Flora and Vegetation of Tasiilaq, Formerly Angmagssalik, Southeast Greenland: A Comparison of Data Between Around 1900 and 2007

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Abstract The changes in the vascular plant flora of Tasiilaq, low arctic Southeast Greenland, between around 1900 and 2007 were studied by comparing the data from historical literature with those of the field observations performed between the late 1960s and 2007. Since 1900, the percentage of widely distributed arctic species distinctly decreased, whereas that of the low arctic species somewhat increased, and boreal species hardly increased. Vegetation monitoring revealed minor changes and showed that several thermophilous and xerophilous species increased between 1968/1969 and 2007, whereas some hygrophilous species decreased. Repeated vegetation mapping of a shallow pond revealed conspicuous changes suggesting increased evaporation/precipitation ratios associated with environmental warming up and decreasing snow accumulation in winter, in line with results of previous investigations. In spite of climate warming, expansion of the town and increasing human impact, flora and vegetation on the whole appeared rather stable during the last 40 years without invading species or introductions.

Keywords Climate change · Flora change · Human impact · Tundra vegetation · Vegetation change · Southeast Greenland

INTRODUCTION

Most research studies on the impact of climate warming on northern vegetation suggest or predict pronounced vegetation changes in the near future (e.g. Walker et al. 2006;

Bhatt et al. 2010). However, near Tasiilaq in Southeast Greenland, vegetation change in general was very minor between 1968/1969 and 2007, and changes were more conspicuous in mire and some snowbed habitats than in vegetation types in drier habitats (Daniëls et al. 2011). In the present study, we expand our analysis (i) by comparing the vascular plant flora of the larger region in 2007 with earlier historic records from around 1900, (ii) by a more detailed analysis of species changes in 110 sample plots between 1968/1969 and 2007, and (iii) by analysis of flora and vegetation observed during this period in the shallow pond Subulariadammen. Thus, this article aims to provide a broader view on possible changes in flora and vegetation in the lowlands around Tasiilaq.

STUDY AREA

Fieldworks in 1968/1969, 1981, and 2007 were carried out on Ammassalik Island, Southeast Greenland, near the town of Tasiilaq (formerly Tasiusak, Angmagssalik/Ammassalik, ca. 65°37'N, 37°40'W) on the southeast coast of Greenland (Fig. 1). The landscape is mountainous with acidic bedrock of anorthosite–granulite complexes with charnockites rich in quartz, feldspar, biotite, pyroxene, and garnet. Permafrost does not occur near Tasiilaq. Wildlife is scarce and herbivorous mammals are absent. Human impact is restricted to the immediate surroundings of the town. The study area belongs to the northern part of the Low Arctic (subzone D) (Walker et al. 2005) and to the middle part of the Southeast Greenland flora province (SEm) (Böcher et al. 1966, 1978).

The climate is low arctic oceanic. Following a period of continued cooling during the Little Ice Age (ca. 1200–1900 AD) (Humlum and Christiansen 2008; Jakobsen

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Fig. 1 Map of the lowlands (<300 m) south, west and northwest of Tasiilaq, with an indication of the localities (1–5) where, in 1968/1969 and 2007, 11 vegetation types were studied by sample plot analyses, and the total vascular plant flora was checked. These localities are by and large congruent with the five localities: Grønlænderpynt, Sømandsfjæld, Elvbakker, Amaga and Sermilikvejen covered by the floristic studies of Kruuse (1906, 1912). The location of Subulariadammen is indicated by the star

Fig. 2 Mean annual temperatures during 1895–2006 compiled from weather data of the weather station at Tasiilaq, slightly modified from Cappelen (2008)

et al. 2008), a period of fluctuating climate warming has been observed within the last decennia (Cappelen 2008; Cappelen et al. 2008; Fig. 2). In particular, the five-year period before 2007 shows that the summers are becoming pronouncedly warmer and longer, whereas the winters are distinctly less cold, shorter and with less precipitation (snow fall) (Table 1) (Carstensen and Jørgensen 2010; Daniëls et al. 2011).

Tasiilaq was not more than a regularly inhabited common winter house of the Inugsuk Inuit up to 1894. With the establishment of the trading post in that year, it started to develop into a permanent settlement and one of the fastest-growing towns in Greenland. In 1960, it had 612

inhabitants; in 1991, 1513 inhabitants; and in 2010, 1930 inhabitants. With the growth of the town and the recent development in tourism, the direct surroundings are under increasing pressure from almost 5000 visitors annually.

Subulariadammen (65°36.990'N, 37°39.607'W; 110 m above sea level; Fig. 1) is a small pond west of Tasiilaq, situated on a flat saddle in a rocky ridge. It is shallow with an almost flat bottom, and the diameter is in the range of 21–25 m. The catchment area of the pond is approximately 1 ha. Superficial discharge has not been observed. The local snow cover on the saddle is relatively shallow and largely melts away before early July. In the past, up to 1995, the seasonal regime of the water level lowering in the

Table 1 Climate parameters of five winter and five summer periods previous to the sample periods of 1968/1969 and 2007 composed with data compiled by Cappelen (2008) and Cappelen et al. (2008) from the weather station Tasiilaq, Southeast Greenland

Winter	Days < 0°C	Prec. (mm)	Mean T (°C)	Max. T (°C)	Min. T (°C)	Coldn. Sum
1962/1963	217	716	−4.6	−0.8	−9.8	−36.7
1963/1964	193	1136	−3.9	−0.2	−8.1	−27.2
1964/1965	204	805	−6.2	−1.7	−9.3	−37
1965/1966	213	503	−6.7	−2.4	−10.2	−47.4
1966/1967	202	646	−6.8	−2.1	−9.6	−45.5
Average	206	761	−5.6	−1.4	−9.4	−38.8
2001/2002	183	672	−5.1	−1.4	−7.0	−30.4
2002/2003	141	650	−2.5	0.4	−4.2	−12.3
2003/2004	153	487	−3.8	−1.3	−6.7	−22.8
2004/2005	167	639	−3.7	−0.9	−6.8	−22.3
2005/2006	163	568	−4.3	−1.3	−8.0	−29.8
Average	161	603	−3.9	−0.9	−6.5	−23.5
Summer	Days > 0°C	Prec. (mm)	Mean T (°C)	Max T (°C)	Min. T (°C)	Warmth sum
1963	136	368.3	5.1	9.2	1.0	21
1964	172	276.9	3.6	7.4	−0.4	21.8
1965	168	282.6	3.6	7.4	−0.2	21.4
1966	150	261.2	4.3	8.1	0.6	21.3
1967	156	208.2	3.8	7.8	0.0	19
Average	156	279.4	4.1	8.0	0.2	20.9
2002	192	616.5	3.9	6.8	1.0	27.4
2003	180	241.3	5.6	8.7	2.8	33.6
2004	193	353.8	4.6	7.7	1.7	27.5
2005	165	284.8	4.9	8.5	1.5	24.4
2006	191	256.6	4.0	7.4	0.7	23.9
Average	184	350.6	4.6	7.8	1.5	27.4

Coldness sum (Coldn. Sum) is the sum of a mean monthly temperature (°C) of months with mean temperature (°C) below zero; warmth sum is the sum of mean monthly temperatures of months with a mean temperature (°C) above zero

pond seems to have been rather constant, without falling dry at the end of the season. Kruuse (1912) observed that most of the shallow flat-bottomed ponds near Ammassalik lack both water supply after snow melt as well as water discharge, so that the water level does not sink more than 10–15 cm below the vegetated shores in the course of the season. An aerial photograph of Subulariadammen in 1955 indicates a water level of at least 6 dm in late July, own observations in 1969 and 1984 from mid-July to the end of July showed a water level of 5–7 dm. In late August 1995, water level was ca. 2 dm, whereas at the end of July 2007, the height of the water level of Subulariadammen was almost zero.

MATERIALS AND METHODS

The vascular plant flora of the direct surroundings of Tasiilaq (Fig. 1) around 1900 (Kruuse 1912), the end of the

1960s, and in 2007 were compared and evaluated (see Supplementary Table 1). Kruuse's records include all the collections made by him and others during the period 1883–1902. This floristic comparison concerns the five lowland (below 300 m altitude) localities studied by the authors in 1968/1969 and 2007 (Fig. 1), which are by and large congruent with the five localities: Amaga, Elvbakker, Grønlaenderpynt, Sermilikvej and Sømandsfjæld covered by Kruuse (1906, 1912). The comparison also considers information in Böcher (1933, 1938, 1954, 1975), Böcher et al. (1966, 1978), Daniëls and de Molenaar (1970), de Molenaar (1974, 1976, 1987), Daniëls (1982), Daniëls and van Herk (1984), Gartmann (1990), Fredskild (1992, 1996), Lünterbusch et al. (1995), Elven et al. (2007), Daniëls et al. (2011), and reports of the Greenland Botanical Survey of 1970–1995, Botanical Museum, Copenhagen. Similarity (%) between the vascular plant floras was calculated according to Sørensen's similarity coefficient (Sørensen 1948).

The biological distribution types (BDT) of vascular plants are taken from Böcher (1975, in Fredskild 1996) (Supplementary Tables 1, 2), and their ecological characterization (Supplementary Table 2) is deduced from the literature and our own field experience from throughout Greenland.

The vegetation of 11 key plant community types was sampled in these localities in 110 plots. Sampling was according to the Braun-Blanquet concept (de Molenaar 1976; Daniëls 1982). Species cover was recorded using the modified Hult-Sernander-Du Rietz scale (Du Rietz 1921; Daniëls et al. 2011). Data analysis of the 11 community types is explained in Daniëls et al. (2011). Change over time (between end of the 1960s and 2007) in all the 110 sample plots was quantified for each of the 213 species (vascular plants, mosses, liverworts and lichens) separately. Significant or other prominent changes are shown in Supplementary Table 2. Fisher's exact test (Sokal and Rohlf 1995) was used for the presence/absence of the species, and the Mann-Whitney *U*-test was applied to evaluate ordinal cover values of the Hult-Sernander-Du Rietz scale (see Daniëls et al. 2011).

Ecological characterization and distribution of bryophytes follow Dierßen (2001). For the lichens, we consulted the literature (e.g. Thomson 1984; Brodo et al. 2001; Bültmann and Daniëls 2001) and used our own expert knowledge. The distribution of lichens refers to Greenland. Plant functional types are according to Walker et al. (2005).

The vegetation of Subulariadammen was sampled according to the same method and mapped in 1969 (de Molenaar 1976, pp. 36–43, Table 2; Fig. 3). The pond was revisited in 1984 and 1995, and in 2007, the sampling and mapping was repeated.

The species concept of vascular plants is taken rather broadly (cf. Fredskild 1996; Elven et al. 2007). Species names and records by Kruuse (1912) and Böcher (1938) have been checked and updated using Böcher et al. (1966, 1978), Fredskild (1996), Elven and Elvebakk (1996) and Elven et al. (2007). Nomenclature follows Fredskild (1996) and Böcher et al. (1978). Nomenclature of bryophytes and lichens follow Dierßen (2001) and Santesson et al. (2004), respectively. Nomenclature of syntaxa follows de Molenaar (1976).

RESULTS

Changes in the Flora of the Lowlands Near Tasiilaq

Kruuse (1912) listed 157 vascular plant species in total for the five localities he visited around Tasiusaq (Tasiilaq) (Fig. 1). Of these, 151 are native Greenland species,

including seven which are considered absent from SEM and Southeast Greenland by Böcher et al. (1966, 1978) and Fredskild (1996). We thus conclude that Kruuse reports 144 native species (see Supplementary Table 1 and “Discussion” section). Of this number, 13 species were not observed by us in the late 1960s, 1981 and 2007: e.g. the boreal *Asplenium viride* and *Poa nemoralis*, the middle arctic *Campanula uniflora*, and the widely distributed arctic species *Juncus triglumis*, *J. biglumis* and *Minuartia cf. rubella* (Supplementary Table 1).

At the end of the 1960s, we observed 146 species (including *Equisetum hiemale*, Supplementary Table 1). Sixteen of these were not mentioned by Kruuse (1912). They include

- the boreal orchid *Listera cordata* and other boreal species, such as *Rumex acetosella*, *Montia fontana*, *Triglochin palustre* and *Potentilla tridentata*;
- the low arctic clubmoss *Selaginella selaginoides* and *Epilobium lactiflorum*, *Carex brunnescens*, *Draba norvegica*, *D. incana* and *Kobresia myosuroides*,
- and the middle arctic *Arabis arenicola* and *Erigeron erioccephalus*.

Potentilla tridentata, *Montia fontana* and *Epilobium lactiflorum* were previously collected in 1933 by Bøgvad and Hammer in Blomsterdalen (Böcher 1938) (Supplementary Table 1), while the authors, in addition observed and collected in 1981, *Equisetum hiemale* (Daniëls and van Herk 1984). The boreal species *Scirpus caespitosus* and *Deschampsia flexuosa* were reported by Kruuse (1912) from just outside the five study areas.

In 2007, we observed 141 species. We did not observe the low arctic *Alchemilla wichurae*, the middle arctic *Arabis arenicola* and *Ranunculus pygmaeus* (the latter was observed in 1933, Supplementary Table 1), the widely distributed arctic species *Draba nivalis*, *Sagina intermedia* and *Saxifraga rivularis* (incl. *hyperborea*) and the boreal *Triglochin palustre*, whose only habitat was destroyed at the end of the 1960s (Daniëls and de Molenaar 1970), and *Equisetum hiemale* (Supplementary Table 1).

Thus, a total of 161 native species and 13 introduced species currently occur or have occurred near Tasiilaq between the period from around 1900 to 2007. During this period, the native Tasiilaq flora has been in general arctic: around 72% are arctic and low arctic species, whereas around 28% are boreal species.

Excluding the seven species considered absent in SE Greenland or in the SEM flora province (see above), the similarity between the 1900 and 2007 native floras was 90%; between the 1900 and 1968/1969 floras it was around 90%, and between the 1968/1969 and 2007 floras 98%. The percentages of species with arctic distribution types in the floras from around 1900, to 1968/1969 and 2007 decreased

from 27, to 23 and 21%, respectively. For the low arctic species, these percentages increased and were 47, 48 and 50%, respectively. For the boreal species, there was little change with values of 26, 27 and 28% for the three periods. For the unclassified group, the percentage was 1% for all periods.

Introductions make up 7% of the total flora of 174 species (161 native and 13 introductions, excluding the seven species considered absent from SE Greenland). Kruuse (1912) observed six introduced species in Tasiusaq (Tasiilaq): *Malva neglecta*, *Brassica campestris*, *Plantago major*, *Hordeum vulgare*, *Pisum sativum* and *Sinapis arvensis*. The first three obviously had disappeared before 1966 from the SEm flora province (cf. Böcher et al. 1966), whereas *Brassica campestris* and *Plantago major* again showed up later (Böcher et al. 1978). In addition, Böcher et al. (1966, 1978) mention *Polygonum aviculare*, *Stellaria media*, *Achillea millefolium* and *Poa annua*. *Malva neglecta* is considered absent now from Southeast Greenland (Böcher et al. 1978). In 1966 and later, we did not encounter any introduced species reported in Böcher et al. (1978) as still occurring in the SEm flora province. The same applies to the three introductions: *Galium verum*, *Silene vulgaris* and *Veronica officinalis*, which were presumably brought in by tourists from Iceland (Gartmann 1990).

Species Changes in the 110 Sample Plots

In the two sets of 110 sample plots of 1968/1969 and 2007, 182 and 192 species occurred, respectively (Daniëls et al. 2011). The total species number was 213. Only 13 species increased in frequency significantly (Supplementary Table 2). They include the widely distributed arctic grasses *Poa arctica* and *Trisetum spicatum*, and the cushion forb *Silene acaulis*, the boreal grass *Agrostis hyperborea*, the boreal forb *Hieracium hyparcticum*, the low arctic rush *Luzula confusa* and low arctic forbs *Hieracium alpinum* and *Veronica alpina*, the acrocarpous bryophyte *Polytrichum commune*, and the macrolichens *Cladonia chlorophaea*, *C. fimbriata*, *C. stricta* and *C. ecmocyna* (Supplementary Table 2). Only three species decreased in frequency significantly: the pleurocarpous moss *Plagiothecium denticulatum*, the foliose liverwort *Cephaloziella* as a species complex, and the macrolichen *Cladonia carneola* (Supplementary Table 2). Only three species, the widely distributed arctic grasses *Poa arctica* and *Trisetum spicatum*, and the macrolichen *Cladonia chlorophaea* increased cover significantly, whereas species with decreasing cover were absent.

There are several other species that clearly increased frequency, although not statistically significant (Supplementary

Table 2). This group includes, for example, the boreal prostrate deciduous dwarf shrub *Thymus praecox* ssp. *arcticus* and the forb *Pyrola minor*, the low arctic deciduous prostrate dwarf-low shrub *Salix glauca* ssp. *callicarpaea*, the forbs *Sedum annuum* and *Euphrasia frigida*, the grass *Poa alpina*, and the middle arctic forb *Erigeron eriocephalus*. Furthermore, a few acrocarpous mosses and macrolichens also increased in frequency. The group with decreased frequency includes, e.g. the boreal forbs *Gentiana nivalis* and *Coptis trifolia*, the low arctic forb *Veronica alpina* and the prostrate dwarf shrub *Loiseleuria procumbens*.

Changes in the Flora and Vegetation of Subulariadammen

Kruuse noted eight vascular plant species in Subulariadammen and another five which most likely occurred, as they did in 1969 and 2007 (see Supplementary Table 3), along the shore of the pond. Of these species, in 1969, the boreal *Sparganium angustifolium* and widely distributed arctic *Ranunculus hyperboreus* were gone from the pond, and the widely distributed arctic *Eriophorum scheuchzeri* had appeared. The low arctic *Carex rariflora* and *Cardamine pratensis* had virtually gone from the shore in 1969. In 2007, as compared with 1969 and 1984, the boreal *Hippuris vulgaris* had become widely spread, and the boreal *Alopecurus aequalis* decreased considerably. In the shallow, northern tip of the pond, the boreal *Viola palustris* and bryophytes appeared to have invaded the shallowest part of the pond bottom.

In 1969, the vegetation in the pond was dominated by the *Callitricho-Subularietum aquaticae* (Supplementary Table 3: 2:1–2). *Subulario-Juncetum subtilis* and *Eriophoretum scheuchzeri* (Supplementary Table 3: 4–6 and 7) were also present in smaller stands. *Ranunculo-Alopecuretum aequalis* and *Caricetum saxatilis* (Supplementary Table 3: 3, 8) occupied smaller areas. In 1984, the situation was approximately the same. In 2007, the vegetation pattern appeared to be strongly different and more complex (Fig. 3). Most striking was the presence and the extent of the *Hippuridetum vulgaris* (Supplementary Table 3: 16–17). In 1969, the boreal *Hippuris vulgaris* occurred only as a few individuals in the *Callitricho-Subularietum aquaticae* in the centre of the pond. This was still so in 1984. In 2007, it covered about a quarter of the pond rather densely, replacing much of the *Callitricho-Subularietum aquaticae* stand during the period 1969 and 1984. The area and especially the site of the *Callitricho-Subularietum aquaticae* has changed, but the floristic composition has not (Supplementary Table 3: 1–2 vs. 9–11) (Fig. 4).

Fig. 3 Vegetation map of Subulariadammen September 1, 1969 and July 30, 2007

DISCUSSION

The low percentage (7%) of introduced species in the flora of Tasiilaq relative to the native flora of the milder South and West Greenland is certainly due to its harsh low arctic climate that is unsuitable for agriculture and farming (Porsild 1932; Böcher et al. 1959; Pedersen 1972). The differences in the vascular plant floras reported by Kruuse (1906, 1912) and by the authors in 1968/1969 and 2007 might partly result from different fieldwork approaches and not being completely identical research areas. Also, misidentifications certainly played a role because of the limited taxonomic knowledge at that time. *Juncus bulbosus* appeared to be a misidentification of *J. subtilis*, and *Pedicularis lanata*, which is absent from SE Greenland (see Böcher 1933, 1938; Böcher et al. 1966, 1978; Fredskild 1996) is almost certainly a misidentification of *P. hirsuta*. A misidentification also applies to *Callitriche hamulata*, which is *C. palustris*. Moreover, the taxonomy of the genera *Poa*, *Draba* and *Salix* is still very complicated and partly unresolved; thus, old records of these taxa should be considered with reservation (Elven and Elvebakk 1996; Fredskild 1996).

We excluded *Draba fladnizensis*, *D. cf. glabella*, *Pedicularis lanata*, *Salix arctophila*, *Poa flexuosa*, *Callitriche hamulata* and *Sagina caespitosa*, the first seven species of the Supplementary Table 1, from our considerations, since they are not recorded so far from Southeast

Greenland or SEm (see Böcher 1933, 1938; Böcher et al. 1966, 1978; Fredskild 1996). We never observed these species during our many field studies.

Nevertheless, it is remarkable that Kruuse (1912) did not observe 14 notable species. Three of these, the boreal *Potentilla tridentata* and *Montia fontana*, and the low arctic *Epilobium lactiflorum* were observed in 1933 (Böcher 1938). Kruuse (1912) might have overlooked the boreal orchid *Listera cordata*, a rare and rather inconspicuous species, mostly detected during plot analyses. The same applies for the low arctic clubmoss *Selaginella selaginoides*. The other, boreal orchids *Leucorchis albida* (collected in 1933, cf. Böcher 1938) and *Platanthera hyperborea* are not at all rare now in the area, the first being rather prominent with many plants in several localities including Blomsterdalen. Other boreal species not recorded by Kruuse (1912) are *Rumex acetosella* and *Triglochin palustre*.

Despite the uncertainties, we have from field observations gained the impression that several boreal species, along with *Leucorchis albida*, are more common now than previously. It is tempting to suppose that some more thermophilous, boreal or low arctic species, such as *Listera cordata*, *Leucorchis albida*, *Rumex acetosella*, *Selaginella selaginoides*, *Potentilla tridentata*, *Equisetum hiemale* and *Montia fontana* were absent or much more rare before and around the beginning of the twentieth century.

In contrast to the observation that several species appear to have established over the period of observation, the

middle arctic *Erigeron humilis*, *Campanula uniflora* and *Ranunculus pygmaeus*, (observed in 1933, cf. Böcher 1938) and the widely distributed arctic *Juncus triglumis*, *J. biglumis* and *Minuartia rubella* and *Woodsia alpina* observed around 1900, were never observed by the authors in 1968/1969 and 2007. We assume that the middle arctic *Arabis arenicola* and the widely distributed arctic *Draba nivalis* and *Sagina intermedia*, as well as the low arctic *Saxifraga rivularis* (incl. *hyperborea*) are absent now. The low arctic *Alchemilla wichurae* might have been overlooked in 2007. *Triglochin palustre* disappeared when oil tanks were constructed. The site of *Equisetum hiemale* was not revisited.

The drivers of change over time for floristic composition and species cover in the 110 sample plots are difficult to identify, since many environmental factors probably interact and individual species responses are likely to be very different (e.g. Walker et al. 2006; Callaghan et al. 2004; Jónsdóttir et al. 2005). However, the decrease of a number of widely distributed arctic and middle arctic species and the increase of several low arctic and some boreal species since 1900 might be due to climatic changes triggering a certain trend towards a ‘sub-arctification’ of the area.

Based on the ecological preferences of the species involved, particularly substrate moisture (hydrotypes) and temperature (thermotypes) (Supplementary Table 2), and to a lesser degree geographical as opposed to local distribution, it is reasonable to suggest that at least in some cases the changes since the end of the 1960 s directly or indirectly results from climatic warming. The general increase of xerophilous and thermophilous species such as *Veronica fruticans*, *Agrostis hyperborea*, *Sedum annuum*, *Euphrasia frigida*, *Thymus praecox* ssp. *arctica* and the moss *Bryum elegans* might have resulted from habitat warming and/or drying of the substrate. The first explanation probably applies too for the increases of *Hieracium alpinum*, *H. hyparcticum*, *Erigeron eriocephalus*, *Salix glauca* ssp. *callicarpaea*, *Poa alpina* and *Pyrola minor*, all species preferring relatively sheltered, warmer habitats. The increase of lichens (cover and richness) suggests substrate drying. Also, the decreases of the rather hygrophilous–mesophilous *Gentiana nivalis*, *Coptis trifolia* and *Veronica alpina* are probably due to substrate drying. The significant increases in the frequency of occurrence and cover of the grasses *Poa arctica* and *Trisetum spicatum*, also reported by Wookey (2007) from elsewhere in the North, are more difficult to explain—as is the increase of *Silene acaulis*.

The changes in Subulariadammen are in line with the conclusion drawn previously for the 11 plant community types separately (Daniëls et al. 2011), i.e. they suggest increased evaporation/precipitation ratios associated with climatic warming and/or decreased snow accumulation in

winter. The temporal changes in species composition, based on presence/absence and cover data, were strongest in the plant communities of relatively wet to moist habitats such as the *Carex* mire, *Carex* snowbed, *Hylocomium* snowbed and *Salix* snowbed (Tables 4 and 5 in Daniëls et al. 2011). On the other hand, floristic changes in vegetation types on drier soils appeared to be very minor and their spatial distribution was very stable as well (e.g. Fig. 3 in Daniëls et al. 2011).

By comparing the vegetation in 2007 with earlier observations, the drying of the Subulariadammen and the development of its vegetation (Fig. 3) also suggest increased evaporation/precipitation ratios associated with climatic warming and decreasing snow accumulation in winter. This might have already been ongoing around 1900. In any case, it is evident that the abundance of the species and the vegetation pattern have changed between 1969/1984 and 2007.

It is likely that the 5-dm drop in water level between 1902, 1984, 1995 and 2007 is associated with this change. The pond fell dry on August 1 in 2007, whereas the available data indicate that it did not fall dry even in autumn in the period 1902–1995.

Of the vascular plant species observed in the pond in 1902, 1984 and 2007, *Juncus subtilis*, *Callitriche palustris*, *Subularia aquatica* and *Alopecurus aequalis* are oligotraphent in Greenland (Fredskild 1992). *Hippuris vulgaris* is indifferent and somewhat salt tolerant (op.cit.). The other phanerogams in the pond, from which no such data are available from Greenland, are also generally considered to be more or less oligotrophent in alpine areas outside the Arctic (e.g. Landolt 1977). The observed decrease in abundance of these four species and the increase of *Hippuris vulgaris* suggests a weak trend towards mesotrophic conditions, which may be attributed to the drying of the pond with increased mineralization of organic material. Local information says that human influence on the pond is minimal, and migratory or breeding ducks and geese are absent.

The changes in the vegetation composition and pattern in Subulariadammen are in line with many observations from elsewhere in the Arctic showing that shallow ponds especially are susceptible to the effects of climatic change (e.g. Riordan et al. 2006; Smol and Douglas 2007).

There are earlier changes in the flora, i.e. between 1902 and 1969 that coincide with paleolimnological records from lakes in the circumpolar Arctic revealing widespread species changes and ecological reorganization of algae and invertebrate communities since approximately 1850. These records show that striking and often unprecedented ecological changes have occurred within the last ca. 150 years, following several millennia of relatively stable communities (Pienitz et al. 2004; Smol et al. 2005). The remoteness

Fig. 4 Subulariadammen. From *top to bottom* August 23, 1995 (photo: Daniëls), July 12, 2007 (photo: Daniëls) and August 1, 2007 (photo: de Molenaar); 1995 image oriented N, 2007 images oriented NW

of these sites, coupled with the ecological characteristics of taxa involved, indicate that these changes are primarily driven by climate warming, particularly a lengthening of the summer growing season and related limnological changes.

In a broader context, the change in climatic warming so far (Table 1) seems to be remarkably low compared to the other regions in the Arctic (Bhatt et al. 2010). It might be that the prevailing west–east circulation over Southeast Greenland suppresses the possible influence of sea ice decline on the coastal climate. Rates of change in flora and vegetation may therefore be expected to be not so rapid that ‘novel’ assemblage of species will develop, as expected by Wookey (2007).

With the growth of the town and the development of tourism, especially since the 1990s, the direct surroundings are increasingly being affected by almost 5,000 visitors annually. In particular, Blomsterdalen, the ‘flower valley’ behind the town, has a unique flora and is a popular area for both short and long hikes. Quite remarkably, the flora and vegetation show visually no influence of human impact from trampling—apart from the presence of a few worn paths and hiking trails, and the litter left behind. However, the expansion of the town went with losses of some interesting natural sites. The mire, directly east of the town, the ‘Pløjemarken’ (Kruuse 1912), where we collected a pollen core sample in 1969 (Bick 1978), is gone, and the sole known occurrence of *Triglochin palustre* near the harbour has been replaced by an oil tank (Daniëls and de Molenaar 1970).

CONCLUSION

The native vascular plant flora of Tasiilaq is distinctly arctic and is comprised of approximately 161 species. Since around 1900, there has been a certain trend of *sub-arctification*. Human impacts are still low and introduced species have not become naturalized. A prominent change was observed in the vegetation of the shallow pond Subulariadammen, where the water level in 2007 was much lower than in the past to the extent that it fell completely dry August 1. This supports our previous conclusion that most conspicuous changes occur in vegetation in wet and (temporarily) moist habitats and are likely due to climatic warming and decreasing snow accumulation in winter.

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