Environmental Change in ice-free Greenland: a Review

Umhvørvisbroyting í tí ísfría Grønlandi: eitt yvirlit

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Úrtak

Lítil kunnleiki er um ikki-havbiotur fyri seinastu avglasialisering, men fyri 2,5 milliónum árum síðan var í Norðurgrønlandi skógartundra við smáum trøum, og tað bendir á ein miðaltemperatur um summarið, ið var 7-8 °C hægri enn í dag. Í seinasta millumístíðarskeiði, fyri um 115-130.000 árum síðan, var kjarr- og lynggróður í Eysturgrønlandi, ið bendir á ein miðaltemperatur um summarið, sum er um 5 °C hægri enn í dag. Tá ið temperatururin var lægstur seinastu ístíð, var tað so kalt, at bert sera harðførar plantur og sera harðbalin dýr komu undan við lívinum í Grønlandi. Eftir seinastu avglasialisering, sum byrjaði fyri 11.600 árum síðan, fór ein slóðbrótandi gróður uttan viðarplantur at breiða seg út yvir landið. Temperatururin var helst hægstur longu tíðliga í tí eftirglasiala tíðarskeiðnum, men nógvar plantur, nógv dýr, og menniskjað, komu til Grønlands, eftir at temperatururin var farin at lækka.

Abstract

Little is known about non-marine biotas prior to the last deglaciation, but at 2.5 million years ago, forest-tundra with small trees indicating a mean summer temperature 7-8°C higher than today existed in North Greenland. During the last interglacial stage, at *c.* 115-130,000 years ago, scrub and healt vegetation in East Greenland indicates a mean summer temperature *c.* 5°C higher than today. During the temperature minimum of the last ice age, temperatures were so low that only very hard plants and animals could survive in Greenland. After the last deglaciation that began at 11,500 years ago, a pioneer vegetation without woody plants began to cover the land. Temperatures probably already peaked in the early part of the postglacial, but many plants and animals, including man, immigrated to Greenland after temperatures had begun to decline.

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The ice-free parts of Greenland cover around 380,000 km^2, corresponding to 20% of the total area of the island. Most parts are mountainous, but major areas of lowlands are found in some regions. Small patches of subarctic birch woodland are found in the far south where the mean July temperature exceeds 10°C. In the far north, polar desert with no woody plants, and a mean July temperature of 0-2°C, is found in coastal areas. Between these extremes, scrub and healt vegetation is widespread in the lowlands.

This small review focuses on non-marine biotic changes during the Quarternary. The main proxies for reconstructions of regional terrestrial biotic changes are pollen and plant macrofossil analyses, which have been applied in many parts of Greenland. In addition, information is available from insects, other invertebrates, and vertebrates. Palaeolimnological studies have been performed using macrofossils, diatoms and Cladocera. Palaeo-environmental studies of near-shore marine waters is primarily based on molluscs.

At the beginning of the Quarternary, a mixture of arctic and boreal plants comprising *Dryas octopetala, Oxyria digyna,*

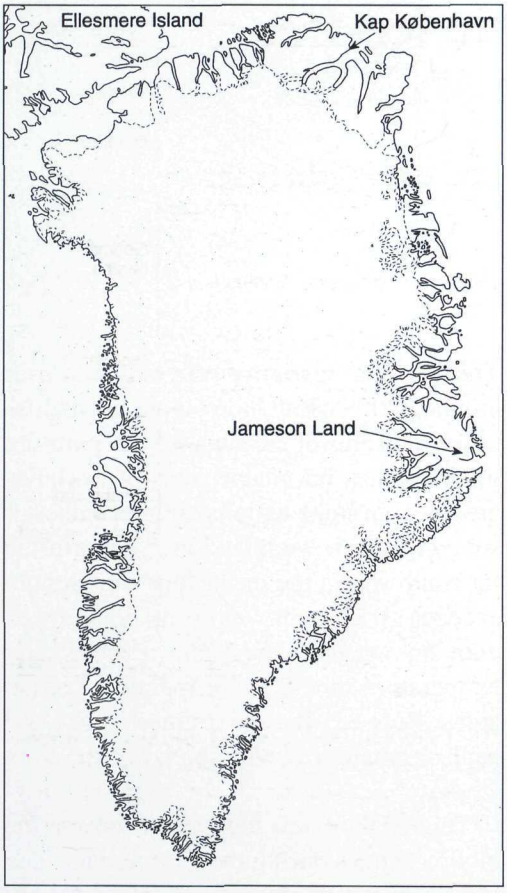

Fig. 1. Map of Greenland ant northernmost Canada showing the location of place names mentioned in the text.
Mynd 1. Kort av Grønlandi og norðasta parti av Kanada, sum vísir summi staðanøvn, ið eru nevnd í tekstinum.

Larix groenlandii and *Picea mariana* grew near Kap København in eastern North Greenland (fig. 1). The flora that is dated to 2-2.5 million years, indicates a forrest-tundra vegetation and an oceanic, subarctic climate, with a mean summer temperature around 10-11°C (Bennike, 1990). The Kap København Formation also contains a rich and diverse insect fauna, with at least 210 species of beetles and four species of ants (Böcher, 1995). Att present, no ants live in Greenland, and the beetle fauna only comprises *c.* 33 species.

A number of Middle Pleistocene marine interglacial occurrences are known from West Greenland, but the dating and correlation of these sites are uncertain (Kelly, 1986; Bennike *et al.*, 1994), and they do not provide evidence about non-marine environments. In contrast, several interglacial sites have been firmly dated to the last interglacial stage by numerous luminescence age determinations, and these sites provide a detailed picture of terrestrial biotas (Bennike and Böcher, 1992; 1994). Floras and faunas from Jameson Land comprise many sourthern extralimital species, such as tree birch and alder, and the mean summer temperature was *c.* 5°C higher than today (Bennike and Böcher, 1994).

During the last glacial stage rather large unglaciated areas were present in East and North Greenland (e.g. Kelly and Bennike, 1992), but according to palaeotemperature reconstructions from the Greenland ice sheet, temperatures were much lower during the temperature minimum of the last ice age than earlier assumed (Dahl-Jensen *et al.*, 1998). It seems inescapable that very few, if any, vascular plants or vertebrates would be able to survive such exremely harsh conditions.

At 11,500 cal. BP (calibrated years before present) the first small lowland areas in

southwest Greenland had been deglaciated, whereas in North and East Greenland larger ice-free areas were present. A pioneer vegetation with bryophytes and herbs, but without woody plants, began to cover the land (Bennike *et al.*, in press). Some hardy species may already have immigrated to Greenland towards the end of the last glacial stage, although no floras or faunas have so far been conclusively assigned to this time interval. The first millennia of the Holocene saw rapid deglaciation due to warm climates; and rapid emergence due to crustal rebound. By 10 cal. ka BP the deglaciated fringe of land in SW Greenland had grown, and the first dwarf shrubs, such as *Empetrum nigrum* had immigrated to Greenland. In the littoral zone in the West Greenland waters *Mytilus edulis* was extending its range. At around 8 cal. ka BP *Betula nana* arrived in East Greenland where it expanded rapidly (Funder, 1978). Some plants and animals extended their geographical ranges further north than at present. The young, »raw« lakes were rich in ions and nutrients and housed a rich flora of macrolimnophytes ((Fredskild, 1992). A similar situation is seen in basins that became isolated from the sea following emergence of the land (Bennike, 1995).

By about 7 cal ka BP the ice sheet margin was situated near its present position. The dwarf shrubs *Salix arctica* and *Cassiope tetragona* colonised East Greenland from the north (Funder, 1978). The Inland Ice reached it's minimum size at 5.5 cal. ka BP, and in some areas the ice margin may have been situated as much as 50 km behind its present location (Weidick *et al.*, 1990). Most local ice caps and ice shelves had probably completely disappeared in the Mid Holocene.

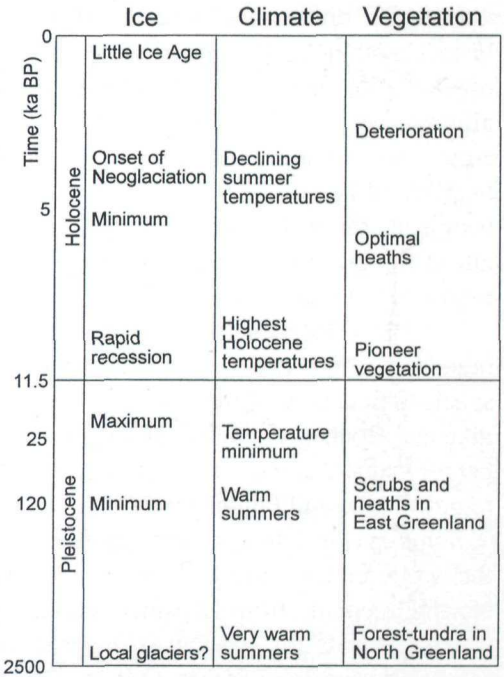

Fig. 2. *Diagram showing a brief summary of environmental changes in the ice-free parts of Greenland.*
Mynd 2. Strikumynd, sum vísir eitt stutt yvirlit yvir umhvørvisbroytingar í tí ísfría partinum av Grønlandi.

After 5.5 cal. ka BP declining pollen deposition rates are registered in East Greenland, and *Mytilus edulis* disappeared (Funder, 1978), but around 4 ka BP some beetle species still occurred further north than today in West Greenland (Böcher and Fredskild, 1993). Oligotrophication of lakes led to local extinctions of water plants. *Alnus crispa* and *Betula pubescens* arrived in West Greenland by 4.2 cal. ka BP (Fredskild, 1985).

Little information is available about the history of the Greenland vertebrates (Bennike, 1997), but the early-mid Holocene non-marine fauna included reindeer, wolf, arctic hare, Lapland longspur and stickleback. By the time of the arrival of the first people at around 4.3 cal. ka BP, most, if not all, of the present-day vertebrates had immigrated to Greenland.

The early Holocene non-marine invertebrate fauna included seven named insesct species (Böcher and Bennike, 1996; Bennike and Böcher, unpublished) and a number of named crustaceans and bryozoans (e.g. Bennike and Funder, 1997).

Some species, such as the reindeer and the wolf, could simply walk to western North Greenland from Ellesmere Island in Canada, across the sea that is covered by fast ice during the winther. Other species, such as most birds and butterflies, could fly to Greenland. The wind could carry spiders, small insects, spores and small seeds to Greenland. Sea currents, aided by drifting logs, sea ice, ice bergs and ice islands, could carry some plants and animals to Greenland. However, birds and storms, perhaps in combination, are considered underappreciated dispersal vectors for vascular plants and other organisms. Long distance chance dispersal of species during the Holocene rather than survival is also compatible with the rarity of endemic species on Greenland.

The onset of the Neoglaciation has been dated to around 4.5 cal. ka BP (Weidick *et al.*, 1996; Bennike, unpublished). Outlet glaciers from the Inland Ice expanded, local ice caps formed, and ice shelves developed in North and Northeast Greenland. In Northeast Greenland some straits and fjords became blocked, so that corpses of marine mammals and drift wood could no longer wash up on the shores. At the same time, the relative sea level rose a few metres (e.g. Bennike, 1987). Whereas the »Little Ice Age« led to a marked growth of the Greenland Ice Sheet and local glaciers, any effects on the terristrial biotas have been difficult to document, but it may have led to wetter conditions (Bennike, 1992).

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