A review of anthropogenic changes in the vascular plant flora and vegetation of the Arctic with special reference to Greenland

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This contribution is dedicated to colleague Prof. Dr. Dietmar Brandes on occasion of his 65th anniversary as a tribute to his geobotanical contributions to the flora of man-made habitats.

Abstract

Typical features and biodiversity of the vascular plant flora of the Arctic are shortly reviewed, followed by an annotated survey of the non-native vascular plant flora of Greenland derived from literature and own expertise. Species number of the Arctic vascular plant flora is moderate with c. 2.218 accepted entities (including species, subspecies, apomictic aggregates, a few collective species and some hybridogenic taxa). There are 106 endemic species whereas 136 primarily non-Arctic "borderline" species just reach the southernmost subzone of the Arctic. The Arctic territory is subdivided into 21 floristic provinces and 5 bio-climatic subzones. A group of 190 species are considered to be non-native within at least one of these Arctic regions. They include stabilized introductions (*) and casual introductions (**). In addition, there are at least 205 species only known as casual introduction (**). These are left out of account here. Many of the 190 non-native species are grasses (*Poaceae*) and composites (*Asteraceae*) being diagnostic of European anthropogenic vegetation classes *Molinio-Arrhenatheretea* R. Tx. 1937 and *Stellarietea mediae* R. Tx. et al. ex von Rochow 1951. Ninety-five of these 190 non-native species are known from Greenland. Stabilized introductions (*) are generally restricted to old cultural landscapes in and around settlements and towns in climatologically favorable parts of Greenland and the Euro-Siberian Arctic. In Greenland this group includes 49 species. All also occur in the Western Greenland floristic province (GW). Human influence on flora and vegetation since the Norse Landnám at the end of the 10th century is described with inclusion of a short survey of Greenland's history. Nowadays human influence is particularly pronounced in sheep-breeding areas and near old historical sites in S and SW Greenland, where many stabilized (*) and casual introductions (**) are found as a result of overgrazing, eutrophication, erosion and tourism and possibly early introduction. Habitat destruction is locally prominent along the west coast of Greenland caused by town expansion and other construction activities. Continuation of climate warming certainly will result into further introduction and expansion of boreal and southern species, drying of snow beds, mires and shallow ponds, and origin and shaping of new landscapes after melting of ice-cover and permafrost. However until now the native flora and vegetation of the Arctic and Greenland are still largely intact without serious influence of invasive species.

Zusammenfassung

Ein Überblick der anthropogenen Veränderungen in Flora und Vegetation der Arktis unter besonderer Berücksichtigung Grönlands

Die typischen Merkmale und die Biodiversität der arktischen Gefäßpflanzen-Flora werden kurz mit einer kommentierten Übersicht der nicht-heimischen Flora Grönlands auf der Grundlage der Literatur und eigener Erkenntnisse besprochen. Die Artenzahl der arktischen Gefäßpflanzen (Arten, Unterarten, Kleinarten, Aggregate, einige Kollektiv-Arten und hybride Taxa) ist auf ca. 2.218 beschränkt (über 205 nicht-eingebürgerten Arten (**) sind in dieser Zahl nicht enthalten). Es gibt 106 Endemiten und 136 primär nicht-arktische Grenzarten, die gerade noch die

südlichste arktische Sub-Zone erreichen. Die Arktis ist unterteilt in 21 Floren-Provinzen und fünf bioklimatische Sub-Zonen. Insgesamt 190 Arten, davon 95 in Grönland, sind irgendwo in der Arktis als nicht-heimisch (eingebürgert * und nicht-eingebürgert **) bekannt. Viele dieser Arten sind Gräser (*Poaceae*) und Korbblütler (*Asteraceae*) und sind diagnostisch für die europäischen anthropogenen Vegetationsklassen *Molinio-Arrhenatheretea* R.Tx. 1937 und *Stellarietea mediae* R. Tx. et al. ex von Rochow 1951. Die Verbreitung der eingebürgerten Arten (*) ist im Allgemeinen an alte Kulturlandschaften in den klimatisch günstigeren Regionen Grönlands und der Euro-Sibirischen Arktis gebunden. In Grönland enthält diese Gruppe 49 Arten, die alle auch in West-Grönland (GW) vorkommen. Der menschliche Einfluss macht sich besonders in den Gebieten mit Schafhaltung im Süden und Südwesten Grönlands bemerkbar. Der anthropogene Einfluss auf Flora und Vegetation seit der nordischen Landnahme (Landnám) am Ende des 10. Jahrhunderts bis heute sowie ein Überblick der Geschichte Grönlands werden vorgestellt. Heute ist der anthropogene Einfluss gut sichtbar in den bewohnten Regionen Grönlands, vor allem in den Gebieten mit moderner Schafzucht, wo noch historische Ruinen aus früheren Siedlungsperioden existieren. Hier finden sich viele eingebürgerte (*) und nicht-eingebürgerte (**) Arten durch Landwirtschaft und Tourismus. Die weitere Klimaerwärmung führt mit Sicherheit zu verstärkten Veränderungen in Flora und Vegetation. Südliche und boreale Arten werden sich ausbreiten; Schneetälchen, Moore und Tümpel trocknen aus und neue Landschaften werden durch Abschmelzen der Gletscher und des Permafrostes entstehen. Doch bis jetzt ist die heimische Gefäßpflanzen-Flora und Vegetation in der Arktis einschließlich Grönland noch weitgehend intakt. Nicht-heimische Arten sind noch keine Bedrohung für die heimische Flora und Vegetation.

Keywords: Global warming, non-native vascular plant flora, casual introduction (**), history, sheep-breeding, stabilized introduction (*).

1. Introduction

The present contribution mainly aims to address the non-native vascular plant flora of Greenland with reference to human activities. It is derived from literature and based on own field-expertise during the last forty years in the Arctic. Concise information on the native flora and vegetation of the Arctic and history of Greenland are included.

2. Research area

2.1. The Arctic and Greenland

The Arctic's total land surface is estimated 7.11 million km^2; 2.11 million km^2 is covered by vegetated land, the remainder by ice (WALKER et al. 2005). Greenland covers c. 30 % of the land surface of the Arctic, whereas Greenland itself is covered for 85 % by world's second largest ice-cap which is largely surrounded by 15 % mountainous ice-free land.

Greenland stretches from 59°46' S to 83°39' N and 11°39' E to 73°08' W. (Fig. 1, CAVM 2003, WALKER et al. 2005). Its coastline is approximately 40.000 km long with countless islands and fjords (JENSEN & CHRISTENSEN 2003). Climate is harsh, with mean annual temperatures varying in the 20th century from plus 1.4 °C in the South (Narsarsuaq) to minus 9° C in the North (Qaanaq) (DANKER 2000). The land surface is still relatively little disturbed by human activities.

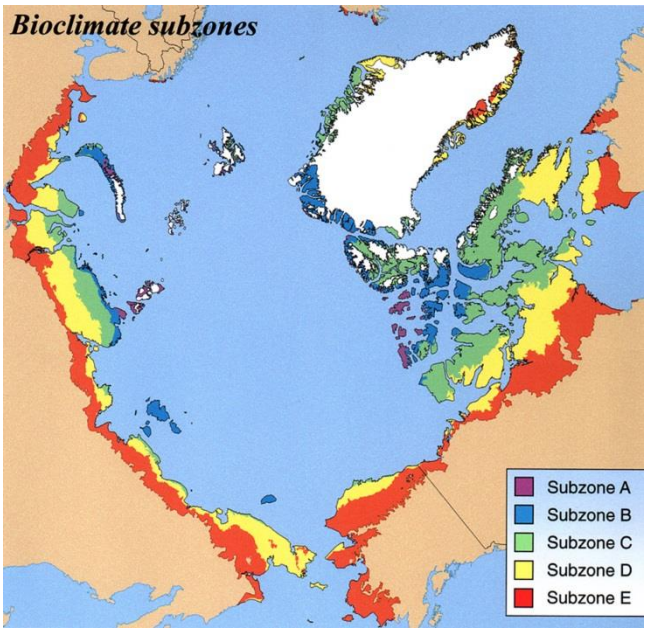

Fig. 1: Circumpolar Arctic Vegetation Map with subzones A-E (CAVM Team 2003).

Abb. 1: Zirkumpolare arktische Vegetationskarte mit Angabe der Subzonen A-E (CAVM Team 2003).

Tab. 1: Some features of the Arctic vascular plant flora composed from ELVEN (2007).

Tab. 1: Steckbrief der arktischen Gefäßpflanzen-Flora nach ELVEN (2007).

- 2.218 native and stabilized introduced (*) species within the Arctic in 430 genera and 91 families
- 600 agamospecies and > 205 casual introductions (**) are excluded.
- 2,028 species are native everywhere across the Arctic, including 106 endemic species (mainly of *Papaver, Puccinellia, Oxytropis, Draba* and *Potentilla*) and 136 borderline species (only reaching the southernmost Arctic subzone)
- 45 species occur solely as both native and stabilized introduction (*)
- 24 species occur solely as both native, stabilized (*) and casual introduction (**)
- 20 species occur solely as both native and casual introduction (**)
- 36 species occur solely as both stabilized (*) and casual introduction (**)
- 65 species occur solely as stabilized introduction (*)
- The Arctic flora and its phytogeographical scenery are still intact, no species loss since 1750
- Features of Arctic floras: High polyploidy level, asexual seed production, perennial life strategy, dominance of chamaephytes and hemicryptophytes, no trees, few gymnosperms, low-species diversity per family

The young post-glacial flora and vegetation of the Arctic are adapted to harsh and variable environmental conditions. These adaptions include low above-ground biomass production, low stature, long life-span, vegetative and asexual reproduction, and high polyploidy levels (Tab. 1). Floristic uniformity is high due to high percentages of circumpolar Arctic and circumpolar Boreal species. The physiognomy of the pan-Arctic vegetation is rather uniform and simple. The main physiognomic units are barrens, graminoid tundra's, prostrate-shrub tundra's, erect-shrub tundra's and wetlands (WALKER et al. 2005). A number of vegetation classes such as e.g. *Carici rupestris-Kobresietea bellardii* Ohba 1974 (non-acidic sedge and dwarf shrub vegetation), *Loiseleurio-Vaccinietea* Eggler ex Schubert 1960 (acidic dwarf shrub heath vegetation), *Drabo corymbosae-Papaveretea dahliani* Daniëls et al. 2015 ined. (cryptogam-rich herb polar desert vegetation) (Fig. 2)

and *Juncetea maritimae* Br.-Bl. in Br.-Bl., Roussine et Nègere 1952 (saltmarsh vegetation) have a circumpolar distribution.

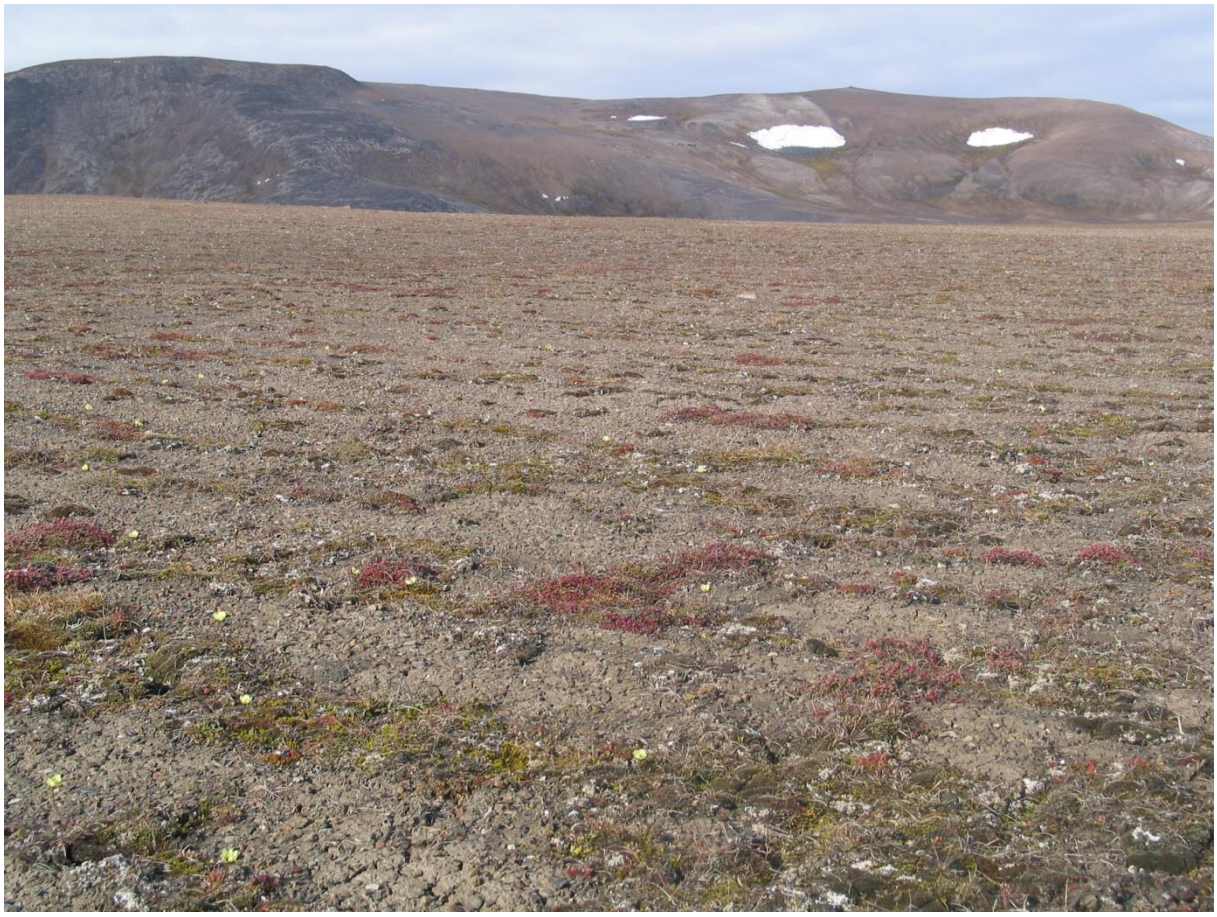

Fig. 2: Polar desert vegetation in Ellef Ringnes, Nunavut, Canada (subzone A) with *Saxifraga oppositifolia*, *Papave*r cf. *dahlianum*, lichens and mosses. Fred J.A. Daniëls, July 2005.

Abb. 2: Vegetation der Polarwüste auf Ellef Ringnes, Nunavut, Kanada (Subzone A) mit *Saxifraga oppositifolia*, *Papaver* cf. *dahlianum*, Flechten und Moosen. Fred J.A. Daniëls, Juli 2005.

Bio-climatically Greenland and the Arctic are divided into five subzones according to climate and zonal vegetation in the lowlands (Fig. 1). The northernmost Arctic herb subzone ("polar desert" or subzone A) is characterized by a mean July temperature of 0-3 °C and absence of woody plants (Fig. 2, Arctic herb subzone); the northern dwarf shrub subzone (B) by a mean of 3-5 °C; the adjacent middle Arctic dwarf shrub subzone (C) by a mean of 5-7 °C. Plant cover in these three high Arctic subzones is open. The densely vegetated low Arctic is divided into the southern dwarf shrub subzone (D) with mean of 7-9 °C and the southernmost low shrub subzone (E) with a mean of 9-12 °C (DANIËLS et al. 2000, WALKER et al. 2005). A minor part of the inland lowland of South Greenland is non-Arctic (FEILBERG 1984, FREDSKILD 1991, FEILBERG & FOLVING 1991). Species richness increases strongly from north to south (DANIËLS et al. 2013): vascular plant species numbers increase from <50 to >500 in local floras and from 102 in the flora of the Arctic herb subzone to 2.180 in that of the Arctic shrub subzone (Tab. 2; see further Fig. 2 in DANIËLS et al. 2013).

Tab. 2: Species groups in Arctic floristic provinces and subzones composed from ELVEN (2007) and DANIËLS et al. (2013).

Tab. 2: Artengruppen in den arktischen Flora-Provinzen und Sub-Zonen nach ELVEN (2007) und DANIËLS et al. (2013).

	Kanin-Pechora	Polar Ural-Novaya Zemlya	Yamal-Gydan	Taimyr-Severnaya Zemlya	Anabar-Olenyok	Kharaulakh	Yana-Kolyma	W Chukotka	Wrangel Island	S Chukotka	E Chukotka	W Alaska	N Alaska-Yukon Territory	Central Canada	Hudson Bay-Labrador	Ellesmere Land-N Greenland	W Greenland	E Greenland	N Iceland-Jan Mayen	N Fennoscandia	Svalbard-Franz Joseph Land	Arctic herb subzone	n Arctic dwarf shrub subzone	middle Arctic dwarf shrub subzone	s Arctic dwarf shrub subzone	Arctic shrub subzone	non-Arctic - Boreal or Boreal-alpine
Floristic province	KP	UN	YG	Tm	Ao	Kh	YK	CW	WI	CS	CE	AW	AN	CC	HL	EP	GW	GE	Ic	FN	SF						
Subzone																						A	B	C	D	E	N
Number of stabilized introduced species (*)	52	32	16	23	1	14	3	8	0	7	20	20	11	8	30	0	50	5	52	63	4	0	0	3	18	101	34
Casual introduced species (**)	18	8	4	16	0	3	0	4	1	2	4	14	3	3	9	0	26	4	2	13	32	0	0	27	10	0	0
Rare species	239	209	238	310	200	184	280	219	89	236	225	316	247	303	355	77	144	136	80	216	53	41	91	204	349	868	195
Species with a scattered distribution	165	228	129	121	144	118	80	151	76		140	212	172	157	174	46	174	105	74	157	47	23	39	85	213	392	563
Borderline species	14	5	23	35	14	13	12	2	0	9	0	50	40	30	58	0	0	0	17	28	0	0	0	0	0	136	0
Frequent species	151	137	96	136	67	223	53	238	145	136	265	210	256	137	141	76	159	141	211	171	79	38	90	188	389	681	1304
Present, abundance unknown	3	6	7	4	2	3	3	14	4	13	14	3	3	2	1	0	1	0	0	0	0	0	0	0	1	2	1
Present, abundance likely rare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
Present, frequency likely scattered or sparse	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Species for which presence is uncertain	22	24	29	38	37	20	46	28	16	33	36	27	26	36	27	5	18	11	16	23	10	11	18	91	65	4	13
Total species number without uncertain occurrencies	642	625	513	645	429	558	432	636	315	549	668	825	732	640	769	199	554	391	436	649	215	102	220	507	980	2180	2097
Mean species number per floristic province group	593			516				621						536			449										

The Arctic territory is longitudinally divided into 21 floristic provinces according to distribution patterns of vascular plants (ELVEN 2007, 2011, DANIËLS et al. 2013; Tab. 2). Floristic differences are prominent between Beringian floristic provinces (eastern Siberia and western N America) and the other provinces related to different glaciation histories and migration routes of the plants. Greenland comprises three floristic provinces: Ellesmere Land-N Greenland (EP), W Greenland (GW) and East Greenland (GE) (Tab. 3).

Tab. 3: Survey table of distribution of stabilized (*) introductions (group 1), stabilized (*) and casual (**) introductions (group 2), native species and stabilized (*) introductions (group 3), native species and casual (**) introductions (group 4), and native species, stabilized (*) and casual (**) introductions (group 5) in the five Arctic subzones, the Arctic, Greenland and the three Arctic Greenlandic floristic provinces. Native occurrences are marked r (rare), s (sparse) and f (frequent), in subzones by capitals. *Gramineae* are highlighted in light grey, *Asteraceae* in grey.

Tab. 3: Übersichtstabelle der Verbreitung der einbürgerten (*) Arten (Gruppe 1), der eingebürgerten (*) und nicht-eingebürgerten (**) Arten (Gruppe 2), der heimischen und eingebürgerten (*) Arten (Gruppe 3), der heimischen und nicht-eingebürgerten (**) Arten (Gruppe 4), sowie der heimischen, eingebürgerten (*) und nicht eingebürgerten (**) Arten (Gruppe 5) in den fünf arktischen Sub-Zonen und floristischen Provinzen, sowie in der Gesamt-Arktis, Grönland und drei floristischen Provinzen Grönlands. Heimische Arten in den floristischen Provinzen sind markiert mit r (selten), s (wenig) und f (häufig), in den Sub-Zonen mit Großbuchstaben. *Gramineae* sind hellgrau und *Asteraceae* sind grau markiert.

	Syntaxon	Arctic herb subzone	northern Arctic dwarf shrub subzone	middle Arctic dwarf shrub subzone	southern Arctic dwarf shrub subzone	Arctic shrub subzone	non-Arctic - Boreal or Boreal-alpine	Number of floristic provinces where the species occurs	Total number of species within the Arctic	Total number of species within Greenland	Ellesmere Land-Northern Greenland	Number of species in Western Greenland	Number of species in Eastern Greenland		Stabilized introduction (*) in GW	Stabilized introduction (*) in GE	Casual introduction (**) in GW	Casual introduction (**) in GE	Native species in GW	Native species in GE
Subzone		A	B	C	D	E	N													
Number of stabilized introductions (*)		0	0	3	18	101	34													
Number of casual introductions (**)		0	0	27	10	0	0													
Region/Floristic province									Arc	Grl	EP	GW	GE		GW	GE	GW	GE	GW	GE
Total number of species in species groups 1-5									190	95	0	94	20							
Numbers of stabilized (*), casual (**) and native species															49	5	26	4	19	11
Group 1 Stabilized (*) introductions									65	13	0	13	0		13	0	0	0	0	0
Elytrigia repens (subsp. repens)	MA	–	–	–	–	*	F	7			–	*	–		*	–	–	–	–	–
Anthoxantum odoratum	MA	–	–	–	–	*	S	3			–	*	–		*	–	–	–	–	–
Dactylis glomerata	MA	–	–	–	–	*	S	3			–	*	–		*	–	–	–	–	–
Alopecurus geniculatus	MA	–	–	–	–	*	F	3			–	*	–		*	–	–	–	–	–
Poa pratensis subsp. angustifolia	MA	–	–	–	–	*	R	3			–	*	–		*	–	–	–	–	–
Achillea ptarmica	MA	–	–	–	–	*	F	4			–	*	–		*	–	–	–	–	–
Lepidotheca suaveolens	PP	–	–	–	–	*	*	10			–	*	–		*	–	–	–	–	–
Cirsium arvense subsp. arvense	Sm	–	–	–	–	*	S	3			–	*	–		*	–	–	–	–	–
Trifolium pratense	MA	–	–	–	–	*	F	8			–	*	–		*	–	–	–	–	–
Spergularia rubra	PP	–	–	–	–	*	S	2			–	*	–		*	–	–	–	–	–
Linaria vulgaris subsp. vulgaris	Av	–	–	–	–	*	S	4			–	*	–		*	–	–	–	–	–
Luzula multiflora subsp. multiflora		–	–	–	–	*	S	3			–	*	–		*	–	–	–	–	–
Papaver croceum		–	–	–	*	*	*	3			–	*	–		*	–	–	–	–	–

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(Tab. 3, continuation)

Group 2 Stabilized (*) and casual (**) introductions									36	29	0	29	2		12	0	17	2	0	0
Phleum pratense (subsp. pratense)	MA	–	–	**	**	*	*	8			–	*	–		*	–	–	–	–	–
Alopecurus pratensis subsp. pratensis	MA	–	–	–	–	*	S	8			–	*	–		*	–	–	–	–	–
Schedonorus pratensis		–	–	–	–	*	*	6			–	*	–		*	–	–	–	–	–
Lolium perenne	MA	–	–	–	–	*	*	4			–	**	–		–	–	**	–	–	–
Bromopsis inermis	Av	–	–	–	–	*	S	7			–	**	–		–	–	**	–	–	–
Leucanthemum vulgare	MA	–	–	–	–	*	F	5			–	**	–		–	–	**	–	–	–
Artemisia vulgaris	Av	–	–	–	–	*	S	6			–	**	–		–	–	**	–	–	–
Tanacetum vulgare subsp. vulgare	Av	–	–	–	–	*	F	5			–	**	–		–	–	**	–	–	–
Tripleurospermum inodorum	Sm	–	–	–	–	*	*	5			–	**	–		–	–	**	–	–	–
Carduus crispus		–	–	–	–	*	R	3			–	**	–		–	–	**	–	–	–
Matricaria recutita		–	–	–	–	*	*	3			–	**	–		–	–	**	–	–	–
Scorzoneroides autumnalis subsp. autumnalis	MA	–	–	–	–	*	F	6			–	*	–		*	–	–	–	–	–
Senecio vulgaris		–	–	–	–	*	S	8			–	*	–		*	–	–	–	–	–
Chenopodium album	Sm	–	–	**	**	*	S	10			–	*	–		*	–	–	–	–	–
Thlaspi arvense	Sm	–	–	**	**	*	R	10			–	*	–		*	–	–	–	–	–
Juncus bufonius		–	–	–	–	*	F	10			–	*	–		*	–	–	–	–	–
Trifolium hybridum (subsp. hybridum)	MA	–	–	**	**	*	*	7			–	*	–		*	–	–	–	–	–
Asperugo procumbens		–	–	–	*	*	F	4			–	*	–		*	–	–	–	–	–
Lamium purpureum	PP	–	–	–	–	*	*	3			–	*	–		*	–	–	–	–	–
Polygonum aviculare	Sm	–	–	–	–	*	F	10			–	*	**		*	–	–	**	–	–
Brassica rapa subsp. campestris	Sm	–	–	**	**	*	*	10			–	**	**		–	–	**	**	–	–
Carum carvi	MA	–	–	–	–	*	F	6			–	**	–		–	–	**	–	–	–
Galium mollugo subsp. erectum	MA	–	–	–	–	*	*	4			–	**	–		–	–	**	–	–	–
Melilotus albus	Av	–	–	–	–	*	*	4			–	**	–		–	–	**	–	–	–
Plantago major (subsp. major)	PP	–	–	**	*	*	S	12			–	**	–		–	–	**	–	–	–
Descurainia sophia	Sm	–	–	–	–	*	*	6			–	**	–		–	–	**	–	–	–
Silene vulgaris (subsp. vulgaris)		–	–	–	–	*	*	5			–	**	–		–	–	**	–	–	–
Rumex sylvestris (subsp. sylvestris)		–	–	**	–	*	*	3			–	**	–		–	–	**	–	–	–
Arabidopsis arenosa (subsp. arenosa)		–	–	–	**	*	S	2			–	**	–		–	–	**	–	–	–
Group 3 Native species and stabilized (*) introductions									45	19	0	19	2		11	2	0	0	8	5
Poa pratensis subsp. irrigata		–	–	–	*	F	F	5			–	r	r		–	–	–	–	r	r
Poa nemoralis		–	–	–	–	S	F	8			–	s	r		–	–	–	–	s	r
Agrostis stolonifera	MA	–	–	–	–	S	F	9			–	r	*		–	*	–	–	r	–
Poa pratensis subsp. pratensis	MA	–	–	–	*	S	F	19			–	*	*		*	*	–	–	–	–
Deschampsia cespitosa	MA	–	–	**	*	F	F	7			–	*	–		*	–	–	–	–	–
Agrostis capillaris		–	–	–	–	S	F	5			–	*	–		*	–	–	–	–	–
Achillea millefolium subsp. lanulosa	MA	–	–	–	–	R	F	2			–	*	–		*	–	–	–	–	–
Campanula rotundifolia		–	–	R	F	F	F	17			–	f	f		–	–	–	–	f	f
Rhinanthus minor	MA	–	–	–	R	F	F	7			–	s	r		–	–	–	–	s	r
Sagina procumbens	Sm	–	–	R	R	S	F	7			–	s	r		–	–	–	–	s	r
Vicia cracca	MA	–	–	–	–	F	F	1			–	r	–		–	–	–	–	r	–
Rumex acetosa subsp. acetosa	MA	–	–	*	*	S	F	5			–	r	–		–	–	–	–	r	–
Anthriscus sylvestris subsp. sylvestris	MA	–	–	–	–	S	F	5			–	*	–		*	–	–	–	–	–
Vicia sepium	MA	–	–	–	–	F	F	5			–	*	–		*	–	–	–	–	–
Veronica serpyllifolia subsp. serpyllifolia	MA	–	–	–	–	S	F	5			–	*	–		*	–	–	–	–	–
Barbarea stricta		–	–	–	–	R	F	5			–	*	–		*	–	–	–	–	–
Rubus idaeus subsp. idaeus		–	–	–	–	R	F	3			–	*	–		*	–	–	–	–	–
Rorripa palustris		–	–	–	–	S	F	16			–	*	–		*	–	–	–	–	–
Sisyrinchium montanum		–	–	*	–	R	S	2			–	*	–		*	–	–	–	–	–

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(Tab. 3, continuation)

Group 4 Native species and casual (**) introductions									20	12	0	11	5		0	0	6	1	5	4
Tripleurospermum maritimum subsp. phaeocephalum		–	–	R	F	F	F	20			–	r	r		–	–	–	–	r	r
Gnaphalium uliginosum		–	–	–	R	R	S	4			–	r	–		–	–	–	–	r	
Crepis tectorum subsp. tectorum		–	–	–	–	R	F	2			–	**	–		–	–	**	–	–	–
Equisetum arvense subsp. arvense	Av	–	–	–	–	F	F	10			–	s	s		–	–	–	–	s	s
Alchemilla filicaulis subsp. filicaulis		–	–	–	S	F	F	5			–	s	s		–	–	–	–	s	s
Juncus squarrosus		–	–	**	–	R	S	4			–	r	r		–	–	–	–	r	r
Alchemilla subcrenata		–	–	–	–	R	F	4			–	**	–		–	–	**	–	–	–
Draba verna		–	–	–	–	R	S	3			–	**	–		–	–	**	–	–	–
Atriplex prostrata (subsp. prostrata)		–	–	–	–	R	F	2			–	**	–		–	–	**	–	–	–
Plantago lanceolata	MA	–	–	–	–	b	S	5			–	**	–		–	–	**	–	–	–
Galium aparine		–	–	–	–	R	F	4			–	**	–		–	–	**	–	–	–
Astragalus alpinus subsp. alpinus		–	–	R	F	F	F	12			–	–	**		–	–	–	**	–	–
Group 5 Native species, stabilized (*) and casual (**) introductions									24	22	0	22	6		13	3	3	1	6	2
Poa annua	MA	–	–	**	R	S	F	9			–	s	r		–	–	–	–	s	r
Poa trivialis (subsp. trivialis)	MA	–	–	**	–	R	F	6			–	*	–		*	–	–	–	–	–
Beckmannia syzigachne		–	–	–	–	R	F	8			–	**	–		–	–	**	–	–	–
Poa palustris	MA	–	–	**	*	S	F	11			–	**	–		–	–	**	–	–	–
Achillea millefolium subsp. millefolium	MA	–	–	**	**	F	F	10			–	*	*		*	*	–	–	–	–
Taraxacum ruderalia agg.	MA	–	–	**	*	R	F	6			–	*	–		*	–	–	–	–	–
Tripleurospermum maritimum subsp. subpolare		–	–	–	–	S	F	9			–	*	–		*	–	–	–	–	–
Ranunculus acris	MA	–	–	**	R	F	F	6			–	s	r		–	–	–	–	s	r
Rumex longifolius		–	–	**	**	S	F	7			–	r	–		–	–	–	–	r	–
Capsella bursa–pastoris	Sm	–	–	**	*	*	S	11			–	r	–		–	–	–	–	r	–
Stellaria media	Sm	–	–	**	*	F	F	14			–	s	*		–	*	–	–	s	–
Polygonum boreale		–	–	**	*	S	F	6			–	s	*		–	*	–	–	s	–
Trifolium repens	MA	–	–	**	–	S	F	13			–	*	–		*	–	–	–	–	–
Ranunculus repens	MA	–	–	**	*	F	F	12			–	*	–		*	–	–	–	–	–
Cerastium fontanum subsp. vulgare	MA	–	–	**	*	S	F	8			–	*	–		*	–	–	–	–	–
Stellaria graminea	MA	–	–	**	–	S	F	6			–	*	–		*	–	–	–	–	–
Lathyrus pratensis	MA	–	–	–	**	R	R	5			–	*	–		*	–	–	–	–	–
Urtica dioica subsp. dioica		–	–	**	*	R	F	6			–	*	–		*	–	–	–	–	–
Urtica urens	Sm	–	–	–	–	R	S	4			–	*	–		*	–	–	–	–	–
Myosotis arvensis	Sm	–	–	**	**	R	S	6			–	*	–		*	–	–	–	–	–
Potentilla norvegica	Av	–	–	–	–	S	F	9			–	*	–		*	–	–	–	–	–
Rumex acetosella subsp. acetosella	PP	–	–	**	?	F	F	10			–	**	**		–	–	**	**	–	–

Diagnostic species of anthropogenic European syntaxa
Molinio-Arrhenatheretea (MA) (37 species) (40 %)
Stellarietea mediae (Sm) (12 species) (13 %)
Artemisietea vulgaris (Av) (7 species) (7 %)
Polygono-Poetea annuae (PP) (5 species) (5 %)
Others (34 species) (36 %)
Gramineae (21 species) (22 %)
Asteraceae (18 species) (19 %)

"Species" richness of the vascular plant flora is moderate with c. 2.218 accepted entities (including species, subspecies, apomictic aggregates, a few collective species and some hybridogenic taxa). More than 600 named entities (at the species level or below, mainly micro-species of apomictic aggregates) are not accepted as distinct entities. Therefor these are excluded here, just as 205 species exclusively known as casual introductions (**) (ELVEN 2007, 2011, DANIËLS et al. 2013). The 2.218 species belong to 430 genera in 91 families. Species-rich families include *Asteraceae* (254 species), *Poaceae* (224), *Cyperaceae* (190), *Brassicaceae* (133), *Rosaceae* (128), *Fabaceae* (109), *Ranunculaceae* (102) and *Caryophyllaceae* (100). Species-rich genera include *Carex* (152 species), *Salix* (72), *Oxytropis* (58), *Potentilla* (50), *Draba* (41), *Ranunculus* (40), *Papaver* (39), *Poa* (36) and *Saxifraga* (35).

There are 106 endemic species and the genera *Papaver, Puccinellia, Oxytropis, Potentilla* and *Draba* account for more than 50 % of the endemic species diversity. Borderline species are primarily non-Arctic species reaching the southernmost subzone of the Arctic (Tab. 2). They include 136 species mainly occurring in the North-American and Siberian Arctic floristic provinces, whereas they are almost absent in Greenland (Tab. 2).

Furthermore c. 900 species of bryophytes and c. 1.750 of lichens are known to occur.

2.2. Human habitation and history of Greenland

Living conditions are harsh in the remote and tree-less Arctic due to cold climate, long winters, short growth season and non-productive soils with permafrost. As a consequence the Arctic is not very attractive for permanent human habitation. Consequently the Arctic was and still is sparsely populated with huge tracts of uninhabited land. Nowadays the entire Arctic houses around 220.000 inhabitants (MELTOFTE 2013). Most of the c. 56.000 Greenlanders lives in small towns and settlements in southern W Greenland. North and E Greenland are very sparsely populated.

Greenland's habitation dates back from c. 2.500 B.C. The early inhabitants were Paleo-Inuit's. They were hunters and came in subsequent migration waves from northern N America each group disappearing again after several centuries. The ancestors of the current Greenlandic population stem from Alaska representing the Thule culture (c. 1.100-1.500 A.D.) known from northern Greenland. The Inugsuk culture developed from the Thule culture and spread around Greenland. These Inugsuk Inuit's mainly lived from seal hunting. After re-colonization of Greenland in the early 18th century they largely mixed with European immigrants (a. o. ANONYMOUS 1968, BARÜSKE 1990).

Until the appearance of the Norse settlers in S Greenland (Eastern Settlement) at the end of the 10th century (e.g. BRUUN 1918, KROGH 1967) and somewhat later in SW Greenland (Western Settlement), human impact on the postglacial flora and vegetation was negligible.

The Norse introduced farming in climatological favorable inland localities, established successfully many farms in small communities and reached a maximum population up to 3.000 inhabitants. In 1124 the Catholic Church appointed the first bishop of Greenland. In 1261 Greenland became part of the kingdom of Norway and 1397 under Danish rule. However the settlers were economically dependent on contact with Europe. They disappeared again at the middle of the 15th century. First the Western Settlement was abandoned, later the Eastern Settlement, possibly due to deterioration of climate, overgrazing, changes in social structure and diminishing interest of Norway.

By then the Thule culture had spread across the whole of Greenland, but in the preceding centuries the two cultures had existed side by side and there had been extensive trading and commerce (DANKER 2000, WÜTHRICH & THANNHEISER 2002).

After a period of European interest in finding the North-West Passage to Asia and conflicts on exploitation rights of the rich fishing and whaling grounds around Greenland a renewed period of colonization and Christianization started in the 18th century (1721) with the arrival of the Danish-Norwegian missionary Hans Egede. In 1747 Greenland became the status of a Danish protectorate. In 1774 the trade was monopolized by the Royal Danish Trade Company (KGH). From that time Greenland was gradually transformed from a Danish colony to a Danish province in 1953.

The German occupation of Denmark in World War II disrupted the connection with Greenland. The US and Denmark agreed on the Danish sovereignty of Greenland and on provision of protection and supplies during the war. Several bases were set up in West and East Greenland to provide air cover for the Atlantic convoys. The subsequent Cold War Period 1951 led to an agreement between the US and Denmark as NATO member in which the authority of defense of Greenland was delegated to the US. As a consequence several large air-bases were built of which only the Thule air-base in the Northwest is still under US control. The costs were covered by the revenues of the increased production of cryolite and products that were sold (DANKER 2000). Greenland's development continued after the World War II and included improvement of infrastructures a. o. organization of medical and social care, reorganization of trade and industry, modernization of shipping and air traffic, building activities and road constructions, all resulting in an increase of population. Moreover the Greenlanders got more and more politically active and organized. Greenland became a sustained economic and political autonomy status within the kingdom of Denmark and became 1979 largely independent with its own government (Home Rule) within the Danish Kingdom (DANKER 2000, WÜTHRICH & THANNHEISER 2002).

At the beginning of the 20th century a more modern sheep farming husbandry was introduced in S and SW Greenland (e.g. FREDSKILD 1988), which is nowadays an important mean of livelihood for many people (FEILBERG & HØEGH 2008). Today, the Greenlandic economy relies heavily on prawn, fish and seafood resources and supplies from Denmark. Hunting and fishing are still the main livelihoods in the East and North, modern sheep farming in the South (Fig. 3; FEILBERG & HØEGH 2008, MASSON-DELMOTTE et al. 2012). Nevertheless Greenland economy is still weak and could not survive without substantial transfers from Denmark. In addition the Arctic becomes more and more attractive for tourists. An example of this development is the increased number of cruise ship landings in Greenland ranging from c. 150 in 2003 to c. 380 in 2008 (MICHEL 2013). Greenland's population grew from 12.000 residents in 1900 to 57.000 in 2012. All these developments resulted in a gradually increased impact on flora and vegetation by local disturbance, eutrophication and introduction of many non-native plant species. Moreover the first signs of changes resulting from global warming during the last three decades became visible.

From the second half of the 19th century scientific exploration of Greenland was coordinated by the "Commission for Scientific Investigations in Greenland" founded in 1878 and publisher of the "Series Meddelelser om Grønland". Later on research facilities in Greenland were built such as e.g. the Arctic Station in Qeqertarsuaq (Disko, W Greenland), the Upernaviarsuk Agricultural Research Institute in S Greenland, the Zackenberg Research Station in NE Greenland, Kangerlugsuak International Science Support (KISS) in Kangerlugsuak, W Greenland and Greenland Nature Institute in Nuuk, SW Greenland. Nature conservation resulted in the establishment of protected areas. World's largest national park comprising almost entire N and NE Greenland was established 1974. Both Greenland and Denmark are members of the Arctic Council and participate in many International Arctic Research Organizations such as e.g. CAFF (Conservation of Arctic Flora and Fauna). Many international climate change related research efforts in

Greenland date from the last three decades. One of these is the Arctic Biodiversity Assessment (MELTOFTE 2013) some results of which are dealt with here.

Fig. 3: Sheep farming area of Brattahlid (Eastern Settlement) in South Greenland with barley fields, meadows and grazing areas. Fred J.A. Daniëls, July 2008.

Abb. 3: Schafhaltung im Gebiet von Brattahlid (Ostsiedlung) in Süd Grönland mit Gersten-Anbau, Wiesen und Weiden. Fred J.A. Daniëls, July 2008.

3. Methods

The results presented here are based on an evaluation of literature (e.g. ROSENVINGE 1896, OSTENFELD 1926, PORSILD 1932, BÖCHER et al. 1959, BÖCHER et al. 1978, PEDERSEN 1972, FEILBERG 1984, FREDSKILD 1988, 1996, BAY 1992, 2003, ELVEN 2007, 2011, RUNE 2011, SCHOFIELD et al. 2012, DANIËLS et al. 2013) and own 40-years field experience. The compilation of the data presented in Tab. 3 is derived from Appendix 9.4 in DANIËLS et al. (2013). If not mentioned otherwise the nomenclature of vascular plants used in the text follows the *Checklist of the Panarctic Flora (PAF) Vascular Plants* (ELVEN 2007).

Native plants include all plant species known to occur before c. 1.750 in the Arctic thus also possibly earlier introductions still persisting today. Non-native plants are divided into two groups, stabilized introductions (marked *) and casual introductions (marked **) (ELVEN 2007, 2011, DANIËLS et al. 2013). Stabilized introductions (*) are self-sustaining somewhere in the Arctic for

at least one generation by generative or vegetative reproduction and persist, whereas casual introductions (**) are species that are present for short periods of time, but do not persist. The *PAF* checklist includes only species that are either native or stabilized introduction (*) in at least one of the Arctic regions (floristic provinces or subzones). However they might change their status within at least one of the Arctic regions and might be considered casual introduction (**) there. The updated *Annotated Checklist of the Panarctic Flora (PAF) Vascular Plants* (ELVEN 2011) also enumerates an additional 205 non-native species that are known to occur in the Arctic only as casual introductions (**). They are not included in the list of 2.218 species because of lack of knowledge of their distribution.

4. Results and Discussion

4.1. Non-native vascular plants of the Arctic

One hundred and one non-native species (5 % of the flora) are considered stabilized introductions (*) in the Arctic (Appendix 9.4 in DANIËLS et al. 2013; see also Tab. 3). In addition there are 89 species (4 %) that are native to one or more floristic provinces and subzones, but that are also found as non-native introduced species (* and **) elsewhere in the Arctic. Of these 89 native species, 45 are found as stabilized introductions (*), 20 as casual introductions (**), and 24 as both stabilized (*) and casual introductions (**) in at least one of the 21 floristic provinces or one of the five Arctic subzones. Thus a total of 170 (8 %) native and non-native species are considered stabilized introductions (*) somewhere in the Arctic. Including the native Arctic species that are also present as casual introductions (**) in some parts of the Arctic increases this number to 190 species (Tab.1, 2; see also Tab. 3).

The group of non-native stabilized introductions (*) is taxonomically rather diverse; however, *Poaceae* and *Asteraceae* account together for 33 % of this group (Appendix 9.4 in DANIËLS et al. 2013; see also Tab. 3). The most widespread species are *Lepidotheca suaveolens* (group 1, Tab. 3, stabilized introduction (*) in 10 floristic provinces), *Plantago major* subsp. *major* (group 2, Tab. 3, stabilized (*) in 9, casual (**) in 2), and *Trifolium pratense* (group 1, Tab. 3, stabilized (*) in 8).

The native Arctic species that occur most widely as stabilized introduction (*) include *Trifolium repens* (group 5, Tab. 3, stabilized (*) in 10, casual (**) in 1, native in 2), *Puccinellia hauptiana* (absent in Greenland; stabilized (*) in 9, native in 3), *Poa pratensis* subsp. *pratensis* (group 3, Tab. 3, stabilized (*) in 8, native in 11), *Stellaria media* (group 5, Tab. 3, stabilized (*) in 8, casual (**) in 1, native in 5) and *Draba nemorosa* (absent in Greenland; stabilized (*) in 8, native in 3).

Floristic provinces with at least 5 % stabilized introductions (*) include Kanin-Pechora (KP) (52, 8 %, Tab. 2), W Greenland (GW) (50, 9 %, Tab. 2; 49, 9 %, Tab. 3), N Iceland-Jan Mayen (Ic) (52, 12 %) and N Fennoscandia (FN) (63, 10 %, Tab. 2).

The occurrence of stabilized introductions (*) generally restricted to old cultural landscapes in and around settlements and towns, in particular in climatologically favorable parts of the S and SW Greenland and the Euro-Siberian Arctic. This group mainly includes common species of anthropogenic European vegetation (Appendix 9.4 in DANIËLS et al. 2013). *Descurainia sophia* (group 2, Tab. 3), *Thlaspi arvense* (group 2, Tab. 3), *Capsella bursa-pastoris* (group 5, Tab. 3) and *Lamium purpureum* (group 2, Tab. 3) are typical of rural and arable weed vegetation (*Stellarietea mediae* R. Tx. et al. ex von Rochow 1951). The grasses *Elytrigia repens*, *Anthoxanthum odoratum*, *Dactylis glomerata, Lolium perenne, Alopecurus geniculatus* and *Poa pratensis* subsp. *angustifolia* (all

group 1, Tab. 3), *Poa supina* (absent in Greenland), and *Phleum pratense* (group 2, Tab. 3), and the forbs *Trifolium pratense* (group 1, Tab. 3), *Primula elatior* and *Veronica chamaedrys* (both absent in Greenland) are typical species of European anthropogenic grasslands (*Molinio-Arrhenatheretea* R.Tx. 1937) (e. g. MUCINA 1997, JAROLÍMEK & ŠIBÍK 2008).

Percentages of casual introductions (**) are relatively low, with the exception of W Greenland (GW) (5 %, 50 species in Tab. 2, 49 in Tab. 3) and in particular Svalbard-Franz Joseph Land (SF) (15 %, 32). Introductions are lacking in two northernmost Arctic subzones, casual introductions (**) are well represented in the middle Arctic dwarf shrub subzone (27), while the southernmost Arctic shrub zone is rich in stabilized introductions (*) (101) whereas casual introductions (**) are completely absent (Tab. 2).

4.2. Non-native vascular plants of Greenland

According to BAY (2003) the species number of the native vascular plant flora is 515. This number is slightly less than 517 calculated from the *PAF* (ELVEN 2007, Appendix 9.1 in DANIËLS et al. 2013).

The total number of species which occur in the Arctic both as native and stabilized (*) and/or casual (**) introduction is 190 (Tab. 3; Table 4 in DANIËLS et al. 2013). For Greenland this number is 79 (Tab. 3). Greenland covers three floristic provinces: Ellesmere Land-Northern Greenland (EP), Western Greenland (GW) and Eastern Greenland (GE) (Tab. 3). In EP introduced species are absent, whereas in GW and GE the numbers of stabilized introductions (*) are 49 and 26, respectively and of casual introductions (**) five and four, respectively (Tab. 3). These numbers reflect the human habitation being almost absent in N Greenland, rather sparse in E Greenland, and concentrated along the coast in W Greenland.

The 13 of the 65 stabilized introductions (*) of the Arctic and from Greenland only known from WG include the grasses *Elytrigia repens, Anthoxantum odoratum, Dactylis glomerata, Alopecurus geniculatus, Poa pratensis* subsp. *angustifolia* and the *Asteraceae Achillea ptarmica, Lepidotheca suaveolens* and *Cirsium arvense* subsp. a*rvense,* as well as *Trifolium pratense, Spergularia rubra, Linaria vulgaris* subsp. v*ulgaris, Luzula multiflora* subsp. *multiflora* and *Papaver croceum* (Tab. 3, group 1).

The 29 of the 36 non-native species occurring both as stabilized (*) and casual (**) introductions in the Arctic and in Greenland only known from WG include *Chenopodium album, Thlaspi arvense, Juncus bufonius, Phleum pratense* subsp. *pratense, Alopecurus pratensis* subsp. *pratensis, Senecio vulgaris, Trifolium hybridum* subsp. *hybridum, Scorzoneroides autumnalis* subsp. *autumnalis, Schedonorus pratensis, Asperugo procumbens* and *Lamium purpureum*. *Polygonum aviculare* is stabilized introduction (*) in GW and casual introduction (**) in GE, whereas *Brassica rapa* subsp. *campestris* is casual introduction (**) in GW and GE. Casual introductions (**) in Greenland restricted to GW include *Carum carvi, Leucanthemum vulgare, Lolium perenne, Galium mollugo* subsp. *mollugo, Bromopsis inermis, Artemisia vulgaris, Tanacetum vulgare* subsp. *vulgare, Melilotus albus, Plantago major* subsp. *major*, *Descurainia sophia, Tripleurospermum inodorum, Carduus crispus, Silene vulgaris* subsp. *vulgaris, Rumex sylvestris* subsp. *sylvestris, Matricaria recutita* and *Arabidopsis arenosa* subsp. *arenosa* (Tab. 3, group 2).

The 19 of the 45 species occurring in the Arctic both as native and as non-native stabilized introduction (*) and from Greenland known from GW and GE include *Poa pratensis* subsp. *irrigata*, *Campanula rotundifolia, Rhinantus minor, Sagina procumbens, Poa nemoralis, Agrostis stolonifera* (casual introduction (**) in GE) and *Poa pratensis* subsp. *pratensis*. *Viccia cracca* and *Rumex acetosa* subsp. *acetosa* are native in WG, whereas *Deschampsia cespitosa, Anthriscus sylvestris* subsp. *sylvestris,*

Viccia sepium, Veronica serpyllifolia subsp. *serpyllifolia, Achillea millefolium* subsp. *lanulosa, Agrostis capillaris, Brabarea stricta, Rubus idaeus* subsp. *idaeus, Rorripa palustris* and *Sisyrichium montanum* are stabilized introductions (**) in Greenland only known from GW (Tab. 3, group 3).

The 12 of the 20 species occurring in the Arctic both as native and casual introductions (**) and known from GW and GE as native and include *Tripleurospermum maritimum* subsp. *phaeocephalum*, *Equisetum arvense* subsp. *arvense, Alchemilla filicaulis* subsp. *filicaulis* and *Juncus squarrosus*, whereas *Gnaphalium uliginosum* is only known from GW. *Alchemilla subcrenata, Draba verna, Atriplex prostrata* subsp. *prostrata, Crepis tectorum* subsp. *tectorum, Plantago lanceolata* and *Galium aparine* occur as casual introduction (**) in WG, and *Astralagus alpinus* subsp. *alpinus* (**) in GE (Tab. 3, group 4).

The 22 of the 24 species occurring in the Arctic both as native, non-native stabilized (*) and casual (**) introduction include for GW and GE the native species *Ranunculus acris* and *Poa annua*, for GW *Rumex longifolius, Capsella bursa-pastoris*, whereas *Stellaria media* and *Polygonum boreale* are native in GW and stabilized introduction (*) in GE. Stabilized introduced (*) species in GW include *Trifolium repens, Ranunculus repens, Cerastium fontanum* subsp. vulgare, *Poa trivialis* subsp. *trivialis*, *Stellaria graminea, Taraxacum ruderalia* agg., *Lathyrus pratensis, Urtica dioica* subsp. *dioica*, *Urtica urens, Myosotis arvensis, Tripleurospermum maritimum* subsp. *subpolare*, and *Potentilla norvegica,* whereas *Achillea millefolium* subsp. *millefolium* occur both in GW and GE. *Beckmannia syzigachne* and *Poa palustris* are known as casual introduction (**) in GW, while *Rumex acetosella* subsp. *acetosella* occurs as such in GW and GE (Tab. 3, group 5).

4.3. The influence of farming and sheep breeding in Greenland

One of the first comprehensive contributions concerning introduced vascular plant species in Greenland was by PORSILD (1932). He distinguished between three main groups: "hemerophilous plants" (favored by culture), "hemerodiaphorous plants" (neither favored nor damaged by culture) and "hemerophobous" plants (suffering from man's activities or neighbourhood). The hemerophilous plants were divided into Apophytes (native on new soil) (with five subtypes, 64 species), Ekiophytes (native, cultivated) and Anthropochores (introduced by men) (with two subtypes, unintentionally introduced and intentionally introduced, 93 species).

PORSILD (1932) summarized existing opinions about the influence of the Norse settlers between c. 1000 and 1500 A.D. on the flora of Greenland in a time when adequate palynological information was not available (chapter 3). He argued that six species were probably introduced by the Norse settlers: *Scorzoneroides autumnalis* (stabilized introduction (*), group 2, Tab. 3), *Vicia cracca* (native, group 3, Tab. 3), *Anthoxanthum odoratum* (stabilized introduction (*), group 1, Tab. 3), *Rumex domesticus* (*longifolius*) (native, group 5, Tab. 3) and *Carex lyngbyei* and *C. rostrata* (both considered native in ELVEN 2007). Another 14 species were considered either introduced by Norse settlers or immigrated by natural way e.g. *Nardus strictus, Juncus squarrosus, Carex panicea, Scirpus pauciflorus* and *Lathyrus maritimus* (all five species are considered native in Greenland by ELVEN 2007). *Capsella bursa pastoris, Poa annua, Stellaria media* and *Gnaphalium uliginosum* were considered by PORSILD (1932) as probably introduced in the last two centuries of colonization (all considered native by ELVEN 2007), and 27 species were considered immigrated by natural way, probably during a more favorable postglacial period, e.g. *Ligusticum scoticum, Zostera marina, Rubus chamaemorus, Geranium sylvaticum, Hieracium hyparcticum* (all considered native by ELVEN 2007), and *Luzula multiflora* considered by ELVEN (2007) as stabilized introduction (*).

The influence of the activities of the Norse settlers on flora, vegetation and landscape was clearly reflected in pollen diagrams from the Eastern Settlement (FREDSKILD 1978, 1988). The most

prominent features were the emergence of *Rumex acetosella, R. acetosa* subsp. *lapponicus* and *Achillea millefolium*, the decrease of *Salix* species*, Betula* species and *Gymnocarpium dryopteris* and the re-flourishing of a number of native herbs from the pioneer vegetation invading the land after the last de-glaciation 7-8 millenaries ago, such as *Sagina* species, *Silene acaulis*, *Plantago maritima*, *Rhodiola rosea* and/or *Sedum* species, *Thalictrum alpinum, Thymus praecox* and a few *Saxifraga* species (FREDSKILD 1988). These changes were explained by the activities of the settlers such as clearing of copses by fire and cutting, trampling of people and animals, grazing and sod cutting for construction of buildings resulting in open-ground for pioneer plants. Soil erosion took place as well documented by mineral layers in peat deposits. Especially in the Western Settlement burning of vegetation likely was common practice as can be concluded from charcoal layers under ruins (IVERSEN 1934) and in lake sediments (FREDSKILD 1985 unpubl.). Sagas also mention the existence of big forests and it is likely that several valleys and lowlands in the areas around the Eastern Settlement were still partly forested at the beginning of colonization (FREDSKILD & ØDUM 1990).

The fields were rich in introduced weeds and apophytes as could be concluded from analyses of soil profiles in the Eastern Settlement areas. Most conspicuous were numerous seeds of introduced annual weeds such as of *Poa annua* (considered now native in GW and GE), *Stellaria media, Capsella bursa pastoris* (both stabilized introductions (*) in GW), *Polygonum aviculare* (stabilized introduction (*) in GW, casual introduction (**) in GE) and the native apophyte *Montia fontana*.

There are no firm indications of agriculture. The economy was mainly based on sheep-raising, later in the 13th century some cattle were holding as well (KROGH 1982). The animal husbandry with field pastures and meadows for winter fodder production likely resulted in changes in species composition of the vegetation. However these changes are not detectable since the pollen of indicator species of increased grazing activities such as *Nardus stricta* and *Kobresia myosuroides* cannot be separated from those of other grasses and graminoids. Some of the conclusions of FREDSKILD (1988) were recently confirmed by SCHOFIELD et al. (2012). They conclude from their detailed palynological studies in the Eastern Settlement that *Alchillea millefolium*, *Polygonum aviculare* and *Rumex acetosella* demonstrate a close connection with a cultural landscape that was shaped and maintained by the Norse settlers predominantly via animal husbandry. It might be summarized that the farming activities of the Norse settlers likely caused a substantial local, however only a temporal mark on the native flora and vegetation at that time. After their disappearance from S and SW Greenland in the course of the 15th century flora and vegetation likely recovered during a four centuries of less human impact (cf. KROGH 1967, FREDSKILD 1988, FREDSKILD & HUMLE 1991, FEILBERG & HØEGH 2008, SCHOFIELD et al. 2012).

Another period of human influence in South Greenland started in the beginning of the 20th century with the introduction of a modern, large scale agriculture and sheep breeding.

The renewed introduction of sheep breeding in South Greenland and its later expansion, intensification and modernization by a more effective infrastructure and sheep management caused loss of natural habitats and changes in the natural vegetation. Nowadays the sheep breeding areas cover almost 1 % of Greenland's total ice-free land.

The present-day large scale agriculture started with the establishment of the Sheep Breeding Experimental Station in 1915 in S Greenland and the introduction of Icelandic sheep. Seventy years later 60-70 families had sheep breeding as their chief occupation. In the period 1915-1970 the management was based on extensively all year round grazing with small supplements of winter fodder (hay) and stabling. Sheep were collected once a year for shearing and slaughtering. A few strong winters (1966/67 and 1971/72) reduced the number of ewes drastically. In 1982 a new sheep management plan was presented with doubling of farms with a better infrastructure and sheep stabling of seven months and five months grazing on the outlying fields (FREDSKILD

1988, FEILBERG & HØEGH 2008). The number of ewes from 1915 – 2006 increased from 250 to 17.000. Nowadays 350 people in 70 households make their living from sheep-farming (Fig. 3).

There is little detailed or systematical information about the impact of sheep grazing on flora, vegetation and landscape (FEILBERG & HØEGH 2008). Overgrazing leads to soil erosion and replacement of shrubs and dwarf shrubs by grasses and graminoids (FREDSKILD 1988, 1992, FEILBERG & HØEGH 2008). Fenced fields for hay-making are grown by species and plant communities of the *Molinio-Arrhenatheretea* R.Tx. 1937, whereas *Stellarietea mediae* R. Tx. et al. ex von Rochow 1951 vegetation is observed in barley fields and along roadsides. Since the ancient Norse settler sites in S Greenland attract many tourists it is likely that many more non-native plant species will be introduced.

4.4. Other local impacts

In their analyses of the vascular plant flora of Greenland BÖCHER et al. (1959) already showed the high percentages of introduced species in the floras of S and SW Greenland, 12 % and 20 %, respectively. These high percentages are clearly related to the relatively strong habitation of these parts of Greenland. Also Tab. 2, 3 indicate that the number of stabilized introductions (*) is much higher in GW (50; 49 in Tab. 3) than in GE (5). The same applies to the casual introductions (**), 26 and 4, respectively.

Fig. 4: Garden with ornamental plants and vegetables in Nuuk, West Greenland. Fred J.A. Daniëls, July 2008.

Abb. 4: Garten mit Zierpflanzen und Gemüse in Nuuk, West Grönland. Fred J.A. Daniëls, Juli 2008.

PEDERSEN (1972) surveyed the flora of adventitious (non-native) and cultivated plants in Greenland. The first group comprises 168 species; the latter group contains forage plants and

plants from lawns (22 species; mostly *Poaceae* and *Fabaceae*), vegetables (25 species; a. o. *Beta vulgaris* L., *Brassica rapa, Daucus carota* L. and *Solanum tuberosum* L.), fruit shrubs (3 species; *Ribes vulgaris* L., *Rubus idaeus* subsp. *idaeus* and *Sambucus nigra* L.), ornamental plants (Fig. 4), such as *Centaurea cyanus* L, *C. montana* L., *Aconitum napellus* L., *Syringa vulgaris* L., and forest trees. This latter group includes species such as *Abies sibirica* Ledeb., *Fagus sylvatica* L., *Larix sibirica* Ledeb., *Picea abies* (L.) Karst., *P. glauca* (Moench) Voss, *P. sitchensis* (Bong.) Carr., *Pinus contorta* Loud., *P. mugo* Turra and *P. sylvestris* L.. The cultivation of shrubs and trees in S Greenland started in 1949 (PEDERSEN 1972). The Greenland Arboretum in Narsarsuaq in the inland of South Greenland near the Eastern Settlement was founded in 1988. It houses now over hundreds of tree and shrub species mainly from the northern taiga and tundra.

Human influence in and around towns and settlements on flora and vegetation mainly results in habitat disturbance and eutrophication. The latter results in vigorous growth of plants such as in *Oxyria digyna, Polygonum viviparum, Cerastium alpinum, Saxifraga cernua, Taraxacum croceum, Rhodiola rosea, Eriophorum scheuchzeri* and in grasses such as *Poa alpina, Alopecurus alpinus* and *Phippsia algida* (see also KRUUSE 1912). In smaller settlements vigorous stands of for example *Eriophoretum scheuchzeri* Fries 1913 (Fig. 5) and *Cerastio-Saxifragion* Hartmann 1980 vegetation (also known from bird-cliffs) are common.

Fig. 5: Luxurious *Eriophoretum scheuchzeri* Fries 1913 on nutrient-rich soil near soccer field inTasiilaq, Southeast Greenland. Fred J.A. Daniëls, July 2009.

Abb. 5: Üppiges *Eriophoretum scheuchzeri* Fries 1913 auf nährstoffreichem Boden am Fussballplatz in Tasiilaq, Südost Grönland. Fred J.A. Daniëls, July 2009.

4.5. Gobal change

Summer temperatures in the Arctic during recent decades have been higher than at any time in the past 2000 years and the Arctic is warming twice as fast as the rest of the world (MELTOFTE 2013). The expectation is that in the course of 21th century temperatures will increase several degrees further from those of the last two decadal means of the previous century. This will accelerate a number of processes so far not observed in the Arctic having a substantial effect on its ecosystems and valuable services they provide (MELTOFTE 2013).

Studies across the Arctic have already shown decadal and multi-decadal changes in species composition of plant communities. These are still minor in dry habitats, however more pronounced in moist and wet habitats, such as snow beds, mires, fens and shallow ponds. For Greenland this was shown by DANIËLS et al. (2011), DANIËLS & DE MOLENAAR (2011), CALLAGHAN et al. (2011) and SCHMIDT et al. (2012); for Canada by HENRY et al. (2012) and for Jan Mayen by KAPFER et al. (2012). Greening and shrub expansion is observed across the Arctic (a. o. KLEIN et al. 2008, HENRY et al. 2012).

It is reasonable to predict that borderline and boreal species will increasingly move into the Arctic and northwards within the Arctic including tree species as well. DANIËLS & DE MOLENAAR (2011) observed already a tendency of sub-arctification of the vascular plant flora near Ammassalik, SE Greenland, during the last 100 years.

Although there is little information about non-native invasive species in the Arctic, the majority appears not to be invasive and is not considered to be a threat to the native vegetation. Invasive species were not noticed in the many areas of Greenland visited by the author. The same applies for the Canadian Arctic (L.J. GILLESPIE, unpubl.), DANIËLS & DE MOLENAAR (2011) and DANIËLS et al. (2011) did not observe such species in the tundra near the town of Tasiilaq (Ammassalik), SE Greenland, during their fieldwork in the last 40 years, although in the town, a few casual (**) non-invasive introductions were occasionally recorded. *Lupinus nootkatensis,* native to NW North America, was introduced around 1970 from Iceland as an ornamental in Greenland and has become a stabilized (*) weedy species in SW Greenland, but is not considered to be seriously invasive since it is mostly restricted to disturbed sites (C. BAY, K. HØEGN pers. comm. 2012). In Iceland it is a threat, also in its very small and narrow northern Arctic part (MAGNUSSON 2010). *Hordeum jubatum* is a troublesome native weed in the western Arctic of North America, but again is primarily restricted to disturbed sites and thus not considered a threat to native vegetation.

Climate change and global change related developments such as increased tourism certainly will likely increase the number of non-native species and possibly invasive species in the Arctic as was shown by WARE et al. (2012) for Svalbard. They found that each visitor to Svalbard transports on average a minimum of four seeds, many of them of species known to be invasive in other regions. Seeds of 26 % of the number of introduced species appeared to be able to germinate under current Arctic climate conditions.

Finally climate change will also offer new possibilities for sheep- and cattle breeding, agriculture and even forestry in S and SW Greenland both for private households as well commercially. Ornamental plants will increase outside as well.

So far loss of native plant species and vegetation types in Greenland and the Arctic is not observed yet. The postglacial native vascular plant flora and vegetation are still relatively intact and little disturbed compared with the situation in boreal and temperate zones.

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