Dorete

– her book

DORETE

– her book

– being a tribute to Dorete Bloch and to Faroese nature

Editors: S-A Bengtson, P. Buckland,
P. H. Enckell and A. M. Fosaa
Illustrations: Bárður Jákupsson

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Preface

Dorete Bloch

Dorete is known to most of us for her combination of tremendous enthusiasm for all aspects of the natural history of the Faroes with a level of hospitality that few could hope to achieve. She started her academic career at the Kalø Biological Station in Denmark, working on hares and the Mute Swan. Arriving in the Faroes in 1974, she began work at the University of the Faroe Islands. In 1980, she became head of the Zoological Department of the Faroese Museum of Natural History and she has been its Director from 1995 to 2009. She defended her PhD thesis on the long-finned pilot whale at the University of Lund in 1994. She has been representative for the Faroes of the Scientific Commission of NAMMCO (North Atlantic Marine Mammal Commission), a new Nordic Arctic research programme, and an expert in the North Atlantic Research Programme.

She is also the Managing Editor of Frodskaparrit (the scientific journal of the Faroese Scientific Academy), she is a member of the Central Nature Conservation Board in the Faroes, Bird Consultant at Vágar Airport, a member of the Faroese Scientific Ethics Committe. She has lectured at the University of the Faroes for many years and was appointed Professor of Zoology there in 2001.

Her current research includes a study of the Faroese hare, reviewing North Atlantic whaling statistics for NAMMCO, working on bottlenose dolphins, and long-finned pilot whales and fin whales. She has identified the introduced pest fauna in the Faroes, worked on the relationship between seabirds and whales, taken part in studies of invertebrates and mammals, problems of the pollution in Faroese fjords, in migration studies of birds, produced a field guide of the most popular Faroese plants, organised an Atlas Cencus of Faroese inland birds (with international cooperation), organised a Nordic seminar on Human influence on the Faroese biota and so it continues. She has even taken part in the production of stamps with biological motifs for the Faroese Postal Office. She has also taken a skipper´s certificate. So the question is perhaps – in what fields has she not taken part? Moreover, as we all know, she has been hostess in her home to innumerable guests and fellow reseachers from all over the world and has supported and and helped to make their stay in the Faroes a most pleasurable experience.

We all owe her this volume.

S-A Bengtson, P. Buckland,
P. H. Enckell and A. M. Fosaa

Carl Julian in the Faroes

Pehr H Enckell

Abstract

Dorete Bloch arrived in the Faroes on 15 October 1974 from Denmark. She became very rapidly involved in scientific activities in the islands – in many fields – and acclimatized quickly to the conditions in the islands. She has become a leading person in scientific work in many areas. This in contrast to the activities of the below mentioned person, who visited the islands for a rather short period and returned to his native country very much relieved. The below is an excerpt of his diary.

*

Carl Julian (von) Graba was a German lawyer in Kiel, born in 1799. He was also an ornithologist. One of his colleagues, Friedrich Boie, who in 1817 had made an ornithological trip to Norway, persuaded him to travel to the Faroes to study the birdlife there – at the time it was practically unknown. Later, Graba wrote a diary from his travels there, „Tagebuch geführt auf einer Reise nach Färö im Jahre 1828".The diary was published in 1830 and was translated into Faroese in 1987. The findings of Graba were mentioned by Charles Darwin in his „On the Origin of Species" in 1872.

The main aim of his journey was ornithological, but Graba also made notations about the country, the people, pilot whale killings, etc. (like others had done before him).

The trip from Kiel to Copenhagen was rapid – it took just 27 hours (!). He depicts his fellow-travellers in detail. Most of them were „solide gebildete Leute", except, possibly a happy Frenchman, who had been „Stabstrompeter unter Napoleon".

When arriving in Copenhagen he encountered the first of his problems – he was not involved with trade (which was monopolized by a Danish company). What was the aim of a German lawyer in visiting the Faroes? It appeared that he would need a special permit to travel to the islands. This took him two weeks, wandering between different offices. To while away his time during this period he bought gifts for the „natives" in the Faroes, mainly cloth and chewing-tobacco, since he calculated that this would facilitate his local trips in the islands.

Already during the trip to Copenhagen he made ornithological observations – and just like his later notations of what he had seen they are very accurate and precise.

He was to sail from Copenhagen on 28 March 1828. Unfortunately there was a dead calm during Easter and the ship could not sail until 9 April. At last they arrived in Elsinore – and after they left Elsinore they met with a storm in the North Sea and the ship was additionally delayed, to the annoyance of the passengers.

When the travellers at last reached the Faroes after having rounded Nólsoy and the ship anchored in the roads outside Tórshavn – Graba could not see the town. The beach and the slope above it was covered with large, moss-covered boulders. But when they approached the beach Graba suddenly realised that the boulders actually were houses and that the „moss" was the roof covering. Graba reflects that if this is the capitol, what will the rest of the country and its settlements look like? He shudders at the thought.

The first days in Tórshavn were taken up by visits to important people in the town. These people are described as hospitable and obliging and their clothing is described in detail. Thereafter he was invited to short excursions in the surroundings. The birds he saw are described in detail, with measurement, weight and colour of the plumage (here, like in his other descriptions, the Latin names differ from those of today).

After these short excursions Graba was invited for a rowing tour in a eight-manned boat (one of many such trips) to the settlement of Kollafjördur. He is duly impressed by the speed with which the boat takes him to the settlement and observes that no horseman on land could obtain the same speed. He also describes – in detail, as always – how the boat is built and how it has been built. During the trip he also describes the westerly and easterly currents, that change direction and speed every so often. He notes that the currents are so strong that the inhabitants of some islands – e. g. Suduroy and Mykines – are not able to leave their islands for months running.

The nature along the coast in Kollafjördur is described with fascination mingled with terror. The coast is „unersteiglich“, impossible to climb. So what happerns if the boat capsizes?

He is not impressed by the church in Kollafjördur. He notes that it must be the most miserable in Christianity – according to his opinion.

In Kollafjördur he stays with the Reverend Holm where the food and drink was of a quality that priests probably enjoy everywhere, as he maliciously remarks.

After his stay he walks along Kollafjördadalur to Leynavatn, where he describes the different varieties of arctic char that live there. He reaches the coastal mountains and is impressed by the sight of Suduroy, Koltur, Sandoy and Vágar. On their way back the group visits a farmer´s wife whose hospitality gives him much pleasure. This hospitality and kindliness is characteristic of the whole population, he writes, and compares it favourably with its German counterparts („I would sooner spend a whole day with a Faroese farmer than with a German one“).

Going back to his ornithological observations he notes that the starlings in the Faroes are sedentary but that they do not form an own species. On his way back to Kollafjördur he also shoots a white raven (he will see more of them later) but he maintains that this also is not a distinctive species. Apparently he has a firm idea about the species concept (both ravens and skuas occur in different colour polymorphs, as shown for skuas by Bengtson & Bloch 2003)

Next visit is to the island of Nólsoy, which he descibes in every detail, like the birds he shoots. He points out that he in one shot brought down three individuals of one species whose beaks differ in size and – maliciously – that Mr. Brehm (the leading German taxonomist at the time) if he had seen them would have described them as belonging to three different species!

Next trip is to Nes on Eysturoy and he stays with the local priest. Graba notes, a little wickedly, that priests in the Faroes are mostly young Danes, who after having survived for six years in the wilderness can go back to Denmark and get the most coveted parishes. Here, like in other instances, he is rather critical to the Danish upper class.

On his way back from Nólsoy, which he visited many times, the boat meets with a storm and the priest from Suduroy became seasick (which implied that Graba did not). Back in Tórshavn the group was struck by a number of days of heavy rain and excursions were out. Instead he describes the cutting of peat, how to fish halibut, the life in the houses in town, the new school where he himself is invited to teach, and so on.

He spends three days in Saksun where he sees many new things, much that is beautiful and interesting and he writes much about this visit. He is astonished by the Faroeses custom that men and women can share the same bed without being married but that there are still so few illegitimate children being born. The visit to Saksun is also stimulated by an auction on wreckage from a frigate that was wrecked on the cliffs below. He is astonished that 500 people from villages all around are coming to the auction.

On his way from Saksun Graba passes the Vestmanna mountains which are very wellknown bird cliffs. He is so touched by the experience – the sounds of the birds, their movements about the cliffs – that he writes a separate chapter about it: „Die Bewohner der Vogelberge“. He describes, probably for the first time, the zonation in the mountain, how different species occur at different heights, how the different species fly. It is a fascinating description (it should be noted that the fulmar had not colonized the Faroes at this time). This description leads him on to another separate chapter, „Der Vogelfang auf Färö“ where he tells how the Faroese exploit different bird poplulations, the mature birds and their eggs (later more thorough descriptions have been given by e. g. Nørrevang 1960 and Salomonsen 1982).

But Grabas hardships pursue him. He rides horseback, goes by boat to Sandoy and Suduroy, describes settlements and people, ends with a description of catches of dolphins and pilot whales. All these are rather detailed, but not as enthusiastic as the description of the bird cliffs (but we should remember that Graba was an ornithologist).

His homeward trip to Germany occurred without any disturbances. He arrives at the coast off Kiel 6 August 1828 and he is so touched by seeing forests, fields of corn and the nature that he wants to swim ashore!

It is clear from the last sentence in his diary that he feels he has had hardships enough: „Nach Färö reise ich aber nicht zum zweitenmale“ (I will not travel to the Faroes a second time).

*

The last sentence could not have been written by Dorete Bloch!

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Abrupt interruptions in the spring bloom on the Faroe Shelf

Bogi Hansen, Eilif Gaard, Høgni Debes,
Karin M. H. Larsen

The Faroe Marine Research Institute, Box 3051, FO-110 Tórshavn, Faroe Islands, email: bogihan@hav.fo

Abstract

Since 1997, phytoplankton abundance (Chlorophyll *a*) has been monitored weekly during spring and summer at a coastal station, „Skopun”, in the central parts of the Faroe Shelf. These measurements have demonstrated a large inter-annual variability both in the timing, and the peak magnitude of the spring bloom. In the most productive years, the bloom starts several weeks earlier than in the bad years and may reach high peak values. In some years, however, a rapidly evolving spring bloom may be interrupted by one or more periods of decreasing phytoplankton abundance, until the bloom recovers. This was the case both in 2008 and 2009. Concurrent temperature measurements at various locations indicate that this may have been due to changes in the circulation pattern on the Shelf. Here, we suggest that the shallow parts of the northern shelf area, including Skopun, in some periods may become relatively isolated from the deeper parts of the shelf. Since this region is shallow, a rapid and intensive spring bloom may develop as long as the isolation is maintained. In some years, such periods of relative isolation seem to alternate with periods of intensive mixing between the shallow and deep parts, in which the phytoplankton in the shallow part is flushed out to the whole shelf. We present a simple box model of the system and show that this can explain the main features of the 2008 and 2009 spring blooms.

Introduction

The shelf area surrounding the Faroe Islands – the Faroe Shelf (Fig. 1) – is influenced by frequent storms and strong tidal currents. In the shallow parts of the shelf, this gives rise to a water mass – Faroe Shelf Water (FSW) – that is very homogeneous vertically and, to some extent, also horizontally (Larsen et al., 2008). FSW is separated from the surrounding water masses by a transition zone, which often can be characterized as a front – the Faroe Shelf Front – usually located outside the 100 m bottom contour (Larsen et al., 2009).

Regular monitoring at the coastal station Skopun (Fig. 1) has demonstrated considerable variation in the seasonal development of the primary production (PP) from one year to

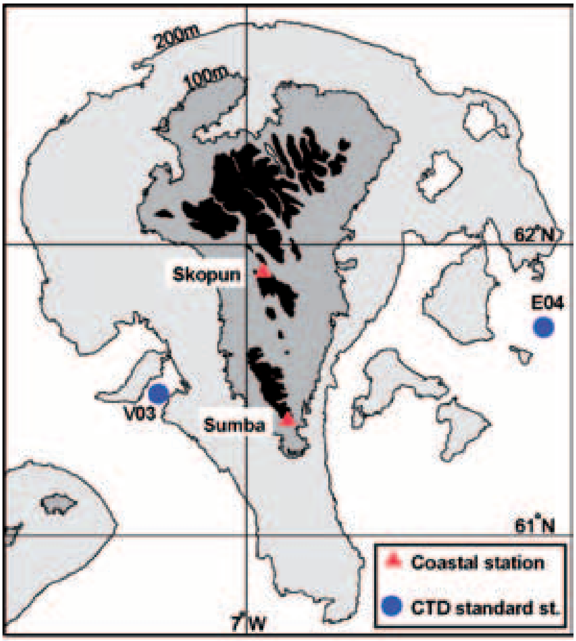

Fig. 1. Bottom topography of the Faroe Shelf with indication of the observational sites.

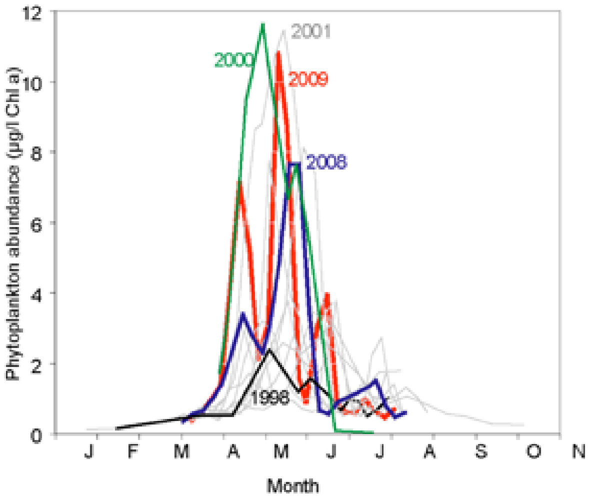

Fig. 2. Seasonal development of phytoplankton abundance at Skopun in different years (thin gray lines). Four years have been enhanced by thicker lines.

another (Gaard et al., 2006). In some years, e.g. 2000 and 2001, there is a pronounced spring bloom with an early and intensive peak in the phytoplankton abundance (Fig. 2). Other years, e.g. 1998, may have a much later and weaker development in the production. An independent measure of the accumulated new production during the spring bloom has been based on the nutrient depletion on the shelf (Steingrund and Gaard, 2005). This PP-index also was exceptionally high in 2000 and 2001, consistent with Fig. 2, and a high correlation has been found between this index and conditions at higher trophic levels, such as demersal fish and seabirds (Gaard et al., 2006).

Early efforts to explain the primary production variations found little correlation with light intensity or other likely physical parameters (Gaard et al., 1998, Eliasen, 2004 a). They revealed, however, a negative correlation with the biomass of imported zooplankton, which was originally interpreted in terms of grazing (Gaard et al., 1998). Modelling efforts (Eliasen et al., 2005) as well as observations (Debes et al., 2008) conflicted with this and, instead, it has been suggested that variable horizontal exchange between the FSW and off-shelf waters may be the main control of the PP. In a homogeneous system, the abundance of phytoplankton cells, $N(t)$, will develop in time according to the equation:

$$\frac{dN}{dt} = (p - r - m) \cdot N - L \qquad (1)$$

where p represents photosynthesis, r respiration, and m mortality. The loss term, L, includes loss (or gain) from (to) the system to (from) the surroundings. In open waters, there is typically a loss by sinking and vertical mixing of cells out of the euphotic layer and the criterion for growth is that L is sufficiently small for the right-hand side of (1) to be positive. In the Sverdrup (1953) paradigm, this implies that the critical depth becomes larger than the mixed layer depth.

On the Faroe Shelf, the critical depth exceeds the bottom depth already in early spring (Debes et al., 2008), but the spring bloom is delayed. This cannot be explained by vertical loss, since the bottom stops this. If, however, the surrounding (deeper) waters have been unproductive, there will also be a loss of phytoplankton cells by horizontal exchange between the shelf and the off-shelf regimes, which becomes relatively more important, the smaller the system is (Eliasen et al., 2005). This mechanism – termed „the horizontal Sverdrup mechanism“ – has been suggested to control the early stages of the FSW spring bloom (Eliasen et al., 2005) and variable air-sea heat exchange has been hypothesized to cause the inter-annual variations in horizontal exchange rate (Hansen et al., 2005).

Several causal mechanisms have been suggested to have the potential for affecting the horizontal exchange rate (Larsen et al., 2009), but no candidate has been clearly shown to be responsible. It is, therefore, still an open question, to what extent this theory can explain the difference between the „good“ years, such as 2000 and the „bad“ years, such as 1998 (Fig. 2). But, there are also years when the PP develops in a more irregular manner. This was the case in 2008 that started out with early and rapid increase in the phytoplankton abundance, which was interrupted by two weeks of decrease, after which the increase was re-established.

Such rapid variations seem hard to explain by changes in physical processes that involve the whole FSW. At the same time, sea temperature measurements at two different coastal sites indicated that the PP variations during the spring of 2008 might be linked to changes in the internal circulation or mixing on the Faroe Shelf. This led to a hypothesis for the rapid PP variations that retains the „horizontal Sverdrup mechanism", but on a more local scale. The spring bloom of 2009 was even more irregular than in 2008 with three clearly separated peaks in the phytoplankton abundance and, again, coastal temperature measurements indicated associated circulation changes consistent with the proposed hypothesis.

In this study, we describe the 2008 and 2009 measurements and present a hypothesis to explain them. In order to test the hypothesis quantitatively, we have constructed a simple box model and present the results from it. Finally, we discuss the validity and generality of the hypothesis and model.

Observational material

The primary dataset on phytoplankton abundance derives from weekly measurements of chlorophyll *a* at a coastal station (Skopun, Fig. 1) established in 1997 (see Debes et al., 2008 for details). At the same station, sea temperature has been measured continuously since 2002. Measurements at other sites have indicated that the sea temperatures measured at Skopun are representative for coastal water throughout the northern part of the Faroe Islands (Larsen et al., 2008) and the phytoplankton abundance values have also been found to be representative for a wider area (Debes et al., 2008).

Sea temperature has also been measured continuously at a site, Sumba, close to the southernmost tip of the islands (Fig. 1) since 2005, although with a gap in 2006-2007 due to instrument failure. For information on the off-shelf temperature, we have used CTD measurements at two standard stations, E04 and V03 (Fig. 1) that are occupied regularly four times a year. Interpolating between the occupation times, a daily time series of off-shelf temperature was constructed by averaging the temperature in the uppermost 100 m at both stations. In addition to our own measurements, we have used the NCEP/NCAR reanalysis data (Kalnay et al., 1996) to construct a time series of daily averaged air-sea heat flux over the Faroe Shelf.

In order to compare these time series, smoothed versions were made of them all. For each day in the period January to September 2008 and 2009, the temperature changes over a week centred at that day were computed for Skopun and Sumba as well as the average temperatures at those two sites and off-shelf and the accumulated air-sea heat flux during the week. Seven day running means were then computed for all these time series.

Observational results

Time series of phytoplankton abundance at Skopun are shown in Fig. 2, where we have highlighted a „good“ year, 2000, a „bad“ year, 1998, and the two irregular years, 2008 and 2009. The Jan - Sept period for 2008 and 2009 is shown in more detail in Fig. 3 where the sea temperatures at Skopun and Sumba are also shown as is the air-sea heat flux. On this figure, vertical dashed lines are inserted to denote shifts between periods when the phytoplankton abundance is increasing and decreasing and there seems to be a correspondence between these periods and the difference between sea temperatures at the two sites.

In both years, the beginning of the spring bloom occurs while the difference in sea temperatures at Skopun and Sumba indicates that the two regions are fairly well isolated from one another. After the first peak, the phytoplankton abundance at Skopun starts to decrease in both years in periods when the two temperatures are very similar, consistent with much less isolation between the two regions. This correspondence continues more or less obviously through the spring and summer of both years, which led to the hypothesis that changes in circulation on the shelf could influence the phytoplankton abundance at Skopun.

As expected, the temperature at Skopun as well as Sumba is seen to react to strong air-sea heat exchanges (Fig. 3). This is seen in more detail in Fig. 4, which shows smoothed weekly temperature changes plotted against the heat flux during the week. At Skopun, the relationship is fairly tight with a correlation coefficient of 0.88 for 2008 and 0.82 for 2009. From regression analyses, the temperature change at Skopun associated with a given heat flux is consistent with the heat being distributed over an average depth of 140 m. This implies that

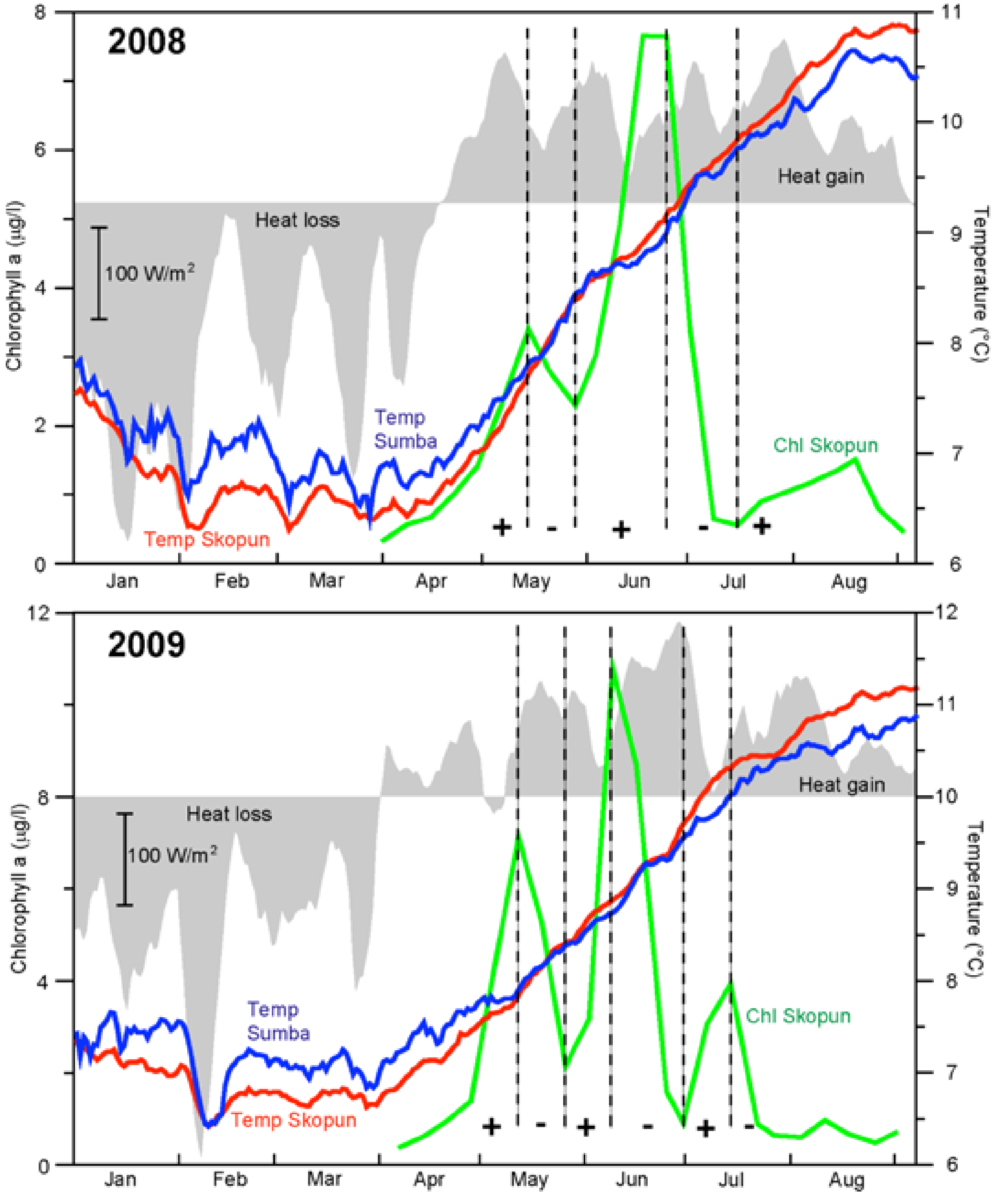

Fig. 3. Time series of phytoplankton abundance (chlorophyll a) at Skopun (green lines), sea temperature at Skopun (red lines) and Sumba (blue lines), and weekly averaged heat flux (shaded areas, positive from air to sea) in January to September 2008 (upper panel) and 2009 (lower panel). Vertical dashed lines indicate shifts between periods with increasing (+) and decreasing (-) phytoplankton abundance.

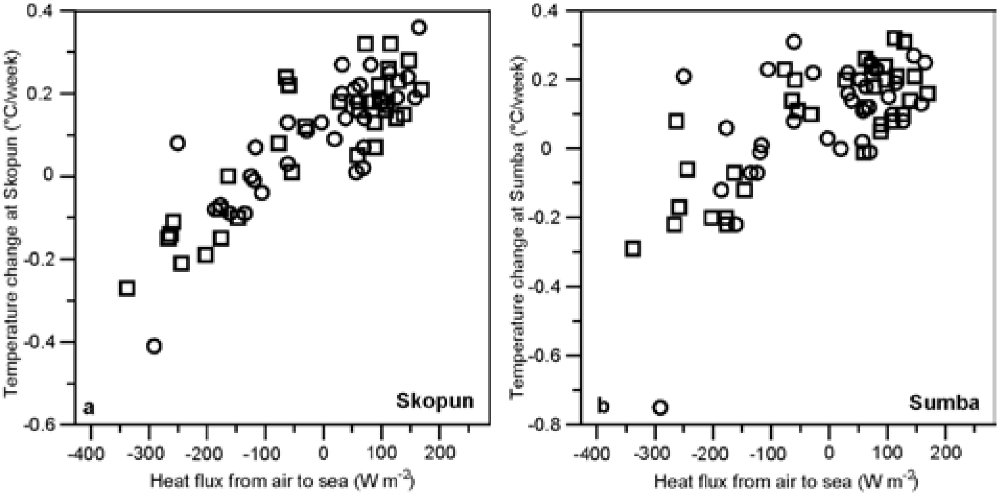

Fig. 4. Temperature change over a week at Skopun (a) and Sumba (b) for the January to early September period 2008 (open squares) and 2009 (open circles), plotted against the average heat flux to the ocean during the week. Each point is an average from seven consecutive days.

the heat usually is distributed over wide areas of the shelf, but even with zero heat gain, there is an average heating of 0.1 °C per week. This indicates heat gain by horizontal exchange during this period (January to early September) with off-shelf temperatures generally higher than on-shelf. The scatter indicates, however, that the heat gained by horizontal exchange varies considerably. This is even more pronounced at Sumba, where the correlation coefficient was 0.78 for 2008 and 0.60 for 2009.

Hypothesis

In previous studies of the Faroe Shelf, the FSW has generally been treated as one homogeneous water mass, mixed by the strong tidal currents and the clockwise residual circulation around the islands (Larsen et al., 2008). As noted by Larsen et al. (2008), this is, however, not always the case. Coastal temperatures in the northern part of the Faroes do seem to correspond very well and follow the Skopun temperature, but in the southern part, the temperature may in some periods diverge considerably from this, as seen in Fig. 3. At other times, however, temperatures in the two regions may be very similar and vary synchronously for long periods (Larsen et al., 2008).

There are various ways to interpret these observations but, in any case, they indicate that the oceanic connection between Skopun and Sumba varies in time. A simple interpretation is illustrated in Fig. 5. There, the shelf area is divided into two homogeneous regimes: a shallow-shelf regime, and a deep-shelf regime. The shallow-shelf regime contains all the near-coastal waters in the northern part, which are homogenized by the strong tidal circulation so that their temperature (Larsen et al., 2008) and, presumably, also phytoplankton abundance (Debes et al., 2008) can be described by the values at Skopun.

The deep-shelf regime contains all the rest of the FSW. In Fig. 5, it has been illustrated as the region bounded by the 150 m depth contour. Assuming all of this regime to be horizontally homogeneous and its properties to be equal to the values at Sumba, may be too optimistic, but it can be taken as a first approximation.

In this framework, the observations presented in Fig. 3 can be understood in terms of a variable exchange between the two shelf regimes. In periods with small exchange, the shallow-shelf regime is almost isolated and its small average depth

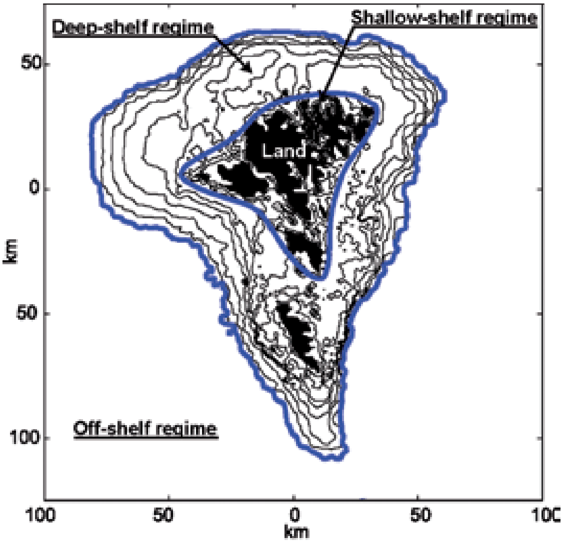

Fig. 5. The three regimes, into which the area is divided in the box model.

allows rapid phytoplankton growth. When the exchange is high, on the other hand, the two shelf regimes operate more like one regime with a much larger average depth and, hence, lower production. This leads to the hypothesis:

- *The rapid variations in phytoplankton abundance at Skopun are generated by variations in the exchange rate between the shallow-shelf and the deep-shelf regimes with good growth in periods of low exchange rate.*

Model description

In order to test this hypothesis quantitatively, we approximate the system by a model that contains three boxes, each of which represents one of the regimes described above (Fig. 5): the shallow-shelf box, (subscript S), the deep-shelf box (subscript D), and the off-shelf box (subscript O). All the boxes are assumed to be well mixed so that properties are homogeneous within them. The shallow-shelf box has a volume of V_S, a surface area A_S, and an average depth D_S ($=V_S/A_S$). The phytoplankton abundance N_S in this box will change according to (1) where the loss term represents exchanges with the deep-shelf box and we assume that this can be written:

$$V_S \cdot \frac{dN_S}{dt} = V_S \cdot (p - r - m) \cdot N_S - R_{SD} \cdot V_S \cdot (N_S - N_D) \qquad (2)$$

The first term on the right-hand side represents the total primary production in the shallow-shelf box. To compute this term, we have used the diatom growth model in Eliasen (2004 b) with half-hourly values of surface irradiance based on satellite data averaged for the years 1996-2000 (www.satel-light.com). Additional input is the average depth of the box, D_S, and the nitrate concentration C_S. The second term in (2) represents the exchange with the deep-shelf box and is proportional to the abundance difference ($N_S - N_D$). The flushing rate, R_{SD}, is the volume of water exchanged between the boxes per time unit divided by the volume of the shallow-shelf box. A similar equation governs the deep-shelf box:

$$V_D \cdot \frac{dN_D}{dt} = V_D \cdot (p - r - m) \cdot N_D - R_{DO} \cdot V_D \cdot (N_D - N_O) + R_{SD} \cdot V_S \cdot (N_S - N_D) \qquad (3)$$

Table 1. Geometrical parameters of the two shelf boxes in the model.

Box	Volume km^3	Surface area km^2	Average depth m
Shallow-shelf	50	1100	45
Deep-shelf	1100	11000	100

If the computed phytoplankton abundance in the shallow-shelf box is to reach the levels sometimes observed (> 10 µg l^{-1} Chl *a*), the average depth of the box has to be fairly small and we have chosen the area inside the 60 m bottom contour in the northern part of the Faroe Shelf as the shallow-shelf box. Similarly, the deep-shelf box has been delimited by the 150 m contour. This determines the geometrical parameters of equations (2) and (3) (Table 1), but the two flushing rates are, *a priori*, unknown. Following Larsen et al. (2008), constraints on their values can be determined by considering the heat budget. If T_S is the temperature of the shallow-shelf box, its variation is governed by:

$$V_S \cdot \frac{dT_S}{dt} = \frac{Q \cdot A_S}{c_v \cdot \rho} - R_{SD} \cdot V_S \cdot (T_S - T_D) \qquad (4)$$

where Q is the air-sea heat flux, c_v the specific heat capacity, and ρ the density of sea water, whereas T_D is the temperature of the deep-shelf box, which is governed by a similar equation:

$$V_D \cdot \frac{dT_D}{dt} = \frac{Q \cdot A_D}{c_v \cdot \rho} - R_{DO} \cdot V_D \cdot (T_D - T_O) + R_{SD} \cdot V_S \cdot (T_S - T_D) \qquad (5)$$

For the 1st April to early September periods in 2008 and 2009, equations (4) and (5) were used to calculate daily estimates of R_{SD} and R_{DO} using the smoothed time series described in the observational materials section. Equations (2) and (3) were then integrated numerically from 1st April assuming start values of 0.1 µg l^{-1} Chl *a* in all three boxes. This value was maintained in the off-shelf box. No grazing was included in the model, but nitrate limitation was, and the nitrate concentration, C, in each box was determined from exchange and assimilation loss, assuming 0.44 µmol N kg^{-1} to be used for each µg l^{-1} of Chl *a* (Eliasen, 2004 b). The equations governing the nitrate concentrations in the two boxes, C_S and C_D, thus, are:

$$V_S \cdot \frac{dC_S}{dt} = -0.44 \cdot V_S \cdot (p - r) \cdot C_S - R_{SD} \cdot V_S \cdot (C_S - C_D) \qquad (6)$$

$$V_D \cdot \frac{dC_D}{dt} = -0.44 \cdot V_D \cdot (p - r) \cdot C_D - R_{DO} \cdot V_D \cdot (C_D - C_O) + R_{SD} \cdot V_S \cdot (C_S - C_D) \qquad (7)$$

where the off-shelf concentration, C_O, is kept constant at the winter value (12 µmol N kg^{-1}).

To determine the flushing rates R_{SD} and R_{DO} from equations (4) and (5), we divide by temperature differences that in some cases become very small. Measurement uncertainties and model approximations also may lead to negative, and hence unphysical, flushing rates. We, therefore, restrict R_{SD} and R_{DO} to be within specified limits. For the shallow-shelf box, we require the flushing rate to be between 1 and 30 days. Similarly, the flushing rate for the deep-shelf box has been restricted to the interval between 1 and 90 days.

Model results

The computed phytoplankton abundance in the shallow-shelf box for 2008 and 2009 is found to compare remarkably well with the observations at Skopun (Fig. 6). The absolute and relative heights of the peaks do not always correspond too well and the first peak in 2009 occurs too early in the computations compared to the observations. Still, the phytoplankton abundance shows two peaks in 2008 and three main peaks in 2009 with relatively good correspondence in timing, especially when noting that the computed values are based on smoothed parameters whereas the observations are obtained at discrete weekly intervals.

The computed flushing rates (Fig. 6) are found to vary considerably and much of the time, they are at either the maximum or minimum specified limit. This makes the computed phytoplankton abundance values dependent on the *ad hoc* specified limits. Varying the limits, shows, however, that the basic structure of the temporal phytoplankton development is not very sensitive to these limits.

Discussion

Although the model (Fig. 5) would appear to be very much simplified, the correspondence between computed and meas-

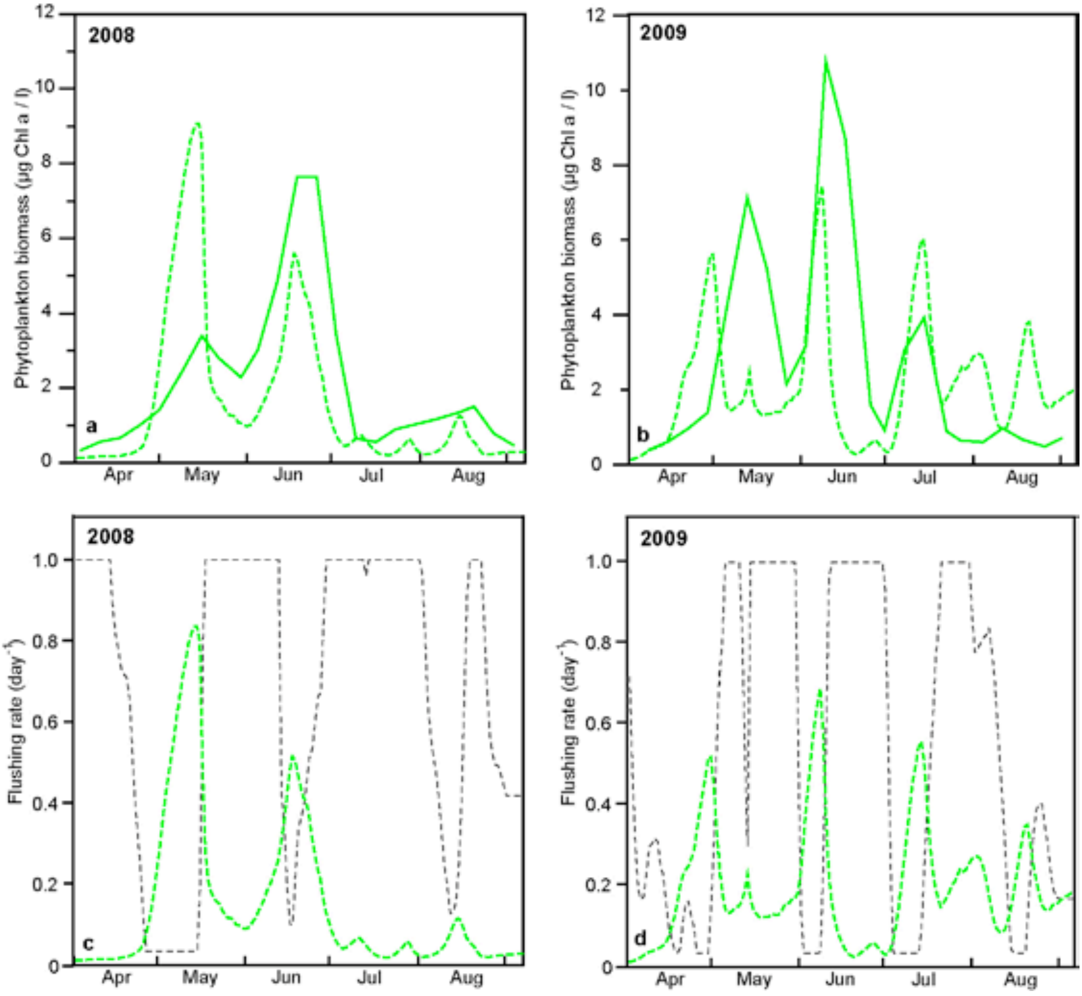

Fig. 6. Upper panels: Comparison of computed (dashed green lines) and measured (continuous green lines) phytoplankton abundance in the shallow-shelf box for 2008 (a) and 2009 (b). Lower panels: The flushing rate (dashed black lines) and computed phytoplankton abundance (dashed green lines in the same scale as in the upper panels) in the shallow-shelf box for 2008 (c) and 2009 (d).

ured phytoplankton abundances (Fig. 6a,b) seems remarkably good. Except for the model geometry and the specified (but not very restrictive) limits on the flushing rates, there are no *ad hoc* assumptions involved. The model results, therefore, support the hypothesis that the shelf can be divided into at least two different regimes and that variations in exchange rate between the regimes dominate the development of the spring bloom in the shallow-shelf regime.

The implied variations in flushing rate (Fig. 6c,d) are quite dramatic and seem most easy to explain by circulation changes on the shelf. What causes these changes is not obvious from this data set. No clear correspondence to the strength of the tidal current or to the wind is seen. Air-sea heat exchange and/or intensive precipitation over land also might induce horizontal density gradients that could affect the circulation and there may be other mechanisms. Perhaps future observational campaigns or high-resolution numerical modelling of the Faroe Shelf may shed some light on this. A numerical model might also give a more realistic interpretation than the simplified box model used here (Fig. 5).

In the model results, we have focused on the production in the shallow-shelf regime, but the results indicate that this may not be representative for the deep-shelf regime, which represents an area that is an order of magnitude larger. This might indicate that the phytoplankton abundance at Skopun may not be a good proxy for the total shelf production in spite of the correspondence of „good“ years (2000 and 2001). Further studies are needed to clarify this.

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Which trees grew on the Faroe Islands before people arrived?

Richard H.W. Bradshaw, Gina E. Hannon, Mats Rundgren and Thomas Giesecke

Introduction

Island floras are often distinctive from those on the nearest mainland primarily because of interactions between dispersal processes, local climatic conditions and individual histories of human settlement and land-use that differ from the mainland. Island floras have often been the subject of special study with the aim of separating out the role of these factors in a type of ‘natural experiment’, although conclusions are usually tentative as it is hard to isolate the effects of individual factors and replicate results. The study of the long-term development of island floras can however contribute to progress through the clear identification of ‘settlement horizons’, when human influence on flora can be separated from climatic and natural dispersal effects, at least temporarily. Reasonably distinct settlement horizons have been described from the Faroes indicating profound human impact on the flora and landscape, particularly through the introduction of arable and pastoral agriculture (Jóhansen 1985; Hannon & Bradshaw 2000; Lawson et al. 2008).

One of the issues raised by the effects of human settlement on the Faroese flora is the ‘natural’ status of trees and shrubs on the islands. A wide variety of woody plants occur on the islands today, although most are presumed introductions (Leivsson 1989, Bradshaw 1995). The mean temperature of the growing season is suitable for tree growth (Körner 1998), although soil conditions, wind and exposure to salt spray may severely restrict suitable habitat. Hannon et al. (2005) reviewed evidence for former tree cover and collated dated wood megafossils from *Betula pubescens* (tree birch), *Salix* spp. (willow) and *Juniperus communis* (juniper). Hannon et al. (2005) also discussed the phenomenon of rare ‘natural’ heathland development on the Faroes (i.e. without human intervention), which contributed to the loss of woody vegetation and possible local species extinctions. This loss was subsequently accelerated by human activities (Hannon et al. 2005). Edwards (2008) reviewed the long-term decline of juniper populations on the Faroes and concluded that „even though natural causes may be involved, such as climate or soil change, anthropogenic factors – of which goat husbandry might have been one – were probably contributory but are not the only answer“ (Edwards 2008). In this paper we develop these discussions by adding to the palaeoecological data about the extent and composition of former woody vegetation.

Current knowledge about past woody vegetation on the Faroes is primarily based on three types of evidence: 1. plant megafossils, or large pieces of wood; 2. plant macrofossils, or visible remains of woody plants such as leaves, buds and seeds; and 3. plant microfossils, particularly microscopic pollen grains. There are problems of interpretation associated with each type of data. Megafossils provide good evidence for species presence when they are preserved in the same position as they lived. Thus the sub-fossil tree birch roots excavated at Argisbrekka, Eysturoy dating from c.4250 calendar years before present, (BP, present = AD1950) show that local stands of trees have grown on the Faroes in the past (Hannon & Bradshaw 2007). However the discovery of younger *Larix* (larch) at an archaeological excavation at the same location shows that exotic driftwood was used in construction, so the stratigraphic context of megafossil samples is important to establish (Mahler 2007). Plant macrofossils preserved in pre-settlement lake sediments are also good evidence of native status, but very few sites on the Faroes have been investigated. Hannon *et al*. (2001) reported mid-Holocene presence of tree birch and willow (*Salix phylicifolia*) from Gróthúsvatn, Sandoy, but *Corylus* (hazel) nuts found at the Argisbrekka excavation are again possibly a human import (Mahler 2007).

Pollen data are the most widely used method for the reconstruction of vegetation, but are notoriously uncertain when used as evidence for local presence of trees. Small quantities of tree pollen can be transported over great distances and can comprise a significant percentage of total pollen counted in a sample when the local vegetation is grassland or heathland. Very low percentages of tree pollen recorded from Faroese sites during the Holocene include tree birch, *Fraxinus* (ash), *Tilia* (lime), *Corylus* hazel), *Sorbus* (mountain ash), *Alnus* (alder), *Ulmus* (elm), *Quercus* (oak), *Populus* (poplar) and *Pinus* (pine) (Jóhansen 1985). These pollen types have often been interpreted as being of long-distance origin, but local occurrence has also been discussed, particularly in the case of tree birch, hazel, mountain ash and poplar (Jóhansen 1985). Mountain ash and poplar pollen can be difficult to identify and in the case of the latter, the pollen does not preserve well and this type is probably vastly underestimated in most pollen records. In this paper we assess the long-distance pollen origin hypothesis, using recent data from a lake site on Sandoy where high dating resolution permits calculation of pollen accumulation rate (PAR) data that can be directly compared with data sampled from appropriate forested and non-forested settings. We test the hypothesis that tree birch and hazel grew on northern Sandoy during the earliest part of the Holocene.

Methods

The southern island of Sandoy, where the investigated site Lykkjuvøtn (61°54'37"N and 6°54'30"W; 52 m a.s.l.) is located, has relatively gentle topography. Lykkjuvøtn consists of two small lakes in a north–west facing basin near the coast. The southern lake (ca. 100×25 m) has a minor inlet from the south and connects to the northern lake through a small outlet. The lake lies in a gently sloping basin with generally low rocky shores immediately around the lake and a hill to the south (412 m a.s.l.). Local vegetation, which is strongly influenced by sheep grazing and cultivation, consists mainly of grasses, sedges, herbs and mosses.

A sediment core of the basal 1 m of the sediments was extracted from the deepest part of the lake using a 7.5 cm diameter Russian peat sampler and has provided the material for earlier studies (Jessen et al. 2007; Jessen et al. 2008; Hannon et al. 2010). The core was sub-sampled at 1 cm resolution for pollen. The basaltic Saksunarvatn Ash, commonly encountered in Faroese lake sediments (Wastegård et al. 2001), was clearly visible as a black layer at 373 cm depth (below water level). Below the ash layer was 68 cm of silt gyttja, with a transition to gyttja clays and silty clays at 441.5 cm. Only the uppermost 3.5 cm of these minerogenic sediments contained pollen. Pollen was sampled from the core every 4 cm except above and below the sediment change at 441.5 cm, where more densely spaced samples were analysed. Pollen preparations followed standard procedures (Berglund and Ralska-Jasiewiczowa 1986), and *Lycopodium* tablets were added in order to estimate PAR. Pollen identifications were made using the key of Moore et al. (1991) and the reference pollen collection at the Department of Geology, Lund University. Pollen of *B. nana* (dwarf birch) and *B. pubescens ssp. tortuosa* (tree birch) were separated using size and morphological criteria based on measurements on recent Icelandic pollen (Rundgren 1995).

The chronology for the sediment sequence was based on twelve AMS radiocarbon dates from *Salix herbacea* (dwarf willow) leaves. Four additional dates on bulk sediment samples yielded dates that were either unexpectedly young (three samples) or old and thus were excluded from the age-depth model. The dates were calibrated using the online Bayesian radiocarbon calibration service BCal (http://bcal.shef.ac.uk/) and the IntCal04 data set (Reimer et al. 2004). A 4-term polynomial was fitted to the weighted averages of the calibrated probability distributions by singular value decomposition using PSIMPOLL v4.26 (Bennett 2007). Confidence intervals were obtained through fitting polynomials to random values from the probability distributions of the calibrated dates. The chronology was used to calculate PAR values (numbers of pollen grains per cm^2 per year) for selected pollen types and the uncertainty of the age model was incorporated in the estimate of the 95% confidence intervals on individual datasets using PSIMPOLL v4.26 (Bennett 2007).

Results

The twelve AMS radiocarbon dates cover a 1000 year period from the early Holocene (11,200-10,200 BP) in c.70 cm of lake sediment, representing the best-dated sequence to date from the Faroes (Fig.1). The age-depth curve is of a regular form and typical for early Holocene north European sediments. This chronology forms a secure basis for accurate estimation of PAR during this time period.

All the selected pollen types have relatively low PARs during the period 11,250-10,800 BP (Fig. 2). Dwarf birch, dwarf willow and *Empetrum* (crowberry) have the highest PARs during this time period and these plants are well represented in the contemporary plant macrofossil flora (Hannon et al. 2010). Maximum PAR values for all taxa were achieved between 10,700-10,250 BP with the following approximate sustained high values of PAR in numbers of pollen grains per cm^2 per year: total birch 1250 of which probable tree birch is 20; juniper 30; *Pinus* (pine) 250; hazel 200; elm 20 (Table 1). There were no macrofossil records for any of these taxa reported during this time period (Hannon et al. 2010).

Discussion

The results reported here from Sandoy are probably representative for other parts of the Faroe Islands as previously published percentage pollen diagrams show similar successions and relative abundances of pollen types (Hannon et al. 2010). The former lake at Hoydalur, Streymoy shows a strikingly similar early Holocene pollen succession involving birch, pine and hazel (Jóhansen 1985), but again provides no basis for distinguishing local pollen production from long-distance dispersal.

Hannon et al. (2010) reported from Lake Lykkjuvøtn that hazel pollen was sporadically present from *c.* 10,900 BP, but had its first noticeable increase after 10,600 BP, more or less synchronous with the increase of hazel pollen on the Shetland Islands, 300 km to the south-east, (Jóhansen 1982, 1985; Bennett et al. 1992), Scotland (Birks 1989) and Southern Norway, the nearest continental mainland, 610 km to the east (Eide 2004; Bjune 2004). In the Setesdalen region of southern Norway, the earliest tree birch macrofossils are found at 11,000 BP (Eide 2004) while at Vestre Øykjamyrtjørn, the local presence of tree birch is shown by the record of macrofossil fruits prior to 10,750 BP (Bjune 2005). At Inver Aulavaig on Skye, low percentages of birch pollen are thought to represent some birch scrub development during the Late Glacial (Selby 2004), while on the Shetlands, birch woodland began to develop *c.* 9000 BP (Bennett et al. 1992). Tree birch and hazel both occur in the macrofossil record from the Shetlands (Lewis 1911), so it is not inconceivable that they could have grown on a similar oceanic island setting such as the Faroe Islands in the past.

There are two principal sources of data with which to compare the tree and shrub PAR estimates from Lykkjuvøtn, Sandoy to distinguish local taxon presence from long-distance pollen transport. These sources are other PAR records, with supporting evidence for local taxon presence and PAR from modern pollen traps. In making such comparisons the long-distance pollen source strength will be site dependent, but the Shetland Islands (320 km distant from Norway and 220 km from Scotland) can be expected to show slightly higher long-distance PARs than the Faroes (610 km to Norway and 380 from Scotland). Bennett *et al.* (1992) published PAR data from Dallican Water, Shetland Islands, where tree birch, hazel, juniper and *Sorbus aucuparia* (mountain ash) are regarded as native species. They interpreted hazel as present on the Shetlands during the early Holocene based on PAR values that ranged from 200-1000, strongly suggesting that the PAR values from Lykkjuvøtn on the Faroes indicate local occurrence of hazel trees (Table 1). This claim is further supported by pollen trapping data where hazel PAR values above about 85 indicate local occurrence of hazel in Fennoscandia where there are source trees on the same land mass (Hättestrand et al. 2008). The PAR values of 200 found on the Faroes and Shetlands most likely indicate local hazel trees probably growing in localized copses.

Conclusions

The original hypothesis is upheld and our evidence indicates that both tree birch and hazel grew on north Sandoy during the earliest Holocene. The likely list of Holocene trees found on the Faroes therefore includes tree birch, willow and juniper, for all of which there is supporting macrofossil evidence in 'natural' settings. To this list we propose to add hazel, based on PAR from the early Holocene. Consequently the 8 cm thick trunk of *Corylus* dating from 890 AD, which was uncovered at Argisbrekka archaeological site with basal axe marks indicating felling (Malmros 1994), was probably an indigenous tree. Elm has a doubtful status while pine is probably a non-native. Mountain ash and poplar are highly likely to be natives but lack evidence to date. Further study of PAR from other sites of mid-Holocene age should also yield information about ash and oak.

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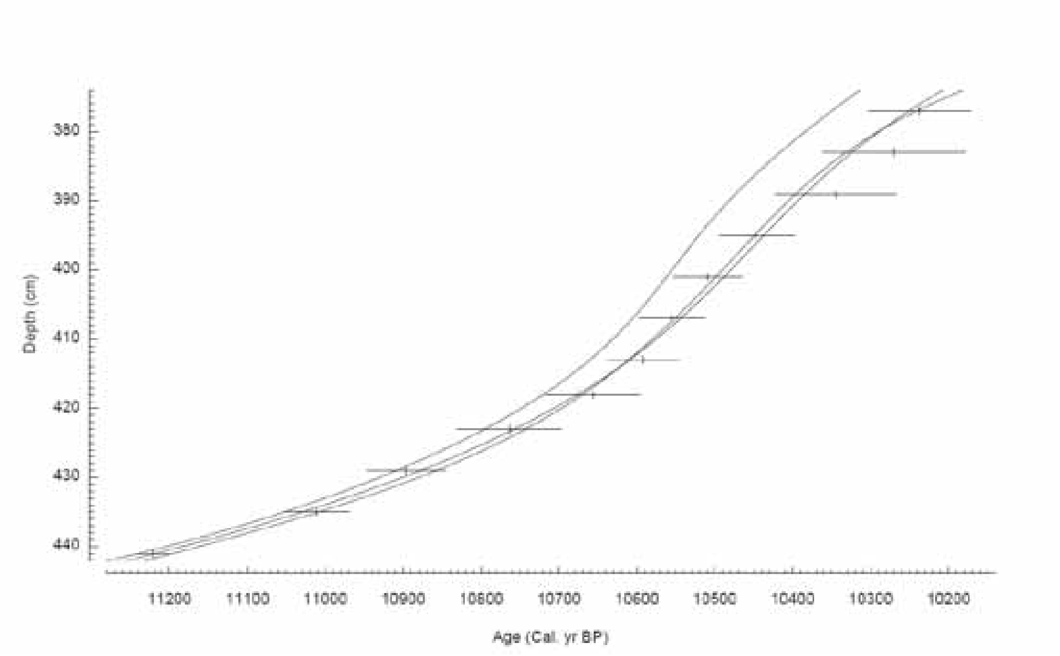
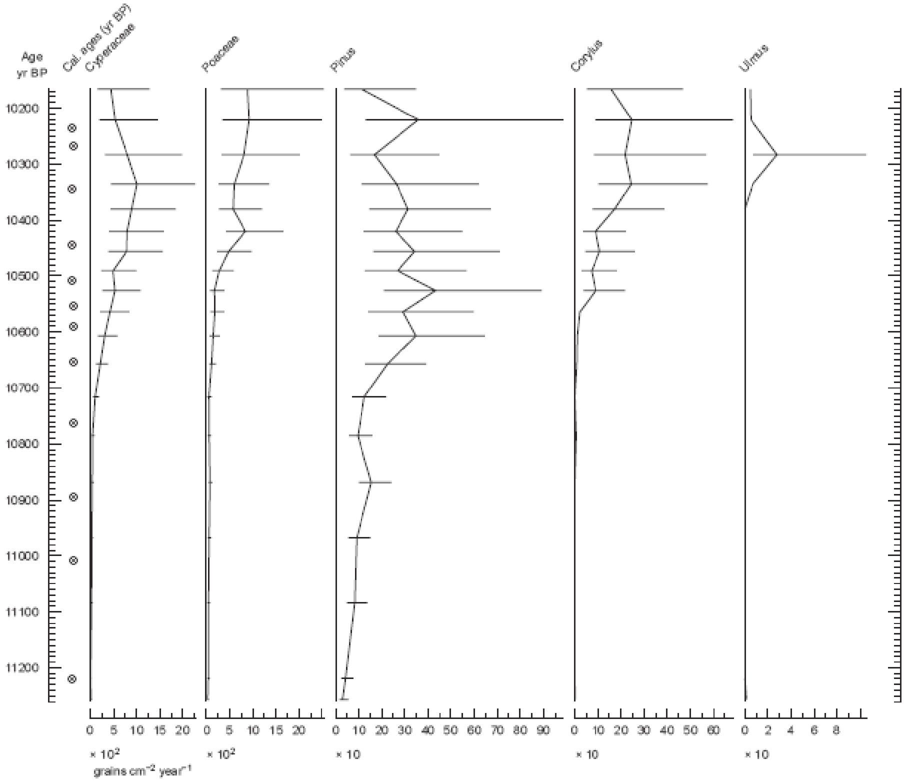
Table 1. Pollen accumulation rate values recorded from Lykkjuvøtn, Faroes and Dallican Water, Shetland Isles (Bennett et al. 1992) during the early Holocene. Modern threshold values are shown from pollen traps. * indicates supporting independent evidence for local taxon presence.

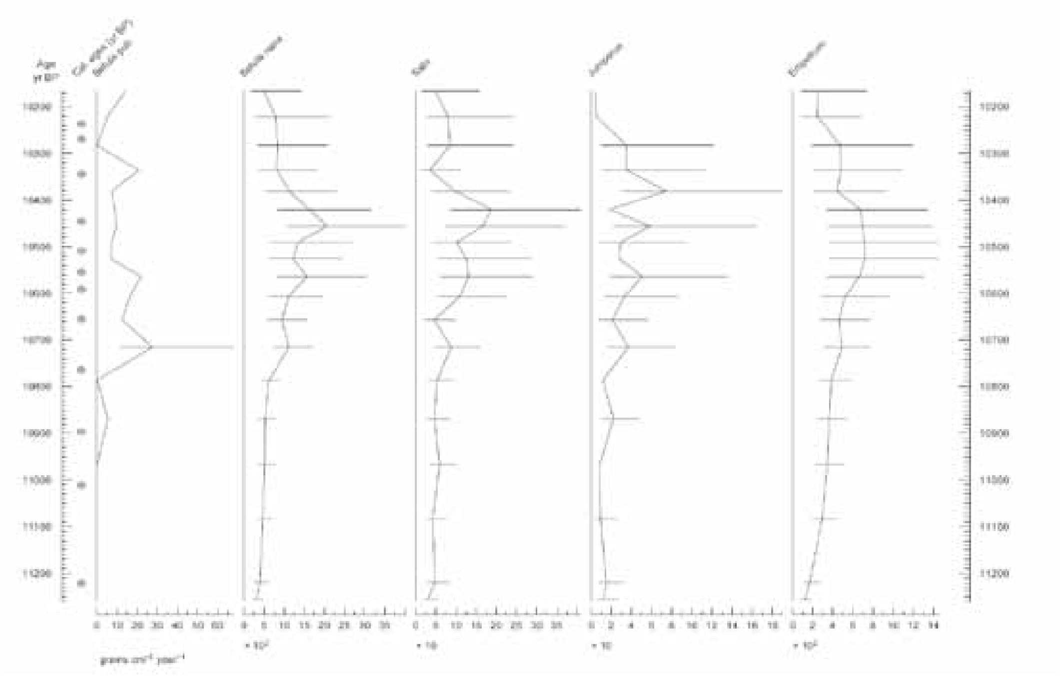
Taxon	Faroes	Shetlands	Approx. threshold for local taxon presence from pollen traps
	Grains cm^{-2} yr^{-1}	Grains cm^{-2} yr^{-1}	Grains cm^{-2} yr^{-1}
Birch	1250	1000*	
Juniper	30	30*	
Pine	250	300	260
Hazel	200	$\geq$200*	85
Elm	20	100	20



Age-depth relationships for the sediments from Lake Lykkjuvøtn.



a) Pollen accumulation rates and 95% confidence intervals from Lake Lykkjuvøtn for Cyperaceae (sedges), Poaceae (grasses), Pinus (pine), Corylus (hazel) and Ulmus (elm).



b) Pollen accumulation rates and 95% confidence intervals from Lake Lykkjuvøtn for Betula nana (dwarf birch), Salix (willow), Juniperus (juniper) and Empetrum (crowberry).

Marine climate, squid and pilot whales in the northeastern Atlantic

HJÁLMAR HÁTÚN AND EILIF GAARD

Abstract

We have identified a clear link between the abundance of long-finned pilot whales and the marine climate in the northeastern Atlantic throughout the last three centuries. During warm periods the whales are observed in high abundances and they can be completely absent from the region during cold periods. The linkage between the marine climate and the abundance of whales probably involves their main prey items, flying squid (*Todarodes sagittatus*) and the large, but highly variable blue whiting (*Micromesistius poutassou*) stock. The latter is preyed upon both by the squid and the whales. The subpolar gyre declined drastically in the late 1990s, resulting in warming and a great increase and a westward shift of the blue whiting stock, but the abundances of *T. sagittatus* and pilot whales in Faroese waters did not increase correspondingly. The post-1980s breaking of this, otherwise stable, multi-century bio-physical link points to anthropogenic interference. We discuss potential causes, rooted in Global Warming and an intensified pelagic fishery, which collectively might explain this breaking rela-

tion. Some new aspects of sub-decadal variability in the marine climate and in the Faroe shelf ecosystem are introduced.

The search for a pilot whale-climate linkage

The time series of long-finned pilot whale catches in the Faroe islands, extending back to 1584 and unbroken from 1709 (Bloch 1994), is one of the longest biological series on record. A strong periodic variability evident in this series has inspired many researchers to look for natural causes. The potential importance of the Faroe Current region to the north of the Faroe Islands (Figs. 1 and 2a) has been acknowledged (Hoydal and Lastein 1993) and a trophic linkage to the abundance of blue whiting in the Iceland-Faroe region has been demonstrated (Hoydal and Lastein 1993), although for a relatively short period (1980-1992). Joensen and Zachariassen (1982) point to the importance of the marine climate in the Rockall region south-west of the Faroe Islands, since the sea surface temperatures (SST) in this region follow the whale catches in the Faroes more closely than does the local SST around the islands (Joensen and Zachariassen 1982). And a comparison between the century-scale fluctuations in the Faroese pilot whale catches and the so-called Dansgaard temperature series from Greenland did not reveal persistent correlations (Hoydal and Lastein 1993).

Building on this knowledge, we have resumed the search

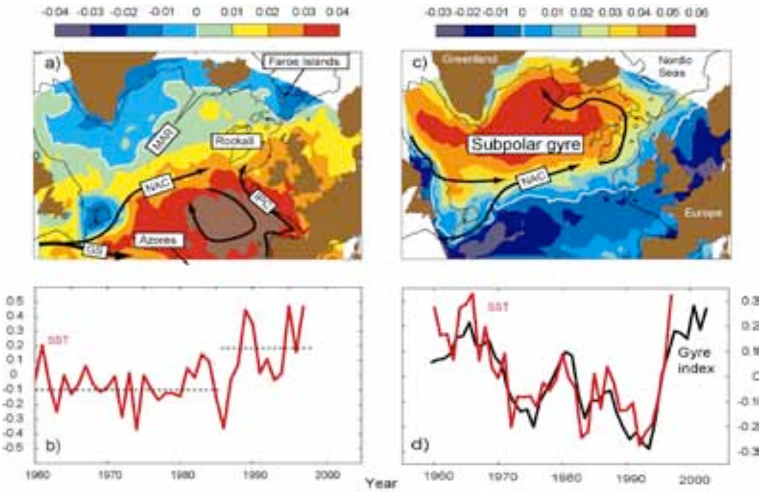


Fig. 1. *Variability sea surface temperature (SST) modes related to Northern Hemisphere Temperature (NHT) and the subpolar gyre, respectively, and the relevant flow systems. a) The spatial imprint of the NHT-like changes, with red colors representing areas with strong impact. b) The NHT-related SST variability over the reddish areas in a). Similarly, c) and d) show the spatial and the temporal gyre-related SST variability. The series are not to scale. The inverted gyre index has been included in d) (black curve). Abbreviations - MAR: Mid-Atlantic Ridge, NAC: North Atlantic Current, GS: Gulf Stream and IPC: Iberian Poleward Current.*

for a climate-pilot whale link, now equipped with much more extensive environmental data (from numerical models, satellites and *in-situ* observations), biological data on plankton and blue whiting, and the recent most additional number of years. The presented results on long-term (multi-decadal to centennial) have previously be presented in two other publications (Hátún et al. 2009a; Hátún et al. 2009b), and will not be reiterated here in their entirety. After a review on the relevant physical oceanography and some important aspects of the blue whiting and squid stocks, we present a relatively tight link between pilot whale abundance in Faroese and the marine climate in the northeastern Atlantic. This links is less clear after the late 1980s, and possible reasons underlying this breaking relation are discussed. Furthermore, a new perspective on this unique whale series is given by considering shorter term (6-10 years) variability in the regional climate, and in the abundance of pelagic fish and squid (prey) on the Faroe shelf.

Ocean Circulation and Climate

Changes in the marine climate in the study region, extending from the Azores in south to the Faroe Islands in north (Fig. 1), have been ascribed to two main drivers – the generally increasing Northern Hemispheric temperatures (NHT) and the subpolar gyre. But before introducing these, a general overview over the main ocean circulation will be given.

Ocean Circulation

The Gulf Stream, which represents the northern periphery of the subtropical gyre proper, leaves the American coast near New Foundland, and flows eastwards to the south of the Azores (Fig. 1a). The North Atlantic Current (NAC) is a poleward branch of the Gulf Stream which crosses the fractures zones in the Mid-Atlantic Ridge (MAR) (Bower et al. 2002) in an eastward direction and turns northward in the vicinity of Rockall (Fig. 1c). This current, which represents the southern and eastern periphery of the subpolar gyre, brings relatively warm and saline *western waters* towards the Rockall region (Holliday 2003). The circulation in the *inter-gyre region* be-

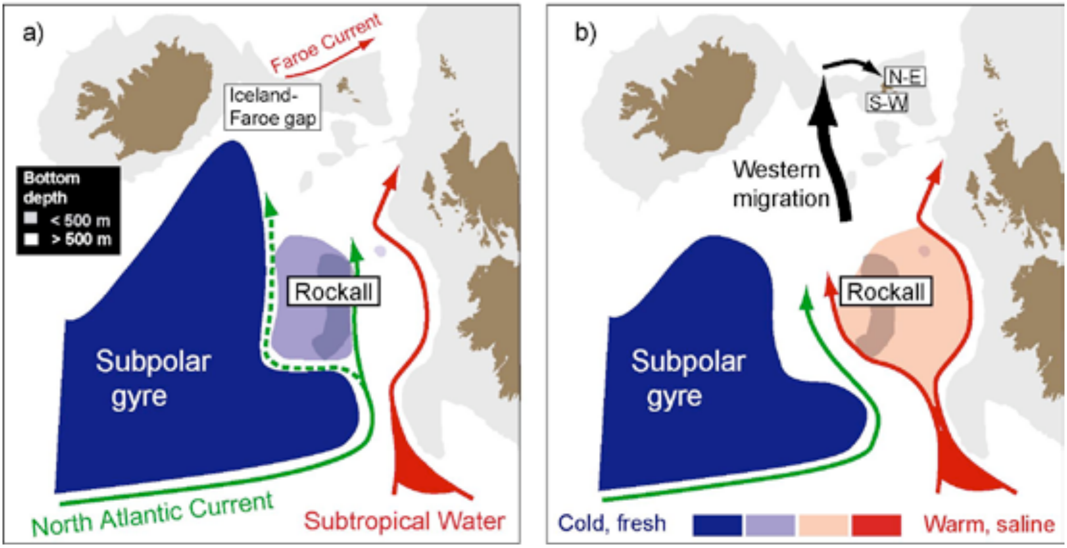


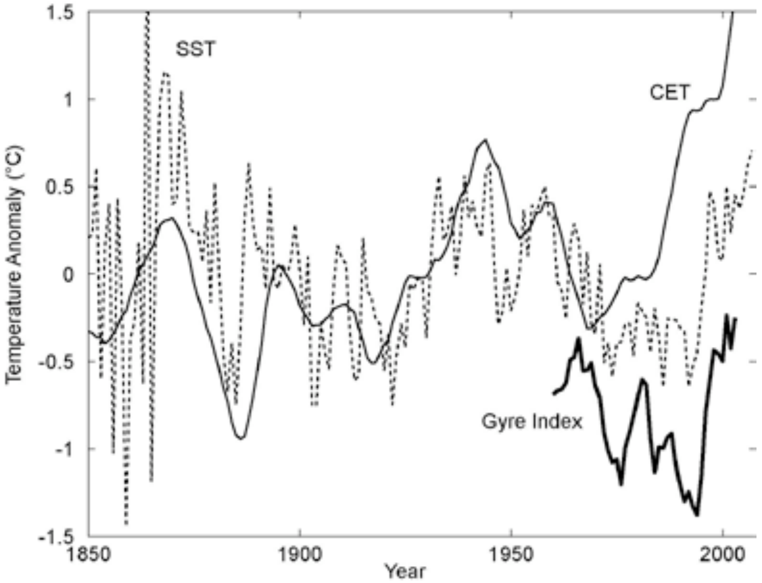
Fig. 2. *Simplified illustration of the source flows to the Rockall Region. a) A strong subpolar gyre results in strong influence of cold subarctic water in the Rockall region. b) A weak gyre results in a warm subtropical anomaly in the Rockal region (based on Hatun et al. 2009b). The variable western migration through the Iceland-Faroe gap, via the Faroe Current and into the northeastern (N-E) bays of the Faroe Islands has been sketched as well.*

tween the subtropical and subpolar gyres is less energetic and more complex (Pollard et al. 1996). A large pool of warm and saline *eastern water* circulates clockwise in an area between the Azores and the Bay of Biscay (Fig. 1a). These saline eastern waters are slowly advected towards the Rockall region (Ellett et al. 1986). An even more saline type of waters flows northwards along the European Continental Shelf in the Iberian Poleward Current (IPC)(Fig. 1a). This water mass, which is influenced by the highly saline Mediterranean outflow, is intermittently entering the Rockall Trough. Finally, the subpolar gyre (Fig. 1c) is a cold and low-saline water mass source for the Rockall area (Wade et al. 1997). So a broad and complex fan of different types of water converges and mixes in the relatively constricted Rockall region. For simplicity, we do here consider the water mass that flows northward past the Faroe Islands to be a mixture of *subtropical* and *subarctic* water.

Temperatures in the inter-gyre region

The NHT has been increasing during the last four decades, likely related to anthropogenic Global Warming. This trend has had a particularly strong imprint on the SST in the inter-gyre region between the Azores and the Bay of Biscay (Beaugrand et al. 2002; Hátún et al. 2009a) (Fig. 1a). The tempera-

Fig. 3. *Climate indices. Annual averages of: the SST west of the British Isles (Rayner et al., 2006) (52.5-62.5°N, 27.5-12.5°W), the inverted gyre index (Hátún et al., 2005). The Central England Temperature (CET) (Parker and Horton, 2005) during the spring months March and April has been plotted over the SST series. The CET is low-pass filtered using an eight-year filter width. The two temperature time series are to scale, the gyre index is not.*



ture trend is characterized by decadal scale fluctuations with a particularly steep increase during the late 1980s (Fig. 1b), a period which led the an ecological regime shift in the North Sea (Reid et al. 2001).

The subpolar gyre

The subpolar gyre is a large body of cold and low-saline subarctic water that circulates counterclockwise south of Iceland and Greenland (Fig. 1c). The circulation strength and the eastward extent of the subpolar gyre are highly variable. Some years it reaches near the European Continental Shelf, where it constricts the northward flow of subtropical water (Fig. 2a). During such years, the subpolar gyre contributes a large proportion of the source water to the mixing region southwest of the Faroes, and the marine climate there becomes both cold and low-saline. When the gyre weakens and retracts westwards, away from the European Continental Shelf, it opens up a „window“ for a northward flush of subtropical water which leads to warming, salinification and a reorganization of the entire marine ecosystem (Hátún et al. 2009a) (Fig. 2b). The weakening can take place relatively suddenly, like it for example did during the mid-1990s, and probably also during the

1920s (Drinkwater 2006). The relative influence of the subpolar gyre on the marine climate in the northeastern Atlantic has been represented by a so-called *gyre index* (Hátún et al. 2005).

The gyre index extends back to 1960 (Hátún et al. 2005), but other climatic indices with longer available time series have been used to characterise the gyre dynamics further back in time in place of the gyre index (Fig. 3). The gyre index is close-

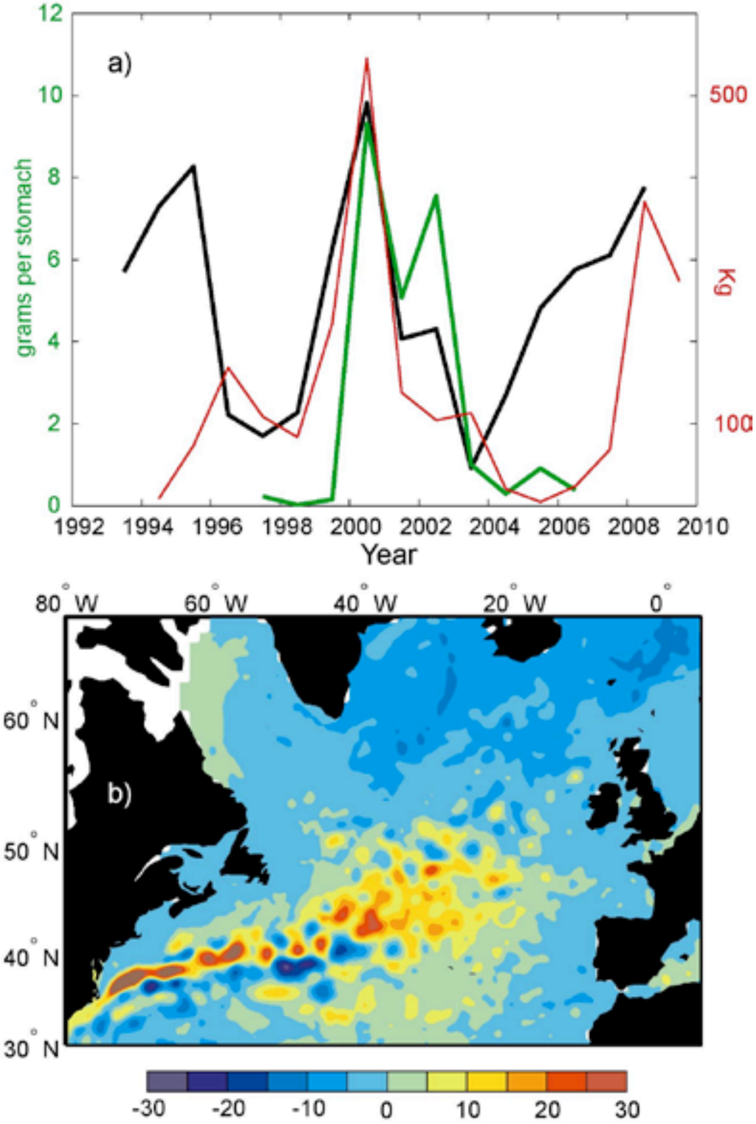


Fig. 4 The sub-decadal oscillations (SDO) in the subpolar Atlantic and biology on the Faroe shelf. a) The SDO index (black), total catches of T. Sagittatus on the Faroe shelf (red) and the abundance of sandeel from stomach samples (green). The amount of sandeel has increased after 2006, although not to the levels around 2000 (pers. comm. Petur Steingrund), b) The associated spatial pattern, showing that the SDO has a coherent impact on the water south of Iceland and within the Nordic Seas (bluish colors).

ly related to SST over the north-eastern Atlantic and this parameter has therefore been used as a gyre proxy (Hátún et al. 2009b). To infer the state of the gyre even further back in time, a second alternative proxy is required. The Central England Temperature (CET) (Parker and Horton 2005) during the spring months March and April represents the Hadley Centre SST series fairly well until around 1980 (Fig. 3) when the relationship breaks down, probably due to anthropogenic warming (Intergovernmental Panel on Climate Change 2007).

Sub-decadal Oscillations in the subpolar Atlantic

Clear sub-decadal oscillations are riding on the slower decadal to multi-decadal variations of the subpolar gyre as represented by the gyre index (Häkkinen and Rhines 2004; Hátún et al. 2005).

Sea surface height (SSH) reflects the buoyancy, and thus temperature and salinity, of the entire water column. The gyre index was obtained by applying multivariate statistics on SSH data from satellites (Häkkinen and Rhines 2004) and from a numerical ocean model (Hátún et al. 2005). We have here applied the same analysis to annually averaged and gridded SSH data from AVISO (www.jason.oceanobs.com), but after a linear trend has been subtracted from each data point (Fig. 4). The sub-decadal oscillations appear as the first *mode of variability*, which demonstrates that this has been the most coherent pattern of SSH in the North Atlantic Ocean, since the early 1990s – disregarding the slower trend. These oscillations reflect the high-passed component of the hydrographic variability in the Nordic waters (Holliday et al. 2009)(Paper In Prep.). The statistical SSH analysis produces a time series (principal component), which we term the sub-decadal oscillation (SDO) index (Fig. 4a), and a spatial pattern which illustrates that this type of variability impacts the waters south of Iceland and in the Nordic Seas in a coherent way (bluish colors in Fig. 4b).

Blue whiting, Flying squid and pilot whales

Blue whiting

The gyre-induced changes of the marine climate shift the biogeographical boundaries of key plankton species (Hátún et al. 2009a), which in turn has consequences for planktivorous fish, such as the small pelagic gadoid, blue whiting (*Micromesistius poutassou*). This large fish stock spawns west of the British Isles in early spring and then migrates past the Faroe Islands to its main feeding grounds in the Nordic Seas (Bailey 1982). Blue whiting is of considerable importance for both regional fisheries and as a food source for both flying squid (*Todarodes sagittatus*) (Gaard 1988) and pilot whales (*Globalicephala melas*) (Desportes and Mouritsen 1993). A weak gyre leads to a westward and northward shifted spawning distribution (Hátún et al. 2009b), good recruitment and thus increased blue whiting stock, and a westerly post-spawning migration through the waters between Iceland and the Faroe Islands (Hátún et al. 2009a).

Flying squid

The flying squid, *Todarodes sagittatus,* is widely distributed in the North Atlantic, from the African shelf in the south to the Barents Sea in the north, and from the MAR in the west to the Mediterranean Sea in the east.

Annual spawning events of *T. sagittatus* are thought to occur in deep waters adjacent to the continental slopes. These occur in late winter-spring in north European waters, around March-April in the Bay of Biscay, mainly between October and December in Portuguese waters and September-November in the western Mediterranean (Lordan et al. 2001; Piatkowski et al. 1998) (Learmonth et al. 2006) refs therein. Spawning is also taking place farther west as Shimko (1989) observed newly hatched larvae (2-7 mm) in winter close to the Azores, and subsequent larval and juvenile drifting north-eastwards during spring. Spawning could also occur farther north along the MAR, although this has, to our knowledge, not been document yet.

In the northern Atlantic, *T. sagittatus* is known to undergo extensive seasonal feeding and spawning migration (Shimko 1989), but the occurrence of squid in the Nordic Seas is highly irregular. During the periods late 1950s-late 1960s and from the late 1970s to the mid-1980s, huge aggregations of these squid appear around Iceland, the Faroe Islands and off the north-western coast of Norway (*squid years*) (Jákupsstovu 2002; Sundet 1985; Wiborg 1972), while the squid have been virtually absent during the early 1970s and after the mid-1980s.

The squid that some years invade the Nordic waters are young and immature. Age estimation, based on statolith daily growth rings (Rosenberg et al. 1981) indicate that squid caught on the Faroes in August 1981 in average were 251 days old (n= 303) and that squid caught in September 1985 in average were 269 days (n = 36). This indicates that these individuals have been hatched in November-December. The squid, caught in Faroese in-shore areas in August in early 1980, had mantle lengths of around 18-30 cm. Age estimates from squid caught off northern Norway similarly indicates that the peak spawning of these individuals is in December-January (Sundet 1985). The concurrent squid periods around Iceland, the Faroe Island and off Norway, the observed ages and the fact that dense abundances arrive off northern Norway about 1-2 months after they have passed the Faroe Islands (Gaard 1988), indicates that these squid belong to the same stock and drift/migrate from the same spawning grounds in southern waters. The flow regime is, however, highly non-isotropic in different regions and depths along plausible migration routes, and this makes it difficult to single out any specific spawning location based on ages and mantle lengths alone.

Although decades with squid abundances in Iceland, the Faroes and Norway roughly coincide, indications of an east-west asynchrony have been observed on an *interannual* timescale. High abundances along Norway are associated with low abundances in Icelandic and Faroese waters, and vice versa (Gaard 1988), which points to an additional east-west shift in the migration route, similar to the east-west migration dynamics of the blue whiting stock, previously related to the dynamics of the subpolar gyre (Hátún et al. 2009b).

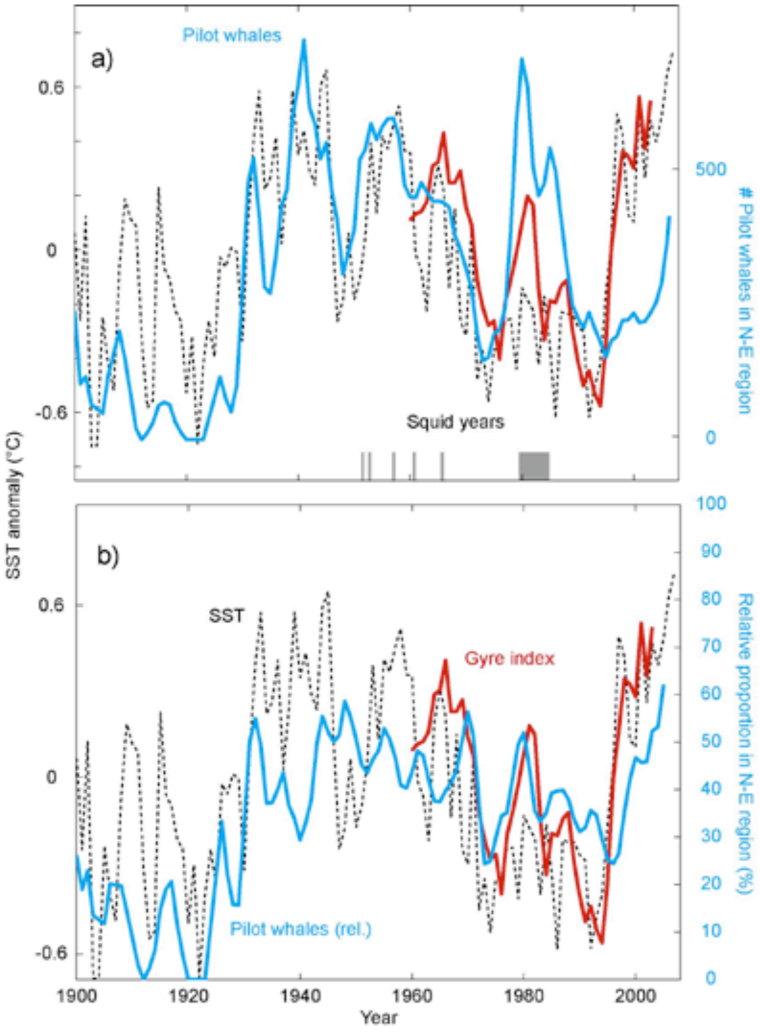


Fig. 5. Pilot whales and the marine climate. a) The number of whales beached at the north-eastern (N-E) bays in the Faroe Islands (low-pass filtered with a three-year band width) (blue), the inverted gyre index (red) and SST anomalies in the north-eastern Atlantic (black dashed). Years when squid were abundant are marked along the bottom axis. b) As a), but with the relative proportion of whales beached in the N-E region of the Faroe Islands (blue).

T. sagittatus enters shallow shelf areas in search of food (Sundet 1985), and probably not due to passive drift. Stomach analysis from squid caught on the Faroe shelf in early 1980s revealed a high diversity of prey items, like crustaceans, worms, fish and squid (cannibalism) (Gaard 1988). Pelagic fish was, however the preferred food item, where sandeel (*Ammodytes tobianus*) and blue whiting ranked on first and second place, respectively.

A special fishery for squid develops during the *squid years* (Jákupsstovu 2002). The fishery always starts in the sounds between the north-easternmost islands, where the catches also are largest, and then progresses gradually further south to the central sounds and fjords of the Faroes (Gaard 1988; Jákupsstovu 2002). This, and the concurrence of squid abundances in Faroese and Icelandic waters, indicates that the squid migrates through the Iceland-Faroe gap (Fig. 2b), drifts eastwards in the Faroe Current from where it makes an on-shelf excursion (Jákupsstovu 2002).

Pilot whales

Very little is known about any annual or seasonal migration pattern of pilot whales. The whales occur year-round in Faroese waters, but years with high abundance are typically associated with much elevated numbers during the months July-September (Jákupsstovu 2002), especially in years when *T. sagittatus* are abundant. It is, thus, likely that the whales follow the squid in search for food (Bloch et al. 1990). When squid abundances are low, blue whiting is a preferred prey item for pilot whales, (Desportes and Mouritsen 1993).

The pilot whale catches seem to be concentrated in whaling bays in a particular region of the islands. A clear change in the distribution of catches by whaling bays may indicate a change in the direction from which schools approach the islands, and may thus shed light on pilot whale migration (Zachariassen 1993). In this respect a grouping into north-eastern (N-E) bays and south-western (S-W) bays has been considered appropriate (Zachariassen 1993). The N-E bay proportions seem to correspond with a high grind rate (Zachariassen 1993), and pilot whale catches in the N-E bays (Fig. 2b) closely follow the gyre index and SST variability in the Rockall-Iceland area during the period 1900-1990 (Fig. 5a) (Hátún et al. 2009a) – a weak gyre and warm conditions have been associated with large catches.

A plausible mechanism is that the warm conditions during periods with a weak gyre allow an increased migration of blue whiting through the Iceland-Faroe gap, which attracts both *T. sagittatus* and pilot whales through this passage. This, in turn, leads to high abundances of all species in the eastward flowing Faroe Current, and the probability of on-shelf migration of T. *sagittatus* and pilot whales to the N-E bays increases.

But although the link between environmental indicators and the catch rate are surprisingly close, the very high catch rate around 1980 and the low catch rates after 1995 cannot be explained by environmental variability alone. The total Faroese catches (N-E and S-W) have persistently declined since the 1980s and this decline is strongest in the S-W area (not shown). The proportion of the total catches (%) from the N-E bays follows the main temperature changes during the twentieth century, illustrating that the climate signal is clearer in the N-E region than in the S-W region (Fig. 5b). This N-E/S-W distribution index does show a large post-1995 increase. Hence, although the number of whales caught in the N-E bays did not increase much after 1995, these catches represent a larger proportion of the total catches in recent years than at any-time previously during the twentieth century.

The pilot whale catches in the N-E region and the Central England Temperature (CET), used as a proxy for the long-term oceanic temperature variability west of the British Isles give a temporally unique perspective of the discussed variability. These series co-vary fairly closely from 1709 to the 1980s, except for periods around 1840 and the mid-18th century (Fig. 6). It therefore appears that large pilot whale catches in the N-E region have coincided with periods of warming in England.

Discussion

The relative proportion of whale catches in the N-E compared to the S-W bays in the Faroe Islands, has increased drastically after the large post-1995 decline of the subpolar gyre, which indicates that the east-west regulation of the gyre might still be in force. But the general abundances of whales have remained low after the 1980s, which points to an ocean-basin scale reorganization of the whale population likely linked to low abundances of *T. sagittatus*.

Possible explanations for the post-1980s decline

The pilot whale is categorized as a data deficit species (www.nammco.no) and the information on *T. sagittatus* is also very scarce, so the proposed explanations for the post-1980 decline of squid and pilot whale abundances in Faroese waters should be considered accordingly.

The decline could be a manifestation of an unprecedented poleward bio-geographical shift, due to Global Warming. The late 1980s warming (Fig. 1b) resulted in increased abundances of warmer water whale species in the cetacean community of north-west Scotland, while the number of colder water species, including pilot whales, declined (MacLeod et al. 2005). The bio-geographical range of pilot whale occurrence is *Warm temperate* to *Sub-polar*, following the definition in MacLoed *et al*. (2005), and if the temperature rise continues, it has been predicted that colder water species like the pilot whale might be entire lost from the north-west Scottish cetacean community (MacLeod et al. 2005). This bio-geographical perspective is strong in its demonstration of simultaneous shifts in several whales occupying similar bio-geographical ranges, but perhaps weak due to its ignorance of direct trophic linkages. We consider this explanation as probable, but not satisfactory, since causal mechanisms are preferred.

The late 1980s temperature increase in the inter gyre region (Fig. 1a,b) might have spatially shifted the spawning distributions of *T. sagittatus*, resulting in less drift/migration towards Faroese waters. Little is known about the relative importance of the individual spawning grounds around the inter-gyre region. If the main spawning grounds are found along the European continental shelves, then it is difficult to see how the warming can drastically change the drift/migration pattern. If, on the other hand, the most important spawning grounds are found along the MAR, then a northward displacement due to warming could place the offspring into the NAC that would take them along a more westerly route towards Iceland and Greenland. We also consider this explanation as being plausible, but since data on *T. sagittatus* is very scarce, the details mentioned here remain speculative.

The declined in abundances of *T. sagittatus* and pilot whales after the late 1980s could be reinforced by the pelagic fleets primarily targeting blue whiting in west of the British Isles. The efficiency of this fleet has increased dramatically during the 1990s, and the huge trawls are filtering large volumes of water and could thus be decimating the northward drifting/migrating squid. Large specimens of *T. sagittatus* are found hanging from the meshes during years when the squid is present (per. comm. Rógvi Mouritsen and Bogi Jacobsen). But just small biomasses of squid are caught by the trawl, and the damage done to the squid that escape through the meshes is unknown, so this explanation is therefore not well supported.

Prey-limited on-shelf migration of squid and whales

Periods with poor or highly variable production on the Faroe shelf might have limited the degree to which the Faroese pilot whale time series is representative for the open-ocean whale population dynamics. Schools of pilot whales must migrate near land in order to be sighted, and subsequently driven into the whaling bays. The whales follow *T. sagittatus*, and the squid in turn probably enter the shelf in search of sandeel or other pelagic fish (Gaard 1988; Sundet 1985). So *i*) could the biomass of small pelagic fish on the Faroe shelf limit on-shelf migration of squid and pilot whales and *ii*) could such a limitation be related to variability in the marine climate?

A preliminary comparison between total annual catches of *T. sagittatus* made by R/S Magnus Heinason on the Faroe Shelf since 1994, and the abundance of sandeel in cod stom-

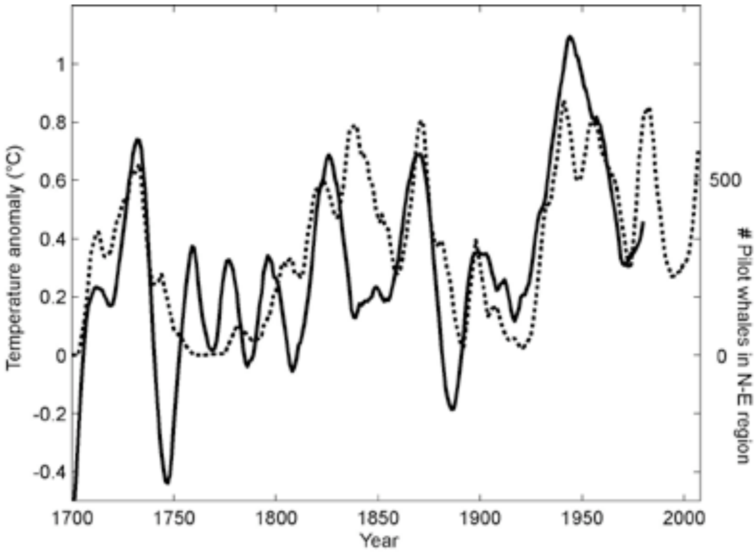


Fig. 6. A three-century perspective. The number of whales beached at the north-eastern (N-E) region of the Faroe Islands (dashed line), and the Central England Temperature (CET) anomaly (solid line). The time series have been low-pass filtered using band widths of 3 and 12 years, respectively. The CET does not represent the SST west of the British Isles after around 1980 (see Fig. 3), and the post-1980 period is thus omitted.

ach samples indicates that there might be a relation (Fig. 4). High abundances of sandeel have previously been associated with increased on-shelf primary production during cold years (Gaard et al. 2002; Hansen et al. 2005) and such years are associated with a high SDO index (Fig. 4). The bio-physical processes represented by the SDO index will be substantiated elsewhere (Paper In Prep.).

Comparing this short-term variability with the whale series did not give any conclusive result (not shown). The statistical quality of these biological series are, however, very low, and these comparisons should merely be regarded as indications.

We are not trying to infer that limitation by the on-shelf ecosystem can explain the large post-1980s decline. But as indicated by cod recruitment variability, the biomass of sandeel or other pelagic prey species has been both smaller and much more variable after 1980s, than previously observed (Steingrund et al. 2010). This mechanism provides a new perspective on the interpretation of the whale series – especially during previous periods when the on-shelf production might have been low.

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Whales and whaling in Lucas Debes' Færoæ & Færoa Reserata from 1673[1]

KATE SANDERSON

From the evidence of available historical sources, in particular surviving bailiff's accounts and parliamentary records, catches of small whales had become quite a regular part of the Faroese subsistence economy by the mid-seventeenth century, and the complex and organised system of message-sending, driving, killing and dividing a school of pilot whales which survives today was well-established. This was probably also true in the late sixteenth century, at the time of Jacob Oudensøn's account to Claussøn Friis (Storm 1881), but neither this source, nor the few other extant records from that time provide explicit detail which can shed light on the exact procedures and methods of whale hunting in earlier centutries.

Joensen (1976) suggests that whale drives most likely became an organised activity from around 1550 onwards, when the Faroes had „declined to the position of a local community without expansive possibilities" (p. 6), controlled largely by absentee landlords, and thus making whale meat a significant supplement to the subsistence diet. From 1599 until around the mid-seventeenth century, records of whale catches show that schools of small whales were stranded and utilised almost every year, and in some years single schools numbered up to 400 or more whales. No records of whale catches have survived for the period from around 1640 to 1709 (Joensen and Zachariassen 1982, 99).

Lucas Debes's account of the Faroes, *Færoæ & Færoa Reserata (Færøernis oc Færøeske Indbyggeris Beskrifvelse)* published in 1673 (Joensen 1963; Rischel 1963), was the fullest and most comprehensive description of the Faroes of its time, and was indeed the prime authoritative source of information on the Faroes until the end of the following century when it was superseded by the work of Svabo (Djurhuus 1976) and Landt (1965).[3] Debes' description was translated into English for the Royal Society in London only three years after it first appeared (Debes 1676), and this translation made the work much more widely accessible in its own time than if it had remained only in the Danish. For an account of the background to the English translation and its reception, see Seaton (1935, 215-18). All English translations of Debes cited in this text are taken from the original translation by Sterpin (Debes 1676).

Lucas Debes, born in 1623 in Stubbekøbing, Denmark, came to the Faroes in 1651 at the age of 28, and in 1652 took over the position of parish priest in South Streymoy, as well as being appointed principal of the Latin school in Tórshavn. As was the custom at the time, he also „inherited“ the wife and nine children of the former clergyman, and he remained for the most part in the Faroes, where he died in 1675. Debes' great interests were theology and the natural world, his interest in the latter stemming from his university days in Copenhagen, where he had the learned Ole Worm as a scholarly supervisor and private tutor. For details of Debes' life and work see Helgason (1940) and Rischel (1963, vol.II).

A detailed description of the pilot whale hunt is contained in Chapter III of *Færoæ & Færoa Reserata*, entitled „Om van-dets Frugtbarhed“ (“Of the Waters Fertility”). This follows a brief discussion of the kinds of fish found in Faroese waters, and a lengthy account of seal hunting, which constituted an important part of the subsistence economy in the seventeenth and eighteenth centuries. Debes’ account of whales and whaling begins:

> Hvale findes her adskillige under Landet; der kommer et Slags til Landet, som kaldes Grindehval (Joensen 1963, 74).
>
> There are found several sorts of Whales under this Land, amongst which there cometh one sort, called Grind-Whale..., (Debes 1676, 171).

Debes then cites Claussøn Friis’s explanation for the origin of the word grind to refer to these whales, and proceeds to describe in detail the circumstances in which the whales are sighted, and the means by which the message *(Grinde-bud)* is sent, including the lighting of bonfires on strategic points to communicate the position of the whales to people on other islands. The methods of driving, beaching and killing the whales are also described at length, including the „great crying, noise and casting of Stones“ which occurs in the process of „driving them as fast as they can upon the Sands“ (Debes, 1676, 173). The dramatic and exciting spectacle of the kill is stressed in his description, in which he says the whales are killed „with such fury on both sides, that the water becometh as red as blood“ (Debes 1676, 174). In his account of the kill, Debes remarks on the apparent passivity of the animals:

> Og er det synderligt at anse, at disse stærke Bæster gøre ingen Modstand, aleneste dukke under for Baadene og Folket, hvor de kunne, indtil Døden griber dennem an...(Joensen 1963, 75)
>
> … it is a strange thing to see that these strong creatures make no resistance, but only plunge as well as they can before the boats, and people, till death cometh upon them..., (Debes 1676, 174)

But he also emphasises the risks facing the participants, particularly from the thrashing of the whales' tails which can „beat sometimes the boats to pieces“ (Debes 1676, 174), and points to the uncertain success of the catch and the possibility that the whales will escape to sea or will not allow themselves to be driven easily, when they continue to dive and evade their pursuers: „.. though it happeneth also sometimes, that they will at last suffer themselves to be driven in no more, plunging and diving so much and a long way under the water, that they must let them go..."(Debes 1676,174-175).

Debes' account makes clear that a pilot whale hunt in the seventeenth century demanded the utmost of the participants and the involvement of the entire community. That a complex system of message-sending by means of bonfires was well established reflects the importance of gathering as many boats and men for the drive as possible, at a time when the total population in the islands probably numbered around 4,000 (Joensen 1987, 102). The duration of the kill, no doubt dependent on the number of whales and available manpower, was obviously not affected by a desire to minimise the suffering of the animals: „When they have killed as many as they can get, which lasteth well a whole day or longer....“ (Debes 1676, 175), but rather to provide as much food as possible for the long winter months ahead.

The self-stranding of large groups of whales is also mentioned by Debes as sometimes occurring in foggy weather, Debes also refers to *Grinde Mørke*, and he cites a particular example of this, „which happened for few years since in Tiorneviig [Tjørnuvík]“ (Debes 1676, 176). Debes, like Claussøn Friis before him, refers to the fact that in ancient times whales came more often and in larger numbers than now, but he also reports that 1000 whales were taken in two catches in Skálafjørður in 1664. Although these catches are not recorded in any other contemporary sources, there is no reason to doubt Debes's information, since these catches are said to have occurred during the time he himself was in the Faroes. They have not, however, been incorporated into the statistics of pilot whale catches which are assumed to begin with the four stranded *nyninger* at Lítla Dímun in 1584 (Joensen and Zachariassen, 1982).

What follows is a physical description of the whales, and from the detail and precision it is clear that Debes must have had plenty of opportunity to examine these animals first hand. He then explains the means by which the meat and blubber is preserved, prepared and eaten. He likens the meat to beef, saying that because of this „...the Inhabitants take these Whales to be, and call them Sea kine *[Sø-kvæg]*“ (Debes 1676, 177). Dry-salted blubber, according to Debes, is to the uninitiated virtually indistinguishable from bacon (Joensen 1963, 76).

Debes' account of the pilot whale hunt can in many ways be seen as a pioneering text in the development of a narrative tradition of the pilot whale hunt. The description of the Faroes was motivated by an external scholarly and antiquarian interest in the lands of the far north and their people, but its author, although not Faroese, was so familiar with conditions of life in the Faroes that it can also be regarded as an „inside“ account of Faroese society. Its speedy translation to English helped to disseminate a broad range of information about the distinctive aspects of folk life, not least of which was the pilot whale hunt.

In this context, Debes' account of the pilot whale hunt is the beginning of what was to become an enormous body of writing about a phenomenon already perceived as a distinctive feature of Faroese life. In later centuries, with the emergence of Faroese written texts, this discourse can perhaps be divided more clearly into local and foreign perceptions of the hunt. In a purely historical sense, the detail of information related by Debes tells us that the whole process of driving, killing, dividing and utilising small whales was certainly a significant part of Faroese life in the seventeenth century. There is little of mystery or superstition about pilot whales as such (apart from the reasons for their mass strandings), simply because they were common, familiar and accessible for practical purposes. The terminology associated with this kind of whale and the methods of the catch *(Grinde-bud, Grinde Mørke)* is obviously well-established by this time, as was probably also true in the late sixteenth century. But Debes's account, more so than that of Claussøn Friis, reflects a perception of these particular whales as being much closer to the domestic sphere of existence. The driving of the whales, for example, is also compared to that of driving domestic livestock, ("... and then when God giveth his blessing, they can drive them where they please as if it were a Flock of Sheep or Cattle", Debes 1676, 172), and the very degree of detail equates the use of these creatures in practical terms with the hunting and even farming of land animals, with their meat and fat likened to that of land mammals such as cattle and pigs.

But the „Grind-Whale" is only one of a variety of whales discussed by Debes. His account of whales is presented within the broad framework of a „natural history", the aim of which was to systematise and order the natural environment in terms of its significance for man ("Of the waters fertility"), appropriately sub-divided into its existing categories (fish, seals, whales). This framework in fact provides Debes with the opportunity to discuss at length the most unusual, and therefore most interesting varieties of whale.

The *Hval-Hunde* surfaces again in Debes' account, and it is Claussøn Friis's earlier report of the same which prompts Debes to include it in his work. Having tried to verify its existence with little success, he then relates that he finally received a first-hand account of this strange beast which was seen at the time of the large catch of whales in 1664, swimming between the whales and the land, and described in the following way:

> ... var aldeles ligt en Hund med den Part som var over Vandet; han var graaagtigt, laadden med lange Øre, som en engelsk Hund (Joensen 1963, 77).
>
> ...(it) was in every manner like a Dog, as for those parts which were above the water, it was of a grey colour, hairy, with long ears like an English rough Spaniel.. (Debes 1676, 178).

To dispel potential doubts and scepticism as to the real existence of this creature, Debes adds: „... this hath been told me by men worthy of credit, and the fame of it grew common over the whole Country" (Debes 1676, 178). He also supports his account by referring to the report of what he suggests is a similar beast mentioned in Johan Theodor de Bry's description of his West India Voyages (1619), although it seems De Bry's „Meerlewen" has little in common with Debes's Hval-Hunde (Rischel 1963, 118). Debes's reliance on references to contemporary literary sources such as De Bry, despite their apparent lack of specific relevance to his Faroese subject matter, would suggest that Debes remained, as his predecessors, largely dependent upon the perceived authority of written sources to give his work the „credibility" of a learned account. The personal verification of such wondrous phenomena by oral informants can then be seen as a means of underlining the primacy of his written sources, rather than the other way around.

No other record of the „whale dog" is known from any other Faroese accounts or folklore, and its widespread fame „over the whole Country", if this was the case at all, must certainly have been short-lived. It seems likely that Debes has taken Claussøn Friis's term for the killer whale, *Hval-Hunde*, and given it a configuration in keeping with its name, adding elements of other known descriptions of the strange sea-counterparts of land animals which formed a part of the popular taxonomy of marine life in the seventeenth century. The very need to embellish the *Hval-hunde* with elements drawn from other sources would suggest that it was most certainly unknown, at least by that name, in the Faroes in the seventeenth century. Significantly, Debes ends his digression on the „whale dog" with the comment:

Der findes vel endnu flere Monstra udi Havet, som ikke ere aabenbarede (Joensen, 1963, 77).

There are doubtless more Sea Monsters yet, then have been known hitherto (Debes 1676, 179.)

The next section in Debes' account of whales deals with the *døglingur*, or bottlenose whale, which is considered worthy of special mention on two counts. Firstly, the unusual manner by which it is caught is described at some length:

... er det stille i Søen, ro de tæt til Hvalen, hvilken bliver stille liggende hos Baaden, muligt han mener at det er hans Mage, midlertid stikke de et Hul udi det tykke Flæsk, gemenlig udi Øjenlaaget, hvor udi de gør Linen fast: Stinget smerter hannem intet, men aleneste kilder hannem, og derfor taaler han det lettligen. Naar de saaledes have gjort Linen fast, ro de til Sanden med hannem, hvort hen han lader sig letteligen drage... Joensen 1963, 77-78)

...if it be calm weather, they row close to the Whale, that lyeth there still by the Boat, thinking it perhaps to be its Mate: in the meantime they pierce a hole in the fat of its eyelid, wherein they fasten the Rope; the piercing whereof hurteth it not, but only tickleth it, wherefore it suffereth the same willingly; when they have thus fastened the Rope, they row to a Sandy Bank, whither it suffereth itself easily to be drawn... (Debes 1676, 180)

Once again, Debes cites De Bry's account, this time accurately, on a description of a similar method of hunting conducted by the Indians on the coast of Florida (Rischel 1963, 119). The record of the stranding of three bottlenose whales in 1584 also includes a brief description of the manner in which they were caught, and agrees in general with Debes' description but makes no mention of the unusual aspect of piercing the eyelid to secure the whale (Zachariasen 1961, 88-89).

The other peculiar aspect of the *døglingur*, as reported by Debes, is the regularity of its occurrence, usually in groups of three or four, or six at the most, „and if they fail one year there comes the next year twice as many“ (Debes 1676,179). Strangest of all, they almost only come to the bay of Hvalba in Suðuroy: „It is very remarkable that this Dogling Whale cometh usually no where in Feroe, but in Suderoe, and that specially in Qualboes Inlet, every year about Michaelmas“ (Debes 1676, 179).

The unusually regular occurrence of bottlenose whales, most often in Hvalba on the southern island, is a phenomenon which has continued to the present day, the reasons for which are still not fully understood. Most interesting in Debes's account is the fact that he includes a version of a local folktale that incorporates a popular explanation for why the døglingur only comes to Hvalba.

Briefly, in Debes's version of the tale the *døglingur* appears after a deal is made between a giant in Mykines who wins a fight against a troll on the opposite island after the troll challenges his right to occupy the island. The troll promises to supply only that island and nowhere else in the Faroes with one kind of whale and one kind of bird each year, on the condition that no-one mocks the whale, in which case it will never return. The troll upholds his part of the pact, but an unwary man mocks the yearly whale because it only has one eye, after which it never returns to Mykines, but goes to Hvalba instead (Joensen 1963, 79).[4]

In the general context of Debes' account it is interesting to note that, although introducing it as nothing more than a „Fable" from „the darkness of Paganism", it nevertheless functions as supportive information about the particular type of whale he is discussing. Having recounted the tale he does, however, qualify his initial scepticism as to its fabulous nature with the following remark:

> ...dog haver der meget hændt sig paa Tider iblandt Vantroens Børn, baade her og andre Steder, som nu for os i dette vort Ljus sjunes ganske urimeligt og utroligt; saa som endnu dagligen udaf Trold-Folk udi deres Mørkhed meget begaas, hvilket Ljusens Børn ikke kunne forstaa, meget mindre gøre dennem det efter (Joensen 1963, 79).
>
> Though many things happened in those dark times amongst the Children of infidelity, both there and other places, that seem now in this our light to be very disconsonant and incredible, as yet dayly many things are perpetrated by Witches [Trold-Folk], which the children of light cannot apprehend, much less imitate them therein. (Debes 1676, 183-4).

The final significant part of Debes's section on whales discusses the *Trold-Hvale*, those whales which are known to be most dangerous and which have a tendency to play with boats. Most alarming of all is when a *Trold-Hval* sometimes „riseth from under the water under the Boat, so that it standeth fast on its back as upon a Rock, which often bringeth the people in great danger“ (Debes 1676, 184). The familiar motif of whale as island is echoed in this fear, but its basis in a genuinely perceived risk from large gregarious whales at sea is also clear. What follows is a lengthy treatise on the various means which can be successfully employed by seafarers to drive these great beasts away from the boat. The most effective of these, according to Debes, is the substance *Bevergel* or castoreum. It is believed to be the strong smell of the substance which causes the whale to sink like a stone to the bottom. In later times it is known that castoreum (or a strong-smelling substance of some kind), known as *bævur* in Faroese (Young & Clewer 1985), was either kept in a hole bored in the bow of the boat, or in a separate wooden cylinder attached to fishing lines.[5] Debes relates that, alternatively, slivers of juniper wood can be cut into the sea as an effective method of repelling the *Trold-hvale*. He goes on to discuss the reasons why such substances can be said to have such an effect on whales, in particular juniper, which was also known to have the property of driving „the dead Foetus out of its mothers Womb; by which vertue the Whale is also driven“ (Debes 1676, 186).

The section dealing with the means of repelling whales from boats was translated to Icelandic only one year after the publication of Debes' book. Not only does this give some idea of the notoriety of Debes' work so soon after publication, but it would also suggest that such information was considered valuable for seafaring Icelanders as well (Rischel 1963, 85). This further points to the perception of large whales encountered at sea as a real peril to fishermen and seafarers. Vivid tales of all kinds of marine monsters, still so much an integral part of popular belief at the time, would certainly have given the general sense of vulnerability at sea an added element of terror.

Debes' interest, as well as that of Olaus Magnus (Granlund 1972) and Claussøn Friis before him, in the appearance of marvellous and legendary sea-creatures and the verification of their existence, was in part a reflection of a desire to classify wherever possible a range of manifestations from the unexplored environment of the sea, and to give them an appropriate place in the structuring of the world. Their existence was supported with reference to analogous examples from standard and popular contemporary written sources, backed up by, rather than reliant upon, the testimonies of local informants.

In digressing at length on such phenomena as the *Hval-Hunde, Throldhval* and the mermaid (a brief account of which concludes his chapter), Debes was catering to the preoccupation with wondrous beasts and supernatural phenomenon prevalent in the scholarly world for which he wrote his description of the Faroes, and which is also borne out by the fact that he was requested to provide Ole Worm with any accounts of unusual fish encountered in the Faroes (Rischel, 1963, 32). Whales in particular constituted an element of the natural world which remained, for the most part, unclassified. In fact, as marine travel and technology gradually expanded, such inherited knowledge of whales and their potential dangers at sea no doubt gained new life, so to speak, in a period when greater expanses of the world's oceans were being explored, but when many of their creatures were still far from fully understood or considered as potentially controllable resources.

Although contained within a text which was largely informed by the scholarly discourse to which it belonged, Debes' specific and detailed account of the driving of pilot whales in the Faroes is a valuable and detailed source of information about the degree of organisation and the conduct of the hunt in the seventeenth century, and the significance it obviously had for the local subsistence economy. Debes' account of the pilot whale drive derived from his own and local Faroese knowledge, although its literary context had the wider and outwardly-focussed purpose of ethnographical and geographical description. As such, it is an invaluable starting point for a more detailed examination of the place of whales and whaling in subsequent foreign and Faroese narrative discourse.

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Notes

1 The article has been adapted from, *Grindadráp – A textual history of whaling traditions in the Faroes to 1900*, Master of Philosopy thesis, University of Sydney, Australia, 1992.

2 Director, Department of Oceans and Environment, Ministry of Foreign Affairs, Faroes. The views expressed are in the author's private capacity.

3 The work of Thomas Tarnovious, however, should be mentioned briefly. In his youth, Tarnovius was a student of Debes in Tórshavn, and wrote a short description of the Faroes which was completed in Denmark in 1669, but which was never published. It was not an influential or widely-used work, and its section on whales contains nothing which is not also found in Debes. It is unlikely, however, that Tarnovius and Debes consulted each other's work, although they may have discussed it in Copenhagen at some point. On the life of Tarnovius and the genesis of his Faroe description, see Hamre (1950).

4 Matras (1960) has discussed the variant versions of the legend of the *døglingur* in detail and the substance of the idea that the whale had only one eye. In conclusion he points to Hammershaimb's explanation that the name *døglingur* (from Norse **dogr*, meaning king or prince) may have originally been connected with a similar myth in which the troll was in fact the god Oðin (who had only one eye) and was thus by extension associated with the whale which the troll provides for the island (Matras, 1960 p. 7).

5 See Thorsteinsson (1976, p. 3). The historical museum in Tórshavn has two so-called *bævurhylki*, containers for this substance, made of wood, dating from the first half of the nineteenth century, which were carried on board when fishing. Thorsteinsson also refers to two other substances, not mentioned by Debes, which were thought to drive large whales away, namely bull dung and chewed tobacco.

The vertical distribution of the vegetation in the Faroe Islands past and present, south and north

ANNA MARIA FOSAA

Abstract

The vegetation in the Faroe Islands can be divided into three altitudinal zones. These are a temperate zone in the lowland characterized by heath, a low alpine zone in the mid mountains characterized by grass-land, and an alpine zone in the high mountains, characterized by fell-fields and *Racomitrium* heaths. These vegetation zones were originally defined qualitatively in the 1930ies. In the beginning of the 21st century, they were re-determined, this time by quantitative sampling. In the later studies, the vegetation zones were found to be around 100 m lower than in the older studies. This could be due to cooling. With the observed cooling of 0.25^{o}C during the period from the old to the new study and a lapse rate of 0.8^{o}C, a lowering of the alpine zone around 30 m would be expected. The length of time between these two studies should also be sufficient for species to migrate such a distance. This conclusion is weakened by the methodological differences between the two studies, but it is strengthened by the fact that all of the five mountains studied showed the same trend. The vertical extent of the zones varied from one mountain to another, but in every case, the boundaries were found to be at lower altitudes than in the older study. The new study included measurements of soil temperature, which were used to interpret differences observed between south- and north-facing transects. It was found that the temperate zone with heath vegetation was missing on the north-facing transects. This can be explained by the difference (0.4°C - 0.8°C) between the observed soil temperatures on the north and south-facing transects at 150 m altitude. The observed relationships between soil temperature and the vegetation also allow inferences to be made about the vulnerability of the vegetation in a climate change scenario.

Introduction

As a result of a warming climate on the earth, it has been predicted that vegetation belts will move northwards in the northern hemisphere and the mountain vegetation will shift towards higher altitudes (IPCC, 2007). This conclusion is supported from past climate changes, which have had strong impacts on the distribution range of species. Similar effects can be expected in the future (Peters & Darling, 1985; Huntley, 1991). Different tolerances to climate change can, however, make different species respond in an individualistic manner to climate in both space and time (Gleason, 1926; Chapin & Shaver, 1985).

The potential impact of climate change has been studied at the individual species level (Chapin & Shaver, 1985; Crawford, 1997; Sætersdal & Birks, 1997) and on a broader scale in plant communities or vegetation zones (Woodward, 1983; Peters & Darling, 1985; Molau & Alatalo, 1998; Duckworth *et al.*, 2000). Although the species respond as individuals, studies at the vegetation level are necessary to put species into a broader context.

The distribution of mountain plants may be seriously affected by climate change (Huntley, 1991; Körner, 1995; Crawford, 1997). The effects of warming can be categorised as: (1) upward migration of plant species; and (2) disappearance of

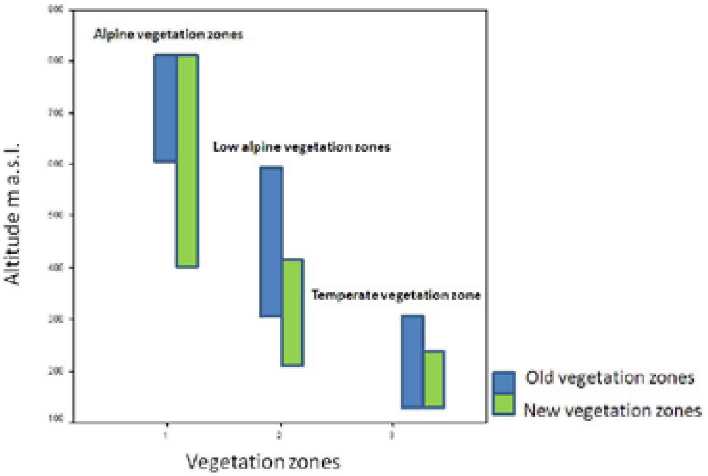

Fig. 1 *The figure shows the three vegetation zones defined by Böcher 1937 (old vegetation zones) and by Fosaa 2004 (new vegetation zones).*

snow patches and their associated communities (Grabherr *et al*., 1995). Both can lead to the disappearance of species if the mountains are not high enough (Grabherr *et al*., 1995).

The discussion of possible effects of climate change on vegetation has tended to focus on continental areas or on the global scale, where zones of extensive homogeneous vegetation or biomes are found in relatively similar climatic regions (Woodward, 1987, 1992; Prentice *et al*., 1992; Sykes *et al*., 1996; Ni *et al*., 2000). Vegetation changes in oceanic and coastal areas have in general had little attention compared to continental areas. Because of a relatively small temperature range during the year, oceanic and coastal areas are different from continental areas and may respond differently, thus, requiring individual consideration (Crawford, 2000, 2001). In particular, the North Atlantic oceanic areas have been little studied in this regard, but according to predictions, global warming in oceanic areas in NW Europe will be accompanied by increased precipitation (IPCC, 2007).

In 1937, Böcher defined three vegetation zones along altitudinal gradients in the Faroe Islands. In the lowland, he proposed a vegetation zone (0-300 m a.s.l) with heathland as the characteristic vegetation. At higher altitudes (300-500 m a.s.l.), the heathland disappears and grassland is the dominant vegetation type, and highest (500-882 m a.s.l.), *Racomitrium* heaths are the characteristic vegetation, and *Salix herbacea* is common (Böcher, 1937).

In 1999 and 2000, three similar vegetation zones were again defined along an altitudinal gradient in the Faroe Islands. This time based on quantitative analysis from five mountains as well as on north- and south-facing slopes. The three zones were found at lower altitudes: A temperate vegetation zone (below 200 m a.s.l.), a low alpine zone (200-400 m a.s.l.); and an alpine zone (above 400 m a.s.l.). This study also included measurements of soil temperature, Fig 1.

The aim of this paper is firstly to discuss the changes in vegetation zones in relation to climate differences between the two studies. Secondly, differences in vegetation zones in different aspects (south and north facing slopes) are compared. Based on these conclusions and on measured tolerance of individual species, the vulnerability of the vegetation zones to the predicted climate change is discussed.

Study area

The treeless Faroe Islands are usually placed in the temperate vegetation zone in the lowlands and in the arctic vegetation zone in the highlands (Ostenfeld, 1905-1908; Böcher, 1937). The highly oceanic climate in the Faroe Islands, with an annual mean temperature of 7°C and an annual mean precipitation of 1,500 mm (lowlands), yields measurable precipitation on 75% of the days in a year (Cappelen, 2003). The climate is greatly influenced by the North Atlantic Current and by proximity to the track of atmospheric low-pressure systems in the North Atlantic region. Consequently, the climate is humid, variable, and windy. Using the ecoclimatic-phytogeographical system, Tuhkanen (1987) included the Faroe Islands in the highly oceanic sector of the hemiboreal sub-zone.

Grazing has a profound impact on the vegetation in the area. Sheep are the most important herbivore, with an average number of around 44 sheep/km2 (Thorsteinsson, 2001). The impact of geese and hares, however, cannot be ignored, and, in addition, there are larger herbivores like cows and horses. The soil in the Faroe Islands is relatively nutrient poor (Olsen and Fosaa, 2002; Lawesson *et al.*, 2003). The pH increases with altitude with a minimum value of 4.8 at low altitudes and a maximum value of 5.8 at high altitudes (Olsen and Fosaa, 2002).

This is a result of a more humus-rich soil in the lowlands and a less acid mineral soil at higher altitudes. Vegetation cover also decreases with altitude (Fosaa, 2004).

Material and methods

In July-August 1999 and 2000, the vegetation on five mountains in the Faroe Islands was investigated along five transects, from the highest elevation (856 m a.s.l.) down to an elevation of 150 m a.s.l. Two of the mountains have north-facing aspects, one has a south-facing aspect, and two have southwest-facing aspects. Both the south-facing and southwest-facing aspects will be referred to as south-facing aspects in the text. The length of the transects varied from a long transect (4.0 km) with a gentle slope to a short transect (1.2 km) with a steep slope along its whole length. A total of 538 plots were sampled on the five mountains. The vegetation was sampled in 50 m altitudinal intervals from 100 m^2 quadrats (macro-plots). In each macro-plot, 8 smaller (0.25 m^2) quadrats (meso-plots) were placed randomly. The meso-plots were subdivided into 25 (0.01m^2) micro-plots and the presence/absence of each plant species was recorded for each micro-plot.

Hourly soil temperatures were measured 1 cm below the soil surface at 50-m altitudinal intervals on the five mountains using TinyTags data loggers. The period of measurement was from September 1999 to August 2000 for all the mountains except for Mosarøkur (M), where the period was August 2000 to July 2001. Details of the measurements and their processing have been reported by Fosaa *et al.* (2002). To extract characteristic features, values for five key parameters were computed: the annual mean temperature, the mean temperature in the warmest month (August), the mean temperature in the coldest month (February), growing degree days, and number of days with snow cover. Growing degree days were calculated by summing the temperature excess over 5°C for all hourly observations in a year and dividing by 24 (Molau & Mølgaard, 1996). Number of days with snow cover was calculated as the number of days with daily temperature range below 0.5 °C and the average daily temperature below 1 °C.

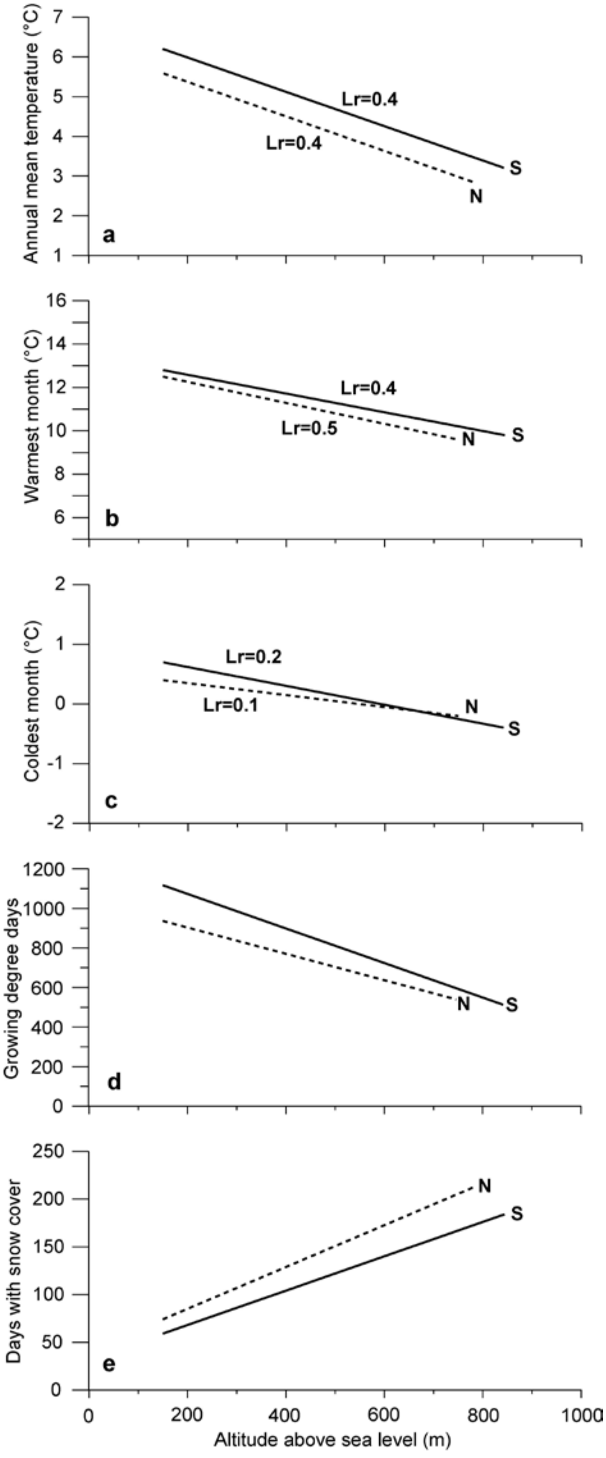

Fig. 2 *Regression lines for five different temperature parameters on two opposing mountain slopes:* **N** *is a north-facing slope and* **S** *is a south-facing slope. (a) the annual mean temperature, (b) the mean temperature in the warmest month, (c) the mean temperature in the coldest month, (d) growing degree days, and (e) number of days with snow cover.*

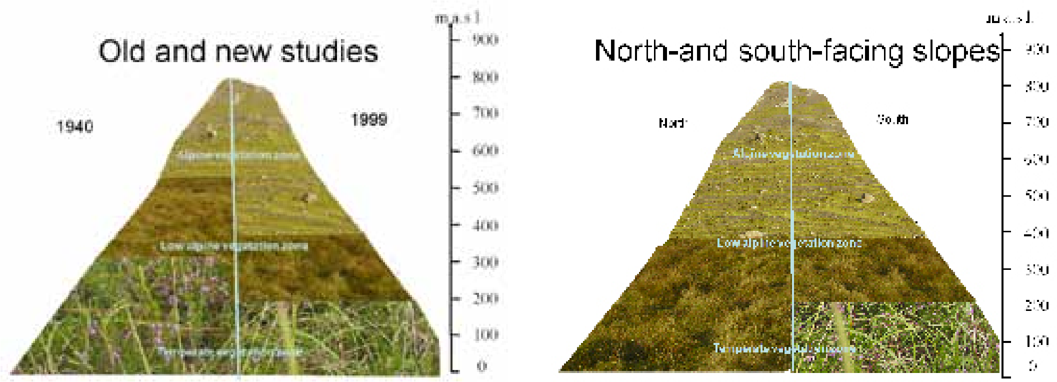

Fig. 3. *An illustration of the difference in vegetation zones between an old and a new study (a) and a north- and a south-facing transect.*

Results

Twelve different plant communities are described. These twelve communities are grouped into four main vegetation types: 1) dwarf shrub vegetation, 2) moist grassland vegetation, 3) *Racomitrium* vegetation, and 4) open grassland vegetation. From these twelve communities it is possible to define three significantly different altitudinal zones (Fosaa, 2004). The temperate lowland zone is characterized by dwarf shrub heath vegetation with two plant communities (*Calluna vulgaris-Nardus stricta* community and *Empetrum nigrum-Calluna vulgaris* community). This zone extends from the lowland up to 200 m a.s.l. and is restricted to south-facing transects only.

Above this vegetation zone, we find the low alpine vegetation zone with moist grassland vegetation. This zone contains three communities (*Thymus praecox-Vaccinium myrtillus* community, *Nardus stricta-Potentilla erecta* community and *Galium saxatilis-Anhtoxanthum odoratum* community). Since the moist dwarf shrub vegetation is missing on north-facing slopes, the moist grassland vegetation covers the altitudes from lowland up to the alpine zone on the north-facing transects.

This vegetation zone is replaced by the alpine vegetation zone above 400 m a.s.l. The alpine zone is characterised by two main vegetation types 1) Open grassland vegetation with the four plant communities (*Koenigia islandica* community, *Festuca vivipara-Agrostis capillaris* community, *Bistorta vivipara-Festuca vivipara* community and *Deschampsia flexuosa-Rhy-*

tidiadelphus loreus community) and 2) *Racomitrium* heath vegetation with three communities (*Racomitrium lanuginosum* community, *Racomitrium lanuginosum-Salix herbacea* community and *Racomitrium fasciculare-Alcemilla alpina* community).

The altitudinal zonation of the plant communities was determined by testing for a significant difference (t-test) in altitude between pairs of communities and then combining those that were not significantly different in altitude into zones. The boundary between the temperate and the low alpine zone was found to be at about 200 m a.s.l. The boundary between the low alpine and the alpine zone was found to be at about 400 m a.s.l.

Results from the soil temperature parameters on two opposing aspects are shown in Fig. 2. Most of the temperature parameters are higher on the south-facing transect than on the north facing transect except for the temperature of the coldest month, which was the same close to the top of the two mountains. The number of days with snow cover was higher on the north-facing slope along the whole transect.

Discussion

The altitudinal distribution of the vegetation into three main vegetation zones identified in this study (Fosaa, 2004), largely agrees with the climate zones, as defined by Humlum & Christiansen (1998) as well as Christiansen & Mortensen, (2002), based on temperature and peri-glacial activity. They propose a low arctic zone from 200 m a.s.l., and an arctic zone from around 400 m a.s.l. The lower boundary of the low arctic zone corresponds to the upper limit of the moist dwarf shrub vegetation and the lower limit of the moist grassland vegetation in this study (Fosaa, 2004), while the arctic zone ranges from the upper limit of the moist grassland and the lower limit of the *Racomitrium* and open grass vegetation to the top.

The shift in vegetation zones is also seen in the change of biodiversity of vascular plant species (Fosaa, 2004a) where two maxima in biodiversity are found, one at 250 m a.s.l. and the other at 500 m a.s.l. These maxima might indicate transition areas between the zones. The interval between these two maxima more or less overlaps with the low alpine vegetation zone. A study on Raunkiær´s life-forms (Fosaa, 2006), also showed that the ratio between Hemicryptophytes/Chamaeophytes was at its maximum in this zone.

Comparing these results to earlier studies on Faroese vegetation zones (Fosaa, 2004), this study finds three zones as defined by Böcher (1937). However, Böcher's zones were found at considerably higher altitudes. In this study, the border between the temperate and the low alpine zones, as well as the border between the low alpine and the alpine zones are found to be around 100 m lower than in the older studies (Fig 3a).

This could be due cooling. Air temperature observations from Tórshavn show a general warming from the beginning of regular observations in 1873 until around 1940. This was followed by a cooling until around 1980, then a subsequent warming occured (Fig. 4). This development is somewhat similar to the changes in global mean temperature, but the cooling from 1940 to 1980 was much more pronounced in the Faroes than for the globe as a whole, while the subsequent warming has been weaker in the Faroes (Fig. 4). This implies that the climate in the Faroes was about 0.25°C colder during the sampling period of this study than in the period (late 1930's) when the earlier vegetation studies were conducted in the Faroes (Böcher, 1937).

From the cooling of 0.25°C during the period from Böcher's (1937) to the present study, a downward shift in the vegetation zones would be expected. For oceanic islands, a lapse rate of 0.8°C per 100 m is commonly used (Köppen, 1920). With this lapse rate, a cooling of 0.25°C should only lead to a lowering of the zone by around 30 m. The temperature measurements in this study do, however, indicate much smaller lapse rates (Fig. 1), which implies much larger zonal migration, consistent with the observed vegetational changes. The length of time between these two studies should also be sufficient for species to migrate such a distance (Grabherr *et al.,* 1995).

This result should be interpreted with caution due to differences in methods and location, but more confidence may be gained by considering each of the five mountains separately. The vertical extent of the zones varied from one mountain to

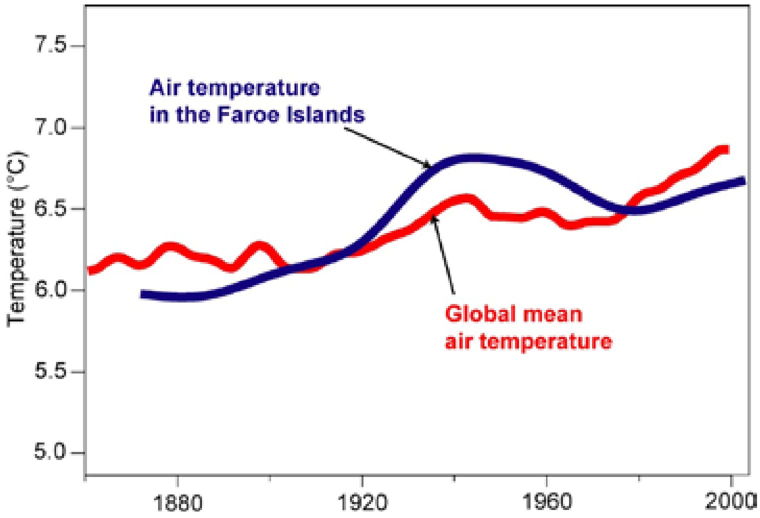

Fig. 4. *Air temperature in the Faroe Islands and global mean during the last 130 years. Annual mean (thin line) and smoothed (Gauss filtered) (thick continuous curve) temperature from Tórshavn, Faroe Islands (source: Cappelen, 2003). Global mean temperature (dashed thick curve)(adapted from: http://www.ipcc.ch/present/graphics.htm) adjusted so that the 1961-1990 average coincides with the average of the Tórshavn temperature for the same period.*

another, but in every case, the boundaries were found to be at lower altitudes than Böcher's (1937) value.

Comparing the vegetation zones on south and north-facing transects identified in this study, the dwarf shrub vegetation is missing on the north-facing transects (Fig. 3b). This can be explained by the difference (0.4°C - 0.8°C) between the observed soil temperatures on the north and south-facing transects at 150 m. a.s.l. (Fosaa *et al.*, 2002).

As the dwarf shrub vegetation, which is used to define the temperate vegetation zone in this study (Fosaa, 2004), is missing on the north-facing transect, the lowest zone on this aspect is the low alpine vegetation zone (Fig 3 b). This differences can be explained by the low tolerance of *Calluna vulgaris* and *Empetrum nigrum* to low temperatures (Fosaa et al 2004). These species have their optima at 12.1 °C and 12.9 °C with tolerances of 0.8 °C and 0.7 °C respectively, based on the soil temperature for the warmest month.

The future climate change in the Faroe Islands is difficult to predict due to the location close to the boundary between temperate and arctic regions, but the regional forecasts by state of the art climate models indicate a warming that may well be considerably above of 2 °C during the 21st century, depending on the scenario (IPCC, 2007). During this century, the temperature change may, therefore, well exceed by an order of magnitude the change between the two vegetation studies cited here and also be much larger than the difference between north- and south-facing transects.

Extrapolating the results from this study to a future with such a high warming is, of course, problematic since the vegetation depends on many other factors than temperature. Also in the future, climate warming in oceanic areas will likely be accompanied by a wetter climate (IPCC, 2007). A direct consequence of oceanicity is a relatively wet soil profile for a long period of the year, as well as warm winter temperature. Increased winter temperature reduces the probability of frost injury to the plant but, at the same time, it creates physiological problems for over-wintering plants by prolonging their metabolic activity in unfavourable times (Crawford, 2000). A study from Sweden of *Vaccinium myrtillus* (Ögren, 1996) showed that this species gradually lost its frost-hardiness when exposed to mild winters.

A potential increase of 1-2°C is likely to be within the tolerance of most alpine species, (Körner 1995; Theurillat, 1995), but 3-4°C is not (Theurillat, 1995, 1998). The Faroese species most vulnerable to increased summer temperature are those that are found with a limited distribution restricted to the uppermost parts of the mountains, especially *Salix herbacea* and *Bistorta vivipara*. For other species, the effect will mainly be a general upward migration. The most sensitive species are those with a low tolerance, especially *Calluna vulgaris*, and also *Empetrum nigrum* (Fosaa et al. 2004).

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The pollen content of so-called 'ancient' field systems in Suðuroy, Faroe Islands, and the question of cereal cultivation

KEVIN J. EDWARDS AND DOUGLAS M. BORTHWICK

Abstract

Supposed ancient field systems have been reported from numerous locations in the Faroe Islands. They are often located on the coast and have very steep (25-60°) slopes, typically with a southerly aspect. Although their antiquity is unproven, they are often popularly assigned to a pre-Norse Irish presence based on an early settlement by Celtic monks (*papar*). In an effort to explore such a putative connection, the pollen content of a field system at Lambi, Mykines, was explored by the late Jóhannes Jóhansen who found barley- and oat-type pollen – the site itself, however, was heavily puffin-burrowed and was sub-optimal for stratigraphic investigations. In this paper, pollen data are presented from field systems on Suðuroy – at á Teigalendi, Hovsfjørður and Akraberg near Sumba. Emphasis is given to the presence of cereal-type pollen in the deposits. Although pollen attributable to cereals and arable weeds was found, dating evidence is uncertain and the sites cannot be proven to show farming by pre-Norse or even early Norse settlers.

Introduction

The antiquity of settlement on the Faroe Islands has long exercised researchers from the humanities and sciences alike. Although little credence should probably be given to the notion of a prehistoric occupation of the Faroes on the basis of finds of *Plantago lanceolata* (ribwort plantain) pollen as advanced by the late Jóhannes Jóhansen (1986-87), his assertion of pre-Norse cereal cultivation at Tjørnuvík, Streymoy and Lambi, Mykines (Jóhansen, 1971, 1979; Fig. 1), has been particularly productive, if not accepted uncritically owing *inter alia* to the disturbed nature of the sites (cf. Buckland, 1990; Buckland *et al.,* 1998; Buckland and Panagiotakopulu, 2008; Edwards and Borthwick, 2010).

Jóhansen was encouraged to investigate Lambi by the state antiquarian Sverri Dahl who saw similarities between that site with its elongated field strips and the field systems of west coast Ireland (Dahl 1968). An Irish connection resonated with information from the monk Dicuil, writing around AD 825, which suggested that Irish hermits (*papar*) occupied an archipelago (generally assumed to be the Faroes) prior to settlement by the Norse (Tierney, 1967; Thorsteinsson, 2005). The inscribed cross slabs on Skúvoy have been used as support for a Hebridean or Irish link to the Faroes (Fisher, 2005), an association which seems to be supported by genetic investigations (Als *et al.*, 2006). Irrespective of the above, no proven archaeological evidence for a pre-Norse presence by *papar* or others has been found (Arge, 1991; Debes, 1993; Stummann Hansen, 2003; Arge et al. 2005).

There are at least 18 supposed 'ancient' (or 'Irish', 'Celtic' or 'Frisian'; Brandt and Guttesen, 1981; Fig. 1) field systems in the Faroe Islands (hereafter termed ancient fields and referring to cultural landscape features rather than carrying implications of temporal certainty). Their form is varied, although they tend to favour steep (25-60°) slopes with aspects in the

Figure 1. *Location of the Faroe Islands within the North Atlantic and sites mentioned in the text (including the so-called 'ancient' fields).*

southern half of the compass. Their origin is traditionally assumed to reflect fields for cereal cultivation (Dahl, 1968; Jóhansen, 1979). As detailed in a document of AD 1412 in connection with an area named *Ruddstaðir* ('cleared place') near Sandur, Sandoy, which had been cleared of stones, such fields (*deildir* ['division']) provide free drainage in otherwise boggy terrain (Thorsteinsson, 1979; Arge, 2001, 2005). They might thus be seen as medieval precursors of the *reinavelta* system (Christiansen, 1989-90), a Faroese method of spade cultivation found on level as well as steep slopes and in use up until 1972, though first recorded in AD 1669; but this still furnishes no date for the start of *deildir* construction. Paul Buckland (pers. comm. and quoted in Edwards, 2005, p. 588) also offers the suggestion that the ancient fields may represent relict turfstripping areas, providing building material (e.g. for walls or roofing) or a guano-enriched mulch for arable soil augmentation at sites located elsewhere.

Jóhansen's early cereal finds (i.e. pre-conventionally Norse, assuming a Scandinavian arrival *ca* AD 800), have been replicated elsewhere – e.g. at Tjørnuvík again (Hannon and Bradshaw, 2000), at Eiði, Eysturoy (Hannon *et al.,* 2005) and Hov, Suðuroy (Edwards *et al.* 2005; Borthwick, 2007). Such studies usually contain qualifications concerning the difficulties surrounding cereal pollen identification, including the fact that wild grasses (especially *Leymus arenarius* [lyme-grass]) may produce pollen indistinguishable from that of *Hordeum* (barley) (cf. Andersen 1979; Tweddle *et al.* 2005). This risk would seem to be minimized for the Faroe Islands in that lyme-grass and two other possible contenders (*Ammophila arenaria* [marram grass] and less problematically *Glyceria fluitans* [flotegrass]) are very rare in the modern flora at least (Jóhansen, 2000).

Pollen studies from so-called ancient field systems might well be thought to offer insights to former cultivation in antiquity. Apart from the investigations at Lambi, there are no published data from the additional 17 or so supposed field systems, although limited information is available from Korkadalur ('oats valley' [Matras, 1981]) on Mykines (Hannon *et al.*, 2001). This paper seeks to add to the corpus by discussion of evidence from two sites on the island of Suðuroy – at á Teigalendi, overlooking Hovsfjørður and at Akraberg near Sumba. A brief outline of cereal growing and related topics is presented at the outset. Plant nomenclature follows Jóhansen (2000).

Select background to cereal cultivation in the Faroe Islands

Six-row barley ('bygg'; *Hordeum vulgare*) was the main grain crop in historical times in the Faroe Islands, although two-row barley (*Hordeum distichon*), oats (*Avena sativa*) and Hungarian ('Tartarian') oats (*A. orientalis*) were also cultivated, but rarely (Ostenfeld, 1901). The barley was grown for a year and followed by 6-10 years of grass fallow as part of a rotational system in which the weeds hemp-nettle (*Galeopsis tetrahit*), chickweed (*Stellaria media*) and shepherd's purse (*Capsella bursa-pastoris*) especially held sway in Suðuroy until annual grasses ousted them (Williamson, 1948; Christiansen, 1996). At the end of the 19th century, common arable weeds in a barley field in Tórshavn were *S. media*, *Ranunculus repens* (creeping buttercup) and *Spergula arvensis* (corn spurrey), while oat (*A. sativa*) fields in Tórshavn and Kirkjubøur frequently contained *G. tetrahit, R. repens* and *S. media* (Ostenfeld, 1901).

Barley seldom ripened fully on the stalk, but after collection seed heads were separated and dried over a peat fire. Corn from the first drying was often set aside for the following year's seed (Williamson, 1948, p. 213) – the germination of green seeds of either barley or oats can be exceptionally good, especially after drying (Andersen, 1965). The dried kernels were ground with a quern or in water mills before being used primarily in bread making. The chaff was mixed with water and used as animal feed and the straw employed as roofing material or fed to the animals in times of famine. More barley was grown in Suðuroy (especially in the Froðba, Sumba and Fámjin areas) than in the rest of the country put together (Williamson, 1948, p. 206 ff.). Potatoes (*Solanum tuberosum*), introduced in the late 18th century, gradually replaced barley as a staple by the start of the 20th century (Ostenfeld, 1901; Brandt, 1996; Gaffin, 1996), although barley was still being grown in the middle of that century (Williamson, 1948). A combination of cool, wet summers diminishing crop yields, and labour-intensive demands at a time when more men became engaged in the fishing industry, would seem to have led to the abandonment of barley cultivation.

Field sites and sample collection

á Teigalendi (S6)

The site of á Teigalendi (61°30'21"N, 6°43'53"W) is located on a south-facing slope overlooking Hovsfjørður (Figs 1 and 2) and within the catchment area here termed Hovsdalur. Narrow parallel banks/walls run downslope at a steep angle (~26°) and a field section beneath a tumbled wall revealed shallow dark brown silt and sandy silt loams which are distinct from the peat- and peaty gley-dominated soils found elsewhere in the Hov infield (*bøur*) (Edwards *et al.*, 2005a).

A trench was dug in 2002 from the surface to the base of the soil profile (designated S6; *ibid.)* and Kubiena tins were used to collect the sediment from a cleaned face of the 50 cm deep trench at depths of 15-21, 28-34 and 43-49 cm.

Akraberg

This dramatic site (61°23'41"N, 6°40'41"W) is an east-facing slope (~40°) at the southern tip of Suðuroy (Figs 1 and 3). Akraberg contains the place-name element *akur*, meaning corn field. Banks of soil and stone run downslope and exposures indicate that the inter-bank areas consist of peat with a silt component overlying rotted basaltic bedrock. In 2005, peat

Figure 2. *The site of á Teigalendi. The sampling location (S6) was located above and to the left of the bay at the far right of the picture. Photo: K.J. Edwards.*

Figure 3. *The site of Akraberg. The sampling location was above and to the right of the person in the centre of the picture. Photo: K.J. Edwards.*

was sampled in a small shovel-pit and a 34 cm deep monolith was extracted.

Laboratory methods and the presentation of results

Palynology

Samples of 1 cm^3 volume were extracted from the Kubiena tins and the peat monolith and treated with HCl, KOH, acetolysis and HF (Fægri and Iversen, 1989). The samples from S6 were also treated with 10% sodium pyrophosphate ($Na_4P_2O_7$) in order to deflocculate clay (Bates *et al.,* 1978). Tablets of 'exotic' *Lycopodium clavatum* spores were added to allow estimates of palynomorph concentrations (Stockmarr, 1971). Silicone oil of 12,500 cSt viscosity was used as a mounting medium.

Pollen and spores at the site of á Teigalendi were identified with the aid of a reference collection and the key in Moore *et al.* (1991). Samples were counted until a sum of 500 TLP (total land pollen) was surpassed. Pollen terminology follows Bennett (2009) and Stace (1997). Cereal pollen was identified as either *Hordeum*-type [barley-type] or *Avena*-type [oats-type] through measurements of grain size, pore diameter and annulus width (cf. Andersen, 1979; Tweddle *et al.,* 2005).

Full pollen counts were not completed for Akraberg. Instead, optimising techniques (Edwards and McIntosh, 1988;

Edwards *et al.,* 2005b; Edwards and Borthwick, 2010) were employed, whereby microscope slides were scanned at x400 magnification to detect the often rare, large cereal-type pollen grains, followed by measurements of grain characteristics at x1000. Counts, but not identification, of other land pollen along with exotic spores enabled estimates of a TLP count equivalent to a mean sum of 1028 grains (range 889-1217) per sampling level.

Individual fragments of microscopic charcoal were measured and summed for S6 and its concentration calculated.

Calculations and the production of pollen diagrams (Figs 4 and 5) were carried out within the computer programs Tilia and TGView (Grimm, 1991, 2009).

Radiocarbon dating

In spite of the likely problems from contamination of samples receiving probable allochthonous inputs from upslope mass movement of materials, and quite apart from the difficulties in interpreting radiocarbon dates from soils, it was decided to obtain ^{14}C AMS determinations from the humic acid fractions of the sample sequences. No plant macrofossils were available. Dates are listed in Table 1 and are shown on the pollen diagrams apart from the lowest one at á Teigalendi which is located below the pollen sequences. Radiocarbon dates were calibrated using the INTCAL04 data set (Reimer et al., 2004) within CALIB 5.02html (Stuiver and Reimer, 1993; Calib, 2009), with estimated date ranges rounded to the nearest 10 years. Uncalibrated conventional dates are in units of ^{14}C years BP ($\pm 1\sigma$) and calibrated dates are cited as age ranges cal. AD ($\pm 2\ \sigma$), with BP referring to AD 1950. The 'modern' sample from Akraberg was calibrated using CALIBomb (2009; Hua and Barbetti, 2004).

Discussion of results

Pollen assemblages will include both locally derived components reflecting natural or anthropogenically-modified plant communities, and secondary inputs from allochthonous and added organic material that may have been used to improve the soil for cultivation. Some vertical mixing might also be

Site	**Lab code**	**^{14}C BP (±1σ)**	**δ^{13}C (‰)**	**Cal. AD (±2σ)**	**Median probability (cal AD)**
á Teiga-lendi (S6)					
15 cm	SUERC-6722	280±40	-29.0	1490-1950	1580
48 cm	SUERC-6723	1540±40	-27.9	430-600	511
Akraberg					
15-16 cm	SUERC-11082	F^{14}C = 1.0894 ± 0.0046	-29.8	Sept. 1956-July 1997	1957
32-33 cm	SUERC-11083	305±35	-30.0	1480-1650	1563

Table 1. *Radiocarbon dates from the Suðuroy sample sites (see text for further details). F^{14}C indicates 'fraction modern'.*

anticipated through bioturbation from burrowing fauna (Andersen, 1986), although neither site showed any physical evidence of extensive burrowing by birds as witnessed at Lambi (Jóhansen, 1979).

á Teigalendi (S6)

Unlike some soils from further west within the Hovsdalur infield, thin section micromorphological investigation at S6 revealed no augmentation (e.g. manuring) and evidence of mixing was not strong other than in a basal 'fossil horizon' of possible topsoil material; indeed, it was concluded that 'if cultivation occurred it was limited in nature' (Edwards *et al.*, 2005a, p. 645). In spite of the steep slopes at the site, the soils are considered to have undergone wetting and drying processes (as indicated by iron-based accumulation features), with the limiting factor for arable activity being soil wetness (*ibid.* pp. 644-645).

The lack of evidence for augmentation would be promising with regard to the unwelcome incorporation of non-contem-

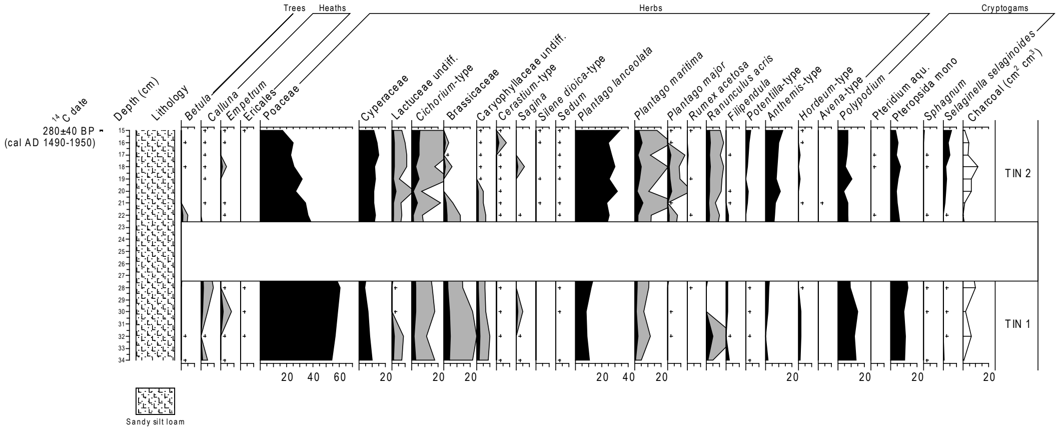

Figure 4. *Selected percentage pollen and spore taxa from á Teigalendi (S6). Exaggeration curves are x5. + indicates <1% TLP.*

poraneous palynomorphs from unknown, even distant, locations within an accumulating soil profile. This is reinforced by pollen preservation data which show that well preserved grains average around 70% of TLP and >85% if folded grains are included (Borthwick, 2007). This does not apply to the basal Kubiena tin samples (43-49 cm) which contained pollen in insufficient quantities for satisfactory analysis, possibly reflecting mixing and palynomorph oxidation in the posited fossil topsoil. There is a decline in average pollen concentrations seen in the two analysed tins, with >100,000 grains cm^3 in Tin 2 declining to *c.* 40,000 grains cm^3 in the Tin 1 sequence (*ibid.*). Such declines in concentration with depth are frequently found in soil pollen sequences (Dimbleby, 1985) and may be indicative of palynomorph loss. Although it can be difficult to claim integrity for pollen spectra in soil profiles (Long *et al.,* 2000; Donaldson *et al.,* 2009), the preservation characteristics for Tins 1 and 2 at S6 do not display a surfeit of corroded grains or resistant taxa (cf. Bunting and Tipping, 2000).

Within the context of many of the pollen floras found within Faroese diagrams (e.g. Jóhansen, 1985; Hannon *et al.,* 2005; Lawson *et al.,* 2008), there is a marked difference between the assemblages of Tins 1 and 2 (Fig. 4). The former is dominated by Poaceae (grass family) pollen and there is a consistent presence of other potential grassland indicators such as *Plantago lanceolata, Ranunculus acris* (buttercup), Lactuceae undiff./*Cichorium*-type (dandelion family), together with taxa

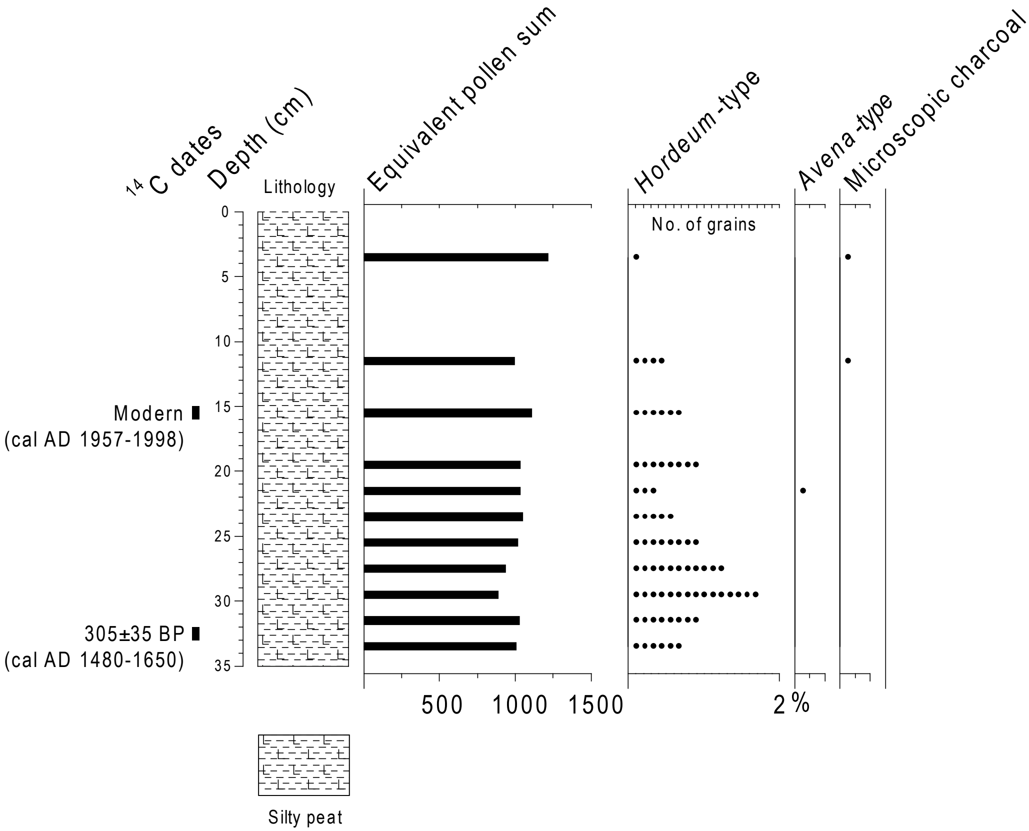

Figure 5. *Cereal-type pollen recorded during scanning of pollen samples from Akraberg (pollen sums are estimated equivalents).*

which are less diagnostic, but which may be found in damp grassland such as Cyperaceae (sedge family), *Potentilla*-type (cf. tormentil), Brassicaceae (cabbage family, but cf. *Cardamine pratensis* [cuckoo flower] or *Cochlearia officinalis* [scurvy grass]), and *Filipendula* (meadowsweet). Cereal-type pollen is also represented by *Hordeum*-type, present in nine levels and attaining 2% TLP (at 32 cm), while weeds of cultivated and/or trampled land may be signified by Caryophyllaceae/ *Cerastium*-type (pink family/chickweed) and *Anthemis*-type (cf. *Achillea* [yarrow]/*Tripleurospermum* [mayweed]). The Brassicaceae pollen could derive from weed or crop plants (cf. *Capsella bursa-pastoris; Brassica rapa* [turnip], *B. oleracea* [cabbage], *B. napus* [rape]). The low frequencies of *Hordeum*-type and other possible arable indicators would support the notion of limited cereal cultivation.

The pollen assemblage for Tin 2 displays the same taxa, but a number of them witness strong changes in abundance. Poaceae is reduced by about half through the sequence, Brassicaceae and Caryophyllaceae also decline, while expansions are seen in the values for Cyperaceae, *Cichorium*-type, *Potentilla*-type, *Plantago lanceolata*, *P. maritima* (sea plantain), *P. major* (greater plantain), *Anthemis*-type and *Selaginella selaginoides* (lesser clubmoss). The impression is one of increased soil wetness in the vicinity of the site. It is also conceivable that an intensification of pastoral activity was taking place, resulting in a reduction of flowering in grasses and the expansion in the frequencies of plants such as ribwort plantain. The single pollen grain of *Avena* at 21 cm could indicate an attempt to grow oats, with some barley continuing to be cultivated, but *Avena sativa* was found as a frequent weed in a field of Hungarian oats at Kirkjubøur (Ostenfeld, 1901).

The charcoal values for the site do not present an easily interpretable pattern. This could reflect domestic (cooking, heating) activity, but *in situ* burning of stubble is unlikely given that grain crops were largely unripened when harvested.

The ^{14}C date from the top of the pollen-analysed section has a median probability of *ca* AD 1580 (but note its wide range), which could suggest a deposition time of 28.1 yr cm^{-1} to the present-day surface of the soil profile. An extrapolated date for the base of Tin 1 (using the basal median date of cal AD 511 to anchor the lower profile; see Table 1) would be *ca* AD 960 and the intervening deposits would then be calculated to have accumulated at a rate of 32.4 yr cm^{-1}. There is no additional evidence to confirm these dates – they may or may not be acceptable and their calibrated age ranges are large. Organic matter was 9.6% at the top of Tin 2 and 2.9% at 43 cm (Edwards *et al.,* 2005a) and the high inorganic fraction might caution against the assumption of constant accumulation rates and could signal the likelihood of introduced allochthonous organic materials (i.e. 'old carbon' error). If the basal 'fossil horizon' represented initial soil working and agriculture at the site, then a date at the more recent end of the range AD 430-600 might conceivably encompass the supposed presence of *papar* in the Faroes. At Hov, the first barley-type pollen grains extend back to an estimated date of AD 540 (Edwards and Borthwick, in press), but radiocarbon dating imprecisions generated by statistical age ranges, a plateau in the calibration curve and extrapolations between dates, complicate the chronological assessment.

Akraberg

The optimising microscopal method employed on deposits from this site revealed the consistent presence of *Hordeum*-type pollen grains in every sample level with *Avena*-type at 21.5 cm only (Fig 5). The maximum estimated percentage for barley-type grains was 1.7% TLP at 29.5 cm with a mean value of 0.7%. There are only trace amounts of microscopic charcoal. *Leymus arenarius* does not grow near the site today, but there always remains the possibility that lyme-grass communities once existed around the foot of the slopes at Akraberg, perhaps occupying habitats that have been lost to coastal erosion (see below).

If the median probability values for the calibrated ^{14}C dates are accepted at face value, the peat accumulation rate between the two dates would be in the order of 23.2 yr cm^{-1}, accelerating to ~3.1 yr cm^{-1} for the peat between 16-15 cm and the top of the profile. Such a discrepancy seems unlikely even allowing for compaction of the lower levels. The steepness of the slopes at Akraberg would make the incorporation of upslope material from sheetwash or mass movement feasible – and such inputs are likely to result in ageing of accumulating peat. The wetness of the site, though, could possibly cause the movement of humic acids down the profile, creating age-estimates that appear too young. No reliance is placed here upon the stratigraphic integrity of the uppermost ^{14}C date and this would be reinforced if cereal cultivation did not take place after the middle of the last century.

Although cereal growing would reasonably seem to have taken place at or close to Akraberg, the radiocarbon dates do not allow a confident assessment of when arable activity might have occurred. If the basal date is approximately correct, and if the cerealia-type pollen denotes on-site cultivation, then the fields at Akraberg, *ca* AD 1480-1650, would be of reasonable antiquity (cf. the *Ruddstaðir* near Sandur, in existence by AD 1412 [Thorsteinsson, 1979]), although not of undeniably greater age and not proven to extend back to even *landnám* times. It might be noted, however, that Poul Joensen (1963; quoted in Brandt and Guttesen, 1978, p. 64) suggested that the fields at Akraberg could have been located above a foreland village of 'í Akrabergi' which disappeared as a result of coastal erosion.

If the ancient fields at Akraberg are essentially a peat capping which overlays a relict area of earlier Norse or even *papar* activity, then we have produced no definite evidence to show that or to support the suggestion of turf stripping; neither can the data reported here refute these possibilities.

Conclusions

In the absence of reliable chronologies, the finds of cereal-type pollen at á Teigalendi and Akraberg cannot prove that pre-Norse cereal cultivation took place and nor do they disprove it. Notwithstanding the difficulties which surround the identification of cereal pollen, there is strong evidence that cereal cultivation took place at both sites or in their immediate vicinities; its antiquity is unknown, although it is almost certainly not recent and it could extend over many centuries.

The relatively low percentage vales for cereal-type pollen at both sites might be thought to denote low intensity cultivation, but this may be an incorrect interpretation here as it would be for the other pollen sites from the Faroes where similar values are found. Firstly, cereal pollen is produced in relatively low quantities and it tends to travel short distances. Secondly, the cool temperature conditions which could inhibit ripening would result in reduced flowering and pollen production. Thirdly, if cereal cultivation was always part of a rotational system, then the Cerealia pollen grains found in the 1 cm thick samples (which might have accumulated over a period of around 20-30 years), would only represent the pollen rain from several years of crop growth, thus diluting the apparent abundance of cereal taxa. The individual field elements do not suggest that the *reinavelta* system was involved at the sites; had it been so, then a consistently higher cereal pollen content might be expected as at least some of the nearby field segments (*teigar*) under that system would have been under barley. This observation may provide support for the pre-*reinavelta* age of the ancient fields.

Irrespective of the age of the supposed field systems, many questions remain. For instance, to modern eyes, the excessively steep slopes of the systems would seem to present difficulties for cultivation. Were they subject to severe soil erosion requiring careful management in the interests of conservation, or was this less important than improved drainage? Were they all used for agriculture (even in combination with turf stripping)? Are some of them the upslope remnants of lower-lying fields which lay on gentler slopes since lost to marine erosion? If under arable crops, were whole slopes used for that purpose or were they partitioned, with cereal crops occupying lower slopes (some of which may have disappeared) and other crops or pasture concentrated on the upper slopes? Can spatially-precise and multiple-profile pollen sampling (Segerström, 1991; Donaldson *et al.*, 2009), or other environmental proxies, provide new insights concerning the distribution of possibly varied agricultural activities? Clearly, the 'ancient fields' of the Faroe Islands remain enigmatic and would repay far more attention than they have received thus far.

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A bookcase in Kongsstova on Nólsoy

NANNA STEFANIA HERMANSSON

Abstract

Kongsstova is one of the older dwelling houses in the village of Nólsoy on the island of the same name. In the sitting room, next to the kitchen, there is a brown, wooden bookcase with glass in the two doors in the upper part and solid doors at the bottom. Books are crammed on the shelves and hidden below is an archive.

This humble cupboard from the end of the 19th century is a special object as few houses at that time had a bookcase and it is linked to a teacher and a family interested in reading and learning. One hundred books span a century of printing, reflecting different interests. The content is a mixture of all kinds and tells something of how the outer world was presented.

I want to describe the background of this random collection of books and leaflets that did not deserve a place in the bookshelves of the better room. In the better room the works of Faroese authors, as well as encyclopedias and other books, are kept on younger bookshelves.

Most of the books originate from a local teacher who had got his training in the islands. In 1878 he started the daily school, where as earlier that had been regarded as unnecessary. The teacher was

also a farmer and his daughter and her husband took over the work on the land. When the daughter, talked of education, learning and books the words had a very special meaning. Perhaps there was both longing and reverence in it from a time when the islands where adapting to the modern world. A time when books were becoming accessible to more than a few. The works in the cupboard reflect a strong link to the state church, but also hints to the improvements of traditional farming in a period when fishing had become the base of the economy.

The family in Kongsstova

Ten years ago as I was talking to Richard Jacobsen, born in 1911, who lived in Kongsstova, I noticed the bookcase, filled with books. It stood behind the door to the kitchen, in the cosy room with a dinnertable and chairs, a daybed, a dresser, TV and an old grandfather clock. This normally closed door led to the better room with fine furniture, a sofa and bookshelves.

In the summer of 1991 I had been listening for days to his wife, Marianna Jacobsen (1905-1997) who told me a lot about her daily life. Her sight was dimmed, she could just discern the colours of the many flowers on the windowsill, but her memory was sharp and clear. She was an excellent narrator and herself listened to readings from tapes. Since my first visit as a student of folk-life in 1964 Marianna and Richard in Kongsstova had been a valuable source of information for me, especially on everything connected with farming and woollen handicrafts.

Now, in the spring of 2010, I have been thinking of the books in the bookcase in Kongstova and how they might reflect a part of life in the village. Marianna has told me how you got hold of books in earlier times and how you knew to which house they did belong. Her father Hanus, the teacher, who inherited many old religious books, was interested in learning and practical information while her mother Julia liked novels. The many kinds of Faroese works that Richard had bound and placed in the better room is also evidence for his reverence for the printed word. As a background to the content of the bookcase I want to tell about the family in Kongsstova.

Nólsoy in the 1960’

When I first came to the Faroes I missed the books that I had been used to see in an Icelandic home where the literary tradition is strong.

The calendar, *álmanakki,* was the most common print document, often laying close to the radio and the table in the kitchens of Nólsoy. It had relevant information about the moon, tides and currents, on boats and ships and a lot of other things as earmarks on sheep as well as advertisments.

With coal or peat as fuel the ironstove was generally the only source of heat and there paper and newspapers were used for kindling. Printed advertisements were rare, but I remember an elegant leaflet advertising freezers from the firm Elektrolux, with pictures from the book *Färöarna, fåglar och fångster*, by Sixten Jonsson and Nils Linnman. Electricity had since 1957 only been for lighting, but the capacity of the supply was growing.

The village of Nólsoy had just over 300 inhabitants in 80 households. Most of the men took part in fishing both deep sea and locally, while the women worked at home, with almost a natural economy. Most households had a piece of land, a cow and some sheep and there were six crown tenants, farmers with more land, sheep and some cattle.

The outer world was coming closer. The Faroese radio had been broadcasting since 1957, the telephone was used for messages and the milkboat arrived three time a week. The 1970’ brought economic growth and paid work in the fishing industry, a new school, a bigger shop and Faroese television. Central heating by oil was installed as well as other commodities. Traditional chores and working groups disappeared and indoor life changed. Knitting for sale was no longer a common spare time occupation. People travelled to Tórshavn or Havn, both for work and for shopping, encouraged by printed leaflets and offers. Life in the village was changing towards that of a suburb of the town.

Schoolhistory

Children were traditionally expected to read and write by the time of their communion, thirteen years old. They were taught at home. In early 19th century a man in Nólsoy offered teaching and a school was to be built in 1836. (A dreadful accident happened as the timber was towed at sea. But the school was opened the following year.) It is known that the school got at least one parcel of books from *Landhusholdningsselskabet* in Denmark.(Tarbensen 1994:82)

When in 1845 a compulsory school system was discussed by Education Board *ständerförsamlingen* in Roskilde there was a petition from the farmers in Nólsoy. They did not want a school as they needed the children at work. In 1849 at a meeting in the county library in Tórshavn or Havn about schools it was reported that the presence of a school in Nólsoy made men wanting to return to the old system. „*The children are more boisterous, and show less respect for their parents than earlier, and household harmony is highly diminished"*. („Børnen ere mere mundkaade, og vise mindre Agtelse for Forældrene nu end forhen, saa den Huuslige Glæde i høi Grad er Formindsket". (Tarbensen 1994:32) (Min översättning.)

Hanus the teacher

Stova means both house and livingroom, related to the word stove. The old, traditional *roykstova* meant the living room and *glasstova* the parlour. The name Kongsstova shows that the *roykstova* and the land was owned by the king or the state. Names of old houses covered the farm, the family and the household and remained even if the actual dwellinghouse was moved.

The old Kongsstova was the western part of a linked houses parallell to the still existing row, Niðasta Lon. There Hans Hansen, known as Hanus, (1852-1931) was born and grew up with his father Antonius Hansen and his mother Maren Anna, Marianna, úr Nýggjastovu, two sisters and two uncles. The father and forefathers of Hanus had been farmers holding the kings land as well as having some of their own, *odalsjørð*. An uncle left some money for Hanus who went to the newly established training-college in Havn. After two years Hanus returned in 1878 as a qualified teacher.

When his father died Hanus inherited the crown tenancy. He had ordered timber and the old joiners of the village erected a new Kongsstova, just north of the original. There he lived with his mother, an uncle, his sister Marsanna and her husband, their children, fosterchildren and a servant. At that time there were less than 200 villagers in around 30 households.

Hanus started teaching in a house belonging to his sister. Six farmers had committed to pay a sum per year for a school and the newly established local council was obliged to find a site for a new school. As nothing happened Hanus donated some of his land, við Klingrugarðin. The council and the state paid for a new building of stone that was was inaugurated in 1885.

The teacher was expected to receive a salary, but it was difficult to get any fee from the farmers, their support just covered the cost of books, Marianna, his daugther tells me. He himself never talked of financial problems, she had heard it from others.

Children of 7 to 14 years of age came to the school. Hanus taught in Faroese in the younger classes, but Danish in the older. Writing was all in Danish as well as the books. The biblical stories, by Joen Poulsen, in 1900 is regarded as the first Faroese reader for children. The second one by A.C. Evensen came in 1906 and his ABC a year later.

Julia the seamstress

Niels Petersen was in charge of the Royal Monopoly trade Norður í Vági, Klaksvík, and when it was abolished for free trade in 1856 he moved back to Nólsoy. He had some land and built a big house á Botni and traded for some time. There his daughter Julia Susanna Petersen (1865-1953) grew up. As other girls Julia took part in daily farmwork and learned to handle the wool along with her two sisters and a brother.

Julia spent one year at school with the new teacher. Then she went to the vicar of Nes to be prepared for the confirmation in Göta. Usually children went to Havn, but by going elsewhere the stipulated period was shorter. The two weeks in Nes was education for life and later she would sit and discuss the vicarage with a friend. There was a housekeeper, the vicar´s wife was sitting with handicrafts and all rooms had Danish placenames. The children lived in „Treasure chamber“ and the the name of the bull was „Ultimus”, Marianna says.

Together with another girl she went to the vicarage in Sandagerði and there she learnt good cooking from the Danish mother of the vicar, who was renovned for her excellent cooking. In Nólsoy there were only common meals served, remarks Marianna.

Julia stayed in Havn and learnt dressmaking from two craftsmen from Nólsoy who had got their training in Copenhagen. She enjoyed the theatre several times and she talked of the beautiful music as the highest official played the violin at church at a wedding. She was interested in politics, was working and missed the renowned Christmas meeting in 1888, but her friend Lena á Mýrini from Nólsoy was there. She had been to the high school in Vágur.

Julia lived at home á Botni, had a sewing machine and made bridal dresses and other clothing. She rent the journal *Nordisk Mønstertidende, Journal for Dame-Haandarbeide* (1877-1951, later *Femina*) to be able to follow fashion and cut up patterns from there.

The brother of Julia, Peter, wanted to become a teacher, went to Denmark but soon returned. Being very interested in nature, especially in birds, he taught himself taxidermy and corresponded with many Danes about birds. Marianna remembers that the book of the old H.C. Müller (1901) did exist á Botni and there was a saying „*Nansen op til Polen vil vinde, han Müllers Fuglebog vil finde"*. Peter inherited the house and the tenancy and the sisters got some *odalsjørð.*

Hanus og Julia

Hanus and Julia got married in 1904 and as the bride was 39 years of age and the bridegroom 52 it was a small wedding in the middle of the week. The schoolchildren sang at church. The couple lived in Kongsstova and there their only child, Marianna, was born in 1905. As she grew up there were only the three of them in the house and an old woman who helped out with the cows.

Hanus worked on the land in addition to teaching. It was difficult for him to care for the barley, but for bigger works like sheepgathering, slaughtering, fowling and harvesting, he hired labour. He was engaged in novelties in farming and early brought his daughter with him to work. Hanus read a lot on theological matters and he helped out as lay reader at church for forty years, reading the text those Sundays the vicar did nor come to the island.

Early on though Hanus brought his daughter with him at work, but quite small Marianna was taught to sweep the floor, wash the dishes and to knit. The family slept in *Innari stovu* and Marianna in her mother´s bed. There Julia read the papers and the girl learned to read.

Papers

Hanus had read *Dimmalætting* since it started in 1878. Firstly it came out once a week, later two and three times. Very seldom there was article in Faroese, but Hanus also had read the Faroese *Føringatíðindi* (1890-1906) and *Fuglaframi* (1898-1902). In competition with the conservative Dimmalætting the weekly *Tingakrossur* was established (1901-1954). It was written in Danish by Jóannes Patursson (1866-1946) among others. It was organ for home rule as the two political parties, Samband and Sjálvsstýri were formed (1906).

Readings for children

Marianna told me that she used to wake up early each day. Her mother used to have a small oillamp burning and had left some milk and a piece of bread for her and then she could read. She had *„Tjaldursbókin"or „Tittulin"*, as her first ABC, and at the age of five she taught an older girl who was going to school to read. (The parents often let children got to somebody else to learn how to read, (Johansen 1970: 192)

An ABC-book with Gothic letters told about the Danish kings and that was one she liked. Her father read *Børnenes Bogsamling* (started in 1896) and twice monthly there came a book by post. It could deal with the Boer war, *Tsarens Kurir*, *Aimaraernes Fange, Helten fra Panama, Nybyggerne i Canada* og *Børnene i Nyskoven.*

Marianna´s education

Her mother had ideas of her own and Marianna was not allowed to start school until she was eight**.** She liked it very much and was quick to learn Danish. Two years later her father was suceeded by Símun Simonsen from Gøta. The retirement of Hanus was result of his bad sight and the fiery discussions about teaching in Faroese. Hanus had never studied Faroese and still spoke Danish to the older pupils, Marianna adds. He was an admirer of Svend Grundtvig, who belived that the language and one's country should be held in high esteem. Svend Grundtvig, philologist and folklorist, (1828-1883) was also known for helping Faroese students in Copenhagen, Richard adds.

Marianna says that in her days there were no schoolbooks in Faroese, but some had just been printed (*Føroysk mállæra* by Jákup Dahl came in 1908 and *Plantulæra* by Rasmus Rasmussen in 1910).

Símun the teacher allowed the children to write an open essay during the Christmas vacation and they could choose the language, most of them used Danish. A booklet with hymns for Christmas hade been printed in Faroese and Símun sometimes wrote a verse on the blackboard and the pupils could copy it into a their notebooks. It was a very good method of learning, Marianna says.

Símun was a good teacher who explained the Faroese grammar so well that she became the best in Faroese. She also managed the history of the Bible and geography quite well, but not arithmetic.

As Jákup Dahl, the dean, and author of the grammar, held the service in the church he stayed in Kongsstova where there was a special chamber for the clergyman. His visits were interesting, especially to Hanus who had been at school, Marianna says. She remembers Símun coming to ask the dean about the plural of the word *æl,* shower of rain.

Marianna went to Havn to prepare for her first communion in 1919. As the dean knew that she was well informed, she did not have to stay long. Her mother needed her help at home and her wish to go to the highschool was not fulfilled. At home she prepared the meals as her mother worked with wool. Marianna had learned to weave at the age of twelve and used to do it after school. She did like it best in the light of summer. Her mother wove all cloth needed in the family, trousers, jackets, coats, skirts and petticoats. They also wove striped cloth for Faroese national skirts and caps and made them up. The tailor in Tórshavn took the garments for sale and it was rather well paid. It was a neccessity, Marianna says.

As Marianna decribes the pressure on her and her husband weaving a *kot*, a man's jacket, in a very short time once for an exhibition, (Landsframsýningin 1952) but even then she calls it sparetime-work. She also tanned sheepskin and made Faroese shoes that were sold through Heimavirkið, the Handicraft´s association, in Havn. She did also like embroidering when there was a spare moment, she worked on tablecloths, an altar piece and for her own Faroese dress.

Travels

Marianna had made visits to Hvalvík, to see a friend she got to know at her confirmation, and they went to Saksun. Sometimes she went to Tórshavn, once staying a whole week with a family friend, the tailor. Several times she went to Kirkjubø for family events, being a relative of the farmer Jóannes Patursson. She remembered him telling the history of the place. From Ólavsøka she used to go to Torshavn, seeing the rowingcompetition and then coming home in the vicar's boat the following day.

After her mother's death in 1953 Marianna twice went to Copenhagen where a friend of Maria Eide showed her around and she also went to Lund. There the cathedral and the museum of cultural history, Kulturen, made a strong impression on her.

Farming

Her father Hanus went on farming and was keen on technical improvements like a new scythe and the dipping of sheep. He had a new byre built, he kept goats and a Scottish ram and two Norwegian ewes. From Norway he ordered better seeds then were known before and to south of the house he grew turnips and kitchen plants.

Moving to Kongsstova

As other houses Kongsstova was a timber building with a roof covered with grass turf and it leaked badly. As a widow Julia in 1936 had a dwellinghouse erected further north on the site, using some of the old timber in the basement.

From the attic of old Kongsstova came chests with old books and a heaps of newspapers. Julia and Marianna took it all to the byre and burned the old papers. Marianna looked through the books before placing them in the attic, under the iron clad roof of the new house in 1936.

Her mother was interested in the old books, but prefered novels. When she had got hold of a good novel she lent it to a friend who let it pass to another unmarried friend who was a fervent reader. In one house, á Mýruni, a sister of the tailor kept newspapers with stories in them and had them bound. They were large and some of them did stem from *Illustreret Familie Journal* (1877-1990). The novels were very virtuous/decent, with nothing ugly them, Marianna says her father found them useless reading, but somebody argued that you could learn from the novels. Hanus replied that it would be like going North to the tip of the island on your way to the lighthouse in the South.

The collection of very old books from the attic were placed in the National Library of the Faroe Islands in 2001.

Richard at Kongsstovu

Marianna took over the lease of the king's farm and lived alone with her mother in the new Kongsstova until in 1936 she married Richard Jacobsen and he moved in.

Richard was born in 1911, the youngest of nine children á Geilinni, and grew up helping out with both indoor- and outdoor work. His mother was Lena, Susanna Malena, born Petersen, in 1871, and his father Kristjan Jacobsen from Kristjansstovu, born in 1867. He owned half share in the fishing smock Arizona and had a skipper´s certificat from Havn for the ship and went deepsea fishing with his older sons. Richard learned to read at home and mentions the stories by Jógvan (Joen Poulsen) Lesibók by Evensen and the Danish reader by Slomann, all now in the bookcase. He went to school at the age of seven.

His mother Lena used to buy the journal *Hjemmet* and through it you could order books from Denmark. Richard was happy to read all the books about kings, like about *The Childhood of Erik Menved*, *Valdemar Sejr* (B.S. Ingemann) and remembers them as being black with a red back. She bought others such as Eleonora Christine (*Jammersminde)* about *The Lady of the Camelias* (by A. Dumas) and) a whole series of novels. In the evenings someone could sit at the oillamp and read all kinds of things to us, he says. His father used to tell stories by H.C. Andersen. He also had a good voice and sang ballads, so strongly that the milkmaids one morning at Ólavsøka heard him all over the fiord from Havn. Richard also had children´s books and from the teacher you could buy them cheaply. Richard thinks that *Bábelstornið* by Rasmus Rasmussen (1909) was the first book in Faroese, but that one they got later. Many people knew *Føringasøga* that had been published in 1904.

One of Richard's brothers, Krebs born in 1888, had a bookcase made by their father, the lower part of it was deeper than the upper and there the china was stored. Onle few houses would have a bookcase, most had a shelf between the beams in the *stova,* Richard says. In Gortrastova there must have been a great interest in reading, there were so many books, and heaps of letters and acts. When a young woman came into the house and she threw all of it in the fire. A similar story is told about the house í Búð where the husband died of tuberculosis in the 1910´s and all books and papers were burnt. There the *Den syngende Mand paa Bølge og Land., Kjærligheds-, Theater-, Søemands- og Soldaterviser* (1-8, 1883-1919) was lost to the village, and that is still in living memory.

Richard's work

Richard says that it was a sad day when he left school. He went to Havn preparing for his first communion in the spring of 1925. Only once before he had been to town to see the dentist, then he travelled with the vicar's boat, now in Føroya fornminnissavn. Richard did not wish to go to sea and further education was not within reach as it cost money. For a period he worked for his uncle Peter Jakup Petersen who traded in fish and sold daily commodities in his shop in Nólsoy.

Then in 1932 Richard went to Landbrugets Forsøgsstation in Hoyvík for a year, one of two pupils. They lived and studied in the buildings now used for offices by Føroya Fornminnissavn. There they learned to use equipment sush as the plough, the harrow and the hay rake. He got prints from the station and from there he bought the first plough and horsedrawn cart to the village.

Most holdings were very small and plots in the infield scattered and therefore the spade, a wodden box for carrying and the heyrope were the general tools. The king's land had never been divided when the owners died and was well assembled so that Richard could use more modern implements. But first he had to remove the rigs from the old field system, a hard but satisfactory work.

Richard and Marianna worked together both in the fields and indoors, but also had to hire help for major undertakings. They had a fosterson, Sjurður, (1955-1984), but as a young man he chose to leave for the town. Some young relatives helped Richard so that he could go on farming and also living alone after 1997. Use to household work he managed very well, kept calves, sheep and hens and cared for the flourishing garden that he and Marianna had established.

Richard joined Føroya Forngripafelag, the Faroese Society of Antiquity and enjoyed their trips among the islands. He also appreciated courses for the elderly offered by the high school in Havn. His first journey to Copenhagen was for medical reasons, but later he returned and enjoyed flying. Now he lives with relatives, his memory is quite clear and he has been able to attend church most Sundays.

Asked about time for reading Richard says there were Sunday afternoons and evenings in the winter. „You could have a while. You could not always be working."

Singing and telling

Julia had a good voice, Richard says, did little singing, but she had learnt old melodies from her grandmother and taught Marianna. She in her turn sang for Carl Clausen and his daughter researching Faroeese singing. (Clausen 1975) Marianna could *taka í vísu,* sing a ballad, for dancing, but women seldom did so if the men were around. Both Maria Skylv and Maria Eide, used to sing at dances and Johanna á Malarenda could also start a ballad. Johanna had many books and she used to bring them to Kongsstova, such as the books by Morten Korch. If anybody had got a good book he or she could come and bring it to Julia. A dozen books by Anna Baadsgaard were very good. „Remember, there was no radio or things like that," Richard adds.

A godmother to Richard was Maria Skylv from Nólsoy who lived in Mykines. She wrote articles on folklife, published in the 1960's. Maria Eide, also from Nólsoy, was a teacher in Funning who also wrote articles and translated hymns. They both were very good friends to Marianna and Richard. „We used to give friends a book at birthdays when you knew that the person liked reading. Earlier books were cheap, now they are so expensive," Richard says.

A young man from Nólsoy, Emil Juul Thomsen, went to Copenhagen to become a shoemaker. At home after the Second World War, he became an agent for Elektrolux and started publishing. One of his first tasks was to reprint the Faroese review *Varðin,* making the popular articles available for everyone. In Kongsstova they already had the periodical bound. They bought all the Faroese books that were published. A friend of Marianna, Mía í Búð, who ran a small groceryshop, took orders on commission. „Marianna was so keen on reading," Richard says.

As long as Marianna could remember she had to care for her mother who had arthritis. She grew quite old and Marianna could not leave her. She had to get a nurse for her at the time of haymaking. Sometimes Richard could go down í Búð where Josefina might tell a story. Richard then brought them home to Marianna. She remembered everything she had been told and she wrote down some of it, 30-40 pages, thinking that it might interest someone in the future. She also wrote articles for competitions arranged by Føroya Fróðskaparsetur. One was *Traditional Faroese Dress*, published in Faroe Isles Review 1978, by Marianna í Kongsstovu.

Bookbinding

In the beginning of 1960's Richard noted an advertisment for an evening course in book-binding in Havn. At that time the milk- and mailboat came three times a week and he could leave in the evening and Marianna cared for the cows. Then he could return for the next milking in the morning. Richard followed the course for three winters. Now over fifty books well bound by him stand in the west *stova,* the better room, in Kongsstova. Among them the selected works of N.F.S. Grundtvig shine in light sheepskin. Hanus had bought them, but never read them, and Marianna had studied some of them. Richard was not interested, but he liked authors like Gunnar Gunnarsson, Selma Lagerlöf and Heðin Brú. He especially mentions *Lognbrá* by Heðin Brú. In the same room there are several bookcases, fine furniture, homewoven carpeting in natural colours, paintings and an organ with a large number of music scores. They originate mostly from a sister of Richard who was organist in the church, but Marianna did play at home.

The bookcase and some comments on it´s content

Hanus ordered the bookcase to be built by Kristjan á Geilini, the father of Richard, who was very handy. He made windows and that kind of things and he built his own house. The case was probably made in the 1890's and it was kept in the outer, eastern *stova* in the older Kongsstova. It was painted brown and as it was very worn, Richard did renewed the paint on the outside. The inside is light green, there are four shelves and some of the six panes are broken. The doors are closed by a small handle. Below behind the solid doors there is what might be called an archive with prints and documents.

There were several old sermons, hymn- and prayer books that have always been stored in the cupboard, never read by Richard. More often *Færøsk Anthologi* by V.U.Hammershaimb written in Faroese (1891) was used, he adds.

In the following list I have roughly grouped the one hundred books in categories listed after the year of printing and they mainly fall in the period 1880-1980. It must be stressed that this is a random collection, as the Faroese works, that all were bought, and also other books bound by Richard are to be found in the better room. Most of the books are in Danish, a few in Norwegian, but there are early books like Bible-stories in Faroese from 1900.

Under the heading religion there is a book from 1779 by the vicar Johan Grundtvig and for some reason it has not been placed in the attic as other works from the old Kongsstova where Hanus was born. Johan Grundtvig was the father of N.F.S. Grundtvig who´s collected works Marianna was interested in and Richard bound.

Hanus must have used several of the books at school and there are two on the the cathechism of Luther in which the young Mariana Hansen has written her name. Children had to learn it by heart. Sjurður, the son, has his name in the New Testament from 1939. A few of the older books are marked by Nólsoyar Lesiklubb which reveals some organised reading, not known to Richard.

Several of the christian books stem from Lohses forlag, publishers that from 1914 was owned by Kirkelig forening for the Indre mission, an Evangelical-Lutheran movement within the State church. The family in Kongsstova was not a member of Indre mission.

Some books on law must have been useful to the teacher and I see them as handbooks. Several of the manuals deal with health and remedies. I can just imagine the importance of them at a time when fetching the doctor in the open boat was a major undertaking. P.A. Panum was the physician who wrote a report on the outbreak of measles in the islands in 1846.

A book on how to write letters is not unexpected as all messages going out had to be shipped as post. The teacher did order books for the school and supplied the children. Probably he also had catalogues to order from.

There only happens to be one calendar, from 1911, printed and published by H.N.Jacobsens Bókahandil, the bookshop in Havn that had started already in 1865.

From 1912 comes a Faroese book, *Frýðka um búgvið*, how to make your home beautiful, written by Helena Patursson, from Kirkjubø, writer and the first political feminist. Among the handbooks is one on the art of drawing from 1953, and it reflects a pastime of Marianna´s. Some drawings of hers hang on the wall

Almost all of the intricate work for the woolen products were made by so called hidden knowledge, traditionally handed down generation to generation. There is a print on knitting from 1934, but the most used Faroese book on old knitting patterns, by H. M. Debes in 1932, surely is to be found in the better room.

Both Marianna and Richard were very keen on plants, both outdoor in the garden and potted in the windows. It is natural that the *Litflora* by Dorete Bloch is in the cupboard as well as a book on succulents. A few booklets from Roskilde, Rosenborg castle and the Zoo in Copenhagen emanate from the visits there by Marianna.

Some of the hymn books originate from Julia and Hanus, using them at school and in church. Marianna was also interested in them as well as in the Faroese epics.

Under the heading literature there are classic Danish authors such as Ingemann and Oehlenschläger represented as well as the Norwegian Jonas Lie. Besides him there is the Norwegian Elisabeth Schøyen who wrote many historical novels. From Sweden same novels by Pär Lagerkvist and August Strindberg, the latter in Faroese translation. A book by the Swedish author Tora Feuk was read in Danish. As his favourites Richards especially mentions Gunnar Gunnarsson from Iceland, writing in Danish and Anna Baadsgaard, a very popular Danish author, disregarded by the critics. In the better room I noticed a row of Danish novels from 1925.

Among the youngest books are some thrillers by the Dane Frits Remar and Wilbur Smith, writing in English, in Danish translation. There is also Alice in Wonderland as well as one of the Icelandic sagas in Faroese.

Under the heading History I have placed some books that also must have been used at school. Young Sjurður has his name in one of them.

Marianna and Richard knew the ancestors of old families of the village and the census´s from 1801 and 1811 have been much used and discussed.

Living in Stockholm I have not been able to specifically ask Richard Jacobsen i Kongsstova about the books. They may become dispersed, but the following list does tell something of a century of reading in Nólsoy.

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Chusters, P.W., Vidnesbyrd i beleilige Tider, København 1868.

Maduft, J.R., Solnedgange paa Palæstinas Bjerge, Kristiania, København 1878.

Poulsen, Joen, Bíbilsøga, Tórshavn 1900.

Tag og læs, korte læsestykker till bibeltekster paa hver dag i aaret for de unge, H. Nielsen og Olfert Richard, København 1909.

Dr Morten Luthers lille Katekismus, København 1909 (Mariane Hansen).

Eggleston, Edward, Fra den store vækkelsens tid, København 1910.

Eggleston, Edward, I Kampens Bulder, København 1910.

Luthers Katekismus, ved C.F. Balslev, København 1912 (Mariane Hansen).

Guds gerning i vort folk, red Johannes Loft, Vammen 1913.

Simpson, A.B., Hellig-Aanden i det Ny testament, København 1916.

Helte på Missionsmarken, København 1917.

Smith, Gypsy, Sigøjneren der blev Prædikant, København 1917.

Bullen, Frank P., Paa Havet med Herren, København 1924.

Nýggja testamentið, København 1937 (Sjúrður).

Jensen, Kaj, Troslivets spænding, De Unges Forlag 1939.

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Fabricius, Adam, Kortfattet Kirkehistorie for Brug i Skolen, København 1905.
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Ny Dansk Læsebog til Skolen og Hjemmet, København 1907
N.C. Roms Geografi med kart for Folkeskulen, I. Bondesen, København 1916 (Mariane).
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Om loven 1-8, Det blå Bibliothek.

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Hver Mands Brev- og Formularbog, København 1887.
Panums Lægebog, Ill. København 1895.
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Dalsgard, Eyvind, Búnaðarfrøði, Tórshavn 1952.
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Tórgarð, Axel, Dagar og nøvn í álmanakkanum, Stiðin 1954.
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Roskilde domkirke 1956.
Rosenborg, København.
Zoo, København.

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Mortansson, Edward, V.U.Hammershaimb, Tvøroyri 1916.
Egeberg, Edv., Af et ungdomsliv, Hjemmenes Bogsamling, København 1916.
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Leopold, Svend, Prinsesse Charlotte, København 1941.
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Baadsgaard, Anna, Kampen for Lykken, København 1945.
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European Heathlands: a case-history in conservation practice

By Nigel R. Webb

Abstract

Dwarf shrub heathlands, which occur on acidic, nutrient-poor soils under an Atlantic climate, have long been a characteristic feature of the landscapes of north western Europe. The origin of these heathlands puzzled ecologists, but now we recognise that the activities of the human populations over several millennia resulted in the absence of trees and the predominance of evergreen dwarf shrubs. By the twentieth century the extensive heathlands of old were no more than isolated fragments of vegetation in an often intensively managed agricultural landscape and lacked human involvement. The documentation of this decline was one of the earliest examples of the practice of historical ecology (Webb 1986). The protection of this patchwork as nature reserves became a symbol of conservation practice in the mid twentieth century. In this, the protection of sites within an otherwise hostile landscape was emphasised and, apart from approved conservation management, humans were excluded. Studies of these patches, particularly the dynamics of their invertebrate fauna revealed that far from being isolated there was considerable interaction between such patches and their surroundings. From this grew the idea that species could

> only be adequately protected when the landscape was considered as a whole and not only isolated protected sites.
>
> Although we knew that human activity had given rise to heathlands, we lacked details of the processes involved in these activities. However, on heathlands of western Scandinavia it was still possible to gain an insight in to these former agricultural systems, and it soon became apparent that vestiges of earlier agricultural practices were to be found elsewhere. In fact, it was realised that throughout the European heathlands a more or less common system operated. These heathlands were agricultural systems developed to enable yields of stock and crops to be obtained from impoverished soils. Heathlands were cultural landscapes. The recognition of heathlands as a cultural landscape has provided a new context and focus. We now know how heathlands operated and we now recognise the extent of their interaction with surrounding biotopes. To conserve for their characteristic biodiversity we need to develop a present day concept of the cultural landscape as a conservation practice. A model which will serve as well for other biotopes as it does for heathland.

Heathlands have been a characteristic feature of the landscape of the Atlanctic region of Europe for millennia. Heathlands are open treeless landscapes where the vegetation is dominated by ericaceous dwarf shrubs (semi-shrubs). The dominance of a single plant family (Ericaceae), and often, in case of *Calluna vulgaris** (L.) Hull, a single species, gives heathlands their unique appearance and has led to the development in many regions of characteristic human cultures.

Heathlands form, as we have long known, under particular conditions of soils and climate. *Calluna* dominates in the vegetation where the soils contain low concentrations of essential plant nutrients, the acidity ranges from pH 3.5 to 6.7, there are small seasonal fluctuations in temperature and humidity, winter protection by snow cover at higher altitudes and adequate levels of light (Beijerinck 1940). Whilst these are the conditions required by *Calluna*, the dominance of this species and its close relatives together with the lack of trees was a puzzle

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*Subsequently referred to as *Calluna* in this text which Beijerinck (1940) recognised by adding further factors; the activity of man, vertebrate grazing or exposure.

Until the mid twentieth century it was generally considered that heathlands had always existed. This primeval character of the landscape appealed to writers and artists who depicted the struggles that were visited upon the inhabitants of these poor lands. The term heathland became synonymous with low agricultural productivity. The early ecologists considered heathland to be a climax vegetation and unless the climate changed would persist. Yet, it was known that the original vegetation cover was woodland, so why were there no trees? Analysis of the pollen record established that heathland spread as early human communities destroyed the forest cover; a process beginning some three to four thousand years ago (Webb 1986).

Although this is the widely accepted view for the origin of heathlands, it has been suggested (Vera 2000) that open patches of herbaceous vegetation including heathland may have occurred from time to time when the landscape of western Europe was still largely covered in trees. Natural processes such as wind or lightening strikes would have caused trees to fall. Large grazing mammals were then attracted to these areas by the new growth of grasses and other herbaceous vegetation, which on poor soils may have been ericaceous species. The persistent grazing of such patches delayed the re-establishment of trees and maintained open patches over an extended period. Eventually the trees would re-establish as seedlings developed under the protection of less palatable plant species.

Nevertheless, we now readily accept that throughout the Atlantic region of western Europe, dwarf shrub vegetation mainly spread as a result of early agricultural activity. By the late Iron Age extensive heathlands had become established. We also know that from the mid eighteenth century onwards there has been a progressive loss of heathland (Webb 1986). From this time, agriculture methods improved and it became possible to convert poor soils in to more productive ones. This happened at differing rates and at different times through the region. Formerly, heathlands must have extended over several million hectares of western Europe, but have been reduced to roughly half a million hectares today (Diemont, Webb & Degn 1996). Accompanying this decline has been the fragmentation of large areas of heathland into isolated patches separated from one another by intensively managed farmland or urban areas.

Probably, one of the first people to study the effects on biodiversity of fragmentation and isolation was Moore (1962) on the Dorset heathlands in southern England. Moore's work was significant in several respects. First, he made use of old maps to interpret the changes in the extent of heathlands that had occurred from the mid eighteenth century to the mid twentieth century. This was an early example of historical ecology and its approach is now widely used to interpret change in biotic communities. Until that time there was little awareness of how past land use had resulted in development of the communities we now see. Too often we attempt to explain the landscape in terms of the processes we now see operating and neglect the fact that processes which no longer operate may have shaped the landscape in the past. Similarly, the countryside is often considered to be as it had always been. Moore followed his historical analysis with a field survey of the extent of the Dorset heathlands and their degree of fragmentation.

Secondly, Moore, by comparing the occurrence of heathland and non-heathland species, showed convincingly that there was an impoverishment of the flora and fauna with decreasing heathland patch area or increasing isolation of the patches. Later this type of finding be came formalised in to the theory of biogeography of MacArthur and Wilson (1967). Twenty-five years after Moore's survey, Webb and Haskins (1970) surveyed the Dorset heathlands again but in greater detail collecting information on the composition of the vegetation, species distributions, physical features and land use and management. Since Moore's survey the extent of the heathlands had been reduced by almost 50% from some 10,000ha in 1960 to about 6000ha. Moore's figure was for heathland in a wide sense, but that of Webb & Haskins was the extent of a more narrowly defined type of heathland: it was really only the extent of plant communities dominated by ericaceous plants. Furthermore, they recorded a very much higher degree of fragmentation than did Moore. Again the definition of a fragment is important and Webb and Haskins (1978) took a much more restricted view of a fragment setting out the principles in their paper. Clearly, the scope for exaggerating the degree of fragmentation is considerable depending on one's initial definition. Webb and Haskins (1978) recognised that it was difficult to establish adequate biological criteria to define a patch of heathland and therefore they relied purely on a physical definition of separation.

The criteria by which we choose nature reserves were the focus of much thinking at this time. Factors such as size (extent), diversity, naturalness, rarity, fragility, typicalness, recorded history, and intrinsic appeal were often cited (Ratcliffe 1977; Webb 1986). Size was clearly one of the most important and it was assumed that a greater number of species or communities would be encompassed the greater the area protected. Nevertheless, all of these characteristics had a static quality. Reserves or protected areas were considered to self-contained with little if any interaction with their surroundings. There was considerable emphasis on what was represented whether or not it was a functioning system with an innate capacity for change. The capacity to change, in the short term by processes such as succession, and the long term through evolution, is a key characteristic of assemblages of living organisms. Yet conservation has too often overlooked this. It takes a static view and sees change as a factor to be resisted. Yet the capacity to change is a innate quality of living systems, and one the greatest challenges to conservation is how to maintain this capacity.

The concept that patches of a particular biotope could be considered as analogous to oceanic islands held considerable influence in conservation science during the 1980s, and further emphasised the self contained nature of protected areas. Attempts were made to apply this theory to conservation practice particularly in the management of nature reserves. The theory was particularly attractive to those who saw protected sites as the principal means by which conservation could be effected. Particularly keen on this idea were those who sought to protect every fragment of a threatened biotope irrespective of whether or not it represented a working ecological system and whether it could be maintained as such in the long term. Were such patches isolated? Did the community present stop at the fence-line? Was this was an administrator's view of the landscape rather than that of an ecologist?

Although one can see patches of heathland fairly clearly in the field or in aerial images, are the patches we see the same as the patches that other species see? For instance, what patchwork do invertebrates see? Once again studies on the heathlands of Dorset contributed to new thinking. Although in floristic terms heathlands are not rich in species in faunistic terms they often are. It is more the case that the species of insect and other invertebrates associated with heathland are characteristic of hot dry and sandy places than associated with the particular plants which characterise heathlands. The invertebrate fauna shows considerable richness. Up to this time conservation had been largely concerned with plants with token animals, such as birds, large mammals and butterflies taking second place. Other animal species seldom featured in conservation decisions. So to be interested in invertebrates on heathlands was a new departure at this time. How did the fragmentation of heathlands and the decrease in extent affect insect and other invertebrate populations?

To address this problem a series of heathlands in Dorset were selected. The approach was that of island biogeography. In this there was considerable background information on the size, location, vegetation composition of the Dorset heathlands from the intensive surveys of Webb and Haskings (1978) and Webb (1990). It was decided to make the same sampling effort on each patch and to collect samples of invertebrates from the centre of each patch; an important factor when considering the results. On one level these results showed that when only heathland species were considered there was, as expected, fewer heathland species on small or more isolated patches than on large or less isolated patches. However, initially it was thought that there would be more species in total found on the large or less isolated patches than on the small or isolated patches. When considering all species of invertebrate this proved not to be the case. Often small and less isolated patches had a high species richness at the central point (Webb & Hopkins 1984). It was soon evident that this elevated species richness was made up of species from the surroundings which had spread on to the heathland. So, although we could recognise a boundary between heathland vegetation and non-heathland vegetation this boundary was not apparent in the composition of the invertebrate fauna. Small heathland patches were not recognisable as heathland when the invertebrate fauna was considered, they were simply part of the heterogeneity of the vegetation type around them. This was an edge effect the magnitude of which depended on the vegetation composition of the surrounding communities with woodlands, particularly mixed deciduous, contributing far more species than grasslands, especially agricultural grassland (Webb et al 1984; Webb 1989). Of course the best thing to surround a heath with is more heathland.

These findings threw a new light on how we should consider biotope patches in a heterogeneous landscape. No longer could we consider them as isolated patches where their community process stopped at the fence line to be replaced by a different set of processes. Further, it was important to consider the scale at which we were examining the landscape (Webb & Thomas 1993). The landscape needed to be considered as having a dynamic which encompassed all of the recognisable elements within it and to be considered at an appropriate scale depending on the organisms. In many respects, this was, perhaps, self-evident, but was so different to the thinking that had pervaded conservation science that it was to be twenty years before the idea came to be more widely accepted in the concept of living landscapes. The concept of the protected area still dominates conservation practice. Understandably so, because its practicality enables conservation to proceed with the competing demands for land.

However, further studies on the European heathlands have re-enforced the appropriateness of the landscape approach to conservation. As outlined above we have long recognised that heathlands were the product of forest clearances some three to four thousand years ago. We were content to say that they were maintained by agricultural practice until developments in agricultural practice, from the eighteenth century onward, enabled higher yields to be obtained from poor soils. Although we know much about the more recent land use history of heathlands, curiously, we previously had little, if any idea, of what actual farming practices maintained heathland over at least two millennia.

There were some clues to these practices (Webb 1998). The plaggen system, widespread in the Netherlands and adjacent regions of Flanders and lowland Germany has been well documented (Gimingham and De Smidt 1983). A shepherd managed a flock of sheep on the open heathland for some six hours each day, but for the remaining time they were confined in a barn. On the floor of the barn turves, cut from the heathland, were laid to absorb the excrement of the sheep. Periodically, this material was dug out of the barn and ploughed into the arable fields surrounding the village and, thereby, creating the raised soils which are characteristic of the landscape surrounding these villages today. Cattle, which were housed in a barn year round, were also supplied with heather turves which were treated similarly. Under this system nutrients, which were deposited by rainfall on the heaths (there were few nutrients in these soils derived from the weathering of the parent rocks) were transferred from the heath to the barn and thence to the arable land the fertility of which was raised by this process. These plaggen soils were thought to have extended over some 300,000ha (Diemont 1996). The outcome of this practice of turf cutting and grazing was to deplete the heathland soil of nutrients and to arrest succession to scrub and woodland.

Despite knowing some details of the plaggen system operating in the heathland areas our knowledge otherwise remained scant. Many authors were content to say that a combination of burning, grazing, cutting, and turf cutting perpetuated the heathlands. However, from the late 1980s evidence of the farming practices on the coastal heathlands in western Norway became available (Kaland 1986; Haarland 2002). Here the farms consisted of an infield area of pasture, hay meadows and arable plots surrounding the farmstead with a separate and extensive outfield on the heathland. Cattle were kept in the byre while sheep and horses grazed the outfield year round. Small patches of heathland were burnt from time to time, which not only provided forage, but created small-scale patterns of diversity in the vegetation. Heather and other vegetation was cut from the heath on a 3-5 year cycle and fed to the cattle in the byre. That the food was brought to the animals and not the animals taken to the food was an important characteristic of these farming systems. Peat was cut from the mire areas both for fuel and to be spread on the floor of the byre to absorb the excrement of the animals. This material together with the remains of the fodder and, often, with additions of seaweed from the nearby beaches and fish remains, were then periodically spread on the arable plots. This practice increased their fertility, enabled crops to be grown, and resulted in raised soils. This farming system operated until within living memory (mid-twentieth century) (Kaland 1986) and has been restored as a conservation practice. The traces of western Norwegian practice can be found in the northern Isles and the north western parts of the British Isles and also in Iceland; areas which were colonised by Vikings (e.g. Williamson 1948, Lucas 1960). Elsewhere, we can see remnants of these systems.

A number of related practices existed in some regions, For instance, in Jutland the heaths were grazed mainly by sheep year round often under the control of a shepherd. Cattle were tethered and periodically taken to their stalls to collect the dung. Winter fodder was cut from the young growth on the heaths and often mixed with lichen. Again turves were cut for fuel and other uses, and to absorb excrement in the animal stalls and farm yards. This material was used to raise the fertility of crop-growing areas. As the soils were so poor additional nutrients were needed and these were obtained by cutting vegetation and turf, burning it, and collecting the ash which was mixed with the manure from the stables. Permanent arable areas were supplemented by a type of shifting cultivation in which areas were ploughed, crops grown on the first flush of nutrients, and then abandoned. Heathland then gradually established and the fertility restored. In some cases it was as long as forty years before the procedure could be repeated. (Højrup 1970; Odgaard 1994).

In the Netherlands and over the German plain we have now been able to piece together the way in which the land was managed. This followed the plaggen system described previously. However, whereas on the coastal or the northern countries seaweed and fish remains were their bonus, on these lowlands stream and riverside meadows were the bonus. Meadows which could be flooded periodically, especially in winter, had their fertility raised through the deposition of sediment. This plaggen system was successful over a long period, but as the population grew and produce was exported to the towns, the system was driven harder. With only a fixed input of nutrients, primarily from rainfall, the system eventually broke down. By then, however, external supplies of nutrients, through import of guano and the manufacture of fertilizer, had then become available, and the heaths were abandoned as an agricultural system.

Further south in Europe we see similar practices. The heaths of the north-western regions of the Iberian Peninsular cover the steep mountain slopes. Like the grazing practices elsewhere, sheep and goats are grazed on the heathland outfield and cattle are confined to the cowshed. Fodder is collected from the heath and fed to the cattle in the shed. The dung and plant remains from the cow shed are then spread on the arable land on springtime. The fertility bonus in this system is water which falls on the mountain tops and is channelled downwards by a series of leats to distribute water to the arable areas (Haaland 2002).

Although we know that the practices of the north and west of the British Isles were similar to those in Scandinavia, we have little idea of the practices in Britain. In Scandinavia and the Iberian Peninsular remnants of the system have persisted until modern times while in the Netherlands and the north German plain the practices continued into the nineteenth century and are documented. So, over these areas we have been able to reconstruct how the heathlands formed part of the everyday farming system.

In Britain traditional farming ceased at a much earlier date, probably at least by the middle eighteenth century. This was due the fact population grew and large towns developed much earlier as the pace of the Industrial Revolution grew. This led to agricultural improvement beginning much earlier than elsewhere assisted by imports of guano and later the development of synthetic fertilizers. Poor heathland soils were rapidly improved to produce higher yields for the growing population.

It has proved very difficult to find documentary evidence for the farming practices in Britain before industrialisation. We know that grazing cutting, burning and turf cutting were all practices which existed, but so far there has been no clear evidence as to how these practices were integrated into a heathland farming system. Neither is it clear whether arable plots were fertilised using manure from the animal sheds or barns or that turf and vegetation were cut from the heathlands. Perhaps the practices were so common and widespread that they were taken for granted and thus, never documented. However, some clues have begun to emerge recently. Raised soils can be found in some small areas on the Dorset heaths, which suggest that material has been incorporated into these soils. It is not known whether this is simply turf from the heath or whether it was material containing dung from the barns or from areas where animals were folded.. On the heathlands in East Anglia there is some evidence that animals were grazed on the heaths during the daytime and folded at night. There are areas where traditional free range grazing has occurred for centuries and are still governed by ancient laws such as the New Forest in Hampshire (Tubbs 1986). The social structure of these grazing herds imparts a particular pattern to the structure and composition of the vegetation. Patterns of ancient settlements on the southern English heaths, as well as farm plans from the eighteenth century, suggest that the farms were on the margins of the heaths and often adjacent to river or streamside meadows. It is tempting to think that there may have been an infield- outfield system in operation, but conclusive evidence has still to be found (Webb unpublished data).

There are still many details to be discovered about the land use practices on the heathlands. Nevertheless, it is remarkable that what amounts to a common agricultural system operated over all of the heathland region (Webb 1998). Of course there are local variants, but we now know sufficient to recognise a common practice and to extract some general principles. The farmers through out the heathland region were faced with the same problem. How to raise fertility of areas sufficiently to grow crops? The answer was more or less the same everywhere. Stock were raised on an out field consisting of the open heath and crops were cultivated on plots near the farmstead. Stock was raised in an extensive system requiring low inputs of labour. Arable cropping which is more demanding of labour was carried out close to the settlements. Cultivation of crops required an increase in soil fertility and this was achieved by concentrating nutrients, which were deposited on the open heathland by precipitation, through the cattle shed. The stock, both free range and confined became, in effect, nutrient scavengers. There were other supplies of nutrients. Fire was one widespread method and ash from burnt vegetation and turf were used to supplement the manure. In addition, forage for the grazing animals was improved by burning small areas to provide a flush of nutrient-rich new growth. Irrigated meadows, which were flooded periodically, or additions of supplements, such as seaweed and offal, were other valuable sources of nutrients.

This system, which operated over several centuries was one in which there was a balance between the nutrient inputs through precipitation and that taken out in produce. Within the heathland cultural landscape people made do with the resources around them. Transport of produce and goods was limited although easier on the coasts by boat travel. Farming was of a mixed variety and there was no intensive cultivation of a single crop which characterises modern agriculture. The low land use intensity produced a diverse vegetation in terms of both structure and composition which in turn created a wide range of habitats for other species (Webb 1998).

There was a limit to the productivity of these systems and this could not be increased to meet the population growth of later times. The soils became exhausted and the land was abandoned. Improved farming practices, which required inputs of nutrients from elsewhere took its place as by now transport had become more efficient. It was at this point heathlands began to diminish in extent throughout Europe. This change occurred in England in the mid eighteenth century but it was well into the nineteenth century before change affected the central parts of the European heathland region. On the margins of this region change was much later and in a few places, such as western Norway and the northern Iberian Peninsula, many of these ancient farming practices persisted to within living memory.

From the foregoing accounts it is very clear that throughout the heathland area of western Europe what amounts to a common system of farming was practiced. We are fortunate that elements of these old practices have survived in some places to enable us to make an interpretation. Considerable light has now been shed on how the heathlands fitted in to the farming practices. It has enabled us to assemble the evidence into a coherent whole and to derive a broader perspective of how one of the principal cultural landscapes of western Europe originated and was maintained.

Over the last fifty years heathlands have been a dominant theme in conservation practice. There has been considerable discussion on how best to manage this biotope in order to maintain its characteristic biodiversity and several handbooks written (e.g. Symes & Day 2003). Our attempts to manage heathland were, in the early years, shaped a few by well established practices that reflected the past management. For instance, from the mid eighteenth century the upland heathland of northern England and Scotland had been managed for sheep production and for grouse shooting. The principal management method was to burn patches of heathland on an 8-12 year cycle. Thus, burning became an accepted method of management over both the uplands and lowlands of Britain (Gimingham 1972). Yet, this was a management practice designed to produce crops of sheep and grouse and not to maintain biodiversity in general. It clearly did not involve other elements in the landscape. Frequently, there was little management in the lowlands where the heaths had ceased to be part of any productive agricultural system. Gradually, these heaths were invaded by scrub and trees. Elsewhere, the heaths were planted with conifers because forestry was excluded from the more fertile soils. While the uplands of Britain continued to be managed as grouse and sheep moors, there was little management of the lowland heaths in Britain even where they were nature reserves. Often it was accidental or wildfires that kept the landscape open. However, this was detrimental because these fires tended to occur at the wrong season – summer rather than winter. Because of the high fuel loads that were allowed to build up through lack of management, these fire were very hot and damaging both to the dwarf shrubs as well as other wildlife. Because of the damaging effects of these uncontrolled fires, burning became unfashionable among certain conservationists. It became impossible to use controlled fires for heathland management yet, no alternative was suggested.

Slowly, conservationists began to recognise the potential of other types of management. Of course, we had long known that heaths were cut and grazed as well as burnt and that peat and turf cutting were important practices. So, some of these methods, particularly grazing, were tried. However, this was often in isolation and without any links to the surrounding elements in the landscape.

One can see the mistake. Management of isolated patches of heathland, subject to influences from their surroundings, was being attempted with a single all purpose method, be it burning, grazing or cutting. Yet this had never been the case. In former times, heathlands were managed on a small scale, if that is the correct term, using a blend of methods such as burning, turf cutting grazing. There was no single 'all purpose' method which conservationists have tended to seek. Obviously, less convenient as a single all-purpose method tends to be a more cost effective way to manage vegetation.

In the early years of heathland conservation our targets were set by the biodiversity that we observed, and which was the result of a single widespread form of management. We have little, if any, idea of the biodiversity that was characteristic of the heathland cultural landscape. As a whole, this landscape was diverse consisting not only of heathland but areas of peatland, mire and grasslands which formed and interacting whole. We can see where there are remnants of these old systems that the vegetation is diverse both structurally and in species composition. The challenge now is to develop conservation management which creates, in a modern form, the variety of the old practices.

Philosophically, this represents a change of view. The approach in conservation practice as a whole, not just the practice relating to heathlands, has been that of someone outside of the system. Hence, the development and use of terms, such as management and environment. This suggests that nature has no autonomy and is full of resources (Cooper & Carling 1999). It can be managed in a industrial or economic sense (Cooper 1995). Humans have not been considered to a component species of the biotopes we have sought to conserve. Much conservation thinking has been of the former type where we have acted almost as cultivators tending this species or that as our fancy took us. Raising biodiversity as if it were a crop. The very term conservation management implies this. Yet this was not so in the cultural landscape. In the past, as we have seen, this was complex integrated system which had evolved. It was a system in which humans, although the beneficiaries, were, nevertheless, were one of its constituents.

We have also failed to recognise change in the landscape. Our baseline as been set at an arbitrary point and we have judged conservation success as to whether or not a species has increased or declined from this point. In Britain this baseline seems to be the biodiversity created by the agriculture and land uses practices of the mid twentieth century. The period before farming intensified. However, we set our baselines in a purely arbitrary way. For instance, we mourn the decline in farmland birds as a result of the change from spring-sown to winter sown cereals. Yet we forget that the high populations of these birds were created by the practice of leaving the cereal fields fallow over the winter creating a food source for the birds of spilt grain. If we go back further in time the extent of cereal fields would have been much less as the human population was much smaller. Where were the large populations of seed-eating birds then? So, our baseline is inevitably arbitrary much as conservationists like to think the opposite when they try to recreate nature. Naturalness becomes a difficult concept in this context; how natural is a nature reserve? The description natural implies that nature exists separately and can be manipulated separately.

We have tended to see nature reserves as little more than a picture of nature; they have had a static character. Our management has been towards maintaining this picture. To be successful we must develop a concept of the landscape as a working entity of which people are one of the components. The concept of cultural landscape, which we have developed from studying heathland, provides us with this more satisfying approach. The human population together with other species populations exist as an integrated system, albeit one which largely benefits the humans. It recognises much more the dynamics that characterise the interactions between species populations and landscape elements. A feature lacking in the protected area approach to conservation. Finally, research on heathlands has pointed the way to the conservation approach of a living landscape that is now being more widely accepted as a way forward for conservation. The idea of providing links within the landscape between protected areas has long been advocated Moore (1987), but has not really taken hold in conservation practice until recently. There has been an added difficulty as we have a poor knowledge of how species disperse within a landscape and this a subject which is difficult to study. Even if we provide links we cannot tell whether species will use them, even if, intuitively, well feel this should be the case.

These are important lessons that we have learnt from studying heathland both as it was in the past and as it is now. We have seen that the heathland cultural landscape is an integrated system of several elements of which heathland is one. We must attempt to maintain this landscape. The key to success in this approach is to ensure that the processes characteristic of these systems are maintained or restored.

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Reconstructing climate in the Faroe Islands since AD 1600

Ole Humlum

Abstract

The Faroe Islands are situated in a sensitive region of the North Atlantic Ocean for registering the timing and severity of Late Quaternary climatic changes that reflect the location of the North Atlantic Oceanographic Polar Front. Oceanic circulation in the North Atlantic plays a major role in determining poleward energy transfer in the northern hemisphere, and is thought to be a key factor regulating global climate change. Thus, the Faroe Islands are well placed to register the terrestrial geomorphic response of large amplitude shifts of the water current boundary in the North Atlantic, past and present.

On this background, using the world's longest existing meteorological series from central England and Greenland ice core chemistry, this paper attempts a first reconstruction of air temperature and storminess in the Faroe Islands since AD 1600. These records are compared to dated, historical events, to evaluate their usefulness.

Introduction

The aim of this paper is to attempt a preliminary reconstruction of air temperature and storminess in the Faroe Islands, since AD 1600. The background for doing this is that the Faroe Islands are situated in a sensitive region of the North Atlantic Ocean for registering the timing and severity of late Quaternary climatic changes. Oceanic circulation in the North Atlantic plays a major role in determining poleward energy transfer in the northern hemisphere, and is thought to be a key factor regulating global climate change (e.g., Ruddiman and McIntyre 1981; Broecker et al. 1985; Rind et al. 1986; Bard et al. 1987; Broecker and Denton 1990; Lehman and Keigwin 1992; Koç et al. 1993; Bigg, 1996; Björck et al. 1996; Rasmussen et al. 1997; Karcher et al. 2005). Warm and saline Atlantic surface water presently flows around the Faroe Islands into the Norwegian and Greenland Seas, where evaporation and cooling during winter produces a gradually higher water density. This dense water then overturns, probably in localised regions up to a few tens of kilometres in diameter, resulting in deep convection (Bigg 1996). The sinking cold water represents a major constituent of North Atlantic Deep Water, part of the global thermohaline circulation, and is considered of importance for the global climate (Broecker 1991). In comparatively warm periods, when generally strong, or northward-displaced, circulation occurs in the atmosphere and ocean, the Faroe Islands lie continually in the main arm of the North Atlantic Drift. In colder periods, when the North Atlantic Drift weakens or its main arms take a more southerly position, a tongue of polar water from the East Iceland branch of the East Greenland Current approaches the Faroe Islands from the north. When this happens, polar sea ice may partly surround the islands, as happened several times during the Little Ice Age (ca. 1320-1910 AD), when sea ice from time to time extended south on both sides of the Faroe Islands. As a consequence, the Faroe Islands are well placed to register the effects of any large amplitude shifts of the water current boundary in the North Atlantic, both past and present (Humlum and Christiansen 1998; Christiansen et al. 2007). Increasing knowledge on the past climate in the Faroe Islands are therefore of special interest, to place known historical and geomorphological events in a proper climatic context.

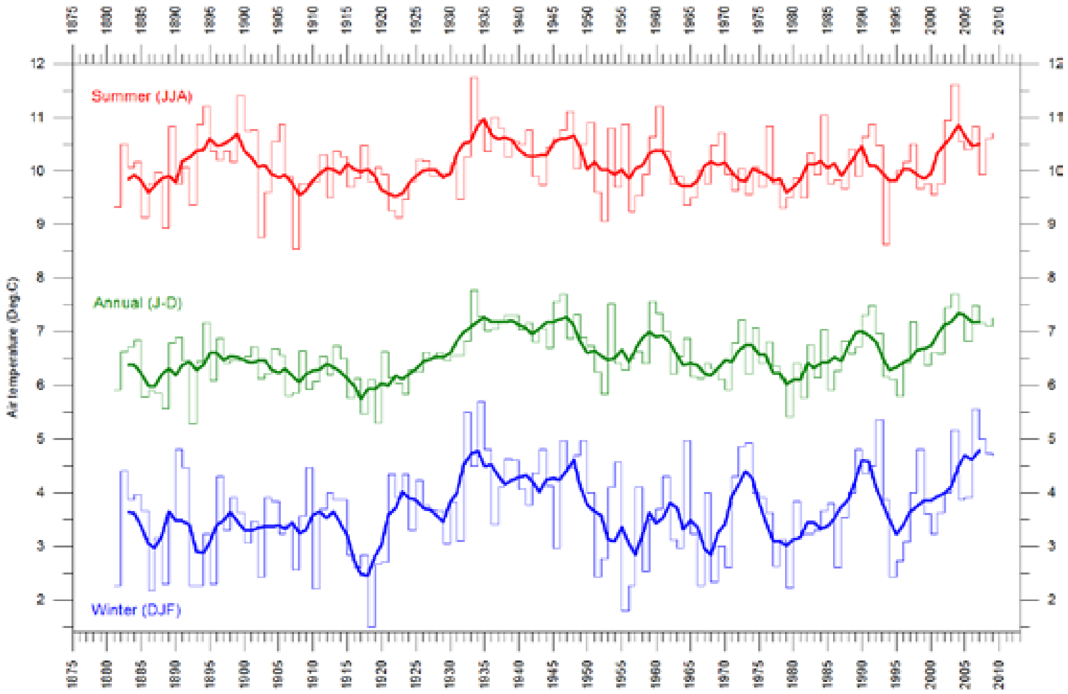


Figure 1. The Tórshavn surface air temperature series since 1881, showing annual, summer (June-August) and winter (December-February) temperatures. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. Source: Goddard Institute for Space Studies (GISS; www.giss.nasa.gov).

Topography and modern climate

The Faroe Islands have a total area of 1397 km^2 and are situated between 61°20’N - 62°24’N and 6°15’W and 7°41’W. The land area is distributed on 18 individual islands, the largest of which is 374 km^2. From the southernmost to the northernmost point is 113 km, and the maximum east-west distance is 75 km. The distance to Scotland is about 350 km, to Norway about 675 km and about 450 km to Iceland.

The topography is mountainous with numerous U-shaped valleys carved by Quaternary glaciers (Humlum et al. 1996). The highlands rise gradually from about 400-600 m above sea level (asl.) in the southern part of the islands to almost 900 m asl. in the northern and SE areas. The highest mountain, Slættaratindur, reaches 882 m asl., and is situated in the northern part of Eysturoy. The NE part of the Faroe Islands is dominated by alpine topography, while rolling highland plateaus delimited by steep, free rock faces characterise the remaining regions.

Meteorological observations were initiated early in Tór-

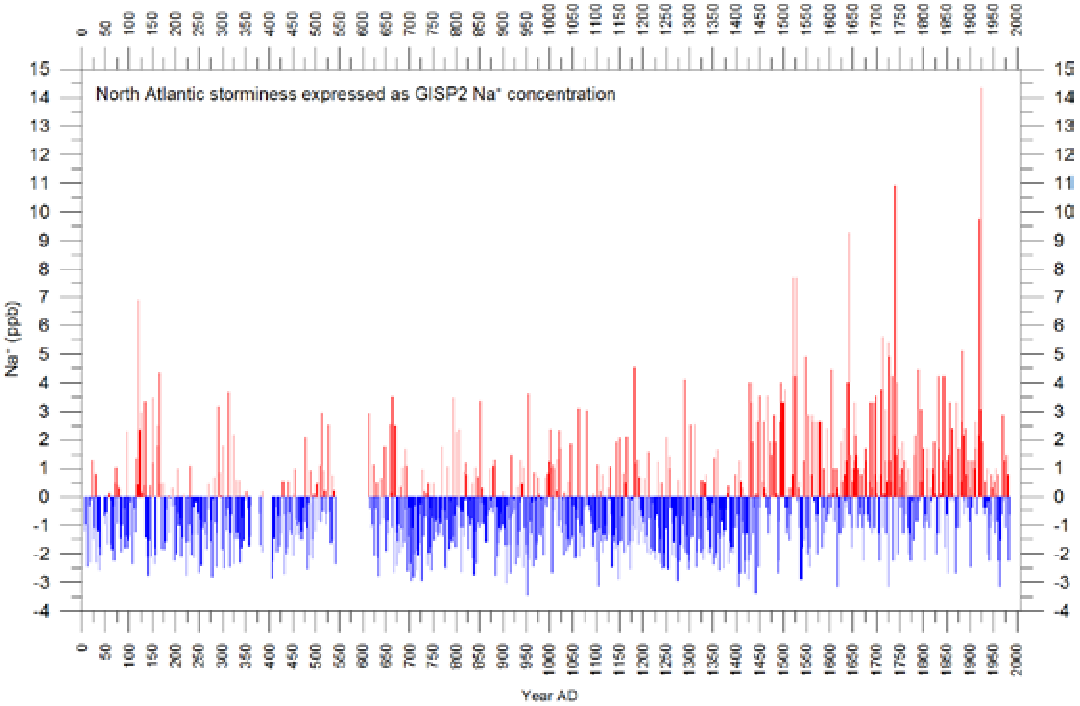


Figure 2. North Atlantic storminess expressed by sea-salt sodium (Na⁺) data for the Greenland GISP2 ice core since AD 0 (Birth of Christ). High values for Na+ is assumed to reflect increased North Atlantic storminess. Blue colours show values below the AD 900-1984 average, and red colours show values above. A prominent transition towards higher inferred storminess is seen around AD 1420.

shavn, in AD 1867. By this, the Tórshavn meteorological series represents one of the longest North Atlantic series. During the latter part of the 19th century the climate was relatively cold, due to the still ongoing Little Ice Age (LIA), with annual mean air temperature (MAAT) of about 6°C (Fig.1). Between 1918 and 1935, however, MAAT increased with almost 2°C, and in the Faroe Island region the termination of the LIA may for that reason be placed around 1915-1920. After the early 20th century warm period 1930-1948 MAAT again decreased with about 1-1.5°C, until a temperature minimum was reached around 1980. Since then MAAT has again increased to about the same level as previous reached 1930-1948 (Fig. 1). Superimposed upon these overall trends are a number of smaller temperature variations (0.5-1°C) with an apparent 6-7, 10 and 15 yr period. In addition to this, a longer variation of about 40-50 years appears to be present in the temperature series, corresponding to the early 20th century warm period around 1940-50 and the early 21st century warm period. These air temperature variations presumably reflect contemporary variations in water temperature and intensity of the North

Atlantic Drift around the Faroe Islands. The short variation appear roughly to be in phase with variations in solar activity and orbital variations of the Moon. The longer variation appears roughly to follow the Pacific Decadal Oscillation (PDO), known to affect fishery on a global scale (see, e.g., Klyashtorin and Lyubushin 2007). The annual number of whales (grinds) landed in the Faroe Islands in certain respects varies according to the MAAT; especially the temperature rise AD 1920-1935 is apparently reflected in the whale statistics, although socio-economic factors may be in operation as well. The North Atlantic Drift presently flows around the Faroe Islands with a typical velocity of 0.1-0.3 ms^{-1} and a mean sea surface temperature (SST) of 8°C (Hansen 1996). In the absence of the North Atlantic Drift, considering the latitude, winter air temperatures would probably be at least 6-7°C lower than at present (Søgaard 1996).

The present climate of the Faroe Islands is strongly maritime in character, windy, humid and changeable, reflecting proximity to the sea and the moderating influence of the North Atlantic Drift (Humlum et al. 1996). Rapid variations in weather (often within few hours) are characteristic for the modern Faroese climate. In Tórshavn, close to sea level, the early 21st century MAAT is about 7°C, with year-to-year variations of 0.5-1.5°C. August is the warmest month with 10.5°C and January is the coldest with 3.2°C (1961-1990). The annual mean precipitation is less than 900 mm water equivalent (w.e.) in the west (Mykines), increasing to more than 3,000 mm w.e. in the mountainous northern and eastern part of the islands (Hansen 1990; Søgaard 1996; Christiansen and Mortensen 2002, Christiansen et al. 2007). As an average, precipitation is registered in Tórshavn on 3 out of 4 days. Fogs are common and relative humidity is high throughout the year. The dominant wind direction is from the W, SW and S. In many places, however, the topography causes a local air flow pattern. The average wind speed is high, 7.2 m/s (1961-1995) at Akraberg, southern Suðuroy, and has shown an increasing trend since the early 1970s to the mid 1990s. From 1990 to 1995 the average wind speed at Akraberg was no less than 10.5 m/s. In the classical Köppen system (Köppen, 1913), the Faroe Islands fall within the type Cfc, a moist,

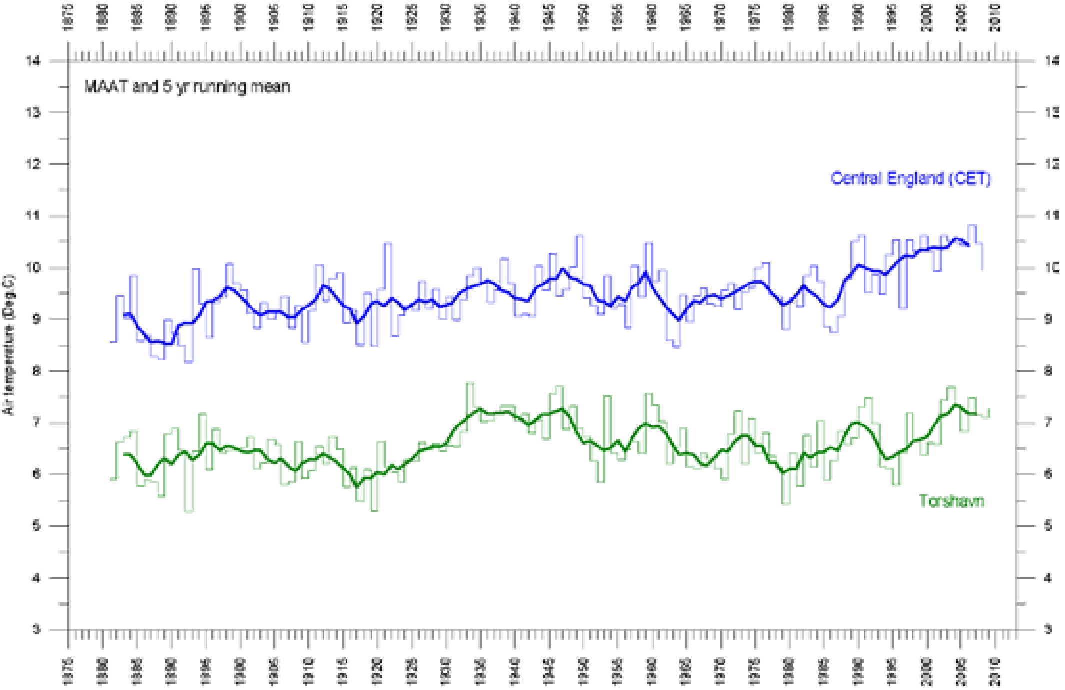


Figure 3. Mean annual air temperature (MAAT) since 1881 recorded at Tórshavn versus the Central England (CET) record. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. Source: Goddard Institute for Space Studies (GISS; www.giss.nasa.gov) and UK Meteorological Office (badc.nerc.ac.uk/data/cet).

temperate climate with cool summers. This, however, only applies for altitudes close to sea level, and polar (arctic) climate conditions prevail above 200-450 m asl., lowest at wind-exposed sites (Humlum and Christiansen 1998).

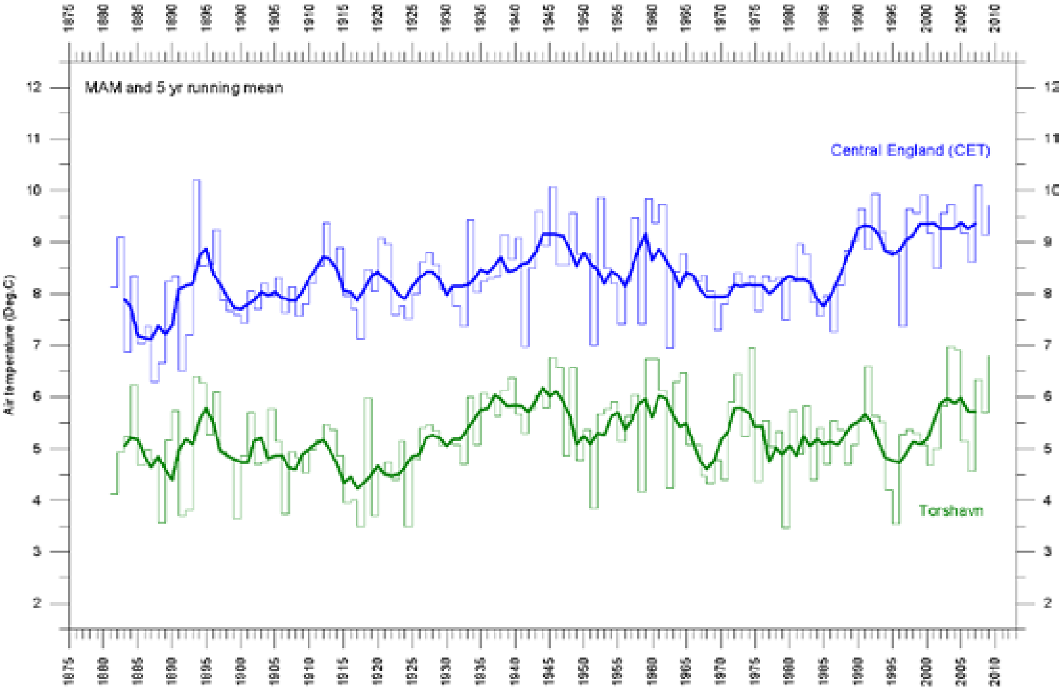
There are no systematic observations on the duration of the snow cover in the Faroe Islands, but in recent time a complete or partial snow cover is typically present in the mountains from October to late May (Humlum and Christiansen 1998). Blizzards at sea level may occur as late as in May, and above 600 m altitude snow may fall in any month of the year. A snow cover is typically established and disappears several times during a normal winter, owing to episodic thaw even in mid winter. A few high-lying snow patches are almost perennial, and usually survives at least into August. The most notable of these is found at 800 m in a shallow corrie on the eastern slope of Slættaratindur, northern Eysturoy.

Reconstructing past climate in the Faroe Islands

Ice cores from glaciers contain an abundance of climatic information. Inclusions in the snow accumulated each year remain in the ice, such as wind-blown dust, ash, bubbles of atmospheric gas, etc. Presumably ice cores provide a greater variety of climatic proxies than any other type of proxy, such as tree rings or sediment layers. Ice cores include proxies for air temperature, ocean volume, precipitation, chemistry and gas composition of the lower atmosphere, volcanic eruptions, solar variability, sea-surface productivity, storminess, desert extent and forest fires. Especially the sea-salt sodium (Na+) content in Greenland ice cores has been interpreted as representing a valuable proxy for North Atlantic winter storminess (see, e.g., Dawson et al. 2004, 2007).

The sea-salt sodium (Na^+) data for the Greenland GISP2 ice core (Fig. 2) indicate a remarkable change in the inferred North Atlantic winter storminess taking place around AD 1420. Prior to this, the GISP2 ice core is was characterised by low sea-salt Na^+ concentrations and from this, low storminess.

Figure 4. Mean spring air temperature (March-April-May; MAM) since 1881 recorded at Tórshavn versus the Central England (CET) record. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. Source: Goddard Institute for Space Studies (GISS; www.giss.nasa.gov*) and UK Meteorological Office (badc.nerc.ac.uk/data/cet).*



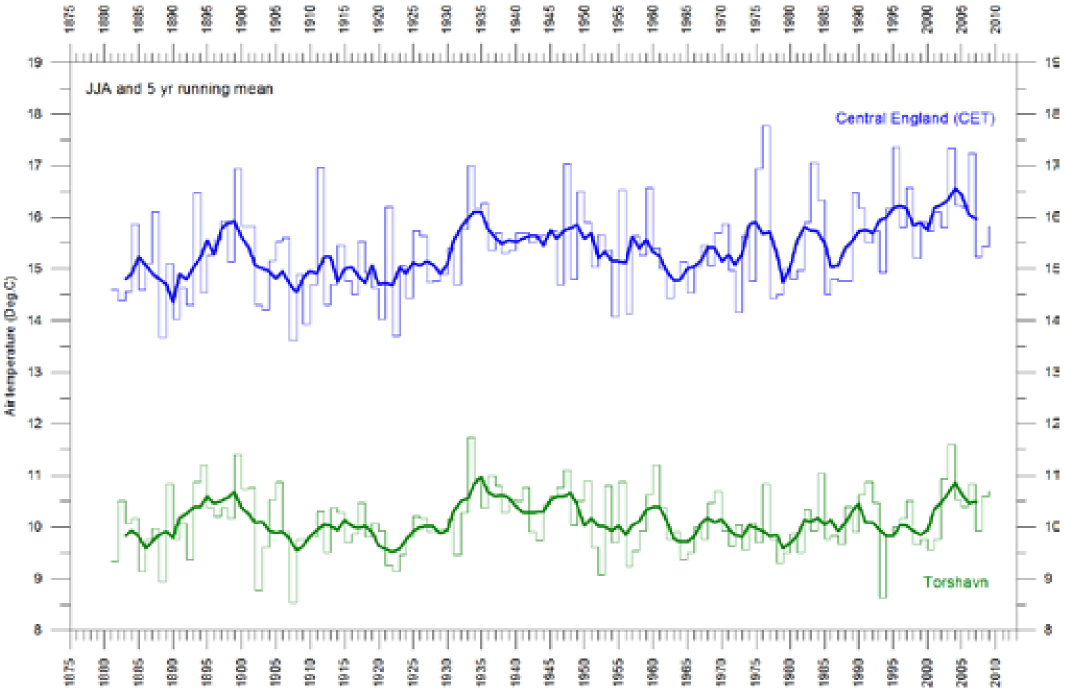


Figure 5. Mean summer air temperature (June-July-August; JJA) since 1881 recorded at Tórshavn versus the Central England (CET) record. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. Source: Goddard Institute for Space Studies (GISS; www.giss.nasa.gov) and UK Meteorological Office (badc.nerc.ac.uk/data/cet).

Around 1420 AD the sea salt content – and inferred North Atlantic storminess – increased markedly and has remained high until the present time. Also Meeker and Mayewski (2002), and Dawson et al. (2004, 2007) have argued, that the pattern of winter storminess that has characterised the North Atlantic region in recent decades is the continuation of a trend in storminess that has remained essentially unchanged for about 600 years.

Concentrations of Na in Greenland snow are strongly influenced by two semi-permanent features of the winter sea level pressure (SLP) field in the North Atlantic (Meeker and Mayewski 2002); the Icelandic Low and the Azores High. Winters in which ice core Na concentrations are lowest exhibit high-pressure anomalies in the region of the Atlantic's subpolar low (the Icelandic Low) and low-pressure anomalies in the region of the eastern extension of its subtropical high (the Azores High). This pattern was found to be reversed in winters in which Na concentrations are highest in the Greenland ice cores, with a deepening of the Icelandic Low (Meeker and

Mayewski 2002). Comparison of the mean winter (December-January-February, DJF) SLP fields for the 30 highest and 30 lowest Na years shows that winters with high Na deposition have a steeper pressure gradient in the North Atlantic region (Meeker and Mayewski 2002). This is consistent with intensified winter circulation in the North Atlantic, enhancing transport of Na to central Greenland.

The observed transition in storminess around 1420 AD is the most rapid onset of any such event recorded in the North Atlantic region over the last 10.000 years according to the GIPS2 data. Meeker and Mayewski (2002) have demonstrated that this transition coincides with a change from a period of relatively weaker winter (DJF) Icelandic Lows to one in which the Icelandic Low was substantially deeper than previously and winter circulation over the North Atlantic therefore more intense. The early fifteenth century also marks a period of abrupt transition from relatively weak spring (March-April-May, MAM) Siberian High to one with a stronger Siberian High, causing the MAM circulation to be significantly stronger after the 1420 AD transition than previously (Meeker and Mayewski 2002). For the whole Atlantic sector of the Arctic, including Iceland, East Greenland and Svalbard, this climatic change probably was associated with a higher frequency of moist air masses advecting into the Atlantic Arctic from south-westerly direction, especially during the winter and spring. In the Faroes Island region, this climatic change presumably was associated not only by an enhanced frequency of strong storms, but also by enhanced precipitation, frontal as well as orographic, especially during the winter. A more detailed figure showing the reconstructed North Atlantic storminess since AD 1600, is shown in figure 10, and will be discussed later in the paper.

Following the above mentioned transition around 1420 AD, the sea-salt sodium (Na^+) data for the Greenland GISP2 ice core suggest the North Atlantic storminess to have peaked around 1640, before again decreasing to lower values around 1680, to be followed by a renewed period of high storminess, peaking around 1740. North Atlantic storminess then decreased until around 1770, where a minimum was reached.

Storminess subsequently increased and remained relatively high until a very marked peak around 1920, the highest during the last 3000 years. Around 1925 storminess once again decreased to lower values, reaching a minimum around 1965.

While the Greenland Ice core chemistry may provide some information to past storminess in the Faroe Island region, long existing temperature records from NW Europe may likewise provide some information on past air temperature in this region of the North Atlantic.

The Central England Temperature (CET) record goes back to 1659, and is the longest existing temperature series anywhere. This remarkable series was originally published by Professor Gordon Manley in 1953 and subsequently extended and updated by him in 1974, following many decades of painstaking work. The monthly mean surface air temperatures, for the Midlands region of England, are given (in degrees Celsius) from the year 1659 to the present. Manley (1953, 1974) compiled most of the monthly series, covering 1659 to 1973. These data were updated to 1991 by Parker et al (1992), when they calculated the daily series. Both series are now updated by the Climate Data Monitoring section of the Hadley Centre, Met Office. Since 1974 the data have been adjusted by 0.1-0.3 degree C to allow for the effect of urban warming.

This record presumably represents the longest accurate series of monthly temperature observations in existence, and is an extremely valuable dataset for meteorologists and climate scientists. It is monthly from 1659, and a daily version has been produced from 1772. The monthly means from November 1722 onwards are given to a precision of 0.1°C. The CET record is useful because the trends in temperatures since the mid-17th century can be followed in some detail. It shows that central England temperatures fell and remained low during the period 1650-1700 and then rose in the early 1700s. During the 18th and 19th centuries, a cool period which coincided with snowy winters and generally cool summers, the temperatures fluctuated widely but with little trend. From 1910, temperatures increased slightly until about 1950 when they flattened before a new rising trend began in about 1975.

The CET record is directly representative for Central Eng-

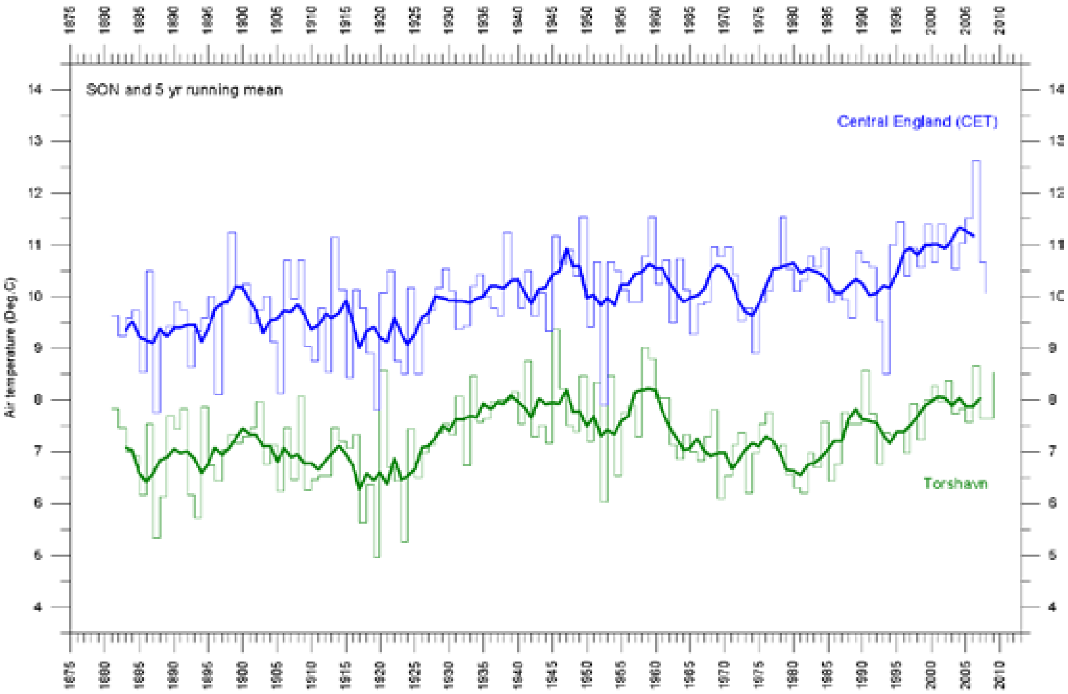


Figure 6. Mean autumn air temperature (September-October-November; SON) since 1881 recorded at Tórshavn versus the Central England (CET) record. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. Source: Goddard Institute for Space Studies (GISS; www.giss.nasa.gov) and UK Meteorological Office (badc.nerc.ac.uk/data/cet).

land, and, to some degree, presumably also for parts of NW Europe. Butler et al. (2005) compared the central England series with data obtained at Armagh Observatory in Northern Ireland (since 1796), and from Stockholm (since 1756) and Uppsala (since 1722) in Sweden (Moberg and Bergstrom 1997; Moberg et al. 2002). The agreement between the central England (CET) series and the Armagh series was shown to be good, with Armagh being somewhat (0-1°C) cooler. The overall agreement with the series from Stockholm and Uppsala was also good, but with larger annual variability shown by the series from Sweden, presumably due to the greater degree of continentality. In addition, it appeared that there was a delay in the peaks of the central England and Armagh data of the order of several years compared with the Swedish data, especially in the peaks that occur in the 1820s and the 1940s. Presumably this delay may be due to the greater oceanic influence on the data from central England and Armagh compared with Sweden (Butler et al. 2005). From this it may be

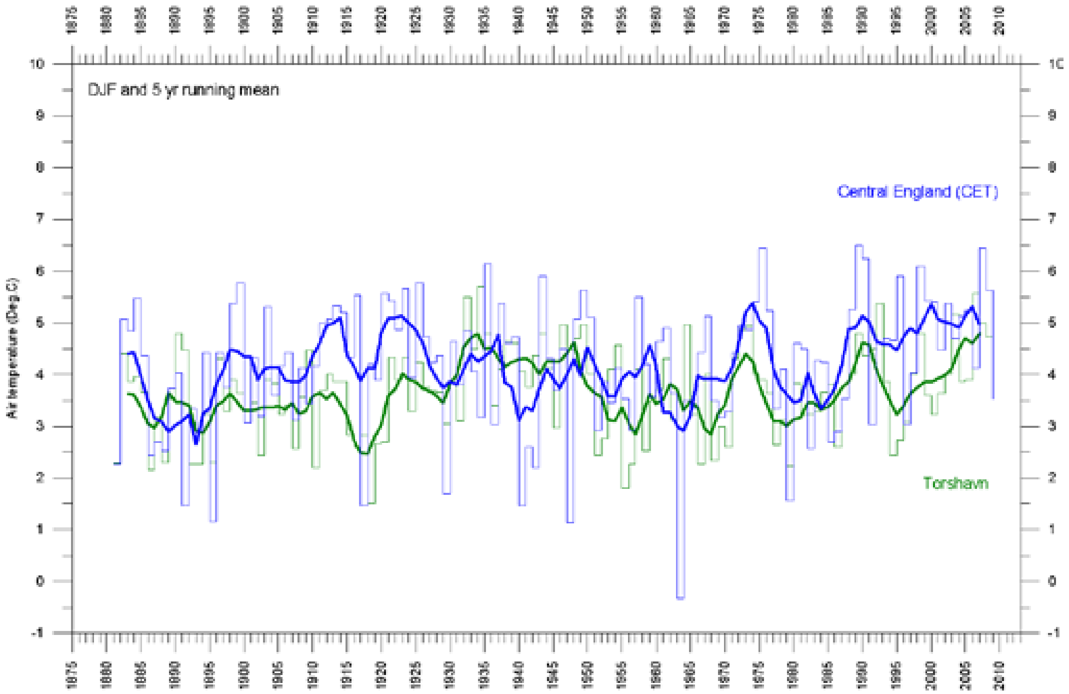


Figure 7. Mean winter air temperature (December-January-February; DJF) since 1881 recorded at Tórshavn versus the Central England (CET) record. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. Source: Goddard Institute for Space Studies (GISS; www.giss.nasa.gov) and UK Meteorological Office (badc.nerc.ac.uk/data/cet).

concluded that the central England (CET) series may be considered a good representation for especially the oceanic parts of NW Europe, and also, but to a somewhat lesser degree, for the more continental parts of NW Europe.

Following this analysis, it might be useful to compare the official Tórshavn meteorological record with the CET data. Here Tórshavn data obtained from the Goddard Institute for Space Studies (GISS; record begins in 1881) are used. The agreement between the two records is not perfect, but there are many features which are in common, both on the detailed and on the more general level (MAAT, Fig. 3). Relatively cold conditions 1885-1888 and 1914-1919 are documented by both records, while relatively warm conditions characterise the 1890s. A temperature maximum 1930-48 is shown by both records, followed by somewhat cooler conditions prevailing until the early 1980s, where a new temperature increase begins. Both series, but especially clearly expressed by the Tórshavn series, show recurrent temperature variations, apparently superimposed upon a longer variation of about 40-50 years, with overall temperature peaks around 1940-50 and 1990-2000.

To further evaluate the potential use of the CET series as a means to reconstruct past Tórshavn temperatures, seasonal changes were plotted for both series from 1882 to 2009 (Fig. 4-7). In general there is good visual agreement between the two series also on the seasonal level, wherefore the agreement as to MAAT (Fig. 3) apparently is not due to chance. Therefore, the average difference between observed seasonal changes were calculated for the two series for the initial 10 years of the Tórshavn record (1881-1890), representing a transition period to past values of the CET series. For all seasons the CET record turned out to be warmer than the Tórshavn record; on an annual basis the average difference was 2.4°C, for spring (MAM) 2.7°C, for summer (JJA) 5.0°C, for autumn (SON) 2.4°C, and for winter (DJF) 0.3°C (Fig. 4-7). The variation in seasonal differences for the two stations suggests that the differences between the two records at least partly might be explained by the greater oceanic influence on the Tórshavn data. Bearing this in mind, the calculated seasonal differences were then subtracted from the CET record, to obtain a simple reconstructed temperature record for Tórshavn, extending back to AD 1659 (Fig. 8). The details of this reconstructed temperature series (TOR) should clearly not be excessively interpreted, but only considered as to its overall features. This will be considered more thoroughly below, by comparing with historical events relating to meteorology and climate in the Faroe Islands.

To attempt a second, independent estimate on past Tórshavn air temperature, the Greenland ice core data may again be brought into use. First, however, the potential value of this proxy for northern hemisphere and North Atlantic temperature conditions must be considered.

Brox et al. (2009) recently investigated the Greenland ice sheet surface air temperature variability back in time, using meteorological station records and regional climate model output, combined to develop a continuous 168-year (1840–2007) spatial reconstruction of monthly, seasonal, and annual mean Greenland ice sheet surface air temperatures. They found that

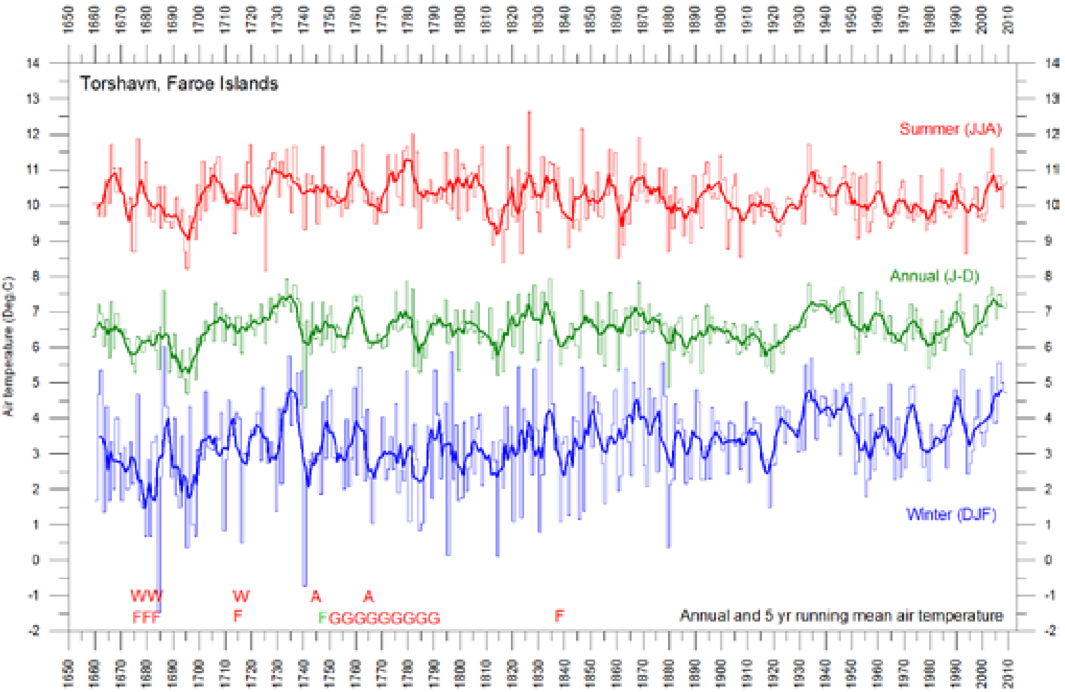


Figure 8. The reconstructed (before 1881) Tórshavn temperature record since 1659, showing annual, summer and winter conditions. The thin lines show the annual values, and the thick lines represent the simple 5-yr running average. The symbols in the lower part of the diagram refer to the timing of certain historical events. W=winter, A=avalanches, F=fishing, G=grinds. Red symbols indicate adverse conditions; green symbols indicate reported good conditions.

Greenland ice sheet temperature anomalies overall are in phase with northern hemisphere temperature anomalies during the 1881–2006 time period, but with a time lag of decadal-scale (11-15 years) between the two records. Given the phase agreement the majority of the time, this provide a possibility of estimating meteorological variations back in time for the North Atlantic area, including the Faroe Islands, using Greenland ice core data as proxy.

In figure 9 Greenland GISP2 annual delta 18O values are plotted, shifted 15 years toward lower age (e.g., 1940 data shifted to 1925), to adjust for the above mentioned time lag determined by Brox et al. (2009). A correction factor of 15 years has been chosen, as this reproduces well-known North Atlantic temperature minima around 1910 and 1965-1970 from the GISP2 data. Other well-known North Atlantic temperature maxima, e.g. shortly before 1820, and the temperature drop due to the Krakatau eruption in 1883, by this transformation also becomes visible. It should however be carried in mind, that this represents a very simple way of estimating the time lag between the Greenland ice core data and the North Atlantic region, and that a more sophisticated analysis may result in a somewhat different correction factor than 15 years used in the present paper.

The frequency of delta ^{18}O isotopes in glacier ice can be used as a proxy for air temperatures when precipitation took place. On this background a temperature scale has been added to the delta ^{18}O isotope diagram along the right y-axis, using measured Tórshavn mean annual air temperatures as simple calibration for the period 1881-1972 (end year of the shifted GISP2 data). By this, figure 9 represents an independent attempt at reconstructing Tórshavn air temperatures back in time. In all three figures illustrating various aspects of the past Faroese climate (Fig. 8, 9, 10), the timing of a number of documented historical events are indicated, as will be discussed in greater detail below.

Comparing the Tórshavn climate record since 1600 AD with history

The first abundant sources relating to the general economical situation on the Faroe Islands appear in 1584 with the cadastre, *Jordebøger*, which comprise the Danish King's accounts of his revenues and expenses in the Faroe Islands. These documents also contain *the tithe accounts*, as the King after the Reformation in the 1530s, received the share formerly taken by the bishop (Guttesen 2004).

In the year 1600 AD, the total population in the Faroe Islands has been estimated to about 4000, with about 1000 living in Tórshavn (Madsen 1990). Pirates were at this time a major problem in the Faroes, especially on Suðuroy, where several inhabitants were dying from hunger due to the recurrent disturbances and robberies. Even the priest on Suðuroy, Ismael Nielsen, was among the unfortunate victims (Madsen 1990).

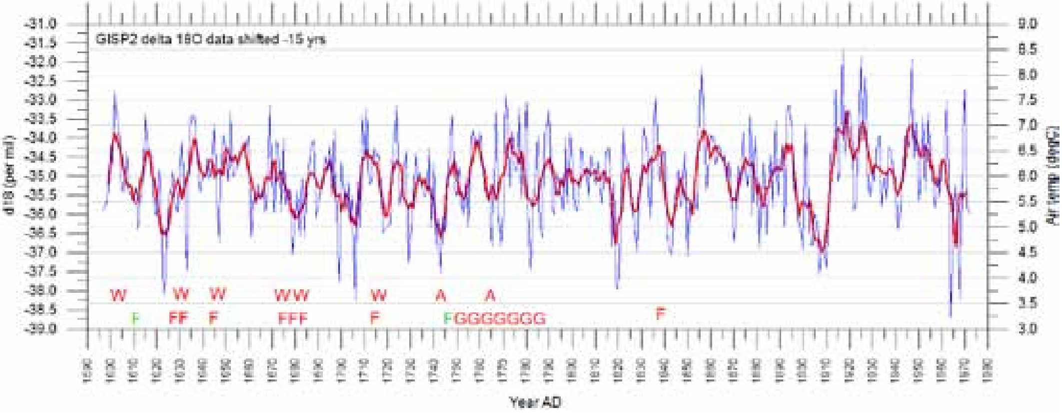


Figure 9. Greenland GISP2 annual delta ^{18}O values, shifted 15 years toward lower age (e.g., GISP2 data from 1940 shifted to 1925), to adjust for inferred time lag between Greenland and average northern hemisphere conditions (Brox et al. 2009). The blue line shows annual values, and the red line represent the simple 5-yr running average. The symbols in the lower part of the diagram refer to the timing of certain historical events. W=winter, A=avalanches, F=fishing, G=grinds. Red symbols indicate adverse conditions; green symbols indicate reported good conditions.

Presumably also the climate was adverse at that time, due to the major Huanyaputina eruption in southern Peru, comparable in size to both the Krakatau eruption in 1883 and the Mount Pinatubo eruption in 1991. In northern Europe, the Baltic Sea is known to have been ice covered during the winter 1600-1601 (Humlum, 2009).

The winter 1601-1602 is reported to have been unusually cold in the Faroes, and most sheep and cattle died due to the cold and lack of nourishment (Madsen 1990, Guttesen 2004). The condition determining the possibilities for the sheep to survive the winter is related to the access to grass, but also the sheep's condition in the beginning of the winter. If the snow and frost continues for long periods, one or two months, sheep depend on their fat deposits for survival (Guttesen 2003). The hard winter 1601-1602 fall into a general North Atlantic cooling period indicated by delta ^{18}O isotopes in Greenland ice cores (Fig. 9). Because of this event, new types of sheep had to be imported from both the Shetland Islands and Iceland. The previously dominant type of sheep in the Faroe Islands was replaced by these new types of sheep (Madsen 1990).

On 25 April 1605 a major storm hits the Faroe Islands. No less than 50 boats with crews are lost at sea. All male persons from Mykines were lost at sea. This disaster was followed by a new law, by which it is no longer allowed to sail in the open ocean by the smallest type of Faroese boat, the 'tristur' (Madsen 1990). It is interesting to note that the sea-salt sodium

(Na^+) data for the Greenland GISP2 ice core indicate a peak in inferred North Atlantic storminess that is dated to about 1604-1605 AD.

In contrast, the year 1611 was characterised by a very fine fishery. On the other hand, the years 1614-1615 are difficult years according to *the tithe accounts* (Guttesen 2004). This is emphasised by the fact that the inhabitants on the Faroe Islands in 1615 are complaining to the Danish King Christian IV about pirates and ships from England and Scotland, which are fishing inside the agreed 16 nautical mile fishing limit surrounding the Faroe Islands. This is to great damage for the local Faroese fishers, who only have access to small boats and therefore depends on being able to exploit fully the coastal waters. The North Atlantic storminess index reaches a short minimum around 1615.

The period from 1617 to 1624 can be characterized as years of relative plenty in the Faroe Islands, mostly because of good fishing (Guttesen 2004). The complaints on English and Scottish fishers are, however, renewed in 1624, and they are said to take a too heavy toll of the relatively low number of fish in the waters around the Faroe Islands. At the same time the Greenland GISP2 ice core again indicates increasing North Atlantic storminess. In 1626 the fishery again fails, and the whole population on the Faroe Islands faces a difficult situation. Also the following year, 1627, brings failure of fishing, and now the result is widespread hunger (Madsen 1990). In 1627 feathers appears for the first time as a *tithe* payment, and reach a high level in 1629 and 1630 (Guttesen 2004). In both years the feather payments come from Suðuroy, and it becomes clear that these were two extremely poor fishing years. An obvious reason for this conversion from fish to feathers could be to retain as much as possible of the scarce supplies of fish as food for the inhabitants of Suðuroy (Guttesen 2004).

The generally sad situation for the Faroe Islands continues in the years 1628, 1629, 1630, resulting in severe hunger on the Faroe Islands. In the year 1630 both fishing and grain harvest fails. The King's fish *tithe* fall to a minimum around 1630 (Guttesen 2004). On top of this, a significant part of all sheep dies during the winter 1631-1632, because of low temperatures.

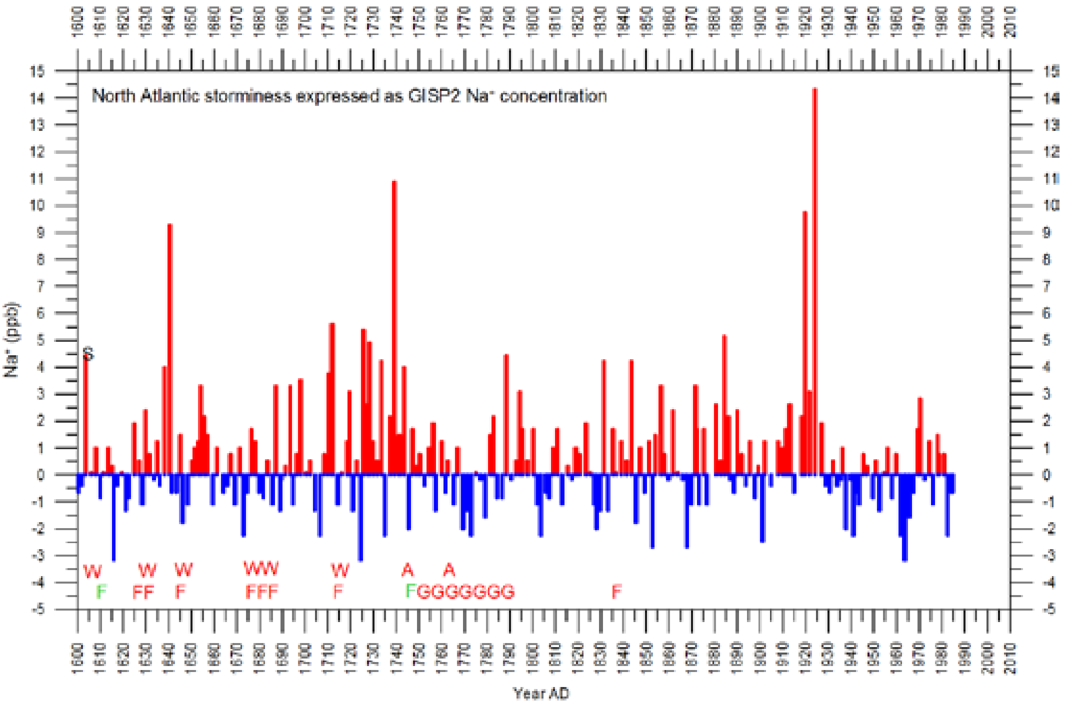


Figure 10. North Atlantic storminess expressed by sea-salt sodium (Na⁺) data for the Greenland GISP2 ice core since AD 1600. High values for Na+ is assumed to reflect increased North Atlantic storminess. Blue colours show values below the AD 900-1984 average, and red colours show values above. The symbols refer to the timing of certain historical events. S=storm, W=winter, A=avalanches, F=fishing, G=grinds. Red symbols indicate adverse conditions; green symbols indicate reported good conditions.

Also the winter 1632-1633 was hard with large losses of sheep and cattle, and the general situation for the Faroese population is very difficult. The years 1633-35 are characterised by meagre results for farming on the Faroe Islands, following the miserable fishing years 1629-31 (Guttesen 2004). The unsuccessful fishery is registered and described in the Minute book, *Tingsbókin* (Joensen 1953, cf. Guttesen 2004). For 1632 the Minute book mentions that many sheep were lost during the bygone winter. For 1633, perhaps one of the worst LIA years on the Faroe Islands, the Minute book informs that „most of the sheep have died, as well as several hundred cows”. The book also report that the grain harvest failed in the previous autumn, indicating that the summer was cold and grass growth probably at a minimum. Winter fodder was sparse and presumably the number of cows had been reduced before the winter had set in (Guttesen 2004). But the winter 1633-34 turned out to be longer than foreseen, and more cows died. Since February 1634 the storage houses at the trading company in Tórshavn were empty of grain and flour supplies.

To improve conditions for the Faroese fishery, King Christian IV in 1636 decides to increase the Faroese fishing limit from 16 to 24 nautical miles (Madsen 1990). The Greenland GISP2 ice core indicates increasing storminess throughout the entire period, before reaching a marked peak in 1640. Considering the small Faroese boats used at this time, the increasing frequency of storms may well have contributed to the general problems for fishing at the Faroe Islands.

In addition to such logistical problems, the abundance of the cod (*Gadus morhua*) and other *Gadidae* is limited to regions of the ocean where the surface waters are not below 2°C. The main outline of past sea temperature in the region around the Faroe Islands may therefore be detected from the records of fishing. It therefore seems likely that the apparent near-failure of the cod fishery around the Faroe Islands between 1625 and 1635 may have marked an extreme advance of the polar water as suggested by Lamb (1977). Advancing polar water masses signals an increasing temperature gradient between the Equator and the North Pole, contributing to the increased level of North Atlantic storminess. It also appears that even the famous bird colonies of the islands may have been partly deserted at these times, and presumably, the many fish which the birds feed on had moved elsewhere (Lamb 1977).

In 1640 fishing is bad (Guttesen 2004) and in 1645 the fishery ends in disaster, supposedly even worse than back around 1630 (Madsen 1990). Storminess reaches a short minimum around 1645, but then again increases during the following 10 years. Concurrent with this 1645 decrease of storminess the mean annual air temperature drops according to the GISP2 ice core (Fig. 9), a situation which repeats itself several times as is evident from an inspection of figures 8 and 9. This might be interpreted as evidence for the Polar Front and main storm tracks moving to a position south of the Faroe Islands. In logical continuation of this, the winter 1647-1648 turns out to be very cold, and much of the sheep and cattle are lost. Many people are now unable to pay taxes to the authorities (Madsen 1990).

From various sources in literature, the time from AD 1650 to 1720 is known to be one of the coldest intervals, if not the coldest, of the Little Ice Age. In 1663 a major landslide destroys a significant part of the infields at Tjørnuvik in northern Streymoy, shortly after the reconstructed TOR meteorological series begins (Fig. 8). The thermal culmination of the Little Ice Age is represented by two very cold periods in the TOR series, one spanning the intervals 1673-1685 and 1690-1702. The winter 1673-1674 is described as very hard, and a major part of all sheep was lost. Another very hard winter comes in 1680-1681, with significant losses of sheep (Madsen 1990). Failures of the Faroe Islands fishery were reported in most years between about 1675 and 1685, where taxes were reduced by 50% because of more or less total failure (Lamb 1977). During the winter 1684-1685 a major part of the Faroese sheep was lost, the fishery failed, and hunger returned (Madsen 1990). Also the winters 1694-95 and 1716-17 are described as very hard (West 1985). During the last of these winters as many as two-thirds of all sheep were killed, especially due to recurrent late spring snow. Also fishery was very bad at that time, and the Faroe Islands suffered an economic disaster (West 1985). Also the following winter 1717-18 was very cold, and many of the cattle died that winter.

Lamb (1982) concludes that the ocean surface temperature between Iceland and the Faroe Island 1690-1699 probably was 5°C lower than today (see also Ogilvie 1992), and in 1695 cod were sparse even as far south as the Shetland Islands, suggesting a significant extension of polar water below 2°C (Grove 1988). In this period, the periglacial environment in the Faroe Islands probably extended almost to sea level.

During these cold intervals, the mean annual air temperature (MAAT) in Tórshavn occasionally might have been as low as 4-5°C, i.e., about 2-3°C below modern values, as suggested by the TOR series (Fig. 8). If so, most likely small firn areas and isolated patches of permafrost would have been forming in certain places in the high mountains in the Faroe Islands during these periods of prolonged cold. While abnormal low temperatures apparently affected all seasons for the latter of these two cold periods, according to the TOR series, low temperatures apparently mainly was a winter phenomena during the early 1673-1685 period. During the 1690-1702 cold period, North Atlantic storminess reached relatively high values according to the sea-salt sodium (Na^+) data from the Greenland GISP2 ice, presumably resulting in periods with very high wind effects in the Faroes, possibly leading to extensive soil erosion (Christiansen 1998; Humlum and Christiansen 1999).

Following these intervals of maximum Little Ice Age cooling, temperatures generally increased until around 1735, where a renewed cooling began. However, in 1715 the air temperature suddenly drops (Fig. 8), and the Faroese fishing fails. Storminess also drops, which might indicate a very southerly position of the Polar Front, just as described for 1645. Also the winter 1716-1717 is known to have been very cold (Madsen 1990). After 1735 very low winter temperatures might have characterised especially the years 1740-45 (Fig. 8 and 9), provoking the foundation of the world's first skating club in Edinburgh, Scotland, in 1742 (McKirdy et al. 2007). More or less in concert with this temperature minimum, the North Atlantic storminess index rises to a pronounced peak (Fig. 10). This might have been caused by the establishment of an extraordinary large temperature gradient between the Equator and the Arctic, known to represent an important driver for Northern Hemisphere mid-latitude storminess.

On 12 March 1745 a major snow avalanche destroyed the farm Gerðar near Klaksvík, located at the foot of a mountain slope with southerly aspect, killing four persons. On 12 March 1765 another snow avalanche again destroys the farm Gerðar, on the day exactly 20 years after the first avalanche. This time 19 persons of the 26 inhabitants on the farm are killed. A large rock fall occurred in 1870 at Tjørnuvik near the northern end of Streymoy, probably triggered by melting snow or extremely large amounts of rain.

In the modern time, most snow precipitation is associated with N-NW winds, during the passing of polar lows drifting moving in from the ocean north of the Faroe Islands. The often strong N-NW air flow encountered on the rear side of these small, but intensive polar depressions presumably resulted in the accumulation of large snow drifts on slopes with S-SE aspect (Humlum and Christiansen 1998, 1999), providing conditions for snow avalanche activity on the slopes below. Modern avalanches are usually generated during periods of intensive snow melt and take the form of slush avalanches, enhancing gullies and eventually forming debris flows or depositing sheets of debris onto cones below (Christiansen et al. 2007). Large dry snow avalanches are comparatively rare in modern time, with notable exceptions in March 1998, but several dry avalanches are described in historical records from the LIA (Madsen 1990). All reported historic snow avalanches occurred on slopes with southerly aspect, suggesting a winter wind regime much like that experienced in modern time, influenced by polar lows.

The year 1750 marks the beginning of a 40 year period with insignificant or no landing of grind on the Faroe Islands. The time interval 1750-1790 is characterised by variable temperature (Fig. 8 and 9), and by low inferred storminess (Fig. 10). The low values for North Atlantic storminess may suggest a southerly position of the Polar Front, driving grinds to more southerly waters.

In general, the Faroese fishery was having a difficult time during most of the eighteenth century. Between 1709 and 1788 there were only four years, 1748-50 and 1757, where there was a significant surplus allowing export of more than 36 tons of fish. Between 1789 and 1828 there were eleven such good years, and between then and 1856 only one year (1839) in which the export failed to exceed 36 tons. Quite often more than ten times this amount was exported in this period (Lamb 1977).

With some variations, the TOR series (Fig. 8) suggests a period characterised by variable, but generally relatively low MAAT until around 1805. A colder period then follows; culminating between 1810 and 1817. Records showing the number of sheep slaughtered in the Faroes show a significant fall in 1816 (Guttesen 2004), and the yield of both grain and potatoes are declining around this time as well (Guttesen 2001). Presumably this cooling was enhanced by the 1816 eruption of Tambora in Indonesia, probably the largest volcanic eruption in historic time. About 150 cubic kilometres of ash were erupted into the atmosphere, more than 150 times the amount associated with the 1980 eruption of Mount St. Helens in USA. The Tambora eruption column is estimated to have reached a height of about 45 km, and an estimated 92,000 people were killed by the eruption. The 1815 eruption of Tambora was followed in North America and Europe by what was called „the year without a summer". It snowed in New England the following June and London experienced snow in August. The Tambora eruption apparently lowered average world temperature by about 0.5-0.7°C over a period of 2-3 years, and crop failures were common throughout Northern Europe and North America.

These cold years are then followed by higher temperatures for about 15 years, and the yield of grain and potatoes again recovers (Guttesen 2001). Around 1830 temperatures again decreases, before reaching a marked minimum in 1836-1840 (Fig. 8). The summer of 1838 was cold and with limited growth of grass, and the following winter 1838-39 was described as being severe with several avalanches and storm damage to houses (Guttesen 2003). The following winter 1840-41 is, however, reported as being mild, while the summer 1841 was cold with limited grass growth. The following winter 1841-42 again turned out being cold with frequent snow avalanches (Guttesen 2003). Along with this development, the beginning of the barley harvest is moved ahead from 30 September to 8 September between 1820 and 1835 (Guttesen 2001), presumably because of a gradually earlier onset of winter. Also within this time window, the length of the growing period for barley decreased from 154 to 137 days (Guttesen 2001).

Following this cold period since 1830, air temperatures slowly recovered, and the spring and summer 1842 is reported as being characterised as mild and with good grass-growth everywhere (Guttesen 2003). The TOR series suggest generally increasing temperatures until around 1850, and the yield of grain and potatoes rises in concert with this. The growing period for barley increases from 137 to 152 days between 1838 and 1842 (Guttesen 2001). However, from 1855 the TOR summer temperatures begin to decrease, followed in 1860 by decreasing yield of grain and potatoes. The sowing period for barley was postponed from about 21 April to about 25 April between 1860 and 1870, while the beginning of the harvest was delayed from 13 September to 1 October (Guttesen 2001), presumably signalling the onset of more adverse weather in the Faroe Islands. The growing period for barley is reduced to 139 days in 1862.

A renewed temperature peak is reached around 1865 (Fig. 8), after which temperatures slowly are dropping until reaching the last LIA minimum around 1915-18, after which the early 20th century warming began, lasting until around 1940. As mentioned previously, a number of 6-15 year variation appears to have been superimposed upon the entire climatic development, more or less in concert with observed variations in the number of sunspots and orbital variations of the Moon. Extensions of European birds to the Faroe Islands, apparently associated with the early 20th century period of warming 1910-1940, included the establishment of breeding pairs of one species of swallows (*Hirondo rustica*) in the 1930s (Lamb 1977). A very high peak of inferred North Atlantic storminess occurs around 1920 (Fig. 10), presumably the result of the previous cooling with maximum around 1915-1918 (Fig. 8), as discussed above for the similar storminess peak around 1740.

Synthesis

Our analysis and historical evidence demonstrate that the Faroese climate during the LIA was characterised by recurring periods of cold winters with snow. The historical documentation suggests that these periods of relatively cold had many adverse effects on the human society on the Faroe Islands, as discussed above. Air temperatures on the Faroe Islands are known to reflect corresponding changes of the sea surface temperature. The existing historical documentation strongly suggests that several past occasions where the

Faroese fishery failed, were associated with periods of low air temperatures, and, by inference, periods with low sea surface temperature. Our attempt of establishing a past record for storminess and air temperature at the Faroe Islands, suggests that the mean annual air temperature in cold periods of the LIA may have been 2-3°C below modern MAAT values, The historical records indicate that this had considerable negative effects not only on fishing, but to a high degree also on terrestrial agriculture, by directly affecting the length of growing season and survival possibilities for cattle and sheep. As discussed above, during the LIA a number of exposed sites within the highlands of the Faroe Islands may shortly have approached the climatic conditions for initiation of either glaciation or permafrost.

The early 20th century warming terminating the Little Ice Age around 1915-1920 reduced the frequency of such adverse meteorological conditions and their associated negative effects on human society. The early 21st century environment in the Faroe Islands is characterised by extreme humidity and strong winds, rather than extreme cold. Storminess is still relatively high, compared to average North Atlantic storminess since AD 900, but below the highest values reached during the LIA. Under this type of more agreeable post-LIA climate, both the theoretical altitude for glaciation and permafrost is located several hundred meters above even the highest mountains on the Faroe Islands. The major part of the archipelago, however, is still within the realm of periglacial conditions, as is exemplified by the widespread occurrence of small-scale sorted phenomena in the Faroese mountains above 250-400 m over sea level. Using early 21st century meteorological observations, the potential permafrost level is probably now situated about 300-450 m above the highest mountains. Likewise, the present potential glaciation level is presumably situated at least 200 m above the highest mountains. However, the landscape on the Faroe Islands still remains in a highly sensitive situation towards negative effects of climatic change, especially cooling. As the air temperature in the Faroe Islands apparently still undergo variations with 6-15 year periods, roughly in phase with solar variations, superimposed on a longer 60 year variation, in phase with the Pacific Decadal Oscillation, this aspect of future climate change should not be entirely ignored, even though the concept of future warming dominates climatic concern in recent times.

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Reflections on North Atlantic Island Biogeography: a Quaternary entomological view

PAUL C BUCKLAND
EVA PANAGIOTAKOPULU

> *Seagoon, „Eccles, what are you doing here?"*
> *Eccles, „Everybody's gotta be somewhere!"*
> *(with apologies to Spike Milligan)*

Introduction

At a conference arranged by Dorete Bloch in Tórshavn in 1998, several papers touched upon the problems of the origins of North Atlantic island biota, and these problems are still with us, despite a significant contribution from study of the fossil record. This paper presents the story so far.

The various arguments and counter-arguments over whether the biota of North Atlantic islands survived *in situ* in *refugia* or immigrated onto a *tabula rasa* after the last glacial maximum on ice, wind or bird has recently been effectively reviewed by Sten Rundgren (2007), essentially updating the earlier overview by Buckland (1988). This was the text of his Darwin lecture to the British Association, given in 1985, itself an outcome of a major research award from the Leverhulme Trust (UK) to the University of Birmingham in 1979 (see also Buckland *et al.* 1986 and Buckland 1992). Other reviews, also centring on the Icelandic evidence has been presented by Coope (1986), Ægisdóttir and Þórhallsdóttir (2004), and Gíslason (2005), who has reviewed the origins of the freshwater fauna. There was also a developing contrast between the Faroes, where the evidence for total glaciation was the stronger, and Iceland where there seemed a stronger case for refugia (e.g. Enckell 1989). Based on their work on the Skagi Peninsula in northern Iceland, Mats Rundgren and Ólafur Ingólfsson (1999) attempt a compromise between 'refugists' and 'clean slaters' in suggesting that survival was supplemented by renewed immigration during each interglacial thereby circumventing a problem which had remained a thorn in the side of even the most ardent refugist, the apparent lack, or at least extreme paucity of endemics, despite the intense selective pressures which climate through the Quaternary would have engendered. A similar, if not slightly more strongly leaning towards survival in refugia is apparent in a recent paper by Caseldine and others (2004). The lack of endemics was a problem which the paramount Swedish entomologist Carl Lindroth (1905-1979) lived with until the end of his life (cf. Lindroth *et al.* 1988). Too good a taxonomist to raise new species on the most minor of characters, he saw the problem of survival through multiple glaciations, the number increasing from a proposed maximum of four during the greater part of his life to over twenty towards the end, in terms of what the late Douglas Adams would have referred to as an SEP – Someone Else's Problem (Adams 1979); the evidence favours survival in refugia, it is up to others in different disciplines to find them. There was, of course, the annoying habit of geologists, like fellow Swede Gunnar Hoppe (1914-2005), dispensing with his, and the Icelandic botanist Steindór Steindórsson's (1902-1997) biological refugia (Steindórsson 1963) on geomorphological grounds (Hoppe 1968). The botanists, however, continued to describe new endemics (for an extreme case, see Ingimar Óskarsson's (1961) treatment of the genus *Hieracium*). The advent of genetics and, even in its most

Figure 1. The Faroe Islands from the top of Slættartindur, at 882m the highest point. The heavily glaciated landscape, deeply riven by fiords is evident. Photo: Paul Buckland 1982

rudimentary of forms, molecular biology, provided hope for the ardent refugist and new species sprang up like the now ubiquitous lupin in the Icelandic landscape (cf. Löve 1970). Some later molecular biologists, whilst supporting the refugia hypothesis (e.g. Abbott *et al.* 2000), were at least more circumspect in their description of new species. In the late 60s the World was changing, land bridges, current since the days of Charles Darwin, and most elegantly discussed by George Gaylord Simpson (1940) sunk under the grey waters of the Atlantic as plate tectonics replaced static land masses. Even Lindroth, himself a pioneer in the study of insect fossils (cf. Lindroth 1942; 1948), saw the 'threat' that the developing science of Quaternary entomology posed to his North Atlantic island biogeographic model. In a conversation with Russell Coope (pers. comm.), the doyenne of Quaternary entomology, he remarked that study of the fossil record should engender a sense of fear in the minds of biogeographers for now their wildest conclusions were subject to evidential scutiny.

The Insect Faunas

As well as research on the Holocene fossil record, over the past thirty years there has been significant progress in knowledge of the insect faunas of the Faroes, Iceland and Greenland, as well as adjacent continental masses, and a number of taxonomic studies since the work with the Holocene fossil record begun.

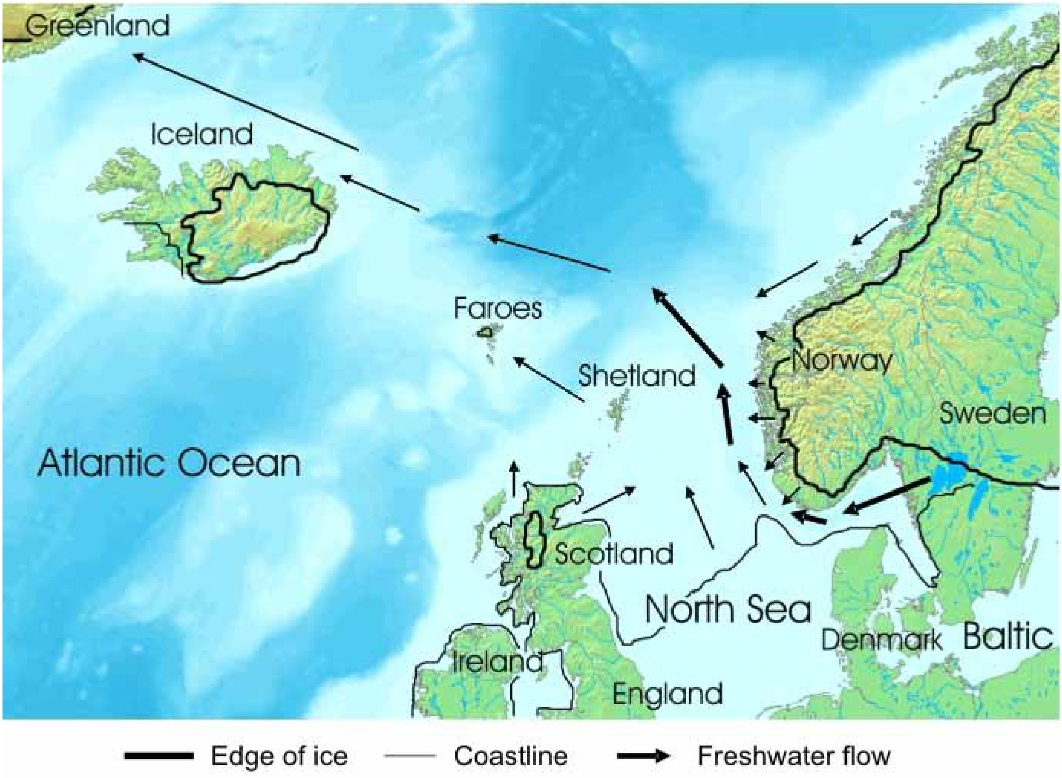

Figure 2. The ice rafting model (modified from Buckland & Dugmore 1991). The earlier form of this diagram is a more diachronous composition, which fails to include the Lateglacial drainage of the Baltic Ice Lake across Västergötland. Positions of ice fronts and sea level at ca. 11,200 B.P. are approximate and no attempt has been made to include the complexities of nunataks and islands.

In the 1980s both the Faroes and Iceland were subject to a detailed research programme organised from Lund by Sven-Axel Bengtson (2007), Most additions to their faunas consist of anthropochorous species (cf. Bloch 1994), but the Coleoptera of Greenland, extensively revised by Jens Böcher (1988), includes several species added to the list from natural habitats, largely small staphylinids previously overlooked (Böcher 2002; Buckland *et al.* 1998); Böcher (1988) also revised others, and the status of some species may require further elucidation (cf. Lohse 1989). An attempt by Bergersen (1995) to define

Greenland as a separate zoogeographic province on the basis of these putative endemics was firmly rebuffed by Sadler (1998). The provision of a new checklist to the Icelandic insect fauna by Erling Ólafsson (1991) clarified a number of issues, and research by Drotz on the morphology and genetics of the water beetle *Agabus bipustulatus* finally submerged the taxon *A. solieri* in the cold water pools of Scandinavia (Drotz *et al.* 2001). The discovery that North European specimens of *Pterostichus nigrita* consisted of two sibling species, *P nigrita* (Payk.) and *P. rhaeticus* Heer (Koch & Thiele 1980) has necessitated the revision of Faroese and Icelandic specimens of the former to *P. rhaeticus*, although these are indistinguishable on the fossils, where technically previous records should be referred to *P. nigrita/rhaeticus.* A series of checklists and taxonomic revisions of the Faroese fauna had been published in a series of studies emanating from Lund, the revised Coleoptera list appearing in 1981 (Bengtson 1981). Foster and Hansen (2004) have recently provided a more detailed discussion of the wetland fauna of the islands. Also relevant is recent work on the faunas of the Canadian littoral, which adds considerably to knowledge of anthropochorous species (e.g. Majka *et al.* 2007; 2008), providing updates to the classic study by Carl Lindroth (1957).

The Fossil Record

In his overview Buckland (1988) listed those taxa, which had been found as fossils in Holocene deposits on the North Atlantic islands, and which occurred before any evidence of human settlement. These lists have been partly updated in later papers (e.g. Buckland & Dugmore 1991). In a paper for a conference on Atlantic island biota in Madeira in 1994, the evidence from the North Atlantic islands was compared with that from the South (Buckland *et al.* 1996). The impact of humans on the insect fauna of Iceland was considered at a meeting in Aberdeen (Buckland *et al.* 1991), and was further explored in the second Atlantic island meeting on the Canary Islands in 1996 (Buckland *et al.* 1998a). The 1998 Tórshavn conference volume provided an opportunity for further updates on the fossil record from the Faroes (Buckland *et al.* 1998b & 1998c;

Buckland & Dinnin 1998). Some updates were included in the more general papers on environmental change on the North Atlantic islands (Dugmore *et al.* 2005), which came out of a further project funded by the Leverhulme Trust, but revised lists of taxa identified were not included. The creation of the Bugs database (www.bugscep.com) has made the collation of data much easier since, as well as the fossil insect record for the whole of Europe, with the Atlantic islands and Greenland, it also includes synonymic data and information on habitat and distribution for most species, as well as tools for interrogating the record (Buckland & Buckland 2006). Recent work has begun the extension of this resource to other groups, ini-

Figure 3. Sediment-laden ice, calved from Kangiata nunata sermia, a glacier at the head of Godhåbsfiord, SW Greenland. Whilst most of the sediment will contribute to bottom sediments as the berg melts, the accumulation on the surface may provide insulation and a suitable habitat for biota. In the case of the colonization of the Atlantic islands, the rapid warming and break up of sediment-laden tabular ice at the foot of glaciers in the Norwegian fiords may have been the most effective colonising mechanism.
Photo: Eva Panagiotakopulu 2003.

Figure 4. Siberian driftwood along the shoreline near Tjörnes, N Iceland. Whilst at the present day this is largely losses from logging in the taiga of the floodplains of the Ob, Lena and Yenesei in Siberia, in the past the material would have consisted of whole trees from similar riverbank sources. Photo: Eva Panagiotakopulu 2003.

tially within Sweden (SEAD, Buckland *et al.* in press), but with the intention of integrating it with other databases to make it both more holoptic and Holarctic. Table 1 is extracted from Bugscep and lists those taxa known from pre-Landnám contexts on the Faroes, Iceland and Greenland. The definition of Landnám in the stratigraphic record is as much a contentious issue as the refugist. In the Faroes, the earliest record of human impact remains a problem, from an optimistic assessment of the stratigraphic integrity of a few grain of Icelandic Landnám tephra (Hannon *et al.* 2001) and a pollen record of larger monoporate grains which might be cereals (cf. Lawson *et al.* 2008) to the more sceptical approach to the historical sources of Thorsteinsson (2005) and the palaeoecology (Buckland & Panagiotakopulu 2008). In Iceland, the tephra signal, at least in the south and east, provides an extensive isochrone, on ice core evidence dated to AD 871±2 (Grönvold *et al.* 1995), and there is little, if any archaeological or palaeoecological evidence that precedes it (cf. Buckland *et al.* 1995). The claims for earlier Irish settlement, based on art historical grounds (Ahronson 2000) have little to commend them. In Greenland, whilst an obvious charcoal layer may define the first burning of the landscape, to encourage grass rather than scrub growth, and may signify Norse landnám (Buckland 1988), palynology has provided an equally precise line on sites in the Eastern Settlement (cf. Edwards *et al.* 2008), although it is well to remember that Nearctic derived Eskimo cultures, Sarqaq and Dorset, preceded the European arrival (Jensen 2006), and had at least a few fellow travellers, if only lice (Panagiotakopulu, unpubl.).

In the table has also been included those species which have a Lateglacial fossil record from sites in southern Norway and Denmark and which are also recorded on the Atlantic islands. Some of the gaps in the list are a reflection of the taphonomy of samples, or lack of secure identifications, either because of taxonomic complexity, as most of the Aleocharinae, or non-recognition in earlier work. It has to be admitted that Occam's Razor to a certain extent simplifies identification on the Atlantic islands – in the absence of evidence to the contrary, sclerites which match those of, for example, *Boreophilia islandica* in Greenland have the highest probability of being that species rather than one of the several others which are indistinguishable without preservation of the genital armature elsewhere in the Holarctic. In Iceland, the identification of *Hydraena britteni* Joy, not recorded in deposits later than the late medieval period, was facilitiated by the survival of an aedeaus (Buckland *et al.* 1983); it might otherwise have been impossible. If Lohse's (1989) description of the minute aleocharine *Gnypeta groenlandica* is confirmed by more specimens, then fossil records of congener *G. cavicollis* Sahl. (Bennike *et al.* 2008) will need revision to the species pair, since they are unlikely to be separable on individual sclerites. More work on the morphometrics of species may allow closer identifications of some of the fossil material.

Taxon	Norway/Denmark Lateglacial	Faroes	Iceland	Greenland
Hemiptera				
Nysius ericae groenlandicus				X
Chlamydatus pullus				X
Coleoptera				
Carabus problematicus		X		
Nebria rufescens	X	X	X	
Notiophilus aquaticus	X			
Trechus obtusus	X	X		
Bembidion bipunctatum	X		X	
B. grapii				X
Patrobus septentrionis	X	X	X	X
P. assimilis	X			
Trichocellus placidus		X		
T. cognatus	X			X
Pterostichus diligens			X	
Pterostichus rhaeticus	X		X	
Calathus melanocephalus	X		X	
C. micropterus		X		
Amara quenseli	X		X	
Hydroporus palustris	X			
H. morio				X
H. pubescens		X		
H. nigrita		X	X	
Stictotarsus griseostriatus	X			
Agabus bipustulatus	X	X	X	
Colymbetes dolabratus	X			X
Gyrinus opacus	X			
Hydraena britteni			X	
Helophorus flavipes		X		
Coelostoma orbiculare		X		

Megasternum obscurum		X		
Anacaena globulus		X		
Micralymma marinum				X
M. brevilingue				X
Olophrum fuscum	X	X		
Eucnecosum brachypterum	X	X		
Lesteva heeri		X		
L. longoelytrata	X		X	
Geodromicus longipes	X			
Stenus carbonarius			X	
S. impressus			X	
Euaestethus laeviusculus				X
Othius angustus		X		
Lathrobium brunnipes		X	X	
Quedius fellmanni				X
Boreaphilia islandica			?	X
Gnypeta cavicollis				X
Aleocharinae indet.	X	X	X	X
Bryaxis puncticollis			X	
Hypnoidus riparius	X	X		
Simplocaria semistriata	X			
S. metallica	X			X
S. elongata				X
Byrrhus fasciatus				X
Cytilus sericeus	X			
Corticaria rubripes				X
Coccinella transerversoguttata				X
C. undecimpunctata	X			
Phratora cf. *polaris*				X
Apion haematodes		X		
Otiorhynchus arcticus	X			X

O. nodosus	X		X	X
Tropiphorus obtusus		X		
Dorytomus taeniatus				X
Rutidosoma globulus				X
Isochnus foliorum			X	

Table 1: Pre-landnám Hemiptera and Coleoptera from the Atlantic islands and relevant Lateglacial fossil records from Denmark and Norway

Does the list, which does not include the Diptera, which, other than chironomids, have only been identified in pre-European contexts at Qeqertasussuk in Greenland (Böcher & Fredskild 1993; Skidmore 1996), extended from that of Buckland (1988), modify the model of a primary origin of the terrestrial biota by ice rafting from Europe? The tabulation also includes a list of species at potential embarkation sites either on the south Norwegian coast or further south in Denmark. Of the 64 species represented, 27 occur in the Scandinavian coastal Lateglacial deposits examined by Coope and Böcher (2000) and Lemdahl (2000; Birks *et al.* 1993). Whilst this goes some way towards Rundgren's (2007) requirement for more fossil data, it does not localise the source areas in the way that molecular studies of island populations and the mainland may one day do (cf. Nilsson & Ribera 2007), and it does not narrow the window of opportunity which allowed the faunas to disperse, a temporary easing of a sweepstake to a harsh filter (*sensu* Simpson 1940). There remain a number of points which require further elucidation before potential source areas might be further defined. Coope (1986) noted the possibility of a northern British Lateglacial origin for the biota, a position endorsed by Böcher (1988), but not supported by Buckland and others (1986; Buckland 1988), who preferred an initial Holocene colonisation from Scandinavia, which would have included the Shetlands in its dispersal. Both may be correct in that Rundgren and Ingólfsson's (1990) work on the Skagi peninsula has confirmed the presence of a Lateglacial pre-Younger Dryas biota, but the cold conditions of the later would have led to

Figure 5. A flock of golden plover, Pluvialis apricaria (L.), arriving at Old Moor Reserve, S Yorks., England, probably from Iceland. Large numbers, and many more in the past, make the annual passage to wintering grounds in Britain every year.
Photo: Joan Buckland 2004

the extinction of several of the cool temperate elements in the Icelandic beetle fauna, requiring a later phase of immigration. Not all the fauna needs to have arrived by this route, and both Downes (1988) and Skidmore (1997) note that the more mobile Diptera and Lepidoptera show a pattern consistent with a New World origin. Several Holarctic species amongst the Coleoptera may be latecomers via this Nearctic route through Arctic Canada. This is likely to be the case with the two true Arctic staphylinids in Greenland, *Micralymma brevilingue* Schødte), according to Makarova and others (2007) the most cold tolerant beetle in the Northern Hemisphere, and *Gnypeta cavicollis* Sahl. (Böcher 1988) , the transverse ladybird, *Coccinella transversoguttata* Fald., a different subspecies of which is widespread in North America (Ková; 2005), and the weevil *Dorytomus imbecillus* Faust, which occurs from Greenland westwards across North America to north east Russia and Mongolia (Anderson 1997). Whilst Ková; (2005) was unable to confirm the record, the ladybird does appear to have northern Scandinavian records, and all three may have used a European jumping off point rather than a Nearctic one.

Repeatedly freezing the islands in a frozen sea stretching from the fringes of the Laurentide and Greenland ice caps in the West to the coast of Portugal in the East, with separate icecaps on Iceland, the Faroes, British Isles and Scandinavia would have left little room for island refugia, whose existence has been further doubted by recent computer modelling of ice sheets (Bingham *et al.* 2003). Finds of *Salix herbacea* in Early Pleistocene deposits in Iceland (Grímsson & Símonarson 2008) do not prove continuity, only that a suitable habitat that could be reached by some means of dispersal existed at least twice during the Quaternary. The same argument and counterargument has been advanced for the insects from the interglacial deposit at Elliðaávogur, near Reykjavík (Thorkellsson 1935; Buckland 1988; Lindroth 1963). Buckland also drew attention to the failure to find contemporaneous biota in the lacustrine deposits immediately south of the Last Glacial Maximum British ice sheet, and whilst the recent finding of a sparse chironomid and tipulid (*s.l.*) fauna in inter-till deposits at Dimlington (Bateman *et al.* in press) may seem to question this, the North Atlantic islands, lying so much further north, are unlikely to have been much different from the dry valleys of Antarctica (cf. Bockheim 2002) on numerous occasions through the Quaternary; the intermittent survival on, or existence of nunataks becomes irrelevant. Both Nordahl (1987) and Birks (1993) effectively demolished the nunatak hypothesis in Norway and their conclusions similarly apply on the islands of the North Atlantic.

Although not relevant for either the Faroes or Greenland, with its one warm pool, the hypothesis that Iceland's geothermal sources provided refuges for elements of the biota, advanced by Tuxen (1944), has recently received renewed attention. Two new endemic species of amphipod have been described from Iceland. Svavarsson and Kristjánsson (2006) have added the species *Crangonyx islandicus* and the same authors (Kristjánsson & Svavarsson (2007) have described a new family of amphipod, the Crymostygidae, and the species *Crymostygius thingvallensis*, on the basis of material from streams emerging from porous lavas and draining into Þingvallavatn. Claims of endemism are always subject to longer term scrutiny (cf. Sadler 1998 on Greenland), but it is currently argued that these gammarids have survived for 30-40 million years, from a time of warm temperate forests with beech, hickory, magnolia and sassafrass (Denk *et al.* 2005) in the expanding North Atlantic, through cooling and ultimately multiple glaciations, as troglobionts, in refugia under the ice sheets. The big problem of living beneath the Ice, however, and ignoring the problems of pressure under the weight of the ice cap, is food. Ultimately all underground communities rely, like H. G. Wells' (1895) Morlocks, on food from the surface, either detrital, or brought in by species using the caverns as day or night refuges. Algae growing in or on ice penetrated by sunlight at the surface (cf. Vincent 2007) may be the ultimate base of the food chain, but more research is required before survival *in situ*, is accepted for these amphipods. Entombment within the ice may allow some plants, particularly Bryophytes, but not animals, to survive decades, if not a century (La Farge *et al.* 2007), but not multiple glaciations.

Bennike (1999) has contended that interpretation has tended to downplay other modes of immigration, in particular anemochorous dispersal, although Buckland (1988) does draw attention to Charles Elton's classic (1925) paper on Svalbard (Spitzbergen), and more recently Rundgren (2007) has highlighted several other examples. That Coleoptera, other than the small staphylinids which could be swept up into the aerial plankton (*sensu* Crowson 1982), could take part in such dispersal has recently been demonstrated by radar tracking of swarms on *Notiophilus biguttatus* (F.) over the English Channel (Chapman *et al.* 2005); a circulation pattern similar to that which occasionally takes takes mainland species of moth (Ólafsson & Björnsson 1976) and dragonfly (Ólafsson 1975) to Iceland may account for this species in the Faroes and Iceland, although it is also prone to anthropochorous dispersal, and has been introduced to Newfoundland (Lindroth 1957; 1961); there are no pre-Landnám fossil records, so far. Compared with Iceland and Greenland, the water and wet mud fauna of the Faroes is much more diverse (Foster & Hansen 2000), and a component dispersed by migrating birds, as suggested 150 years ago by Darwin (1859), is probable. Whilst both Buckland (1988) and Rundgren (2007) stress the fact that birds will preen themselves effectively before long distance flight and the chances of survival of invertebrates, as opposed to plant propagules, in the crop and gut seems slight (but see Green & Figuerola 2005), in the many millions of passages on migration to summer breeding grounds in Iceland and Greenland during the Holocene only one successful hitchhiker, gravid female or string of eggs, would be necessary to establish a population. Some of the beetles found in the eutrophic accumulations in and around bird nests and cliffs may also have arrived with their occupants, but all this is a case of chicken, or rather guillemot or goose, and egg. Until the high productivity of Arctic island ecosystems had been established by the prior immigration of terrestrial and freshwater biota, there could be no migration. Although some mites (cf. Elton 1925) and beetles (cf. Woodroffe 1967) are phoretic on both vertebrates and other insects, it is unlikely that this has resulted in more than a minor contribution to North Atlantic island faunas, and the problem of establishment of the base biota remains.

Figure 6. A föhn wind blowing off the ice cap whips up spray in the fiord off Igaliku, SW Greenland. Similar winds rolling down off the decaying Scandinavian ice sheet would have deposited plant propagules and invertebrates onto sediment-laden ice and icebergs during the Lateglacial. Photo: Eva Panagiotakopulu 2004

A further mechanism which has been re-considered is that of Arctic driftwood, emanating largely from the great rivers of Siberia, the Ob, Yenesei and Lena, flowing into the Arctic Ocean, and bringing with them significant amounts of wood (Eggertsson 1994), in recent years, largely lost logging timber, but in the past trees undercut on the river banks and often carrying sediment and peaty soil. In a discussion which also examines the role of drift ice, Johansen and Hytteblom (2001), point to the disjunct distribution of several plants around the Arctic Ocean, which seem best explained by chance arrival by rafting. Whilst plant propagules may survive trapped in crevices in driftwood for several years, it is unlikely that insects could do the same since their need to respire and often annual generations would not allow them to survive several years in the Arctic gyre. In addition, unless taken up into drift ice, trees tend to waterlog and sink within two years (Häggblom 1982). Having survived transport, and a grinding in the ice which removes bark and trims broken ends of trunks like pencils, the problem for any biota would be making the transition from crevice protected against saltwater to dry land and suitable habitat. There is no doubt that winter storms will send driftwood scudding over the mash of intertidal sea ice and across frozen ground and wood derived in this way can occasionally be seen in coastal peats on the Northwest Peninsula in Iceland (Buckland, pers. obs. Finnbogarsstaðir 8/97), but such events are likely to have been rare, unless there was some occurrence in which increased ice rafted debris and reduced salinity were also associated, and the Lateglacial and early Holocene provide the most likely, and most recent event for this.

The hypothesis of ice rafting as a mechanism to disperse biota to the Atlantic islands, consequent upon rapid warming and the more rapid retreat from the coast of the British and Scandinavian ice sheets, compared with the Laurentide one, remains the most viable alternative to the SEP of survival *in situ*. Rundgren and Ingólfsson's (1995) attempted compromise may be true, but it does not dispense with the need to spread biota across the northern ocean. The periodic presence of European derived ice rafted debris in cores from off the coast of southeast Greenland (Verplank *et al.* 2009) provides the necessary evidence to substantiate the model, although the dating regime requires much closer scrutiny. Recently the concept of rafting by a large number of agents, from kelp to ice, driftwood and pumice has been thoroughly reviewed (Thiel & Gutow 2005a & b; Thiel & Haye 2006), and whilst this discussion largely concentrates upon the terrestrial fauna and its fossil record, it is well to remember that marine littoral species may face similar problems in dispersal (cf. Johannesson 1988), and ice rafting may be equally relevant to them. Ingólfsson (1992) noted the frequency of amphiatlantic taxa in this habitat, and suggested a European origin, a position supported on genetic grounds by Wares and Cunningham (2001). Both Ingólfsson (1992) and Thiel and Haye (2006) hypothesise that floating algae was the mechanism for dispersal but, as this would indicate movement against the prevailing current of the North Atlantic Drift, it seems more probable that these taxa were also caught up in the outwash of the European ice sheet during rapid deglaciation. Certainly it is probable that the principal phase of outwash of sediment-laden ice into the North Atlantic coincided with a phase of catastrophic drainage (*jokulhlaup*) of the Baltic Ice Lake, (Bodén *et al.* 1997), sending a slick of additional freshwater into the Norwegian Sea and across the Atlantic. Whilst this event itself, dated to *ca.* 12 800 cal. yr BP by Nesje and others (2004), may have been partially responsible for the sudden cooling into the Younger Dryas stadial, it cannot account for the evidence for Lateglacial interstadial biota on the Atlantic islands (e.g. Rundgren 1995; Björk *et al.* 2002), and if catastrophic freshwater forcing is to be invoked, an earlier event has to be sought, perhaps associated with the initial deglaciation. Drainage associated with the beginning of the Preboreal Oscillation at *ca.* 11 335 cal. yr BP (Nesje *et al.* 2004) may have facilitated Early Holocene colonisation, but it is as well to heed Blaauw and others' (2007) recent *caveat* on the use of radiocarbon dates, and that correlation does not guarantee causation. Indeed examining the putative base faunas from the key sites of Nørre Lyngby on the modern Danish coast (Coope & Böcher 1988) and Kråkanes on the southwest Norwegian coast (Lemdahl 2000), there are several points, both temporal and spatial, at which the biota could have boarded the metaphorical ship.

A Final Conundrum

The latridiid *Corticaria rubripes* Mann. (= *linearis* (Payk.) of Bugscep) from Greenland, is a mould-feeding beetle which, like many other species of latridiid, cryptophagid, and mycetophagid, might be expected to have formed part of the accidental baggage of Norwegian sailors, yet it occurs long pre-Landnám on the Sarqaq site of Qeqertasussuk (Böcher & Fredskild 1993). Its European records suggest a strong association with burnt wood (e.g. Palm 1959; Kullingsjö 1999). Although this is an unlikely habitat in Greenland, the species does increase in frequency in charcoal-rich horizons at Tasiusaq in the SW, where burning is probably to be associated with Norse settlement (Panagiotakopulu *et al*. in press). The few modern Greenlandic records, however, from the Kangerlussuaq area (Böcher 1988), are in moss and from pitfalls in rich vegetation and the sparse Canadian records include an example from a bracket fungus (Majka *et al.* 2009). The North American distribution is similar to that of many introduced species, but that is another story.

Conclusion

It has to be recognised that the refugia argument is not dead, even if severely dented in the light of geological, palaeoecological and palaeoclimatic evidence. The tabula rasa and ice rafting hypothesis, with the addition of the occasional tramp by wind or bird ferry, still has many problems, not least of which is an insecure dating framework, which should eventually be resolved, probably with tephrochronology rather than radiocarbon and other dating techniques alone. Similar biota from earlier interglacials do not imply survival, merely similar dispersal mechanisms. Whatever the final conclusions are – and there may never be any, despite the present authors' geological, rather than biological standpoint leading towards clean slates and ice – the answers must still lie in the fossil record. Interpretation of modern data, where derived from the hard sciences genetics and molecular biology or simpler morphometrics, is inevitably influenced by the standpoint of the researcher: if one is seeking refugia then one will find them (cf. Maggs *et al.* 2008) and alternative hypotheses of greater dispersal potentials will not be considered. The contrary, of course, is also the case. There is little dialogue between neontologists and palaeontologists, and still limited macrofossil evidence from the Faroes, Iceland and Greenland. Potential Lateglacial and Early Holocene Scandinavian, or British, emigration areas are a little better served (for insects, see the data in Bugscep, Buckland & Buckland 2006), but this still leaves much room for the exercise of Ball's Law, „The less the evidence, the stronger the hypothesis."

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Notes on the synanthropic and native tineid and oecophorid species on the Faroe Isles

with a special reference to Tinea pallescentella Stainton, 1851 (Lepidoptera: Tineidae)

Svend Kaaber

Abstract

The biology of the six synanthropic microlepidoptera species being mentioned in the literature from the Faroe isles has been reviewed based on field observations and collecting work during 1990-1998. *Tinea pellionella* (L.) is mentioned by the early Danish author Jørgen Landt (1800) but has not been recorded since that time. *Niditinea pellionella* (Hummel) is an indoor pest species which has been observed only in Tórshavn. *Tinea pallescentella* Stt. is an overlooked species, which has been observed partly in small synanthropic populations where its larva lives in unheated storehouses on air-dried animal and fish products, but also as a native species associated with nesting seabirds. *Monopis laevigella* (Den.& Schiff.) is at present only observed as a synanthropic species feeding in the larval stage on stored wool and feather in outhouses , but is probably also native and associated with nesting seabirds . The oecophorid species *Hofmannophila pseudospretella* (Stt.) was not recognized until 1910, but is at present a widely distributed and mainly indoor synanthropous species, while *Endrosis sarcitrella* (L.)being recognized already in the nineteenth century, is a widely distributed anthropochorous species with synanthropic indoor populations in most human settlements on the isles.

Introduction

Human impact on nature is usually a long-term and more indirect process. On the Faroe isles the process is evident by their name that originates from the sheep being introduced by Irish anachoretes at about A.D. 650 (Jóhansen, 1985). The subsequent colonization of the isles by norsemen at AD 850 and the even later establishing of commercial centres like Tórshavn at about AD 1550 initiated an urbanization with a steadily increasing number of anthropochorous plant and animal species.

The anthropochorous elements are well documented in the vegetational history of the Faroes (Jóhansen 1985) and also in its avian and mammal faunas. Their role and importance on the lepidopteran fauna is at present largely unknown with the exception of a the subgroup of synanthropic species connected with indoor habitats as houses, outhouses, barns and warehouses where they under the adverse outer conditions can maintain breeding population for shorter or longer periods of time. On the Faroe isles the subgroup consists of only 5 or 6 species, which belong to the two families Tineidae and Oecophoridae, where several of them are well-known and have been recognized for a long period of time.

The first record of Lepidoptera from the Faroe Isles dates back to 1800, when the Danish priest Jørgen Landt published a book ‘Beskrivelse over Færøerne’, in which various aspects of the Faroe nature are mentioned. In his description of the insect fauna the main focus is on the indoor and human-associated species as lice (*Pediculus*) and fleas (*Pulex*) (Landt, 1800). His two lepidoptera species were listed with contemporary Linnean names belonged also to that cathegory. The first one, *Phalaena Tinea sarcitrella* was provided with two additional Faroe designations ‘hexmadur’ and ‘húsvætti’; names which are still used to characterize indoor microlepidoptera species (Dahl 1954). The second one, *Phalaena Tinea pelionella* was characterized with the Danish name 'pelsmøl' , a designation which clearly reflects a different species, being most likely a tineid species and not *Hofmannophila pseudospretella,* as suggested by Wolff (1929).

The next treatise on the Faroe insect fauna was published 80 years later and was mainly based upon material in the Zoological Museum, Copenhagen, collected by the Danish district physician A. Berg, who practised on Suduroy from 1863 to 1868 (Hansen, 1880). Hansen's list included two probable tineid species '*Tinea fuscipunctella*?' and an undetermined species, both of which were later redetermined as the two outdoor species, *Plutella senilella* (Zett.) and *Plutella xylostella* (L.) by Wolff (1929). In a later publication on some microlepidoptera collected on Suduroy in 1910 by A. von Klinckowström were two synanthropous oecophorid species *Endrosis lacteella* Schiff. (now *E. sarcitrella* (L.) and *Borkhausenia pseudospretella* Stt. which was recorded from the Faroe Isles for the first time (Hamfelt, 1917).

During the summer months in 1925 and 1926 the Danish entomologist Jens Peter Kryger paid visits to a number of the Faroe Isles, where he collected material of different insect groups such as Hymenoptera, Diptera, Coleoptera, Plecoptera and also Lepidoptera to the Zoological Museum in Copenhagen. His large material of Lepidoptera, consisting of more than 700 specimens and 25 species included the tineid *Monopis rusticella* Hb., which was discovered by N.L Wolff during his analysis of the material and later published in a comprehensive treatise on the Lepidoptera fauna of the Faroe Isles (Wolff, 1929). During the British occupation of the Faroe Isles in World War II the officer and entomologist E.S. Brown discovered a further tineid species, *Tinea pallescentella* Stt. while sugaring at Tórshavn in October 1943 (Brown, 1944). From 1953 to 1959 the Faroe physician Leif Dahl practiced at Eidi on the northernmost part of Eysturoy. During these years he collected Lepidoptera, mainly at Eidi but also on other places across the Faroes . In 1954 and 1956 he published two papers in Faroe language with a focus on the native fauna, where he discussed the biology of the common Faroe Lepidoptera species , including the three synantropous species *Monopis rusticella* (húsvættid svarta), *Endrosis sarcitrella* (húsvættid gráa) and *Hofmannophila pseudospretella* (húsvættid brúna) (Dahl 1954, 1956). In a later survey covering indoor pest insects in the Faroe isles during 1986 -1992 the well-known clothes moth *Tineola bisselliella* Hummel was included as a new synanthropous tineid species (Bloch & Mourier 1994). Between the years 1990 and 1999 systematic field studies were undertaken by the present author and the soil invertebrate specialist and acarilogist Peter Gjelstrup from the Museum of Natural History, Aarhus in cooperation with Føroya Náttúrugripasavn in Tórshavn, where the aims of the author were to study the native lepidopterous fauna of various ecological niches on the islands and to assess the role of lepidoptera migration on the native fauna. Within two or three annual visits field work during daytime was made on most isles, and continuous light trap collecting was performed on 11 sites on ten isles (Kaaber,1997). Representative voucher material was also prepared from most collecting places and supplied with detailed field records on all species recorded.

The aim of this study is to bring forward field records and light trap observations on the synanthropic tineid and oecophorid species during the study and to compare with earlier and subsequent observation of these species from the Faroe isles and the neighboring faunal areas.

Results

Tineidae

Tineola bisselliella (Hummel, 1823)

Was not recognized by the author 1990-98, but observed as an indoor pest on Streymoy: Tórshavn (Bloch & Mourier 1994).

Tinea pellionella Linnaeus, 1758

Was not recognized by the author 1990-98 and was not observed in the material investigated by Bloch & Mourier (1994).

Tinea pallescentella Stainton, 1851
Two observations during 1990-98: Eysturoy: Rituvik 29.VI.1991, 2-3 males flying freely in sunshine at 2 p.m close to a breeding colony of *Fulmarus glacialis* (før. Havhestur). Vágar: Midvágur 10.VII.1997, a female at rest outside on an uninhabited storehouse.

Monopis laevigella (Denis & Schiffermüller, 1775) (syn: *Monopis rusticella* Hb.)
Field observations: Only found outdoors as a synanthropic living species.Nolsoy: Bygdin a male at rest 29.VI.1993. Mykines, common among stored wool-bags 16.VIII.1994, Skúvoy, a male at rest 25.VIII.1994. Kunoy, a female at rest 2.VIII.1998.

Light trap catches: Nolsoy: Bygdin a male 25-30.VII.1994, a male 24-30.VII.1995, Sandoy: Sandur 3 males 24.VII-3.VIII.1995.

The present observations were only made on smaller isles, thus suggesting that the synanthropic populations there were depending on a native population with a biology which has to be studied more closely.

Oecophoridae

Endrosis sarcitrella (Linnaeus, 1758)
Field observations: The species was observed commonly in any settled area visited in June and July, mainly outdoor at rest on houses, trunks and fences, but also as dead specimens on church-window sills or in shop-windows. It was also observed at dusk, flying freely between houses and along stone fences, often at considerable distances (more than 500 metres) from the settlement e.g. on Svínoy 1991, Vidoy 1996, Kunoy 1997-98 , on southern Eysturoy at Rituvik in 1991, on Streymoy at Leynum in 1996 and Kaldbak in 1997, thus indicating stable outdoor populations in these areas.

Light trap catches: The species was caught regularly in 10 of 11 trap sites, but not in the trap on Vidoy: Dalar in 1996.

Hofmannophila pseudospretella (Stainton, 1849)
Field observations: The species was found commonly in most

of the settled areas which were visited during July and August, mainly indoors in window sills or inside shop-windows. In Tórshavn 29.IV.1991 several hundred dry specimens were observed indoor in a closed shop. As a larva it was found commonly in stored wool-bags on Kunoy and Mykines during VIII.1994 together with newly hatched imagines. Outdoors it was observed singly, at rest on walls during late afternoon. Sandoy: Sandur in VII.1991, on Vidoy: Vidareidi in VIII.1996 and on Kunoy VIII.1996 and VIII.1998.

Light trap catches: The species was caught regularly in the traps placed close to human settlings on Suduroy: Trongisvágur, Sandoy: Sandur, Vágar: Midvagur, Nolsoy: Bygdin, Streymoy: Hoyvik, Kunoy: Bygdin and Fugloy: Kirkja, but not in the traps placed more than 100 metres from inhabited buildings, as at Suduroy: Akraberg, on Stóra Dimun, and on Vidoy: Vidareydi and Dalar.

Discussion

Most native European species in the genus *Tinea* Linnaeus and *Monopis* Hübner feed on animal fibres or products, preferably on the organic material and detritus of birds´ nests, on pellets from owls and other birds of prey, or on faeces from animals of prey. Due to their preference for organic matter in the larval stage many of them are also able to establish synanthropic populations on stored human products of animal origin, or indoors on clothes made of furs and wool.

The larva of *Tinea pellionella* Linnaeus, 1758 was well-known by the early naturalists in the sixteenth century and was also later recognized by lay people due to its portable case. In the nineteenth century it was an important indoor pest on clothes and fur material both in Norway (Schøyen, 1876) and Great Britain (Robinson 1979, Pelham-Clinton, 1985). The old Faroe record of the Linnean species '*Phalaena Tinea pellionella*' seems therefore quite reasonable, although the species has not been recorded since. As a native species in Northern and Western Europe its larvae feed on organic substrate in bird's nests and on owl pellets or faeces from animals of prey (Robinson, 1979). In Northeastern Ireland *T.pellionella* has also been recorded from puffins' burrows (Thompson, 1937), suggesting that it might also be a native species on the Faroes. As an indoor pest it was during the nineteenth and in the twentieth century replaced by the more competitive *Tineola bisselliella* (Hummel), which is better adapted to higher room temperatures. In World War II when the author lived as a young boy in Tórshavn , *Tineola bisselliella* was a well-recognized indoor pest , and its presence still allows me to recollect the characteristic smell of the cloth-protecting chemical naphthalene from those years. The recent Faroe observations suggest that the species still maintains a small indoor population in Tórshavn.

The remaining four Faroe species show differing levels of anthropogenic behavior: *Monopis laevigella* (Den.& Schiff.) and *Hofmannophila pseudospretella* (Stt.) are seemingly able to breed in both inhabited and uninhabited buildings, while *Endrosis sarcitrella* (L.) and *Tinea pallescentella* (Stt.) have an association with both synanthropic populations and populations reproducing themselves under natural conditions. A similar behavior characterizes *M. lavigella, H. pseudospretella* and *E. sarcitrella* on Iceland (Wolff,1971) and on Shetland (Pennington, 1999), while on the Orkney Islands *M.laevigella* is more frequently met outdoors on heaths than under indoor conditions (Lorimer, 1983, 1994). *T.pallescentella* has till now only been observed once in a light trap in 1980 in the Orkneys, while it on Shetland has been observed near unheated out-houses (Pennington, 1999).

The natural habitats in the North Atlantic area of *Tinea pallescentella* are at present largely unknown . The Faroe observation in 1991 at the coast near Rituvik on southern Eysturoy points to an association with nesting seabirds as fulmars (*Fulmarus glacialis*). This association has also been observed in Norway, where the Norwegian entomologist Reidar Mehl, while working professionally with insect pests in 1969 discovered, that *T. pallescentella,* which is a recognized pest species in store-houses with dried fish, was also occurring naturally at bird-cliffs in West Norway. There the larvae lived on remnants from feathers and dry fish in the nests of seabirds such as cormorants (*Phalacrocorax carbo*), puffins (*Fratercula arctica*) and kittywakes (*Rissa tridactyla*) (Mehl, 1977, Opheim, 1973).

The second observation of *T.pallescentella* during the field study was made in the town of Midvágur on Vágar in early July 1997 where a female was found at rest on the wall of an unheated storehouse, in which dried animal and fish products were stored in open air during the winter. Due to the strict time schedule on that day a more thorough search inside the building was not made. The outhouse was located about 50 metres from an automatic light trap, which was operative at Midvágur until the middle of September in 1997, but the species did not turn up later that year.

In view of the Norwegian observations the specimen most likely originated from a local synanthropic population in the outhouse where the larvae fed on stored remnants of stockfish or dried sheep meat , both of which are traditional foodstuffs in general use in many Faroe households. Similar small and overlooked synanthropic populations seem to be the probable origin of those specimens , which due to light trapping have recently been recorded on Nolsoy in September 2000 (Jensen 2001), on Suduroy: at Sumba in December 1997, and on Streymoy: Argir and Hoyvik near Tórshavn in July, August and October 2001-2006 (Jensen & Sivertsen, 2004, 2007). On the Shetland Islands the synanthropic populations of *T.pallescentella* are probably also dependent on a stable native population linked to seabird-colonies. This connection may explain the presence of *T. pallescentella* on the two isolated islets, Fair Isle and Fugla off the Shetland Islands (Pennington, 1999), as well as on the Orkney Islands (Lorimer, 1983), and in the coastal areas of Scotland, where it has been found, see Pelham-Clinton (1985).

The present observations indicate that *Tinea pallescentella* is native on the Faroe Isles with a biology connected with seabird's nests and a rather insignificant synanthropic population. The same situation may also be the case of *Monopis laevigella,* as its larvae under natural conditions live in the nests of various birds. In Norway they are found in the nests of Kittiwakes (*Rissa tridactyla*) (Opheim, 1973). On St. Kilda, an isolated islet 50 miles off northwestern Scotland *M. laevigella* has developed a distinct local race frequenting the cliffs and not the buildings of the small village (Corbet, 1945). These observations are suggestive of similar overlooked Faroe populations in *M. laevigella* connected with nesting seabirds. At present the native biology in the North Atlantic area for both species under the harsh oceanic conditions during the winter is quite unknown. In *T. pallescentella* the conditions point to a connection with colonially living seabirds in burrows such as puffins (*Fratercula arctica*) and Manx shearwaters (*Puffinus puffinus*). If such a natural connection between *T. pallescentella* and breeding colonies of *P. puffinus* can be verified in this area , this may throw a more clear light on the recognized transatlantic occurrence of *T. pallescentella* in Patagonia (Robinson, 1979). Field studies aimed to solve these open questions initiated at Føroya Náttúragripasavn in the coming years would therefore be much appreciated.

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Illustrations

Fig. 1. The six microlepidoptera species mentioned in the study. The specimens are from the Faroe Isles, except the female of *Tineola bisselliella,* and the male and female *Tinea pellionella*, being of Danish origin.

The two topmost rows from left to right. Male and (below) female of: *Tineola bisselliela* (Hummel), *Tinea pellionella* L., *Tinea pallescentella* Stt. (both males) and *Monopis laevigella* (Den.& Schiff.).

The two bottom rows from left to right: Male and (below) female of *Endrosis sarcitrella* (L.) and *Hoffmannophila pseudospretella* (Stt.)

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Man-dependence of House Sparrows (Passer domesticus) in the Faroe Islands: habitat patch characteristics as determinants of presence and numbers

Sven-Axel Bengtson, Kirstin Eliasen,
Laura Mary Jacobsen, Eydfinn Magnussen

Abstract

The House Sparrow (*Passer domesticus*) began to colonize the Faroe Islands in the mid-1940s and occurs in most built-up areas. Breeding is confined to the discrete human habitations (settlements) that form a pattern of patches (”habitat-islands”). In 2002 all settlements were surveyed and the number of pairs of sparrows (total number *ca.* 2,700 pairs) and amount of vegetation (”green space”) were estimated. The settlements ranged in size from 0.01 km^2 (a single farmstead) to 8.72 km^2 (the capital) and 68% of them (n=118) were occupied by sparrows. Patch occupancy was positively correlated with both area and amount of vegetation ($p < 0.001$) but not quite with the degree of isolation ($p = 0.15$). The latter was crudely scored as a function of distance to nearest settlement with > 10 pairs (a possible source area) and topography (mainly mountains and open sea). The patch variables area, human population, number of houses and houses were strongly intercorrelated. Abundance (number of pairs) of sparrows was positively correlated with the number of houses (r = 0.84, p < 0.001). In all but one of the settlements with < 10 houses sparrows were absent, and also in many of those with 10-60 houses where the scatter swas wide (no significant correlation p = 0.25). All but one of the settlements with > 60 houses supported sparrows and the correlation with abundance was highly significant (p < 0.001). The absence of sparrows in small settlements is discussed in terms of risks of associated with small populations such as stochastic extinctions, Allee effects, competition, and predation (incl. persecution by Man). Various anthropogenic effects on abundance of sparrows are discussed; *e.g.* age, type and conditions of buildings and the presence of gardens, cultivations, and plantations all contributing to shelter and food resources. The Faroese House Sparrow as a metapopulation is briefly discussed.

Introduction

Most populations are spatially structured in respons to landscape heterogeneity and patchiness of resources at various levels of scale. For species that have evolved specific habitat requirements that occur as discrete habitat patches this may result in a patchy distribution pattern, where at any given time, however, only a fraction of the suitable patches may be occupied; thus a metapopulation model. Among birds many species occupy discrete habitat patches („habitat islands“) on a local scale, *e.g.* the House Sparrow (*Passer domesticus*), which is a worldwide companion of Man and infrequently found breeding outside human habitations (Summers-Smith, 1988, 2005); hence, usually exhibiting a distinctly patchy geographical and local distribution. The House Sparrow has received considerable attention especially since the mid-1970s when the populations began to decrease dramatically in several north-west European rural, suburban, and in particular urban areas. This caused much concern and prompted intensive research that has generated a number of hypotheses in attempts to explain the decline (Crick, 2002; Summers-Smith, 2003; Anderson, 2006; De Laet and Summers-Smith, 2007). Previous studies have demonstrated a number of relationships between density of House Sparrows and *e.g.* human population density (Rand, 1956; Summer-Smith, 1963), conditions of buildings and hence availability of nest-sites (Deckert, 1969; Coleman, 1974; Heij, 1985), food supply (Summers-Smith, 1959), and amount of vegetation (green space) on breeding grounds (Heij, 1985). These and other habitat variables such as presence of predators (Tinbergen, 1946; Churcher and Lawton, 1987; Beckerman *et al.,* 2007) contribute to qualitative differences between habitat patches on a local scale; differences that may be amplified by climatic factors manifested by effects of weather conditions on recruitment (Ringsby *et al.*, 1998; Saether *et al.*, 1999; Ringsby *et al.*, 2002).

Present study explores the association between certain patch properties (*i.e.* habitat quality) and the distribution (occupancy of suitable habitat patches) and abundance of the House Sparrow on the Faroe Islands. The House Sparrow first colonized the Faroes a few years prior to the Second World War, and within *ca.* 50 years it had spread to, and bred at least once in effectively all built-up areas (settlements), though not yet found breeding outside any of them; the total population in 2002 was estimated at *ca.* 2,700 pairs (Bengtson *et al.*, 2004). We surveyed and subsequently estimated the number of breeding pairs in virtually all the settlements on the islands from the very smallest, solitary farmsteads to the capital of Tórshavn. The aim of the study was to analyse this snapshot picture to determine whether settlement area and isolation (*i.e.* traditional metapopulation parameters) and other variables more directly associated with human presence can predict patch occupancy and abundance of House Sparrows.

Material and methods

The islands and settlements

The Faroes consist of 18 islands (0.8 – 374 km^2; total area 1,399 km^2) that are separated by narrow straits or short stretches of water (Fig. 1); all islands are inhabited except for the smallest one (Lítla Dímun). Topographically the shorelines that are facing west and north are characterised by spectacular, precipitous cliffs. Inland the terrain consists of valleys, mountain ridges and upland hills; the northern islands being the most mountaineous (highest peak 882 m a.s.l.). The climate is pronouncedly oceanic with a mean temperature of 4 and 11°C during the coldest (January -February) and warmest (July) months, respectively. Mean annual precipitation varies locally (800-2,200 mm) and fog or strong winds frequently prevail.

All but one of the settlements are situated on the coast and constitute a network of distinctly discrete patches of land (infields) placed in a landscape (outfields) of more or less natural habitats (see Enckell *et al.*, 1987; Enckell and Bengtson, 2010). In principle a settlement consists of a densely build-up area with some adjoining cultivated land (mostly for haymaking and potatoes) that is usually separated from the surrounding outfield by stonewalls or other kinds of fences. Hence, the boundary between infields and outfields is usually very conspicuous. There is no natural tree vegetation on the islands, but small plantations (mostly coniferous) occur in some of the settlements. We recognized 118 settlements (*i.e.* potential House Sparrow habitat patches) ranging in size from 0.01 to 8.72 km^2 and constituting 4.5 % of total island area. For names of islands and geographical position for some of the settlements mentioned in the text see Bengtson *et al.* (2004: Fig. 1).

Surveying the House Sparrows

The fieldwork was carried out intermittently between early April and mid-June. Each settlement was surveyed by slowly walking along the streets and lanes inspecting the entire area and plotting all House Sparrows seen or heard. Chirping males were readily located when openly pearched on top of roofs, eaves and in bushes and they were also heard when hidden and out of sight under roofings or inside buildings. We scrutinized gardens, cementaries, areas with weeds and dense vegetation, cultivations and allotments, warehouses, older building, backyards, enclosures for poultry (including ducks, and geese), and farmhouses. Particular attention was paid to birds moving in or out of sections already surveyed and to this end the configuration of many settlements proved helpful as several of the smallest ones are less than 100 m across and many of the smaller and medium-sized ones consist of buildings along a single main street running parallel to the shoreline. In the larger settlements there are usually several parallel streets or a much more irregular network of roads. Each area was surveyed only once and the time spent ranged from some 15 minutes (a single farmstead) to several hours depending on area, complexity of habitation, number of sparrows and prevailing weather conditions. The largest settlements were divided into sections that were surveyed over two (Klaksvík and the large settlements on Suduroy) or several (Tórshavn) days. The estimates of number of pairs are considered conservative. However, the degree of accuracy of the surveys was not tested but the procedures were consistent and the methods, although being one-visit-surveys, were in reasonably good agreement with recommendations given by Summers-Smith (*in litt.*). Further information on the data collecting is given by Bengtson *et al.* (2004).

The patch variables

For each settlement, we collected various data considered biologically relevant and/or being potential predictors of presence and abundance of House Sparrows. Among the data collected some did not reach the qualitative requirements (*viz.* presence of domestic cats (*Felis catus*), Norwegian rats (*Rattus norvegicus*), and domestic fowl) and the following patch variables are included in this study:

(i) Settlement *area* (km^2) was obtained from the MapInfo computer program using the topographical electronic map for the Faroes (scale 1:20 000).

(ii) *Human population* (official statistics; Anon., 2002) and *number of households* (equivalent to number of electricity meters) were used as an overall measure of resources provided by human activities (*e.g.* nest-sites, shelter and anthropogenic food in terms of scraps, stores, gardening, cultivation and farming).

(iii) *Number of houses* (data from local municipal administrations) since buildings provide nest-sites and shelter and family houses are often associated with gardens and cultivated plots.

(iv) Amount of *vegetation* was scored (rich-medium-poor; denoted +1, 0, -1) taking into account presence of old, overgrown gardens with shrubs and a lush vegetation (providing both plant and animal food), occurrence of commons, allotments and open, often untidy patches with grass and weeds; *i.e.* green space.

(v) Degree of *isolation*. By assuming that the probablity of (re)colonisation and hence presence of House Sparrows is a function of isolation (distance and/or topography) from a potential source area arbitrarily defined as the nearest neighbour settlement with > 10 breeding pairs we used a three-scaled classification: (0) adjoining or marginally distant; *i.e.* effectively fused with the source area, which in a few instances has occurred when neighbouring settlement have expanded in size, (1) < 5 km to nearest neighbour, and (2) > 5 km from a source settlement, or separated by mountains higher than 300 m.

Treatment of data

The numerically described patch variable are interrelated; thus, human population, number of house holds, and number of houses are pairwise strongly correleted (Spearman correlations for untransformed and transformed data all give r = 0.96) and can effectively be used interchangeably and all 3 variables are correlated with settlement area (r = 0.87-0.89). In the following the number of houses is being used as the independent variable with respect to describing House Sparrow abundance. Since two of the settlements (Tórshavn and Klaksvík) are considerably larger than, and in all other variables deviate markedly from the others, and since the data includ a number of zero-values the correlation analyses were performed on arcsinh transformed data. Chi-square tests were used to analyse the association between patch variables and the presence of House Sparrows. The statistical analyses were carried out by using the SYSTAT 8.0 programme.

Results

House Sparrows were present in 68 % of the 118 settlements and found on all islands except on the relatively small one-settlement islands Stóra Dímun, Koltur, Hestur, and Mykines, and on Fugloy where there are two settlement (see Bengtson *et al.* 2004: Figs 1 & 4). Furthermore, empty settlements (all in the range 1-38 houses; mean: 12) also occurred on 8 of the larger islands. As shown in Fig. 2 patch occupancy was positively correlated with both area and amount of vegetation ($p < 0.001$), whereas the negative influence of degree of isolation on occupancy was weak and not statistically significant ($p = 0.15$). The overall positive correlation between the number of houses and abundance of House Sparrows is highly significant ($r = 0.84$, $p < 0.001$); though by dividing the x-axis arbitrarily into three sections a different and more informative pattern emerges (Fig. 3). Only one of the settlements with < 10 houses held sparrows while among those with 10-60 houses there was a wide scatter and many settelements were empty while others held between 2 and 35 pairs and the correlation was not statistically significant ($p = 0.25$). In contrast, sparrows were absent in only one of the settelements with > 60 houses (Nes on Eysturoy with 71 houses) and a statistical correlation between number of houses and number of pairs was highly significant ($p < 0.001$).

Discussion

This study on the Faroes, a marginal area for the focal species, corroborates the close association between House Sparrows and Man (Summers-Smith, 1988). Besides, it elucidates some of the essential habitat requirements of the species *viz.* suitable nest-sites, shelter, and food resources provided by Man. Initially, the House Sparrow was much aided by Man in colonizing the Faroes (see Bengtson *et al.*, 2004) and also the ensuing success is governed by anthropogenic factors. The Faroese House Sparrows are exclusively found breeding within human inhabitations and patch occupancy is, as elesewhere and for many other taxa (Hanski, 1999), influenced by patch area; *i.e.* size of settlement (Fig. 2). The number of houses in a settlement was found to be a key (but rather crude) determinant of the number of sparrow pairs. When the human population increases so does the number of house holds and buildings and consequenly also the area of the settlement.

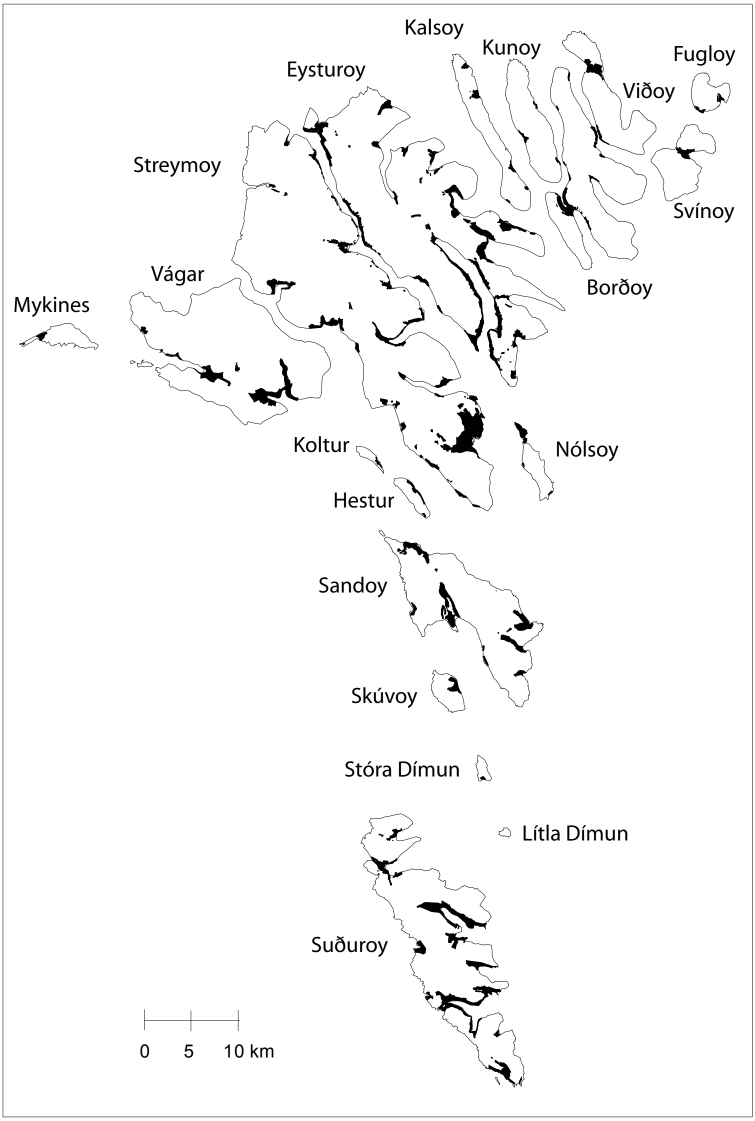

Fig. 1. The infield areas of the settlements in the Faroes. Numbers refer to the study sites (see Bengtson & Hauge, 1979, T=Tórshavn (the capital), and K=Klaksvík (the largest town on the northern islands).

When, on the other hand, a settlement is being depleted of inhabitants its area remains more or less unchanged. Hence, there are, of course, many additional factors involved, such as age of the settlement (small, old and well-developed gardens) and architecture of the buildings (see Mason, 2006; Shaw *et al.*, 2008 and references therein; Murgui, 2009). With respect to the relationship between number of houses and House Sparrows there appears to exist some threshold values. Among settlements with < 10 houses only one contained sparrows (Sydradalur on Streymoy with two houses and 3 pairs), while for settlements with > 38 houses (as shown by the actual data) the opposite prevailed, and all settlements but one were occupied. Sparrows were absent in many of the medium-sized settlements, (*i.e.* those with 10-60 houses) and there was no statistically significantly correlation between abundance and number of house; hence in sharp contrast to settlements with > 60 houses. This pattern may be due to the influence of a variety of patch variables, some mentioned above and others discussed below. Although we found no significant correlations between number of houses and vegetation ($r = 0.15$, $p > 0.05$) or degree of isolation ($r = 0.11$, $p > 0.05$) the scoring of these variables may not have been sensitive enough to capture essential differences in *e.g.* the suitability of the houses from the birds´ perspective. The House Sparrow seeks food and shelter within and in the vicinity of buildings, and the nests are usually placed under tiles or corrugated iron sheet or sod roofs, the latter being typical of Faroese architecture. Modern buildings provide fewer possibilites for the House Sparrows. For instance, on Fugloy the House Sparrow is considered a pest and is actually denied access to building by covering holes and openings with nets (Absalon Lydersen pers. comm.). The importance of suitable nest-sites is illustrated by what happened on the island of Nólsoy where a small, declining colony of House Sparrows quickly recovered and doubled in numbers when provided with nest-boxes (Jens-Kjeld Jensen pers. comm.). Thus, both number and condition of buildings is likely to influence patch occupancy and especially number of pairs in a settlement. The absence of House Sparrows in most small and many medium-sized settlements may be associated with a small population size; stochastic events, predation by domestic cats, and Allee effects (Allee, 1938). There are few potential predators on sparrows in the Faroes but domestic cats kill a substantial number (Magnussen and Jensen, 2009) quite conceivably could cause the extermination of small local populations; which, indeed, could also apply to the Faroese Wren (*Troglodytes t. borealis*) (Bengtson, 2001). Allee effects, leading to a collapse of the social environment when population size drops below a certain level, have also been suggested to explain the decline of House Sparrows (Summers-Smith, 2005). As to possible effects of competitors, Williamson (1945) suggested that the House Sparrow and the Faroese Starling (*Sturnus vulgaris faeroensis*) may compete for nest-sites; the latter being ubiquitous and abundant in the islands. As to the larger settlements, these contain proportionally more public parks, allotments, plantations, warehouses, food merchandizing, public litter bins, fishing industry and other things typical of urban habitats and potentially useful to the House Sparrow (*e.g.* Gilbert, 1989; Wilkinson, 2006; Chamberlain *et al.,* 2007; Skórka *et al.,* 2009).

The House Sparrow usually avoids woods and plantations (Roselaar in Cramp & Perrins 1994) and the statistically significant effect of vegetation on the occurrence of sparrows was, for obvious biological reasons, expected as House Sparrows were frequently seen in overgrown, old gardens feeding on buds of ornamental bushes, on seeds on the ground, and on insects amongst herbs. They were also commonly seen on patches of cultivations and wasteland, less frequently in newly built-up areas. The only plantation that attracted substantial numbers was the one in central Tórshavn, possibly because of the presence of ponds with ducks that were regularly being fed by people.

The vegetation score is not entirely independent of the number of houses, and old buildings surrounded by gardens with lush vegeation are commonplace and maintained in most settlements. The settlement Tjörnuvík, albeit small (0.14 ha and 27 houses) and relatively isolated at the northern end of Streymoy, may be taken to illustrate the interaction between houses providing suitable nest-sites and the existence of rich vegetation. Suitable old family houses and farm building occur but no House Sparrows were recorded, probably due to the recent removal of shrubby and untidy vegetations and garbage. Although detrimental to the House Sparrows such action awarded Tjörnuvík the titel of being the cleanest settlement in the Faroes. Other studies have suggested that the decrease in numbers of House Sparrows in many urban areas in Europe is associated with a reduction in green patches and

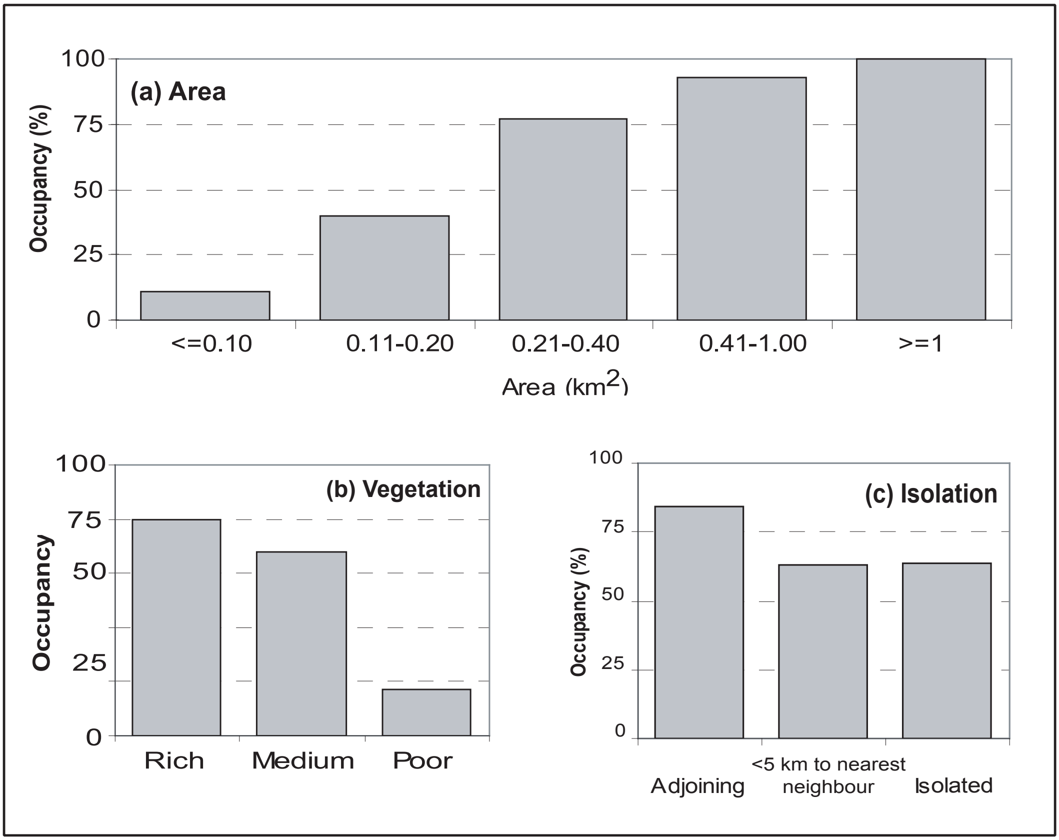

Fig. 2. Patch occupancy (n = 118) of House Sparrow in the Faroe Islands as an effect of (a) area, (b) amount of vegetation, and (c) degree of isolation.

thereby food resources, especially insects (Summers-Smith, 1999). Hence, there appears be a socioeconomic component to the occurrence of House Sparrows in the Faroe Islands as suggested for other regions in north-western Europe (Shaw *et al.,* 2008).

Many empirical and theoretical studies of various taxa have demonstrated effects of isolation on patch occupancy (see Hanski, 1999). At first sight the occurence of House Sparrows in the Faroese settlement seems to be consistent with such a pattern. House Sparrows were absent on the relatively distant small islands of Mykines, Fugloy, and Stóra Dímun and also in several semi-isolated settlements such as Saksun, Tjörnuvík, Árnafjördur, Múla, Tröllanes, Gásadalur, Skarvanes, and Vikarbyrgi (see Bengtson *et al.*, 2004:Fig 1). However, the influence of isolation on patch occupancy was weaker than

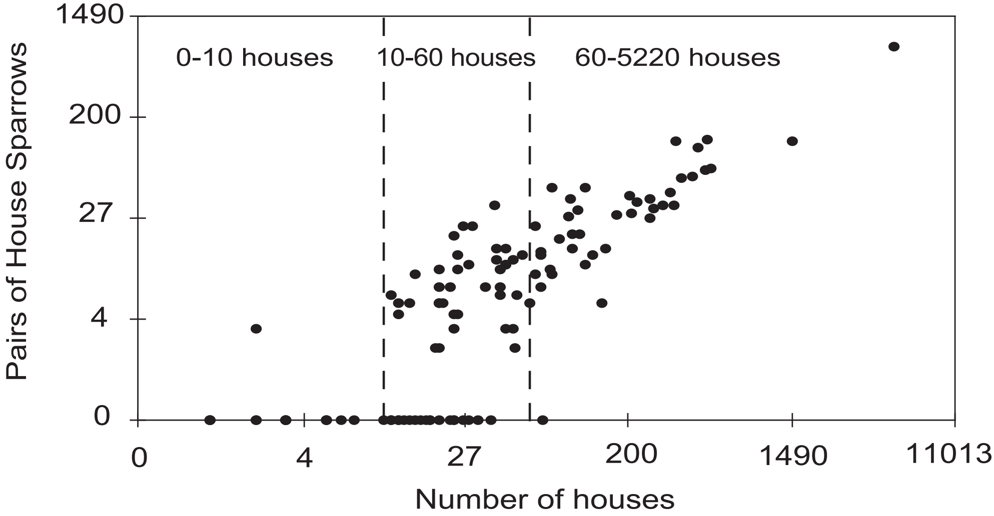

Fig. 3. Relationship between arcsinh transformed data for number of house and estimated number of pairs of House Sparrow in the Faroe Islands in habitat patches with (a) < 10 houses, (b) 10 - 60 houses, and (c) > 60 houses.

expected (Fig. 2) and the association between degree of isolation and number of pairs was not statistically significant. Possibly the index of isolation employed in this study is not sensitive enough, or does not take into account the pertinent criteria. A House Sparrow is capable of flying (and possibly occasionally does so) from one end of the archipelago to the other in a matter of a few hours, which makes predictions about dispersal and effects of isolation exceedingly difficult (Lewis, 1997). However, in practice House Sparrows is highly sedentary (Summers-Smith, 1988, Cramp & Perrins, 1994), as is also convincingly shown by ringing recoveries of Faroese sparrows (Magnussen and Jensen, 2009). In fact, of 225 Faroese recoveries of House Sparrows only two were made outside the settlement where they had been ringed; from Nólsoy they had crossed over to Kaldbak (20 km) and Tórhavn (4.5 km), respectively. House Sparrows colour banded in Tórshavn in late winter and early spring were, during the following breeding season, mostly sighted within 500 m (max. *ca.* 1600 m) of the place where they were first captured (Eliasen and Jacobsen, 2002), which is consistent with other studies (see Cramp & Perrins, 1994).

In a metapopulation context a fraction of suitable habitat patches is expected to be unoccupied at any given time. The recurrent question is how to know that a patch is suitable or not at any particular time. To begin with, we assumed that all the settlements, irrespective of size, were suitable, though the observation that nearly all 10 patches < 0.1 km^2 were unoccupied indicates otherwise. For the remaining 28 unoccupied patches ranging in size from 0.1 to 0.57 km^2, we know that at least 14 of them have been occupied once or on several occasions in the past. Consistent with general theory it is the small local populations that are most prone to extinctions due to, for instance, persecution by man (on Fugloy and Stóra Dímun), habitat destruction (the „keep-your-village-clean" programme in Tjörnuvík, and the pulling down of an old, delapidated building on Hestur), and perhaps primarily demographic and environmental stochasticity. In the absence of adequate data on local demography and dispersal the presence of sink-source populations (Pulliam, 1988) and rescue effects (Brown and Kodric-Brown, 1977) on a hypothetical Faroese House Sparrow metapopulation will be no more than speculations. Tórshavn alone supports a network of patches with colonies of House Sparrows that comprises about one-third of the total Faroese population (*ca.* 810 pairs; see Bengtson *et al.*, 2004). Hence, Tórshavn may by itself constitute a metapopulation and at the same time supply other settlements with immigrants. Similar mainland-island situations, with one or several large populations with a negligible risk of extinction surrounded by smaller populations (Harrison, 1991), may exist on the northern (Klaksvík, 125 pairs) and southern islands (Vágur and Tvöroyri, each 125-130 pairs), in the west (Sandavágur and adjacent Midvágur, together 95 pairs), and in central parts of the Faroes (Runavík, 110 pairs). The geographical distribution of these presumed House Sparrow strongholds may be related to the early stages of suggested multiple colonizatione of the islands (Jensen & Kampp, 1997; Bengtson *et al.*, 2004). However, with respect to the concept of sinks and sources, abundance is not necessarily a good indicator of between-patch differences in reproductive success (Pulliam, 1988, 1996). Moreover, studies of a metapopulation of House Sparrows on islands in northern Norway have demonstrated spatiotemporal asynchrony in local demography related to weather conditions (Saether *et al.*, 1999, Ringsby *et al.*, 2002).

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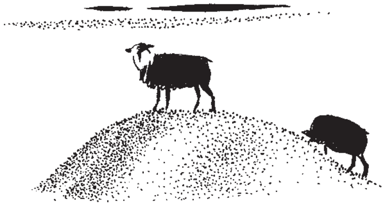

Palaeoecology of Skálafjørður, the Faroe Islands

Ole Bennike

Abstract

A sediment sequence from Skálafjørður on Eysturoy, Faroe Islands, has been analysed for macroscopical plant- and animal remains. The sequence contains remains of a number of water plants and animals that live in lakes, and no marine fossils, thus the sequence was deposited in a lacustrine environment, and the present day threshold fjord was a lake. A preliminary chronological framework suggests that the lake formed just after deglaciation at around 11,300 calendar years before present, and the threshold was inundated by the sea around 8800 cal. years before present, after which marine conditions were established. The flora and fauna comprise a number of plants and animals that are new to the fossil biota of the Faroe Islands, and two fresh water bryozoans that have not been recorded from the archipelago at the present.

Introduction

Over the past decades, marine geological work has been carried out in the Faeroese region, on the shelf, on the slope and in the fjords. Shallow seismic investigations were carried out in Skálafjørður on Eysturoy (Larsen 1991), and sediment cores were collected during several cruises. Most of the cores retrieved on the cruises contained Holocene marine sediments, which have been subject to a number of detailed studies of microfossils (e.g. Juul, 1992; Roncaglia, 2004; Witak et al., 2005; Witon et al., 2006).

However, one core, which is 172 cm long and was taken in Skálafjørður off Skáli during a cruise in 1995 from *R/V Skagerak* contains a sequence of lacustrine sediments. The upper part of the core is 87 cm and consists of olive grey silty clay with shells and shell fragments of marine molluscs. This part of the core was not analysed. Below the marine sediments dark olive grey silty clay without shell fragments is found; this deposit is characterised by layers rich in fine grained organic detritus, and by remains of lacustrine plants and animals. At 130–131 cm below the core top a prominent black layer of volcanic ash is found; this layer is correlated with the Saksunarvatn volcanic ash layer that is often 5–10 mm thick in lake sediment records from the Faroe Islands.

The Saksunarvatn volcanic ash layer was first recognised on the Faroe Islands, and it has been dated to 10,297 years BP in the NGRIP ice core from Greenland (BP = AD 1950; Rasmussen et al., 2006). The ash layer that originates from central Iceland has been widely recognised in the eastern North Atlantic, as far away from Iceland as northern Germany. The presence of this ash layer shows that the lower part of the sediment core formed in the early Holocene.

In order to shed light on the local environments and biotas, a series of samples have been analysed with respect to macroscopical plant and animal remains. Redeposition and long distance transport is generally a smaller problem with macrofossils than with microfossils, and macrofossil analyses can be a good supplement to other analyses. A preliminary account of the results was published by Bennike et al. (1998).

Setting

The climate of the Faroe Islands is oceanic, with a mean July temperature around 11°C. The present vegetation is strongly influenced by sheeps, but the pre-landnám, natural vegetation on well drained sites on the islands would be dominated by

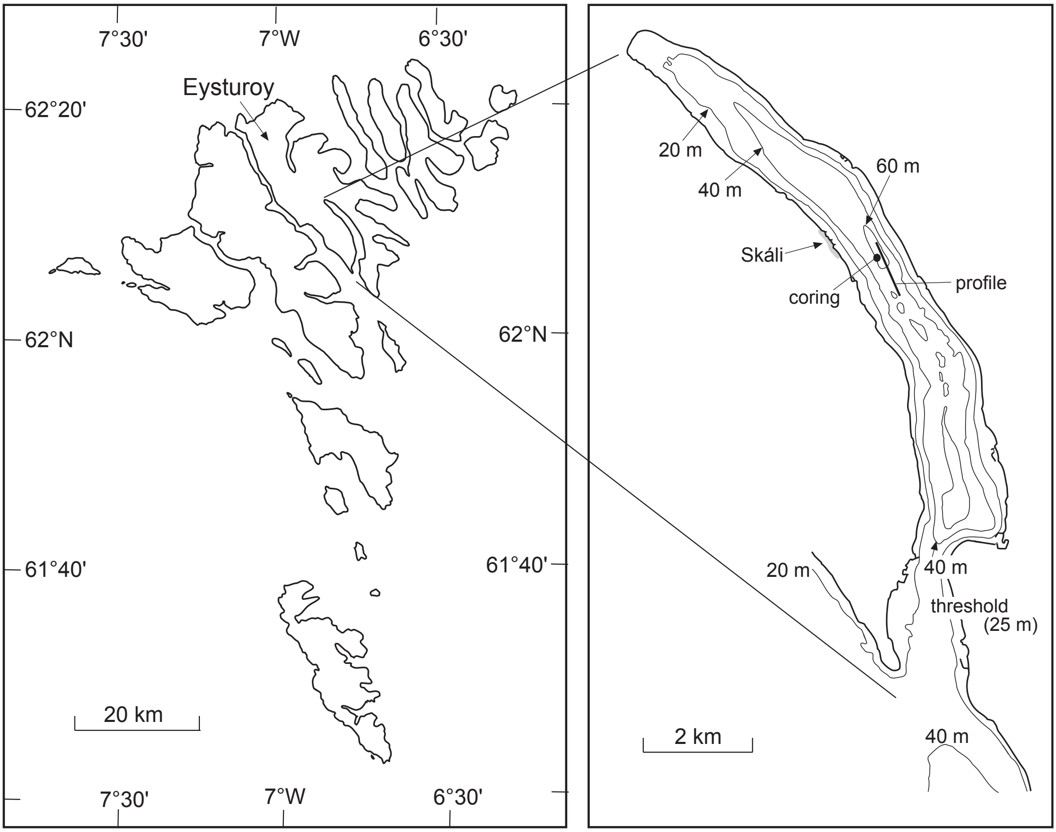

Fig. 1A. Map of the Faroe Islands showing the location of Skálafjørður. 1B. Map of Skálafjørður showing the rough bathymetry of the fjord (20, 40, 60 metres depth contours), the location of core SKPC18, and the track line of the seismic profile shown in Fig. 2. The bathymetry is from Dýpdarkort Føroyar Landsverkfrødingurin 1:20,000.

shrub heaths with *Juniperus*, *Salix*, *Empetrum*, *Calluna*, Poaceae and Cyperaceae (Jóhansen, 1985).

Skálafjørður is a U-shaped through that was eroded during the Pleistocene glaciations. The valley slopes are steep, and the mountains around the fjord reach altitudes of 500–600 metres. The fjord is a 13 km long threshold fjord situated on Eysturoy (Fig. 1). The fjord is up to about 70 m deep, and the threshold is at *c.* 25 m depth. Fig. 1 shows the location of the coring site, where the water depth is 61 m. Due to the presence of the threshold, bottom water exchange in the fjord is limited. A stratification of the water masses is present most of the year, and it only disappears during the winter months (DHI, 1986; Hansen et al., 1990).

Results from shallow seismic boomer surveys in Skálafjørður indicate the presence of two larger depositional basins, where the maximum thickness of sediments deposited after deglaciation is between 15 and 20 m (Larsen, 1991). The core discussed here was sampled from the margin of the innermost depositional basin, where the shallow seismic record shows the presence of only a few metres of postglacial sediments (Fig. 2).

Material and methods

The core (SKPC18) was sampled by *R/V Skagerak* of Göteborg University on October 5, 1995, using a piston corer with an inside PVC liner (diameter 75 mm). The location of the core is at 62°09.404'N, 6°45.824'W. After retrieval, the core was cut into two sections, which were split lengthwise, and the core was visually described (Fig. 3), and sub-sampled in the laboratory. Magnetic susceptibility was measured at 3 cm intervals using a portable Bartington MS2 Meter. Only the lowermost core section was sub-sampled for the present study. The volume of most of the macrofossil samples was 2 ml, but larger samples were collected at 154 and 140 cm (20 ml) and at 148 cm (5 ml), where layers of organic detritus were present. The sediment samples were wet sieved on 0.4, 0.2 and 0.1 mm sieves, and the residue left on the sieves analysed using a dissecting microscope. In the somewhat simplified diagram, only the relative frequency of the taxa is given, although some remains were counted. Remains of terrestrial plants (*Salix herbacea*) from two levels have been submitted for AMS radiocarbon dating. The radiocarbon dates performed on shells of marine molluscs have been corrected for a sea water reservoir effect of 400 years.

Chronology and magnetic susceptibility

The chronology of the core is based on the Saksunarvatn volcanic ash layer (10,297 years BP) at a depth of 130–131 cm and on four AMS radiocarbon age determinations (Table 1). A shell sample from the upper part of the core was dated to *c.* 6400 cal. years BP, and another shell sample near the base of the marine sediments was dated to *c.* 8600 cal. years BP. This age provides a minimum date for the marine transgression of the threshold, and it is the oldest marine date from the fjord. We have also dated a sample from the youngest lake

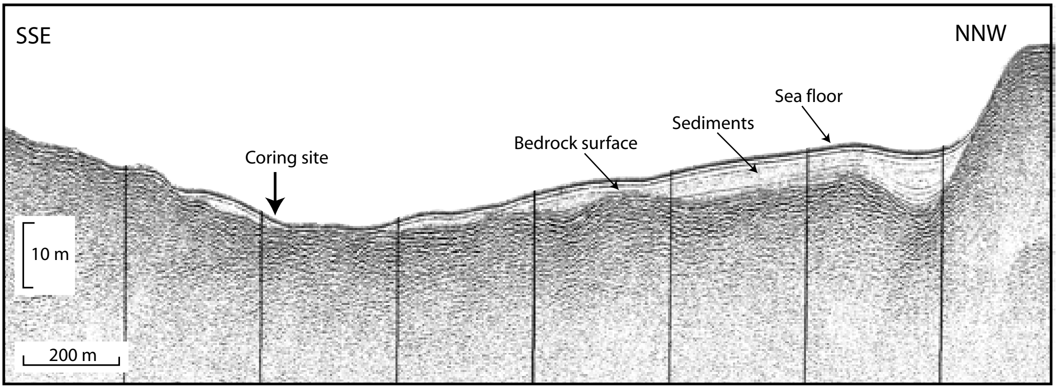

Fig. 2. Shallow seismic (boomer) profile along the fjord axis (for location, see Fig. 1) indicating a condensed postglacial sediment sequence (light coloured upper unit). The arrow shows the approximate location of core SKPC18.

sediments, which yielded an age of *c.* 8600 cal. years BP. It is similar to the oldest marine date, which indicates that there is no hiatus between the lacustrine and the marine sediments. A sample from the lowest part of the core was dated to 10,600 cal. years BP, and provides a minimum date for the last deglaciation of the fjord. It is only slightly older than the age of the Saksunarvatn ash layers, and indicates a high sedimentation rate in the lowest part of the sequence.

According to the radiocarbon dates (Table. 1), sedimentation rate was high in the oldest part of the core and near the transgression level (*c.* 10 cm/100 years) and around 2 cm/100 years for the rest of the core. The age of the core top is about 4000–5000 years. Although this is highly uncertain because good chronological control is missing in the upper part, we suggest that bottom currents have removed sediments or hindered accumulation of sediments at the coring site.

The magnetic susceptibility (MS) profile shows highest values at the bottom of the core, where glaciolacustrine silty clay is present (Fig. 3). Generally, the marine sediments display higher MS values than the lacustrine sediments below, in which the Saksunarvatn ash layer shows only slightly elevated values. In the marine part, an interval with high MS values corresponds to coarser-grained sediments containing, amongst others, gravel-sized basaltic material.

Macrofossils

Considering the small sample size, the diversity of macrofossils is surprisingly high, and the concentration of remains of lacustrine animals is high (Fig. 4). Some of the taxa, notably Chironomidae, represent several different species. The preservation is usually good to excellent, although the *Salix* leaves were fragmented, and only a few leaf fragments retained the dentate leaf margin and could be safely identified as *Salix herbacea*. A few small, worn twig fragments were present at 140 cm, these were avoided for dating.

The lowest analysed sample, from 170 cm, only contained two head capsules of midge larvae, and these sediments were probably deposited in a glaciolacustrine environment. The sediments between c. 167 cm and 87 cm are characterised by a diverse and rich flora and fauna of obligate freshwater taxa that clearly indicate that these sediments were deposited in a former lake basin. At 87 cm the first marine fossils occur, and at the same time lacustrine fossils become rare. This shows that the threshold was transgressed by the sea. The rare lacustrine fossils present at this level and above could represent redeposition or inwash from freshwater environments in the catchment area.

Salix herbacea leaves were also recorded from early Holocene lake sediments by Jóhansen (1985) and by Jessen et al. (2007), and this species was also an early immigrant to Iceland and East Greenland (M. Rundgren, 1998; Bennike et al., 1999; Bennike, 1999). *S. herbacea* is an indicator of snowpatch vegetation, and the species is common on high elevation sites on the Faroe Islands at present. Jóhansen (1985) did not separate pollen grains of *Oxyria digyna* and *Rumex acetosa*, but he suggested that most pollen came from *Oxyria digyna*. The presence of a few nutlets and perianths of *Rumex acetosa* shows that this species that today often grows as a weed, is native to the Faroes, and that it arrived early. Microspores of *Selaginella selaginoides* were reported from the early Holocene by Jóhansen (1985), and the presence of macrospores in the Skálafjørður sediments shows that it grew locally.

Coleoptera remains include three elytra, of which one

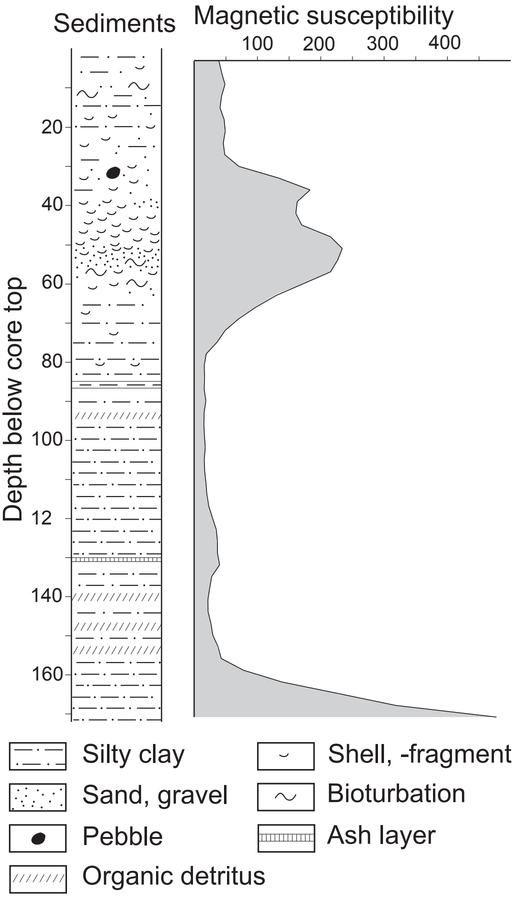

Fig. 3. Sedimentological log and magnetic susceptibility profile of core SKPC18. For further explanation, see text.

could be identified as *Nebria rufescens*. This is a medium sized ground beetle that is common on the Faroe Islands at the present (West, 1937: *Nebria gyllenhali*). It is most frequent in damp biotopes, but is geographically and ecologically widespread on the archipelago. Its geographical range is circumpolar, including Iceland and southwest Greenland, and it lives in northern temperate and low arctic climates (Böcher, 1988).

It appears that *Potamogeton filiformis* and *Nitella* sp. are new to the fossil flora of the Faroe Islands, but this merely reflects that few macrofossil studies of lake sediments have been carried out. It is not surprising that these taxa arrived early, since the fruits or oospores are effectively spread by migrating birds. Along the same line, most of the lacustrine animals recovered are new to the fossil fauna of the Faroes. The lacustrine sediments did not contain carbonates, but the inner chitinous linings of freshwater ostracodes were present in most samples. *Daphnia* was represented by ephippia, whereas the other cladocerans were represented by shells and head shields. *Eurycercus* remains were not present in the lower part of the sequence, and it is possible that this genus immigrated somewhat later to the Faroe Islands than the other taxa of Cladocera found during this study. Three statoblasts belonging to two taxa of freshwater bryozoa (*Plumatella* sp. and *Cristatella mucedo*) were found. These are present in such low numbers, which makes it difficult to know when these taxa colonised the lake.

About 10 gemmules of freshwater sponges were found in a single sample and identified as *Racekiela ryderi* (Tendal 2004). This amphi-atlantic species has its main geographical range in eastern North America, but it has also been found in lakes in Ireland, Scotland, the Faroe Islands and Norway (Økland and Økland 1989, 1996). The distribution of this species has been widely discussed, and it has been suggested that it was spread by humans. However, the early Holocene record from Skálafjørður shows that it is was an early immigrant. The gemmules are well adapted to dispersal by birds, and we follow Økland and Økland (1989) who suggested that long distance transport by birds is the most likely explanation for the occurrence of this species in Europe. However, no bird species living in freshwater environments migrates from eastern North America to north-western Europe. Nevertheless we consider chance dispersal by birds possible because a number of North American ducks, waders and other birds are regular visitors to Europe. The population on the Faroe Islands could have arrived from North America or from coastal north-western Europe, which was deglaciated earlier than the Faroe Islands.

All taxa probably represent species that still live on the Faroe Islands, and thus a climate similar to that at the present is inferred. To our knowledge there are no records of freshwater bryozoa from the Faroes, but *Plumatella repens* is widely distributed in Europe and has been reported from the Shetland Islands and Iceland, and it also lives on Greenland (Lacourt, 1968; Røen, 1977; Steingrímsson, 1985). Finds of statoblasts of *Cristatella mucedo* from Iceland and Greenland indicate that this species also lives on these islands, and it has been reported from the Shetland Islands (Lacourt, 1968; Fredskild, 1983; Steingrímsson, 1985). *Cristatella mucedo* is the most warmth demanding species identified; it's northern geographical range limit coincides more or less with the arctic tree line.

A sample from 87 cm below the core top contained a few specimens of the foraminifer *Egerelloides scabrus*. The test of this species consists of small sand grains that are agglutinated together. The species can tolerate somewhat lowered salinities (Lutze, 1965), as would be expected just after the first inflow of marine waters into the former freshwater basin.

The origin of the flora and fauna of the Faroe Islands has been much debated, and it has been speculated if some species could have survived the last glacial stage in ice free refugia, or

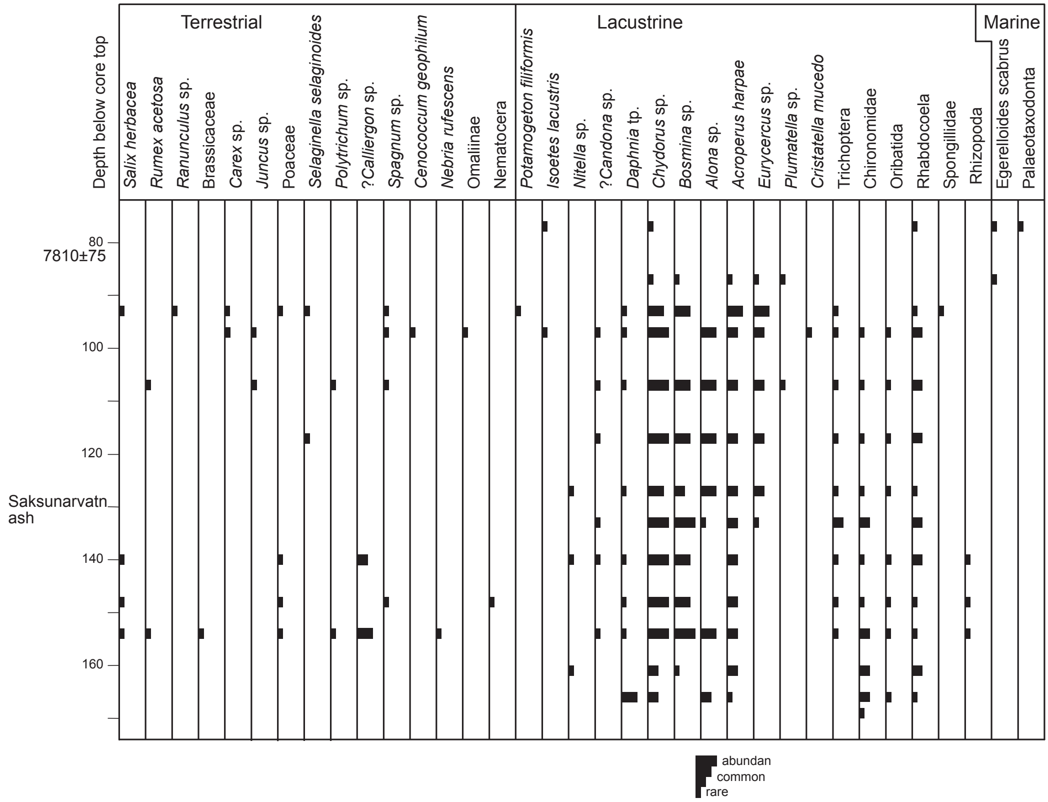

Fig. 4. Macrofossil concentration diagram of the lower part of core SKPC18 from Skálafjørður (62°09.4'N, 6°45.8'W).

whether all species have immigrated after the last deglaciation. The sedimentary record on the islands holds a great potential to study the history of the flora and fauna. Whereas the history of the vascular flora has been studied in some detail (Jóhansen, 1985), few concrete data are available about the history of the fauna. The history of a number of taxa can now be extended back to the early Holocene.

Some insects have been reported from pre-landnám layers (Buckland, 1988), but it appears that the insect remains reported here are the first that are firmly dated to the early Holocene. It has been suggested that a major part of the fauna on the North Atlantic Islands was carried by ice from north-west Europe at the transition from the last glacial stage to the Holocene (Coope, 1979; Coope, 1986; Buckland et al., 1986). Although rafting be ice bergs or sea ice floes may account for the transport of some species, palaeoceanographic studies indicate that the directions of the surface currents in the eastern North Atlantic were not much different from those at the present during the late-glacial or Holocene (Koc et al., 1993; Hald & Aspeli, 1997). Hence ice floes or ice bergs would be transported northward along north-west Europe, rather than in the direction of the Faroe Islands and Iceland.

Deglaciation and sea-level changes

The Faroe Islands were covered by a local ice cap during the last glacial stage (Jørgensen and Rasmussen, 1986; Humlum et al., 1996), and the oldest minimum dates for the deglaciation are around 11,300 cal. years PB (Jóhansen, 1985; Jessen et al., 2007). In our core, nearly 40 cm of lacustrine and glaciolacustrine sediments is present below the Saksunarvatn volcanic ash layer. The lowest C-14 age, about 24 cm below the ash layer and about 300 years older indicate a high sedimentation rate in the basal part of the core, and a date for the bottom of the core around 10,700 cal. years BP. On this basis we suggest that Skálafjørður was deglaciated at 11,000–11,500 cal. years BP.

There are no traces of marine deposits or shorelines above the present sea level on the Faeroe Islands, whereas submarine peat occurrences are known (Jessen and Rasmussen,

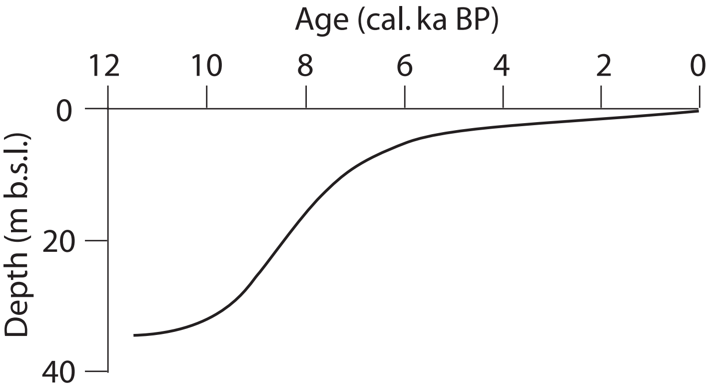

Fig. 5. Hypothetical relative sea-level changes on the Faroe Islands after the last deglaciation.

1922), so the global eustatic rise of the sea level has surpassed the glacio-isostatic rebound. The presence of submarine lake sediments in Skálafjørður shows that the 25 m deep threshold of this fjord was transgressed by the sea, and the ages of the youngest lake and oldest marine deposits show that the threshold was inundated in the early Holocene, around 8800 cal. years BP. A highly tentative curve showing relative sea level changes on the Faroe Islands after the last deglaciation is presented in Fig. 5. It is based on two fixpoints: 0 m at present and –25 m at 8800 cal. years BP. In addition, it is based on the assumption that the mid and late Holocene development more or less followed the global eustatic development (according to Behre (2007)) and that some isostatic rebound took place in the early Holocene.

Marine development

Reconstruction of the marine development of Skálafjørður is based on studies of microfossils, mainly diatoms and dinoflagellate cysts (Roncaglia, 2004; Witak et al., 2005; Witon et al., 2006). The main conclusion from these studies is that climate and environment were fairly stable during the mid and late Holocene, but characterised by an overall cooling trend. This is in accord with evidence from numerous studies in Scandinavia and Greenland that show a thermal maximum around 7000 cal. years BP, when temperatures were 2–3°C higher than during the late Holocene. The main change from the Holocene thermal maximum to colder conditions is dated to around

5500 cal. years BP in sediments from Skálafjørður (Witak et al., 2005).

The upper part of DAPC01 from Skálafjørður shows increasing magnetic susceptibility values, which may indicate increased erosion, perhaps due to lower temperatures and more open vegetation or increased precipitation. However, more open vegetation and increased erosion could also result from the Norse Landnam.

Table 1. Radiocarbon age determinations

Laboratory No	Depth[1] (cm)	Material	Date, ^{14}C years BP	Res. cor.[2]	Calibrated years BP[3]
AAR-3364	50	Mollusc shell	6030 ± 55	5630 ± 55	6469–6320
AAR-3563	83	Mollusc shell	8210 ± 75	7810 ± 75	8700–8457
AAR-4219	93	*Salix* leaf fragments	7850 ± 70		8770–8546
AAR-4218	154	*Salix herbacea* twig	9420 ± 65		10,735–10,570

[1]depth below core top, [2]corrected for the sea water reservoir effect by subtracting 400 years, [3]calibrated according to the INTCAL04 data set, using the OxCal program

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Physical nature of streams in the Faroe Islands with notes on their biota

LEIVUR JANUS HANSEN AND GÍSLI MÁR GÍSLASON

Abstract

A total of 2100 km of streams were identified in the Faroe Islands. They have small catchment areas, mostly between 0.1 to 1 km^2 with the largest drainage basin being 35 km^2. The mean length of the longest stream channel in each basin was 831 m (n=1205; SD=955) and the longest 7.3 km. The Faroe Islands are mountainous, with 50% of streams above 200 m a.s.l. The slopes of the streams are rather steep, with more than one third of reaches sloping 5° or more. Maximum mean annual discharge is estimated to be 2128 for the largest river.

Measurements show discharge fluctuated with precipitation as the bedrock is impermeable to water resulting in little retention time. Average discharge of measured streams was 55^{-1}, and only 8 streams had greater discharge than 100 L s^{-1}. The water temperature followed the ambient air temperature, but could when the streams were small be warmed up by the sun-baked bedrock. Conductivity of the streams was measured around 100 µS cm^{-1} (between 58 µS cm^{-1} and 227 µS cm^{-1}) influenced by sea spray, with high conductivity on Suðuroy. The pH was usually around 7.

Animal communities in Faroese streams were dominated by Chironomidae larvae, and other groups were Oligochaeta, Acarina and Crustacea. Other insect groups had low densities.

Introduction

Geography

The Faroe Islands are situated at 62° N, 7° W and consist of 18 small islands and numerous islets and skerries. The total land area is 1399 km^2, and extends 113 km from north to south and 75 km from east to west. The highest elevations, reaching nearly 890 m above sea level are found in the northern part of the country.

The topography of the land has been formed by erosion of the Ice Age glaciers. The long, narrow islands are divided by sounds and fjords with a distinct orientation from northwest to southeast. The bedrock is layers of tertiary basalt of varying thickness interspersed with red tuff and, infrequently, clay and coal (Rasmussen, 1981).

The bedrock is mostly impermeable to water. This means that the retention time of precipitation is short and the discharge fluctuates accordingly, with some streams drying out during dry periods.

Climate

The climate in the Faroe Islands is greatly influenced by the warm North Atlantic Current and by the passage of frequent cyclones. Consequently the climate is humid, unsettled and windy, with mild winters and cool summers. The northern part of the islands almost always experiences wintry weather with snow or frost for a prolonged period during the winter. West- and south-westerly winds predominate on an annual basis (Cappelen and Laursen, 1998).

The mean temperature for the warmest month in the Faroe Islands is 11°C, one degree higher than the 10°C which is usually used to define the limit for tree growth as well as the lower limit of the arctic-alpine zone in temperate areas (Fosaa, 2004).

There has been proposed a low arctic zone from 200 m a.s.l.

and an arctic zone from around 400 m a.s.l. based on temperature and periglacial activity (Humlum and Christiansen, 1998; Christiansen and Mortensen, 2002). This has been found to correspond with the altitudinal distribution of vegetation. 200 m a.s.l. corresponds with the upper limit of the moist dwarf shrub vegetation as well as the lower limit of the moist grassland vegetation. The altitude 400 m a.s.l. corresponds with the upper limit of the moist grassland as well as the lower limit of the *Racomitrium* moss cover and open grassland vegetation. Despite a lack of trees, the islands are situated south of the limit of tree growth (Fosaa, 2004).

Areas above 300 m have a significantly extended winter season with more precipitation, snow and days with frost than lowland areas. The basins are therefore characterized by profound slope instability, reflected by events of high precipitation rates and high sediment load in inlet rivers and high precipitation rates in the autumn (Mortensen, 2002).

Precipitation totals are highest in autumn and winter and lowest during summer. There are large geographical variations in annual rainfall. The precipitation pattern reflects the topography of the islands, with lowest precipitation near the coastal areas rising to a peak at the centre of the most mountainous islands. Nearly all coastal areas receive around 1000 mm per year, rising to above 3000 mm in the central parts. Investigations have shown that some places receive more than 4000 mm. The number of days with precipitation greater than 0.1 mm varies from 206 days at Strond Power Station to 300 at Hvalvík. Number of days with precipitation of more than 10 mm also varies, from fewer than 20 days at Akraberg Lighthouse to more than 100 at Hvalvík and Hellur (Cappelen and Laursen, 1998). Record precipitation measurements include 37 mm h^{-1} and 204 mm 20 h^{-1} (Samuelsen, 2008).

Rain intensity can be classified as light, moderate or heavy: < 0.25 mm h^{-1}, 0.25 - 0.75 mm h^{-1} or > 0.75 mm h^{-1} respectively (Glickman, 2000). Precipitation measurements at two locations by Landsverk (Faroese Office of Public Works) throughout 2008 show that no rain was measured on less than 60 days and more than 270 days experienced heavy rain. Intensities above 10 mm h^{-1} occurred almost every month.

Biota

Faroese fresh waters have not been studied in depth and only few studies have focused on streams.

In streams and springs the mosses *Fontinalis antipyretica* and *Philonotis fontana* are the most conspicuous and common vegetation. *Fontinalis antipyretica*, grows mainly where the velocity is high and *Philonotis fontana* is abundant in springs and rivulets. Freshwater flowering plants include *Potamogeton polygonifolius* and *Myriophyllum alterniflorum* as well as riparian species, e.g. *Saxifraga stellaris*, *Epilobium alsinifolium*, *Montia fontana* and S*tellaria alsine* (Ostenfeld, 1908; Lützen *et al.*, 2006). Freshwater flora has been described in some additional works (e.g. Lyngbye, 1819; Börgesen, 1901; Östrup, 1901; Rasmussen, 1958; Fosaa, 2004).

There are several works which include freshwater animal species as part of a broad description of the Faroe Islands (Landt, 1800; Annandale, 1905; Svabo, 1976; Bengtson, 1982; Lützen *et al.*, 2006). However, since the early 20th century research has been done on specific taxa or specific localities (Engel, 1915; Kieffer, 1915; Mjöberg, 1916; Mannheims *et al.*, 1964; Shire *et al.*, 1964; Leeuwen, 1969; Lützen, 1978; Kristjánsson, 1979; Bengtson, 1981; Enckell and Rundgren, 1983; Jensen, 1987; Andersen et al., 1992; Jensen, 2001; Foster and Hansen, 2004; Tendal, 2004; Hansen and Foster, 2009; Jensen, 2009).

In 1920's work began on The Zoology of the Faroes, by far the most comprehensive and important work on animal composition of the Faroe Islands, as it is based on both large-scale sampling and previously conducted research. In addition to being a comprehensive work on all major animal groups, this contribution lists the known distributions and ecological aspects of most animal groups in the Faroe Islands and neighbouring countries. The first publication of this work was in 1928, and the last book of the series was published in 1971.

During July and August in 2000 a large survey of Faroese lakes was conducted. The resulting publications describe important aspects of five Faroese lakes e.g. chemistry (Jensen *et al.*, 2002), zooplankton communities (Lauridsen and Hansson, 2002), zoobenthos (Malmquist *et al.*, 2002) and ecology (Jeppesen *et al.*, 2002). Although it is clear that freshwater systems and streams in particular, are in need of further study, much of this research verifies the expectations that the Faroese freshwaters are indeed species poor.

Six species of fish occur naturally in Faroese freshwaters: Three-spined Stickleback (*Gasterosteus aculeatus*), Flounder (*Platichthys flesus*), Eel (*Anguilla anguilla*), Brown Trout (*Salmo trutta*) and Arctic charr (*Salvelinus alpinus*); Salmon (*Salmo salar*) is mentioned in the oldest literature, but has been re-introduced. Rainbow trout (*Oncorhynchus mykiss*) has been introduced (Lützen *et al.*, 2006). Arctic charr can be found in only one lake and two water basins. These species, except Arctic charr and Rainbow trout, can be found in streams although Brown trout is the most common.

It is worth noting the absence of Plecoptera, Ephemeroptera, Odonata and Amphibia. It has been suggested that the paucity of the stream fauna and the absence of Plecoptera and Ephemeroptera is due to the extensive grazing by sheep (Jensen, 1987), but it is also likely that they have not been carried to the islands by winds or other means, as the occurrence of freshwater invertebrates on North-Atlantic Islands is of stochastic nature (Gíslason, 2005).

Methods

Stream Model

In order to give an overview of Faroese streams and their properties, a model of streams and basins was created in ArcGIS 9.3 software using the Hydrology toolset (ESRI, 2008). The model was derived from data, based upon 1:20,000 altitude data.

A 3D vector image (TIN) of the Faroe Islands was converted to a raster image, with pixels consisting of 5 x 5 m cells. The value of each pixel was an integer corresponding to the altitude in metres. All natural depressions (lakes, marshes, etc.) were filled up in the raster image, using the Fill function. Direction of flow from each cell was calculated using the Flow Direction function and, based on this, the accumulation of flow was calculated for each cell using the Flow Accumulation function. Cells which are part of an accumulated flow of more than 4000 cells – i.e. part of drainage basins which are larger than 0.1 km^2 – were used in further drainage basin analyses and cells which received flow from more than 4000 cells – i.e. are part of streams with a drainage basin larger than 0.1 km^2 – were used in further stream analysis. Cells which were considered to be part of a stream were given values corresponding to altitude, slope, stream order, basin area and accumulated precipitation built in the toolset functions. Note, that the total length and number of streams is not constant in all features due to GIS processing.

The annual precipitation received by each basin was derived from an isohyetal map showing 1000 mm isohyetal lines (Davidsen *et al.*, 1995; Samuelsen, 2008). The area between two lines was given the lower line value so the area between 1000 mm and 2000 mm was given the value of 1000 mm and this was used in the model to give estimates of annual discharge. It is expected that the model will underestimate precipitation because of this, but that it will be consistently low. Interpolation of values between isohyetal lines would yield better results, and better isohyet data would be better still.

Relief Ratio of basins were calculated by dividing basin lengths by the difference in altitudes. The length of basins was found using the Bounding Container script for ArcMAP (Patterson, 2010).

Sampling

Stream macroinvertebrates were sampled with a 0.14 x 0.14 m Surber sampler with a net mesh size of 200 μm (Surber, 1937). Attached to the net was a removable bottle which gathered the sampled material. At each sampled location 10 Surber samples were taken at random locations along a 10 m reach of the stream. Water velocity, depth, vegetation cover and substrate type was noted for each sample.

Samples were taken by placing the square metal frame of the sampler on the bottom of the stream and the bedrock was lightly scraped with fingers until all surfaces of the bedrock had been cleaned. Vegetation and diatom cover and gravel was lightly worked by running fingers through it. It is likely that sampling efficiency varies among taxa in moss cover. After sampling the bottle was removed and either filled with alcohol for later sorting or stored cold and sorted within a day or two. The material used in this paper is a subset of the sampled material and macroinvertebrates were counted and identified to Class or Order, and to Family in the case of Chironomidae (Diptera). Macroinvertebrate densities were calculated from the 0.0196 m^2 area of the Surber sample and are reported as individuals pr. m^2.

Conductivity was measured using EcoSense EC300 (YSI Environmental, 2003), pH was measured using Orion 230A (Orion Research Inc., 2000) and temperature was measured with both the pH and conductivity meters, if the temperature differed the mean was used. Discharge was estimated by taking 10 depth and velocity measurements across the stream.

Vegetation cover and substrate

Samples were grouped according to vegetation cover: 0%, 1% - 10%, 11% - 20%, ..., 91% - 100%, with 11 groups in total. Samples were similarly grouped according to substrate, which was divided into two types: loose (gravel and finer) and solid (bedrock and stones). Mean number of individuals were calculated for these groups.

Numbers of individuals were tested against pH, conductivity, depth, velocity, drainage area and relief ratio.

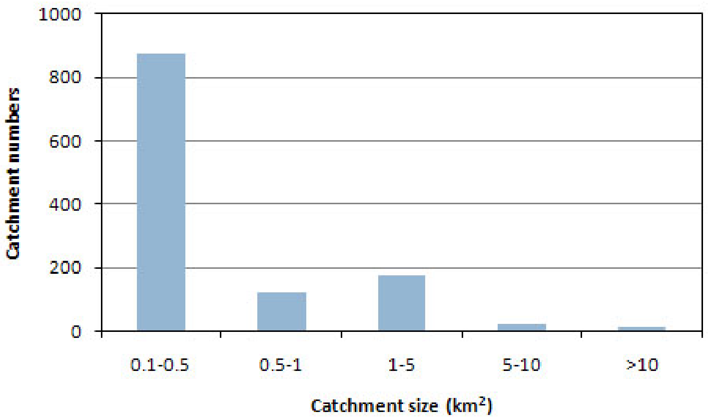
Results

Drainage basins

Many streams in the Faroe Islands are characterised as short and steep, with a high relief ratio. These are small basins that do not reach far inland. Five of the 6 Northern Isles group have the highest mean basin relief ratio, from 0.49 to 0.61 indicating a hydrological regime which differs from, especially, the five largest islands, which all have a relief ratio below 0.34.

A total of 1205 basins larger than 0.1 km^2 were identified (Fig. 1).

Fig. 1. Catchments grouped by size and counted.



The two largest basins are located in Vágar and the two largest lakes are located within them. The largest basin is 35 km^2 and contains Lake Leitisvatn (also named Lake Sørvágsvatn) which is 3.4 km^2. The short stream draining this basin runs less than 100 m from Lake Leitisvatn to a 45 metre drop into the ocean (Fig. 2).

The second largest basin is 27 km^2 and contains Lake Fjallavatn which is 1.0 km^2. The River Reipsá which constitutes the outlet stream of Lake Fjallavatn is 1.5 km long, has maximum widths up to 40 m and drains an area of 24 km^2. This river joins

Fig. 2. Bøsdalafossur waterfall, at the south end of Lake Leitisvatn.

River Gullringsá (Fig. 3) which drains an area of 3 km^2 including Lake Hvilvtkinnavatn.

Fig. 3. The River Gullringsá drains into the River Reipsá 70 m a.s.l. which drops into a gorge and drains into the ocean.

Lengths

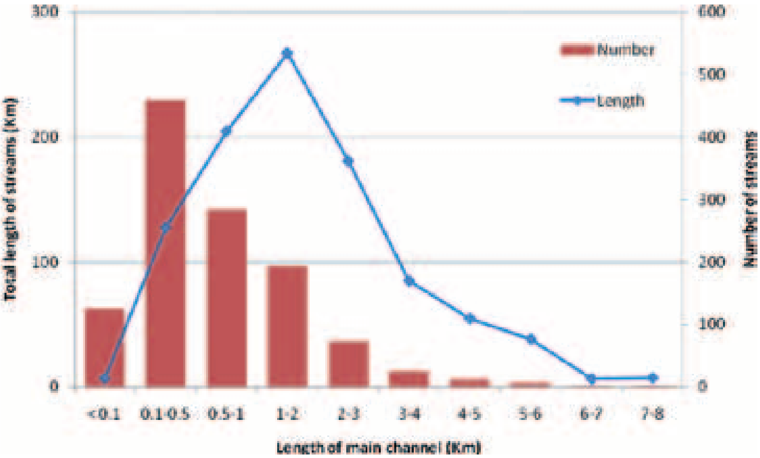
A total of 2100 km of streams were identified (Fig. 4). The mean length of the longest channel in each basin is 831 m (n=1205; SD=955). The 10 longest channels are 5 km to 7.3 km: 1 on Sandoy, 1 on Eysturoy, 2 on Vágar and 6 on Streymoy. One on Vágar flows into Lake Leitisvatn, and one in Streymoy flows from a dam and the one on Sandoy flows from a pond into a lake.

Discharge

The annual mean discharge was 1,442 L s^{-1} at the gauging station in Stórá, Hvalvík. Measurements from December 1994 revealed the variability of the discharge. Over the course of five days the discharge varied from less than 500 L s^{-1} to more than 15,000 L s^{-1}, down again to 1000 L s^{-1} and up to more than 20,000 L s^{-1} (Samuelsen, 2008).

Annual discharge of five streams was measured (Samuelsen, 2008) and was compared to the modelled discharge (Table 1).

Fig. 4. Number of main channels (columns) and their cumulative lengths (line) in different lenght categories of the main channels (n=1178; total=965 Km).



As expected the model yielded lower results. In the absence of additional data results should be increased by 25% to give a better estimate of mean discharge (results here have not).

	Modelled L s^{-1}	**Measured L s^{-1}**	
Stórá, Hvalvík	1169	1445	124%
Kvígandalsá, Vatnsoyrar	266	343	129%
Á Fossum, Vestmanna	233	299	128%
Saksunarvatn, Saksun	1065	1419	133%
Prestá, Skáli	115	127	110%

Table 1. Comparison of measured discharge (Samuelsen, 2008) and modelled discharge (see methods) in five streams.

The estimated mean discharge of modelled streams is 55.5 L s^{-1} (n=1203; SD=150.4). Only 8 streams have an estimated mean discharge of more than 1000 L s^{-1}, two on Vágar, one on Eysturoy and five on Streymoy. Maximum estimated mean discharge is 1702 L s^{-1} for the largest river in the Faroe Islands and if increased by 25% as suggested above the result would be 2128 L s^{-1}.

Stream order

The largest streams in the Faroe Islands are fourth Strahler order and there are 20 streams of this same order. The total length of these fourth order reaches is 27 km. Total length of third, second and first order are 196 km, 507 km and 1262 km, respectively.

Slope

In the hilly landscape streams are relatively straight. In a few valleys however, streams tend to meander. The meandering course cannot be estimated from elevation maps; instead streams in this model have been given the shortest straight route through the flat area. Since flat areas and meandering streams are uncommon in the Faroe Islands, this is not considered to affect slope estimates.

An important feature of the Faroese hillsides are the many small streams, but a large proportion of these will have basins less than 0.1 km^{-2} and will not be included in this model. The result is that the model does not adequately convey the general impression of many steep streams.

Length of horizontal reaches is 457 km.

Altitude

Areas above 300 m have a significantly extended winter season with more precipitation, snow and days with frost. The

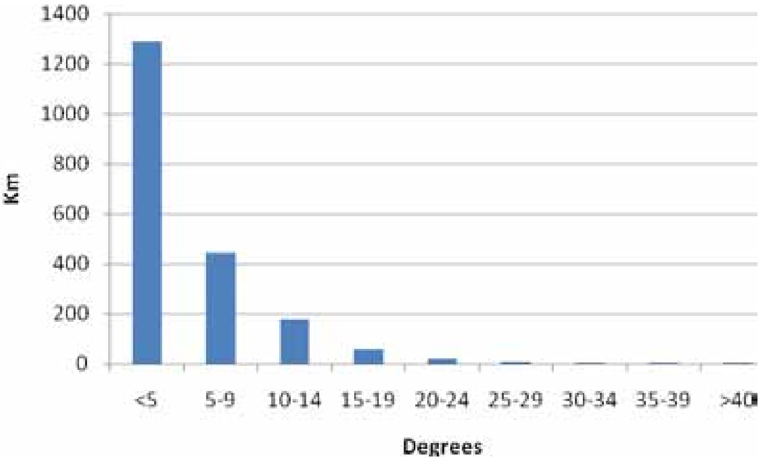


Fig. 5. Stream lengths grouped by slope.

basins are therefore characterized by slope instability, high precipitation rates in the autumn and high sediment load in streams (Mortensen, 2002). The highest sources of free flowing water were small springs which well 100-200 m from the mountaintops.

1307 km of streams were below 200 m a.s.l., 663 km were between 200 and 400 m a.s.l. and 52 km were above 400 m a.s.l. In this model we found only a total length of 162 m of streams above 600 m a.s.l.

Temperature

There are a few homothermic springs in the Faroe Islands. These are springs where the water temperature is relatively constant and generally a little higher than the ambient air temperature. Measurements from two such springs show a temperature of 10-12°C (Birna Vár Trygvadóttir *pers. com.* 2010). In addition there is one well known spring which is warmer than others situated close to the village of Fuglafjørður, its temperature was 18-20°C (Rasmussen, 1981).

It has been noted, that the temperature of the smaller rivers and shallow lakes follows very closely the air temperature (Fig. 6), rising and falling very rapidly according to the fluctuations of the air temperature (Kiilerich, 1928).

Their streambeds are typically dark basalt, and as such have the potential to absorb energy from the sun. As a result, the stream temperature can reach several degrees above the air temperature e.g. on 15 June 2008 at 1300 hours the River Ljósá water temperature was 18°C, while Norðskála air temperature was 8°C and 30 June 2009 at 1300 hours at Sund, the water temperature was 18°C, and air temperature 14°C.

pH

Stream pH had a mean value of 7.11 (SD=0.75, n=51). One measurement, 3.91, fell outside the 99% confidence limits, and may be due to measurement or equipment error, but other measurements ranged from 5.53 to 8.48. This is, not unexpectedly, a larger variation than measurements of raw drinking water by the Food and Environment Agency (HFS) where the most variable water source varied between 6.39 and 7.82;

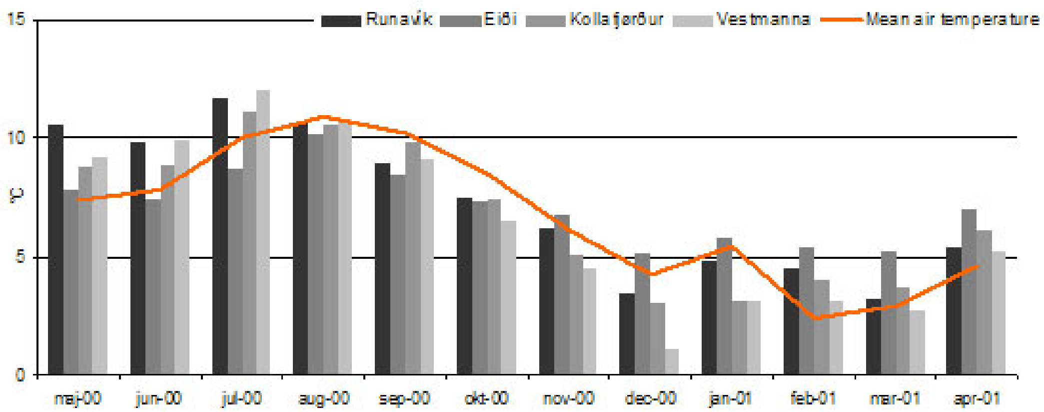


Fig. 6. Mean monthly air temperature at Tórshavn (line) by DMI (Cappelen et al., 2006) and mean water temperature (columns) at Runavik and Eiði on Eysturoy, Kollafjørður and Vestmanna on Streymoy based on measurements approx. twice a month by HFS (Róin and Larsen, 2004).

while the most stable varied between 7.00 and 7.44 (Róin and Larsen, 2004).

Conductivity

Freshwater conductivity was generally low. Measurements of unprocessed drinking water at six sites by HFS were mostly stable around 100 µS cm^{-1} but lowest and highest values were 58 µS cm^{-1} and 227 µS cm^{-1} respectively. In Tvøroyri, conductivity was slightly higher than average, with a mean of 150 µS cm^{-1}. The source of the conductivity is chiefly chloride (r^2=0.89, n=19) which was between 16.6 mg L^{-1} and 42.8 mg L^{-1} (Larsen, 2000; Róin and Larsen, 2004).

Fifty five spot measurements of conductivity in the present study confirm the range as the results varied between 39 µS cm^{-1} (Breiðá, Oyri) and 379 µS cm^{-1} (Stórá, Sumba). There is a latitudinal gradient with the highest conductivity in the south (Fig. 7).

The most likely source of chloride is sea spray which can be transported over large distances under the right circumstances e.g. when it is windy with strong surf or spraying waves. This can indeed be source to some of the variation since Sumba on Suðuroy is more exposed to waves and surf than other localities and was measured with the highest conductivity. But Syðradalur on Streymoy is also known for great surf, and here the conductivity was low. Without further data on transport of sea spray conclusions are weak in this regard.

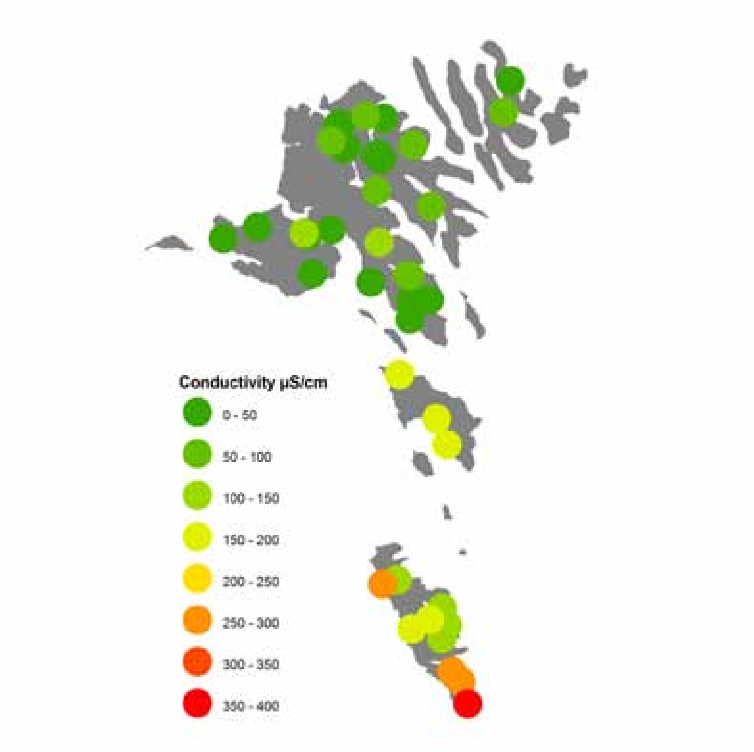


Fig. 7. Regional differences in conductivity in the Faroe Islands. Conductivity was highest on Suðuroy. Differences between islands (Viðoy and Borðoy grouped) was significant (Kruskal-Wallis: H=35.191; df=5; p<0.001).

Biology

Animal communities in streams have been sampled from July 2007. In the study we examined regional and seasonal community structure in relation to environmental variables. Preliminary results are presented.

Small stream, Sund, Tórshavn, Streymoy

At Sund, Tórshavn, there is a small stream which was sampled four times during 2009: in March, May, October, November (Fig. 8). The upper part of the stream is a slightly sloping valley with a pond. The last 150 m a.s.l. the stream flows down a more steeply sloping hillside on which the sampling site is located. The sampling reach itself only slopes a few degrees. Mean water velocity for individual samples was 0.9 m s^{-1}. The substrate was bedrock with moss and diatoms, and in the sampled reach there was a small shallow pond with gravel and detritus.

Fig. 8. Small stream, Sund, Tórshavn, Streymoy

The basin is approx. 0.3 km^2 and modelled discharge is 11 L s^{-1}. Four conductivity measurements were from 74 µS cm^{-1} to 100 µS cm^{-1} and three pH measurements were from 5.5 to 7.2.

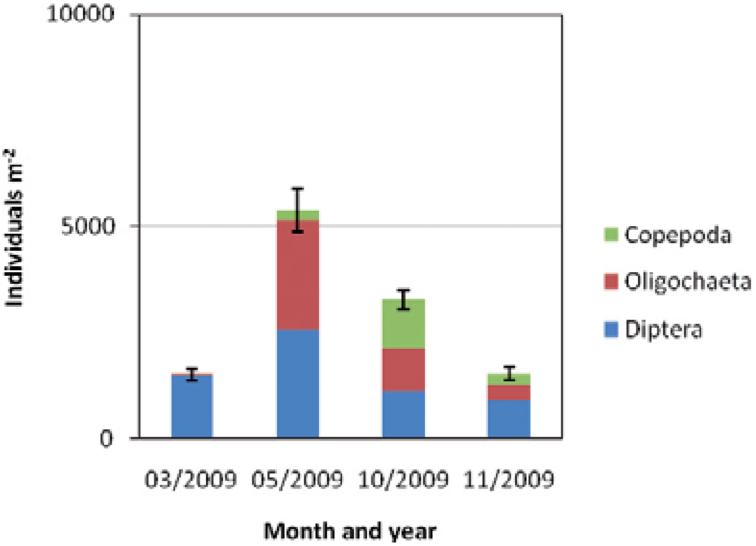
In March total invertebrate density was 1556 individuals m^{-2} and Diptera larvae dominated (95%), in May density had increased to 556 and Diptera and Oligochaeta co-dominated (47% and 46%), in October density had decreased to 3337 and Diptera, Oligochaeta and Copepoda co-dominated (33%, 30% and 35%) (Fig. 9). In November the density was approximately the same as in March, 1577 individuals m^{-2}, and Diptera dominated again (57%) while Oligochaeta and Copepoda were almost equal (23% and 18%).

Acarina and Turbellaria were found in all four samples. Trichoptera were fund in May and October and Cladocera and Ostracoda in May. Collembola were also in the samples, but most likely caught on the water surface.

Large stream, Sund, Tórshavn, Streymoy

At Sund, Tórshavn, there is also a large stream (Fig. 10) which was sampled three times: in October 2009, November 2009 and December 2007. This stream is part of the same valley and the last 150 m a.s.l. runs down the hillside, albeit less steeply.

Fig. 9. Mean densities of individuals m^{-2} with standard deviation in a small stream. Sund, Tórshavn, Streymoy.



Mean water velocity for individual samples was 1.2 m s^{-1}. The bedrock substrate contains very little moss.

The basin is approx. 3.4 km^2 and modelled discharge is 196 L s^1. Measurements were only taken two times. Conductivity was 43 µS cm^{-1} and 74 µS cm^{-1} and pH was 6.5 to 7.4.

In October the density was 321 individuals m^{-2} and Diptera, Oligochaeta and Copepoda co-dominated (33%, 30%, 33%) (Fig. 11); in November density was 786 and Diptera dominated (73%) and did so completely in December (100%) with a density of 684. Although Oligochaeta was proportionally less in November (21%) the density went from 97 individuals m^{-2} in October to 163 in November.

Trichoptera was found in October and November and Acarina in October.

Numbers of individuals for each sample were 63, 154 and 134.

Fuglafjørður, Eysturoy

The sampling site in Fuglafjørður is in a cultivate area and downstream of a small sewage outlet (Fig. 12). This side sampled two times: in August and October 2008.

Fig. 10. Large stream, Sund, Tórshavn, Streymoy

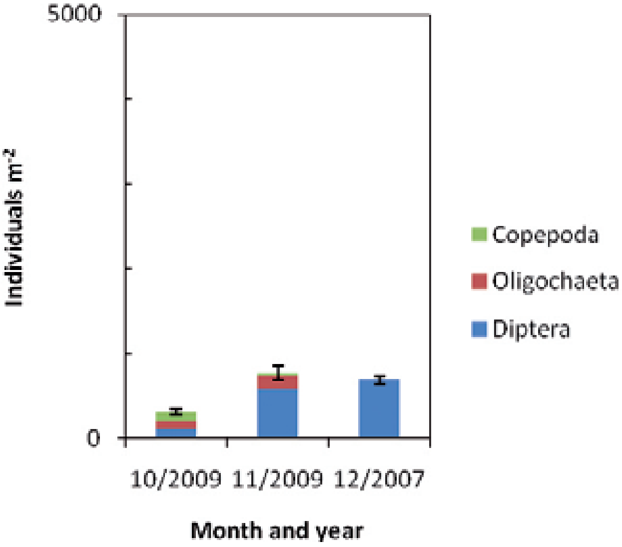


Fig. 11. Mean densities of individuals m^{-2} *with standard deviation in a large stream, Sund, Tórshavn, Streymoy.*

Fig. 12. Fuglafjørður, Eysturoy.

The sampling site is in an evenly sloping reach few degrees and mean water velocity of individual samples was 0.6 m s^{-1}. The substrate was bedrock with moss and shallow areas with detritus. The basin is approx. 2.8 km^2 and modelled discharge is 256 L s^1. Conductivity was 43 µS cm^{-1} and 74 µS cm^{-1} and pH was 6.9 to 7.9.

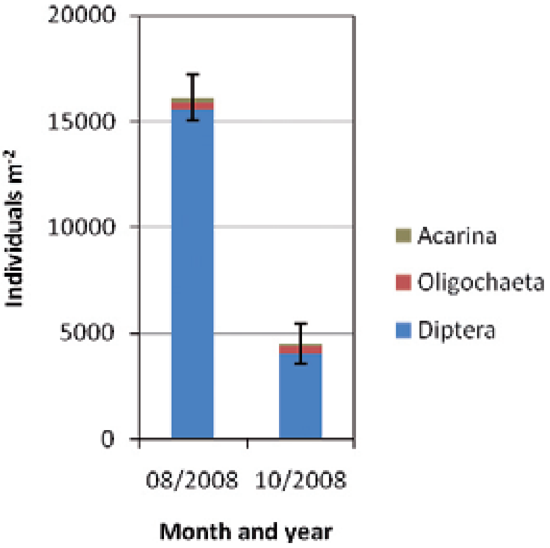


Fig. 13. Mean densities of individuals m^{-2} with standard deviation in Fuglafjørður, Eysturoy.

In August the density was 16,311 individuals m^{-2} and in October 4500, Both samples were dominated by Diptera (96% and 89%). Acarina and Oligochaeta were between 1% and 9% in both samples, and Trichoptera less than 1% (Fig. 13).

The August sample contained a Coleoptera and the October sample four Collembola.

Akrar, Suðuroy

The sampling site in Akrar is a brook in the outfield (Fig. 14). It was sampled once in April 2009. The sampling site was narrow and uneven and mean water velocity was 0.5 m s^{-1} The basin is approx. 0.3 km^{2} and estimated discharge is 11 L s^{1}. The substrate was bedrock and stones with some vegetation and diatoms. Conductivity was 253 µS cm^{-1} and pH was 7.8.

The sample was dominated by Diptera larvae (92%) with

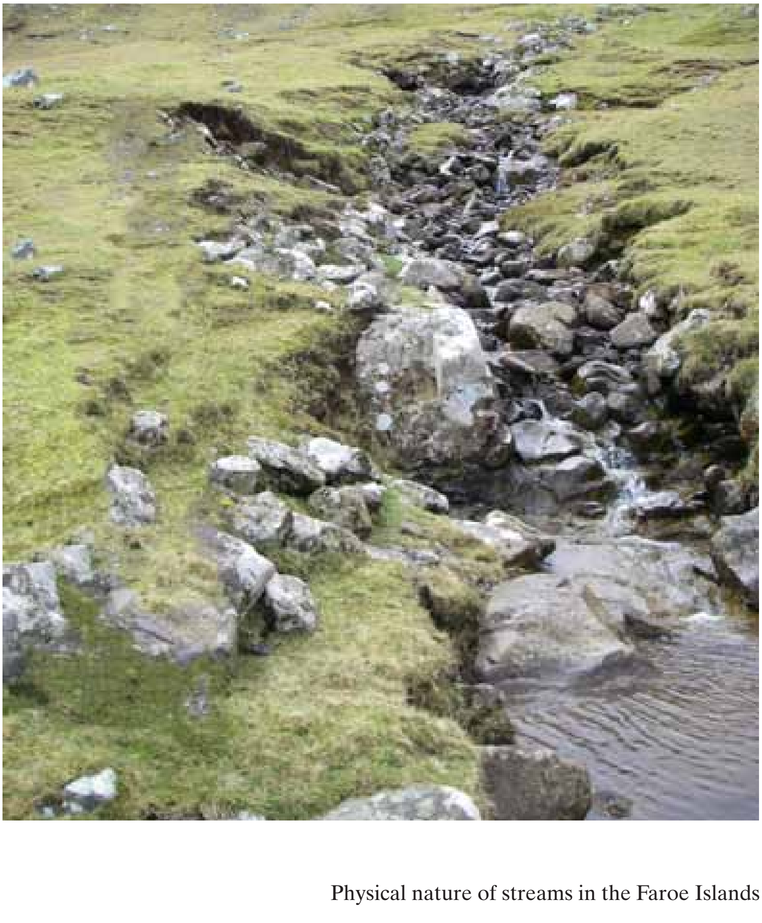
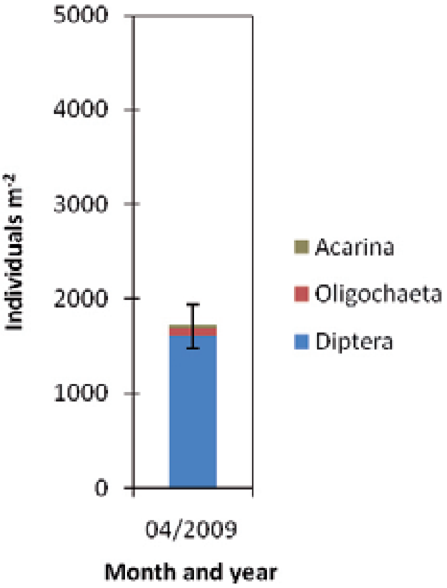


Fig. 14. Akrar, Suðuroy.

Fig. 15. *Mean densities of individuals* m^{-2} *with standard deviation in Akrar, Suðuroy.*



some Oligochaeta (4%) and Acarina (1%). Density was 1750 individuals m^{-2} (Fig. 15).

Other taxa present were Trichoptera, Turbellaria, Collembola, Coleoptera, Copepoda and Cladocera.

Tjaldarvík, Suðuroy

The sampling site in Tjaldarvík is a small stream below a road, close to a soil dump (Fig. 16). It was sampled once in April 2009. The basin is approx. 0.2 km^2 and estimated discharge is 7 L s^{-1}. The sampling site was narrow and uneven and mean water velocity was 0.1 m s^{-1}.

The substrate was bedrock with some vegetation. Conductivity was 145 µS cm^{-1} and pH was 5.7.

The sample was dominated by Diptera (91%) with some Oligochaeta and Copepoda (7% and 1%). Density was 2872 individuals m^{-2} (Fig. 17).

Other taxa present were Acarina, Trichoptera and Collembola.

Fig. 16. Tjaldarvík, Suðuroy.

Densities

In 46 samples there was a large difference in density which ranged from 62 to 24,684 individuals m^{-2} with an average of 2554 m^{-2} (SD=4.285; n=46). The highest numbers of individuals were found where there is a possible influx of material and nutrients into the stream from cultivation or a sewer e.g. Funningur, Eysturoy (cultivation), Fuglafjørður, Eysturoy (cultivated and downstream of sewer) and Hov, Suðuroy (downstream of Salmon aquaculture) (unpublished date) but also where the substrate is favourable such as vegetation e.g. Sund, Tórshavn, Streymoy.

Fig. 17. Mean densities of individuals m^{-2} with standard deviation in Tjaldarvík, Suðuroy.

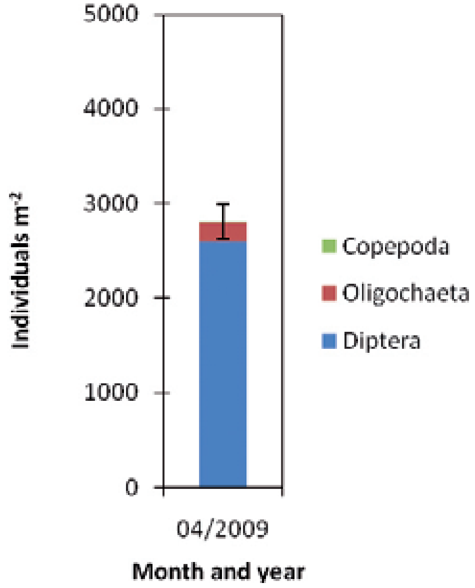
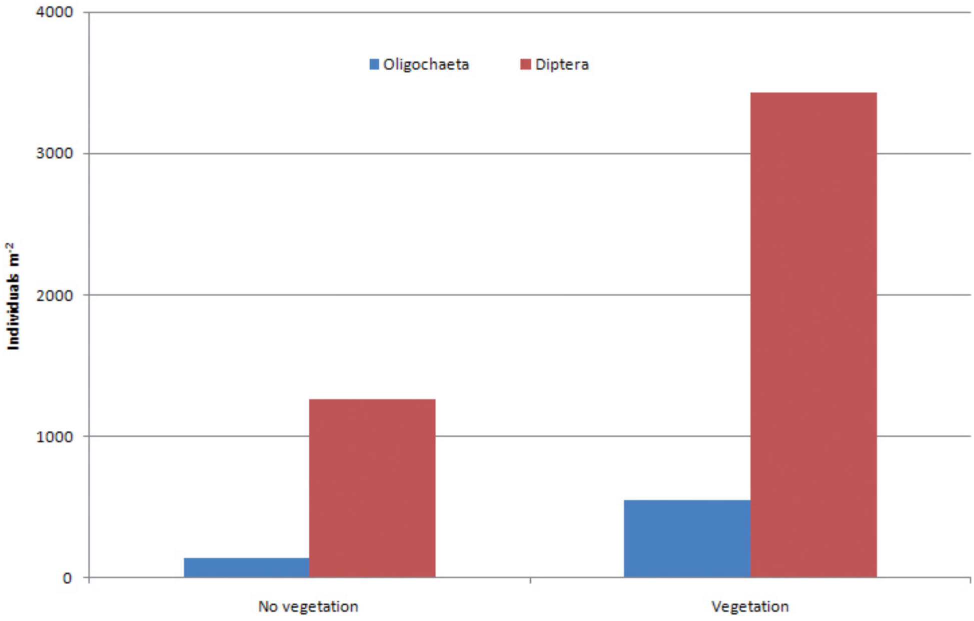


Fig. 18. Average densities (individuals m^{-2}) of Oligochaeta and Diptera on substrate with or without vegetation including 95% confidence interval.



Vegetation cover and substrate

Densities of both Oligochaeta (Kruskal-Wallis test: H=25.558; df=1; p<0.001) and Diptera (Kruskal-Wallis test; H-29.059;

df=1; $p<0.001$) were positively influenced by vegetation cover (Fig. 18). No significant influence was found by loose substrate, nor was any significant influence found by solid substrate. Some groups contained less than 10 in the samples, so care should be taken when interpreting the results.

Discussion

The fauna and flora in streams in the Faroe Islands is to a large extent structured by the hydrological regime and geology. The impermeable bedrock, the poor water retention and at times high rain intensity result in variable discharge with an effective scouring effect on the stream bed. Reaches of streams were commonly bedrock without vegetation and very low macroinvertebrate densities. Vegetation primarily grew where the scouring effect was low, e.g. in protected cracks, waterfalls and wide soft bottomed reaches. Jensen (1987) compared streams and moss-carpets in waterfalls and concluded that in moss-carpets the Oligochaeta dominate while Chironomidae dominate in the streams. While Chironomidae dominated bare bedrock, densities of Chironomidae and Oligochaeta were low. However, in substrate with vegetation cover, the densities of both Oligochaeta and Chironomidae were significantly higher ($p<0.001$). Indeed, very high numbers of Chironomidae were found in moss, while Oligochaeta do not reach the same high numbers. However, this discrepancy may be due to differing sampling techniques and how effective one technique is to sample both Oligochaeta and Diptera.

Larsen (1948) reports densities from 132 individuals m^{-2} to 6248 individuals m^{-2}.

Widespread but less numerous are Acarina and Trichoptera, Turbellaria, Collembola and Copepoda, are often found, but although Collembola can exist under water, they probably entered samples from the water surface. Unlike Turbellaria and Collembola, Copepoda can be found in high densities. Other taxa were *Radix peregra* (Gastropoda) which were widespread, but apparently unlikely to be found in Surber samples; *Gammarus pulex* (Amphipoda) which were only found in River Reipsá, Vágar, but were numerous there; Nematoda too were found in samples but it is uncertain how effectively they were sampled. Coleoptera and Hemiptera were more common in ponds and pools, but they occationally occured in streams. Only in four of 46 samples were Copepoda or Oligochaeta more numerous than Diptera. Variation in numbers, especially of Copepoda, Cladocera and Ostracoda may be linked to precipitation and wind.

As indicated by the results from Sund and Fuglafjørður both frequencies and densities of taxa change during the year.

As expected vegetation cover in the streams had an influence on number of individuals. Neither solid nor loose substrate was found to have a significant effect on the number of individuals.

Comparable to the Faroese streams are the direct run-off rivers of the old basalt formation in Iceland (10-15 million years old). The catchments in Iceland are comparable in many ways, they have impermeable bedrock, catchment vegetation consists of grasses, sedges and mosses and their altitutes are similar or higher. The densities in the Faroese streams were similar or lower than in comparable streams in Iceland (Gíslason *et al.*, 1998; Brittain *et al.*, 2009). The lowest densities in the Faroese streams were similar to the densities found in glacal rivers in Iceland (Gíslason *et al.*, 2000; Gíslason *et al.*, 2001). Same groups of invertebrates were found in Iceland and the Faroe Islands, though in some cases other species were found, especially the Trichoptera. One of the reasons for lower densities in Faroese streams could be the streams substrate, in Iceland it consists more of sand, gravel, stones and boulders, whereas in the Faroe Islands solid streambed floor, with no or little loose material, was common. Common to both regions is the lack of shredders, i.e. Trichoptera, Plecoptera and Ephemeroptera, which are common in adjacent European continent and Britain. That is presumably due to lack of woodlands in the regions, which provide streams in Britain and Europe with allochthonous material.

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Both size and money matter: márkatal and invertebrate species richness in Faroese infield areas

PEHR H ENCKELL, SVEN-AXEL BENGTSON

Abstract

In the Faroe Islands historical causes for the immigration and abundance of invertebrate species in infield areas are predominant. The settlements with their infields cover about 7% of the total area of the islands, mostly along the coasts. They are habitat islands, covered with lush and diverse vegetation, in a sea of sheep grazed grass heaths. The infields have also over the years been evaluated by the old Faroese márkatal system, grading the luxuriance of the areas (based on grain yields and other valuables). The infields – ranging from about 7 to 600 ha – are the most species-rich areas in the islands for both plants and invertebrates. Many of the infields have been manured for perhaps 1000 years with sheep droppings, seaweed and crushed mussel shells. The soil layers in the infields are therefore deep compared to the surrounding grass heaths. This provides a habitat especially for anthropochorous species that need such deep soil layers and a luxuriant vegetation. Moreover, shieling areas in the outfields (dating from Viking or Medieval times) have also shown that such species can survive in

habitats otherwise unsuitable for them. On the other hand, anthropochorous species like the Spanish slug *Arion lusitanicus* and the flatworm *Artioposthia triangulata* have also been introduced with negative effects.

This illustrates that human influence might have a profound effect on the biodiversity of local habitats and that a small country like the Faroes is especially sensitive to such influences.

Introduction

Historical causes for the distribution and abundance of animal species at local and regional scales have often in the past been considered to be less important than ecological ones (for a discussion of the development of ecological theory in this field see references below). For instance, the theory of island biogeography rests on ecological reasoning, including areas of the studied islands, distances from source areas, time, and immigration and extinction processes (MacArthur & Wilson 1967) but processes like competiton, predation or human activities, or abiotic factors were not considered. Recently, some patterns have been shown between energy supply to ecosystems and species richness (Wright 1983, Currie 1991, Hernandez-Acuedea & Currie 2003, Francis and Currie 2003); most of these studies, however, are large scale and are often concerned with latitudinal patterns. The energy discussed in these cases is mainly solar energy (i. e. often related to latitude). What is apparent, however, is that area or distance from the souce area are not the dominating factors for island communities on continental islands as once thought but that energy input might be decisive in certain cases. As usual when a pattern is dissected in more detail a multifactorial explanation seems more promising than a single-cause explanation.

In agricultural habitats external (non-solar) energy input incrases yields but is generally associated with a decrease in species richness (especially in modern societies); probably because the energy input is combined with additions of various herbicides and pesticides, decreasing both plant and animal diversity. But what happens when there is an input of external energy only, without the accompanying chemicals?

During the last 1100 years the Faroe Islands have received a considerable proportion, possibly the majority of their present-day terrestrial invertebrate species from the surrounding areas (Shetland, Scotland, western Norway; see Enckell et al. 1987b). Euryoecious and easily dispersed species have dispersed widely over the archipelago , while anthropochorous species exhibit various distribution patterns, partly dependent upon their respective modes of dispersal (aerial, non-aerial, dispersing by eggs or cocoons etc.; Enckell et al. 1987b).

The human settlements and their infields in the Faroes (7% of the total area) stand out as habitat islands, covered by lush and diverse vegetation and surrounded by stone walls, in a surrounding landscape dominated by sheep-grazed grass heaths. The number of people in the settlements differs greatly, from around a dozen to the capital´s 15000. The sizes of the settlements vary between about 6 and 700 ha. The complexity also varies, but even the largest still contain parts used for haymaking, growing potatoes or keeping sheep.

These infields are the most species-rich sites for both plants and animals in the Faroes (together with the ravines and cliff-ledges that are inaccessible to the sheep). Many of them have ben manured for perhaps up to 1000 years with sheep droppings, seaweed, crushed mussel shells and the like. The soil layers in the infields are deep in contrast to the thin soils in the surrounding grass heaths.

Effectively all of the infields lie at the coast (Fig. 1). The larger infields often climb higher up the mountains (for example Frodba to 50 m a.s.l. and Sumba to 90 m a.s.l.) while the majority of the smaller ones lie below 20 or 30 m a.s.l. This implies that the infields of the larger settlements contain higher placed, often more barren areas (scree, steep slopes, areas with sparse vegetation). The settlements can thus be said to belong to two different types, arbitrarily distinguished by area (see Material and methods for a discussion of the division of the infields in the analysis).

The species-area relationship between invertebrates and island areas in the Faroes exhibits the common pattern previously shown for a large number of island/island groups (Fig. 3). The anthropochorous species, mainly confined to infield areas, might be expected to show a similar pattern with regard to, first, island area, and second, the area of the respective infield (islands within islands). But in this special case an additional factor can perhaps be expected to exert some influence, namely the difference in productivity between the different infields – a difference caused by human activities.

The Faroe Islands are unique with respect to land evaluation. Since probably Medieval times each settlement – and each individually owned part within each settlement – has been set an old-time value, both in the infields and the corresponding outfields. This land evaluation system (márkatal) was based not only on the carrying capacity of land with respect to husbandry and crops but also to e.g. sea-bird fowling, drift wood, pilot whaling and other assets. The márkatal-system can be used as an integrated index of habitat quality (see e.g. Bengtson & Bloch 1983). At the end of the 19th century the márkatal system was revised and the old-time values were converted into monetary ones (for taxation purposes; see below).

This gives us a unique opportunity to test if the species richness of invertebrates can be related to the value (productivity) of land as set by human estimation, and thus supplement the species-area/energy discussion. To do this we relate first the total number of invertebrate species (so far known), and second the number of anthropochorous species (so far known), against the respective areas of the infields of the settlements, but also against the per-area monetary value of the infields. This should be seen against the degree of human activity and thus also the difference between low-lying and higher situated settlements..

Material and methods

Data on the taxation values of the infields used in the analysis are taken from Anon. (1873). In 1867 the existing values of every single ownership in every village were re-calculated from the old ”mark-gyllen-skind” system (”Mk”) to a monetary system (Rigsdaler, ”Rd”); for details see Danielsen (1981). Certain discrepancies were discovered and corrected and the evaluation was more fine-tuned. Reasons were,

e. g. that certain parts of the infields had been opened up for cultivation after the previous evaluation. The evaluation systems are thus not directly comparable (Fig. 2). There is an obvious correlation between the old avaluation system ("Mk") and the monetary system ("Rd"; Anon. 1873). The Rd system, however, shows a finer resolution and will therefore be used in the following, considering that the corrections are directly related to cultivation – and thus to human activity – and that the scale resolution in Rd is considerably finer than in Mk (Fig. 2).

The data on the occurrence of invertebrate species in the infields are from an extensive survey in the Faroes in 1978 and 1979 (see Bengtson & Hauge 1979, Kauri 1980, Bengtson 1981, Solhøy 1981, Enckell & Rundgren 1983, Meidell & Solhøy 1990). A total of 112 sites were sampled, evenly distributed over the archipelago and between infields and outfields (see Bengtson & Hauge 1979 for a description of sites, habitats and collection efforts). A few additional localities are reported in Enckell et al. (1986) and Enckell & Rundgren (1988) and the few anthropochorous species then found have been included here. A general discussion of the distribution patterns of invertebrates in settlement areas over the islands (a between-island comparison) is given in Enckell et al. (1987a).

The invertebrate groups used in the analysis are spiders (Araneae), harvest-spiders (Opiliones), beetles (Coleoptera), slugs and snails (Gastropoda), earthworms (Lumbricidae) and "Miscellaneous", including e. g. centipedes and millipedes (Chilopoda, Myriapoda). All are soil/surface-living and thus can be expected to be to some extent dependent upon the vegetation cover of the respective site, and general "habitat quality" (especially soil fertility).

In the analysis of the occurrence of species in the infield sites, the classification of certain species as anthropochorous is that used by Enckell et al. (1987b); i. e. it is based on the <u>total</u> distribution of the given species over all habitat types (not only the infields); anthropochorous species are those that occur exclusively (or nearly so) in infields. The different modes of dispersal of the different species have not been considered here; they are treated by Enckell et al. (1987).

All infield samples have not been included here, for various reasons. For example the island of Skúvoy has been excluded because the sample of Gastropoda disappeared during sea transport. In the general species-area diagram (Fig. 3) Skúvoy and Lítla Dímun (with no settlement) are lacking; Skúvoy for the reason mentioned above and Lítla Dímun because the sampling effort on this island was considerably lower than for other sites (for logistic reasons; the island has to be reached by helicopter). Likewise, the sampling effort in a few infield sites differed in such a way from the general pattern that it was felt the results would not be comparable (for example pitfall traps were not used). Data from a total of 38 infield sites (see Appendix) are included. The settlements in the Faroes and their locations are shown in Fig. 1. All, except Saksun in the NW of Streymoy, are located on the coast.

The data are summarized in the Appendix. They will be used for, first an analysis of species-area relationships, and second, for species-value-of-area relationships. The infields will in the analysis also be divided into two size groups (17-65 ha and 95-299 ha), for reasons mentioned above and apparent in the section below.

Results and discussion

Effects of area on land value and number of species

The distribution of all species over the total island areas exhibits the general pattern of a species-area relationship (Fig. 3) and for the anthropochorous species there is a very similar pattern not shown here. However, when the number of species (total or anthropochorous), land value (as an integrated measurement of habitat quality), and infield area are plotted against each other in different combinations, the results are a complex of inter-relationships (Figs. 4-31). Although it should be emphasised that the analyses are based on snapshot data and lack in statistical rigour, the plots suggest trends or tendencies (or an absence thereof) exhibiting patterns that purportedly link number of terrestrial invertebrate species to human activities, especially land use in the past.

As shown in Fig. 4 the total number of species seems only slightly or not at all related to infield area. The monetary value of the infields increases only slightly with area, less so than expected (Fig. 7). But the value per areal unit decreases clearly with infield area (Fig. 8). The total number of species does not increase with infield area (Fig. 9), while the number of anthropochorous species shows some increase (Fig. 10). The same goes for the total number of species when related to the height of the infields (Fig. 11), while it is clear that the total number of anthropochorous species decreases with height (Fig. 12). This can be related to the decreasing values of the larger infields (see Appendix and the values – Rd/ha of the infields).

With increasing Rd value the total number of species seems to increase slightly (Fig. 13), while the number of anthropochorous species shows a more marked trend (Fig. 14).This again illustrates the value of the smaller (and often more low-lying) infields where the Rd values are higher, for the anthropochorous species (compare Figs 15 and 16).

The pattern exhibited by the anthropochorous species is very similar to the general picture (data not shown). The total number of species found was only slightly influenced by infield area (Fig. 4).The same was found for the anthropochorous species (Figs 5, 6). The monetary value of the infields increases only slightly with area, less so than expected (Fig. 7). But the value per areal unit decreases clearly with infield area (Fig. 8). The total number of species increases only slightly with infield area (Fig. 9), while the number of anthropochorous species increases more steeply (Fig. 10).The same goes for the total number of species when related to the height of the infields (Fig. 11), while it is clear that the total number of anthropochorous species decreases clearly with height (Fig. 12). This can be related to the decreasing values of the larger infields (see Appendix and the values – Rd/ha of the infields).

As appears from Figs. 17 and 18 the monetary value of the infields seems to increase more steeply for the smaller infields (see also Appendix). The total number of species in the larger and smaller infields increases slightly with infield size while the number of anthropochorous species increases more steeply in both cases (Figs, 19 – 22). This can possibly be explained by the fact that also the larger infields contain considerable low-lying parts where human influence has been more intense (see Appendix). This difference can also be seen when it comes to monetary values of the different sizes of the infields (Figs, 23 –25, note especielly Fig. 25; data for Rd per 17 – 65 ha vs total species not shown).

The same general pattern can be seen in Figs. 26 – 31, where the smaller infields, generally exhibit slightly, though distinctly steeper slopes for anthropochorous species than for total number of species.

For the larger infields the correlation between infield area and total number of species is significant (tau =0 .47, P =0.05); for the anthropochorous species the related correlation is slightly less (tau =0.43). The number of species increases with infield area for the larger infields; again, perhaps, an indication that anthropochorous species tend to be restricted to the more low-lying infields and do not occur in the more mountainous barren areas. (It should be remembered, however, that our data are snapshots, collected on single occasions, and a repeated collection effort could change this picture.)

There is a clear distinction beteen small and large infields in value per area. This reflects the influence of human activities from about AD 800 onwards. The first settlers who came to the Faroes chose coastal locations for their dwellings (as can be seen from a number of excavations of Viking houses, stables and byres). The parts of the infields that were mountainous were presumably not attractive (or indeed necessary) for the immigrants or their animals. The small coastal settlements and infields were enriched with manure, seaweed, mussle shells, excrement from the animals of the people and so on. Eventually the small coastal infields increased in luxuriance, the number of introduced species increased with ballast animals, feed for cattle, and later introduced exotic plants, and the soil layers in the vicinity of the houses became deeper and more fertile than those further away in the outfields. This process has been going on for hundreds of years. On the other hand it should be kept in mind that the settlements are of a different age and that human influence has probably been different in different settlements. All this, of course, has influenced the influx of plant and animal species to various areas, and which species has arrived. Moreover, the dispersal of species between the islands has also been different.

In addition, there is a constant flux between the infields and the outfields. The outfields receive species that cannot normally live there for example because the soil layers are too thin for deepburrowing species (e.g. some earthworms). But examples exist of anthropochorous species existing in the outfields, e. g. in shielings where cattle were kept during summertime (Enckell & Rundgren 1988). But the flow of energy from infields, stables and byres continues all the time.

This process is continuing. More anthropochorous and habitat-specific specics are arriving in the Faroes all the time – not only benign ones. Striking examples of the opposite are the Spanish slug *Arion lusitanicus* and the flatworm *Artioposthia triangulata*. This will change invertebrate species patterns and our pictures from 1978 and onwards will inevitably change.

Unfortunately we cannot compare our data with corresponding data on plant species, since published accounts have not distinguished between infields and other areas in the settlements. What we know is that many ruderal species have been introduced (perhaps 25% of the total number of introduced species).There are also studies showing the vertical distribution of plant species, but not distribution in different settlements (Fosaa 2003).

There is a large number of studies that deal with esoteric indices that can or cannot explain certain aspects of the relation between species number and the area they inhabit. Many of these are mathemantical and not biological. We will abstain from listing such studies here. This is not the place to discuss such theories. What we are talking about is why certain certain anthropochorous species occur in certain areas in the Faroes and not in others. We maintain, without mathematical arguments, that human influence has determined where certain species occur and that this is the main explanation for their occurrence.

Man´s role as a key species that enhances species richness

Human activities have both intended and unintended consequences for biotas and are almost universally considered synonymous with degradation. The terrestrial invertebrate communities found in the infields of the Faroes are among the most species-rich found in the islands and the anthropochorous elements are substantial (Enckell et al. 1987b). The colonization of the Faroes is of course an ongoing process and due to increasing human populations and oversea contacts more anthropochorous and habitat-specific species are arriving – not only benign ones. Examples of the opposite are e. g. the Spanish slug *Arion lusitanicus* and the flatworm *Artioposthia triangulata.*

On the whole we can say that human activities in the islands are associated with an increased species-richness, today and in the past (e.g. Vickers et al 2005). The history of human colonization of the Faroes and that of the terrestrial fauna are entangled and interacting as the settlements were established and subsequently expanded in size at the same time as land use practices changed.

We claim that historically, by being a key species that bridges the gjogv (Faroese for gorge) between life sciences and social sciences, Man´s influence and activities has created many of the habitats where anthropochorous species occur today and have substantially enriched the invertebrate terrestrial fauna in the Faroes.

Appendix

The headings are self-explanatory except perhaps for the last one, species-a, which denotes the number of anthropochorous species in the different sites. The data are arranged with the site areas increasing from the smallest (Koltur) to the largest (Midvágur). It is evident that there is a slight trend for increase in the value in mk and in rd with increasing size of sites; however the values of mk/ha and rd/ha show a decreasing trend with increasing size of sites, possibly caused by larger high-level areas in the the larger sites. No clear trends can be seen in the number of species or of anthropochorous species with increasing size of sites.

Island	area, km2	site no.	site	area, ha	value. Mk	value, rd	mk/ha	rd/ha	no. Species	no. Species-a
Koltur	2.50	94	Koltur	17	17	4666	1	275	39	10
Streymoy	373.5	29	Tjörnuvík	20	24	2133	1.2	107	40	14
Bordoy	94.9	49	Arnafjördur	20	16	2402	0.8	120	24	4
Bordoy	94.9	50	Nordoyri	20	24	3819	1.2	191	34	9
Streymoy	373.5	27	Sáksun	22	29.5	4233	1.34	192	55	16
Eystoroy	286.4	58	Nes	23	24	6816	0.34	81	41	14
Streymoy	373.5	93	Sydradalur	25	16.75	3222	0.67	129	36	10
Sandoy	112.1	32	Skarvanes	26	12	3844	0.46	148	48	21
Kalsoy	30.9	91	Husar	27	24	4716	0.89	175	35	10
Eysturoy	286.4	17	Aeduvík	29	24	6816	0.83	37	36	8
Vágar	177.6	66	Böur	30	18	4211	0.6	140	34	8
Stóra Dímun	2.7	111	Stóra Dímun	30	13	6933	0.43	231	37	5
Streymoy	373.5	3	Kirkjuböur	33	39	7800	1.18	236	50	17
Fugloy	11.2	73	Hattarvík	33	27	6576	0.82	199	36	9
Kunoy	35.5	87	Kunoy	38	32.5	6671	0.86	176	47	18
Sandoy	112.1	36	Söltuvík	44	21.25	6179	0.48	140	47	6
Mykines	10.2	101	Mykines	49	40	10820	0.82	221	43	11
Kalsoy	30.9	82	Mikladalur	52	25	6021	0.48	116	26	8
Eysturoy	286.4	43	Oyndarfjördur	56	32	14589	0.57	261	50	26
Hestur	6.1	98	Hestur	65	18	7117	0.28	110	45	16
Nólsoy	10.3	26	Nólsoy	95	48	12100	0.51	127	37	18
Suduroy	166	52	Famjin	95	24	9467	0.25	100	61	17
Svinoy	27.4	81	Svínoy	103	32.25	9081	0.31	88	27	8
Suduroy	166	60	Hov	124	24	11333	0.19	91	39	14
Sandoy	112.1	35	Húsavík	126	31	9900	0.25	79	34	12
Eysturoy	286.4	90	Sydrugöta	138	30.2	10764	0.22	78	40	13
Suduroy	166	61	Porkeri	139	37	16800	0.27	121	46	12
Eysturoy	286.4	44	Leirvík	147	32.2	13533	0.22	92	34	9
Streymoy	373.5	69	Vestmanna	148	56	13432	0.38	91	32	6
Vidoy	41	104	Vidareidi	172	48	12423	0.28	72	31	15
Streymoy	373.5	41	Kvívík	173	48	10127	0.28	59	48	17
Vágar	177.6	11	Sørvágur	208	46	12230	0.22	59	35	17

Sandoy	112.1	33	Skálavík	209	42	13600	0.2	65	47	17
Suduroy	166	59	Frodba	232	24	6344	0.1	27	55	17
Suduroy	166	62	Sumba	241	64	16250	0.27	67	46	16
Bordoy	94.9	107	Klaksvík	243	59.75	11859	0.25	49	34	12
Vágar	177.6	68	Sandavágur	276	48	13775	0.17	50	43	18
Vágar	177.6	67	Midvágur	299	48	15868	0.16	53	47	18

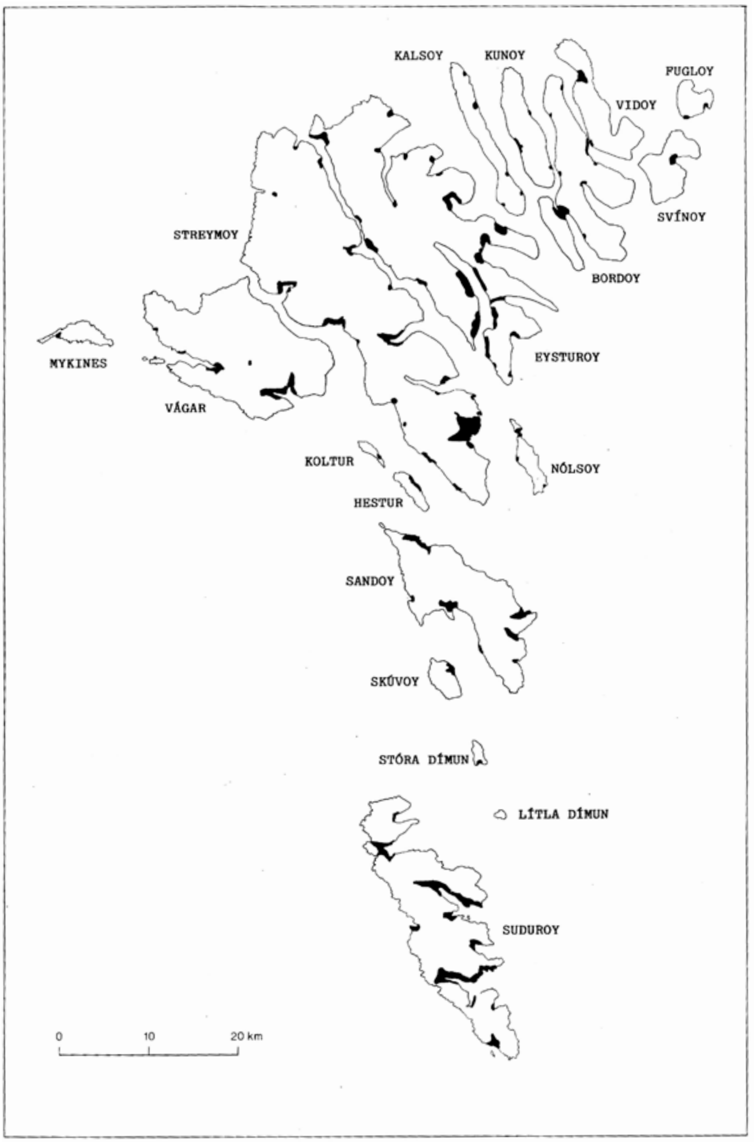


Fig. 1. The infield areas of the settlements in the Faroe Islands. The total infield area covers 7% of the area of the islands. Note that all settlements lie on the coast except one, Saksun, in the northern part of Streymoy.

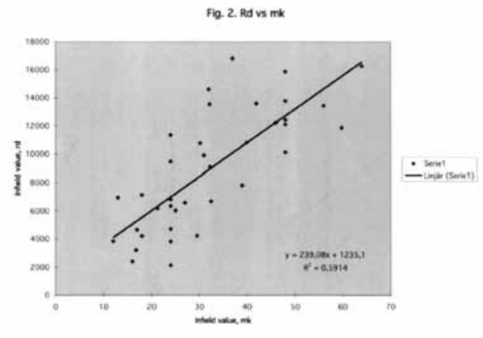


Fig. 2. Rd vs mk

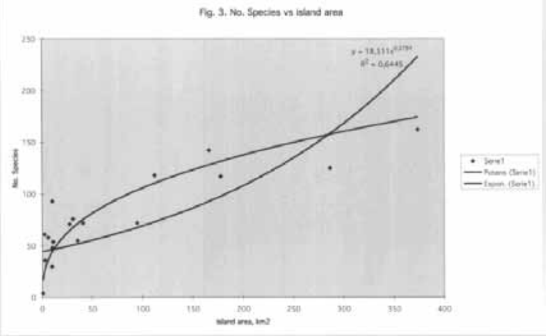


Fig. 3. No. Species vs island area

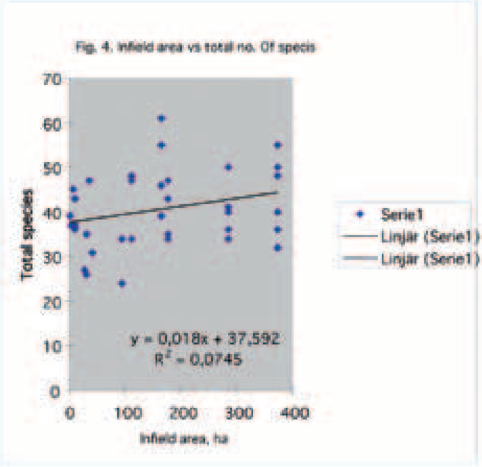


Fig. 4. Infield area vs total no. Of specis

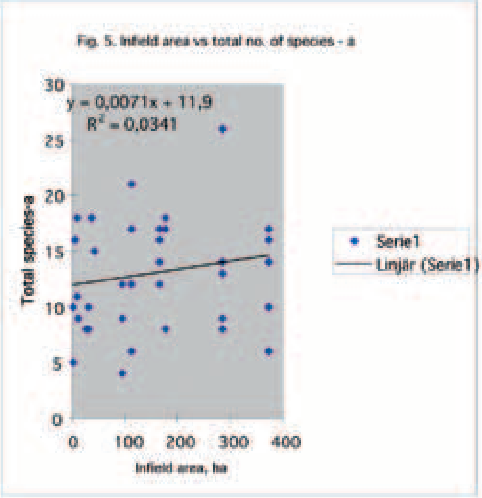


Fig. 5. Infield area vs total no. of species - a

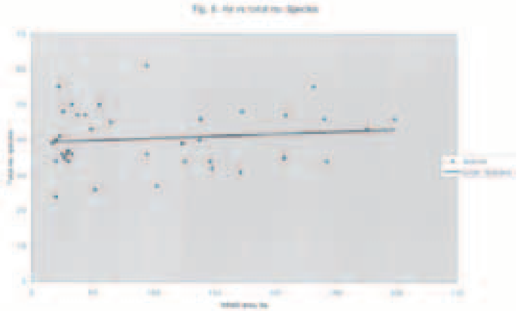


Fig. 6. Ha vs total no. Species

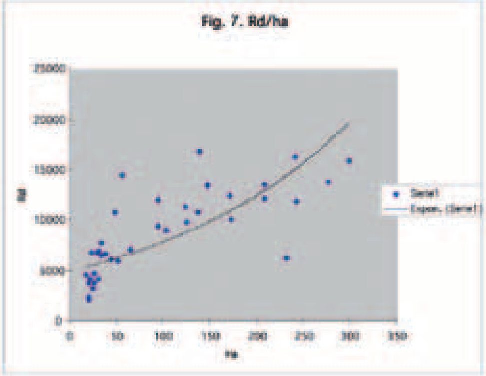


Fig. 7. Rd/ha

Fig. 8. Rd/ha vs infield area (ha)

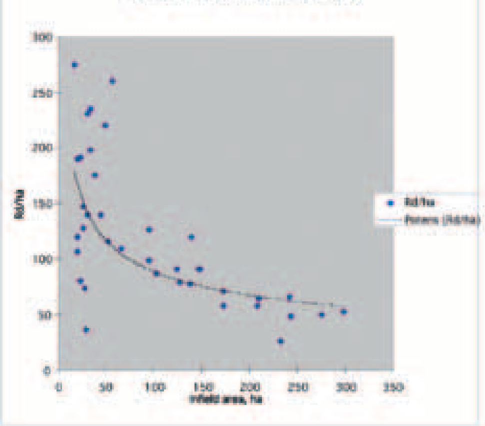


Fig. 9. Ha vs total no. Species

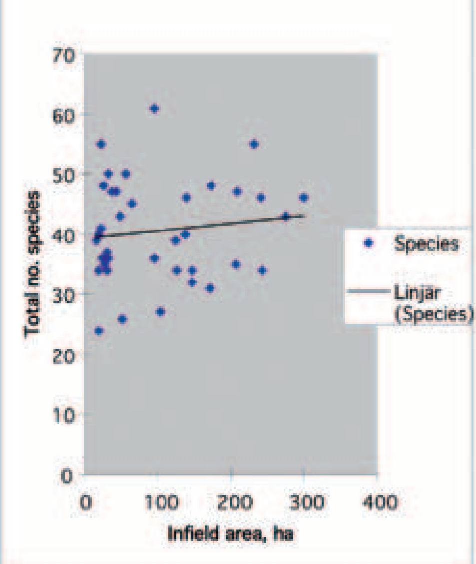


Fig. 10. Ha vs total no. Species - a

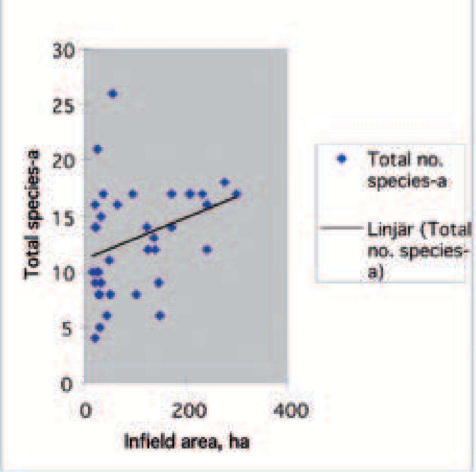


Fig. 11. Height vs total species

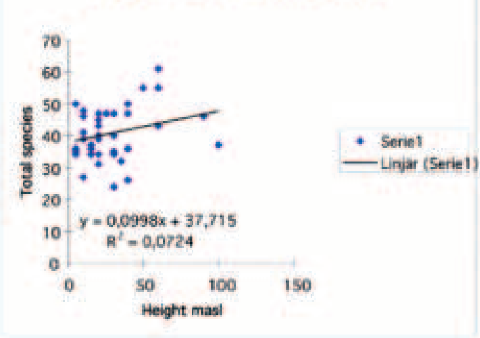


Fig. 12. Height vs total species - a

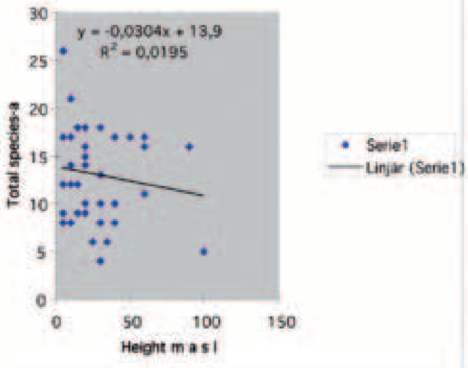


Fig. 13. Rd vs total no. species

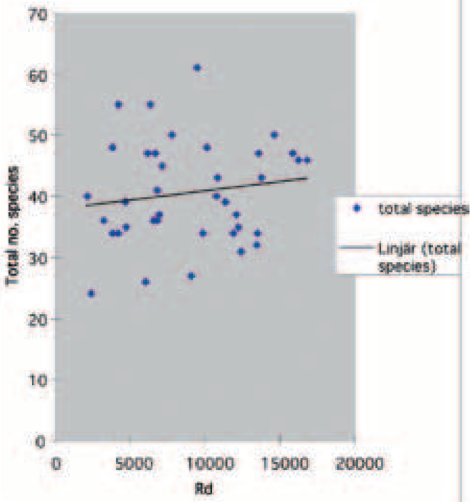


Fig. 14. Rd vs total no. Species - a

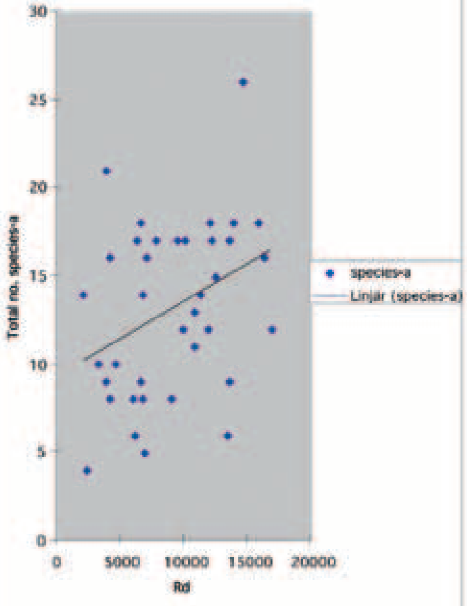


Fig. 15. Rd/ha vs total no. Species

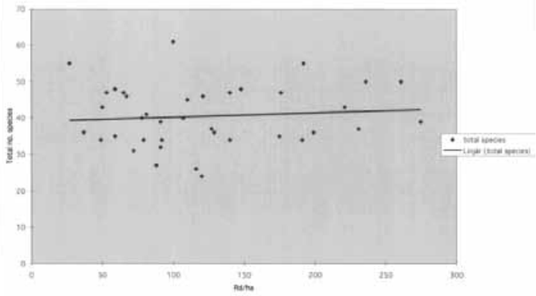


Fig. 16. Rd/ha vs total species - a

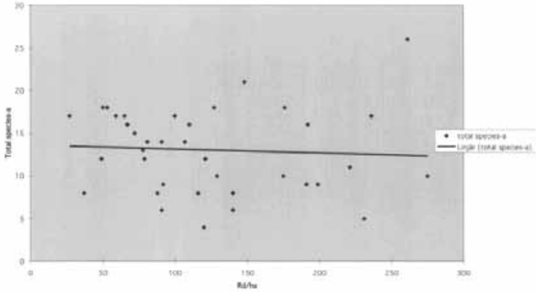


Fig. 17. 95-299 ha vs rd

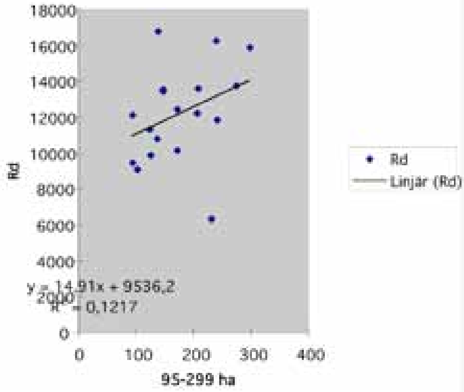


Fig. 18. 17-65 ha vs rd

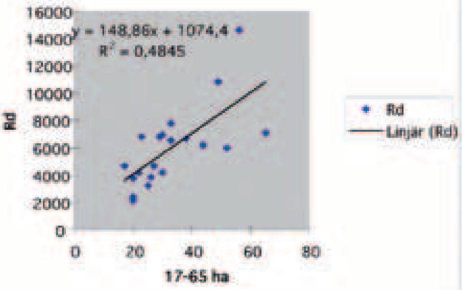


Fig. 19. 95-299 ha vs total no. Species

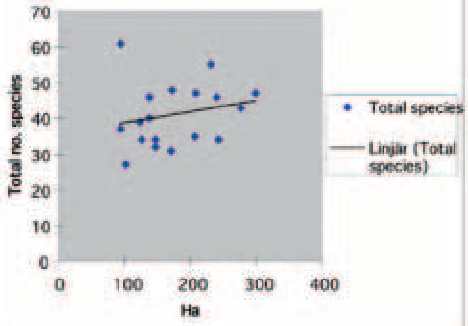


Fig. 20. 95-299 ha vs total no. Species - - a

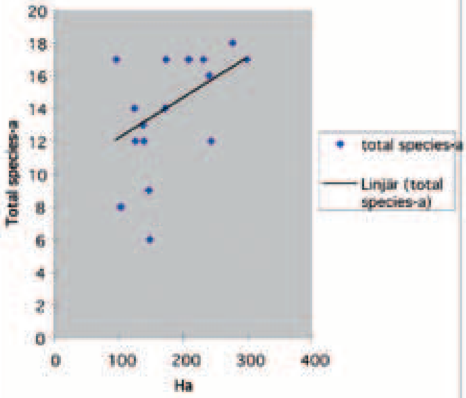


Fig. 21. 17-65 ha vs total no. of species

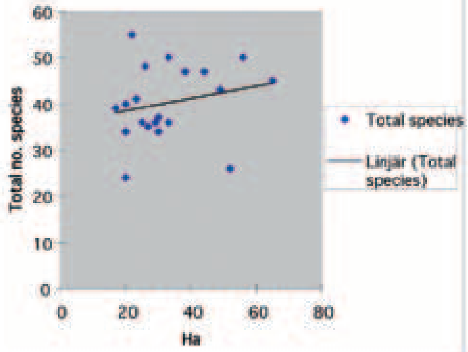


Fig. 22. 17-65 ha vs total species - a

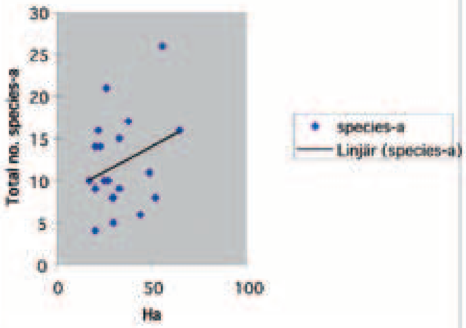


Fig. 23. Rd (95-299 ha) vs total no. Species

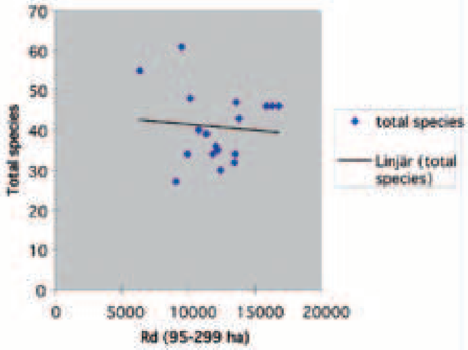


Fig. 24. Rd (95-299 ha) vs total no. of species - a

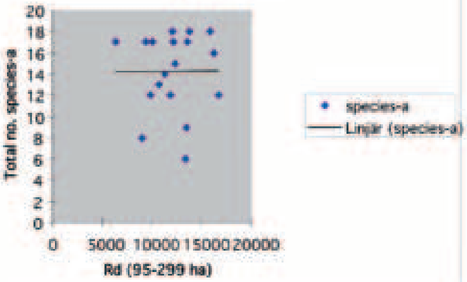


Fig. 25. Rd (17-65 ha) vs total no. species -a

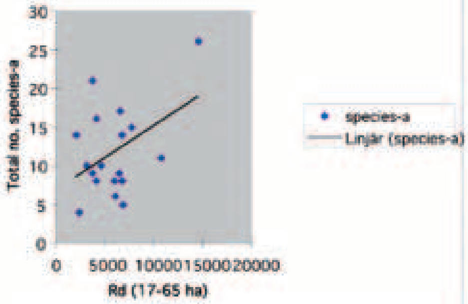


Fig. 26. Rd/ha vs total species

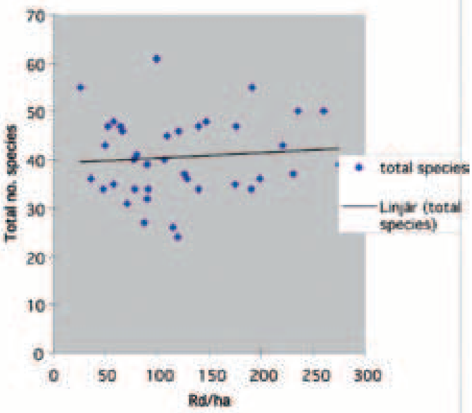


Fig. 27. Rd/ha vs total species - a

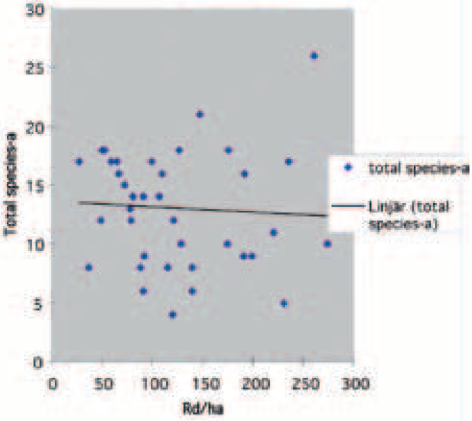


Fig. 28. Rd/ha (95-299 ha) vs total no. species

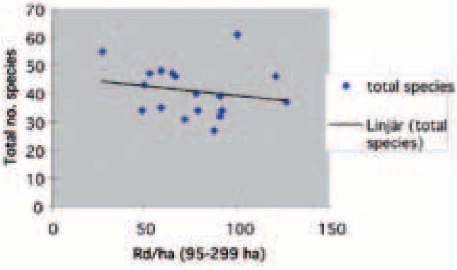


Fig. 29. Rd/ha (95-299 ha) vs total species - a

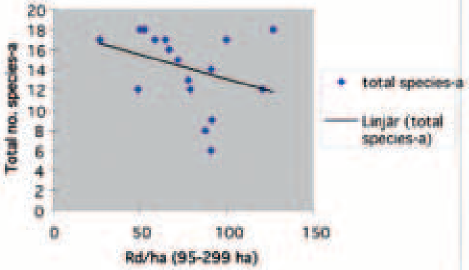


Fig. 30. Rd/ha vs total no. species

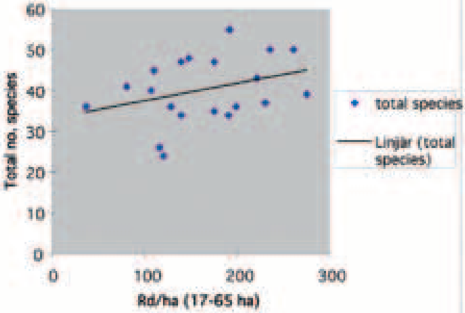
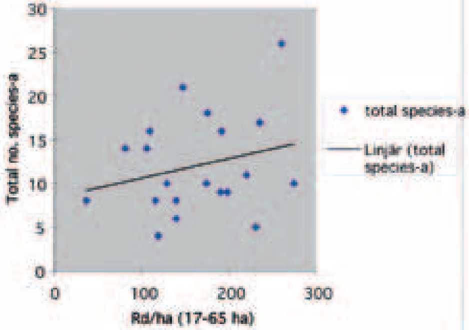


Fig. 31. Rd/ha (17-65 ha) vs total species - a



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