University of Antwerp

Faculty of Science

LONG-TERM DYNAMICS IN RUDERAL PLANT COMMUNITIES THROUGH CLIMATE AND LAND USE CHANGE IN THE SCANDINAVIAN MOUNTAINS

By

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Master project submitted to obtain the degree of

Master in Biology, specialization Global change biology

September 2022

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ACKNOWLEDGEMENTS

I am much grateful to my promotor Jonas J. Lembrechts, postdoc researcher at the University of Antwerp, for his sincere involvement, and quick, constant feedback. Without his skillful guidance and advice this thesis was not possible. I have learned a lot from him throughout the entire process.

My thanks are also extended to my co-promotor Keith Larson, Project Coordinator and Science Communicator and CIRC, the Climate Impacts Research Centre, in Abisko, for his help to setup this study and his on-point suggestions. His expertise of the Abisko region was essential to complete this work.

Thanks must also go to Jan Clavel, doctoral researcher at the University of Antwerp, for his dedicated assistance with the fieldwork.

I am thankful to the employees of the Abisko Scientific Research Station for giving us a pleasant stay during our fieldwork.

Finally, I am deeply grateful to my husband, Steven, for his continuous support and understanding throughout my academic journey.

SUMMARY

The contemporary interaction of climate change and land use change disturbances drive vegetation composition and distribution shifts simultaneously. Therefore, these drivers are difficult to disentangle. Our study investigated long-term and current ruderal vegetation shifts along the Rallarvägen in Abisko, subarctic Sweden – a trail that is paralleled by a railroad (since 1903) and a road (since 1982). We obtained vegetation and climate data from 1903, 1913, 1983, and 2021. Together with Ecological Indicator Values for Temperature (EIV-T), we analyzed these shifts for both the total and the non-native ruderal community.

Investigating long-term ruderal compositions showed that not only climate change can cause an influx of warm-adapted species to a subarctic region. Many non-native ruderals with high EIV-Ts, that were present in 1903 and 1913, have- disappeared in recent years. In general, the communities have been very dynamic through time, but the total number of ruderal species has been roughly constant.

We studied ruderal species distributions along the Rallarvägen in 2021 and uphill migration patterns from two hiking trails leading from the Rallarvägen into the mountains. Railroad building had long-lasting effects on the ruderal vegetation as most ruderals resided closer to the railroad tracks. The total ruderal community was also most numerous at anthropogenically disturbed sites, e.g., train stations. From these introductory points, they were progressively filtered out according to the degree of disturbance intensity. We named this process Horizontal Directional Ecological Filtering (HDEF), a term derived from the Directional Ecological Filtering (DEF) by Alexander et al. (2010). Newest ruderal introductions were residing on average farther uphill, suggesting that uphill migration is not necessarily determinant in time.

We conclude that it is important to know the disturbance history of a system to get a good understanding of the long-term dynamics in the vegetation community, and thus its possible future.

LAYMAN SUMMARY

Climate change is affecting subarctic mountainous ecosystems by rapidly changing vegetation compositions and distributions since the 1980s. It is occurring four times faster in subarctic regions than in most others, but this is not the only major driver. Land use change and tourism are two common disturbances that may disrupt native subarctic vegetation.

We investigated these impacts on the ruderal vegetation along the Rallarvägen, in Abisko, subarctic Sweden – a hiking trail paralleled by a railroad (since 1903) and a road (since 1982). The Rallarvägen was constructed to serve as a transport road to build the railroad. After railroad completion, it turned into a hiking trail. We obtained vegetation and climate data from two distinct periods: when disturbance was a major influence (1903 and 1913), and when climate change and disturbance were both a major influence (1983 and 2021).

We found that railroad building had a long-lasting effect on the ruderal vegetation along the Rallarvägen as most ruderals were residing closer to the railroad and most were present in 1903-13, the years following railroad building. The road, on the other hand, did not have a noticeable effect in 1983, as the Rallarvägen was not used during construction. Disturbance intensity is thus a key player. This also became apparent from the highest number of ruderal species close to train stations, which are frequently visited places. We also found that not only climate change can cause an influx of warm-loving species to a subarctic region as many ruderal species that were introduced abundantly in 1903 and 1913, have disappeared again in recent years.

We conclude that it is important to know the disturbance history of a system in order to have a better understanding of current and future vegetation dynamics.

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1. INTRODUCTION

At the beginning of the 20th century, botanists were already interested in the impacts of disturbance on plant species distributions (Sylvén, 1904 and 1913-15). Anthropogenic climate change was already in discussion but did not reach the core of the scientific community as it does today (Callaghan et al. 2010). Dominance of ruderal species in the vegetation composition was thus a direct consequence of human impacts, such as land use changes and human activities and the intensity thereof. While this remains valid, climate change is undeniably present since the 1980s (Callaghan et al. 2013), and slowly but surely affects our ecosystems as well.

Over the past few decades, researchers have studied the consequences that a changing climate will have on our subarctic mountainous ecosystems (Dainese et al. 2017; Elmendorf et al. 2021; Pearson et al. 2013), noting also that the effects can be accelerated by human activities (Chiuffo et al. 2018; Hulme, 2014; Lembrechts et al. 2016b; Liedtke et al. 2020). Climate change and disturbances happen concurrently but at a different pace. The effect of disturbance on vegetation is fast, causing a local influx of ruderal species (Chiuffo et al. 2018; Guo et al. 2018; Rendeková et al. 2019), while the effect of climate change is slow, causing introductions of warm-adapted non-native species that become established in disturbed areas as the climate warms (Taylor et al. 2017; Thuiller et al. 2005). Warming signs are mainly visible on mountains (Dainese et al. 2017; Frei et al. 2010). In the lowlands, communities often lag climate change (Bertrand et al. 2011). The exact drivers that cause shifts in vegetation compositions and distributions are thus difficult to disentangle (Thuiller, 2008).

In this thesis, we will discuss the multifactorial interactions between climate change, land use change, and human-mediated dispersal on the ruderal vegetation along a hiking trail in the mountainous area of Abisko in subarctic Sweden.

1.1 CLIMATE CHANGE EFFECTS AND UPHILL MIGRATION

Climate change is known to cause rising global temperatures and increasing extreme weather events (Callaghan et al. 2010; IPCC, 2007). It is proven to be four times the global rate in the arctic circle (Rantanen et al. 2022) and is especially pronounced in mountainous areas (Callaghan et al. 2013). Rising global temperatures has already led to shifts in vegetation composition in mountainous areas in recent decades (Elmendorf et al. 2012; Heijmans et al. 2022; Pearson et al. 2013; Thuiller et al. 2005). In addition to the establishment of warm-adapted non-native species, vegetation productivity and the length of the growing season have also increased, which appears to be related to the degree of warming in summer and the decrease in snow cover (Elmendorf et al. 2012; Pearson et al. 2013). Some species generally respond positively to these changes with increased growth rates and/or distribution, but this response can also be negative for other, more essential species to the ecosystem. Thus, the impact of climate change per se is quite difficult to predict, as responses can vary widely in speed and magnitude across species and functional groups (Klanderud & Totland, 2005; Parmesan & Hanley, 2015). It appears that in particular trees, shrubs, and grasses will benefit from a warmer climate, allowing them to outcompete other species, resulting in changes in composition (Callaghan et al. 2011; Hedenås et al. 2016; Milbau et al. 2009). In the end, this could have cascading effects on the biodiversity and functioning of these pristine ecosystems.

Due to their cold, unfriendly environment, subarctic mountainous ecosystems were previously believed to be relatively resistant to the influx of non-native species (Pauchard et al. 2009), but climate change and increased anthropogenic disturbance are gradually changing this (Pauchard et al. 2009; Walther et al. 2009). Most non-native species have a ruderal growth strategy (Alexander et al. 2016; Chiuffo et al. 2018; Kowarik, 2003). They are known to be good dispersers that can reach great altitudes twice as fast as native species (Alexander et al. 2016; Dainese et al. 2017; Parmesan & Hanley, 2015), but their climatic tolerance may constrain their survival to the next growing season (Rendeková et al. 2019). However, a widespread uphill migration of non-native species that are climatic generalists has been observed along elevational gradients in response to climate change (Alexander et al. 2016; Dainese et al. 2017; Kueffer et al. 2013; Pauchard et al. 2009). Most native subarctic species are relatively fixed in their range and climate tolerance (Parmesan & Hanley, 2015), and it is unclear whether these species will shift their distribution or disappear altogether (Dainese et al. 2017; Frei et al. 2010).

1.2 LAND USE CHANGE AND HUMAN-MEDIATED DISPERSAL

Land use change and tourism are two common disturbances that cause ruderal dominance in vegetation composition and non-native species introductions (Chiuffo et al. 2018; Guo et al. 2018; Lembrechts et al. 2014; Rendeková et al. 2019). Human-mediated dispersal facilitates non-native ruderal influxes from all over the world as tourists are often bringing in hitch-hiking seeds that are sticking to clothing, boots, and the tires of cars (Frenkel, 1977). Consequently, ruderals mostly appear first near train stations (Brandes, 2002), parking lots (Frenkel, 1977), roadsides (Lembrechts et al. 2014), and other places where land use changes take place and human displacement is most abundant (Guo et al. 2018; Liedtke et al. 2020). The degree of invasion in a community is thus related to the intensity of human activity (Kowarik, 2003).

Mountainous regions are becoming more accessible through improved infrastructure. Roads and hiking trail are also major conduits for human-mediated dispersal in the region (Dainese et al. 2017; Lembrechts et al. 2014 and 2016a, Liedtke et al. 2020; Wedegärtner et al. 2022), allowing for faster uphill migration than by climate change impacts (Hulme, 2014). These disturbed sites are often characterized by changes in soil, such as soil compaction and chemistry, which affect species diversity and composition, creating an environment that promotes ruderal species (Guo et al. 2018; Frenkel, 1977). Roadside dispersion is related to traffic intensity and the size of the road network (Chiuffo et al. 2018; Pauchard et al. 2009). Hiking trails facilitate dispersal into the mountains (Liedtke et al. 2020). Consequently, introductions tend to take place in the lowlands where anthropogenic pressures are greatest (Alexander et al. 2010; Guo et al. 2018; Liedtke et al. 2020; Pauchard et al. 2009), and from these sites species either move through human-mediated dispersal or spread out on their own. *S*ince climate warming and mountain recreation are expected to further increase, these disturbances may boost an overrepresentation of native and/or non-native ruderal species in the vegetation composition over time.

1.3 MULTIFACTORIAL INTERACTIONS INVOLVING CLIMATE CHANGE AND DISTURBANCES

The unidirectional expansion of non-native species from low to high altitudes on mountains is explained by Alexander et al. (2010) through a process called Directional Ecological Filtering

(DEF). The DEF hypothesis states that; indeed, introductions of non-native species take place at anthropogenically disturbed sites in the lowlands and from here they migrate to higher altitudes. Richness of non-native species gradually declines with increasing elevation, but a species' elevational range also increases with its maximum elevation. Regardless of their upper elevational limit, a species' lower limit is in the lowlands and thus climatic generalists succeed to reach high altitudes. Non-native species are thus progressively filtered out along the elevation gradient, likely due to their climatic niche (Alexander et al. 2010) or time since introduction (Pyšek et al. 2011). Non-native invasions are thus determined by their introduction pathways, caused by both anthropogenic disturbances in the lowlands and by a climate gradient uphill.

1.4 THE RALLARVÄGEN TRAIL AND THE ABISKO REGION

Abisko is a small village that is known for its hiking trails and the Abisko Scientific Research Station. The local climate is defined as subarctic with cool summers and relatively mild winters with extensive snow cover. The Scandes mountains to the west create a rain shadow directly over Abisko making it is the sunniest area in northern Sweden (Callaghan et al. 2010 and 2013). However, as everywhere in the Arctic, the Abisko region has been subject to increasingly severe climate change impacts, while it has also been subject to significant anthropogenic disturbance since over a century. Over the past decade, the average annual air temperature in the region has gradually increased from 0 to 1 °C (Callaghan et al. 2010), while it was approximately -0.6 °C in previous century (ANS, 2019). The rising air temperatures have increased the soil temperatures and caused decline in the permafrost layer and lake ice (Callaghan et al. 2013; Christensen et al. 2004), altering the soil hydrology (Johansson et al. 2011). This has already had several consequences, such as an increase in the thickness of the active layer that resulted in changes in vegetation with more trees, shrubs, and grasses (Callaghan et al. 2011; Christensen et al. 2004*;* Rundqvist et al. 2011).

In 1903, a railroad was built from Kiruna to Narvik, soon followed by the first tourist hotel in Abisko (Callaghan et al. 2013). The Rallarvägen trail runs parallel to the railroad and served as a transport road during construction. In 1982, a paved road (E10) was constructed that followed the Rallarvägen and the railroad. The impacts of the E10 on the vegetation in the region were thoroughly investigated. Yet, in contrast to studies that have examined the role of roads on the influx of non-native species (Lembrechts et al. 2014 and 2016a), only a minor effect of non-native species influxes was detected in the years following the road construction (Bäck & Jonasson, 1998). Since the opening of the road, the infrastructure has contributed to a steady increase in tourism in the region, so it is possible that effects in vegetation composition may be noticeable now. These effects in combination with the railroad, tourism, and climate change may have caused a steady increase in ruderal species in the vegetation and dynamic changes in the ruderal composition over the past 100 years.

Mountainous regions are of particular interest for studying climate warming decoupled from disturbances, since there is a pronounced uphill climate gradient (Frei et al. 2010). In this thesis, we have an exceptional opportunity to decouple climate change and land use change through time and elevation by using historical vegetation data (from the early 1900's) at a time when disturbance was the dominant driver and recent vegetation data (from 1983 and 2021) when both disturbances and climate change were at play.

1.5 OBJECTIVES

Here, we compiled and synthesized long-term data of vegetation compositions and climate conditions from and around the Rallarvägen trail. We obtained historic vegetation data from 1903, 1913 (Sylvén, 1904 and 1913-15), and 1983 (Lewejohann & Lorenzen, 1983), as well as corresponding climate data (ANS, 2019). In 2021, we resurveyed the trail and divided it into 40 transects of 1-km. In addition, we collected more recent vegetation data from two trails leading from the Rallarvägen into the mountains: the Björkliden and Låktatjåkka trail (Wedegärtner et al. 2022). Using these unique long-term datasets, we answer two key research questions:

1. **WHAT ARE THE TEMPORAL DYNAMICS OF RUDERAL SPECIES INTRODUCTIONS, AND DO THESE DYNAMICS CORRELATE MOST STRONGLY WITH CLIMATE CHANGE AND/OR LAND USE CHANGE?**
2. **IS THE SPATIAL EXPANSION OF RUDERAL SPECIES SINCE INTRODUCTION IN THE ABISKO REGION MOSTLY LIMITED BY CLIMATE OR DISTURBANCE?**

Analyses are performed on (1) native and non-native ruderals combined, and (2) non-native ruderals separately. We aim to investigate these research questions through the following supporting questions:

1.1 What are the temporal dynamics of ruderal species along the Rallarvägen?

We investigate the influence of climate change and disturbance on dynamic shifts in ruderal vegetation composition over time. Using historical vegetation data, we analyze the dynamics of ruderal species presence along the different settlements of the trail and assess when and where the greatest influx of ruderals has taken place. We expect the greatest influx of ruderal species to have occurred since 1983, as climate change and disturbance have been simultaneously affecting the vegetation since then. We also calculated beta diversity to measure the temporal variation in species composition across settlements. Beta diversity can be understood as the difference in species composition between communities. Essentially, the Beta diversity of the communities in 1903, 1913, 1983, and 2021 is the result of the environmental differences between those communities. Usually, communities with similar environments have similar species composition; thus, we expect to find at least some heterogeneity between the historical years (1903 and 1913) and the recent years (1983 and 2021). Beta diversity is usually the result of environmental, abiotic influences or dispersal processes. It could therefore reflect colonization and extinction patterns through time (Fontana et al. 2020).

1.2 Are ruderal species that have established after railroad or road building, moving due to climate or disturbance?

This synergy of climate and disturbance effects on lowland vegetation can only be evaluated separately if the temporal distance is large enough. We aim to explore possible trends by including long-term air temperature data (ANS, 2019). We also include a species temperature index as a proxy for a species' climate niche – Ecological Indicator Values for Temperature (EIV-T) – to substantiate possible dynamic changes associated with climate change. As climate change reportedly allows for the introduction of new species adapted to a warmer climate, we expect our data to show an influx of species with higher EIV-Ts, at least after 1983 in comparison to 1903 and 1913. We also expect the presence of certain species in 1903-13 but the absence of these species in 1983-2021 to be caused by dispersal limitations due to the Rallarvägen, the railroad, or the settlements from which these species originated. When the reverse occurs, i.e., certain species present in 1983 but absent in 1903-1913, we expect that this may have been caused by the E10 road or climate change. The introduction of species in 1903-13 was not driven by global warming and thus these species may be easier labeled as disturbance followers. Species introduced after 1983, possibly required a warmer climate to survive in the region, which would result in a rising trend in EIV-T after 1983. However, climate change impacts remain difficult to predict.

2.1 Are current ruderal species distributions related to land use or climate?

Here, we analyze the current distribution (2021) of ruderal species along the Rallarvägen. We assess whether the distribution of ruderals is related to either the E10 road or railroad, by distances determined from the Rallarvägen to the E10 road or railroad. Incorporating soil temperatures enables us to analyze ruderal distributions as a function of an interaction between anthropogenic disturbances and soil temperatures as an indirect climatic variable. We might reveal a trend regardless of climate change or disturbance, but we expect to find an interaction as these drivers simultaneously affect vegetation.

2.2 Is the anthropogenic pressure gradient acting as a filter on ruderal species?

To assess if the distribution of ruderal species is related to sites of high anthropogenic pressure, we determined the abundances of ruderal species along the trail and how these abundances are distributed. It is well known that ruderals are disturbance followers, and we therefore expect to find higher biodiversity at sites that are under high anthropogenic pressure such as trains stations or settlements. By analyzing relative abundances as a function of the ruderal counts along the trail, we identify sites that harbor ruderal species that are uncommon along the trail. When such a site has many ruderal species but a low average abundance, it may be a corridor for species introductions. We expect that most of the ruderals will be introduced at

Abisko Östra and Björkliden train stations and that most dispersal takes place between these train stations as this part of the Rallarvägen is most intensively used.

2.3 Do non-native ruderals reach long-term establishment in the Abisko region?

By using counts and abundances of ruderal species in relation to their first year of observation (i.e., when according to our data a species was first observed along the Rallarvägen) and their native status, we determine how the current composition of ruderal species reflects dynamic changes over the past century. This means that we determine whether non-native ruderal species that were introduced in historical years are still present in 2021 and whether they are spreading successfully. We expect that oldest introductions to be abundant along the trail. We also expect that most non-native ruderal species present in 2021 are newcomers due to the synergy of climate change and disturbance.

2.4 Are ruderal species moving uphill?

As the Rallarvägen has only a minor elevation gradient, we also include vegetation data from two trails leading from the Rallarvägen into the mountains. This allows us to investigate whether ruderal species are expanding their distribution uphill. We focus only on those species that were also present along the Rallarvägen. Using their first year of observation, we analyze their migration as a function of time and EIV-T. We expect to reveal an uphill migration according to their time of introduction, i.e., species that have resided the longest in the area have migrated the furthest uphill. Newest introductions, potentially requiring the warmer climate to establish, are then found at the lowest elevations with highest EIV-Ts. However, we are aware that species migration is not always in line with what one would expect, as it is not only climate that drives species distributions (Pyšek et al. 2011).

2. MATERIALS AND METHODS

2.1 STUDY REGION

The Rallarvägen trail is 61 km long and starts in Abisko (68°21'N, 18° 49' E), at the Abisko Östra train station, and ends in Rombaksbotn in Norway. This study is conducted along a 40-km stretch, from Abisko to Riksgränsen, the Swedish settlement near the Norwegian border (Fig. 2.1). The Rallarvägen was built to serve as a transport road for the railroad construction and is since then used as a hiking trail. The trail follows the railroad track through the mountain valley, with a minor elevational gradient ranging from approximately 368 m a.s.l. near Abisko till 522 m a.s.l. near Vassijaure. The Rallarvägen is intersected by a few settlements with train stations in Abisko, Björkliden, Vassijaure, and Riksgränsen. The E10 road between Kiruna (Sweden) and Narvik (Norway) intersects the Rallarvägen as well and for a 1-km stretch, near Koppårasen (transect 18, see section 2.2), the road lies directly next to the trail. Between Abisko and Björkliden lies the Abisko National Park (1909), which attracts many tourists in summer and in winter, with most summer tourism focused on hiking, resulting in extensive use of hiking trails. Especially through this park many hiking trails intersect the Rallarvägen before diverging to different parts of the area, for instance onto Mt. Nuolja (1,164 m a.s.l).

Not every part of the Rallarvägen trail is equally popular. Some parts near Koppårasen are overgrown and in bad condition, while other parts, such as the stretch between Abisko and Björkliden, are easily accessible and extensively used. The trail substrate itself is at popular sections graveled, at others there is bare soil. In some places it is completely overgrown, while in wetter areas it is often layed out with wooden planks (see SM Figs. 6 to 9). For the most part, the vegetation along the trail is characterized by mountain birch (*Betula pubescens* ehrh.) and willow (*Salix sp.*), with an understory of mainly berry-bearing shrubs (e.g., *Empetrum nigrum* L. and *Vaccinium sp.*), ferns (e.g., *Dryopteris expansa* C. presl. and *Gymnocarpium Dryopteris* L.), and herbaceous plants (e.g., *Bistorta vivipara* L. and *Cornus suecica* L.). In wetter areas, the vegetation is dominated by graminoids (*Carex sp.* and *Juncus sp.*) and horsetails (*Equisetum sp.*). Near train stations species composition was usually most diverse, with characteristic disturbance followers (e.g., *Alopecurus geniculatus* Lindh ex. Scheele*, Arabidopsis thaliana* L., and *Epilobium ciliatum* Raf.)

2.2 VEGETATION DATA

In this project, we combine 1) historical vegetation data with 2) a new resurvey of the Rallarvägen in 2021 and 3) an additional survey performed in 2016 by the Mountain Invasion Research Network (MIREN) along two trails intersecting the Rallarvägen and leading into the mountains.

2.2.1 Historical vegetation data

In the summer of 1903 and 1913, vegetation surveys were conducted along the Rallarvägen that mainly focused on ruderal species (Sylvén, 1904 and 1915-17). During railroad construction, the surrounding vegetation was destroyed, leaving bare soil whereupon construction materials were transported and assembled. Near the end of railroad construction in 1903, botanist Sylvén observed an influx of ruderal species, most notably near the settlements of Abisko, Björkliden, and Vassijaure, where various dump piles of horse manure and rubbish had arisen. Along the Rallarvägen, then the transport road, several ruderal species had appeared as well. Sylvén therefore surveyed presence of ruderal species along the Rallarvägen near these settlements in 1903. Upon his return to the Abisko region in 1913, Sylvén observed remarkable changes in human influences on vegetation composition. Houses were greatly expanded, with plantations or lawned gardens, mainly concentrated around the Abisko tourist station and train stations along the trail. In Riksgränsen, where no outstanding developments in the vegetation had been observed in 1903, large areas had now to be considered ruderal-dominated vegetation. Only in Vassijaure the vegetation had remained in the same state as in 1903. These new developments led Sylvén to resurvey the same regions, this time including Riksgränsen.

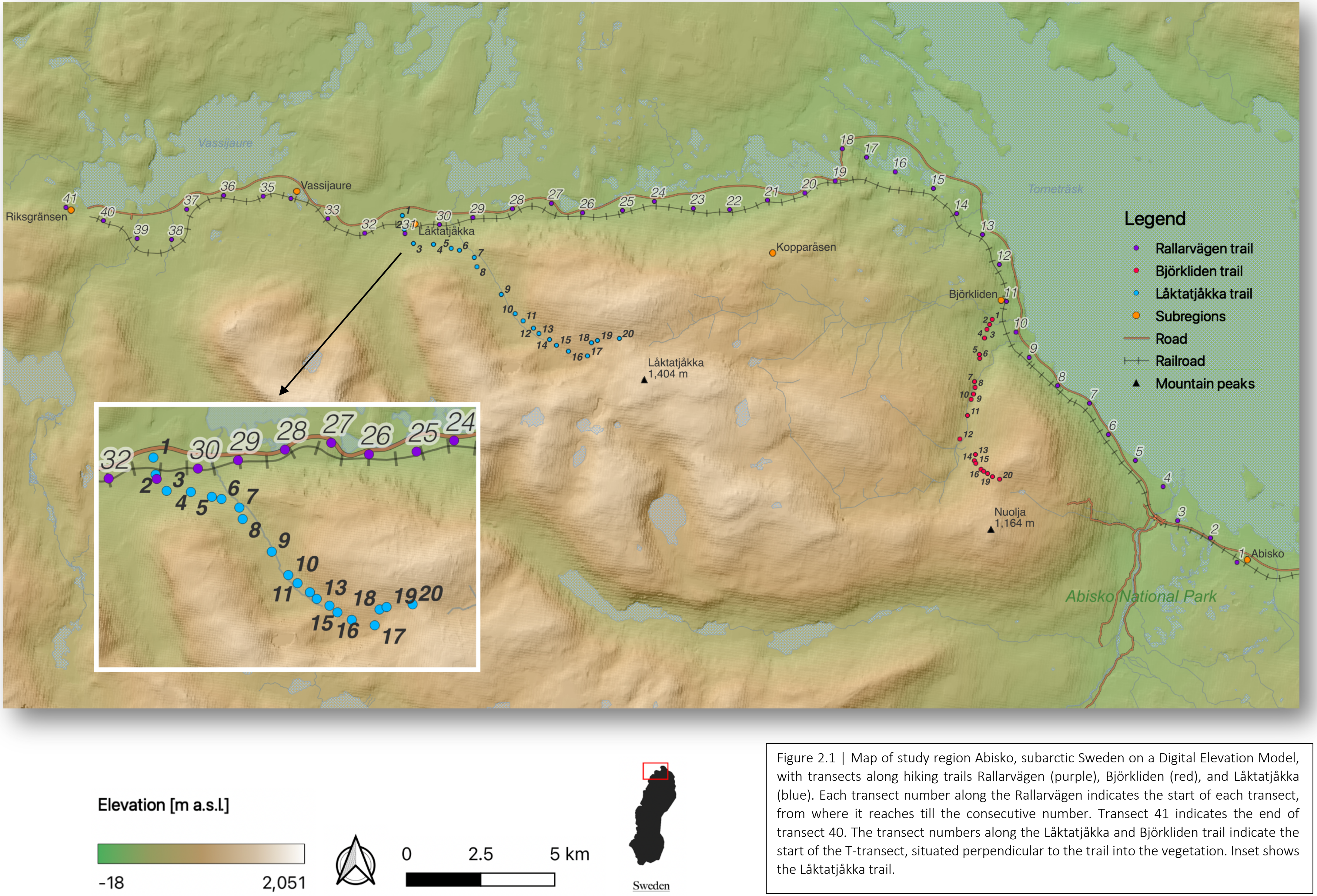


Figure 2.1 | Map of study region Abisko, subarctic Sweden on a Digital Elevation Model, with transects along hiking trails Rallarvägen (purple), Björkliden (red), and Låktatjåkka (blue). Each transect number along the Rallarvägen indicates the start of each transect, from where it reaches till the consecutive number. Transect 41 indicates the end of transect 40. The transect numbers along the Låktatjåkka and Björkliden trail indicate the start of the T-transect, situated perpendicular to the trail into the vegetation. Inset shows the Låktatjåkka trail.

Since Abisko became more accessible when the railroad was completed, numerous scientists visited the region, including E. Asplund, who summarized the Abisko flora in a guide to the Taxonomical Excursion of the 7th International Botanical Congress in Stockholm in 1950 (Asplund, 1950); a survey itself not included here because it is not needed to answer our research questions. This attracted more scientists to the region, resulting in published or unpublished surveys. When the E10 road from Kiruna to Riksgränsen was opened in 1982, botanists Lewejohann & Lorenzen wanted to provide a new survey of the vegetation in the Abisko region. They were expecting possible changes in vegetation due to the road construction and increasing tourism because of that, as compared to the 1950 survey by Asplund (Lewejohann & Lorenzen, 1983). Therefore, during the summer of 1983, they documented all vascular plant species in 20 areas of unspecified in size around the Abisko region, using Flora Europaea vol. I (Tutin et al. 1980). This survey included areas intersecting the Rallarvägen: Abisko, Björkliden, Kopparåsen (from Kopparåsen to Vadvetjåkka), Låktatjåkka, Vassijaure, and Riksgränsen. From this publication, the Abisko area, although including the Abisko settlement and train station, is not included in this study as the covered survey area lies outside our area of interest: from Abiskojåkka to Tjuonavaggejåkka – about 25 km distance from the Rallarvägen – which includes other hiking trails and encompasses the Abisko National Park.

2.2.2 2021 Rallarvägen resurvey

These publications served as a baseline for comparison with our own data – a resurvey of the Rallarvägen vegetation in the summer of 2021. We documented every vascular plant species using 'Den nya nordiska Floran' (Mossberg & Stenberg, 2003) every 1-km over the 40-km stretch mentioned in section 2.1 and surveyed the trail twice to reduce survey bias due to seasonal patterns in species presence. To be able to make comparisons with the historical data, transects were merged to represent nearby subregions as delineated in the historical surveys:

Abisko = transect 1-5
Björkliden = transect 6-15
Koppårasen = transect 16-25
Låktatjåkka = transect 26-30
Vassijaure = transect 31-35
Riksgränsen = transect 36-40

Combining vegetation data from Sylvén (1903 and 1913), Lewejohann & Lorenzen (1983), and our own, the following vegetation dataset (Historical dataset) is obtained with the settlements (hereafter named subregions) from east to west along the trail in different observational years:

1903: Abisko, Björkliden, Vassijaure
1913: Abisko, Björkliden, Vassijaure, Riksgränsen
1983: Björkliden, Koppårasen, Låktatjåkka, Vassijaure, Riksgränsen
2021: Abisko, Björkliden, Koppårasen, Låktatjåkka, Vassijaure, Riksgränsen

A total of 401 species were documented in the Historical dataset. As Sylvén focused on ruderal species only, we filtered the species based on ruderality (see below). To be able to distinguish between 'a complete list of ruderal species observed in each year' (observational year) and 'species that are observed for the first time in a particular year' (first year of observation), we manipulated the data to get their status for each temporal community at one of the subregions using the *dplyr* function from the tidyverse package in R (Wickham et al. 2019). The statuses were defined as follows:

New = species is observed for the first time in a subregion
Recurring = species has been observed previously in a subregion
Disappeared = species has been observed previously in a subregion, but not in this observational year
Not present = species is not observed in this observational year and has disappeared or was not observed in previous observational year(s)

In a similar way, we obtained a species' first year of observation to the whole region.

Our own survey was additionally used as a separate dataset (Rallarvägen 2021 dataset) to investigate the current species distribution of ruderal species in detail. For these analyses, we calculated a species' abundance along the trail using the *Z*-score transformation for population abundance (Clark-Carter, 2005). It is defined as: $Z = [X - \mu]/\sigma$, where X is the abundance of species x (between 1 and 40 transects), μ is the mean abundance of the entire set of ruderal species along the Rallarvägen, and σ is the standard deviation of the mean abundance of the entire set of ruderal species along the Rallarvägen. This method allows us to interpret a species' abundance as standard deviations deviated from the mean – i.e., how abundant a ruderal species is relative to the entire set of ruderal species along the Rallarvägen trail. This way we consider both the mean value and the variability around that mean in species distributions. The mean of a *Z*-score is always zero, and species can have up to 3 standard deviations above or below it (see SM Figs. 2 and 3 for the obtained Z-scores). Rescaling to *Z*-scores is a linear transformation: $Z = [X - \mu]/\sigma \Rightarrow Z = (1/\sigma)X - (\mu/\sigma)$, whereby σ and μ are constants, and the result can thus be used in linear models. Transforming this data enables comparison with other similar trail-disturbance studies that used the *Z*-score transformation (Clark-Carter, 2005, and examples such as Ohana-Levi et al. 2018; Zalatnai et al. 2008).

2.2.3 MIREN trail survey

A third dataset (T-trails dataset) consists of the obtained data from the Mountain Invasion Research Network (MIREN), comprising vegetation survey data from along elevational gradients of the Björkliden and Låktatjåkka mountain trails that are stemming from the Rallarvägen trail (Wedegärtner et al. 2022). On both mountain trails, presence/absence of every plant species was documented at fixed distance intervals in one sampling area (20 in total) consisting of three plots of 2 x 10 m forming a T-shaped transect (T-transect), situated perpendicular to the hiking trail (see SM Fig. 1). For every plant species we calculated the 95th percentile of their elevational range – hereafter named elevational maximum. To calculate the 95th percentile, we used the *quantile* function in R (R core Team, 2021).

The Låktatjåkka trail diverges from the Rallarvägen on Mt. Låktatjåkka near transect 31 at approximately 440 m a.s.l. and ends at the Låktatjåkka mountain station at 1,228 m a.s.l. (see Fig. 2.1). The Låktatjåkka trail has a trail length of 7.5 km with the first T-transect starting at 467 m and the last at 1,186 m a.s.l., the total sampling site gains 719 m in elevation (for more details, see SM Table 36). At the beginning of the trail, the vegetation is dominated by an open mountain birch forest. Above the tree line, the vegetation is first dominated by (willow) shrubs, and further uphill by forbs and grasses. Near the end of the trail, vegetation becomes scarcer with mostly bare rocks with lichens (see SM Figs. 10 to 12). The trail substrate itself is mainly bare soil and gravel. The Björkliden trail diverges from the Rallarvägen trail in Björkliden near transect 10-11 at approximately 403 m a.s.l. and ends on top of Mt Nuolja (see Fig. 2.1). The Björkliden trail has a trail length of 4.61 km with the first T-transect starting at 428 m and the last at 1,045 m a.s.l., the total sampling site gains 617 m in elevation (for the exact description, see SM Table 35). This trail is consistently greener than Låktatjåkka and mostly dominated by forbs, grasses, and shrubs (see SM Figs. 13 and 14). The trail substrate itself is again mainly soil and gravel.

For all datasets, all plant species names were standardized using the canonical name from the Catalogue of Life obtained by using the taxize package in R (Chamberlain & Szocs, 2013). Additionally, for approximately 80% of the plant species, we obtained their plant strategy (Grime, 1979), life cycle, plant functional type (PFT, e.g., forb or grass), Landolt's Ecological Indicator Value for Temperature (EIV-T; Landolt et al. 2010), and their native status (Weidema, 2000). A species is identified as at least partially ruderal when its Grime's strategy classification contains an R, e.g., CRS, CRR, or RRR. EIV-Ts are highly useful indices to reflect the environmental temperature where a plant species is most likely to sustain a population. They range from 1 to 5 (1 = cold-loving and 5 = warm-adapted; Landolt et al. 2010), therefore providing a one-dimensional optimal niche for each species.

Of the 401 observed species in the Historical dataset, 240 were identified as ruderal and 100 were identified non-native ruderals. The Rallarvägen 2021 dataset contains 268 species of which 94 were identified as ruderal and 36 were identified as non-native ruderals. The T-trails dataset contains 128 species of which 39 were identified as ruderal and 12 were identified as non-native ruderals. We managed to obtain the PFT, life cycle, and EIV-T for every identified ruderal species.

2.3 TEMPERATURE DATA

We combined long-term climate data with the historical species dataset to analyze ruderal species observations as a function of temperature changes. This analysis has been made possible by data provided by Abisko Scientific Research Station (ANS) and the Swedish Infrastructure for Ecosystem Science (SITES). ANS was established in 1912 (Andersson et al. 1996), and a year later started climate monitoring in their meteorological station (ANS, 2019). At present, they carry out recordings of 13 climate variables, including air temperature, precipitation, humidity, and snow layer thickness. We summarized daily mean air temperatures, based on hourly measurements, as annual means and preformed linear regressions to predict Mean Annual Air Temperatures (MAAT) for each observational year: 1903 (-0.58 °C), 1913 (-0.61 °C), 1983 (-0.60 °C), and 2021 (1.01 °C). These temperatures were predicted from slopes of two distinct climate periods: 1913-1983 and 1983-2021 (Fig. 2.2), using linear models in R (function *lm*, R Core Team, 2021). We do believe that the estimate for 1903 – while outside the range of monitored data – is accurate as the linear trend in MAAT for the first period is very flat and estimates are thus relatively constant.

As plant species typically do not shift their distribution as a function of temperature in one specific year, predicted rather than exact measurements of MAAT in a specific year were preferred for our analyses. Nevertheless, we also report on the weather in each observational year to allow assessing if specific weather conditions within a survey year affected the ability to detect certain species (Table 2.1).

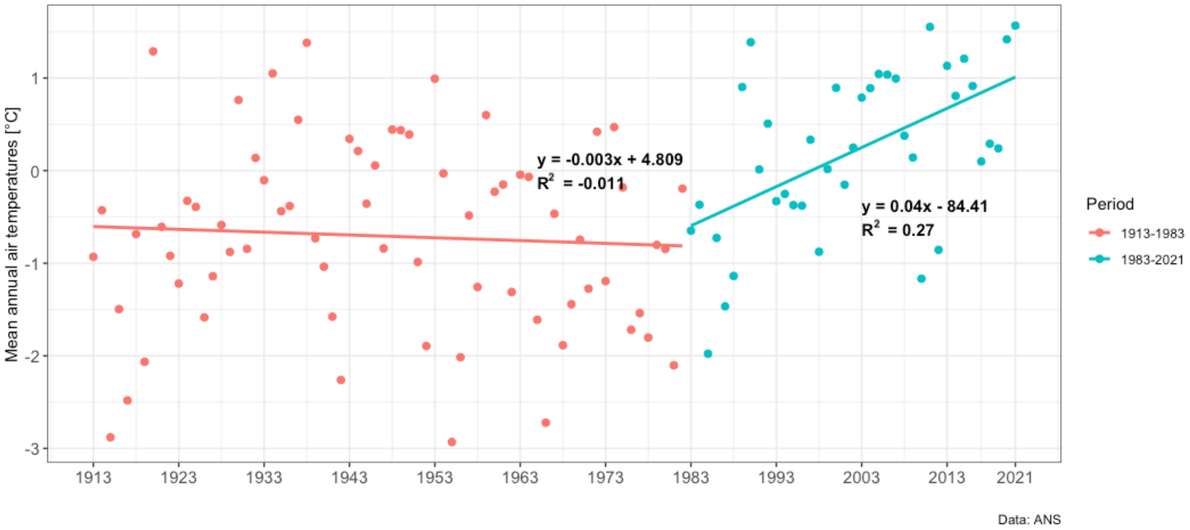


Figure 2.2 | Annual means of the daily mean air temperatures, measured by the ANS meteorological station. The mean annual air temperatures show two distinct periods: 1913-1983 (in red) and 1983-2021 (in blue). Modelled Mean Annual Air Temperatures (MAAT) were obtained through linear predictions using the linear formulas depicted near the regression lines: y = ax ± b. R-squared (R^2) represents how well the datapoints fit the regression line. It determines how well the proportions of the variance of the dependent variable can be explained by the independent variable.

TABLE 2.1

Descriptive data from each observational year obtained from www.vizchange.net (a website using the climatological data from ANS, 2019) and modelled temperatures (MAAT). Summer measurements are taken from June to August. Growing season length of 2021 is an average based on previous years: 2018 = 152, 2019 = 149, and 2020 = 154.

	1903	1913	1983	2021
Survey month	July	July	July	July
Landmarks survey	Train stations and settlements	Train stations and settlements	Train stations and settlements	Train stations and settlements
Summer average temperature [°C]	/	9.5	8.5	10.8
Summer min. temperature [°C]	/	-0.9	-0.6	4.8
Summer max. temperature [°C]	/	25.6	22.9	21.3
Annual average temperature [°C]	/	-0.9	-0.6	1.6
MAAT [°C]	-0.6	-0.6	-0.6	1.0
Summer precipitation [mm]	/	69.8	238.8	97.0
Date of last frost in spring	/	Jun-14	Jun-05	May-08
Growing season [days]	/	138	144	~151

We combined the Rallarvägen 2021 dataset with local soil temperature estimates from the 'Global maps of soil temperature', which provides global modelled soil temperatures averaged from the period 1979-2013 at a spatial resolution of 1 km^2 for 0-5 cm depth (SoilTemp; Lembrechts et al. 2020). These maps were constructed by calculating differences (i.e., offset) between *in situ* soil temperature time series from over 1,200 1-km^2 pixels, summarized from 8,500 unique temperature sensors, across all the world's major terrestrial biomes, and coarse-grained air temperature estimates from ERA5-Land (Lembrechts et al. 2020). ERA5-Land provides a reanalysis dataset with monthly soil temperatures at a spatial resolution of 0.1 x 0.1 degrees at 0-7 cm depth (Copernicus Climate Change Service (C3S), 2019). Soil variables that are used in this study are the mean annual temperature (SBIO1), mean temperature of the warmest quarter (SBIO10; in this thesis named Mean Summer Soil Temperature (MSST), see section 2.5), and mean temperature of the coldest quarter (SBIO11). We extracted temperatures for each transect using the *extract* function from the raster package in R (Hijmans, 2021).

2.4 MAPS AND MEASUREMENTS

For the start and end of every transect in the Rallarvägen 2021 dataset, we obtained the geographical coordinates with a GPS system (see SM Table 34). Geographical coordinates for train stations were obtained through Google Maps (maps.google.com). At every starting point of a transect we measured the perpendicular distance to the railroad and road (in meters) using the measuring line and the Basemap ESRI 102113 – WGS 1984 from the QuickMapServices plugin in the QGIS software 3.22.0 (QGIS Development Team, 2021). This Basemap was also used to produce the ruderal distribution maps (SM Figs. 4 and 5). The elevational gradient in the map of the study region (Fig. 2.1) was produced using Copernicus data and information funded by the European union – EU-DEM layers (WGS 4258), that are available as tiles of 1,000 by 1,000 km. The EU-DEM is a 3D raster dataset with elevations captured about every 30 m. Other aspects of the maps were produced using the Sweden shapefile Map Layers that were obtained from the global community-owned project OpenStreetMap and downloaded from the MapCruzin website (Meuser, 2019).

2.5 DATA PREPARATION AND ANALYSIS

All data manipulations and statistical analyses were performed in R version 4.1.3 (R Core Team, 2021).

Every analysis was carried out for two groups: the total ruderals and the non-native ruderals only (see all model variables in Table 2.2). In almost all analyses, the observational year and the first year of observation were treated as a continuous variable (numerical), to account for sequential relationships between years, and as a discrete variable (factor levels), to account for the uneven distances between each time step. We therefore subsequently used a combination of generalized linear models or linear models (for continuous data) and analysis of variance models (ANOVAs; for factorial data) to analyze our data. Post hoc pairwise comparisons testing for the ANOVA-models was done with the Tukey HSD method. Model selection was carried out separately for models containing the observational year or the first year of observation on a continuous and a discrete scale. Analyses consisting of a dependent variable with count data (number of species) were analyzed using generalized linear models (function *glm*, *poisson* or *quasipoisson* distribution), otherwise linear models were used (function *lm*). One-way or Two-way ANOVAs were applied, depending on the number of independent variables analyzed. One exception arose for the analysis of the number of ruderals as a function of the observational year and MAAT (SM Tables 13 and 14). For this analysis no ANOVA was possible as for one factor level in MAAT (namely 1.0°C) no average could be taken since only one observation was present for this level.

Importance of interactions were first tested with the *drop1* function. This function is appropriate for *glm*, *lm*, and ANOVA depending on the test used: F for *lm* and ANOVA, Chisq for *glm*. It returns the terms that can be considered for dropping when not significant. We then identified the best fitting models using the Akaike Information Criterion with a correction for smaller sample sizes (AICc) from the AICcmodavg package (Mazerolle, 2020).

TABLE 2.2

Dependent and independent variables used in the statistical analyses.

Dependent variables	Independent variables
Total ruderal count or non-native ruderal count (per subregion or transect or Trail ID)	Native status Transect Subregion Observational year First year of observation (per subregion) First year of observation in the whole region Mean Annual Air Temperature (MAAT) [modelled] Mean Summer Soil Temperature (MSST) Distance to the railroad Distance to the road Elevation
Elevational maximum (along the MIREN trails) (total ruderals or non-native ruderals)	First year of observation to the whole region EIV-T Trail ID (Björkliden and Låktatjåkka trail)
EIV-T	Subregion Observational year First year of observation (per subregion)
Z-scores (of species abundances)	Total ruderal count Transect First year of observation Native status

For the analysis of the total and non-native ruderal count as a function of the distance to the railroad and the mean summer soil temperature (MSST), we centered the MSST at its sample mean (subtracting the sample mean of each value) to make interpretation easier (SM Tables 15 and 16; Schielzeth, 2010). There is an advantage in centering data as statements can be made about the average change in the response variable to the first independent variable while the second independent variable is at its sample mean, i.e., the slope between Y and X2 doesn't change. In the presence of an interaction, centering enables the interpretation of the intercept and main effects, that are less meaningful otherwise (Schielzeth, 2010). While the two models (original and with centered data) have different parameters, they are statistically equivalent, meaning that the substantive meaning and the made predictions are the same.

Normality of the residuals was checked with the Shapiro-Wilk test of normality; the cut-off value was 0.90. For datasets with observations greater than 5,000, we checked the distribution with a histogram, as the Shapiro-Wilk test overpredicts non-normality for large datasets. The 'elevational maximum of non-native ruderals' was the only variable that was skewed (SM Table 24), we therefore used a log-transformation to obtain a normal distribution. Outliers were identified using the Cook's distance; cut-off value was -3 to 3 (Cook, 1977). When more than one outlier occurred, we visually checked their effect on the regression line by plotting a robust linear model with the *rlm* function from the MASS package (Ripley, 2022) on top of the linear model and highlighted the outlying datapoints. Outliers were assumed to not have an influence (their effects canceled each other out) when the robust regression line visually followed the linear regression line. If the robust regression line deviated from the linear regression line, the outliers were removed one-by-one.

In multiple regression analyses, we checked for possible multicollinearity of independent variables by calculating the variance of inflation (vif) factors using the *vif* function from the car package (Fox & Weisberg, 2011). The vif was used for two models. First, when testing for the total and non-native ruderal count as a function of the distance to the railroad, and the road and the MSST, no multicollinearity was detected between the railroad and the road (vif < 5), but the AICc revealed that the road did not explain any additional variation to our model anyway (SM Table 15 and 16). Second, when testing for the mean *Z*-scores as a function of the total ruderal count and distance to the railroad, multicollinearity was detected between the total ruderals and the distance to the railroad (vif > 5). Distance to the railroad was then removed from our model (SM Table 16).

To assess compositional dissimilarities between subregions and observational years, we calculated the Beta diversity to characterize species heterogeneity of a given temporal community (Anderson et al. 2010). Dissimilarities between communities can arise from two different processes: species replacement and richness differences. Replacement (or turnover) is the exchange of species in communities through time and space. Species tend to replace each other in time and over ecological gradients. Richness differences (or nestedness) is the difference in the number of species between communities. This considers that a subset of species from community A exists in community B (overlap). The beta diversity is calculated using the *beta.div.comp* function and the contributions of each temporal community is calculated using the *LCBD.comp* function, both from the adespatial package (Dray, 2022). The Jaccard dissimilarity calculates the unique species as a proportion of the total number of species occurring in two communities. We used the Jaccard coefficient of the Podani family and computed the quantative forms of turnover and nestedness (Podani, 2021). The Jaccard dissimilarity index is defined as: *Jaccard = (b+c)/(a+b+c)*, whereby *a* is the number of the shared present species (overlap), *b* is the number of species present in community A but not in community B, and *c* is the number of species present in community B but not in community A.

To visualize the dissimilarities in vegetation composition between subregions and observational years, we conducted a Principal Coordinates Analysis (PCoA, = Multidimensional scaling, MDS). PCoA is an ordination technique to explore and visualize dissimilarities in species composition of data by focusing on distances. The more similar the compositions are, the closer together they are plotted. Distances are calculated with the function *vegdist* from the Vegan package (Oksanen, 2022), and from this distance matrix the principal coordinate scaling was computed with the *pcoa* function from the ape package (Paradis, 2022). We used the Jaccard distance which is defined as: *Jaccard distance = 2B/(1+B)*, where *B* is the Bray-Curtis dissimilarity. Bray-Curtis dissimilarity usually focusses on the abundance of dissimilarity, but by specifying *binary = TRUE* in the function it calculates distances based on presence-absence data. The obtained dissimilarity is a number between 0 and 1 – this value is 0 when two datasets share all the same species, and 1 when they do not share any species.

Graphs were constructed with the *ggplot* function from the ggplot2 package (Wickham, 2016), and prediction plots with the *plot_model* function (type prediction) from the sjplot package (Lüdecke, 2021).

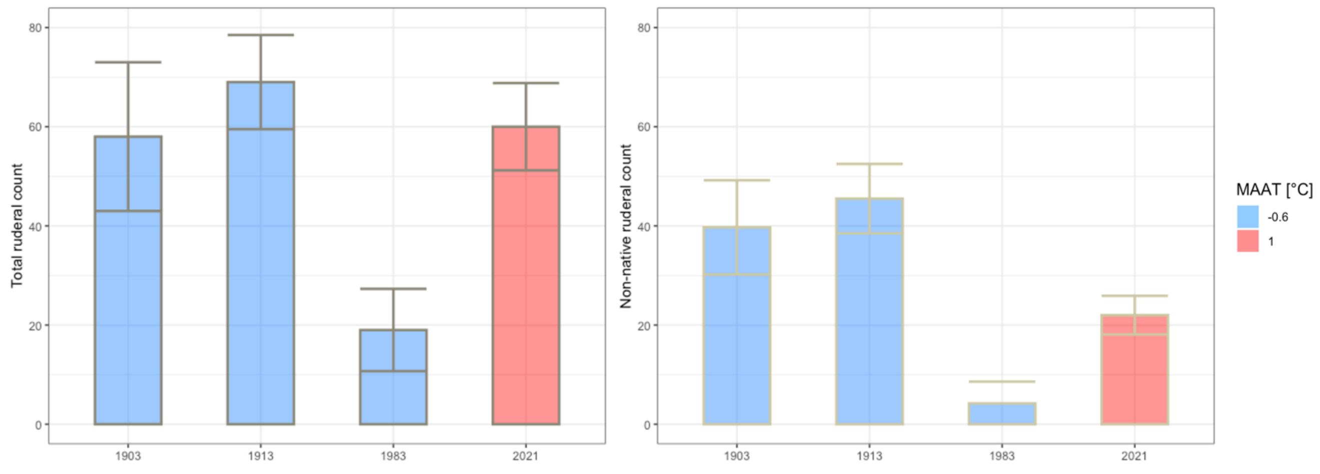
3. RESULTS

1. WHAT ARE THE TEMPORAL DYNAMICS OF RUDERAL SPECIES INTRODUCTIONS, AND DO THESE DYNAMICS CORRELATE MOST STRONGLY WITH CLIMATE AND/OR LAND USE CHANGE DISTURBANCE?

1.1 What are the temporal dynamics of ruderal species along the Rallarvägen?

1.2 Are ruderal species that have established after railroad or road building, moving due to climate or disturbance?

Unexpectantly, the total number of ruderal species did not increase significantly over time from 1903 till 2021 (SM Table 1 [*glm*, *quasipoisson*, $t_{11} = -0.32$, $p = .8$]). When treating year as a factor rather than a continuous gradient, we saw that the total number of ruderals differed significantly in observational year 1983 compared to 1903, 1913, and 2021, with highest richness values surprisingly in the historical records (1913) (Fig. 1 (left), SM Table 2 [ANOVA $F_{3,14} = 23.66$, $p < .001$]). The number of non-native ruderal species did decrease significantly over time (SM Table 3 [*glm*, *quasipoisson*, $t_{16} = -3.45$, $p = .003$]), also when year was treated as a factor (Fig. 1 (right), SM Table 4 [ANOVA $F_{3,14} = 44.31$, $p < .001$]). Here again, 1983 showed the lowest richness. For non-native ruderals, subregions did not explain any additional variation. Mean Annual Air Temperature (MAAT) increased significantly between 1983 till 2021, in parallel with the observed increase in (non-native and all) ruderals (Fig. 1, SM Tables 5-6).



Data: Historical and ANS

Figure 1 | Average ruderal species richness over time along the Rallarvägen. Total number of ruderal species (**left**) and the number of non-native ruderal species (**right**) as a function of the observational year (SM Table 1 to 4) and as a function of the observational year and Mean Annual Air Temperature (MAAT) (SM Tables 5-6). Data are average number of spec ies over all present total ruderals (n = 239) and non-native ruderals (n = 100) per subregion in the historical dataset. Modelled values for MAAT for observational years 1903 (-0.58 °C), 1913 (-0.61°C), and 1983 (-0.60) all roundup to -0.6 °C and are thus placed in the same category to make visual interpretation easier. MAAT values are shown in classes for clarity, -0.6 °C (in blue) and 1 °C (in red). Error bars denote ± s.d. Model coefficients and p-values are shown in Supplementary Tables 1 to 4 and 5-6.

Surprisingly, the mean community temperature index (expressed as mean EIV-T value per subregion per time step) was also higher in historical records than in recent times. For total ruderal species, there was additionally a significant interactive effect of observational year and subregion (Fig. 2 (left), SM Table 7 [*lm*, $t_{873} = 2.43$, $p < .001$]). This result was supported when year was treated as a factor (SM Table 8 [ANOVA $F_{9,867} = 3.02$, $p = .001$]), with mostly lowest EIV-Ts in general observed in 1983 and highest in 1903 and 1913 (except for Kopparåsen). In 2021, the EIV-Ts are on average increasing again, yet still lower than in 1903 and 1913. Mean community temperature index for non-native ruderal species decreased gradually through time (Fig. 2 (right), SM Table 9 [*lm*, $t_{451} = -6.11$, $p < .001$]). When year was treated as a factor, it differed significantly for observational year 2021 compared to 1903 and 1913 (SM Table 10 [ANOVA $F_{3,449} = 12.6$, $p < .001$]). For non-native ruderals, subregions did not explain any additional variation.

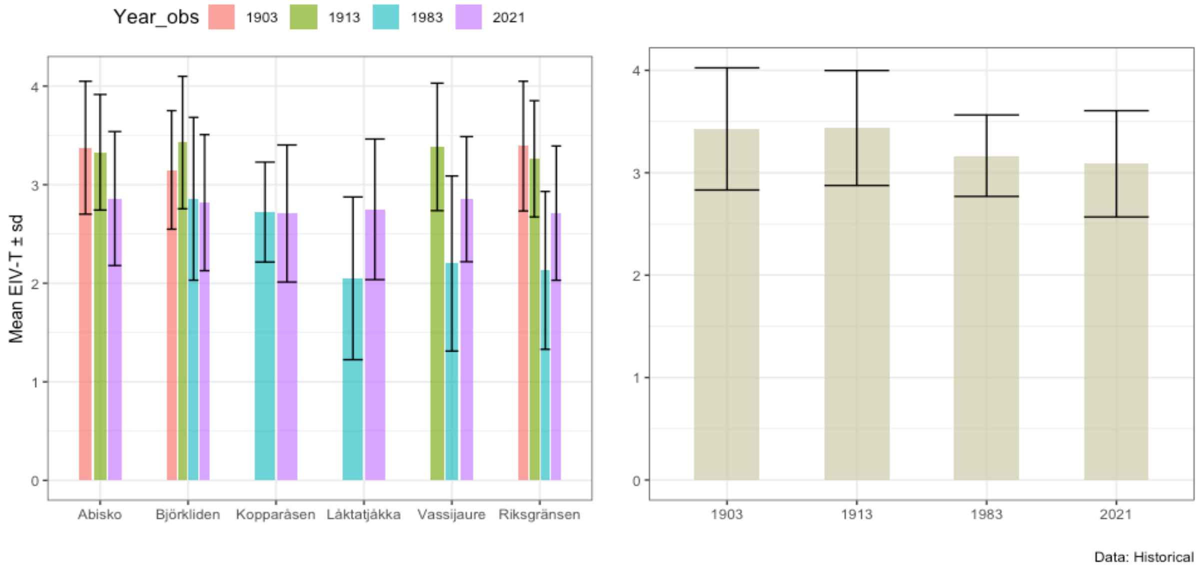


Figure 2 | Community temperature index of ruderal species observed over time. Ecological Indicator Values (EIV-T) of the total number of ruderal species (**left**) as a function of the observational year (Year_obs) and subregion, and the EIV-T of the number of non-native ruderal species (**right**) as a function of the observational year. Data are averages over all present total number of ruderals (n = 239) and non-native ruderals (n = 100) per subregion in the historical dataset. Error bars denote ± s.d. 1903 (red), 1913 (green), 1983 (blue), 2021 (purple). Subregions ordered from East (Abisko) to West (Riksgränsen). Model coefficients and p-values are shown in Supplementary Tables 7 to 10.

Similar trends occurred for the mean community temperature index as a function of the first year of observation in a subregion. For total ruderal species, there was a significant interactive effect of first year of observation and subregion (SM Table 11 [*lm*, $t_{611} = 2.80$, $p < .001$]), while for non-native ruderals the EIVT-s decreased gradually through time (SM Table 13 [*lm*, $t_{282} = -5.52$, $p < .001$]). When year was treated as a factor, historical introductions showed significantly higher EIV-Ts (1903, 1913) than more recent introductions (1983, 2021), for both total ruderals (Fig. 3 (left), SM Table 12 [ANOVA $F_{3,619} = 87.33$, $p < .001$]), and non-native ruderals (Fig. 3 (right), SM Table 14 [ANOVA $F_{3,280} = 13.31$, $p < .001$]). Subregions did not explain any additional variation for the total ruderals when year was treated as a factor (seen in Fig. 3), and for non-native ruderals when year was a continuous gradient and treated as a factor.

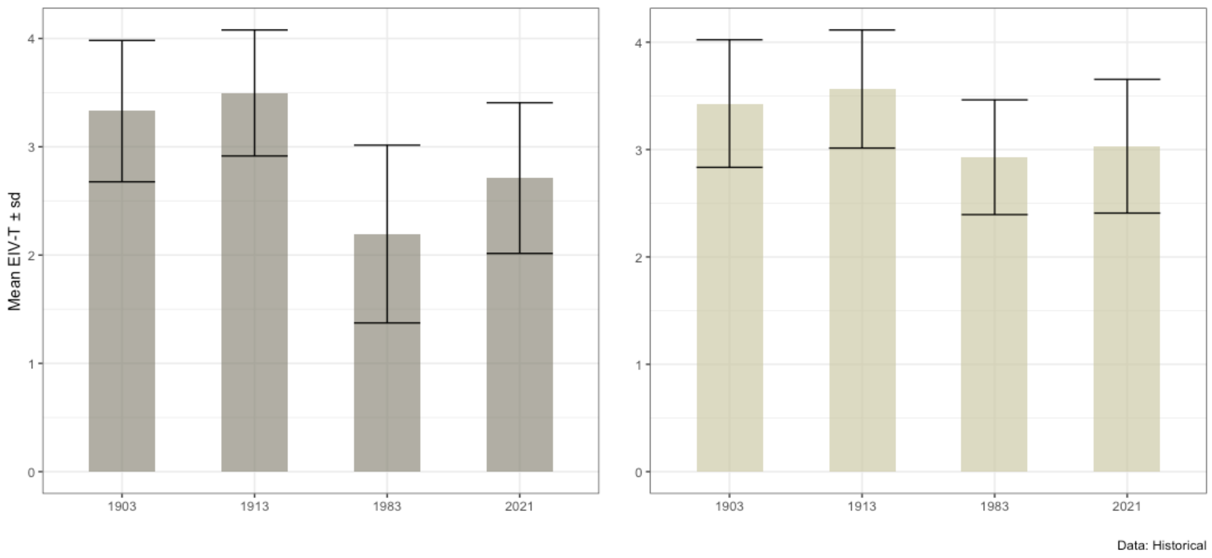


Figure 3 | Community temperature index of ruderal species as a function of their first year of observation. Ecological Indicator Values for Temperature (EIV-T) of the total number of ruderal species (**left**) as a function of the year of first observation to a subregion. EIV-T of the number of non-native ruderal species (**right**) as a function of the first year of observation. Data are averages over all – first time observed – total number of ruderals (n = 239) and non-native ruderals (n = 100) per subregion in the historical vegetation dataset. Error bars denote ± s.d. Model coefficients and p-values are shown in Supplementary Tables 11 to 14.

Many ruderals, and mostly non-natives, with an EIV-T of 4 and higher have disappeared from the region between 1903-1913 and 1983-2021 (see SM Table 28). As a result, the average EIV-T was 1.3 times higher in the beginning of the 20th century, surprisingly despite the cooler climate at the time. In more recent years (1983-2021), the average EIV-T of the total ruderal community was relatively low but increased again with non-native introductions (Fig. 3). Additionally, vegetation composition along the Rallarvägen has proportionally declined in non-native species throughout the 20th century. These lost species were thus largely responsible for the decline in EIV-T that we have discussed previously (Figs. 2 and 3). Indeed, proportions of non-native ruderals were highest in the historical records (0.66) and then declined in 1983, with only a partial recovery in 2021 (1903: 54/82 (0.66), 1913: 69/104 (0.66), 1983: 14/57 (0.25), 2021: 36/94 (0.38)).

Beta diversity of total ruderal communities between observational years equaled 0.387, of which 56% resulted from turnover, and 44% from nestedness (Table 3.1). Hence, differences between the communities were most strongly related to species replacement.

TABLE 3.1

Beta diversity (Jaccard dissimilarity) between subregions and observational years, and the proportion to which the Beta diversity is partitioned into turnover (Turn/BDtotal) and nestedness (Nest/BDtotal).
BDtotal = total Beta diversity.

BDtotal	Turnover	Nestedness	Turn/BDtotal	Nest/BDtotal
0.3874205	0.2157136	0.1717069	0.5567946	0.4432054

Communities were more dissimilar between surveys than subregions (Fig. 4). Only in 1983 there is a lot of variation between subregions. In addition to possible monitoring differences between publications, we expected 1983 to be an anomalous year due to the weather conditions that summer (see Chapter 2, Table 2.1). The excessive rain could have delayed the onset of the growing season, with significant implications for the detection of annual species. We therefore identified the life cycle for each ruderal species which revealed a low number of annuals that year (1903: 44/82 = 0.54, 1913: 51/104 = 0.49, 1983: 7/57 = 0.13, 2021: 15/94 = 0.16) (see SM Table 33 for the number of annuals per subregion).

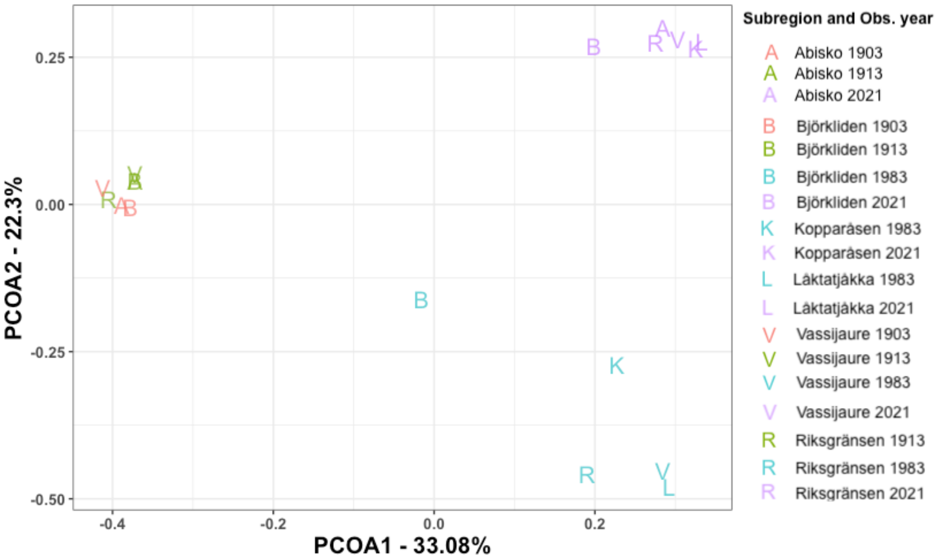
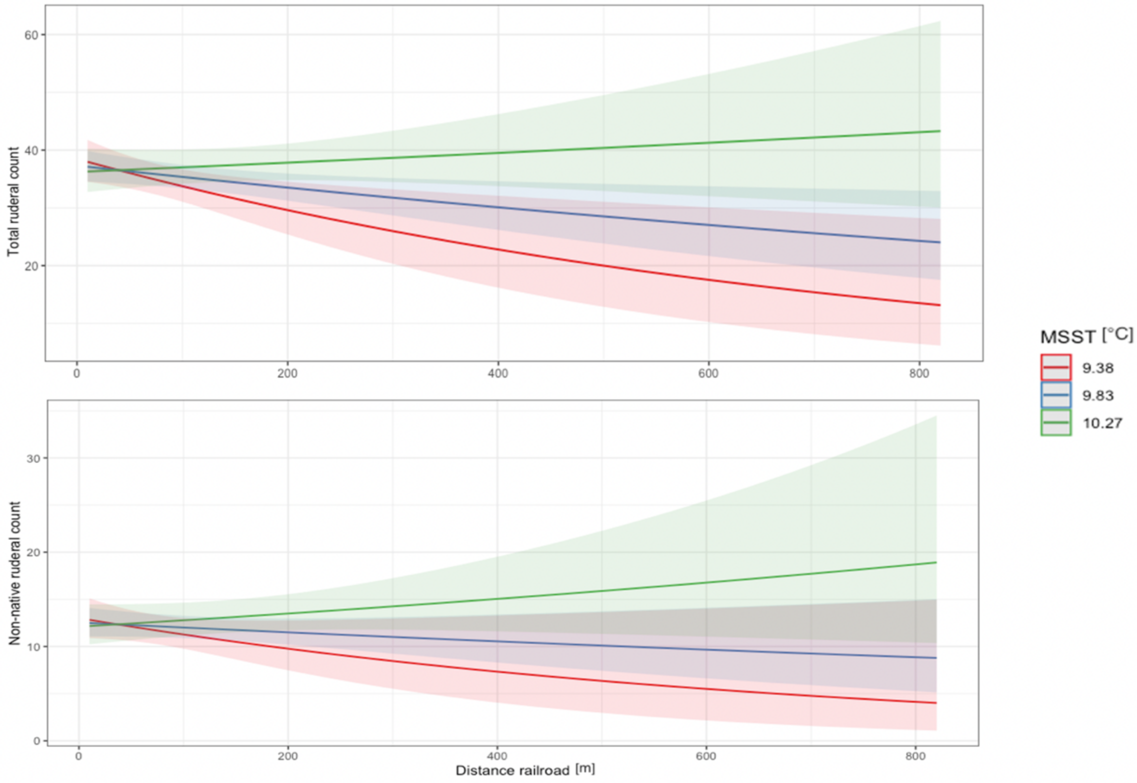


Figure 4 | Dissimilarities between temporal ruderal species communities in different subregions. Principle Coordinate Analysis (PCoA) on the dissimilarities in ruderal compositions between subregions and observational years (Subregion and Obs. year). 1903 (red), 1913 (green), 1983 (blue), 2021 (purple). Abisko (A), Björkliden (B), Kopparåsen (K), Låktatjåkka (L), Vassijaure (V), and Riksgränsen (R). Distances are calculated based on presence-absence data with the Jaccard distance (with Bray-Curtis dissimilarity). The first principal coordinate accounts for 33% of the variation, the second for 22%.

2. IS THE SPATIAL EXPANSION OF RUDERAL SPECIES SINCE INTRODUCTION IN THE ABISKO REGION MOSTLY LIMITED BY CLIMATE OR DISTURBANCE?

2.1 Are current ruderal species distributions related to land use or climate?

The predicted number of total ruderal species and non-native ruderal species declined with distance to the railroad in all but the warmest parts of the gradient, where these numbers increased slightly with distance to the railroad (Fig. 5, SM Table 15-16). The estimated average total number of ruderal species is 37.7 and non-native ruderal species is 12.5 for a transect with a mean distance of 154.9 m and mean MSST of 9.8 °C. No multicollinearity was detected between the road and railroad (vif < 5), but the road did not explain any additional variation in our models. No additional variation was explained by the mean winter soil temperature, the mean annual soil temperature, and the soil pH.

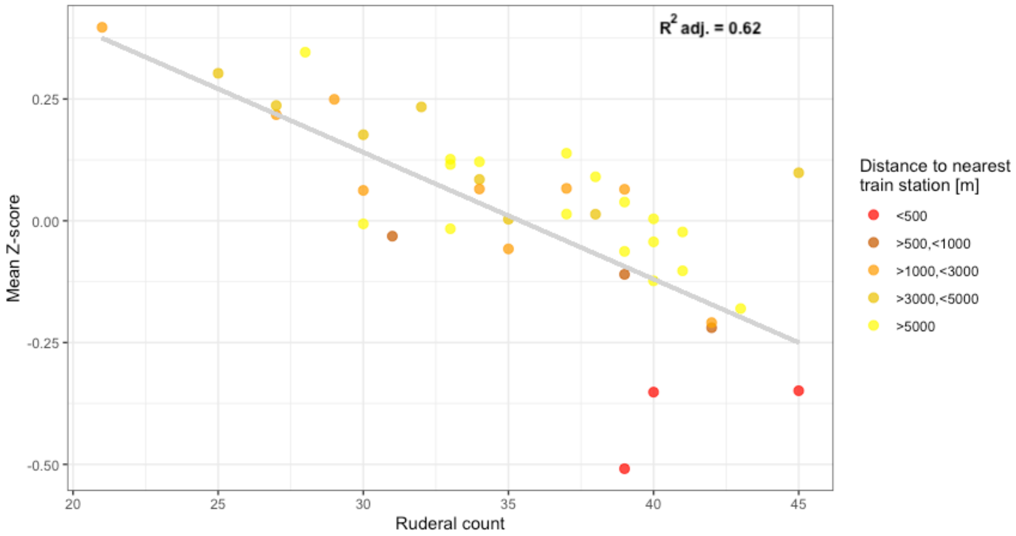


Data: Rallarvägen 2021

Figure 5 | Effects of Mean Summer Soil Temperature (MSST) and distance of the Rallarvägen trail to the railroad on the number of ruderal species. Total number of ruderal species (**top**) and the number of non-native ruderal species (**bottom**) per 1-km transect along the Rallarvägen as a function of distance to the railroad (x-axis, in m) and MSST (in °C, green, blue, and red lines). To make interpretation easier we centered the covariate MSST at its sample mean (see methods). Graphs are prediction plots with the estimated marginal effects. Lines show model means (blue) with standard deviation (green and red); shading shows standard deviations from model predictions. Raw datapoints are not shown for clarity. Model coefficients and p-values are shown in Supplementary Tables 15 and 16.

2.2 Is the anthropogenic pressure gradient acting as a filter on ruderal species?

We next investigated the abundances (expressed as *Z*-scores per species over all transects) of all current ruderal species present along the Rallarvägen. The average *Z*-score of a transect – and thus how common the average ruderal species in it is – decreased significantly with increasing number of ruderal species (Fig. 6, SM table 17 [*lm*, $t_{38} = -7.97$, $p < .001$]).

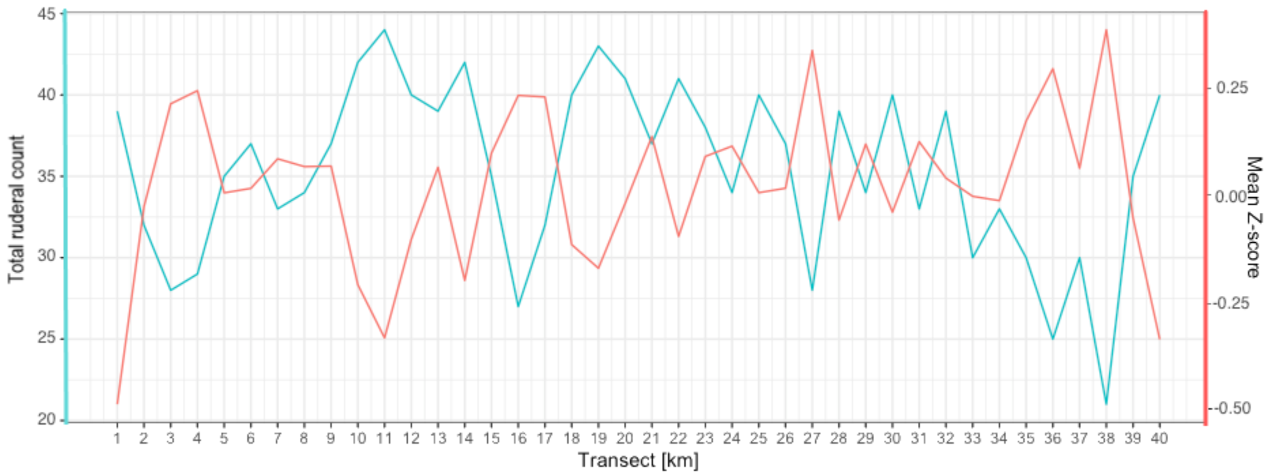


Data: Rallarvägen 2021

Figure 6 | Relationship between ruderal species abundance (expressed as mean *Z*-scores of all species per transect, with a higher Z-score indicating more common species, see methods) and the total number of ruderal species (in counts) along the Rallarvägen. Colors indicate the distance to the nearest train stations of Abisko, Björkliden, and Riksgränsen. Model coefficients and p-values are shown in Supplementary Table 17.

The combination of the average abundances with the total number of ruderal species identified transects with relatively low average abundances in relation to a high species count, indicating that rarer species are proportionally more present in plots with more ruderals. These transects accommodate many different species that rarely occur elsewhere along the trail. As seen in Figure 7, these transects are mainly located at train stations and/or settlements, e.g., transects 1, 10, 11, and 40. Transects in more natural areas, further away from the railroad/train stations, have higher average *Z*-scores, e.g., transects 27, 36, and 38, suggesting that rare ruderals are more present close to the disturbances, while common ruderals are present everywhere along the trail. Distance to the railroad did not explain any additional variation. SM Figures 2 and 3 list the *Z*-score abundances of all native and non-native ruderal species, respectively.

In addition, new ruderal species introductions in subregions in 2021 mainly occurred between Björkliden and Kopparåsen, that presumably having spread from Björkliden train station (see SM Figs. 4 and 5).

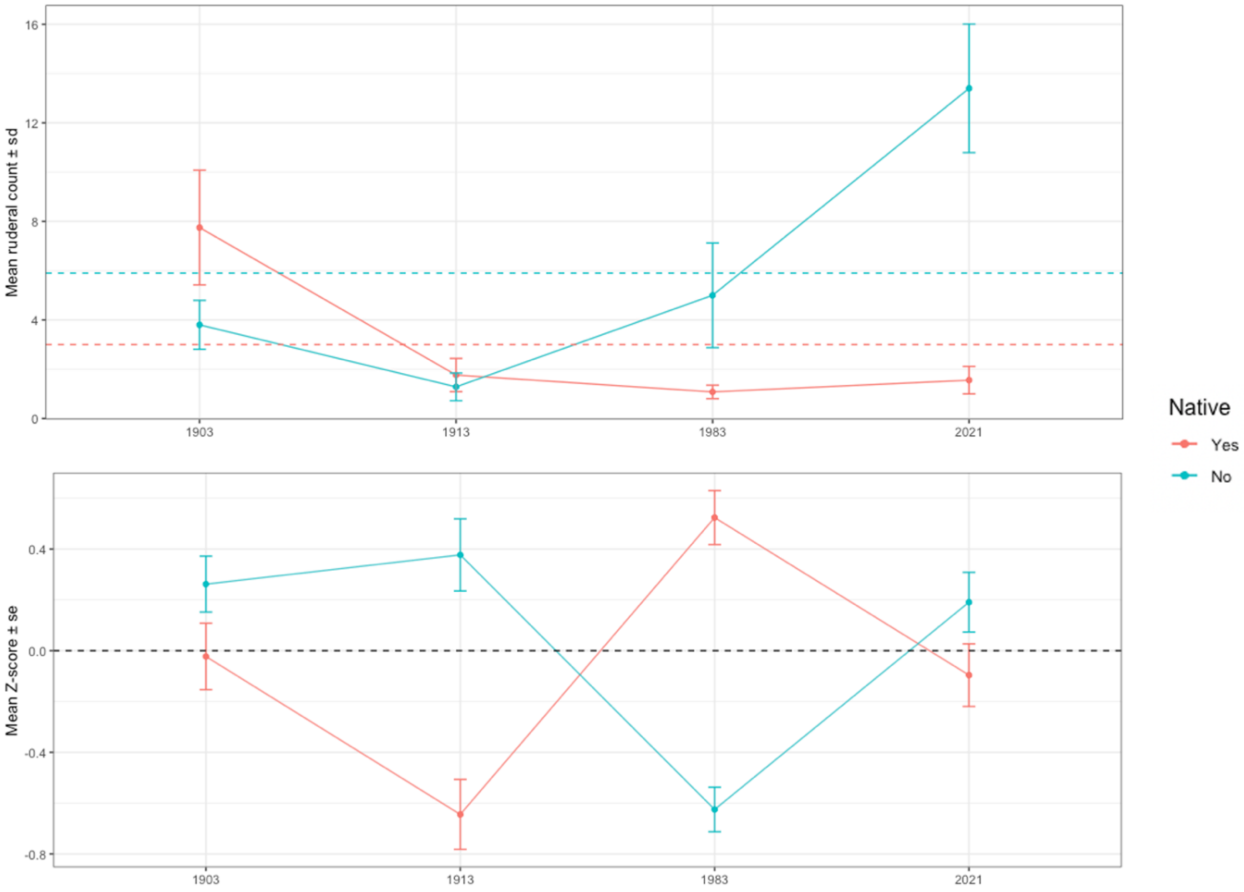


Data: Rallarvägen 2021

Figure 7 | Relationship between total number of ruderal species and average abundances (*Z*-scores) per 1-km transects along the Rallarvägen from east to west. Ruderals (counts, in blue), abundances (*Z*-scores, in red). Ruderals average abundance = 14.9 transects (*Z*-score = 0). Average number of ruderals per transect = 35.5 ruderals. Transects 1, 10-11, and 40 have the lowest mean abundance (train stations and settlements). Transects 16-17, 27, 33-36 have high mean abundances (more natural areas).

2.3 Do non-native ruderals reach long-term establishment in the Abisko region?

As described above, the average abundances decrease with the total number of ruderal species across transects. Additionally, we found significant interactions for the first year of observation to the whole region and native status, for both the total number of ruderal species (Fig. 8 (top), SM Table 18 [*glm*, *poisson*, $z = 19.94$, $p < .001$]) and the average abundances (Fig. 8 (bottom), SM Table 19 [ANOVA $F_{39,1365} = 31.29$, $p < .001$]). Native species, observed for the first time in 1983 (e.g., *Omalotheca norvegica* (Gunnerus) Sch.Bip. & F.W.Schultz and *Stellaria nemorum* L.), were fewest in numbers but together were on average most abundant in 2021. Interestingly, most non-native species that were found along the Rallarvägen in 2021 were recent introductions, as also described earlier, indicating that non-native species did not survive well in the region. Nevertheless, non-native species that had persisted since their introduction in 1903 and 1913, were species that had above average abundances.

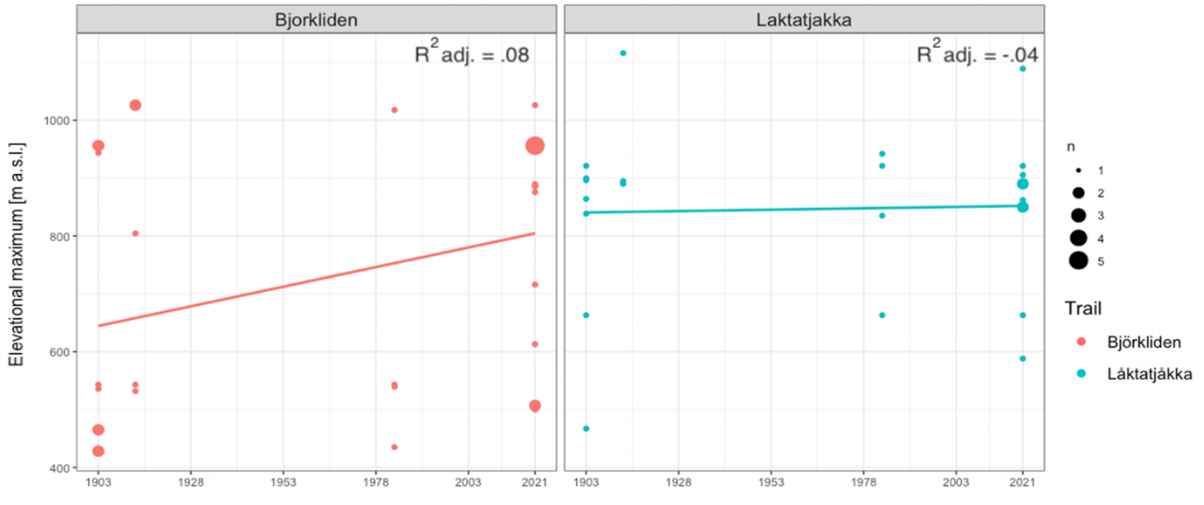


Data: Historical and Rallarvägen 2021

Figure 8 | Relationships between current total number of ruderal species (**top**) and abundance (**bottom**) and the first year of observation for native and non-native species along the Rallarvägen. Total number of ruderal species and abundances as a function of their first year of observation to the whole region and native status. Total number of ruderals are average number of species per transect, the abundances are averages per transect normalized with *Z*-scores, error bars denote s.d. and s.e., respectively. Natives in red, non-natives in blue. Dashed lines (**top**) indicate average counts per first year of observation, native status, and transect (n_{red} = 3, n_{blue} = 5.9). Dashed line (**bottom**) indicates the average abundance (n = 14.9 transects). Model coefficients and p-values are shown in Supplementary Tables 18 and 19.

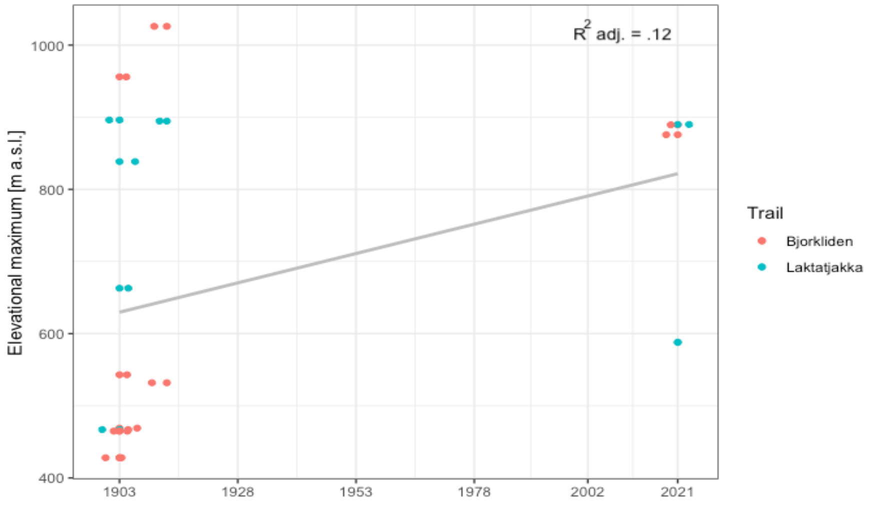
2.4 Are ruderal species moving uphill?

The mountain T-trail dataset contains 39 ruderal species of which 12 are non-native to the region (SM Table 35), corresponding to 37% and 33% of the current ruderal community along the Rallarvägen, respectively. For total ruderal species, linear regression revealed that the average elevational maximum was significantly higher for the Låktatjåkka trail compared to the Björkliden trail (SM Table 20 [$t_{57} = 2.25$, $p = .03$]). The elevational maximum showed a positive association with the first year of observation in the whole region for the Björkliden trail (Fig. 9 (left), SM Table 22 [$t_{34} = 2.03$, $p = .05$]), yet not so for the Låktatjåkka trail (Fig. 9 (right), SM Table 23 [$t_{22} = 0.17$, $p = .9$]). When treating year as a factor, results were the same (SM Table 21). For non-native ruderals as well, a marginally significant positive association was found between the elevational maximum and the first year of observation to the whole region (Fig. 10, SM Table 24 [$t_{17} = 1.75$, $p < 0.1$]). This was confirmed when we treated year as a factor (SM Table 25). We did not detect any differences between the two mountain trails here and there were no non-native ruderals introduced in 1983 on the mountain trails. There was no additional variation explained by EIV-T for both total ruderals and non-native ruderals.



Data: T-trails and Historical

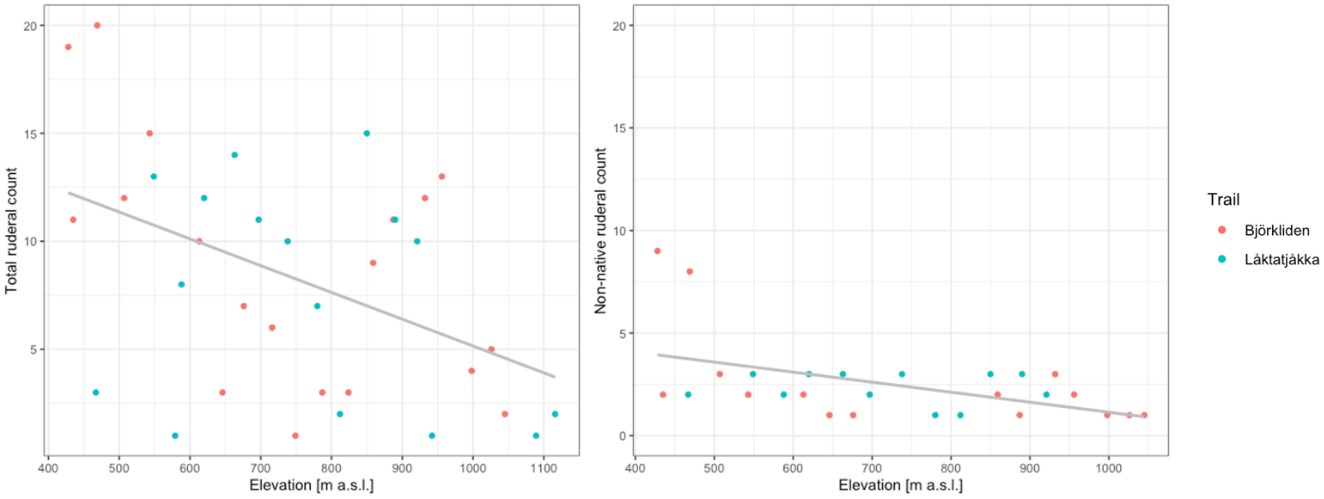
Figure 9 | Relationship of ruderal species elevational occurrence in time on two hiking trails. The elevational maximum for total ruderals as a function of the first year of observation in the whole region. On the **left** the Björkliden (in red) and on the **right** the Låktatjåkka (in blue) mountain trails, n indicates the number of species per datapoint ($n_{total} = 39$). The elevational maximum is defined as the 95th percentile, calculated from a species' elevational occurrences. Model coefficients and p-values are shown in Supplementary Tables 20 to 23.



Data: T-trails and Historical

Figure 10 | Relationship of non-native ruderal species elevational maximum in time. The elevational maximum for non-native ruderals as a function of the first year of observation in the whole region. Björkliden (in red), Låktatjåkka (in blue). Datapoints are non-native ruderal species in the mountain T-trail vegetation dataset (n = 12) and are jittered with 40% in width (x-axis). The elevational maximum is defined as the 95th percentile, calculated from a species' elevational occurrences. There were no species observed with 1983 as the first year of observation. Model coefficients and p-values are shown in Supplementary Tables 24 and 25.

As expected, we found a significant negative association between richness and elevation for total ruderals (Fig 11, SM Table 26 [*glm, quasipoisson,* t_{33} = -2.88, p = .007]), and a similar negative, but less pronounced, relationship was found for non-native ruderals (Fig. 11, SM Table 27 [*glm, poisson, z* = -3.01, p = .003]). There were no significant differences in these relationships between mountain trails for both total ruderals and non-native ruderals.



Data: T-trails

Figure 11 | Relationship between ruderal species richness and elevation on two different mountain trails. Total number of ruderal species (**left**) and the number of non-native ruderal species (**right**) as a function of elevation and mountain trail identity. Data are in number of species per transect (**left** n = 39, **right** n = 12). Björkliden (in red) and Låktatjåkka (in blue) mountain trails. Model coefficients are shown in Supplementary Tables 26 and 27.

4. DISCUSSION

Ruderal species compositions changed dynamically through time

For the first research question we expected to find an increase of ruderal species over time as nowadays climate change and disturbances are simultaneously impacting the vegetation composition, and both have shown to be advantageous for ruderal species (Chiuffo et al. 2018; Guo et al. 2018; Thuiller et al. 2005). Surprisingly, however, ruderal species were most numerous along the Rallarvägen in the historical years during the time of the railroad building and settlement expansion (Fig. 1). The building of the E10 road before 1983 did not have the same impact. On the contrary, ruderal species observations suddenly dropped in 1983, to rise again in 2021 to similar, yet slightly lower, numbers as in the historical years. Even though we thus observed a clear increase in ruderal species observations from 1983 to 2021, concurrent with an increase in mean annual air temperature (MAAT), we cannot make confident conclusions about a climate change effect in the total ruderal community (Fig. 1). The drop in 1983 was at least partially an anomaly (see further below), and we thus must consider the total number of ruderal species to have been roughly constant through time.

Non-native ruderals, on the other hand, have significantly decreased in numbers over time (Fig. 1), but proportionally show a similar trend to the total number of ruderal observations in the community: with the highest contribution in 1903-13 (66%), a drop in 1983 (25%), to rise again in 2021 (38%). Ordination of the temporal communities and subregions revealed very dissimilar vegetation compositions (Fig. 4). This further substantiates that, although the total ruderal community is quite stable in numbers, the temporal compositions are very dynamic.

What is more, patterns in the community temperature index (expressed as the Ecological Indicator Values for Temperature; EIV-T) revealed that both a disturbance and climate change can cause an influx of warm-adapted species to the Abisko region (Figs. 2 and 3). We observed most warm-adapted species as a result from railroad building, with only little evidence of an influx of warm-adapted species due to climate change in recent years. Our data shows that 36 (mostly non-native) ruderal species with high EIV-Ts (≥ 4) in the historical years, have disappeared by 1983, not to recover in 2021 (SM Table 28). Those early warm-adapted ruderal introductions did not manage to sustain a population, which is potentially due to a combination of harsh winters and the lack of continuous disturbance (Niittynen & Luoto, 2017; Rendeková et al. 2019).

Ruderal distributions in 2021 confirm this diminishing effect in dominance (Fig. 8). Most non-native ruderals along the Rallarvägen in 2021 were recent introductions. We observed that non-natives that were first observed in 1903-13 were on average particularly low in numbers but were very abundant along the trail. This leads us to believe that indeed many ruderals disappeared again over time, yet that the few that do become permanently established are dispersing successfully (Rendeková et al. 2019). In time, ruderal species were thus again outcompeted by native species that thrive in subarctic mountainous environments – demonstrating community resilience. However, as climate change progresses, we expect that warmer temperatures might tip the scale, allowing subsequently introduced warm-adapted non-native species to gradually establish successfully in areas where disturbance is prominent. When this would be in congruence with the die-off of native specialist heathland species, this might change the outlook of the subarctic vegetation compositions as we know it.

Deviations in 1983

The anomaly in our data of species observations in 1983 is interesting and yet to be expected when we consider the following aspects: 1) monitoring differences, 2) weather conditions, 3) disturbance intensity.

The vegetation survey of Lewejohann & Lorenzen (1983) is not fully complete from our point of view. Their survey was conducted during the same month (July) as Sylvén's surveys (1904 and 1913-15) and our own, but the covered area was much larger – they covered 20 areas in one summer. This warns for caution when we interpret their data as they presumably had the time to survey the whole area only once, therefore likely missing ruderal species that appear later in the season. We also noticed that their data missed perennial species such as *Trifolium pratense* L., *Trifolium repens* L., and *Vicia cracca* L. (SM Table 31). These species were present in 1903 and 1913 and are currently very abundant along the Rallarvägen trail (SM Tables 29-30 and SM Fig. 3). Even when these ruderal species are not flowering, they are quite distinguishable. It can therefore be argued that there has occurred some selectivity in documenting species during their survey. An unexpected discovery, as Lewejohann & Lorenzen set out to survey vegetation changes following the disturbance caused by the building of the E10 road, and thus should have shown particular interest in ruderal species (Lembrechts et al. 2014). We did learn that tourism in the area declined significantly in the early 1980s due to the bankruptcy of the tourist station. Consequently, we cannot exclude a recovery period from ruderal dominance in the vegetation, but this is from our point of view unlikely as the train stations would have seen continuous disturbance, even in those days. We do believe that all survey locations are still comparable as the landmarks in the surveyed villages have remained the same since 1903: the train stations have always been an anchor point for the villages. Inaccuracies in the 1983 data thus likely arise from the number of species observed (Fig. 1), more so than the dynamic composition changes that occurred over time (Table 3.1 and SM Table 28).

1983 is also an anomalous year in terms of weather conditions (see Table 2.1). Summer temperatures were on average 1 °C lower than in 1913, and summer precipitation was exceptionally high (238.8 mm). Snow cover and snowmelt timing are among the important drivers of structuring subarctic community composition and distribution (Wipf, 2010). Depending on the thickness, snow cover insulates species from the harsh winter conditions as it decouples the soil surface temperature from the air temperature (Niittynen & Luoto, 2017). If the snow layer disappears too early, the species underneath will be exposed to the spring frost. Snowmelt timing determines the growing season length (Niittynen & Luoto, 2017; Wipf, 2010). Moderate rainfall can speed-up the snow-melting process, expediting the onset of the growing season. Heavy rainfall, on the other hand, causes temperatures to drop, potentially reducing a species' possibility to exploit the whole growing season (Li et al. 2019). Such negative effects are especially disadvantageous for annual species as they do not get the chance to adapt their physiology and/or morphology like perennial plants do (Li et al. 2019). While we do not have information on the spring snow cover in 1983, the anomalous precipitation value could suggest that the latter happened.

The contribution of annual ruderals observed in 1983 is indeed rather low – about 13% – in comparison to other years: 54% in 1903, 49% in 1913, and 16% in 2021 (SM Table 33). Seven of 57 of the observed species in 1983 has an annual life cycle, and five of those occur at Björkliden. Interestingly, this is also the subregion in 1983 that accommodates species with highest average EIV-Ts (Fig. 2 (left)). The PCoA substantiates a certain degree of heterogeneity between the subregions in 1983 (Fig. 4), that is probably caused by the timing of observation, which seems of particular importance during that summer. Since Lewejohann & Lorenzen probably surveyed the area only once, the area around Björkliden was likely surveyed later in the season than the other subregions – the moment when the growing season was in full swing. Although the proportion of annual species does not differ much from 2021, the distribution of annual species along the Rallarvägen in 2021 is quite even across subregions – which indicates that our survey covered at least the entire growing season, which we achieved by surveying the whole trail twice.

Another aspect that we think contributed to the low number of ruderal observations in 1983, is the low disturbance intensity during the E10 road building between 1976 and 1982 (Bäck & Jonasson, 1998). We found that ruderal species distributions along the Rallarvägen are nowadays still clearly correlated to the railroad, rather than the road (Fig. 5). In contrast to the railroad construction, the road was not built using the Rallarvägen as a transport road, and hence its direct impact on the Rallarvägen vegetation has been significantly smaller. However, since the road has opened, it facilitates easier movement in and around the area by cyclists, cars, and trucks, and parking lots now enable hikers to enter the trail at almost all transects (SM Fig. 15) (Bäck & Jonasson, 1998; Frenkel, 1977; Lembrechts et al. 2014). The response in the vegetation along the Rallarvägen could therefore have been delayed and have not yet been detectable in 1983. Ruderal species are increasing again in numbers since then. Whether this is methodological, or disturbance, or climate related we do not know, but the proportionally rising number of non-native ruderal species is potentially an indication of a delayed response.

Directional Ecological Filtering on a horizontal gradient

The results for the second research question clearly show a climatic response on ruderal species distributions as the predicted number of both the total ruderals and non-native ruderals increased with distance to the railroad in transects where summer soil temperatures (MSST) reached above average values (10.3 °C; Fig. 5). This could indicate a potential role for climate change: if climate warms, this climatic limitation might weaken, allowing for non-natives to expand further. However, this again cannot be disconnected from the railroad as the interactive effect confirms our expectations that climate change and disturbances go together. Disturbance is yet again the strongest driver – especially for the total ruderal community – since the number of ruderals decreased significantly with distance to the railroad at average and below average MSST (9.8 and 9.4 °C; Fig. 5). This complies with studies that illustrate that disturbance is key for new plant species introductions (Alexander et al. 2010; Lembrechts et al. 2016b).

Average ruderal species abundances were negatively correlated with the total number of ruderal species per transect (Fig. 6), revealing a gradient from sites that accommodate relatively few and predominantly common ruderal species to sites that accommodate relatively many and often rare ruderals. Common ruderals were very abundant along the whole Rallarvägen, while rare ruderals do not or rarely do occur anywhere else along the trail. In other words, rare ruderals are expected to have been recently introduced or reintroduced to the Abisko region. Transects with train stations, such as Björkliden, Abisko Östra and Riksgränsen, are under continuous disturbance and appear to be the sites where rare ruderals reside and are thus (re)introduced (Fig. 7) (Brandes, 2002). From here they must spread out through local human-mediated dispersal (e.g., hiking) or on their own. In more natural transects along the Rallarvägen, few ruderals reside, and the ones present were only common species. Those sites are not easily accessible, lie further away from train stations, and are places where significant disturbance (outside of occasional hiking) only happened once (i.e., during railroad building) (Rendeková et al. 2019). Other transects at various distances from the train stations showed more variability in this relationship between the average abundance and the number of ruderals. Exact drivers for this relationship are therefore difficult to determine, but we believe it goes together with a certain degree of disturbance intensity. Distance to the E10 road, railroad, and train station, and hiking-intensity are all intertwined and sum-up to a certain degree of disturbance intensity that facilitates species dispersal (Kowarik, 2003; Pauchard et al. 2009). This correlation between human impact and ruderal species distributions demonstrates Horizontal Directional Ecological Filtering (HDEF). The term Directional Ecological Filtering (DEF) was first coined by Alexander et al. (2010) for elevational (climatic) gradients, but here we demonstrate that the term is applicable to a horizontal anthropogenic pressure gradient as well. The DEF hypothesis states that non-native species migrations happen from anthropogenically disturbed sites in the lowlands to higher altitudes on mountains, and that their richness declines with elevation but their elevational range increases with its maximum elevation (Alexander et al. 2010). Non-native species are thus progressively dropping out with increasing elevation. Unlike in the DEF, where climate harshness is considered the most likely filter, ruderal species originating at the train stations were here thus progressively filtered out with increasing distance to these introductory points as the degree of disturbance intensity declines. This leads us to believe that disturbance should not be ruled out as a critical driver of the DEF either. It can also not be ruled out that climate is at play in our system here – in fact, we do have the interaction between railroad and MSST as shown in Fig. 5 – but evidence here favors a disturbance driven HDEF, showing that such directional filters can still be strong when climatic gradients are minimal.

Migrations uphill are not necessarily determinant in time

The observed declining non-native ruderal richness with increasing elevation is consistent with other studies (Fig. 11 (right)) (Alexander et al. 2010; Dainese et al. 2017; Lembrechts et al. 2014; Liedtke et al. 2020; Wedegärtner et al. 2022). As discussed earlier, high anthropogenic pressure sites in the lowlands ensure quick and repeatable introductions of non-native ruderals and from here they evidently move uphill until they reach their (current and species-specific) elevational limit, resulting in decreasing richness with elevation, as stated in the DEF hypothesis (Alexander et al. 2010).

Non-native species invasions have recently been a topic of discussion in terms of climate change (Alexander et al. 2010; Asos et al. 2015; Dainese et al. 2017; Hulme, 2014; Pauchard et al. 2009; Walther et al. 2009). In mountainous areas, non-native species are found to reach high elevations as a response to a warming climate. In contrast to these studies, our results showed that non-native ruderal species distributions uphill in the region were not correlated to their climatic niche (EIV-T), but more so with their first year of observation to the whole region (Fig. 10). Newest introductions were residing on average farther uphill, evoking two possible interpretations. First, there is no visible uphill migration over time. This suggests that mountain migration of non-native species is not necessarily linear over time. Human-mediated dispersal is as said faster than climate change (Hulme, 2014), resulting in faster uphill migration or introductions that also happen farther uphill where no viable population can establish itself. This is in accordance with what we said earlier and suggests that the DEF is often as much disturbance-driven as it is climate-driven. These higher elevation populations might thus not be stable and long-term monitoring is thus needed to verify these patterns (Lembrechts et al. 2016a). Second, our analysis is missing variables that would explain more variation. The goodness-of-fit for these regression analyses is also very low (see Fig. 10-11), further substantiating the fact that the first year of observation to the whole region does not fit the elevational maximum very well. Additionally, the steeper slope for migration of the total ruderal community on the Björkliden trail suggests that the total ruderal community moves faster uphill than non-native ruderals do (Fig 10-11, SM Tables 22 and 24). Other findings revealed that non-native migration can happen twice as fast as that of native species (Dainese et al. 2017). That our result disagrees with this, could again be caused by the changing weather conditions in combination with disturbance that may cause unpredictable compositions near mountains tops. In any case, our data confirms that non-native species can reach high elevations, irrespective of their climatic niche.

Limitations and recommendations

The challenge in this study lies in the surveys. First and foremost, the monitoring differences. The clustering of the subregions of all temporal communities indicates that, to some extent, all surveys have picked-up different vegetation types (Fig. 4). Second, seasonal bias. Depending on abiotic factors including snow and the start and length of the growing season, some species might have been missed, especially in 1983 when timing was such that likely only one survey per subregion was performed. Species missed may grow later in the season than normal. Nonetheless, we believe that the temporal observations are a reasonable proxy of the ruderal communities over time. As said, we believe the total ruderal richness did not change substantially over time, but the observed changes in non-native ruderals over time shows us how dynamic the composition is.

Since the vegetation composition seems to show resilience or is slow to adapt to climate change, we recommend resurveying the Rallarvägen in 10 years. When disturbance happens, there are quick vegetation changes with ruderal dominance as a result. With climate change the response is slow and thus harder to pick up in such a temporally sparse dataset. Given the current rate of climate change, 10 years should be enough time to pick up such changes.

Due to time and/or space limitations, we have not included all analyses that were possible with this kind of data. Outside the scope of this thesis, we aim to further investigate the ruderal group with high EIV-Ts that have disappeared between 1903-13 and 1983-2021. There are no clear discrepancies in plant functional types or life cycles between these periods (see SM Table 28). Our next step is to investigate if there are other traits that are predominantly gone to get a grip on what caused their disappearance.

5. CONCLUSION

In this study, ruderal species compositions and distributions along the Rallarvägen showed to be mostly related to land use change disturbances, while climate change effects were not (yet) easily prominently revealed. Different parts of our investigation support this: 1) the temporal influxes of ruderals that has remained stable and the higher influx of non-native ruderals during railroad building back in 1903 and settlement expansion in 1913, 2) the abundance of ruderals that was more numerous closer to the railroad and train stations, and 3) the uphill migration of ruderals that was not necessarily determinant in time, even less so by their climatic niche. Most importantly, not only climate change can cause for an influx of warm-adapted species to a subarctic region. We therefore conclude that these findings warrant for discretion when we make conclusions about the exact impacts of climate change to ecosystems. Significant disturbance events can have long-lasting effects on vegetation compositions and distributions and therefore climate factors do not always shape the observed vegetation (Lenoir et al. 2022).

Disturbance intensity is important in restructuring vegetation compositions. Continuous disturbance causes subsequent non-native ruderal introductions and the dominance of ruderal species in the vegetation, while ceased disturbance may cause ruderals to be outcompeted by native heathland species in time. However, the rapid changes in climate observed in the Abisko region suggest that a different outlook might be expected in the coming years.

Our results highlight the importance of the knowledge of disturbance history of a system. It is important to get a good understanding of the long-term dynamics in the vegetation community, and thus its possible future.

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APPENDIX

Long-term dynamics in ruderal plant communities through climate and land use change in the Scandinavian mountains

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September 2022

Supplementary Tables

This appendix consists of Supplementary Tables (for Figures see page 35). Tables consist of model coefficients or are ordered lists of ruderal species. Tables with model coefficients are arranged according to the research and the supporting research question.

Interaction terms were first tested with the *drop1* function in R (R Core Team, 2021), and when not significant were removed from the model. Other independent variables that appeared not significant were also removed from the model. The following tables list *drop1* results with interactions that were not significant, but do not list other independent variables that were excluded from the final model.

1. WHAT ARE THE TEMPORAL DYNAMICS OF RUDERAL SPECIES INTRODUCTIONS, AND DO THESE DYNAMICS CORRELATE MOST STRONGLY WITH CLIMATE AND/OR LAND USE CHANGE DISTURBANCE?

1.1 What are the temporal dynamics of ruderal species along the Rallarvägen?

SM TABLE 1

Results from a generalized linear model analysis of the total ruderal count in function of subregion and observational year.

Parameter estimates *glm* (*quasipoisson*)						
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**Exp(B)**	**df**
(Intercept)	5.845	5.228	1.118	0.29	345.5	11
Björkliden	-0.160	0.361	-0.444	0.67	0.852	11
Kopparåsen	-0.498	0.520	-0.957	0.36	0.608	11
Låktatjakka	-0.472	0.516	-0.915	0.38	0.624	11
Vassijaure	-0.230	0.367	-0.103	0.54	0.795	11
Riksgränsen	-0.440	0.428	-0.627	0.33	0.644	11
Observational year	-0.001	0.003	-0.318	0.76	0.999	11
Interaction terms	**Residual deviance**	**AIC**	**LRT**	**p-value(>Chi)**		**df**
Subregion:Observational	166.1	90.74	5.577	0.350		5

SM TABLE 2

Results from a One-Way Analysis of Variance in total ruderal count between subregions and observational years.

			One-way ANOVA results		
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-statistic**	**p-value(>F)**
Observational year	3	7007	2336.62	23.66	9.58x10^{-6} ***
Residuals	14	1382	98.73		

			Multiple comparisons		
	Observational year	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD	1913-1903	11.08	0.49	-10.97	33.14
	1983-1903	-38.67	5.00x10^{-4} ***	-59.76	-17.58
	2021-1903	2.50	0.98	-17.92	22.92
	1983-1913	-49.75	2.00x10^{-5} ***	-69.12	-30.38
	2021-1913	-8.58	0.56	-27.23	10.06
	2021-1983	41.17	4.00x10^{-5} ***	23.68	58.65

*** P < .001

SM TABLE 3

Results from a generalized linear model analysis of the non-native ruderal count in function of observational year. Subregion did not explain any additional variation.

			Parameter estimates *glm* (*quasipoisson*)			
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**Exp(B)**	**df**
(Intercept)	21.39	5.237	4.084	8.70x10^{-4} ***	1.94x10^{9}	16
Observational year	-0.009	0.003	-3.449	0.003 **	0.991	16

*** P < .001. ** P < .01

SM TABLE 4

Results from a One-Way Analysis of Variance in non-native ruderal count between observational years. Subregion did not explain any variation.

One-way ANOVA results					
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-statistic**	**p-value(>F)**
Observational year	3	4542.6	1514.21	44.31	2.15x10^{-7}
Residuals	14	478.5	34.18		
Multiple comparisons					
	Observational year	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD	1913-1903	5.833	0.57	-7.144	18.811
	1983-1903	-35.467	4.70x10^{-6} ***	-47.876	-23.056
	2021-1903	-17.667	0.004 **	-29.682	-5.652
	1983-1913	-41.300	3.00x10^{-8} ***	-52.699	-29.901
	2021-1913	-23.500	1.16x10^{-4} ***	-34.468	-12.532
	2021-1983	17.800	9.39x10^{-4} ***	7.511	28.089

*** P < .001. ** P < .01

1.2 Are ruderal species that have established after railroad or road building, moving due to climate or disturbance?

SM TABLE 5

Results from a generalized linear model analysis of the total ruderal count in function of the mean annual air temperature (MAAT) and observational year.

Parameter estimates *glm* (*quasipoisson*)						
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**Exp(B)**	**df**
(Intercept)	-102.660	55.572	-1.847	0.09 •	2.60x10^{-45}	14
MAAT	-231.530	94.051	-2.462	0.03 *	2.80x10^{-101}	14
Observational year	0.052	0.027	1.901	0.08 •	1.053	14
MAAT:Observational year	0.115	0.047	2.473	0.03 *	1.122	1

* P < .05. • P < .1

SM TABLE 6

Results from a generalized linear model analysis of the non-native ruderal count in function of the mean annual air temperature (MAAT) and observational year.

	Parameter estimates *glm* (*quasipoisson*)					
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**Exp(B)**	**df**
(Intercept)	-122.810	65.326	-1.880	0.08 •	4.62x10^{-54}	14
MAAT	-312.716	112.701	-2.775	0.01 *	1.55x10^{-136}	14
Observational year	0.061	0.032	1.901	0.08 •	1.063	14
MAAT: Observational year	0.156	0.056	2.788	0.01 *	1.168	1

* P < .05. • P < .1

SM TABLE 7

Results from a linear regression analysis of the EIV-T (total ruderal count) in function of subregion and observational year.

	Parameter estimates *lm*				
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	11.670	1.872	6.230	7.23x10^{-10} ***	873
Observational year	-0.004	9.64x10^{-4}	-4.520	7.02x10^{-6} ***	873
Björkliden	0.511	2.571	0.199	0.84	873
Kopparåsen	-8.185	13.140	-0.623	0.53	873
Låktatjåkka	-46.140	9.681	-4.767	2.20x10^{-6} ***	873
Vassijaure	4.692	2.644	1.775	0.08 •	873
Riksgränsen	1.991	3.023	0.659	0.51	873
Observational year:Björkliden	-2.83x10^{-4}	0.001	-0.214	0.83	11
Observational year:Kopparåsen	0.004	0.007	0.610	0.54	11
Observational year:Låktatjåkka	0.028	0.005	4.725	2.67x10^{-6} ***	11
Observational year:Vassijaure	-0.002	0.001	-1.832	0.07 •	11
Observational year:Riksgränsen	-0.001	0.002	-0.671	0.50	11
Interaction terms	**Sum sq.**	**RSS**	**F-statistic**	**p-value(>F)**	**df**
Subregion:Observational year	14.015	428.4	5.905	2.23x10^{-5} ***	5

*** P < .001. • P < .1

SM TABLE 8

Results from a One-Way Analysis of Variance in EIV-T (total ruderal count) between subregions and observational years.

			Two-way ANOVA results		
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-**	**p-value(>F)**
Observational year	3	100.24	33.413	73.730	$< 2.20x10^{-16}$ ***
Subregion	5	3.02	0.604	1.333	0.25
Observational year:Subregion	9	12.33	1.370	3.024	0.001 **
Residuals	867	392.91	0.453		

			Multiple comparisons		
	Observational year:Subregion	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD[1]	1983:Björkliden-1913:Björkliden	-0.570	0.0266 *	-1.114	-0.027
	2021:Björkliden-1913:Björkliden	-0.610	$1.03x10^{-5}$ ***	-1.011	-0.210
	2021:Abisko-1903:Abisko	-0.515	0.008 **	-0.970	-0.061
	1983:Låktatjåkka-1983:Björkliden	-0.807	0.010 **	-1.526	-0.088
	2021:Låktatjåkka:1983:Låktatjåkka	0.700	0.015 *	0.060	1.340
	1983:Vassijaure-1983:Björkliden	-0.727	0.026 *	-1.418	-0.035
	1983:Vassijaure-1903:Vassijaure	-1.261	$< 1.00x10^{-8}$ ***	-1.852	-0.669
	2021:Vassijaure-1903:Vassijaure	-0.680	$1.35x10^{-5}$ ***	-1.131	0.229
	1983:Vassijaure-1913:Vassijaure	-1.132	$< 1.00x10^{-8}$ ***	-1.736	-0.528
	2021:Vassijaure-1913:Vassijaure	-0.551	0.004 **	-1.018	-0.084
	1983:Riksgränsen-1913:Riksgränsen	-1.183	$8.64x10^{-5}$ ***	-2.022	-3.442
	2021:Riksgränsen-1913:Riksgränsen	-0.530	0.009 **	-0.998	-0.063

[1] Due to very long list only significant Tukey HSD results are given.

*** P < .001. ** P < .01. * P < .05.

SM TABLE 9

Results from a linear regression analysis of the EIV-T (non-native ruderal count) in function of observational year. Subregion did not explain any additional variation.

			Parameter estimates *lm*		
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	9.339	0.985	9.481	$2.00x10^{-16}$ ***	1
Observational year	$-3.09x10^{-4}$	$5.06x10^{-4}$	-6.113	$2.12x10^{-9}$ ***	451

*** P < .001.

SM TABLE 10

Results from a One-Way Analysis of Variance in EIV-T (non-native ruderal count) between observational years. Subregion did not explain any additional variation.

			One-way ANOVA results		
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-statistic**	**p-value(>F)**
Observational year	3	11.51	3.837	12.57	6.64x10^{-8} ***
Residuals	449	137.08	0.305		
			Multiple comparisons		
	Observational year	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD	1913-1903	0.009	0.99	-0.160	0.177
	1983-1903	-0.261	0.19	-0.599	0.076
	2021-1903	-0.341	9.20x10^{-6} ***	-0.521	-0.160
	1983-1913	-0.270	0.15	-0.599	0.058
	2021-1913	-0.350	3.00x10^{-7} ***	-0.513	-0.187
	2021-1983	-0.080	0.93	-0.414	0.255

*** P < .001

SM TABLE 11

Results from a linear regression analysis of the EIV-T (total ruderal count) in function of subregion and the first year of observation.

			Parameter estimates lm		
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	16.140	2.368	6.815	2.27x10^{-11} ***	611
First year of observation	-0.007	3.287	-5.459	6.97x10^{-8} ***	611
Björkliden	1.894	3.287	0.576	0.57	611
Kopparåsen	-12.810	13.450	-0.952	0.34	611
Låktatjåkka	-57.000	10.100	-5.639	2.62x10^{-8} ***	611
Vassijaure	4.638	3.370	1.375	0.17	611
Riksgränsen	1.177	3.601	-0.327	0.74	611
First year of observation:Björkliden	-9.95x10^{-4}	0.002	-0.588	0.56	11
First year of observation:Kopparåsen	0.006	0.007	0.953	0.34	11
First year of observation:Låktatjåkka	0.028	0.005	5.618	2.94x10^{-8} ***	11
First year of observation:Vassijaure	-0.002	0.002	-1.421	0.16	11
First year of observation:Riksgränsen	6.06x10^{-4}	0.002	0.327	0.74	11
Interaction terms	**Sum sq.**	**RSS**	**F-statistic**	**p-value(>F)**	**df**
Subregion:First year of observation	18.987	314.96	7.839	3.63x10^{-7} ***	5

*** P < .001

SM TABLE 12

Results from a One-Way Analysis of Variance in EIV-T (total ruderal count) between the first years of observation. Subregion did not explain any additional variation.

One-way ANOVA results					
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-statistic**	**p-value(>F)**
Observational	3	118.8	39.59	87.33	< 2.20x10^{-16} ***
Residuals	619	280.6	0.543		

Multiple comparisons					
	First year of observation	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD	1913-1903	0.167	0.12	-0.027	0.361
	1983-1903	-1.135	< 1.00x10^{-8} ***	-1.139	-0.885
	2021-1903	-0.619	< 1.00x10^{-8} ***	-0.793	-0.444
	1983-1913	-1.303	< 1.00x10^{-8} ***	-1.557	-1.048
	2021-1913	-0.786	< 1.00x10^{-8} ***	-0.967	-0.605
	2021-1983	0.517	3.00x10^{-7} ***	0.276	0.757

*** P < .001

SM TABLE 13

Results from a linear regression analysis of the EIV-T (non-native ruderal count) in function of the first year of observation. Subregion did not explain any additional variation.

Parameter estimates *lm*					
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	11.138	1.408	7.913	5.78x10^{-14} ***	282
Observational year	-0.004	0.001	-5.519	7.71x10^{-8} ***	282

*** P < .001

SM TABLE 14

Results from a One-Way Analysis of Variance in EIV-T (non-native ruderal count) between the first years of observation. Subregion did not explain any additional variation.

			One-way ANOVA results		
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-statistic**	**p-value(>F)**
Observational year	3	12.65	4.216	12.31	1.38x10^{-7} ***
Residuals	280	95.91	0.342		

			Multiple comparisons		
	First year of observation	Mean diff.	p adj.	95% confidence interval	
				lwr bound	upr bound
Tukey HSD	1913-1903	0.135	0.34	-0.073	0.344
	1983-1903	-0.500	0.13	-1.088	0.088
	2021-1903	-0.397	9.87x10^{-5} ***	-0.632	-0.163
	1983-1913	-0.635	0.03 *	-1.228	-0.043
	2021-1913	-0.533	3.00x10^{-7} ***	-0.778	-0.287
	2021-1983	0.103	0.97	-0.500	0.705

*** P < .001. * P < .05.

2. IS THE SPATIAL EXPANSION OF RUDERAL SPECIES SINCE INTRODUCTION IN THE ABISKO REGION MOSTLY LIMITED BY CLIMATE OR DISTURBANCE?

2.1 Are current ruderal species distributions related to land use or climate?

SM TABLE 15

Results from a generalized linear model analysis of the total ruderal count in function of distance to the railroad and mean summer soil temperature (MSST). No multicollinearity was detected between distance to the railroad and the road, but distance to the road did not explain any additional variation.

		Parameter estimates *glm* (*poisson*)			
Coefficients	B	Std. error	*z*-value	p-value(>|*z*|)	df
(Intercept)	4.702	0.841	5.591	2.25×10^{-8} ***	35
Distance railroad	-0.033	0.010	-3.136	0.002 **	35
MSST	-0.109	0.086	-1.277	0.2	35
Distance railroad:MSST	0.003	0.001	3.115	0.002 **	1
		Centered parameter estimates *glm* (*poisson*)			
Coefficients	B	Std. error	*z*-value	p-value(>|*z*|)	df
(Intercept)	3.629	0.0377	96.270	$< 2.00\times10^{-16}$ ***	35
Distance railroad	-0.001	0.0003	-3.212	0.002 **	35
MSST (centered)	-1.092	0.0856	-1.277	0.2	35
Distance railroad:MSST	0.003	0.0010	3.115	0.002 **	1

*** P < .001. ** P < .01

SM TABLE 16

Results from a generalized linear model analysis of the non-native ruderal count in function of distance to the railroad and mean summer soil temperature (MSST). No multicollinearity was detected between distance to the railroad and the road, but distance to the road did not explain any additional variation.

	Parameter estimates *glm* (*poisson*)				
Coefficients	B	Std. error	*z*-value	p-value(>|*z*|)	df
(Intercept)	3.327	1.4043	2.369	0.02 *	36
Distance railroad	-0.022	0.013	-1.688	0.09 •	36
MSST	-0.081	0.143	-0.568	0.57	36
Distance railroad:MSST	0.002	0.0022	1.687	0.09 •	1
	Centered parameter estimates *glm* (*poisson*)				
Coefficients	B	Std. error	*z*-value	p-value(>|*z*|)	df
(Intercept)	2.529	0.0637	39.714	< 2.00×10^{-16} ***	36
Distance railroad	-4.40×10^{-4}	0.0004	-1.162	0.25	36
MSST (centered)	-0.081	0.1429	-0.568	0.57	36
Distance railroad:MSST (centered)	0.002	0.0013	1.687	0.09 •	1

*** P < .001. * P < .05. • P < .1

2.2 Is the anthropogenic pressure gradient acting as a filter on ruderal species?

SM TABLE 17

Results from a linear regression analysis of the mean *z*-score abundances per transect in function of the total ruderal count. Multicollinearity was detected between the total ruderal count and distance to the railroad.

	Parameter estimates *lm*				
Coefficients	B	Std. error	t-statistic	p-value(|>t|)	df
(Intercept)	1.002	0.124	8.059	9.53×10^{-10} ***	38
Total ruderal count	-0.028	0.003	-7.972	1.24×10^{-9} ***	38

*** P < .001

2.3 Do non-native ruderals reach long-term establishment in the Abisko region?

SM TABLE 18

Results from a generalized linear model analysis of the total ruderal count in function of transect, the first year of observation, and native status. Transect was not significant and removed from the model.

	Parameter estimates *glm* (poisson)					
Coefficients	**B**	**Std. error**	***z*-value**	**p-value(|>*z*|)**	**Exp(B)**	**df**
(Intercept)	29.49	2.408	12.24	$< 2.00 \times 10^{-16}$ ***	$6.40 \times 10^{+12}$	307
First year of observation	-0.02	0.001	-11.70	$< 2.00 \times 10^{-16}$ ***	0.986	307
Native yes	-56.62	2.853	-19.84	$< 2.00 \times 10^{-16}$ ***	2.57×10^{-25}	307
First year of observation:Native status	0.03	0.001	19.94	$< 2.00 \times 10^{-16}$ ***	1.030	307
Interaction terms	**Residual deviance**	**AIC**	**LRT**	**p-value(>Chi)**		**df**
Transect:First year of observation	366.8	1311.3	0.65	0.42		1
Transect:Native status	367.2	1311.6	1.02	0.31		1
First year of observation:Native status	884.4	1828.9	518.3	$< 2.00 \times 10^{-16}$ ***		1

*** P < .001

SM TABLE 19

Results from a Two-Way Analysis of Variance in mean z-score abundance between transects, the first years of observation, and native status.

Two-way ANOVA results					
Predictor	**df**	**Sum**	**Mean sq.**	**F-statistic**	**p-value(>F)**
Transect	39	46.630	1.170	1.325	0.09 •
First year of observation	3	68.860	22.95	26.00	$2.35x10^{-16}$ ***
Native status	1	4.4100	4.415	5.000	0.03 *
First year of observation:Native status	3	82.870	27.62	31.289	< 2.20x10-^{16} ***
Residuals	1365	1205.2	0.883		

Multiple comparisons					
	First year of observation: Native status	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD	1913:NativeNo-1903:NativeNo	-0.626	$2.31x10^{-5}$ ***	-1.011	-0.242
	1983:NativeNo-1903:NativeNo	0.531	0.02 *	0.057	1.005
	2021:NativeNo-1903:NativeNo	-0.076	0.99 •	-0.49	0.338
	1903:NativeYes-1903:NativeYes	0.271	0.07 •	-0.011	0.554
	1913:NativeYes-1903:NativeNo	0.393	0.11	-0.042	0.828
	1983:NativeYes-1903:NativeNo	-0.623	< $1.00x10^{-8}$ ***	-0.882	-0.364
	2021:NativeYes-1903:NativeNo	0.192	0.08 •	-0.012	0.395
	1983NativeNo-1913:NativeNo	1.158	< $1.00x10^{-8}$ ***	0.592	1.723
	2021:NatveNo-1913:NativeNo	0.551	0.03 *	0.034	1.067
	1903:NativeYes-1913:NativeNo	0.898	< $1.00x10^{-8}$ ***	0.479	1.316
	1913:NativeYes-1913:NativeNo	1.019	$2.00x10^{-7}$ ***	0.486	1.552
	1983:NativeYes-1913:NativeNo	0.003	1.00	-0.399	0.406
	2021:NativeYes-1913:NativeNo	0.818	< $1.00x10^{-8}$ ***	0.449	1.188
	2021:NativeNo-1983:NativeNo	-0.607	0.04 *	-1.193	-0.021
	1903:NativeYes-1983:NativeNo	-0.260	0.77	0.242	0.766
	1913:NativeYes-1983:NativeNo	-0.138	1.00	-0.739	0.463
	1983:NativeYes-1983:NativeNo	-1.154	< $1.00x10^{-8}$ ***	-1.643	-0.665
	2021:NativeYes-1983:NativeNo	-0.339	0.33	-0.802	0.123
	1903:NativeYes-2021:NativeNo	0.347	0.26	-0.099	0.793
	1913:NativeYes-2021:NativeNo	0.469	0.17	-0.086	1.024
	1983:NativeYes-2021:NativeNo	-0.547	0.003 **	-0.978	-0.116
	2021:NativeYes-2021:NativeNo	0.268	0.46	-0.133	0.668
	1913:NativeYes-1903:NativeYes	0.122	0.99	-0.343	0.587
	1983:NativeYes-1903:NativeYes	-0.894	< $1.00x10^{-8}$ ***	-1.201	-0.587
	2021:NativeYes-1903:NativeYes	-0.0793	0.98	-0.341	0.183
	1983:NativeYes-1913:NativeYes	-1.016	< $1.00x10^{-8}$ ***	-1.467	-0.565
	2021:NativeYes-1913:NativeYes	-0.201	0.84	-0.623	0.221
	2021:NativeYes-1983:NativeYes	0.815	< $1.00x10^{-8}$ ***	0.578	1.051

*** P < .001. ** P < .01. * P < .05. • P < .1

2.4 Are ruderal species moving uphill?

SM TABLE 20

Results from a linear regression analysis of the elevational maximum (expressed as the 95th percentile) of the total ruderal count in function of the first year of observation and Trail ID.

	Parameter estimates *lm*				
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	-978.54	921.20	-1.062	0.29	1
First year of observation	0.87	0.47	1.855	0.07 •	57
Trail ID	116.24	51.61	2.252	0.03 *	57
Interaction terms	**Sum sq.**	**RSS**	**F-statistic**	**p-value(>F)**	**df**
First year of observation:Trail ID	65771	2186176	1.737	0.19	1

* P < .05. • P < .1

SM TABLE 21

Results from a Two-Way Analysis of Variance in elevational maximum (expressed as the 95th percentile) of the total ruderal count between the first years of observation and Trail ID.

	Two-way ANOVA results				
Predictor	**df**	**Sum sq.**	**Mean**	**F-statistic**	**p-value(>F)**
First year of observation	3	316872	105624	2.922	0.04 *
Trail ID	1	210798	210798	5.832	0.02 *
Residuals	55	1988099	36147		
Interaction terms	**df**	**Sum sq.**	**RSS**	**F-statistic**	**p-value(>F)**
First year of observation:Trail ID	3	91741	1988099	0.839	0.48
	Multiple comparisons				
	First year of observation	**Mean diff.**	**p adj.**	**95% confidence interval**	
				lwr bound	**upr bound**
Tukey HSD	1913-1903	175.92	0.14	-38.115	389.95
	1983-1903	58.91	0.88	-155.128	272.94
	2021-1903	154.57	0.049 *	0.124	309.12
	1983-1913	-117.01	0.61	-368.866	134.84
	2021-1913	-21.35	0.99	-224.998	182.30
	2021-1983	95.67	0.60	-107.986	299.32

* P < .05

SM TABLE 22

Results from a linear regression analysis of the elevational maximum (expressed as the 95th percentile) of the total ruderal count on the Björkliden trail in function of the first year of observation.

	Parameter estimates *lm*				
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	-1936	1316	-1.470	0.15	34
First year of observation	1.356	0.670	2.025	0.049 *	34

• P < .1

SM TABLE 23

Results from a linear regression analysis of the elevational maximum (expressed as the 95th percentile) of the total ruderal count on the Låktatjåkka trail in function of the first year of observation.

	Parameter estimates *lm*				
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**df**
(Intercept)	657	1130	0.584	0.57	22
First year of observation	0.096	0.572	0.169	0.87	22

SM TABLE 24

Results from a linear regression analysis of the elevational maximum (expressed as the 95th percentile) of non-native ruderal count in function of the first year of observation and Trail ID. Trail ID was not significant and removed from the model.

	Parameter estimates *lm*					
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**Exp(B)**	**df**
(Intercept)	1.455	2.867	0.507	0.62	4.284	1
First year of observation	0.003	0.001	1.747	0.098 •	1.003	17
Interaction terms	**Sum sq.**	**RSS**	**F-statistic**	**p-value(>F)**		**df**
First year of observation:Trail ID	0.194	1.474	2.275	0.15		1

Note. a log transformation was performed on the response variable Maximum elevation.

• P < .1

SM TABLE 25

Results from a Two-Way Analysis of Variance in maximum elevation (expressed as the 95th percentile) of non-native ruderal count between the first years of observation and Trail ID.

		Two-way ANOVA results			
Predictor	**df**	**Sum sq.**	**Mean sq.**	**F-statistic**	**p-value(>F)**
First year of observation	2	220402	110201	2.830	0.09 •
Residuals	16	623024			
Interaction terms	**df**	**Sum sq.**	**RSS**	**F-statistic**	**p-value(>F)**
First year of observation:Trail ID	2	80452	579082	1.049	0.38
		Multiple comparisons			
				95% confidence interval	
	First year of observation	**Mean diff.**	**p adj.**	**lwr bound**	**upr bound**
Tukey HSD	1913-1903	227.1	0.21	-101.6	555.7
	2021-1903	220.4	0.16	-73.6	514.3
	2021-1913	-6.7	1.00	-395.6	382.2

• P < .1

SM TABLE 26

Results from a generalized linear model analysis of the total ruderal count (expressed as ruderal richness) in function of elevation. Trail ID was not significant and removed from the model.

			Parameter estimates *glm* (*quasipoisson*)			
Coefficients	**B**	**Std. error**	**t-statistic**	**p-value(|>t|)**	**Exp(B)**	**df**
(Intercept)	3.230	0.398	8.319	1.31x10^{-9} ***	25.280	1
Elevation	-0.002	5.37x10^{-4}	-2.881	0.007 **	0.998	33
	Residual deviance	**AIC**	**LRT**	**p-value(>Chi)**	**/**	**df**
Elevation:Trail ID	106.9	105.8	0.367	0.54	/	1

*** P < .001. ** P < .01

SM TABLE 27

Results from a generalized linear model analysis of the non-native ruderal count (expressed as ruderal richness) in function of elevation. Trail ID was not significant and removed from the model.

Parameter estimates *glm* (*poisson*)						
Coefficients	**B**	**Std. error**	***z*-value**	**p-value(|>*z*|)**	**Exp(B)**	**df**
(Intercept)	2.320	0.462	5.024	$5.05\text{x}10^{-7}$ ***	10.18	1
Elevation	-0.002	0.001	-3.01	0.003 **	1.00	25
	Residual deviance	**AIC**	**LRT**	**p-value(>Chi)**		**df**
Elevation:Trail ID	19.06	96.51	2.137	0.14		1

*** P < .001. ** P < .01

SM TABLE 28

Unique ruderal species observations in two distinct periods: 1903-1913 and 1983-2021.

Values are sorted by EIV-T. Species that are observed in both periods are not shown.

PFT = Plant Functional Type

	Ruderal species	PFT	Life cycle	EIV-T	Grime's strategy	Observational year	Native
1	Anethum graveolens	forb	annual	5	crr	1913	yes
2	Anchusa officinalis	forb	biennial	4.5	crr	1903	no
3	Barbarea stricta	forb	biennial	4.5	crr	1903-1913	yes
4	Bromus secalinus	grass	annual	4.5	crr	1913	no
5	Bromus tectorum	grass	annual	4.5	rrr	1913	yes
6	Epilobium ciliatum	forb	perennial	4.5	crr	2021	no
7	Lepidium ruderale	forb	annual	4.5	rrr	1913	no
8	Malva pusilla	forb	biennial	4.5	crr	1903	no
9	Melilotus sp.	forb	biennial	4.5	rrr	1903-1913	no
10	Pisum sativum	forb	annual	4.5	crr	1913	no
11	Pisum sp.	forb	annual	4.5	crr	1903-1913	no
12	Potentilla norvegica	forb	biennial	4.5	crs	1903-1913	no
13	Vicia sativa	forb	annual	4.5	crr	1903-1913	no
14	Vicia sativa subsp. Nigra	forb	annual	4.5	crr	1903-1913	no
15	Agrostis spica venti	grass	annual	4	crr	1913	yes
16	Avena sativa	grass	annual	4	crr	1913	no
17	Berteroa incana	forb	biennial	4	crs	1903	no
18	Bidens tripartita	forb	annual	4	crr	1903	no
19	Brassica sp.	forb	biennial	4	ccr	1913	yes
20	Carduus crispus	forb	biennial	4	crr	1913	no
21	Centaurea cyanus	forb	annual	4	crr	1903-1913	no
22	Crepis tectorum	forb	annual	4	crr	1913	no
23	Cynoglossum officinale	forb	biennial	4	ccr	1903	no
24	Dactylis glomerata	grass	perennial	4	crs	1913	no
25	Erysimum cheiranthoides	forb	annual	4	rrs	1903-1913	no
26	Galium spurium	forb	annual	4	crr	1903-1913	no
27	Hordeum vulgare	forb	annual	4	crr	1903-1913	yes
28	Matricaria chamomilla	forb	annual	4	rrr	1903-1913	yes
29	Medicago lupulina	forb	perennial	4	rrs	1903	no
30	Papaver somniferum	forb	annual	4	crr	1913	no
31	Pastinaca sativa	forb	biennial	4	ccr	1903-1913	no
32	Polygonum aviculare	forb	annual	4	rrr	1903-1913	no
33	Sinapis arvensis	forb	annual	4	crr	1903-1913	no
34	Stachys annua	forb	annual	4	rrr	1903	yes
35	Trifolium arvense	forb	biennial	4	rrr	1903	yes
36	Vicia hirsuta	forb	annual	4	crr	1903-1913	no
37	Viola tricolor	forb	annual	4	crr	1903-1913	no
38	Agrostis pourretii Willd.	grass	annual	3.5	crs	1913	yes
39	Anthoxanthum odoratum	grass	perennial	3.5	crs	2021	yes
40	Arabidopsis thaliana	forb	annual	3.5	rrr	2021	yes
41	Arabis hirsuta	forb	perennial	3.5	crs	1983	yes
42	Barbarea vulgaris	forb	biennial	3.5	crr	1903-1913	no
43	Brassica rapa	forb	annual	3.5	ccr	1903-1913	no

44	Bromus hordeaceus	grass	annual	3.5	crr	1903-1913	no
45	Campanula patula	forb	biennial	3.5	crs	1913	no
46	Cardaminopsis arenosa	forb	biennial	3.5	crs	1983	no
47	Carex globularis	sedge	perennial	3.5	crs	2021	yes
48	Cochlearia officinalis	forb	biennial	3.5	crs	1913	no
49	Descurainia sophia	forb	annual	3.5	crr	1903	no
50	Elymus caninus	grass	perennial	3.5	crs	1983	yes
51	Fallopia convolvulus	forb	annual	3.5	crr	1903-1913	no
52	Fumaria officinalis	forb	annual	3.5	rrr	1913	no
53	Galium mollugo	forb	perennial	3.5	crs	1913	yes
54	Juncus bufonius	grass	annual	3.5	rrs	1903-1913	no
55	Lappula squarrosa	forb	biennial	3.5	crr	1903	yes
56	Lapsana communis	forb	annual	3.5	crr	1903-1913	no
57	Linaria vulgaris	forb	perennial	3.5	crs	1903	yes
58	Lolium arundinaceum	grass	perennial	3.5	ccr	1903-1913	yes
59	Lolium perenne	grass	perennial	3.5	ccr	1913	no
60	Matricaria discoidea	forb	annual	3.5	rrr	1983-2021	yes
61	Milium effusum	grass	perennial	3.5	crs	2021	yes
62	Mycelis muralis	forb	annual	3.5	crs	1983	yes
63	Nasturtium palustre	forb	annual	3.5	crr	1903-1913	yes
64	Platanthera bifolia	forb	perennial	3.5	crs	2021	yes
65	Rhinanthus serotinus	forb	annual	3.5	rrs	1903-1913	yes
66	Rumex crispus	forb	perennial	3.5	crr	1983-2021	no
67	Sagina nodosa	forb	perennial	3.5	crs	2021	yes
68	Senecio sylvaticus	forb	annual	3.5	crr	1903	yes
69	Senecio vulgaris	forb	annual	3.5	rrr	1913	no
70	Solanum nigrum	forb	annual	3.5	rrr	1913	no
71	Solanum tuberosum	forb	annual	3.5	ccr	1903-1913	yes
72	Solidago virgaurea	forb	perennial	3.5	crs	2021	yes
73	Spergula arvensis	forb	annual	3.5	rrs	1903-1913	no
74	Achnatherum calamagrostis	grass	perennial	3	rss	2021	yes
75	Agrostemma Githago	forb	annual	3	crs	1903	yes
76	Andromeda polifolia	heath	perennial	3	rss	2021	yes
77	Caltha palustris	forb	perennial	3	crs	2021	yes
78	Capsella bursa pastoris	forb	annual	3	rrr	1903-1913	no
79	Chamaenerion angustifolium	forb	perennial	3	ccr	2021	yes
80	Chenopodium album	forb	annual	3	rrr	1903-1913	yes
81	Cirsium oleraceum	forb	perennial	3	ccs	2021	no
82	Cystopteris fragilis	fern	perennial	3	rss	1983-2021	yes
83	Dactylorhiza maculata	forb	perennial	3	crs	1983-2021	yes
84	Epilobium montanum	forb	perennial	3	crs	2021	yes
85	Epilobium palustre	forb	perennial	3	crs	1983-2021	yes
86	Equisetum fluviatile	fern	perennial	3	crs	1983-2021	yes
87	Galeopsis bifida	forb	annual	3	crr	1903-1913	yes
88	Galeopsis speciosa	forb	annual	3	crr	1903	no
89	Galeopsis tetrahit	forb	annual	3	crr	1903	no
90	Gymnadenia conopsea	forb	perennial	3	crs	2021	yes
91	Hieracium sp.	forb	perennial	3	crs	1983-2021	yes
92	Leontodon autumnalis nigrolineatus	forb	perennial	3	crr	1903-1913	yes
93	Lotus corniculatus	forb	perennial	3	crs	1913	no
94	Luzula multiflora multiflora	grass	perennial	3	crs	2021	no
95	Melampyrum pratense	forb	annual	3	rrs	2021	yes

96	Paris quadrifolia	forb	perennial	3	crs	2021	yes
97	Pilosella officinarum	forb	perennial	3	crs	2021	yes
98	Poa angustifolia	grass	annual	3	crs	1913	yes
99	Poa trivialis	grass	annual	3	crs	1903-1913	no
100	Prunella vulgaris	forb	perennial	3	crs	1913	yes
101	Scorzoneroides autumnalis subsp. autumnalis	forb	perennial	3	crr	1903-1913	yes
102	Scorzoneroides autumnalis subsp. Borealis	forb	perennial	3	crr	1983	yes
103	Secale cereale	grass	annual	3	crr	1903-1913	no
104	Veronica chamaedrys	forb	perennial	3	crs	1913	yes
105	Cirsium heterophyllum	forb	perennial	2.5	ccs	1983-2021	no
106	Equisetum variegatum	fern	perennial	2.5	crs	2021	no
107	Galeopsis ladanum	forb	annual	2.5	rrr	1903	no
108	Gentianella amarella	forb	annual	2.5	crs	2021	yes
109	Melampyrum sylvaticum	forb	annual	2.5	rrs	2021	yes
110	Montia fontana fontana	forb	annual	2.5	rrs	1903-1913	yes
111	Neottia cordata	forb	perennial	2.5	crs	1983-2021	yes
112	Stellaria nemorum	forb	annual	2.5	crs	1983-2021	yes
113	Trifolium spadiceum	forb	annual	2.5	crs	1913	no
114	Antennaria dioica	forb	perennial	2	crs	2021	yes
115	Arabis alpina	forb	annual	2	crs	2021	yes
116	Arnica angustifolia	forb	perennial	2	crs	1983	yes
117	Asplenium viride	fern	perennial	2	rrs	1983-2021	yes
118	Bartsia alpina	forb	perennial	2	rss	2021	yes
119	Botrychium lunaria	forb	perennial	2	crs	1983	yes
120	Cystopteris montana	fern	perennial	2	rss	2021	yes
121	Dactylorhiza viridis	forb	perennial	2	crs	1983-2021	yes
122	Epilobium hornemannii	forb	perennial	2	crs	1983-2021	yes
123	Epilobium lactiflorum	forb	perennial	2	crs	1983-2021	yes
124	Equisetum pratense	fern	perennial	2	crs	2021	yes
125	Gentianella campestris	forb	biennial	2	crs	1983	yes
126	Linnaea borealis	forb	perennial	2	crs	2021	yes
127	Luzula sudetica	grass	perennial	2	crs	1983-2021	yes
128	Myosotis decumbens	forb	perennial	2	crs	1983-2021	yes
129	Omalotheca norvegica	forb	perennial	2	crs	1983-2021	yes
130	Pseudorchis albida	forb	perennial	2	crs	2021	yes
131	Bistorta vivipara	forb	perennial	1.5	crs	2021	yes
132	Carex atrata	sedge	perennial	1.5	crs	1983-2021	yes
133	Cerastium fontanum scandicum	forb	annual	1.5	crs	1983	yes
134	Cerastium fontanum	forb	annual	1.5	crs	2021	no
135	Cerastium holosteoides	forb	annual	1.5	crs	1903-1913	yes
136	Cryptogramma crispa	forb	perennial	1.5	crs	1983	yes
137	Cystopteris dickieana	fern	perennial	1.5	rss	1983	yes
138	Dryas octopetala	forb	perennial	1.5	crs	2021	yes
139	Luzula spicata	grass	perennial	1.5	crs	1983-2021	yes
140	Poa alpina	grass	perennial	1.5	crs	2021	yes
141	Poa glauca	grass	perennial	1.5	crs	1983	yes
142	Cardamine bellidifolia	forb	perennial	1	rss	1983	yes
143	Cerastium arctium edmonstonii	forb	biennial	1	crs	1983	yes
144	Cherleria biflora	forb	perennial	1	crs	1983-2021	yes
145	Comastoma tenellum	forb	biennial	1	crs	1983	yes

146	Trisetum spicatum	forb	perennial	1	css	1983-2021	yes

SM TABLE 29

Ruderal species observations along the Rallarvägen in 1903 (Sylvén, 1904).

PFT = Plant Functional Type

	Ruderal species	PFT	Life cycle	EIV-T	Grime's strategy	Native
1	Achillea millefolium	forb	perennial	3	ccr	no
2	Agrostemma Githago	forb	annual	3	crs	yes
3	Alopecurus geniculatus	grass	annual	3.5	crs	no
4	Anchusa officinalis	forb	biennial	4.5	crr	no
5	Barbarea stricta	forb	biennial	4.5	crr	yes
6	Barbarea vulgaris	forb	biennial	3.5	crr	no
7	Berteroa incana	forb	biennial	4	crs	no
8	Bidens tripartita	forb	annual	4	crr	no
9	Brassica rapa	forb	annual	3.5	ccr	no
10	Bromus hordeaceus	grass	annual	3.5	crr	no
11	Capsella bursa pastoris	forb	annual	3	rrr	no
12	Carum carvi	forb	biennial	2.5	ccr	yes
13	Centaurea cyanus	forb	annual	4	crr	no
14	Cerastium holosteoides	forb	annual	1.5	crs	yes
15	Chenopodium album	forb	annual	3	rrr	yes
16	Cynoglossum officinale	forb	biennial	4	ccr	no
17	Descurainia sophia	forb	annual	3.5	crr	no
18	Erysimum cheiranthoides	forb	annual	4	rrs	no
19	Euphrasia stricta	forb	annual	3	rrs	yes
20	Fallopia convolvulus	forb	annual	3.5	crr	no
21	Galeopsis bifida	forb	annual	3	crr	yes
22	Galeopsis ladanum	forb	annual	2.5	rrr	no
23	Galeopsis speciosa	forb	annual	3	crr	no
24	Galeopsis tetrahit	forb	annual	3	crr	no
25	Galium spurium	forb	annual	4	crr	no
26	Hordeum vulgare	forb	annual	4	crr	yes
27	Juncus bufonius	grass	annual	3.5	rrs	no
28	Lappula squarrosa	forb	biennial	3.5	crr	yes
29	Lapsana communis	forb	annual	3.5	crr	no
30	Leontodon autumnalis nigrolineatus	forb	perennial	3	crr	yes
31	Leucanthemum vulgare	forb	perennial	3	crs	no
32	Linaria vulgaris	forb	perennial	3.5	crs	yes
33	Lolium arundinaceum	grass	perennial	3.5	ccr	yes
34	Malva pusilla	forb	biennial	4.5	crr	no
35	Matricaria chamomilla	forb	annual	4	rrr	yes
36	Medicago lupulina	forb	perennial	4	rrs	no
37	Melilotus sp.	forb	biennial	4.5	rrr	no
38	Montia fontana fontana	forb	annual	2.5	rrs	yes
39	Myosotis arvensis	forb	annual	3.5	crr	no
40	Nasturtium palustre	forb	annual	3.5	crr	yes

41	Pastinaca sativa	forb	biennial	4	ccr	no
42	Phleum pratense	forb	perennial	3.5	crs	no
43	Pisum sp.	forb	annual	4.5	crr	no
44	Plantago major	forb	perennial	3	crs	no
45	Poa annua	grass	annual	1.5	crr	no
46	Poa palustris	grass	perennial	4	crs	yes
47	Poa pratensis	grass	perennial	3	crs	no
48	Poa trivialis	grass	annual	3	crs	no
49	Polygonum aviculare	forb	annual	4	rrr	no
50	Potentilla norvegica	forb	biennial	4.5	crs	no
51	Ranunculus acris	forb	perennial	3	crs	no
52	Ranunculus repens	forb	perennial	3	crr	no
53	Rhinanthus minor	forb	annual	3	rrs	yes
54	Rhinanthus serotinus	forb	annual	3.5	rrs	yes
55	Rubus parvifolius	shrub	perennial	3	crs	no
56	Rumex acetosa	forb	perennial	3.5	crs	yes
57	Rumex acetosella	forb	perennial	3.5	crs	no
58	Rumex longifolius	forb	annual	2.5	ccr	no
59	Scorzoneroides autumnalis subsp. autumnalis	forb	perennial	3	crr	yes
60	Secale cereale	grass	annual	3	crr	no
61	Senecio sylvaticus	forb	annual	3.5	crr	yes
62	Silene vulgaris	forb	perennial	3	crs	no
63	Sinapis arvensis	forb	annual	4	crr	no
64	Solanum tuberosum	forb	annual	3.5	ccr	yes
65	Spergula arvensis	forb	annual	3.5	rrs	no
66	Stachys annua	forb	annual	4	rrr	yes
67	Stellaria graminea	forb	perennial	3.5	crs	no
68	Stellaria media	forb	annual	3	crr	no
69	Taraxacum sp.	forb	biennial	1.5	crs	yes
70	Thlaspi arvense	forb	annual	3.5	rrr	no
71	Trifolium arvense	forb	biennial	4	rrr	yes
72	Trifolium hybridum	forb	perennial	3	ccr	no
73	Trifolium pratense	forb	perennial	3.5	crs	no
74	Trifolium repens	forb	perennial	3	crs	no
75	Tripleurospermum inodorum	forb	perennial	3.5	rrs	yes
76	Urtica dioica	forb	perennial	3.5	ccr	no
77	Veronica serpyllifolia	forb	perennial	3.5	crs	yes
78	Vicia cracca	forb	perennial	3.5	crs	no
79	Vicia hirsuta	forb	annual	4	crr	no
80	Vicia sativa	forb	annual	4.5	crr	no
81	Vicia sativa subsp. Nigra	forb	annual	4.5	crr	no
82	Viola tricolor	forb	annual	4	crr	no

SM TABLE 30

Ruderal species observations along the Rallarvägen in 1913 (Sylvén, 1915-17).

PFT = Plant Functional Type

	Ruderal species	PFT	Life cycle	EIV-T	Grime's strategy	Native
1	Achillea millefolium	forb	perennial	3	ccr	no
2	Agrostis capillaris	grass	perennial	3	crs	no
3	Agrostis pourretii Willd.	grass	annual	3.5	crs	yes
4	Agrostis spica venti	grass	annual	4	crr	yes
5	Alopecurus geniculatus	grass	annual	3.5	crs	no
6	Anethum graveolens	forb	annual	5	crr	yes
7	Avena sativa	grass	annual	4	crr	no
8	Barbarea stricta	forb	biennial	4.5	crr	yes
9	Barbarea vulgaris	forb	biennial	3.5	crr	no
10	Brassica rapa	forb	annual	3.5	ccr	no
11	Brassica sp.	forb	biennial	4	ccr	yes
12	Bromus hordeaceus	grass	annual	3.5	crr	no
13	Bromus secalinus	grass	annual	4.5	crr	no
14	Bromus tectorum	grass	annual	4.5	rrr	yes
15	Campanula patula	forb	biennial	3.5	crs	no
16	Campanula rotundifolia	forb	perennial	3.5	crs	no
17	Capsella bursa pastoris	forb	annual	3	rrr	no
18	Carduus crispus	forb	biennial	4	crr	no
19	Carum carvi	forb	biennial	2.5	ccr	yes
20	Centaurea cyanus	forb	annual	4	crr	no
21	Cerastium arvense	forb	perennial	4	crs	no
22	Cerastium holosteoides	forb	annual	1.5	crs	yes
23	Chenopodium album	forb	annual	3	rrr	yes
24	Cochlearia officinalis	forb	biennial	3.5	crs	no
25	Crepis tectorum	forb	annual	4	crr	no
26	Dactylis glomerata	grass	perennial	4	crs	no
27	Equisetum arvense	fern	perennial	3.5	ccr	yes
28	Erysimum cheiranthoides	forb	annual	4	rrs	no
29	Euphrasia stricta	forb	annual	3	rrs	yes
30	Fallopia convolvulus	forb	annual	3.5	crr	no
31	Fumaria officinalis	forb	annual	3.5	rrr	no
32	Galeopsis bifida	forb	annual	3	crr	yes
33	Galium mollugo	forb	perennial	3.5	crs	yes
34	Galium spurium	forb	annual	4	crr	no
35	Hordeum vulgare	forb	annual	4	crr	yes
36	Juncus bufonius	grass	annual	3.5	rrs	no
37	Lapsana communis	forb	annual	3.5	crr	no
38	Lathyrus pratensis	forb	perennial	3.5	crs	no
39	Leontodon autumnalis nigrolineatus	forb	perennial	3	crr	yes
40	Lepidium ruderale	forb	annual	4.5	rrr	no
41	Leucanthemum vulgare	forb	perennial	3	crs	no
42	Lolium arundinaceum	grass	perennial	3.5	ccr	yes
43	Lolium perenne	grass	perennial	3.5	ccr	no
44	Lotus corniculatus	forb	perennial	3	crs	no
45	Luzula multiflora frigida	grass	perennial	3	crs	yes
46	Luzula pallescens	grass	perennial	3.5	crs	yes

47	Matricaria chamomilla	forb	annual	4	rrr	yes
48	Melilotus sp.	forb	biennial	4.5	rrr	no
49	Montia fontana fontana	forb	annual	2.5	rrs	yes
50	Myosotis arvensis	forb	annual	3.5	crr	no
51	Nasturtium palustre	forb	annual	3.5	crr	yes
52	Papaver somniferum	forb	annual	4	crr	no
53	Pastinaca sativa	forb	biennial	4	ccr	no
54	Phleum pratense	forb	perennial	3.5	crs	no
55	Pisum sativum	forb	annual	4.5	crr	no
56	Pisum sp.	forb	annual	4.5	crr	no
57	Plantago major	forb	perennial	3	crs	no
58	Plantago media	forb	perennial	3	crs	no
59	Poa angustifolia	grass	annual	3	crs	yes
60	Poa annua	grass	annual	1.5	crr	no
61	Poa nemoralis	grass	perennial	3	crs	yes
62	Poa palustris	grass	perennial	4	crs	yes
63	Poa pratensis	grass	perennial	3	crs	no
64	Poa trivialis	grass	annual	3	crs	no
65	Polygonum aviculare	forb	annual	4	rrr	no
66	Potentilla norvegica	forb	biennial	4.5	crs	no
67	Prunella vulgaris	forb	perennial	3	crs	yes
68	Ranunculus acris	forb	perennial	3	crs	no
69	Ranunculus repens	forb	perennial	3	crr	no
70	Rhinanthus minor	forb	annual	3	rrs	yes
71	Rhinanthus serotinus	forb	annual	3.5	rrs	yes
72	Rubus parvifolius	shrub	perennial	3	crs	no
73	Rumex acetosa	forb	perennial	3.5	crs	yes
74	Rumex acetosella	forb	perennial	3.5	crs	no
75	Rumex longifolius	forb	annual	2.5	ccr	no
76	Sagina procumbens	forb	perennial	3.5	rrs	yes
77	Scorzoneroides autumnalis subsp. autumnalis	forb	perennial	3	crr	yes
78	Secale cereale	grass	annual	3	crr	no
79	Senecio vulgaris	forb	annual	3.5	rrr	no
80	Silene dioica	forb	perennial	3	crs	no
81	Silene L.	forb	perennial	3.5	crs	no
82	Silene vulgaris	forb	perennial	3	crs	no
83	Sinapis arvensis	forb	annual	4	crr	no
84	Solanum nigrum	forb	annual	3.5	rrr	no
85	Solanum tuberosum	forb	annual	3.5	ccr	yes
86	Spergula arvensis	forb	annual	3.5	rrs	no
87	Stellaria graminea	forb	perennial	3.5	crs	no
88	Stellaria media	forb	annual	3	crr	no
89	Taraxacum sp.	forb	biennial	1.5	crs	yes
90	Thlaspi arvense	forb	annual	3.5	rrr	no
91	Trifolium hybridum	forb	perennial	3	ccr	no
92	Trifolium pratense	forb	perennial	3.5	crs	no
93	Trifolium repens	forb	perennial	3	crs	no
94	Trifolium spadiceum	forb	annual	2.5	crs	no
95	Tripleurospermum inodorum	forb	perennial	3.5	rrs	yes
96	Tussilago farfara	forb	perennial	3	crs	no
97	Urtica dioica	forb	perennial	3.5	ccr	no
98	Veronica chamaedrys	forb	perennial	3	crs	yes

99	Veronica serpyllifolia	forb	perennial	3.5	crs	yes
100	Vicia cracca	forb	perennial	3.5	crs	no
101	Vicia hirsuta	forb	annual	4	crr	no
102	Vicia sativa	forb	annual	4.5	crr	no
103	Vicia sativa subsp. Nigra	forb	annual	4.5	crr	no
104	Viola tricolor	forb	annual	4	crr	no

SM TABLE 31

Ruderal species observations along the Rallarvägen in 1983 (Lewejohann & Lorenzen, 1983).

PFT = Plant Functional Type

	Ruderal species	PFT	Life cycle	EIV-T	Grime's strategy	Native
1	Achillea millefolium	forb	perennial	3	ccr	no
2	Arabis hirsuta	forb	perennial	3.5	crs	yes
3	Arnica angustifolia	forb	perennial	2	crs	yes
4	Asplenium viride	fern	perennial	2	rrs	yes
5	Botrychium lunaria	forb	perennial	2	crs	yes
6	Campanula rotundifolia	forb	perennial	3.5	crs	no
7	Cardamine bellidifolia	forb	perennial	1	rss	yes
8	Cardaminopsis arenosa	forb	biennial	3.5	crs	no
9	Carex atrata	sedge	perennial	1.5	crs	yes
10	Carum carvi	forb	biennial	2.5	ccr	yes
11	Cerastium arctium edmonstonii	forb	biennial	1	crs	yes
12	Cerastium fontanum scandicum	forb	annual	1.5	crs	yes
13	Cherleria biflora	forb	perennial	1	crs	yes
14	Cirsium heterophyllum	forb	perennial	2.5	ccs	no
15	Comastoma tenellum	forb	biennial	1	crs	yes
16	Cryptogramma crispa	forb	perennial	1.5	crs	yes
17	Cystopteris dickieana	fern	perennial	1.5	rss	yes
18	Cystopteris fragilis	fern	perennial	3	rss	yes
19	Dactylorhiza maculata	forb	perennial	3	crs	yes
20	Dactylorhiza viridis	forb	perennial	2	crs	yes
21	Elymus caninus	grass	perennial	3.5	crs	yes
22	Epilobium hornemannii	forb	perennial	2	crs	yes
23	Epilobium lactiflorum	forb	perennial	2	crs	yes
24	Epilobium palustre	forb	perennial	3	crs	yes
25	Equisetum fluviatile	fern	perennial	3	crs	yes
26	Euphrasia stricta	forb	annual	3	rrs	yes
27	Gentianella campestris	forb	biennial	2	crs	yes
28	Hieracium murorum	forb	perennial	3	crs	yes
29	Luzula multiflora frigida	grass	perennial	3	crs	yes
30	Luzula spicata	grass	perennial	1.5	crs	yes
31	Luzula sudetica	grass	perennial	2	crs	yes
32	Matricaria discoidea	forb	annual	3.5	rrr	yes
33	Mycelis muralis	forb	annual	3.5	crs	yes
34	Myosotis arvensis	forb	annual	3.5	crr	no
35	Myosotis decumbens	forb	perennial	2	crs	yes

36	Neottia cordata	forb	perennial	2.5	crs	yes
37	Omalotheca norvegica	forb	perennial	2	crs	yes
38	Phleum pratense	forb	perennial	3.5	crs	no
39	Plantago major	forb	perennial	3	crs	no
40	Poa glauca	grass	perennial	1.5	crs	yes
41	Poa nemoralis	grass	perennial	3	crs	yes
42	Poa palustris	grass	perennial	4	crs	yes
43	Poa pratensis	grass	perennial	3	crs	no
44	Rumex acetosella	forb	perennial	3.5	crs	no
45	Rumex crispus	forb	perennial	3.5	crr	no
46	Sagina procumbens	forb	perennial	3.5	rrs	yes
47	Scorzoneroides autumnalis subsp. Borealis	forb	perennial	3	crr	yes
48	Silene L.	forb	perennial	3.5	crs	no
49	Silene vulgaris	forb	perennial	3	crs	no
50	Stellaria nemorum	forb	annual	2.5	crs	yes
51	Taraxacum officinale	forb	biennial	3	crs	yes
52	Taraxacum sp.	forb	biennial	1.5	crs	yes
53	Thlaspi arvense	forb	annual	3.5	rrr	no
54	Trifolium hybridum	forb	perennial	3	ccr	no
55	Tripleurospermum inodorum	forb	perennial	3.5	rrs	yes
56	Trisetum spicatum	forb	perennial	1	css	yes
57	Veronica serpyllifolia	forb	perennial	3.5	crs	yes

SM TABLE 32

Ruderal species observations along the Rallarvägen in 2021.

PFT = Plant Functional Type

	Ruderal species	PFT	Life cycle	EIV-T	Grime's strategy	Native
1	Achillea millefolium	forb	perennial	3	ccr	no
2	Achnatherum calamagrostis	grass	perennial	3	rss	yes
3	Agrostis capillaris	grass	perennial	3	crs	no
4	Alopecurus geniculatus	grass	annual	3.5	crs	no
5	Andromeda polifolia	heath	perennial	3	rss	yes
6	Antennaria dioica	forb	perennial	2	crs	yes
7	Anthoxanthum odoratum	grass	perennial	3.5	crs	yes
8	Arabidopsis thaliana	forb	annual	3.5	rrr	yes
9	Arabis alpina	forb	annual	2	crs	yes
10	Asplenium viride	fern	perennial	2	rrs	yes
11	Bartsia alpina	forb	perennial	2	rss	yes
12	Bistorta vivipara	forb	perennial	1.5	crs	yes
13	Caltha palustris	forb	perennial	3	crs	yes
14	Campanula rotundifolia	forb	perennial	3.5	crs	no
15	Carex atrata	sedge	perennial	1.5	crs	yes
16	Carex globularis	sedge	perennial	3.5	crs	yes
17	Carum carvi	forb	biennial	2.5	ccr	yes
18	Cerastium arvense	forb	perennial	4	crs	no

19	Cerastium fontanum	forb	annual	1.5	crs	no
20	Chamaenerion angustifolium	forb	perennial	3	ccr	yes
21	Cherleria biflora	forb	perennial	1	crs	yes
22	Cirsium heterophyllum	forb	perennial	2.5	ccs	no
23	Cirsium oleraceum	forb	perennial	3	ccs	no
24	Cystopteris fragilis	fern	perennial	3	rss	yes
25	Cystopteris montana	fern	perennial	2	rss	yes
26	Dactylorhiza maculata	forb	perennial	3	crs	yes
27	Dactylorhiza viridis	forb	perennial	2	crs	yes
28	Dryas octopetala	forb	perennial	1.5	crs	yes
29	Epilobium ciliatum	forb	perennial	4.5	crr	no
30	Epilobium hornemannii	forb	perennial	2	crs	yes
31	Epilobium lactiflorum	forb	perennial	2	crs	yes
32	Epilobium montanum	forb	perennial	3	crs	yes
33	Epilobium palustre	forb	perennial	3	crs	yes
34	Equisetum arvense	fern	perennial	3.5	ccr	yes
35	Equisetum fluviatile	fern	perennial	3	crs	yes
36	Equisetum pratense	fern	perennial	2	crs	yes
37	Equisetum variegatum	fern	perennial	2.5	crs	no
38	Euphrasia stricta	forb	annual	3	rrs	yes
39	Gentianella amarella	forb	annual	2.5	crs	yes
40	Gymnadenia conopsea	forb	perennial	3	crs	yes
41	Hieracium sp.	forb	perennial	3	crs	yes
42	Lathyrus pratensis	forb	perennial	3.5	crs	no
43	Leucanthemum vulgare	forb	perennial	3	crs	no
44	Linnaea borealis	forb	perennial	2	crs	yes
45	Luzula multiflora frigida	grass	perennial	3	crs	yes
46	Luzula multiflora multiflora	grass	perennial	3	crs	no
47	Luzula pallescens	grass	perennial	3.5	crs	yes
48	Luzula spicata	grass	perennial	1.5	crs	yes
49	Luzula sudetica	grass	perennial	2	crs	yes
50	Matricaria discoidea	forb	annual	3.5	rrr	yes
51	Melampyrum pratense	forb	annual	3	rrs	yes
52	Melampyrum sylvaticum	forb	annual	2.5	rrs	yes
53	Milium effusum	grass	perennial	3.5	crs	yes
54	Myosotis arvensis	forb	annual	3.5	crr	no
55	Myosotis decumbens	forb	perennial	2	crs	yes
56	Neottia cordata	forb	perennial	2.5	crs	yes
57	Omalotheca norvegica	forb	perennial	2	crs	yes
58	Paris quadrifolia	forb	perennial	3	crs	yes
59	Phleum pratense	forb	perennial	3.5	crs	no
60	Pilosella officinarum	forb	perennial	3	crs	yes
61	Plantago major	forb	perennial	3	crs	no
62	Plantago media	forb	perennial	3	crs	no
63	Platanthera bifolia	forb	perennial	3.5	crs	yes
64	Poa alpina	grass	perennial	1.5	crs	yes
65	Poa annua	grass	annual	1.5	crr	no
66	Poa nemoralis	grass	perennial	3	crs	yes
67	Poa palustris	grass	perennial	4	crs	yes
68	Poa pratensis	grass	perennial	3	crs	no
69	Pseudorchis albida	forb	perennial	2	crs	yes

70	Ranunculus acris	forb	perennial	3	crs	no
71	Ranunculus repens	forb	perennial	3	crr	no
72	Rhinanthus minor	forb	annual	3	rrs	yes
73	Rubus parvifolius	shrub	perennial	3	crs	no
74	Rumex acetosa	forb	perennial	3.5	crs	yes
75	Rumex acetosella	forb	perennial	3.5	crs	no
76	Rumex crispus	forb	perennial	3.5	crr	no
77	Rumex longifolius	forb	annual	2.5	ccr	no
78	Sagina nodosa	forb	perennial	3.5	crs	yes
79	Silene dioica	forb	perennial	3	crs	no
80	Silene vulgaris	forb	perennial	3	crs	no
81	Solidago virgaurea	forb	perennial	3.5	crs	yes
82	Stellaria graminea	forb	perennial	3.5	crs	no
83	Stellaria media	forb	annual	3	crr	no
84	Stellaria nemorum	forb	annual	2.5	crs	yes
85	Taraxacum sp.	forb	biennial	1.5	crs	yes
86	Trifolium hybridum	forb	perennial	3	ccr	no
87	Trifolium pratense	forb	perennial	3.5	crs	no
88	Trifolium repens	forb	perennial	3	crs	no
89	Tripleurospermum inodorum	forb	perennial	3.5	rrs	yes
90	Trisetum spicatum	forb	perennial	1	css	yes
91	Tussilago farfara	forb	perennial	3	crs	no
92	Urtica dioica	forb	perennial	3.5	ccr	no
93	Veronica serpyllifolia	forb	perennial	3.5	crs	yes
94	Vicia cracca	forb	perennial	3.5	crs	no

SM TABLE 33

Ruderal species life cycle count per subregion and observational year. Counts are not of unique species; one species can occur in several subregions.

Observational year	Subregion	Life cycle	Count
1903	Abisko	Annual	37
		Biennial	10
		Perennial	15
	Björkliden	Annual	24
		Biennial	3
		Perennial	14
	Vassijaure	Annual	36
		Biennial	9
		Perennial	25
1913	Abisko	Annual	36
		Biennial	7
		Perennial	34
	Björkliden	Annual	37
		Biennial	7
		Perennial	33

	Vassijaure	Annual	29
		Biennial	5
		Perennial	26
	Riksgränsen	Annual	32
		Biennial	5
		Perennial	24
1983	Björkliden	Annual	5
		Biennial	4
		Perennial	19
	Kopparåsen	Annual	0
		Biennial	0
		Perennial	9
	Låktatjåkka	Annual	2
		Biennial	2
		Perennial	17
	Vassijaure	Annual	2
		Biennial	2
		Perennial	20
	Riksgränsen	Annual	2
		Biennial	3
		Perennial	6
2021	Abisko	Annual	10
		Biennial	1
		Perennial	47
	Björkliden	Annual	14
		Biennial	2
		Perennial	59
	Kopparåsen	Annual	11
		Biennial	1
		Perennial	54
	Låktatjåkka	Annual	8
		Biennial	1
		Perennial	48
	Vassijaure	Annual	11
		Biennial	1
		Perennial	41
	Riksgränsen	Annual	8
		Biennial	1
		Perennial	43

SM TABLE 34

Descriptive information about the transects along the Rallarvägen trail.

MSST = Mean Summer Soil Temperature.

Transect code	Latitude start	Longitude start	Latitude end	Longitude end	Transect description	Subregion	Distance road [m]	Distance railroad [m]	Distance train station [m]	MSST [°C]
1	68.349051	18.825034	68.354410	18.809020	Abisko Östra Station	Abisko	292.3	82.1	167.4	10.1
2	68.354410	18.809020	68.358240	18.789350	Abisko Research station	Abisko	28.6	66.5	1007.5	9.9
3	68.358240	18.789350	68.365790	18.780690	Abisko Turist station and canyon	Abisko	98.0	147.0	1923.7	9.5
4	68.365790	18.780690	68.371580	18.763860	Short part is swampy area	Abisko	397.2	486.1	2727.3	9.9
5	68.371580	18.763860	68.377330	18.747800		Abisko	184.5	283.4	3669.1	10.2
6	68.377330	18.747800	68.384200	18.736440		Björkliden	75.0	148.9	4111.4	10.1
7	68.384200	18.736440	68.388080	18.717370		Björkliden	44.8	196.2	3241.4	10.1
8	68.388080	18.717370	68.394360	18.700370		Björkliden	78.3	251.0	2436.7	9.9
9	68.394360	18.700370	68.399940	18.692410	Björkliden village	Björkliden	164.6	111.4	1485.4	10.4
10	68.399940	18.692410	68.406696	81.686579	Björkliden train station	Björkliden	69.4	234.8	789.9	10.3
11	68.406696	81.686579	68.414860	18.682300		Björkliden	316.6	27.3	27.3	8.8
12	68.414860	18.682300	68.421440	18.672410		Björkliden	320.6	126.3	922.1	10.1
13	68.421440	18.672410	68.426090	18.656770		Björkliden	175.2	108.6	1752.1	10.2
14	68.426090	18.656770	68.431620	18.642690		Björkliden	612.6	89.8	2485.4	10.4
15	68.431620	18.642690	68.435300	18.619890		Björkliden	489.9	174.3	3315.7	10.0
16	68.435300	18.619890	68.438550	18.602670		Kopparåsen	758.1	445.4	4212.4	9.9
17	68.438550	18.602670	68.440400	18.588140		Kopparåsen	509.8	515.3	4963.7	10.1
18	68.440400	18.588140	68.433290	18.583790	Alongside road	Kopparåsen	5.3	817.9	5531.7	10.1
19	68.433290	18.583790	68.430670	18.565760	Higher elevation/ Swampy parts	Kopparåsen	32.0	48.1	5156.2	9.4
20	68.430670	18.565760	68.429050	18.543430	Paktajaure lake/Kopparråsen	Kopparåsen	94.9	52.6	5644.6	9.8
21	68.429050	18.543430	68.426930	18.520640		Kopparåsen	274.6	40.1	6393.5	10.1
22	68.426930	18.520640	68.427270	18.498810	Rough area	Kopparåsen	578.9	65.8	7169.1	10.3
23	68.427270	18.498810	68.428800	18.475300	Rough area	Kopparåsen	371.2	72.4	8029	10.0
24	68.428800	18.475300	68.426790	18.456450		Kopparåsen	84.2	110.7	9039.7	10.2

25	68.426790	18.456450	68.426290	18.432570		Kopparåsen	313.3	69.0	9701.6	10.2
26	68.426290	18.432570	68.428410	18.413560		Låktatjåkka	82.3	91.5	10647	10.4
27	68.428410	18.413560	68.427160	18.390390		Låktatjåkka	52.7	221.5	10320.1	10.1
28	68.427160	18.390390	68.425200	18.366740		Låktatjåkka	18.6	124.4	9358.4	9.7
29	68.425200	18.366740	68.423630	18.346570	Låktatjåkka trail	Låktatjåkka	134.3	32.7	9825.3	9.6
30	68.423630	18.346570	68.421749	18.325851		Låktatjåkka	302.6	14.5	9010.5	8.7
31	68.421749	18.325851	68.421810	18.301720		Vassijaure	645.8	199.2	8175.2	8.8
32	68.421810	18.301720	68.424940	18.279680		Vassijaure	243.3	31.6	7178.4	9.9
33	68.424940	18.279680	68.429400	18.257570	Vasijaure train station	Vassijaure	226.5	48.5	6266	9.3
34	68.429400	18.257570	68.429930	18.240820		Vassijaure	422.6	17.7	5363.3	9.4
35	68.429930	18.240820	68.430160	18.217120		Vassijaure	412.3	20.5	4685.3	9.5
36	68.430160	18.217120	68.427090	18.195090		Riksgränsen	134.2	72.3	3727.8	9.4
37	68.427090	18.195090	68.420400	18.185900		Riksgränsen	229.0	155.8	2800.5	9.8
38	68.420400	18.185900	68.420570	18.165070	Swampy area	Riksgränsen	714.7	189.9	2479.4	9.7
39	68.420570	18.165070	68.424490	18.144860	Swampy area	Riksgränsen	507.6	179.2	1658.8	9.7
40	68.424490	18.144860	68.427505	18.122447	Riksgränsen/Riksgränsen train station	Riksgränsen	310.8	25.1	260.5	9.1

SM TABLE 35

Ruderal species observations along the Björkliden and Låktatjåkka mountain trails (2016) that were documented along the Rallarvägen in the historical dataset.

Elevational maximum of a species is calculated as the 95th percentile.

First obs. = First year of observation to the whole region.

		Elevational maximum [m]				
	Ruderal species	Björkliden	Låktatjåkka	EIV-T	First obs.	Native
1	Achillea millefolium	469	838.5	3	1903	no
2	Agrostis capillaris	1026	894.65	3	1913	no
3	Andromeda polifolia	507	/	3	2021	yes
4	Antennaria dioica	956	/	2	2021	yes
5	Anthoxanthum odoratum	956	890	3.5	2021	yes
6	Arabis alpina	953.6	/	2	2021	yes
7	Bartsia alpina	956	905.5	2	2021	yes
8	Bistorta vivipara	1026	1089	1.5	2021	yes
9	Botrychium lunaria	887	/	2	1983	yes
10	Carex atrata	539.3	834.95	1.5	1983	yes
11	Cerastium fontanum	875.8	588	1.5	2021	no
12	Dactylorhiza viridis	435	663	2	1983	yes
13	Dryas octopetala	885.6	921	1.5	2021	yes
14	Equisetum arvense	804.4	890	3.5	1913	yes
15	Equisetum pratense	956	850	2	2021	yes
16	Equisetum variegatum	889.5	890	2.5	2021	no
17	Euphrasia stricta	943.4	899.7	3	1903	yes
18	Gymnadenia conopsea	507	/	3	2021	yes
19	Linnaea borealis	716	663	2	2021	yes
20	Luzula multiflora frigida	1026	1116	3	1913	yes
21	Luzula spicata	1017.6	921	1.5	1983	yes
22	Luzula sudetica	/	942	2	1983	yes
23	Melampyrum pratense	613	/	3	2021	yes
24	Melampyrum sylvaticum	499.8	/	2.5	2021	yes
25	Plantago major	428	/	3	1903	no
26	Poa alpina	956	850	1.5	2021	yes
27	Poa annua	466.95	467	1.5	1903	no
28	Potentilla norvegica	543	663	4.5	1903	no
29	Ranunculus acris	956	896.2	3	1903	no
30	Rhinanthus minor	535.8	921	3	1903	yes
31	Rumex acetosa	956	864	3.5	1903	yes
32	Rumex acetosella	428	/	3.5	1903	no
33	Sagina procumbens	543	/	3.5	1913	yes
34	Silene dioica	531.9	/	3	1913	no
35	Solidago virgaurea	887	862	3.5	2021	yes
36	Stellaria nemorum	543	/	2.5	1983	yes

37	Taraxacum officinale	956	896.2	3	1903	yes
38	Trifolium pratense	464.9	/	3.5	1903	no
39	Trifolium repens	464.9	/	3	1903	no

SM TABLE 35

Descriptive information about the T-transects along the Björkliden trail.

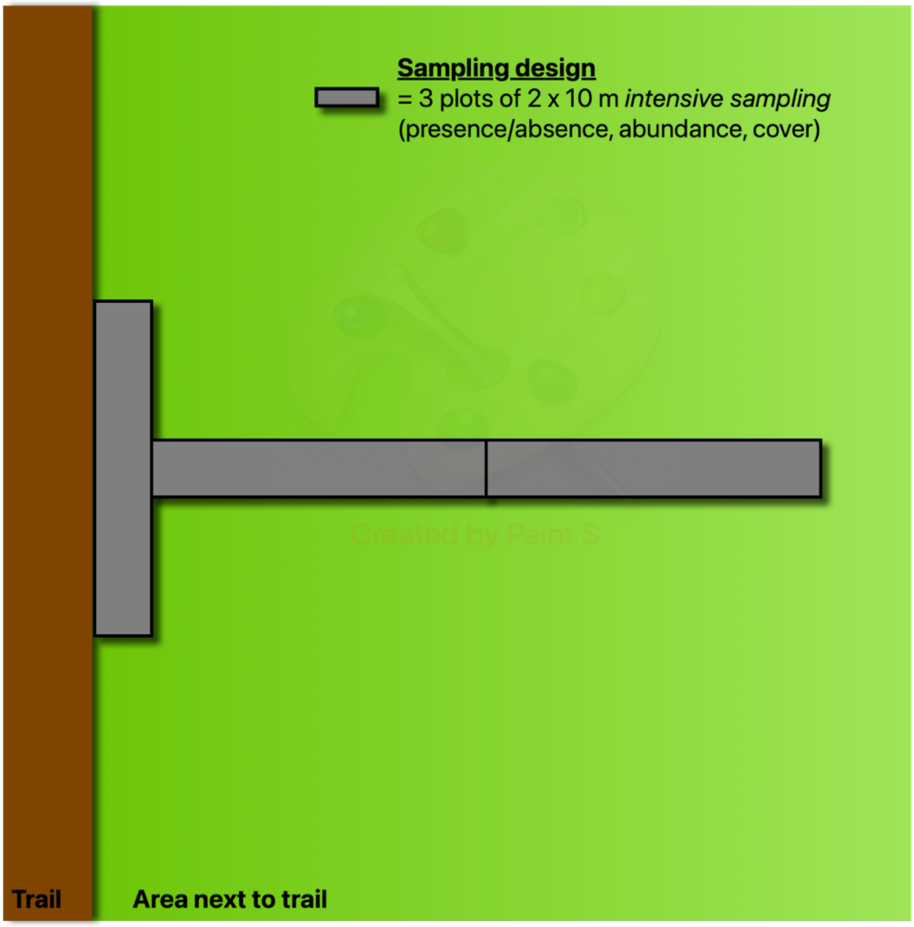
T-transect	Elevation [m]	Habitat	Latitude	Longitude
1	428	forb-grass	68°24.164	18°40.684
2	435	open forest	68°24.099	18°40.596
3	469	forb-grass	68°24.032	18°40.494
4	507	forb-grass	68°23.919	18°40.420
5	543	forb-grass	68°23.704	18°40.224
6	573	shrubland	68°23.652	18°40.242
7	613	shrubland	68°23.339	18°40.063
8	646	shrubland	68°23.263	18°40.072
9	676	forb-grass	68°23.177	18°40.012
10	716	shrubland	68°23.106	18°39.929
11	749	forb-grass	68°22.892	18°39.792
12	787	forb-grass	68°22.580	18°39.526
13	824	forb-grass	68°22.375	18°40.087
14	859	shrubland	68°22.290	18°40.044
15	887	forb-grass	68°22.257	18°40.100
16	932	forb-grass	68°22.180	18°40.285
17	956	forb-grass	68°22.153	18°40.386
18	998	forb-grass	68°22.120	18°40.525
19	1026	forb-grass	68°22.081	18°40.694
20	1045	forb-grass	68°22.045	18°40.956

SM TABLE 36

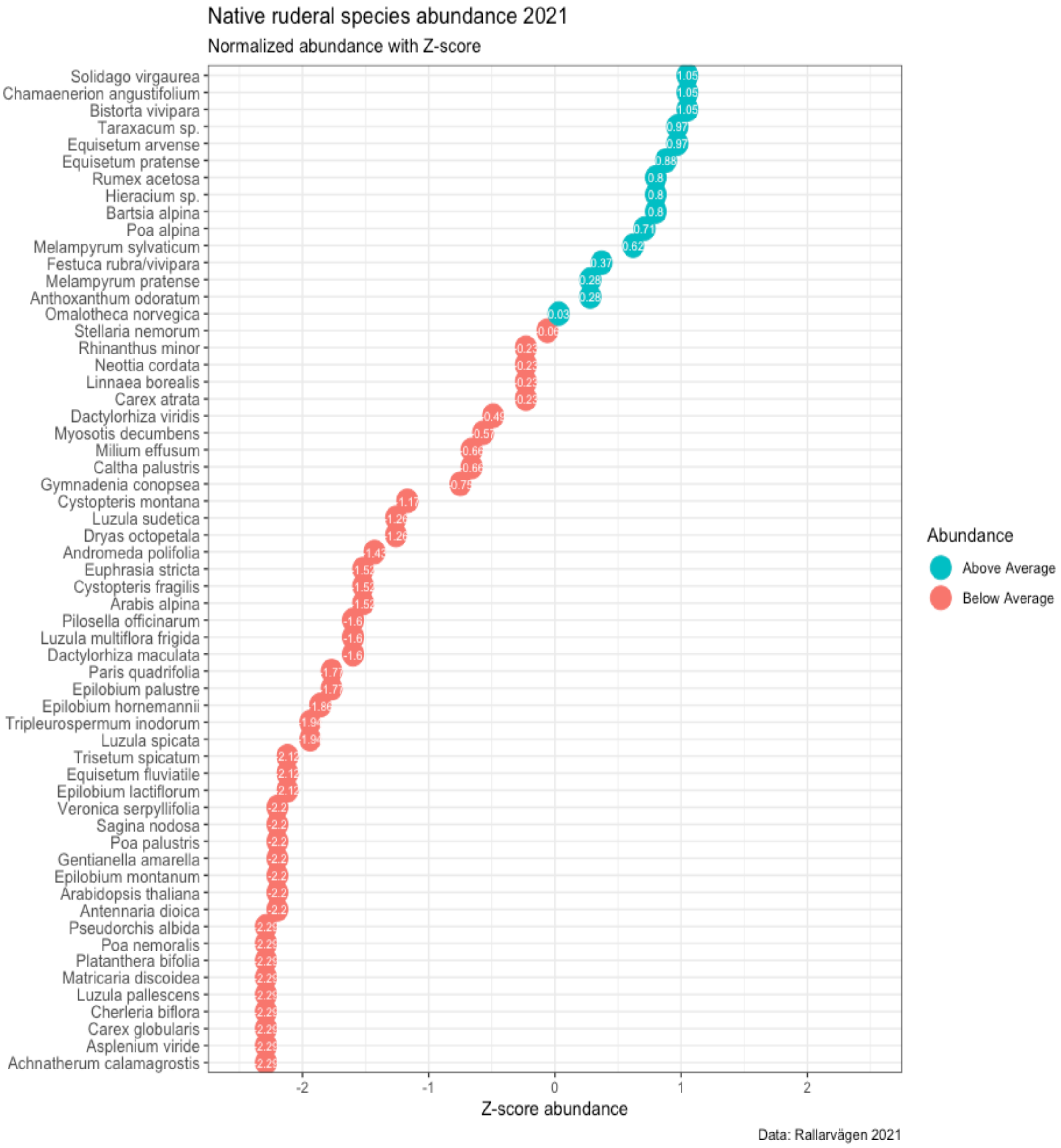
Descriptive information about the T-transects along the Låktatjåkka trail.

T-transect	Elevation [m]	Habitat	Latitude	Longitude
1	467	open forest	68°25.542	18°19.453
2	579	forb-grass	68°25.353	18°19.523
3	549	shrubland	68°25.172	18°19.856
4	588	shrubland	68°25.159	18°20.583
5	620	forb-grass	68°25.106	18°21.218
6	663	forb-grass	68°25.081	18°21.507
7	697	forb-grass	68°24.985	18°22.048
8	738	forb-grass	68°24.860	18°22.144
9	780	forb-grass	68°24.498	18°23.021
10	812	forb-grass	68°24.238	18°23.523
11	850	forb-grass	68°24.147	18°23.799
12	890	forb-grass	68°24.048	18°24.168
13	921	forb-grass	68°23.975	18°24.376
14	942	forb-grass	68°23.898	18°24.760
15	965	forb-grass	68°23.825	18°24.999
16	997	forb-grass	68°23.742	18°25.435
17	1043	bare-rock	68°23.680	18°26.126
18	1089	bare-rock	68°23.857	18°26.271
19	1116	bare-rock	68°23.884	18°26.483
20	1186	bare-rock	68°23.913	18°27.269

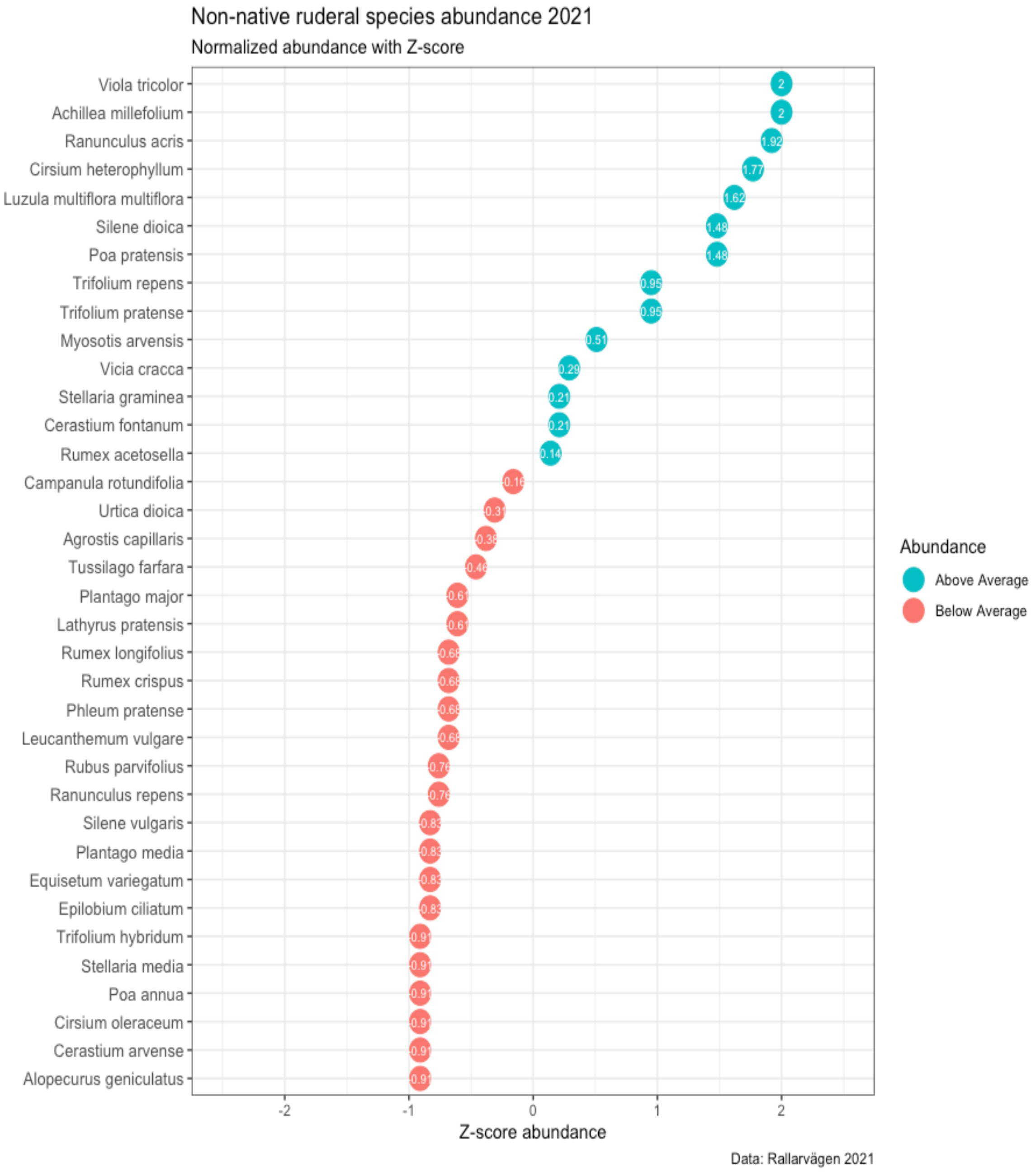
Supplementary Figures



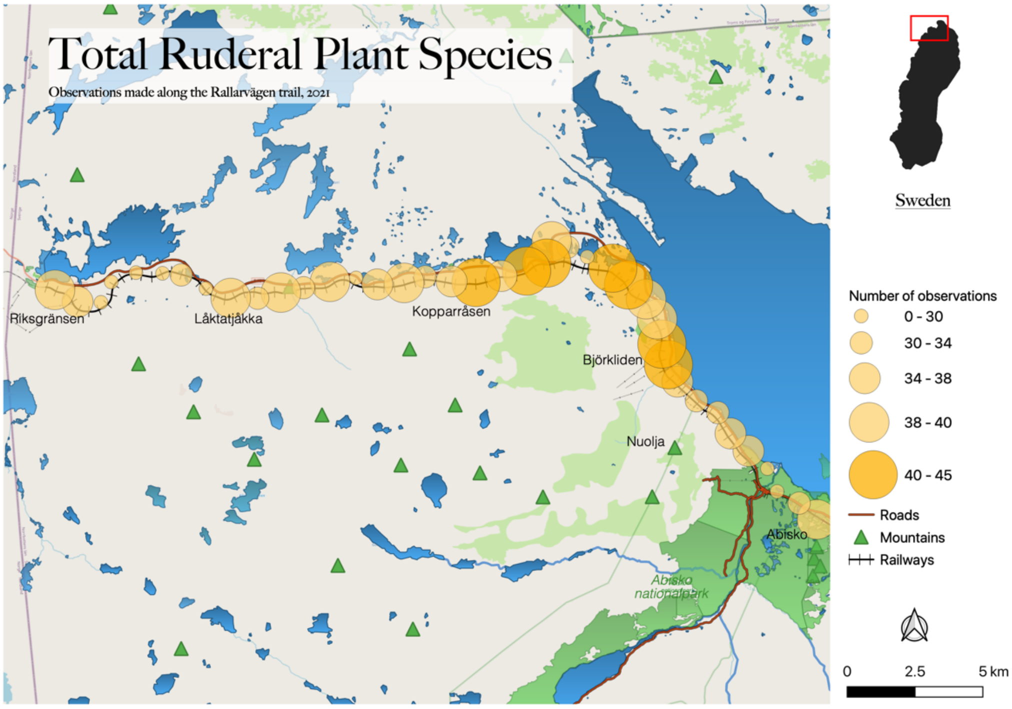
SM Figure 1 | Details of plot layout of the MIREN T-trail survey and sampling design. The trail is indicated in brown, the T-transect in grey.



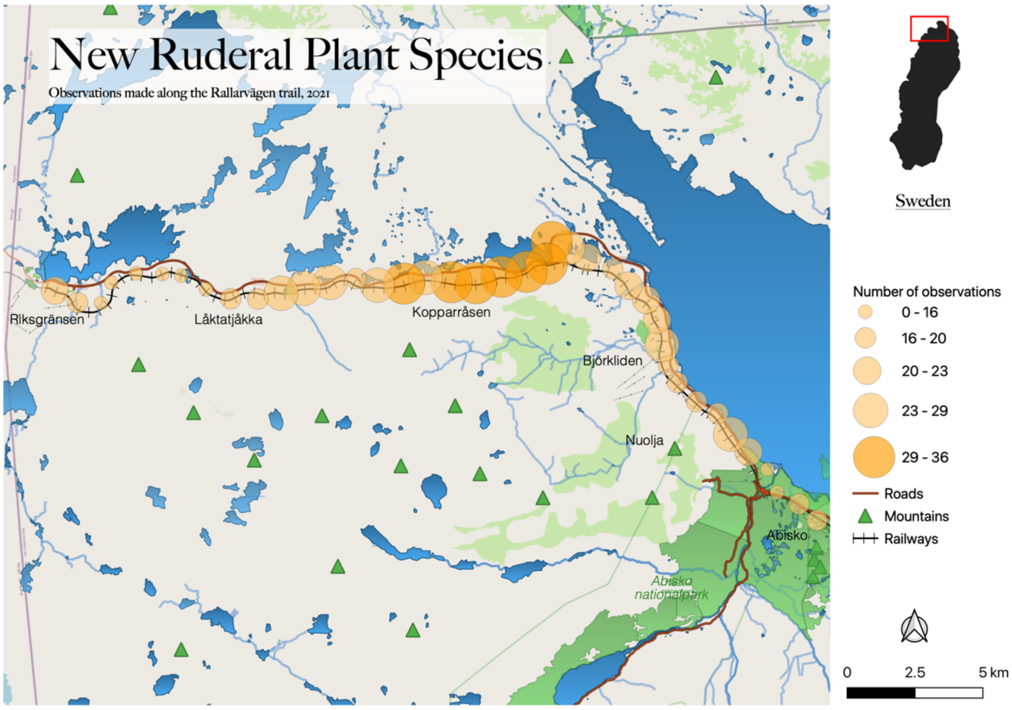
SM Figure 2 | Calculated Z-scores of the native ruderal species along the Rallarvägen in 2021.



SM Figure 3 | Calculated Z-scores of the non-native ruderal species along the Rallarvägen in 2021.



SM Figure 4 | Map of the Rallarvägen trail with the total number ruderal species per transect. The number of observations is indicated by orange circles, roads are in red, railways in black, and mountains in green triangles.



SM Figure 5 | Map of the Rallarvägen trail with the number of new ruderal species introductions in 2021 per transect. The number of observations is indicated by orange circles, roads are in red, railways in black, and mountains are green triangles.

SM Figure 6 | Picture from the Rallarvägen trail between Abisko and Björkliden.

SM Figure 7 | Picture from the Rallarvägen trail between Björkliden and Låktatjåkka.

SM Figure 8 | Picture from Rallarvägen trail near Transect 19.

SM Figure 9 | Picture from the Rallarvägen trail near Vassijaure.

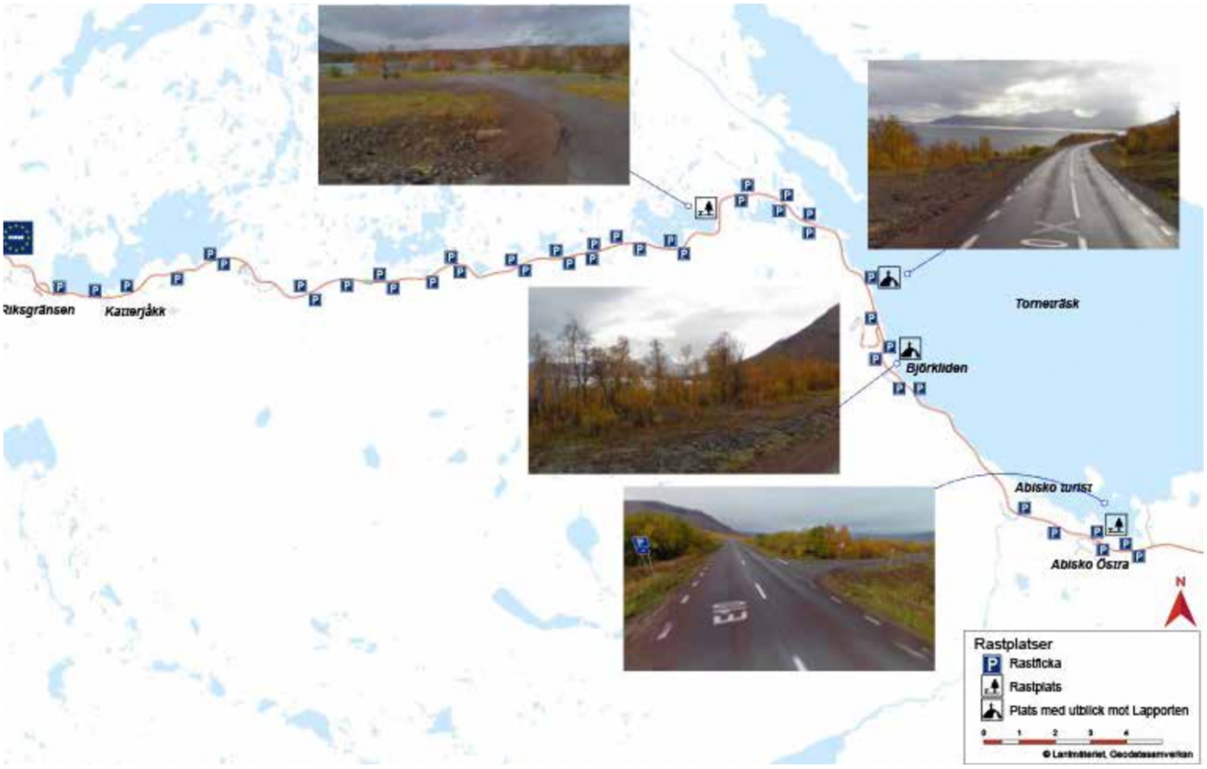
SM Figure 10 | Picture from Låktatjåkka trail (open forest area).

SM Figure 11 | Picture from the Låktatjåkka trail (forb-grass area)

SM Figure 12 | Picture from the Låktatjåkka trail (near the top).

SM Figure 13 | Picture from the Björkliden trail (shrubland area).

SM Figure 14 | Picture from the Björkliden trail (near the top).



SM Figure 15 | Parking places along the E10 paralleling the Rallarvägen. Figure obtained from Trafikverket (2018) (https://trafikverket.ineko.se/se/%C3%A5tg%C3%A4rdsvalsstudie-e10-tornetr%C3%A4skomr%C3%A5det)