**Senecio pseudoarnica** Less. (Asteraceae): a new non-native species invading coastal areas in arctic and subarctic Europe

Pawel Wasowicz · Torbjørn Alm

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**Abstract** We report the human-assisted spread of *Senecio pseudoarnica*, native to the northern coasts of North America and the Far East, to arctic and subarctic regions of Europe. Our findings indicate that the species, imported as a decorative plant, is currently rapidly spreading along coastal areas of Iceland and Norway. An exponential model comprehensively explained the increase in the number of known localities. Close climate matching between the native and non-native ranges, as well as practically exact environmental matching, are the main factors that facilitate the process of naturalisation and invasion. It is likely that a complete eradication of the species is already impossible, and further studies are needed to guide effective management strategies.

**Keywords** Iceland · Norway · *Senecio pseudoarnica* · Invasive species · Arctic · Subarctic

**Introduction**

The Arctic and Subarctic are among the few areas in the world where ecosystems remain only minimally affected by non-native plant species, and where only a small number of non-native plants are considered to be invasive (Wasowicz et al. 2020). It is mainly because these regions are inhabited by small human populations, which generates limited large-scale human disturbance, modest traffic volumes and low propagule pressure (Lassuy and Lewis 2013). Harsh climatic conditions and a short growing season are the main constraints that limit the invasion of more southern species (Alsos et al. 2015). However, with warming climates and growing human populations, these constraints are now weaker, indicating that, in the future, the Arctic and Subarctic may become an arena for plant invasions on an unprecedented scale, as no biosecurity measures are currently in place to protect these fragile ecosystems (Wasowicz et al. 2020).

Here, we report on the spread of *Senecio pseudoarnica* to the arctic and subarctic regions of northern Europe. To date, this species is known only from its native range covering the North Atlantic coasts of North America (from Nova Scotia, Gulf of St. Lawrence and Newfoundland to Labrador Peninsula) as well as the Northern Pacific coast (from Japan and British Columbia to the Bering Strait) (Fig. 1). In the present paper we document the species’ present non-native range, time of residence and pathway of its
introduction to Europe, describe basic ecological data (such as preferred habitat types, climatic conditions etc.) and estimate the dynamics of its expansion.

**Materials and methods**

Data acquisition in the native and introduced distribution areas

We searched all available data sources, including gardening books and catalogues, data from botanical gardens and other relevant sources, for information on the time that *S. pseudoarnica* was first imported to Iceland and Norway. Data on the species distribution in Iceland and Norway were collected during field excursions carried out by the authors, by searching local databases (from both countries), as well as by directly contacting individuals who had sightings of the species. Each occurrence point was confirmed either via collections stored in the AMNH and TROM herbaria or, at a minimum, by a high-quality photograph. All occurrence points were georeferenced either directly (using a GPS unit) or indirectly. Fully georeferenced point distribution data from the native distribution range were downloaded from GBIF (2021). Points falling evidently outside the species native range were discarded.
range or falling outside land areas were excluded from analysis.

Climatic data and inference on environmental conditions in the native and introduced distribution areas

Climatic data representative for 1970–2000 were downloaded as bioclimatic variables from WorldClim version 2.1 (Fick and Hijmans 2017). We used mean annual temperature and mean annual precipitation to characterise climate type in native and non-native part of the species range. GIS layers containing climatic data were sampled using sample raster values tool integrated into QGIS (QGIS Development Team 2021). Data were visualised on a scatterplot using ggplot2 package in R. Densities of the points on scatterplot were visualised on density plots for each climatic variable separately.

Linear and non-linear model fitting

The relationship between the number of localities and time was assessed by fitting a linear and non-linear model to our observations. Regression models were fitted using the lm() function in R (R Core Team 2013). We used standard error of regression (residual standard error) as well as Akaike information criteria (AIC) to assess and compare the goodness-of-fit between models. AIC values for models compared were calculated using AICcmodavg package (Mazerolle 2020). Predictions and 95% prediction intervals were calculated using the predict() function in R.

Results

Distribution and ecology

Iceland

In Iceland, the presence of *S. pseudoarnica* was confirmed in more than 30 sites along the whole coastline (Fig. 2A), and several localities were also discovered inland. The species is typically present on beaches above or on the drift line, as well as on backshore berms formed from organic matter deposited by the ocean. It grows in plant communities dominated by *Leymus arenarius* and *Mertensia maritima* – often classified as Icelandic sand beach perennial communities. *S. pseudoarnica* can also thrive and reproduce on upper shingle beaches with open vegetation, between pebbles and cobbles, with limited sources of organic matter. Inland sites in Iceland include mostly man-made habitats such as bar ditches, roadsides, or garden waste disposal sites. *S. pseudoarnica* was also identified from a streamside. Regardless of location, this species usually forms dense monotypic stands. The spread of numerous single plants over wide areas suggests that reproduction by seed occurs, at a minimum, in a few locations in southern Iceland.

Norway

So far, approximately 50 stands of *S. pseudoarnica* have been recorded in northern Norway (Fig. 2B). Most (except four) of these are in seashore habitats, and only one is a little more than 100 m away from the shoreline. Based on extant records, sandy shores are their preferred habitat, with these stands being by far the largest found in habitats otherwise dominated by *Leymus arenarius* (and, in a single site, *Alopecurus arundinaceus*). *S. pseudoarnica* can potentially also grow on gravelly shores, but seemingly not in areas dominated by silt or clay. Smaller stands exist on driftwalls of kelp, associated with annual or perennial herbs, e.g. *Atriplex prostrata* and *Honckenya peploides*. Outside of near-shore areas, *S. pseudoarnica* has, to date, only been recorded in compost heaps associated with gardens, and on the meadow slopes of downside gardens. It thrives on fertile soils forming dense stands.

Time of residence and pathway of introduction

Iceland

The first account of the presence of *S. pseudoarnica* in Iceland dates back to 1968, from the registers of the Botanical Garden in Reykjavík. An index card containing information on the species mentions that the plant material was transferred to Reykjavík from Skrúður, the oldest botanical garden in Iceland, located in the Western Fjords. The species was subsequently removed from the Botanical Garden in Reykjavík owing to its markedly expansive properties, which created difficulties for the staff (Hjörtur Þorbjörnsson pers. comm.). The presence of *S.
pseudoarnica was also confirmed from the Botanical Garden in Akureyri, based on Index Seminum from the 1970s; however, the origin of plant material and time of its arrival is unknown. An Icelandic expedition to the Russian Far East collected and, subsequently, imported seeds of the species from Talan island in Magadan Oblast in 1989 (Tómasson 1992). Today, S. pseudoarnica is grown in private gardens.

Norway

The species was imported from Alaska by a well-known horticulturist in Nordkjosbotn (Balsfjord, Tromsø), circa 1990. From his garden, it could be tracked to several other gardens in Lenvik and Tromsø municipalities as an ornamental plant. Because its growth was difficult to control, the species was often removed from gardens to compost heaps.

Climate matching

A scatterplot comparing climatic conditions in native and non-native ranges of the species showed that sites from both ranges were closely co-located on the plot (Fig. 3). Moreover, maximal densities of points representing sites from native and non-native ranges showed similar patterns for both annual mean temperature and annual mean precipitation.

Expansion dynamics

For Icelandic data, the linear model had a much higher standard error (4.337) when compared with exponential model (0.3702). Similarly, for Norwegian data, standard error of the regression for linear model was higher than that of exponential model: 1.684 and 0.4949, respectively. For each compared model pair (Iceland linear vs. Iceland exponential, Norway linear vs. Norway exponential) the value of AIC was lower in the case of the exponential model (Fig. 4). Predictions based on our models showed a vigorous, exponential growth in the number of sites occupied by the species in Iceland (Fig. 4B), while only limited growth in the number of sites was predicted for Norway (Fig. 4D).

Discussion

Our data show that S. pseudoarnica is a new non-native species naturalised in at least two regions of northern Europe (Iceland and Northern Norway). These data also indicate that the species meets all the criteria to be classified as invasive (Richardson et al. 2000). S. pseudoarnica is currently invading natural coastal habitats in both regions. The first isolated population found in Sandøya (N Norway) in 2007 (Sortland et al. 2007) and hypothesised to be a product of trans-Atlantic natural dispersal was undoubtedly already the product of an ongoing invasion process (Alm and Often 2008). We acknowledge that our data are most probably incomplete and that more populations are present in both countries. Unfortunately, both Iceland and Norway are characterised by extremely long and diverse coastlines that are generally difficult to access.

Residence time

It is evident that S. pseudoarnica arrived in Iceland before 1960; however, owing to the lack of more detailed sources, we were unable to provide a more accurate arrival date. The first observations of wild populations on the seashore dates back to 1980, which suggests that approximately two decades had passed from the species’ introduction to the first sightings. In Norway, the time between the importation of the species and discovery of the first wild populations is approximately 16 years.

Pathway of introduction

Senecio pseudoarnica was introduced to both countries as an ornamental plant. There is little doubt that rhizomes were removed from gardens and disposed into the ocean (or close to the ocean shore) together with other gardening waste, producing the first Icelandic populations of the species. In Norway, compost heaps served as an intermediate habitat, before the species reached natural coastal habitats.

Environmental and climate matching

Field observations from both countries suggest that S. pseudoarnica is colonising habitats that are almost the same as within the native range (Talbot and Talbot
1984), e.g. beach meadows, located on young dunes that are influenced by salt spray on lower foredunes (Fig. 5A). It seems, therefore, that in both regions within its non-native range, the species is invading natural habitats, taking advantage of perfect environmental matching (Fig. 5C). In addition, we found that man-made habitats (e.g. roadsides and ditches) are also readily colonised by the species and are likely to act as corridors for further inland spread (Fig. 5B). This observation suggests that carrying capacity for *S. pseudoarnica* can be higher than expected when based strictly on initial records that document the colonisation of seashore communities.

A high degree of climatic matching was evidenced by our analyses; both Norwegian and Icelandic populations showed a clear tendency to co-locate within...
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Expansion dynamics

We tested two different models for each population considered in this study. The results showed, that in both cases exponential models performed better than linear models, what was evidenced by the lower values of the standard error of the regression for these models and lower values of AIC. Our results suggested that, in Iceland, the species have already reached the expansion phase, characterised by an exponential growth in abundance (Arim et al. 2006) (Fig. 4B). In Norway, S. pseudoarnica appears to still be in the initial establishment phase, characterised by a slow spread (Arim et al. 2006) (Fig. 4C, D). However, recent field observations in northern Norway that documented thousands of flowering stems spread across approximately 2 km of shoreline along the seashore at the Slettmo area in Balsfjord, and a single outlier 7 km further north (Alm 2020), suggest that the expansion phase may already be underway. Not knowing the approximate carrying capacity for the species makes predictions difficult and prevents us from presenting a logistic model. However, considering the length of the Icelandic coastline (4970 km) and the fact that the species is also spreading inland,

Fig. 4 Fitting observation data with linear and non-linear models and corresponding predictions: A a linear model for Iceland; B an exponential model for Iceland; C a linear model for Norway; D exponential model for Norway. Values of the standard error of the regression (S) and Akaike Information criterion (AIC) were used to compare the goodness-of-fit between models
it seems to us unlikely that the carrying capacity will be reached any time soon. It is likely that a complete eradication of the species is already impossible, since in both regions it occurs on multiple sites and in large numbers. What is more, the persistence of *S. pseudoarnica* in private gardens ensure continuous flow of propagules. High degree of climate and environmental matching, vigorous growth and a tendency to form dense monotypic stands (Fig. 5B,C) increase chances that the species can cause environmental damage in seashore communities by replacing native elements of the flora. It seems to us highly probable that *S. pseudoarnica* will be able to spread widely across coastal environments of Northern Europe. The pattern of its natural distribution (Amphi-Pacific/Berigian and American Atlantic) suggests that it possesses the ability for wide and effective spread. Further research is needed, to learn more on the environmental impact of the species, the extent of its environmental niche, and what is crucial for development of effective management strategies.

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**Authors’ contributions** P.W. conceived and designed the study. P.W. analysed the data. P.W. and T.A. contributed data. P.W. and T.A. wrote the paper.

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**Availability of data and material** New distribution data collected during this study are made available through GBIF: https://doi.org/10.15468/gf5nr5

**Declarations**

**Conflict of interest** The authors declare no conflict of interest.

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