantly heavier body mass and flight muscle mass than birds in poor condition. This supports the observation by others that the weight of flight muscles, the largest source of endogenous protein in birds, can be used as an objective measure of a bird's nutritional condition when its body mass is unreliable because of postmortem changes in the carcass (Swain 1992; Lindström et al. 2000). Emaciation was considered the primary cause of death in more than half of Northern Fulmars. The body mass of Northern Fulmars in good condition in the present study was well within the range of reported body masses in other studies (Mallory et al. 2020). Mean mass of birds in poor condition was 17% lower than that of birds in good condition, which is less than the proportion of body mass lost in birds of some other species dying of starvation, which can be 30–40% (Loesch and Kaminski 1989; Boismenu et al. 1992). However, that proportion is influenced by endogenous factors, such as body size (birds of smaller species being able to store lesser amounts of energy reserves), and exogenous factors, such as environmental conditions (particularly, inclement weather; Boismenu et al. 1992). Short-tailed Shearwaters (*Anous tenuirostris*) died from starvation at a body mass that was 23% or less of their normal weight (Baduini et al. 2001).

Emaciation as a primary cause of death is expected in a sample composed primarily of immature (70%), presumably less-experienced, birds (Barrett et al. 2007; Haman et al. 2013). Changes in food availability could also result in emaciation. However, it was not possible to evaluate that factor, considering the huge habitat range of Procellariiformes and their highly varied diet, from invertebrates to fish, including offal from fishing vessels (Carboneras et al. 2020a, b; Mallory et al. 2020). A lower proportion of Northern Fulmars was emaciated (56%) compared with that of Sooty (94%) or Great Shearwaters (88%). This disparity may be partially explained by species-specific movements and home ranges: Northern Fulmars are trans-Atlantic migrants, breeding in the Canadian Arctic or western Europe and wintering in the western North Atlantic (Huettmann and Diamond 2000; Mallory 2008), whereas both shearwater species are transequatorial migrants, breeding in the southern hemisphere (Huettmann and Diamond 2000). Longer migratory pathways for shearwaters may be associated with greater energetic stress and more-frequent emaciation.

Northern Fulmar stranding events are usually dominated by immature birds in poor nutritional condition (Donnelly-Greenan et al. 2014); however, 45/104 (43%) immature Northern Fulmars in this study were considered in good condition compared with just 2/23 (9%) adults. Those immature birds represented most (45/54, 83%) of the unexplained deaths among Northern Fulmars in good nutritional condition. Large numbers of Northern Fulmars, most of them nonbreeders, are reported in the Gulf of Maine and Georges Bank, in relative proximity to Sable Island, in fall, winter, and spring (Huettmann and Diamond 2000). In our study, most immature Northern Fulmars in good nutritional condition were collected in winter and spring. Birds caught in nets and drowned in fisheries bycatch would presumably be in good condition, and immature seabirds may be more susceptible to fisheries bycatch (Afán et al. 2019). Northern Fulmars are commonly caught in demersal longline fisheries on the Scotian Shelf in winter and spring (Hedd et al. 2016). However, we did not find lesions suggestive of drowning or capture in fishing nets as described by Hamel et al. (2009), although extensive autolysis of many of the carcasses may have obscured some of those lesions. We identified traumatic injury associated with a fishing hook in a single bird: an immature Northern Fulmar in good nutritional condition. The hook had penetrated through the proventriculus, but the portion protruding in the coelomic cavity had been sequestered by fibrous tissue and did not appear to have been clinically significant. Although carcasses of oiled birds were not submitted as part of our study, few oiled fulmars and shearwaters have been found on Sable Island since 2000, corresponding to a decline in the oiling rate of beached birds on the island (Lucas et al. 2012).

Another unexplained observation related to nutritional condition in this study was the discordance between the relative size of pectoralis muscles (poor) and fat reserves (good) of eight Northern Fulmars, most or all of them immature birds. This goes against the usual pattern of the use of endogenous energy reserves during fasting, when much of the fat tends to be used before muscle protein (Cherel et al. 1988; Sears 1988; Boismenu et al. 1992). This pattern can be reversed physiologically in species such as waterfowl and shorebirds in winter, during molting, or at staging areas during migration, when flying activity is reduced and when it is more adaptive to retain or gain fat as an endogenous source of insulation or energy at the expense of the mass of flight muscles (Evans and Smith 1975; Gaunt et al. 1990; Piersma and Lindström 1997). Such discordance between fat reserves and muscle mass can also occur pathologically in domestic animals suffering from chronic protein-losing renal or gastrointestinal disease, in which there is a loss of endogenous proteins through the affected organs, sparing fat reserves (Cianciolo and Mohr 2016; Uzal et al. 2016). However, none of these scenarios seems to apply to Northern Fulmars. For example, molting in this species in eastern Canadian waters peaks in July (Huettmann and Diamond 2000), whereas the eight birds with discordance between size of pectoralis muscles and abundance of fat reserves were collected in fall and spring.

Most primary diagnoses other than emaciation were of a traumatic or infectious (bacterial, fungal, or parasitic) nature, and most could not be specifically characterized because of the advanced state of decomposition of the carcasses. The case of severe systemic mycobacteriosis in an immature Northern Fulmar was highly unexpected. Although mycobacteriosis has been reported in free-living birds of many species (e.g., Converse 2007; Siebert et al. 2012), it has not previously been reported in Northern Fulmars. *Mycobacterium avium* subspecies *avium* has been isolated from lesions of tuberculosis in humans, usually restricted to the lungs and lymph nodes, but *M. avium* subspecies *silvaticum* has only been reported in birds (Cousins 2013). Northern Fulmars spend a limited amount of time on land, mostly at isolated breeding colonies. The presence of the bacterium in these colonies illustrates the widespread distribution of *M. avium* in the environment and is a reminder of the importance of proper education, biosafety measures, and personal hygiene when handling animals or their carcasses (Siebert et al. 2012).

The low prevalence of neoplasia encountered in Northern Fulmar (3/173, 1.7%) is similar to the results found by Effron et al. (1977), who necropsied 5,957 captive wild birds of various species and found neoplasia in 1.9%. The relatively long lifespan of Northern Fulmar, 30 years or longer (Mallory et al. 2020), could predispose them to tumor development, but two of the three affected birds were immature. Two of those tumors were morphologically similar and identified as benign round-cell (mesenchymal) tumors, suggesting a potential relationship between these two cases. For example, as discussed by Daoust et al. (1991), there are several precedents for a viral cause of mesenchymal tumors in domestic birds and in domestic and wild mammals, whereas Gaynor et al. (2015) described discrete, benign tumors composed mainly of mesenchymal cells associated with a papillomavirus on the left foot of a Northern Fulmar. The identity of the cells infiltrating the liver of an immature Northern Fulmar could not be determined, because of severe autolysis. Lymphoma would be a possible candidate because it has been reported to be the most common neoplasm encountered in a variety of avian species, usually having a multicentric distribution but confined to single organs in some cases (Effron et al. 1977; Nemeth et al. 2016; Smith et al. 2018).

Our four cases of proventricular ulcers, three in Great Shearwaters and one in a Sooty Shearwater, with at least three being associated with nematodes, expand the information provided by Nemeth et al. (2012), who described severe, fatal proventricular ulceration and perforation with secondary coelomitis caused by infection by *Anisakis* spp. in a Great Shearwater. Nemeth et al. (2012) also noted that the definitive hosts of *Anisakis* spp. are marine mammals and suggested that birds, especially immature birds, as aberrant hosts may be more susceptible to severe infection by these parasites. All four affected birds in our study were immature.

As in some other species (Acampora et al. 2014; Avery-Gomm et al. 2016; Krug et al. 2021), there was no relationship between either nutritional condition or body mass and mass of ingested plastic in Northern Fulmars. However, that does not preclude a potential negative effect of plastic ingestion on the nutritional condition of younger birds at the nest, as observed in fledglings of other Procellariiformes (Lavers et al. 2014). Although plastic ingestion is pervasive and increasing in seabirds globally (Wilcox et al. 2015) and direct mortality from marine debris ingestion in Procellariiformes is well documented (Roman et al. 2019), the sublethal impact of ingested plastic and its effect on body condition are still not well understood.

Studies of causes of mortality in beached birds are important for tracking trends among different species, especially those that are rarely seen near land. Because Sable Island is the only site in Atlantic Canada in which large numbers of beached birds, particularly Procellariiformes, are encountered regularly (Lucas et al. 2012), it is an important monitoring site for assessing threats to the health of these populations.

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