Non-native species in the vascular flora of highlands and mountains of Iceland

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Abstract

Highlands and mountains of Iceland (defined here as areas located above 400 m a.s.l) are considered to be the largest remaining wilderness areas in Europe. The present study provides first comprehensive and up-to-date data on non-native plant species from this area. The study was aimed to provide a checklist of alien plant species recorded from highland and mountain areas of Iceland, assess their naturalisation status, define spatial patterns and hotspots of their distribution, analyse temporal trends in the data and to create a reference for future research. The presence of 16 non-native vascular plant species was evidenced including 11 casuals and 5 naturalised taxa (1 invasive). The results showed that the central highland is most vulnerable to alien plant colonisation, while mountain and highland areas in other parts of the country are much less impacted by non-native plant taxa. Clear hotspots of occurrence of alien flora can be defined and their geographic location corresponds to places of touristic interest such as hot springs, geothermal areas, mountain huts and shelters as well as main roads and tracks. Temporal trends characterizing non-native plant colonization show clearly that the process is still in its initial phase. The research suggests that human-mediated dispersal is the major force contributing to increased invasion risk within the investigated area.

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Key words

alien flora, Iceland, highland, mountain flora, invasive species, Arctic

Introduction

There are conflicting views on the question whether the Arctic should be considered a pristine, virgin environment or whether it has been changed and influenced by human activities (Elven et al. 2011). It seems that if vascular plants are taken into account, the former point of view is closer to the reality. There is no evidence of extinction of any arctic vascular plant species, the total number of naturalised alien plant species is low or negligible in most of phytogeographic regions within the Arctic and natural "phytogeographic" pattern is intact in the Arctic (Elven et al. 2011). However, the North Atlantic region including Greenland, and Iceland, with settlements back to Medieval times (McGovern 1990) is different. The share of non-native species in regional floras is much higher, especially in regions with long history of human activity (e.g. Wasowicz et al. 2013).

Unlike lowlands, highlands and mountains of Iceland (defined here as areas located above 400 m a.s.l, and accounting for ca. 40% of the country) remain the most pristine environments of Europe mainly due to very difficult access and harsh climate (Einarsson 1994). The central highlands are considered to be largest territories south of the Arctic Circle in Europe that has never been permanently settled by humans (Vésteinsson 1998). During thousands of years that have passed since the retreat of the ice sheet, undisturbed processes of ecological succession created a variety of unique, natural plant communities that have been found to be one of the key factors in maintaining natural plant distribution patterns in Iceland (Wasowicz et al. 2014). It seems, however, that the combination of growing anthropogenic pressure and the

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climate change may contribute to significant alterations in these fragile ecosystems (Wasowicz et al. 2013).

Non-native plant species can be considered one of the main threats to unique biodiversity of highland areas in Iceland. Studies carried out around the world showed that alien plant species have significant and negative impact on species richness (Gaertner et al. 2009) survival of resident biota and on productivity of native communities (Pysek et al. 2012a). It was also proved that non-native plant colonization is far more likely to cause significant impacts on resident plant and animal richness on islands rather than mainland (Pysek et al. 2012a). The ongoing climate change is another risk factor that may contribute to serious changes in the flora of highland areas of Iceland by (i) deterioration of habitat conditions for native, cold adapted species (Lassuy and Lewis 2013, Wasowicz 2013) and (ii) by favouring the spread of alien species leading to new invasions and range expansion of already naturalised aliens (Thuiller et al., 2007).

In light of these findings the present study was aimed to assess and document the impact of non-native plant taxa on the vascular flora of highland and mountain areas in Iceland in order to create a reference for future research. The research aimed to:

(1) provide a checklist of alien plant species recorded from these areas

(2) assess their naturalisation status

(3) define spatial patterns and hotspots of their distribution

(4) analyse temporal trends in the data.

Materials and methods

Definitions used

The present study is focused on non-native plant species defined after Pysek et al. (2004) as taxa whose presence in a given area is due to intentional or unintentional human involvement

or which have arrived there without human involvement from an area in which they are alien. Non-native species were further subdivided into two categories: casual and naturalised species. Casual species were defined as alien plants that may flourish and even reproduce occasionally outside cultivation in an area, but that eventually die out because they do not form self-replacing populations, and rely on repeated introductions for their persistence. Naturalised species were defined as alien plants that sustain self-replacing populations for at least 10 years without direct intervention by people (or in spite of human intervention) by recruitment from seed or ramets (tillers, tubers, bulbs, fragments, etc.) capable of independent growth. Both definitions follow Pysek et al. (2004). Within naturalised taxa invasive alien species were also recognised following Pysek et al. (2012 b).

Data origin

Data used in the present study were retrieved from the database of the Icelandic Institute of Natural History, the biggest and richest biodiversity data repository in Iceland containing over 500,000 georeferenced records of plant species distribution. Only records of non-native taxa (Wasowicz et al. 2013) were taken into account. In total 9,396 records (collected between 1840 and 2014) were examined including vouchered specimens deposited in AMNH and ICEL herbaria, field observations and literature data records.

Spatial analyses

All georeferenced data from the database were converted into shapefiles using QGIS software. Elevation data were retrieved from digital elevation model of Iceland (20 m per pixel) downloaded from http://gatt.lmi.is . Elevation in meters was then assigned to each data point using point sampling tool in QGIS. Resulting database containing georeferenced species occurrences and elevation data was queried and only records with altitude ≥ 400 m a.s.l. (130 in

total) were included into the present study. The data could be found in ESRI shapefile that was included as electronic supplementary material. In order to identify areas with high concentration of non-native species records a heat map was prepared in QGIS using the radius of 5.000 m.

Checklist, temporal trends

Non-native taxa included in the present study were placed on the checklist, that summarizes information concerning taxonomy, time of residence, naturalisation status, biogeographical affinities and a life form (Raunkiær, 1934). Native distribution of alien taxa was recorded in continent scale. In cases when taxa were present in two continents, they were included in both totals.

The year of observation for each species record was retrieved from the database and cumulative number of species introduced and number of observations was plotted against time. Curves were plotted in SigmaPlot using locally weighted regression - LOESS (Cleveland 1979), with sampling proportion of 0.1 and polynomial degree set to 1.

Results

There were 16 non-native plant taxa recorded in highland and mountain areas of Iceland between 1840 and 2014 (Table 1). According to the criteria proposed by Pysek et al (2004) 11 taxa (69% of total non-native flora), were classified as casual aliens, while 5 taxa (31% of non-native flora) were classified as naturalised. It seems, that following the criteria established by Pysek et al. (2012b), only one species can be classified as invasive within the investigated area: *Lupinus nootkatensis*.

Non-native vascular plants in highland and mountain areas of Iceland belong to 11 families and 16 genera. Only two families were represented by more than one genus: *Poaceae* - 5 genera, and *Boraginaceae* - 2 genera.

Hemicryptophytes are the most common life form among non-native plants in highland and mountain areas of Iceland (10 taxa, 62% of total non-native flora). Therophytes are much less common (2 taxa, 12%). Geophytes, nano-phanerophytes and phanerophytes were represeted by only one taxon each (6%) (Table 1).

Geographic origin of non-native taxa was also investigated: 10 taxa were included in European group of origin, 9 taxa in Asian group and 6 taxa in Northern American group (Table 1).

Analysis of geographic distribution of non-native taxa records showed they are concentrated mainly within the central highland (Fig. 1). Closer inspection of the pattern of occurrence within the central highland revealed that hotspots of non-native plant occurrence followed the location of disturbed areas connected with man made objects such as huts, shelters and roads. Clearly, highland areas around the Myvatn Lake could be also pointed out as a hotspot of the occurrence of non-native species. Highland and mountain areas located outside the central highlands seem to be less colonised by non-native plants. Highland areas located within the Western Fjords peninsula (NW Iceland) and in the eastern part of the country seem to be least impacted by the occurrence of non-native plant taxa. Results show clearly that naturalised species are much more frequent and wider distributed than casual aliens (Fig. 2 b,c)

Cumulative number of first taxa records was plotted against time to examine temporal trends in alien taxa immigration to highland and mountain areas. The analysis shows that the trend recorded for highland and mountain areas is very similar to the general trend of non-native species immigration to Iceland (Fig. 2a). It seems, however, that steady, linear increase in the number of non-native taxa records started much later in highlands than in Iceland as a whole (Fig 2a). The same situation is clearly visible when the number of observations of non-native plant

taxa is taken into account (Fig.2 b). Clear growth trend is visible in highlands few decades after it started in lowlands (or Iceland as a whole). The curve for highland areas seems to be much steeper than the curve plotted for Iceland as a whole (Fig. 2b).

Discussion

Over 300 non-native plant taxa have been recorded in Iceland so far (Wasowicz et al. 2013, Wasowicz 2014). It seems therefore that only very small percent of these alien species is able to reach highland and mountain areas. The results obtained during the present study suggest that 95% of non-native taxa recorded in Iceland were never recorded from highland and mountain areas. This suggests that there are still strong environmental factors preventing unlimited spread of non-native plants from lowland areas to highlands.

It seems that climate can be one of the factors responsible for low rate of colonization success among non-native plants in the highlands. With some minor exceptions, most of the area investigated during the present study has a mean temperature of July lower than +10^{o}C (Einarsson 1984), and thus can be treated as arctic according to the climatic criterion (Przybylak 2002). These unfavorable conditions with low temperature and very short vegetation period certainly restrict growth of many species within highland and mountain areas of Iceland including non-native taxa (Wasowicz et al. 2013). Research on biogeographical patterns present in native Icelandic flora has also evidenced that climatic factors are crucial in shaping geographic distribution of native flora (Wasowicz et al. 2014).

It is well known that non-native species richness increases with level of urbanisation and is positively correlated with human population density (McKinney 2001, Holway 2005). From the beginning of the settlement farms and and other centres of human activity in Iceland were located almost exclusively within lowland areas, especially within flooded wetlands

(Vésteinsson 1998), where climatic conditions were good enough for agriculture. This pattern of settlement in turn, limited the economic significance of highland and mountain areas that were used almost exclusively for sheep grazing until the mid-1960 (Sæþórsdóttir and Saarinen 2015). Low rate of human penetration and almost negligible economic use contributed to extremely small propagule pressure and resulted in limited spread of non-native plant taxa within these areas.

The results presented here suggest, that only taxa previously naturalised within lowland areas are able to effectively colonise highlands. All taxa naturalised within highland and mountain areas have been recorded as naturalised from lowlands (Wasowicz et al. 2013) and most of the taxa being now causal within highlands are considered as naturalised in lowlands (Wasowicz et al. 2013). This shows that colonization of highland environments in Iceland is a "second step" in the process of naturalisation of the species within the country. There is no evidence available so far showing a different direction of naturalisation process (i.e. a species naturalised in highlands and spreading down into lowlands).

The geographic origin of non-native plant taxa was examined during the present study focused on highlands as well as during previous research of a broader scope (Wasowicz et al. 2013). Comparison of results showed that in both cases taxa of European origin constitute the core of non-native flora both in highlands - 62% of the total non-native flora; and in Iceland as a whole - 49.2% of the total non-native flora (Wasowicz et al. 2013). Also taxa of Asian and Northern American origin scored high in both cases accounting for 56% and 37% of the total alien flora of highlands, respectively. The share of Northern American taxa in the alien flora of Icelandic highlands (37%) is significantly higher than the value established for Iceland as a whole (8.9%, Wasowicz et al. 2013). This is due to the fact that several non-native species of

Northern American origin have been deliberately introduced to the flora of highland areas, and became naturalised much faster than other non-native species. *Lupinus nootkatensis*, *Deschampsia caespitosa* subsp. *beringensis* and *Salix alaxensis* are good examples here. Due to high level of environmental matching between their native range and highland areas of Iceland these species are most probably able to spread quickly and effectively in investigated area. Alaska lupine (*L. nootkatensis*) is at the moment the most widespread and invasive non-native plant in Icelandic highlands.

Clearly, non-native plants have been recorded mostly from the central highland. Relatively easy accessible highland areas close to the Myvatn Lake in North-Eastern Iceland have been also influenced by naturalised alien plant species. In north-eastern part of the country climatic conditions allowed human settlement and farming activities even above 400 m a.s.l. Areas located above 400 m a.s.l. in other parts of Iceland (e.g. the Western Fjords peninsula - NW Iceland or highland areas located within the Eastern Fjords) still seem to be almost free of non-native plant species. This pattern of spatial occurrence can be explained by high impact of human-mediated dispersal. Closer inspection of places with very high number of non-native species records have shown, that they are mostly distributed areas around tourist attractions such as hot springs (e.g. Hveravellir, Laugafell), places with other type of geothermal activity highly visited by the tourists (e.g. Reykjahlíð, Námafjall and Krafla volcano) as well as around huts and shelters for tourists located within highland areas (e.g. Jökullheimar). The road network is another source of propagules and can be considered as an important factor facilitating the spread of non-native plants within highland areas. The results of the present research seem to confirm recent findings that human-mediated dispersal along road network is one of the most important factors contributing to plant dispersal (von der Lippe et al. 2013).

Temporal trends characterising non-native plant colonization show clearly that the process is still in its initial phase. Relatively low number of non-native plant species was recorded within highland areas when compared to the rich alien flora in the lowlands (Wasowicz et al. 2013). This suggests that further colonisation may occur, especially if climatic constraints will be significantly reduced or even removed by ongoing climate change, what has been already suggested by recent modelling experiments (Wasowicz et al. 2013). Sharp increase in the number of species observations after 1960 may suggest that first large hydropower plants built the central highland in the mid-1960s contributed to increased alien plant colonisation. The construction of these hydropower plants involved significant improvements in road infrastructure. That lead to increased access to some areas such as Landmannalaugar (Sæþórsdóttir and Saarinen 2015). Very steep shape of the curve showing the number of non-native plant observations within highland and mountain areas may suggest that the rate of spread of existing populations is quite high.

In recent years Arctic wilderness environments has become a major attraction for tourists and the central highlands are now considered as one of the largest remaining wilderness areas in Europe (Sæþórsdóttir and Saarinen 2015). The increase in international tourist arrivals is particularly high in Iceland, where number of tourists have grown from 72,600 in 1982 to ca. 1 million in 2014 (Sæþórsdóttir and Saarinen 2015). It is estimated that about one third of tourists visit the central highlands (Icelandic Tourist Board 2012). These values show that influx of propagules carried in the clothing and gear of visitors to the central highland is at the moment higher than ever and will probably continue to grow in predictable future. Recent studies in the Antarctic have shown, that this type of plant propagule transfer should be considered as very important source of propagules of non-native species (Whinam et al. 2005, Lee and Chown .

2009, Chown et al. 2012, Huiskes et al. 2014). The increased transfer of propagules poses a great danger to fragile environments of highland and mountain areas of Iceland and will surely contribute to increased spread of existing non-native species through facilitated seed transport along roads and tracks (von der Lippe et al. 2013) as well as to arrival of new alien species brought by tourists from lowland areas and even from outside the country. *Digitaria ischaemum* (*Poaceae*) seems to be a good candidate as the spread of the species (probaby carried on boots of vistitors) between thermal areas in southern Iceland is already evident. It seems that any actions aiming to facilitate travel through the central highlands (e.g. construction of new road tracks or improvement of existing routes) will inevitably lead to increased number of visitors and consequently to increased inflow of seeds and other plant propagules of non-native taxa and more efficient dispersal.

Conclusions

The present research showed that non-native plant species are one of the major threats to preservation of pristine environments of highland and mountain areas of Iceland. The presence of 18 non-native plants was evidenced. The data collected during the present study suggests that almost 30% of those species is naturalised within highland and mountain areas. Some of those species (L*upinus nootkatensis*, *Deschampsia caespitosa* subsp. *beringensis* and *Salix alaxensis)* due to good environmental matching between native environments and secondary habitats within Icelandic highlands can be considered as invasive (*L. nootkatensis*) or potentially invasive. The research identified the central highland as the region of increased colonisation by non-native plant species and suggested that human-mediated dispersal is now a major force contributing to increased invasion risk.

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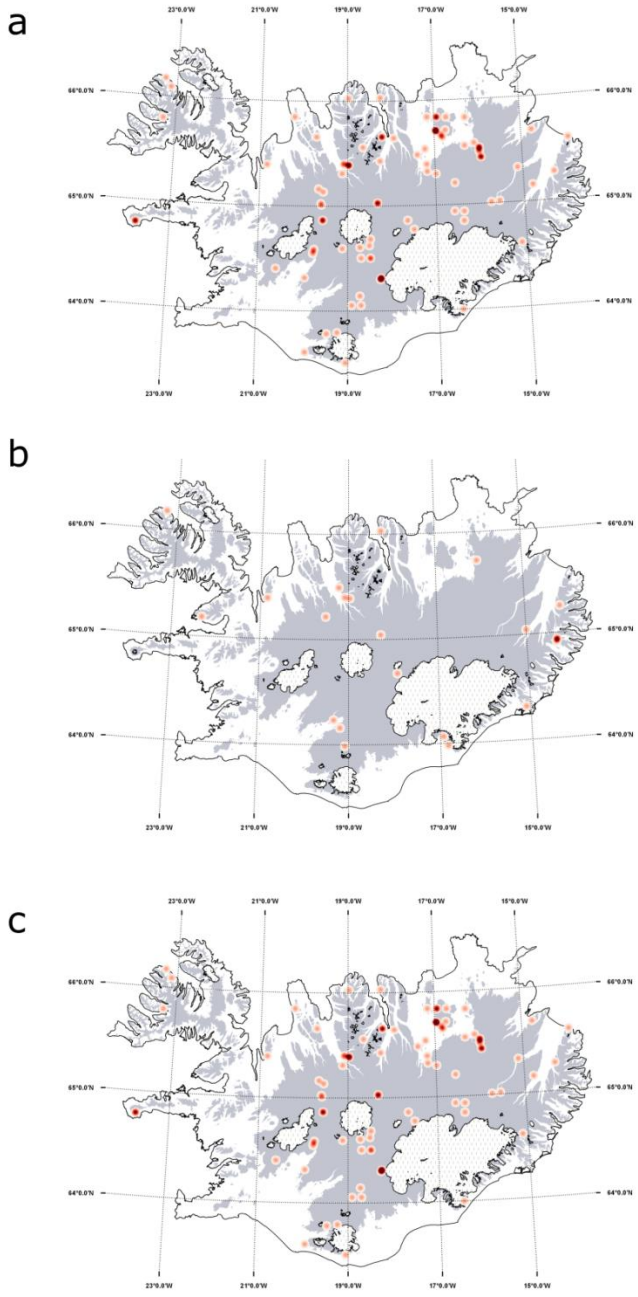

Fig. 1 Heat map showing the clusters of observations of non-native vascular plant species in highland and mountain areas in Iceland. a - all species, b - casual species, c - naturalised species

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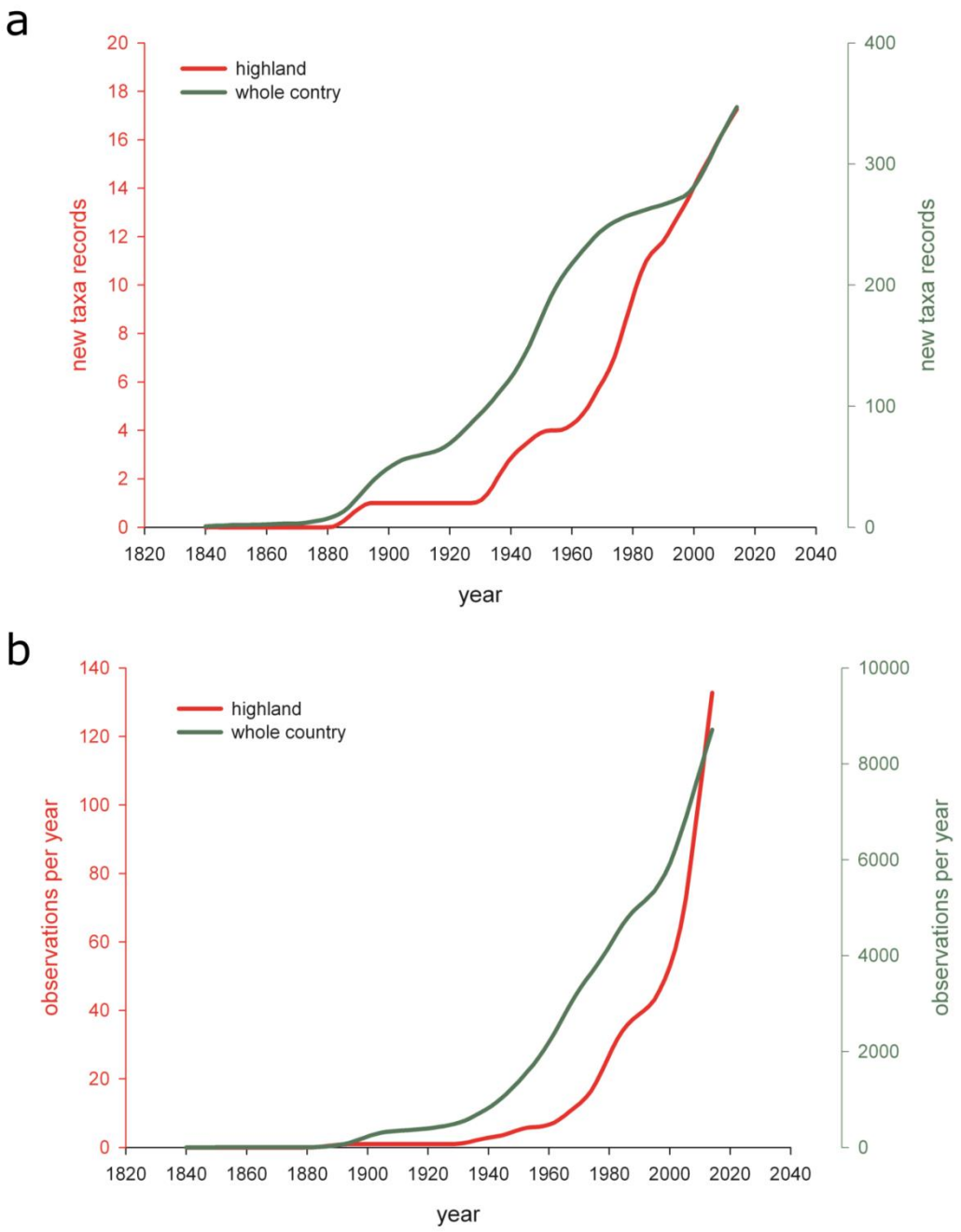

Fig. 2 LOESS curves showing dynamics and temporal trends in non-native flora of highland and mountain areas of Iceland (1840-2014) - LOESS curves. a - number of species, b - number of observations. Cumulative numbers were calculated on the basis of *per annum* new taxa records/observations

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Table 1. Checklist of non-native vascular plants in highland and mountain areas of Iceland.

	Species	First record[a]	Last record[b]	Naturalisation status[c]	Life form[d]	Origin[e]	N[f]
1	*Alnus viridis* (Chaix) DC. ssp. *sinuata* (Regel) Á.Löve & D.Löve	2005	2005	CAS (NAT)	N	NAm, Asi	2
2	*Alopecurus pratensis* L.	1963	2011	**NAT** (NAT)	H	Eu, Asi	15
3	*Avenula pubescens* (Hudson) Dumort.	1978	1978	CAS (NAT)	H	Eu, Asi	1
4	*Claytonia sibirica* L.	2004	2004	CAS (CAS)	H	Asi, NAm	1
5	*Deschampsia cespitosa* (L.) Beauv. ssp. *beringensis* (Hultén) W.E. Lawr.	1996	2012	**NAT** (NAT)	H	NAm, Asi	24
6	*Lamium amplexicaule* L.	1988	1988	CAS (NAT)	T	Eu	1
7	*Lappula squarrosa* (Retz.) Dumort.	1888	1888	CAS (CAS)	H	Eu, Asi	1
8	*Lepidotheca suaveolens* (Pursh) Nutt.	1969	1999	CAS (NAT)	T	Eu, NAm, Asi	3
9	*Lolium perenne* L.	1981	1981	CAS (CAS)	H	Eu, Asi	1
10	*Lupinus nootkatensis* Donn ex Sims	1980	2014	**INV** (INV)	H	NAm	44
11	*Myosotis scorpioides* L.	1978	1980	CAS (NAT)	H	Eu, Asi	2
12	*Phleum pratense* L.	1935	2010	**NAT** (NAT)	H	Eu	22
13	*Rheum rhabarbarum* L.	1996	1996	CAS (CAS)	G	cult	1
14	*Salix alaxensis* (Andersson) Coville	2011	2011	**NAT** (NAT)	P	NAm	1
15	*Sinapis arvensis* L.	1937	1937	CAS (CAS)	T	Eu	1
16	*Stellaria graminea* L.	1946	2000	CAS(NAT)	H	Eu	7

a) year of the first record is usually taken from databased herbarium collections. In some cases, however, they are based on observations only. This usually refers to taxa that are not present in herbaria collection in Iceland but were listed on the basis of literature reports

b) the data on most recent record are based on both herbarium and observation data

c) established after Pysek et al. (2004): CAS - casual alien species, NAT - naturalised alien species, INV - Invasive alien species. Naturalisation status in the country was given in brackets accoring to Wasowicz et al. (2013).

d) assigned according to Raukiær (1934) classification: G - geophyte, H - hemicryptophyte T - therophyte N - nano-phanerophytes P - phanerophytes.

e) geographic origin of the species: Eu - Europe, Asi - Asia, NAm - North America, cult - cultivated taxon.

f) total number of examined records

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