EFFECTS OF A VAGRANT ARCTIC FOX *ALOPEX LAGOPUS* ON AN ISOLATED NEWFOUNDLAND SEABIRD COMMUNITY

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ABSTRACT

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We report predation by an Arctic Fox *Alopex lagopus* on two seabird species, Atlantic Puffins *Fratercula arctica* and Leach's Storm Petrels *Hydrobates leucorhous*, nesting on Bakeapple Island, Little Fogo Islands, Newfoundland, Canada. This event took place in 2022, when a whole-island inspection revealed that fox, facilitated by over-ice invasion, killed at least 139 adult storm petrels and 8 puffin chicks. The fox also dug out 83 storm petrel and 4 puffin burrows. Breeding by seabirds on the island, which harbours some of the northernmost colonies in Newfoundland, was also largely disrupted; we documented extremely low egg and chick production values associated with the fox's presence and activity. We discuss the implications of such events for local seabird populations and the need for long-term monitoring to fully understand the impact of these predation events.

Key words: predator disturbance, Atlantic Puffin, Leach's Storm Petrel, Arctic Fox, breeding failure

INTRODUCTION

Over 95% of seabirds are colonial nesters, a proportion higher than most other avian groups (Lack 1968). In these aggregations, adults, eggs, and chicks inside burrows are less vulnerable to predators of any kind (other than by digging), while seabirds on the ground or on the ledges of vertical cliffs are exposed and extremely vulnerable to predation or disturbance. As a result, seabird colonies are usually located on isolated offshore islands or on very steep terrain (cliffs) that are free of terrestrial predators against whom most seabirds have no defense (Wittenberger & Hunt 1985). As such, the impact on seabird colonies can be devastating if and when predators gain access to these islands. One of the only defense mechanisms colony-nesters have against terrestrial or even aerial predators is burrow nesting. About a third of seabird species nest in burrows or natural cavities in the substrate (Del Hoyo *et al.* 1992). While this behaviour may offer some protection, especially against aerial predators, it is rather ineffective against those that can access the burrow, either directly or by digging out the contents. Various predator groups, mainly mammals such as canids (Burke *et al.* 2011), rodents (Cruz & Cruz 1996), mustelids (Harfenist *et al.* 2000), felines (Cooper & Fourie 1991), and pigs (Howell & Webb 1989, Ainley *et al.* 2020), can access the interior of burrows and predate on their inhabitants, although some bird species have also shown this capacity (Harper 2007). These predators may access seabird colonies by natural or anthropogenic means. When this happens, mass seabird mortality and poor breeding success can result (Towns *et al.* 2011). This may lead to steep population declines, sometimes creating the need for predator removal measures (e.g., poisoning or shooting; Towns *et al.* 2011 and references therein).

Arctic Foxes *Alopex lagopus* are carnivorous mammals that inhabit the Arctic and Subarctic (Hersteinsson & MacDonald 1992). Lemmings *Synaptomys* spp. are their main prey, but they consume a variety of terrestrial and marine food resources (Audet *et al.* 2002). They are highly territorial and select their home ranges based on the overall habitat, type of terrain, location of fluctuating resources, and developmental stage of their young (Grenier-Potvin *et al.* 2021). Despite this territoriality, in times of seasonal or annual resource scarcity, individuals may opportunistically leave their territories and/or switch to alternative prey sources (Wrigley & Hatch 1976, Tannerfeldt *et al.* 1994). This may be particularly likely to occur during the winter, as Arctic Foxes range and forage across larger areas in the winter compared to the summer (Rioux *et al.* 2017). The winter season also provides opportunities to use sea ice as part of their foraging grounds and as a platform for dispersal, resulting in journeys that can extend over thousands of kilometres (Fuglei & Tarroux 2019). As a result, they are one of the land predators that most commonly access isolated arctic and subarctic seabird colonies (Birkhead & Nettleship 1995, Lavers *et al.* 2009, Burke *et al.* 2011).

When Arctic Foxes, which prey on ground- and burrow-nesters, arrive at seabird colonies, they can cause high adult mortality and breeding failure (Birkhead & Nettleship 1995, Burke *et al.* 2011). This is not always the case, as previous evidence revealed the limited impact of resident Red Fox *Vulpes vulpes* predation on the Leach's Storm Petrel *Hydrobates leucorhous* population on Baccalieu Island in eastern Newfoundland, Canada, which hosts the world's largest colony for this seabird species (Sklepkovych 1986). Because these predation events are not often documented, we know little about the impact of Arctic Foxes and similar canid species on breeding seabird populations. Furthermore, in declining species, high seabird mortality due to naturally vagrant or introduced predator attacks can further threaten populations or species.

Little Fogo Islands (49°49′N, 054°07′W) is an archipelago situated ~10 km north of Fogo Island in northeastern Newfoundland, Canada. The archipelago is composed of over 50 islands of different sizes and substrates and serves as a breeding ground for a large seabird community, including Black Guillemots *Cepphus grylle*, American Herring Gulls *Larus smithsonianus*, Great Black-backed Gulls *Larus marinus*, Common Terns *Sterna hirundo*, Razorbills *Alca torda*, Common Murres *Uria aalge*, Atlantic Puffins *Fratercula arctica*, Black-legged Kittiwakes *Rissa tridactyla*, and Leach's Storm Petrels (Cairns *et al.* 1986, W.A. Montevecchi pers. obs.). The latter three species are listed by the IUCN as Vulnerable due to severe declines, although Atlantic Puffin classification is heavily driven by reductions in the European populations, while their numbers are growing in North America (BirdLife International 2023). Some of the Little Fogo Islands were traditionally used as fishing stages, but human presence in the area sharply declined following the Canadian Cod Moratorium in 1992, when all commercial offshore fishing for Atlantic Cod *Gadus morhua* was banned (Hutchings & Myers 1994). The climate of the archipelago is heavily influenced by the Labrador Current, which carries arctic water and sea ice southwards, especially during the spring (Petrie & Anderson 1983). Although there is no permanent presence of mammal predators on any of these small islands, arctic sea ice may serve as a platform for land mammals to reach the isolated archipelago. Here, we report the deleterious effects of an Arctic Fox on Bakeapple Island, a small island in the Little Fogo Islands archipelago that is home to two globally declining seabird species: Leach's Storm Petrels and Atlantic Puffins.

STUDY AREA AND METHODS

Bakeapple Island (49°48′56″N, 054°6′44″W) is part of the Little Fogo Islands archipelago. The seabird community nesting on this island includes Leach's Storm Petrels (storm petrels hereafter), Atlantic Puffins (puffins hereafter), and Razorbills. The island has two very distinct habitats: a central area covered primarily by ferns *Polypodiopsida* sp. where mainly storm petrels nest, and a grassy periphery dominated by dogwood *Cornus canadensis* (locally known as crackberry), bakeapple *Rubus chamaemorus*, and bare soil that primarily hosts puffin habitat. The nesting areas of these two seabird species exhibit no overlap (Fig. 1). However, in 2021, we detected two instances of an inhabited puffin burrow also containing a storm petrel egg and incubating adult in a side chamber.

The presence of a predator on the island was suspected after researchers discovered several puffin and storm petrel carcasses and a roaming trail during a routine visit on 29 June 2022.

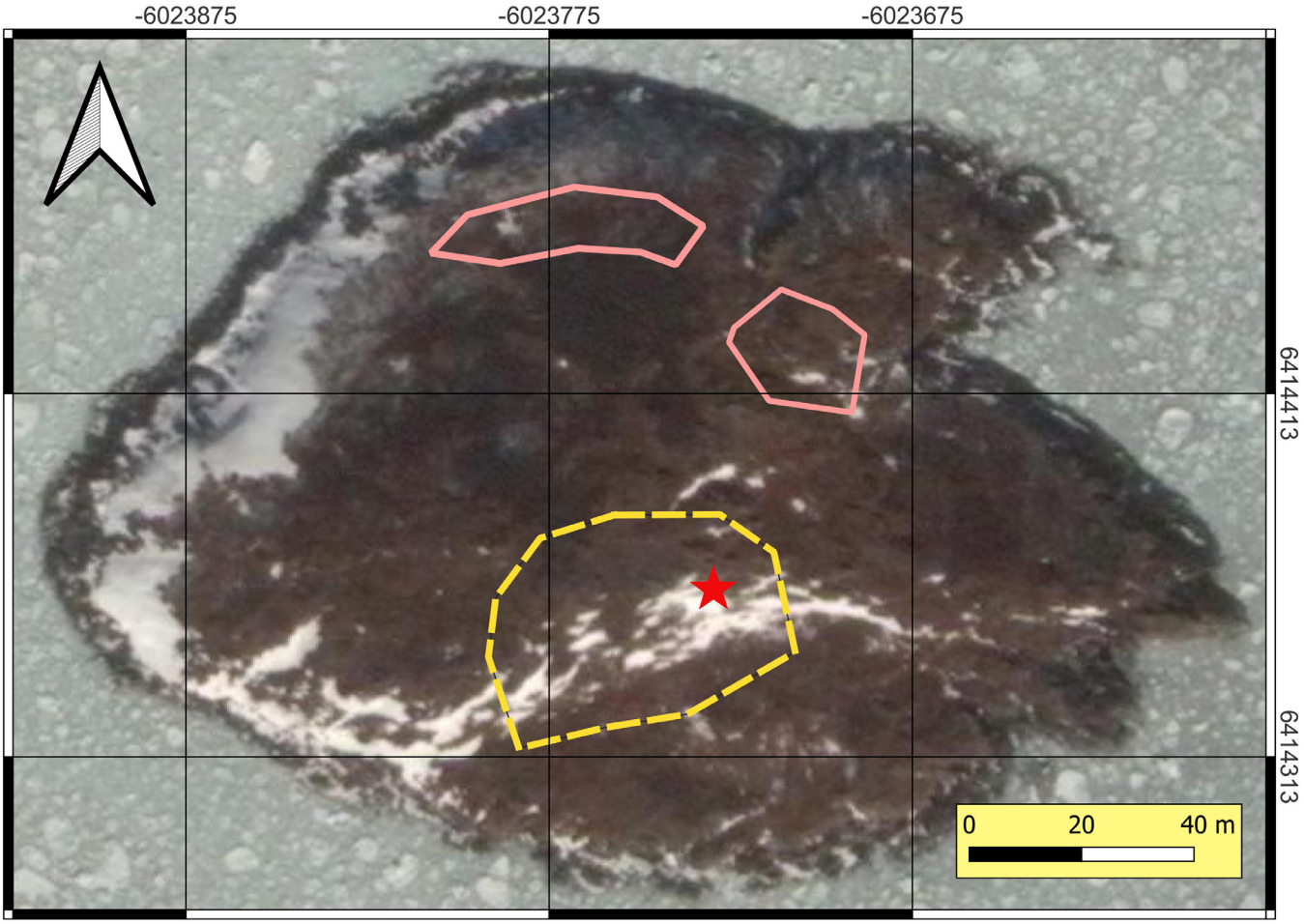

Fig. 1. Bakeapple Island in Newfoundland, Canada, with the main Atlantic Puffin *Fratercula arctica* (red continuous line) and Leach's Storm Petrel *Hydrobates leucorhous* (yellow dashed line) habitats indicated, together with the location of the Arctic Fox *Alopex lagopus* den (red star). Little to no burrowing activity was detected outside these areas. Photo credit: Google Maps 2023; sea ice was not present during our data collection visits.

Subsequent visual inspections with binoculars were conducted from a neighbouring island to confirm predator presence.

To assess the impact of the predator on the local breeding seabird population, a series of individual 3×3-m grids were randomly placed in areas deemed as storm petrel or puffin habitat (12 in puffin habitat and 20 in storm petrel habitat) on 12 August 2022. Surveyed grids were marked with sticks placed at the edges to prevent double counting. The contents of every burrow within the grids were assessed using a handheld burrowscope (EMS2021 Gopher Tortoise Camera System with infrared detection; Environmental Management Services, Canton, Georgia, USA). A burrow was defined as any excavation within seabird habitat longer than half an arm's reach and/or containing a seabird (i.e., breeding contents). Every burrow checked was then classified as occupied if it contained an adult, chick, or egg; or empty if it did not. Burrow density (burrows/m^2) was calculated as the number of burrows found within the grids, divided by the total surveyed area. Burrow occupancy was calculated as the proportion of burrows that were assessed as occupied (occupied burrows divided by the total number of burrows assessed). The total extent of both storm petrel and puffin habitat was calculated using a handheld GPS.

For puffins only, a subset of 50 burrows in a productivity plot that was set in 2021 were assessed two times during the 2022 breeding season, as part of a breeding success monitoring program (Zabala Belenguer 2023). The first visit was conducted midway through incubation, and the second was conducted 14 days before expected mean fledging date. The timing of these visits was based on previous information on puffin phenology (mean hatching date) specific to this island (Zabala Belenguer 2023). These two visits allowed for the calculation of puffin fledging success (chicks ready to fledge divided by the total number of burrows with eggs in the plot) and productivity (chicks ready to fledge divided by the total number of burrows in the plot). This sort of data was not available for storm petrels. All work conducted here was approved by the Memorial University of Newfoundland Animal Care Committee (21-03-PB) and a Canadian Wildlife Service permit (SC4061).

RESULTS

Storm petrel habitat extended over ~1690 m^2, with a burrow density of 2.54 burrows per m^2 (standard error or SE = 0.57) and a total estimate of 4275 burrows. Puffin habitat was split between two areas and in total covered 1067 m^2, with a burrow density of 1.78 burrows per m^2 (SE = 0.25) and an estimated total of 1896 burrows on the island (Fig. 1).

Evidence of the Arctic Fox (e.g., burrow diggings, presence of a trail on the ground) was detected during a visit to the colony on 28 June 2022. Visual identification of the animal was made during a visit on 27 July. The observation of small ears clearly distinguished this species from the dark morph of the Red Fox commonly found on the larger Fogo Island. The only fox den on the island was located within storm petrel habitat (Fig. 2). Due to safety concerns, we did not inspect the den's interior. Therefore, we cannot rule out the presence of more than one fox inside the den, although we visually confirmed only one from distant observations. The highest density of dug burrows and bird carcasses was found within a 9-m^2 grid around the entrance of the den (Fig. 2). During a survey conducted on 28 July, 87 adult storm petrel and five puffin chick carcasses were found within this area, but a lack of inspection tools for a safe assessment prevented a thorough check of the den's contents. During a survey conducted on 13 August, at least 139 adult storm petrel and eight puffin chick carcasses were found without signs of decomposition in the same den, evidence of semi-recent killings (Fig. 2). Because no carcasses were removed during the first inspection, we cannot exclude some degree of double counting. The surveys also revealed the presence of at least five puffin chicks that were still alive and able to move at the entrance of the den, evidence that the fox was transporting live chicks (Fig. 2). No adult puffin carcasses were found in the den or on the island.

Storm petrel burrows were the most affected by fox digging. During the island-wide survey on 13 August 2022, only four puffin burrows had external signs of digging (e.g., partially excavated entrances), compared to approximately 83 storm petrel burrows. Nevertheless, because some individual burrows could not be differentiated, it was very hard to quantify the exact number of storm petrel burrows that were excavated in the area adjacent to the den (Fig. 2). Since the average burrow density in storm petrel habitat was 2.54 burrows per m^2 and the den area was ~9 m^2, we estimate that at least 22 storm petrel burrows were fully dug out by the fox, while the remaining digging activity occurred outside this area.

Puffin occupancy (occupied burrows divided by total burrows found inside the grids) was 0.309 (SE = 0.105, n = 64 burrows), fledging success (chicks ready to fledge divided by eggs in the productivity plot) was 0.053 (SE = 0.032, n = 50 burrows), and productivity (chicks ready to fledge divided by total burrows in the productivity plot) was 0.02 (SE = 0.02, n = 50 burrows; Table 1). None of the empty burrows had signs of breeding (i.e., eggshells or dead chicks). Storm petrel occupancy was 0.25 (SE = 0.056, n = 216 burrows).

DISCUSSION

Here we report the natural occurrence of an Arctic Fox and its deleterious effects on the seabird population on Little Fogo Islands. The puffin population on Bakeapple Island showed a 40.1% reduction in occupancy and an 83.5% reduction in fledging success in 2022 when compared to the breeding parameters estimated in 2021 (Table 1), a year when no Arctic Fox was found in the colony (Zabala Belenguer 2023). This near-complete breeding failure due to the presence of an Arctic Fox is in concordance with a prior study reporting similar effects on Funk Island (Burke *et al.* 2011), a puffin colony that hosts about 2000 breeding pairs (Cairns *et al.* 1986). Furthermore, the observed breeding failure cannot be explained by alternate hypotheses such as food shortages. When compared to the neighbouring Puffin Island in 2022 (49°48′37″N, 054°06′40″W), puffin occupancy on Bakeapple Island was 40.7% lower, fledging success was 85.2% lower, and productivity was 82.4% lower (Table 1). It is thus highly likely that this breeding failure was solely explained by the fox activity.

There are no data to compare storm petrel breeding parameters in 2022 with other colonies in the archipelago, but storm petrels were likely similarly affected by the fox, as occupancy was 45% lower than the last estimates obtained in 2014 (Table 1). Furthermore, even though our estimate is conservative, the mortality associated with this predation event represents 1.6% of the total breeding population on Bakeapple Island in a single year. This increase in mortality is likely significant, as small changes in adult mortality (or at least those that are repetitive or long-term) are commonly associated

Fig. 2. A: One fully downy Atlantic Puffin *Fratercula arctica* chick found alive close to the entrance of the den on Bakeapple Island in Newfoundland, Canada—evidence of live transportation. At this stage, Atlantic Puffin chicks are not likely to leave the burrow—evidencing active digging. B: Remains of Leach's Storm Petrel *Hydrobates leucorhous* burrows and carcasses aggregated in the surroundings of the Arctic Fox *Alopex lagopus* den. C: Entrance to the Arctic Fox den. Several storm petrel adults and a puffin chick can be observed. Photo credit: Amy C. Wilson

TABLE 1
Summary of Atlantic Puffin *Fratercula arctica* and Leach's Storm Petrel *Hydrobates leucorhous* breeding effort for 2014, 2021, and 2022 at Bakeapple Island and Puffin Island in Newfoundland, Canada

Species	Colony	Year	Occupancy (SE)	Fledging success (SE)	Productivity (SE)
Puffins	Bakeapple Island	2014	0.576	NA[b]	NA
		2021	0.716 (0.05)	0.888 (0.03)	NA
		2022[a]	0.309 (0.105)	0.053 (0.032)	0.02 (0.02)
	Puffin Island	2014	0.558	NA	NA
		2021	0.681 (0.035)	0.900 (0.042)	NA
		2022	0.715 (0.057)	0.905 (0.058)	0.844 (0.05)
Storm petrels	Bakeapple Island	2014	0.701	NA	NA
		2022[a]	0.25 (0.057)	NA	NA

[a] Arctic Fox *Alopex lagopus* present in the colony
[b] NA not available

with population declines in seabirds (Croxall & Rothery 1993). The population on Bakeapple Island may be particularly susceptible, considering that Atlantic Canada populations are declining and have reduced adult survival rates of 81%–88% (Calvert *et al.* 2024), compared to North Pacific colonies that have stable numbers and high adult survival rates (97%, Rennie *et al.* 2020).

Ice-mediated introduction of land predators on Fogo Islands is not a rare phenomenon. For instance, Polar Bears *Ursus maritimus* are regularly sighted in the surrounding sea ice (e.g., 2018; Crockford 2019). Therefore, land mammal appearance and predation are likely part of the natural dynamics of this seabird community. Climate change is likely to affect these dynamics; regardless of the amount of sea ice that occurs in the future, it is predicted to drastically decrease in prevalence around Newfoundland and Labrador in the next decades (Han *et al.* 2019). Nevertheless, the fact that the presence of a single land predator can have such severe consequences in small colonies of seabirds, especially shrinking ones, is worthy of note. Although both species were heavily impacted by the presence of the fox, our observations suggest a greater impact on storm petrels. Two non-exclusive hypotheses may explain this differential impact. First, adult puffins are relatively large and strong seabirds, with powerful beaks and claws that can deter a fox attack, while adult storm petrels have no defensive weapons. Olfactory and visual cues may have aided the fox to target storm petrels and avoid puffins for this reason. Second, when at the colony, storm petrels are confined to the burrows; they leave only at night to forage in the waters around the island (Pollet *et al.* 2021). In contrast, puffins are known to regularly rest on the waters near the colony throughout the day (Harris & Wanless 2011). Arctic Foxes show no clear daily activity patterns, hunting both day and night (Fuglei *et al.* 2017, Poulin *et al.* 2021), leaving storm petrels more exposed to predation than puffins. Regardless of the mechanism, differences in puffin and storm petrel behaviour could result in differing long-term effects of predation on the two species. Due to high longevity in seabirds, adult survival has the largest effect of all seabird demographic parameters on population dynamics (Croxall & Rothery 1993). When adult mortality is not drastically affected, as observed in puffins, occasional low breeding success can be buffered by high success in subsequent years (Croxall & Rothery 1993). Therefore, the overall influence of predation events on the colony dynamics depends on its frequency and the degree of adult mortality associated with each event.

Leach's Storm Petrel and Atlantic Puffin populations are declining worldwide, although trends differ regionally for various reasons, most of which are human induced. Storm petrels are affected by marine pollution, fisheries bycatch, extreme weather events, prey shortages due to climate change, and light attraction (Pollet *et al.* 2023) whereas puffins are affected by the overfishing of prey species and prey shortages due to climate change (Cury *et al.* 2011, Hansen *et al.* 2021). However, this is not necessarily reflected in the local population trends of these two species. While there are no available data on storm petrel population trends for the Little Fogo Islands, the puffin population has increased from an estimated 150 breeding pairs in the 1970s (Cairns *et al.* 1986) to a minimum estimate of 16 401 pairs found in a partial survey in 2014 (S.I. Wilhelm unpubl. data). It has been proposed that Newfoundland puffin populations increased due to reduced bycatch in the gill-net fishery following the 1992 cod moratorium (Regular *et al.* 2013). However, the connection between the two events remains unclear, as there were signs of population increases before the ban (Wilhelm *et al.* 2015). An alternative explanation is that the first population estimate corresponds to early colonization stages of puffins on the archipelago. Puffins are known to visit several colonies in an area before choosing where to breed (Coulson 2016), and it is easy to use social attraction to colonize or re-colonize locations (Jones & Kress 2012). The presence of few breeding pairs in an area of plentiful suitable habitat could have attracted more individuals to Little Fogo Islands, similar to the re-colonization process of puffins on Eastern Egg Rock and Seal Island, Maine, USA (Kress 1997). Regardless of the reason for the observed population increase, there are signs of continued expansion to other islands within the archipelago that did not traditionally host an active Atlantic Puffin breeding colony. This is the case of St. Anne's Island (49°48′44″N, 054°07′06″W), which hosts 58 burrows with 48% observed fledging success at the time of writing (Zabala Belenguer 2023). Such population increases have not been observed for storm petrels in Newfoundland, which hosts some of the largest colonies of this species. These colonies have undergone significant declines (> 50%) over the past few decades (Wilhelm *et al.* 2015, Bond *et al.* 2023), representing a significant loss for the North Atlantic population (COSEWIC 2020). This general downwards trend is likely mirrored in Little Fogo Islands, but updated local data are necessary.

Our observations raise important questions about whether or how to manage predation events involving naturally occurring predators. Although predation alone by natural predators is unlikely contributing to the global decline of puffins and storm petrels, it may become a problem at local scales, particularly in the case of introduced predators. Conservation programs have been implemented in colonies of these and similar species (BirdLife International 2023), some of which have included predator-control measures. However, these actions respond to human-mediated predator introductions, while the event observed here is completely natural. Even so, there are records of active removal of native Eastern Coyote *Canis latrans* in response to Northern Gannet *Morus bassanus* predation risk near important colonies in Newfoundland (Montevecchi *et al.* 2019). Nonetheless, removal of naturally occurring predators can lead to controversy and ethical debates, both among the general public and between conservation professionals, and should be approached with caution (Brook *et al.* 2015). This is particularly true for a species like the Arctic Fox, which is predicted to face severe declines related to climate change effects on its habitat (Fuglei & Ims 2008). Therefore, we recommend long-term studies to understand the present and future frequency and effects of these predatory events on the Little Fogo Islands seabird community and to ultimately assess the need for implementation of predator-management programs.

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