Difference in diet and age structure of blue and white Arctic foxes (*Vulpes lagopus*) in the Disko Bay area, West Greenland

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Abstract

The stomach contents of 41 Arctic foxes (*Vulpes lagopus*) killed during winter and spring (December to June 1991–93) on Disko Island were examined. Fish, seabirds and marine invertebrates were found to be the most important winter food for Arctic foxes on Disko Island. Most fish remains in the stomachs were identified as capelin (*Mallotus villosus*), and cached fish appear to be important winter food for coastal foxes in the Disko Bay area. The stomachs of blue foxes contained more fish and marine invertebrates than those of white foxes, and stomachs of blue males contained more fish than those of blue females and white foxes of either sex. The age of 26 foxes was determined by X-rays and counting of annual lines in canine root cementum. Almost all the white foxes but less than a quarter of the blue foxes were in their first winter when harvested. The results of this study suggest that most of the white foxes were immigrants to Disko Bay while the blue foxes originated locally.

Arctic foxes (*Vulpes lagopus*) have a circumpolar distribution and are found in tundra habitats of mainland North America and Eurasia as well as on the major islands of the Arctic (Angerbjörn et al. 2004). There are two colour morphs: the blue and the white morph. The former is dark throughout the year but the latter is white in winter while in summer it is brown dorsally and light grey ventrally. The white morph comprises more than 99% of the population in most of the continental ranges of the species while blue foxes are more common in coastal habitats (Hersteinsson & Macdonald 1982; Vibe 1990). Hersteinsson (1989) found that the proportion of the white morph was positively correlated with snow cover in Iceland, suggesting that camouflage is an important function of coat colour. Both morphs are common along the west coast of Greenland while the white morph is in a great majority in north-eastern Greenland (Vibe 1990).

The diet of Arctic foxes in tundra regions of mainland North America and Eurasia as well as in north-eastern Greenland consists mostly of rodents, especially lemming (*Lemmus* and *Dicrostonyx* spp.) (e.g., Zetterberg 1945; Sdobnikov 1958; Pedersen 1959; Chesemore 1968; Macpherson 1969; Smits et al. 1989; Angerbjörn et al. 1999). The 3–5 year cyclical fluctuation in the population density of lemmings is reflected in cycles in Arctic fox populations (e.g., Angerbjörn et al. 1999; Tannerfeldt & Angerbjörn 1998; Gilg et al. 2006). In areas where lemmings are absent, e.g., in West Greenland, Iceland and Svalbard, ptarmigan (*Lagopus muta*), seabirds, geese, fish, shellfish and crustaceans as well as the carcasses of reindeer (*Rangifer tarandus*), sheep (*Ovis aries*) and seals appear to be the most important winter food (Hersteinsson 1984; Birks & Penford 1990; Prestrud 1992; Frafjord 1993; Hersteinsson & Macdonald 1996; Kapel 1999; Eide et al. 2005). In some coastal areas, e.g., in Alaska, Canada and north-east Greenland, foxes move far out on the sea ice to prey upon ringed seal (*Phoca hispida*) pups in their subnivean birth lairs (Smith 1976) or scavenge upon the remains of marine mammals killed by polar bears (*Ursus maritimus*) (Pedersen 1959; Underwood 1983; Andriashek et al. 1985; Hiruki & Stirling 1989).

Studying trading statistics, Braestrup (1941) and Vibe (1967) revealed large annual fluctuations in foxes harvested and thus presumably in the fox population size along the west coast of Greenland. Furthermore, the fluctuations could be largely explained by interannual variations in the number of white foxes harvested. They hypothesized that these fluctuations were linked to winter immigrations of white foxes from Canada, after summers with peaks in the lemming population in the Canadian tundra. Thus Braestrup (1941) termed white foxes "lemming foxes" and blue foxes "coast foxes". Vibe

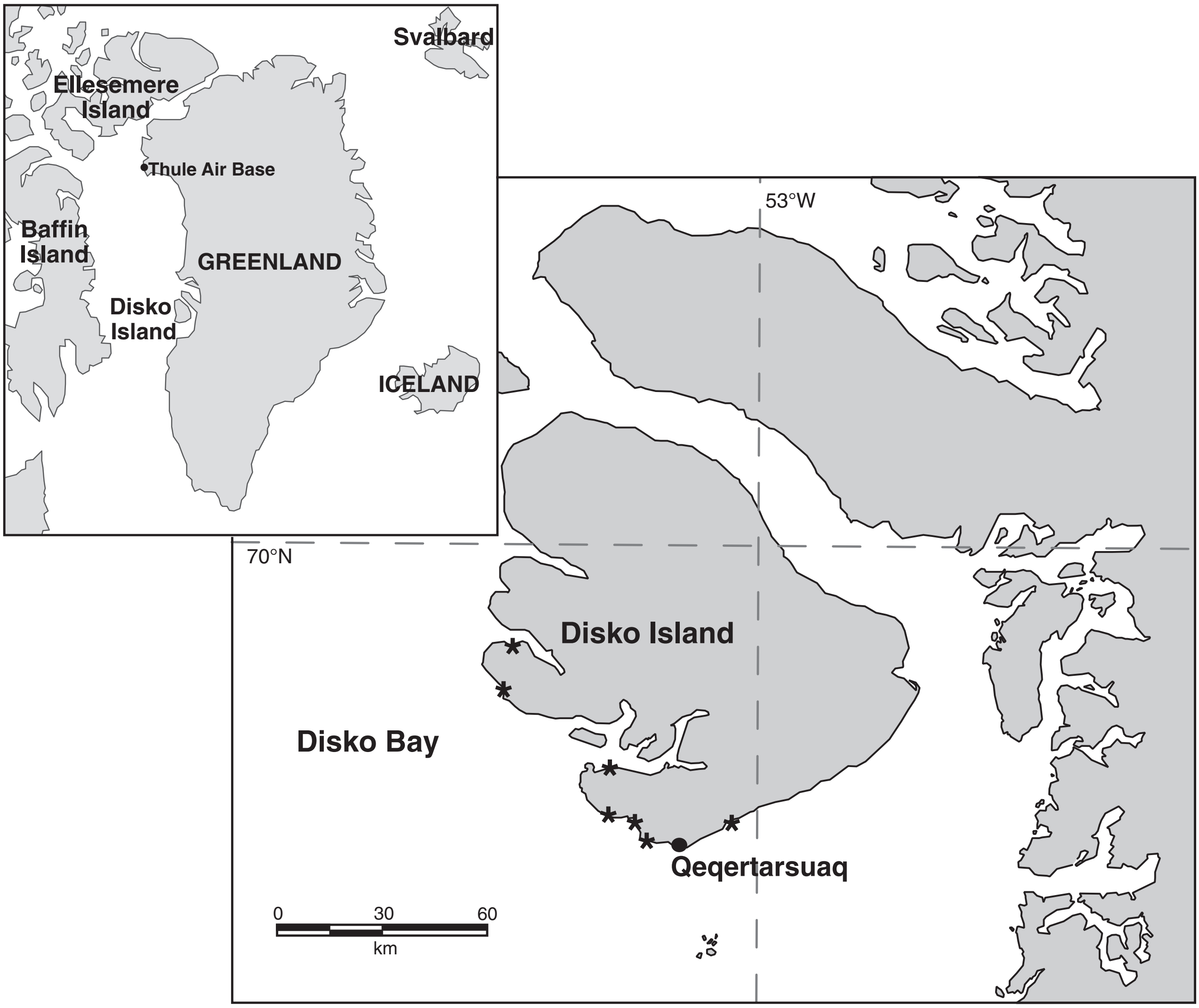

Fig. 1. Study area. Asterisks indicate locations where foxes were killed.

(1967) also found differences in the mean body weight of white and blue foxes in the same areas, supporting the hypothesis of a mixed population along the west coast of Greenland during winter.

The objectives of this study were to (1) describe the winter food and age structure of blue and white Arctic foxes in a coastal area of West Greenland where rodents and reindeer are absent, and (2) to discuss the hypothesis of Braestrup (1941) and Vibe (1967) in relation to food selection and age structure in the two colour morphs.

Study area

The study was carried out in Disko Bay, West Greenland. Foxes were collected on Disko Island which is 8575 km^2 and located at 68–72° N, 51–55° W (Fig. 1). The vegetation is Low Arctic and the mean monthly winter temperatures ranged between –2.4°C (October) and –25.0°C (February) during the study period (weather measurements taken at Arctic Station, Qeqertarsuaq, 1991–92). Snow is the dominant precipitation from late September to late May and sea ice covers Disko Bay from mid-January to mid-April.

Disko Bay is a staging area for numerous migrating birds (Salomonsen 1990; Frimer 1991) and a moulting area for common eider (*Somateria mollissima*) and large numbers of king eider (*S. spectabilis*) (Frimer 1993). Occasionally, and especially in association with heavy storms, seabirds such as king eider, black guillemot (*Cepphus grille*) and little auk (*Alle alle*) may congregate in open patches of water. The only terrestrial animals foxes can rely on for food during winter are rock ptarmigan and Arctic hare (*Lepus arcticus*).

In the period with open water, marine invertebrates, fish, carcasses of marine birds and occasionally corpses of marine mammals are washed ashore. On rocky coasts, fish caught in shallow rock pools at low tide are an important food source for the foxes (Nielsen 1991). During the ice-covered period bearded seal (*Erignathus barbatus*) and ringed seal breed in the area. More details on the animal life of the area are given in Salomonsen (1990), Frimer & Nielsen (1990) and Frimer (1991, 1992, 1993).

Materials and methods

A total of 41 Arctic fox carcasses were collected from local hunters on Disko Island during two winter seasons, 1991–92 and 1992–93, from 1 December to 30 June. Foxes had either been shot or killed instantly by trapping. The hunters provided information on the locality and date of capture. Sex and colour morph was recorded and the stomachs were removed and deep-frozen until analysis. The stomach contents were weighed and subsequently washed through a 250 μ wire sieve. Stomach contents were analysed and identified according to Day (1966) and Debrot *et al.* (1982) and our own reference collection. Prey remains were identified to the lowest taxon possible and separated into ten main food categories: mammals, sea birds, terrestrial birds, eggshells, fish, marine invertebrates, seaweed, terrestrial plant material, garbage and other or unidentified items. As the food items in the stomachs were too mixed together to separate adequately, the volume of each category was visually estimated to the nearest 5% of the total stomach content. The weight of a food category was calculated by multiplying the estimated volume of the category by the total weight of the stomach content.

The estimated weight of the main food categories in the stomachs were compared in relation to sex, age, colour morph and winter period ("sea ice period": 15 January to 14 April; "open water period": 15 April to 14 January) using Mann Whitney and Kruskal-Wallis one-way analysis of variance (PAST; Hammer et al. 2001). As the amount of plant material accidentally eaten with other food items was not expected to depend on the amount of other particular items eaten, Fisher's exact test (Chi-square 2*2 test of independence) was performed. Difference in the proportion of blue and white foxes in their first winter (hereafter "young foxes") was examined using Fisher's exact test and differences in the stomach contents of young blue and white foxes was examined using the Mann Whitney test.

The ages of a subsample of 18 blue and 8 white foxes were determined by X-ray photography and counting annual cementum lines in the roots of canine teeth (Grue & Jensen 1976; Allen & Melfi 1985).

Results

Of the Arctic foxes collected, 28 (16 females and 12 males) were blue and 13 (6 females and 7 males) were white; 31 foxes were from the sea ice period and 10 foxes from the period with open water. No significant difference was found in the food of foxes from the two winter seasons (sea ice and open water), or the two winter periods. Fish, sea birds, marine invertebrates and plant material were the most frequent food categories found, and combined these made up more than 80% of the total weight of the stomach contents (Fig. 2). Not all remains could be identified due to progressive digestion. Fish could be identified as capelin (*Mallotus villosus*; n = 7) and father-lasher (*Myoxocephalus* sp.; n = 1). Seabird remains were identified as anatids, Anseriformes (n = 10), alcids, Alcidae (n = 7), fulmar (*Fulmar glacialis*) (n = 3) and seagulls Laridae (n = 1). Marine invertebrates were mainly identified as sea urchins (*Strongylocentrotus droebachiensis*; n = 7), stone crabs (*Hyas araneus* or *H. coarctatus*; n = 6), *Gammarus* spp. (n = 2) and blue mussels (*Mytilus edulis*; n = 3). Seal (Phocidae) was found in three stomachs and terrestrial birds (Passeriformes) were found in two stomachs. Plant materials (leaves, twigs, mosses and lichens) and seaweeds were frequently found in the stomachs, but occurred only in small amounts and were therefore considered as secondary food, i.e., items ingested accidentally or with other prey. The mean weight of the stomach contents was 35.21 g (±48.15 sd). More than half of the stomachs contained less than 50 g of food and four stomachs were empty. A test of independence (Fisher's exact test) revealed a significant relationship between the occurrence of fish and terrestrial plant material ($\chi^2 = 10.798$, $p = 0.001$, df = 1).

Stomachs of blue foxes contained more fish and marine invertebrates than stomachs of white foxes ($U_b = 110.5$, $p = 0.046$, $n_{\text{white foxes}} = 13$, $n_{\text{blue foxes}} = 28$). Main food categories tested separately showed no differences in frequency of occurrence in the stomachs of the two morphs though this may be due to small sample size. Stomachs of blue males contained significantly ($H = 8.111$, $p = 0.043$, df = 3) more fish than those of the blue females, white males and white females. However, when separating by age (young vs. older) no significant difference was found between the sexes of either morph.

There was a significant difference (Fisher's exact test: $\chi^2 = 9.669$, $p = 0.003$, d.f. = 1) between blue and white foxes in the proportion of young foxes. While the oldest white fox was in its third winter, half of the 18 blue foxes were over four years old (Fig. 3). The stomachs of

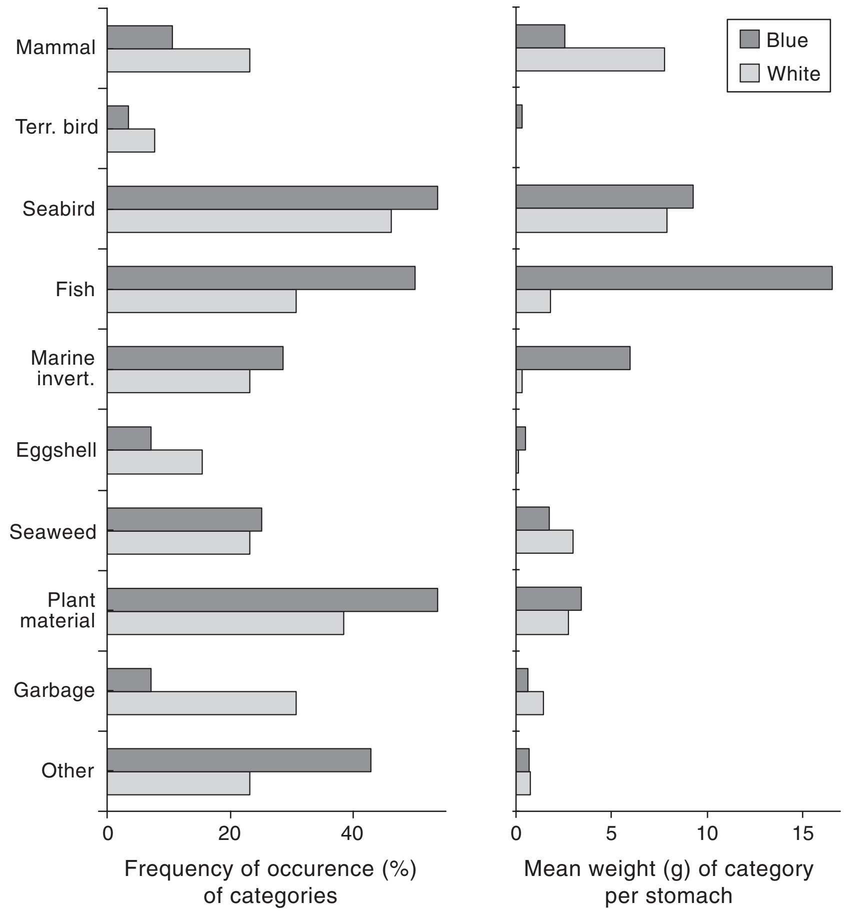

Fig. 2. Main food types in stomachs of blue and white foxes shown as both frequency of occurrence and as the mean weight (g) of the food item per stomach.

young blue foxes contained significantly more food (mean $_{\text{blue foxes}}$ = 80.1 g, sd = 37.6; mean $_{\text{white foxes}}$ = 23.8 g sd = 32.9, n $_{\text{blue foxes}}$ = 4) (Ub = 2, p = 0.03) in general and significantly more fish (mean $_{\text{blue foxes}}$ = 43.7 g, sd = 31.5; mean $_{\text{white foxes}}$ = 2.4 g sd = 6.0, n $_{\text{white foxes}}$ = 7) (Ub = 1, p = 0.02) than the stomachs of young white foxes. The stomachs of young blue foxes also contained more marine invertebrates and plant material than those of young white foxes.

Discussion

Due to differences in the digestibility of food items (Nielsen 1994) the exact amount of each prey species can not be revealed by stomach analysis, although the method is probably more reliable than scat analysis. As frequency of occurrence tends to overestimate the importance of traces of highly digested food items found in the stomachs as well as small items eaten accidentally with other food, the estimated weight of the food items was considered be the most accurate measure of the importance of the different items.

Fish, seabirds and marine invertebrates was found to be the most important food for the foxes on Disko Island during the winter. Arctic hares and rock ptarmigans appear to be of minor importance as food in this area at this time of year. Kapel (1999) also found a high frequency of occurrence of fish, birds (not identified) and marine invertebrates, but few Arctic hares in the stomachs of Arctic foxes in other areas of Greenland, e.g., in coastal areas of northern, southern and eastern Greenland. Fish has been recorded in the food of Arctic foxes outside West Greenland, e.g., in Siberia (Sdobnikov 1958), northern Alaska (Chesemore 1968), St. Lawrence Island, Alaska (Stephenson 1970), Canada (Macpherson 1969), Svalbard (Frafjord 1993) and Iceland (Hersteinsson 1984; Hersteinsson & Macdonald 1996), but in most cases in small amounts only. On islands in the Bering Sea, e.g., the Aleutian Islands (West 1987) and Copper Island (Barabash-Nikiforov 1938), fish has been found to make up as much as 15% of the diet. Although analyses of stomach contents to some extent underestimate highly digestible food items such as fish, it provides more precise information about the diet than scat analysis (Nielsen

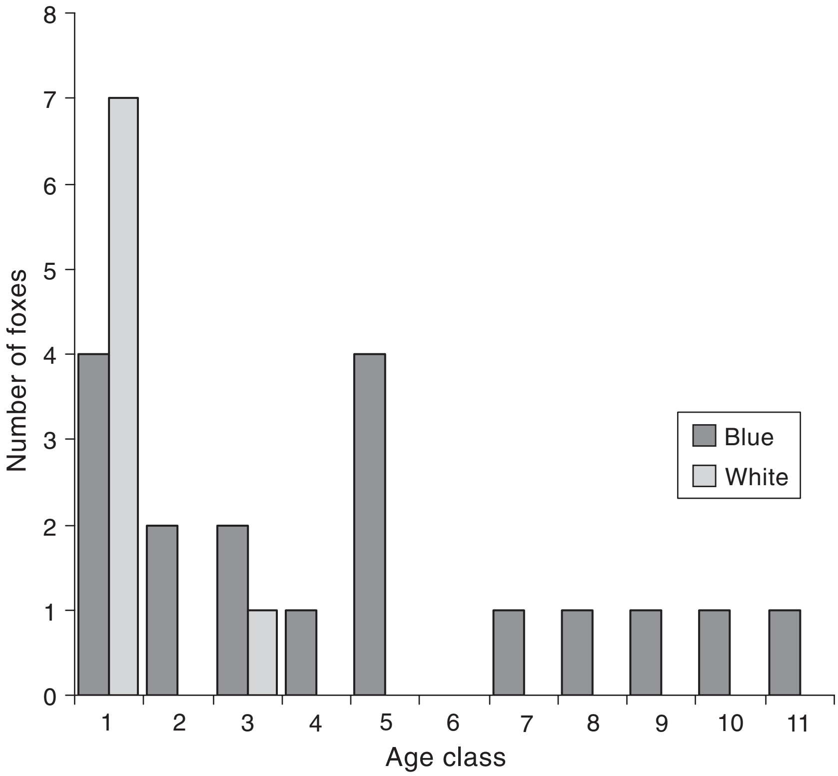

Fig. 3. Age structure of blue and white foxes harvested on Disko Island during the study. Age class 1 comprises foxes in their first winter, age class 2 is foxes in their second winter, and so on.

1994), and it is less time-consuming than direct observations of Arctic foxes searching for food in the field. Most previous studies of the food habits of Arctic foxes have been made by analysing scat contents and the small amount of fish recorded may be partly due to the use of this method. During summer foxes have been observed to catch live father-lashers (*Myoxocephalus* sp.), banded gunnels (*Pholis fasciatus*) and lumpsuckers (*Cyclopterus lumpus*) in rock pools in the Disko Bay area (Nielsen 1991). Father-lashers, both *Myoxocephalus scorpius* and *M. scorpioides*, are common in the intertidal zone at the Greenlandic coast (Muus 1990). Fish may also be found stranded on the beach during the open water period. Spawning capelins have a tendency to strand on the beaches of Disko Island in huge numbers from late June to mid-July.

Food caching is common among foxes (Macdonald 1976) and this behaviour has been described for Arctic foxes in Greenland (Gibson 1922; Freuchen 1935; Pedersen 1959; Nielsen 1991) and Canada (Stephenson 1970; Careau et al. 2007). By definition, food caching will only directly benefit a fox that stays in the area for long enough to utilize the cache at a later date but caches may also increase its fitness indirectly by being available to its offspring. The relationship between the occurrence of fish and terrestrial plant material (pieces of twigs, leaves, moss and lichens) in the stomachs leads to the conclusion that most of the fish consumed had been cached by the foxes. Furthermore, the capelin found in fox stomachs in this study must have been from the previous summer and almost certainly retrieved from caches. Vibe (1967) found that yearly winter catches of foxes correlated with the catch of capelin from the previous summer. The finding of an eggshell in the stomach of a fox killed 16 January 1993 also indicates food caching.

The fact that the stomachs of young blue foxes contained more food, mostly due to a greater amount of fish, than the stomachs of young white foxes suggests that the blue foxes may be more adept at finding this source of food than their white counterparts. Thus it is possible that young foxes originating in the area might have had time to map out some of the available fish caches from the previous summer which would give them a clear advantage over immigrants. It is not clear why the stomach contents of blue males contained more fish than the stomach contents of blue females.

Dalén et al. (2005) found that the genetic structure of Arctic foxes suggested more gene flow between (a) widely spaced Arctic fox populations from lemming areas than between (b) such populations and populations in coastal habitats without lemmings and (c) between coastal habitats without lemmings. Geffen et al. (2007) showed that a combination of geographical distance and the presence of sea ice explained 40–60% of the genetic distance between Arctic fox populations. However, the results of the study reported here suggest that migration does not necessarily result in much gene flow. The different age structure of blue and white foxes in the catch at Disko Island suggests that the white foxes are mostly (7 of 8 foxes) dispersing young foxes while a minority of the blue foxes are in their first winter (4 of 18 foxes). Thus it is likely that the majority of the blue foxes have stayed in the area for a year or more and that very few white foxes bred on Disko Island during the years of study. This begs the questions where the white foxes originated and why white foxes appear not to have settled and bred on Disko Island.

Our results support the hypothesis of Braestrup (1941) and Vibe (1967) that blue and white Arctic foxes are adapted to different habitats and that the majority of white foxes harvested in winter in West Greenland originate from elsewhere. Braestrup and Vibe, based mostly on interannual fluctuations in the number of white foxes harvested, suggested that the white foxes arrived from Canada, after years with lemming population peaks. The shortest straight-line distance between Disko Island and Canada is a little less than 500 km to Baffin Island while the distance to the southernmost point of Ellesmere Island is about 1000 km, both within known dispersal distances in Canada (Eberhardt & Hansson 1978; Garrot & Eberhardt 1987). Unfortunately, we have been unable to locate data on the status of lemming or Arctic fox populations in the eastern Arctic Canada during the period of interest. However, it has to be borne in mind that Birks & Penford (1990), Nielsen (1994), Kapel (1999) and Dalerum & Angerbjörn (2000) found significant differences between the food habits of Arctic foxes in inland and coastal areas of Greenland. The fluctuations in the proportion of white foxes killed in coastal habitats of western Greenland during the winter may therefore be due to fluctuations in food availability in inland areas of western Greenland from which foxes might migrate to the coast in some years. In any case, the fate of immigrants to coastal habitats is unknown but our results suggest that they may have problems adapting to or finding the food available to them there.

In a study of the genetics of Arctic foxes in Greenland, Meinke et al. (2001) revealed no differentiation between the two colour morphs and concluded that the white and the blue morph shared the same habitat. That study did not cover areas of north-west Greenland (only one white fox was included from Thule Air Base) and many of the foxes were sampled in the breeding season from May to August (at least 27 of 75).

Our interpretation of the data is that most white foxes caught in winter on Disko Island are immigrants to the area. At least three non-mutually exclusive explanations are conceivable for the observed pattern of food habits and age structure of blue and white foxes there: (1) the white foxes return to their area of origin to breed; (2) the fitness of white foxes is low in habitats where there are no lemmings and they are therefore out-competed by local foxes and suffer high mortality; and (3) the white foxes are only passing through Disko Island, without trying to settle there, as they search for an area with lemmings, a result of habitat training (*sensu* Stamps 2001). Further investigations are needed on this subject, and we suggest that many remaining questions can be resolved by detailed genetic comparisons of foxes harvested in West Greenland during winter and breeding foxes in summer.

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