INSECT FOSSILS AND IRRIGATION IN MEDIEVAL GREENLAND

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ABSTRACT. Initial European, Norse, settlement in south-west Greenland lasted from the late tenth to the fifteenth century, with an economy largely based on secondary products from sheep, goats and cattle, supplemented by caribou and marine mammal hunting. Sustainable subsistence farming required acquisition of sufficient fodder, principally hay, to feed stalled animals through extended subarctic winters. At the cathedral site of Garðar, the modern sheep farm of Igaliku, artefact scatters and geoarchaeological evidence show that infields were improved by manuring, and systems of ditches have been interpreted as evidence for controlled irrigation in an area liable to a potential water deficit. Further palaeoecological evidence, largely from insect remains, is presented which indicates the build up of thick plaggen soils as a result of large-scale manuring with animal, domestic and structural waste, perhaps supplemented by pared turf. It is suggested that the technique of irrigated hayfields was utilized principally to provide fodder for the large numbers of cattle maintained on the bishop’s farm. The system appears to have been abandoned abruptly in the late medieval period, when wetland takes over from irrigated hayfield.

Key words: caddis flies, Greenland, hayfields, insects, irrigation, manure, medieval

Introduction

European settlement in south-west Greenland began at the end of the tenth century and lasted until some time in the fifteenth century. Greenland’s foundation myth or history is told in Erik the Red’s Saga and the Vinland Saga, as well as other near contemporary sources. The date is confirmed by several radiocarbon dates on both archaeological and natural contexts (Vésteinsson et al. 2002). The latest document, prepared at the cathedral at Garðar, modern Igaliku, in 1409, affirms wedding banns for a ceremony at Hvalsey in the previous year (Halldórsson 1978, 143); thereafter all is silent until the missionary Hans Egede went looking for the lost colony in the early eighteenth century to find only Inuit, the Eskimos of earlier sources, who had moved into the region from the far north-west during the late medieval period. There is no convincing evidence of direct contact, other than occasional conflict, between the two groups, although this is disputed (Gulløv 2008; Park 2008), and the presence of Norse artefacts on early Inuit sites seems more likely to reflect scavenging of the abandoned farms than trade. As the archaeological and slim documentary record suggests, the settlers maintained their European farming economy until final desertion, a process which seems likely to have been a process of gradual attrition, declining population and migration to Iceland, rather than anything more dramatic (Lynnerup 1998; Seaver 2010).

At its height, the Eastern Settlement, the larger and more southerly of the two settlement areas in Greenland, consisted of over 400 farms (Keller 1989), dispersed in a landscape of subarctic tundra and birch–willow forest. Pollen evidence shows the rapid destruction of the latter (Fredskild 1992; Schofield et al. 2007; Gauthier et al. 2010) as the incoming farmers, practising a subsistence economy based on secondary products from cattle, sheep and goats, supplemented by hunting of caribou (reindeer) and seals (McGovern 1994), sought to change woodland into grass pasture for their animals. Subsistence-based, in a landscape no more severe than that colonized by many other European communities on the pioneer fringe, the Greenlanders had little need for European contacts, other than spiritual, and it is this latter which leads to the acquisition of a bishop during the twelfth...
century, an event neatly summarized in the Saga of Einar Sokkason, where gifts of some of Greenland’s prestige export items, including a polar bear, to the king in Denmark, procure the somewhat reluctant bishop Arnald, who eventually arrived in Greenland in 1126. Thereafter Greenland figures as a source of tithes, drawn in walrus ivory, hides, furs and other high value materials, a contrast with Iceland where stockfish rapidly supplements woollen cloth (waðmal) as an export staple (Amundsen et al. 2005). Dugmore et al. (2007) argued that the primary purpose of the Greenland settlements was as outstations to enable powerful Icelandic landowners to engage in the lucrative trade in the high value products of the Norðsetr hunt, but whilst the Icelandic connection remained strong until the final abandonment, it was inconsequential to the survival of farms in Greenland as viable entities. Pastoral farming in Greenland, however, had, and still has, a number of problems, related not only directly to the cold and accumulated number of day-degrees through the growing season, but also to the probability of a net water deficit, leading to low productivity (Adderley and Simpson 2006) of hay, critical as fodder to overwinter core stock (Amorosi et al. 1998). This problem was perhaps most acute at Igaliku, medieval Garðar, the farm of the bishop at the head of Einarsfjörður, now Igalikup Kangerlua, where excavations by Poul Nörlund in the 1920s exposed byres with the capacity to hold up to 100 head of cattle (Nörlund 1929). With this capacity, it is not surprising that Garðar, which before being gifted to the Church, had been occupied by the family of Erik the Red’s daughter Freyðis, appears to have been the only farm at the head of the fjord. As the fourteenth century description of Greenland by the bishop’s reeve, Ivar Barðarson, states, the farm also pastured its animals in woodland which it owned on the south side of the fjord (Halldórsson 1978, 135). Archaeological and palaeoecological evidence indicates that it is probable that the arrival of bishop Arnald from Norway also led to agricultural innovation to improve yields.

Insect remains from three sections at Garðar are analysed in order to:

1. obtain information on environmental change in the area from Landnám, from the beginning of Norse settlement;
2. assess the effects of Norse colonization on both indigenous and introduced elements of the insect fauna;
3. discuss the problems of identification of larval caddis flies (Trichoptera) from Greenland and their palaeoecology.

**Garðar/Igaliku**

Igaliku (Fig. 1) lies on a gently sloping, east-facing plain close to the head of Igalikup Kangerdlua, the Norse Einarsfjord. Ringed by mountains, there is an easy passage over a low coll to Tunulliarfik, Eriks Fjord, to the north, and there are further lowlands to the south across the fjord. The site was reoccupied in the late eighteenth century by the Danish merchant Anders Olsen, who established a small cattle farm, and since the 1930s it has formed the base for more extensive sheep farming. As a result, there are few visible vestiges of the cathedral, bishop’s palace and ancillary buildings (Figs 2 and 3) and the surrounding landscape has suffered extensive erosion. The remains of the drystone and turf-walled structures of the farm were largely uncovered during excavations by Nörlund (Nörlund 1929, 1936). Skeletal material from the cemetery has been re-assessed by Lynnerup (1998), and research is also in progress on
the isotopic composition of Greenland bone as a pathway to dietary information (Arneborg et al. 1999). The plan of the cathedral has recently been reinterpreted by Høegsberg (2007), and Arneborg (2005) has also re-examined the morphological and archaeological evidence for irrigation.

In 2005 the farmer at Igaliku cut new drainage ditches from a point between the large byre excavated by Nørlund and the so-called Bishop’s Well eastwards towards the fjord, joining a north–south ditch 50 m to the east (Fig. 4). The upcast from the ditches was dumped to either side of the excavation, and examination of the spoil heaps produced a number of artefacts, including a merchant’s tally stick, fragments of wooden bowls and a putative prayer stick (Fig. 5) (Buckland et al. 2008). Ditch sections also included much other archaeological debris in a peaty organic matrix, and profiles throughout revealed similar successions of varying depths of up to 0.7 m of peat over an irregular surface of light grey silts with scattered rounded to subrounded pebbles. These underlying deposits relate to a series of earlier Holocene raised beaches evident as a series of inclined steps in the landscape (Sparrenbom et al. 2006). The upper part of the peat

Fig. 2. Remains of the Norse farm at Garðar/Igaliku looking south across the modern hayfield and eroded areas of former pasture and woodland, August 2005.

Fig. 3. Plan of the remains and ditches at Igaliku, based on Ingstad (1960).

Fig. 4. Igaliku, ditch section looking north. The sampling localities A, B and C are indicated.

Fig. 5. Fragments of coopered bowls from spoil heaps and sections at Igaliku.
sequence consists of light brown fibrous peat which extends up into the roots of the modern grass ley of the drained surface of the modern hayfield. This has an abrupt lower contact with a very dark brown, more silty peat containing much archaeological material, from twigs, woodchip and woodwork to charcoal, animal bone fragments and cracked pebbles. This deposit is attenuated to the north, but is clearly visible in all the new ditch sections and must reflect the extensive spreading of occupation debris across the areas adjacent to the cathedral and farm. The size of some of this material, with cracked rocks up to 150 mm across, as well as pieces of worked wood, clearly precludes a natural process of flooding and sheet flow across the site, and the material must reflect one or more deliberate acts. Sampling for insect remains was designed to elucidate the origin of this material.

Materials and methods
Several ditch sections were cleaned back and columns of 5 litre samples in 50 mm slices were taken through the archaeological horizon into the underlying silts in three locations, A, B and C (Figs 4 and 6), the first being at the beginning of the ditch approximately 60 m from the wellhead, and the last some 40 m to the east in the ditch at right angles to the west–east one. Section C was extended upwards to immediately beneath the modern root horizon of the improved hayfield and samples C1–C5, with their more sparse faunas, reflect the period after the abandonment of the medieval farm. A total of 21 samples were sealed in polythene bags and returned to the UK for processing.

Each sample was washed out over a 300 μm mesh and the residue retained on the sieve subjected to paraffin (kerosene) flotation (Coope and Osborne 1968). Insect remains were picked out under a low-power binocular microscope and stored in ethanol. Identification of all insect groups other than Trichoptera was achieved by comparison with a reference collection of Greenlandic insects housed in the Department of Geography, University of Edinburgh. The larval fragments of Trichoptera from each sample were mounted on microscope slides in Hoyer’s medium, a colourless, water-soluble mountant. During ecdysis (moulting), the larval cuticle disarticulates into its various components. In the samples presented here there were the parietal plates and the frontoclypeal apotome from the larval head capsule, together with both pro- and meso-notal sclerites from the thorax. The analysis of the present study is based primarily on the characteristics of the frontoclypeal apotome (Greenwood et al. 2003, 2006). From each sample the mounted fragments were observed under a binocular dissecting microscope at ×16 and characters such as details of colour, pattern, shape and microsculpture (surface structure) used for comparison. A minimum number of individuals for both Coleoptera and Hemiptera were obtained by counts of the most abundant sclerite. Diptera numbers reflect counts of puparia and pupal parts for Nematocera.

Results
Table 1 lists the minimum number of individuals of each taxon identified and Table 2 details the larval Trichoptera. Habitat information and other fossil records derive from the database BugsCEP (Buckland and Buckland 2006, http://www.bugscep.com, 17-Jul-12), checked against primary ecological data from Greenland (e.g. Böcher 1976, 1988, 2002) where appropriate. The data from section B have been discussed in relation to a palynological study of an adjacent profile to the sampling site (Buckland et al. 2009). This paper presents a broader view of the fossil insect evidence in relation to the historical record.
Table 1. Insect remains from Columns A–C at Igaliku.

| Samples | A1 | A2 | A3 | A4 | A5 | A6 | A7 | B1 | B2 | B3 | B4 | B5 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

**Species list**

- **Coleoptera**
  - Carabidae
    - *Nebria rufescens* (Ström.)
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    - *Bembidion grapii* Gyil.
      - 1
    - *Patrobus septentrionis* Dej.
      - 1
    - *Trichocellus cognatus* (Gyll.)
      - 1
    - *Dytiscidae*
      - *Hydroporus morio* Aubé
        - 1
      - *Colymbetes dolabratus* (Psykm.)
        - 1
    - Staphylinidae
      - *Omalium excavatum* Siegb.
        - 1
      - *Xylodromus concinus* (Marsham)
        - 1
      - *Philonthus politus* (L.)
        - 1
      - *Quedius mesomelinus* (Marsham)
        - 1
      - *Q. fellmanni* (Zett.)
        - 1
      - *Athena* (s.l.) spp.
        - 1
      - *Byrrhidae*
        - *Simplocaria metallicaeformis* Sturm/Suhb.
        - 1
      - *Byrrhus fasciatus* (Forst.)
        - 1
      - *Cryptophagidae*
        - *Atomaria apicalis* Er.
        - 1
      - *Atomaria* spp.
        - 1
      - *Latridiidae*
        - *Latridius minutus* (grp.) (L.)
        - 1
      - *L. pseudominutus* (Strand)
        - 1
      - *Coccinellidae*
        - *Nephus redbandatus* (Muls.)
        - 1
      - *Coccinella transversoguttata* Fald.
        - 1
      - *Ptinidae*
        - *Tenuipenis* (Afr. & Mitt.)
        - 1
      - *Curculionidae*
        - *Oriohystenus arcticus* (O. Fabricius)
          - 1
        - *O. nodosus* (Müll.)
          - 1
        - *Oriohystenus* spp.
          - 1
      - *Mallotus* spp.
        - 1
      - *Pediculidae*
        - *Pediculus humanus* L.
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Table 2. The numbers of larval caddis fly sclerites from the three profiles (Garðar A, B and C), together with larval caddis cases and head capsules from larval Chironomidae.

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<th>Depth (cm)</th>
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The natural fauna

Numerically, the faunas (Fig. 7) are dominated by the froghopper *Psammotettix lividellus* and the aphid *Utanphorophora (=Thripsaspis) vibei*. *P. lividellus* is an essentially Nearctic species, extending westwards into Siberia. In his revision of the genus, Greene (1971) notes that specimens from North Carolina fed exclusively on the meadow grass *Poa pratensis*, although Hamilton (1997), who does not record the species south of Québec, suggests, as Böcher (2002) does for Greenland, that it is a general feeder on grasses. The species was abundant in pitfalls set in improved hayfields and their margins at Qassiarsuk and Qoqortoq on the north side of Tunulliarfik fjord (Buckland and Panagiotakopulu, unpubl.). The aphid *U. vibei* was initially described from Greenland (Hille Ris Lambers 1952) and has since been found in Iceland and northern Sweden (Böcher 2002). It feeds on the sap of sedges, *Carex* spp., rather than grasses. The other plant-feeding bug, *Nysius ericae gronlandicus*, present in all samples in columns A and B but in only one sample in C, is a polyphagous feeder on seeds (Böcher 1975). The one plant louse *Cacopsylla gronlandica* develops on a range of willows in Greenland, including *Salix glauca*, *S. arctophila*, *S. uva-ursi* and *S. herbacea* (Hodkinson 1997), where the ladybird *Coccinella transversoguttata*, also present as a single individual in another sample, is likely to have preyed upon it, as well as aphids. The smaller coccinellid, *Nephus redenbacheri*, is recorded as feeding on shield lice, coccids, in Iceland (Lindroth et al. 1973) and Böcher suggests that its principal prey in Greenland is the soil-dwelling shield louse *Arctothecia cataphracta*. Although this species is not recorded from any of the Garðar samples, the two polyphagous weevils of the genus *Otiorynchus*, *O. arcticus* and *O. nodosus*, present in virtually all samples, are almost ubiquitous in south-west Greenland, and share a similar habitat, the larvae feeding on the roots of higher plants in the soil. The byrrhids, largely the species pair *Simpleocaria metallica/elongata*, feed on bryophytes and are frequent in the mosses growing between grass tussocks and on rocks in the region, occurring in some numbers in pitfalls set in hayfields, where the small predatory staphylinids, *Quedius fellmani* and species of *Atheta* (s.l.), and the few carabids also occur. The other elements in the natural fauna which is well represented are the water beetles. *Hydronorus morio* is virtually eurytopic in pools in Greenland, occurring everywhere from rock pools with little vegetation to small ponds in bogs (Böcher 1988), whilst the larger dytiscid *Colymbetes dolabratus* is more characteristic of the more permanent water bodies, including the margins of lakes. Both occur with trichopteran larvae (caddis flies), which are also present in most samples.

Part of the natural assemblage includes some of the larval Diptera. The maggots of species of the semi-aquatic ephydrid genus *Scatella* feed on algal crusts on eutrophic soils, and similar deposits by salt lakes and warm springs (Smith 1989; Böcher 2002), whilst anthomyids, including *Delia fabricii*, are largely associated with grasses and low herbs. These are outdoor elements of the fauna, which may also be found inside farms (Panagiotakopulu et al. 2007). *Scatophaga furcata* Say, which lives as a predator on herbivore dung, is another outdoor species which is also present in high numbers at the Western Settlement farm of Gården under Sandet (Panagiotakopulu et al. 2007).

Caddis flies are particularly useful indicators of aquatic systems because their larvae have readily preserved skeletal parts (frontoclypeal apotome, pro- and meso-notal thoracic sclerites) and because they comprise an ecologically diverse group whose species are adapted to many different combinations of freshwater conditions (Greenwood et al. 2003). Members include free-living predators, net-spinning filter feeders and case builders, whose shelters are constructed from plant and mineral particles, held together with silk. Functional groups, based upon feeding mechanism, include shredders, collectors, scrapers, piercers and predators (Merritt and Cummins 1996). Caddis flies are holometabolous insects, that is, they have life cycle stages comprising, egg–larva–pupa–imago (adult).
The current list of taxa in Greenland is based upon knowledge of adults only and a full description of associated larvae has yet to be undertaken (Table 1). It is therefore essential in studying the material from fossil assemblages that the larval exuviae are carefully matched with the named adult: this can only be achieved by rearing individual larvae through to the adult stage and retaining the shed cuticle, a procedure successfully developed by Hiley (1969, 1973). In this study and as a consequence of this lack of information, an empirical procedure of assembling like-types has been used.

From the present study, species labelled A–F are illustrated in Fig. 8. All images except that of species F are of the larval frontoclypeal apotome. Species F is of a pronotal sclerite of *Apatania zonella* (Zett.). All species illustrated are from the family Limnephilidae and are characterized by a frontoclypeal apotomal sclerite with wide, broad ‘shoulders’ at the aboral end of the sclerite. Other characteristic features used for comparison between types are width, overall shape, size and position of muscle scars, presence of a pale area at the aboral end of the sclerite, and the arrangement of setal pores. The three images labelled species E have been problematic and a conservative approach has been taken in determining possible character differences. As such, they are considered as a ‘type’ (variants of the same taxon). Insets (i) and (ii) show details of the surface sculpturing, and it is suggested that the variation has been caused by a level of deterioration in preservation.

Overall, six ‘species’ from the Family Limnephilidae were identified and counts for each sample are given in Table 2. The Limnephilidae form the largest single family of Trichoptera: their diversity, as an expression of ecological opportunity, made possible by the secretion of silk, a proteinaceous secretion of all larval caddis flies. By using silk to construct a variety of shelters and feeding nets, larval caddis flies have evolved adaptive systems to exploit a wide range of habitats and trophic resources (Mackay and Wiggins 1979).
Limnephilids are known to develop in water bodies ranging from temporary pools to those of permanent water; from fast flowing to slow and stagnant water. Section A contained the most material; section C the least. Only a variant of species E and *Apatania zonella* occur in each section. There appears to be no apparent pattern between sections, and therefore the dataset will be treated as representing one unit. No analogues for species A–C and E have been found, other than at the family level. Species D, however (*Grammotaulius* type), is a large species, resembling related species found in both Iceland and in the UK. In the current list of taxa (Table 2) only *Grammotaulius interrogationis* (Retz) has been identified from Greenland, and it is not unreasonable to suggest that species D is the larval stage of this species. The frontoclypeal apotome of species A is small and unicolorous. Species B is larger, more robust and with a pale area at the aboral end. Species C is red/brown in colour with muscle scars forming a strong ‘tear-shaped’ pattern and Species E, in its variety of forms, shows a robust pattern of muscle scars, along with some evidence of a pale area at the aboral end and possibly a trichose microsculpturing of the surface.

Two larval caddis cases are also recorded. Cases are described according to material and shape: straight or curved and made of mineral particles or vegetative materials. The case shown in Fig. 9 is made of small and medium-sized sand grains. It is curved and tapers posteriorly, measuring 7.6 mm in length. This is very similar to *Apatania* spp., as shown and described in Gíslason (1979; see also Lepneva 1971; Hiley 1976).

In Greenland only *Apatania zonella* is present. It is a species of springs, small spring-fed brooks and rivulets (Lepneva 1971), and in Iceland, it is found in stony streams and rivers, as well as on the shores of lakes (Gíslason 1979). The case found in section C (Fig. 9) is made of vegetative materials, arranged tangentially on a framework of silk and measures 12.5 mm in length. Gíslason (1979) reports that only *Limnephilus sparsus* builds its case in such a way. This species does not occur in the present Greenland faunal list but the case may belong to a closely related species, as yet undetermined.

The Greenland caddis fauna is dominated by North American species (Böcher 2002; see also Morse 1993), and in contrast with the Coleoptera (Coope 1986; Buckland 1988), there are no exclusively Palaeartic species; *Apatania zonella* and *Limnephilus griseus* are circumpolar. The checklist consists of eight species of which *A. zonella* occurs throughout Greenland, the rest being restricted to the low arctic (Böcher 2002; Johansen, pers. comm.). Life cycle strategies amongst many invertebrates with aquatic stages have evolved in these harsh conditions. Periods of larval growth are limited to warmer months and with the onset of winter, caddis fly larvae may be completely embedded in ice for a period of 6 months and able to survive temperatures down to −10°C (Solem 1981). As a consequence of this, the life cycle may be extended. *A. zonella* from Svalbard (latitude 80°N), where freshwaters are only ice free during August, has a life cycle of 2 years, possibly longer (Solem 1985). *A. zonella* (species F) is the only species of this genus recorded in Greenland, but elsewhere in the arctic-boreal region, other species of *Apatania* coexist (Solem 1985). In Norway, it inhabits streams and lakeshores in mountainous (alpine) areas, where a maximum water temperature is estimated to reach 10–12°C (Solem and Birks 2000). It is a scraper, feeding on benthic algae. *Grammotaulius interrogationis* is the only representative of this genus recorded in Greenland to date. The larval frontoclypeal apotome found in section C (35–40 cm) is a large sclerite and shows similar characteristics to other species known from the UK, where larvae have been bred through to the adult stage (Hiley 1976; Wallace *et al.* 1990). All species of this genus are found in small, stagnant, overgrown water bodies, some of which may dry out in summer. Larval cases are made of large, long plant fragments arranged in a more or less distinct spiral (Lepneva 1971; Hiley 1976). In Canada, *G.
interrogationis larvae are known to inhabit detritus rich, slow-running water bodies (Clifford 1969).

Until the necessary link between the larval exuviae and adult of the Greenland caddis fauna are established, their use as bio-indicators for environmental reconstruction is limited. One could speculate, however, that the samples for this study came from a site of permanent water, perhaps one with both a degree of flow and with quiet areas where vegetation has developed. From the variety of forms found in this study, it is not unreasonable to speculate that the wider landscape at Garðar comprised a mosaic of habitats made up of springs and flushes with permanently flowing streams and with small pools, which froze during winter months.

The diversity of the natural insect faunas, associated with the horizon with a significant component of material clearly derived from waste from the farm, can be compared with the assemblages from the upper part of section C, samples C1–5, where sampling was carried up to the base of the modern turf is significant. After the abandonment of the farm, despite the renewed growth of peat, the wetland component is much reduced and the surface becomes much drier, with the carabid Trichocellus cognatus, a species of drier, if damp heathland rather than wetlands (Lindroth 1986; Böcher 1988), occurring in samples C2–4 and Bembidion gracii, with which T. cognatus is often associated (Böcher 1988), in the top sample C1. Both also occur in samples from sites A and B, but there they are associated with a much stronger wetland component. The changes in frequencies of some taxa, including the rise in numbers of the aphid Utamphorophora vibei at the top of section C, also suggests an increase in sedges over grasses and mosses, perhaps a reflection of renewed attempts at drainage by the new occupants of Igaliku during the nineteenth century. There is, however, no synanthropic element in the fauna, indicating the use of manure, as in the assemblages associated with the Norse occupation.

The synanthropic fauna

The import of domestic stock to Greenland by colonists intent upon pursuing an essentially pastoral economy inevitably led to the accidental introduction of a range of other species, which travelled in the ballast and dunnage, as well as in fodder (Sadler 1991). Ectoparasites, of both humans, the flea Pulex irritans, and lice, Pediculus humanus, and sheep, the ked, Melophagus ovinus, a wingless fly which spends its entire life cycle on its host, sucking its blood, and lice, Bovicola ovis, appear scattered through samples in all three sections. Whilst occasional individuals are likely to be lost from their hosts, and be recovered from other unrelated deposits, the finds across the Garðar landscape appear particularly frequent when compared with the remainder of the fauna. Several species of beetle in the samples also have a strong association with manmade habitats. The rove beetle Omalium excavatum occurs in the improved grassland around modern farms in southwest Greenland (Böcher 1988; Buckland, unpubl.) but appears largely to be confined to such localities, whilst Xylodromus concinnus is more exclusively synanthropic. Along with the larger predatory rove beetle Quedius mesomelinus, it has been recorded from Inuit turf winter houses, but both are probably now extinct in Greenland (Böcher 1988), their most recent records, X. concinnus from Nuuk in 1945 and Q. mesomelinus in 1944 (Böcher 1988), perhaps representing recent reintroductions, which failed to establish breeding populations; they are widely recorded from archaeological deposits associated with Norse and later farms in Iceland as well as Greenland (e.g. McGovern et al. 1983; Buckland et al. 1992). A further large predatory staphylinid, Philonthus politus, which feeds principally on fly maggots in dung (Larsson and Gígja 1959; Skidmore 1991), is also anthropochorous in Icelandic and Greenlandic medieval insect assemblages, but it has not established itself as part of the current fauna of Greenland. Two taxa, which feed on slime moulds and fungal hyphae, Latridius – all fossil specimens identifiable to species from Greenland being L. pseudominutus – and Atomaria – at Garðar one specimen is A. apicalis – are essentially indoor animals in the colder parts of Europe, and have become widely distributed with commerce, although the former has been much confused with two congeners (Tozer 1973; Johnson 1993). Macropterus, both may be found in natural habitats away from farms (e.g. Guðleifsson 2005), but any North Atlantic island breeding populations would have required the artificially warmed environments around humans and their domestic animals. The ability to fly, and thereby disperse from primary indoor habitats, of this group of species, and the possibilities of casual loss from their hosts of the ectoparasites perhaps imposes some limitation on interpretation if other, more archaeological lines of evidence from Norse farms
and fields are ignored. One species, however, present through much of section A, is less easily explained as adventitious. The spider beetle *Tiphus unicolor* has fused elytra and is thereby clearly flightless. It is widespread in archaeological deposits, particularly those that have been interpreted as cess pits. In some cases, as the several thousand individuals in the garderobe shaft at Carrick Castle in Argyll, Scotland (Warsop and Skidmore 1998), there can be no doubt that the species was associated with human faecal material, and in other cases the archaeological and other environmental evidence leaves little room for doubt; for example, in the barrel latrine excavated in Worcester (Osborne in Greig 1981) and the privy at Ferryland, Newfoundland (Bain and Prévost 2010). Osborne’s (1983) experimental study of a modern cess pit produced few individuals, but this was an outdoor situation at around 300 m a.s.l. in the Welsh Borders and reinforces the view that the species is essentially exclusively an indoor one in northern environments. So far, the species has not been produced few individuals, but this was an outdoor situation at around 300 m a.s.l. in the Welsh Borders and reinforces the view that the species is essentially exclusively an indoor one in northern environments. So far, the species has not been found in samples from the Western Settlement, but it is recorded from several sites in Iceland (e.g. Buckland et al. 1992): it seems to have arrived in England during the Roman period. Its presence in the Garðar fields represents the spreading of waste, probably including human faeces, from the farm and associated buildings.

The use of Diptera from manmade environments was developed by the late Peter Skidmore and much of his interpretative work involved material from Norse Greenland (Panagiotakopulu et al. 2007). The Garðar material included frequent sclerites of adult flies, but their active nature means that fossils may be poor indicators of immediate environments. Their metamorphosis from maggot through pupa to emergent imagine, however, takes place in or close to their developmental habitat, and their occurrence in deposits which on other evidence are inimical to their survival requires explanation. *Heleomyza borealis* is present in many of the samples. Whilst the larva is tolerant of freezing (Block 2002) down to −60°C, it will not breed in a wet, manured hayfield. The maggots proliferate in carrion or protein-rich faeces, often being found in debris below bird cliffs in the Arctic, but it was equally characteristic of floors and other accumulations of foul material on medieval farms in Greenland (Panagiotakopulu et al. 2007). Although *H. borealis* would have been able to reproduce in outdoor middens, puparia of the fly *Telomerina flavipes* confirm the indoor origin of at least part of the material spread on the field. A Norse introduction on the Atlantic islands (Panagiotakopulu 2004), it does not appear to have survived the abandonment of the farms and has not been reintroduced with modern sheep farming. Like *T. unicolor*, it could only maintain breeding populations within the artificially warmed houses of the farmers and would have fed on decaying animal materials, completing its entire life cycle indoors (Panagiotakopulu 2004).

The bug *Nabis flavomarginatus* may have been introduced to this landscape as it has a restricted distribution to subarctic areas of Greenland (Jensen and Christensen 2003). Its instars are predatory, but it is recorded as laying its eggs into the stems of grasses, particularly Yorkshire fog, *Holcus lanatus*.

Whilst chironomid larvae were not systematically identified from samples, three taxa were noted. *Chironomus plumosus* type and *C. anthracinus* type (*Chironomini*) are both morphotypes that occur in Arctic lakes, mostly confined to the profundal and/or the littoral zones. They are tolerant of low oxygen concentrations and low pH, and are often an early colonizer of soft sediments (Brooks et al. 2007). There are a number of morpho types in the genus *Microspecta* (Brooks et al. 2007) and with only one recorded specimen, any ecological interpretation should be treated with caution. However, *M. insignilobus* type is regarded as indicative of cold stenothermic conditions and is often abundant in oligotrophic lakes; it is also aci-dophbic. As fossils they are however indistin-guishable from *M. atrofasciata*, this taxon being known to occur in eutrophic rivers, associated with sewage outfall (Brooks et al. 2007).

**Discussion**

The wide scatter of artefactual material in the dark, humified peat extends throughout the exposed ditch sections, and on this evidence alone, it is apparent that domestic waste had been spread extensively across the area between the farm and fjord. In the light of contemporary evidence for manuring elsewhere in Europe (Guttmann et al. 2005), such evidence is hardly surprising and had already been noted by Nörlund (1929, 1936) in his excavations of the 1920s. His suggestion that carts were employed to clear out the extensive byres onto the fields (Nörlund 1929, 109) is unlikely, given the absence of anything other than packhorse and sledge transport on the medieval Atlantic islands. However, it does show that he was
impressed with the scale of both byres and improved fields, which he measured at 15 ha within an enclosing wall 1.3 km long (Nörlund 1929, 106).

Evidence for manuring with farm waste is not confined to Garðar. A similar, less well preserved scatter of debris located in test pits dug in the former hayfield in 1982 of the principal church farm at Sandnes (Kílaarsavík) (Arneborg and McGovern unpubl.) indicates similar activity in the Western Settlement, and Schweger (1998) has expanded this with a geoarchaeological study of the environs of Gardar under Sandet in the same fiord. Using the isotopic composition of modern grasses, Comniso and Nelson (2006, 2007, 2010) have also been able to confirm manuring around other farms in the Eastern Settlement. The fossil insects provide a more precise dimension to the process. A significant component of assemblages is essentially indoor, associated with house, byre and the occupants. Finds of sheep ectoparasites have been connected with wool processing rather than the animals themselves (Buckland and Perry 1989) and their presence probably relates to household rather than byre waste. The most effective interpretation therefore is of a plaggen soil utilizing materials cleared out from the farm. This has led to the accumulation of up to half a metre of sediment over much of the hayfield.

Whilst the inclusion of discarded structural turves and of peat utilized as animal litter could account for the presence of some of the water beetles and caddis larvae, their frequency throughout the plaggen is unusual, particularly when compared with their relative paucity in the samples which post-date abandonment of the medieval farm (C1–C5), where the moss peat clearly accumulated in a wetland environment. A much wetter field with many semi-permanent pools seems unlikely in the context of a regularly scythed hayfield, and the eutrophication that would result from the manuring of the field would also have been detrimental to the aquatic and wetland elements in the insect fauna. Modern analogues are difficult to come by, since mechanized hay cutting relies on the ground being firm enough to support vehicles, but pitfall traps in damp hayfields around Qassiarsuk and Qaqortoq on the northern side of Tunulliarfik, north of Igaliku, produced no aquatic invertebrates (Buckland and Mcineff 2005) in northern Iceland showed a similar picture. In the recent past, however, before the ready availability of chemical fertilizers and tractors, the high productivity of wetlands was exploited as a source of fodder and attempts were made to improve yields by modification of water supply.

At Garðar, the evidence is best interpreted in line with a suggestion first put forward by the Norwegian explorer Helge Ingstad (1960, 1966) that the dams, noted previously but not interpreted by Nörlund (1929, 109), formed part of a system of controlled irrigation for the hayfield. This model has been extended by Krogh (1974), and irrigation ditches have been mapped on several other Greenland farms, including Erik’s farm at Brattahlíð, modern Qassiarsuk (Fredskild 1969, Fig. 3). The evidence has recently been reviewed by Arneborg (2005), who notes the use of similar systems in two regions of Norway, Gudbrandsdalen in Uppland and Lærdal in Sogn; both lie in the rain shadow of mountains, necessitating irrigation to increase crop yields. Manipulation of water supply was once widespread in Scandinavia (e.g. Vasari and Väätäinen 1986; Michelsen 1987; Emanuelsson and Möller 1990), but most authors ascribe their origin to post-medieval agricultural improvements emanating from England and Germany. In both Jutland and Gudbrandsdalen, however, irrigation systems can be tracked back to the seventeenth century on the documentary evidence (Hatt 1916; Rasmussen 1964), later than the abandonment of Norse Greenland, and contemporary with the beginnings of water meadow innovation in England (Bettey 1999). Cook and others (2003), however, have recently pointed to a number of medieval sources which imply hayfield water management on both lay and monastic estates. The most detailed contemporary account occurs in a twelfth century description of the abbey of Clairvaux, founded in 1115, in the Aube region of northern France, where the complex diversion of the river to power mills and irrigate gardens also encompasses what must be water meadows (Cook et al. 2003; full translation in Matarasso 1993; Tobin 1995). The philosophy behind meadow irrigation in regions of mild winter climate, as England, and more continental areas, however, was different, although ultimately the objective was the same, increasing hay and other crop yields, and manuring, either naturally from nutrient-rich waters or more intensively by hand was an essential part of both systems. In the former case, shallow flooding by moving water in early spring warmed the ground, promoted early growth and protected the new growth against frost (Cutting and...
Cummings 1999), providing early grazing, whilst a second inundation in May removed any water deficit before growth and cropping for hay. In areas, like Gudbrandsdalen, where there was annually a potential water deficit, irrigation itself was the prime objective but it was also combined with manuring. Although Arneborg (2005) notes that Hatt’s (1916) detailed description refers to cereal cultivation, he does also mention hayfield irrigation. The two objectives were not mutually exclusive, and depending upon supply, both may have been necessary at different times of the year. In south and west Iceland, although the wartime British Admiralty Handbook (Anon 1942) comments adversely on a system spreading silt from the Hvitá in Borgarfjörður over adjoining hayfields, even here, where rainfall is relatively high, the poor water retentive properties of clay-deficient soils added another motive for irrigation, and there is ethnographic and archaeological evidence for more modest schemes elsewhere in Iceland (Preusser 1976, 75–76; Sveinbjarnardóttir et al. 1982). Preusser also refers to Gruner’s early twentieth-century study of Icelandic agriculture (1912, 88–90), and draws attention to the fact that this cycle of controlled irrigation and drainage favours the growth of true grasses, presumably as opposed to sedges (Buckland et al. 1991), which would be advantageous to a cattle-based economy.

Steensberg (1976), in a commentary upon Hunt and Hunt’s (1976) paper on the social context of irrigation, follows Hatt (1916) and notes a number of medieval Icelandic references. That in the best known source, Egil Skallagrímsson’s Saga (ch. 83), perhaps first written down by Snorri Sturlason in the first half of the thirteenth century, is ambivalent, but the reference in the Saga of Hávarður of Isafjarður is more explicit and indicates shared use of water resources in agriculture. Hávarður’s Saga purports to refer to events in the period leading up to the adoption of Christianity in Iceland (Durrenberger and Durrenberger 1996), but its descriptive context remains the fourteenth century.

Somewhat earlier is the Icelandic law code known as Gráagás, first written down in 1271–2, but probably containing cases concerning the resolution of disputes in the early eleventh century (Dennis et al. 2000). It has provision for the resolution of similar conflicts without recourse to violence (section 188, transl. Dennis et al. 2000, 115).

It is apparent therefore that irrigation systems were not alien to North Atlantic settlement, and all that might be atypical in the Garðar case is the scale of both water diversion and manuring, necessitating significant investment in labour in construction, maintenance and effective use.

Both Arneborg (2005) and Michelsen (1987) reproduce an illustration from Gudbrandsdalen in 1785 which shows heaps, presumably of manure, placed regularly in ditches, which are fed from a wooden aqueduct. Material from the ditches is shown as being spread by hand with a shovel or scoop (Hatt 1916) across the fields. Nörlund’s (1929, 117) estimate of a capacity of approximately 100 cattle for the byres partly excavated at Garðar indicates that much dung and litter was available for spreading, and this would have required labour which is likely to have been in excess of that resident on the farm. When this method of cultivation was introduced to Greenland is presently impossible to say, but the farm at Garðar given to bishop Arnald in c. 1126 had belonged to Erik’s daughter Freyðr, and is likely to have been a prime location; even compared with Brattahlíð, it seems to have had control of a remarkably large potential territory.

The sharp contact between the plaggen and the underlying silts throughout the exposed ditch sections indicates a break in sedimentation, probably as a result of the removal of turves, large numbers of which would have been necessary for construction and maintenance of farm and ancillary buildings. Organic preservation in the silts underlying the plaggen soil of the improved hayfield was not evident and these were not sampled for insect remains. The pollen sequence examined by Edwards and Schofield (Buckland et al. 2009) suggests that Landnám may have preceded the beginning of intensive manipulation of the landscape, but it is not possible to estimate how much of the sequence had been removed in cutting turves, a problem not unique to Garðar (Edwards et al. 2008; Panagiotakopulu and Buckland unpubl.) before renewed growth was encouraged by manuring. The bare, manured ground would have provided an ideal habitat for Rumex acetosa/acetosella, the pollen of which forms up to 5% of the total sum, in the lake and bog profiles around Qassiarsuk examined by Fredskild (1973).

Buckland et al. (2009) have suggested that the organization of the landscape into an extensive system of wetland management, which would have required the organization of labour, not only for its construction but also for its maintenance, may be associated with the acquisition of the holding by Arnald and his retinue, who had travelled from
Norway via Oddi in south-west Iceland. Whether the system relates to Icelandic prototypes or can be referred directly back to Norway is uncertain, but Arnald’s Norwegian connections were maintained, since in 1150 he returned to Norway and 2 years later was appointed bishop of the newly constituted See of Hamar, whose cathedral lies on Lake Mjøsa into which Gulbrandsdalslågen flows. Although Nørlund (1929, 12) suggests that Arnald was of German origin, it is possible that he returned to his home area in his old age. It is unlikely that the irrigation and manuring of pasture in Greenland was an indigenous development (contra Adderley and Simpson 2006), and it was probably brought in by Norwegians with a remarkable grasp of the problems of dairy farming in an intermittently arid subarctic landscape.

The widespread abrupt break in the stratigraphy at the top of the plaggen soil implies that the process was abandoned abruptly rather than gradually declining with a reduced availability of labour. This would support a model of a decisive final abandonment rather than slow attrition. Down to the last few boat crews and their dependents, did the Bishop’s representative in Garðar finally take the decision when enough was enough and follow the wedding party back to Iceland? There is clearly a need for more detailed palaeoecological research at Garðar.

Conclusions

The insect faunas, Coleoptera, Trichoptera, Diptera and ectoparasites, recovered from the bishop’s farm in Gardar provide an interesting insight into the environmental history of the area. Although the samples were recovered from outside the immediate environs of the farm, they indicate a mixture of synanthropic and natural faunas.

During the Norse period, the natural faunas are dominated by aquatic invertebrates. In particular the wealth of the caddis flies has provided the opportunity for the first study of Trichoptera from a North Atlantic context. The synanthropic assemblages are typical of faunas associated with the interiors of Norse farm houses and their residents.

The combination of an extensive wetland and grassland insect fauna with species which must derive from the artificially warm habitats provided by the farm and its outbuildings, taken with the archaeological evidence, combine to indicate an integrated system of manuring and irrigation in order to increase yields in the extensive hayfields which surrounded the cathedral farm at Garðar during the medieval period.

The abrupt nature of the contact at the base of the stratigraphic succession suggests the removal of the previous soil surface, perhaps as turves for fuel and construction. It is suggested that the extensive landscape modification which allowed this process to be carried out reflects the arrival of the first bishop, Arnald, in 1126, who with previous experience in Norway, was able to organize labour to construct ditches and carry farmyard and domestic waste out onto the fields.

The change in the nature of organic accumulation and changes in the insect faunas in the upper part of the sequence are consistent with the abandonment of the Norse farms in the late medieval period. The landscape then became an extensive wetland.

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