Can the disappearance of the forest orchid *Goodyera repens* be linked to clearcutting?

A spatial analysis using citizen science data from southern Sweden.

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Master's thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
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Abstract

Habitat transformation through forestry has an impact on boreal species in northern Europe. In Sweden, even-aged plantations with clearcut harvesting are forestry practices that affect the understory vegetation. This study focuses on the red-listed *Goodyera repens*, a rhizomatous evergreen orchid. Because it is adapted to the stable environment of humidity and shade found in closed conifer forests, it is thought to be negatively affected by clearcuts. The aim of this project was to study the relationship between disappearances of *G. repens* and conducted clearcuts. Citizen science reports of presence and disappearance of *G. repens* from Artportalen in southern Sweden from 1997 to 2022 were used to define disappearance sites. A GIS analysis was conducted with this data together with information about carried-out clearcuts. In 13.9% of the sites a clearcut occurred in between presence and disappearance. This suggests that clearcutting may have caused *G. repens* to disappear in these sites, which is in accordance with the ecology of the species and previous studies. However, in 86.1% of the sites *G. repens* disappeared without being preceded by a clearcut, so there may be other reasons behind it. Half of the sites with clearcut between presence and disappearance observations had more than 66% of their surface area occupied by the clearcut. From the other half, most of them had less than 33%, suggesting that *G. repens* could be affected even by a small clearcut area in its proximity. Biases and errors from working with citizen science data should be considered, such as different observer's experience, temporal efforts or spatial efforts. Today's conservation efforts often focus on avoiding clearcutting where *G. repens* is present. However, this study shows that the disappearance of *G. repens* may be caused to a large extent by other factors. More research about the causes of its decline would be needed to improve *G. repens* conservation's work.

Keywords: Goodyera repens, knärot, Artportalen, forestry, clearcut, citizen science, southern Sweden, conservation

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1. Introduction

1.1 Forestry influence on boreal plants

Habitat loss, fragmentation and degradation due to anthropogenic transformation and land use change are some of the main threats to biodiversity at a global scale (Banks-Leite et al., 2020). Forestry has historically been (and still is) a driver of transformation of the boreal forest in northern Europe, where it is the most extended terrestrial ecosystem (Hansen et al., 2010).

Not many boreal regions are as affected by forestry as Sweden, which is one of the countries in Europe with the highest forest harvesting intensity (Levers et al., 2014). In Sweden, modern forestry has been based on even-aged plantations and clearcut harvesting to maximize production, with the consequent reduction of old uneven-aged forests that are being replaced by young homogeneous post-harvest forests (Kuuluvainen et al., 2015; Linder & Östlund, 1998). This has led to concerns about if this forest management approach and its timber production aims are compatible with the maintenance of the boreal forest's biodiversity and ecosystem services (Hertog et al., 2022). In fact, felling is one of the factors with a major impact on red-listed species in Sweden, affecting more than 1,800 species (Eide et al., 2020).

Plants, and understory plants in particular, are a key component and ecosystem drivers of boreal forests (Nilsson & Wardle, 2005). Plant species response to clearcutting is diverse and species-dependent: while some species, like early colonizers or shade-intolerant plants, benefit from clearcuts, mature forest-related plants are affected in a negative way when forests are cut (Česoniene et al., 2018; Paillet et al., 2010).

1.2 *Goodyera repens*, an orchid dependent on forest continuity

Goodyera repens (L.) R. Br. is an example of a vascular plant species that is adapted to the stable environment of closed forests and disadvantaged by its disturbance (Delin, 1992; Ståhl, 2012).

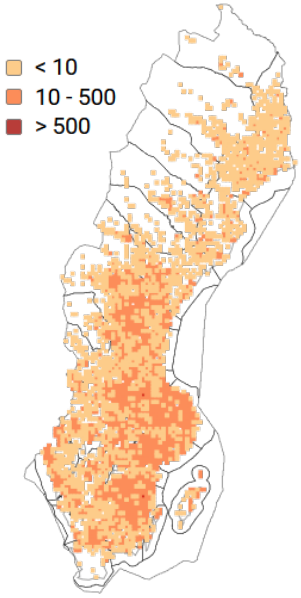
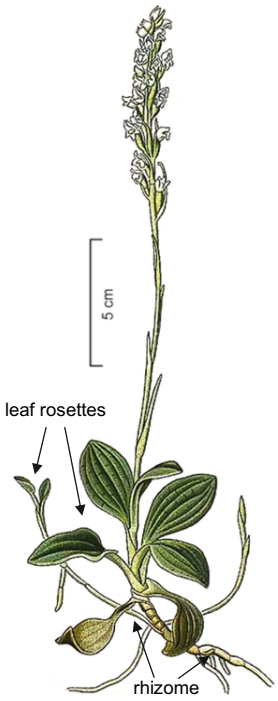


Figure 1. Distribution of reported observations of Goodyera repens *from Artportalen in Sweden. From: SLU Artdatabanken. (2023). Knärot [*Goodyera repens*]. Retrieved in December 2023.*

This plant is a terrestrial orchid (Orchidaceae family) distributed through the north of Europe, Asia and North America (Ståhl, 2012), where it is mainly found in coniferous forests. In Sweden *G. repens* occurs in most of the country, but it is rarer far north and far south (SLU Artdatabanken, 2023b) (Fig. 1). The main habitat in Sweden constitutes of humid Scots pine and Norway spruce forest, but it can also be found in dry sandy pine forests in the south and in mixed conifer-birch forest in the northernmost parts and in the mountains (Ståhl, 2012).

The habitat and distribution of *G. repens* is explained by its biology and its ecological requirements. *G. repens* is an evergreen rhizomatous species. It spreads clonally with branching rhizomes that creep in the upper layer of the soil and grow leaf rosettes (Brzosko et al., 2013; Delin, 1992) (Fig. 2). Like other orchids, *G. repens* is dependent on mycorrhizal fungi for its nutrient uptake, especially in its first heterotrophic and subterranean phase (Cameron et al., 2006). It demands high and even humidity in combination with moderate to deep shade (Berglund, 2015; Tyler et al., 2021). Therefore, it also depends on a persistent moss layer that helps preserving moisture (Delin, 1992) and a relatively dense canopy (Pitkin et al., 1995). These characteristics are mostly found in old undisturbed forest environments (Berglund, 2015).



Previous studies have found that *G. repens* cannot tolerate major disturbances and that it disappears after the forest has been clearcut (Johnson, 2014; Lõhmus & Kull, 2011). Clearcutting affects *G. repens* by directly removing the trees and the moss layer that maintain the environmental conditions of moisture and shade to which it is adapted (Delin, 1992; Pitkin et al., 1995; Ståhl, 2012). In addition, after a clearcut, nitrophilous and heliophilous plants are favored and can outcompete *G. repens*, whose growth and colonization rate are slow (Johnson, 2014). In Sweden, the population of *G. repens* is estimated to have declined by 50% during the 1990s

Figure 2. Illustration of Goodyera repens *showing the creeping rhizome from which the evergreen leaf rosettes grow. Modified from Mosclef, A. (1891).* Atlas des plantes de France, utiles nuisibles et ornamentales*, vol. 3, p. 281, Fig. A.*

and to have stabilized at a low level during the 2000s (Skogsstyrelsen, 2023b). Like all orchid species in Sweden, *G. repens* is protected by the Species Protection Ordinance 2007:845 (Artskyddsförordningen). This protection means that it is prohibited to pick, remove or damage the plant or parts of it (SFS 2007:845). In addition, it is categorized as Vulnerable (VU) in the Swedish Red List (SLU Artdatabanken, 2020). However, at the European level, it is categorized as Least Concern (LC) (Maxted et al., 2011).

Because *G. repens* is protected but steady declining in Sweden, it is of interest to monitor the remaining populations and to determine what can be done to reverse the negative development.

1.3 Citizen science data from Artportalen, the Swedish Species Observation System

One way to monitor *G. repens* would be by using citizen science data. Citizen science is the participation of non-professional scientists, mostly volunteers, in activities that contribute to scientific research, such as collection of data (Bonney et al., 2009; Dickinson et al., 2010). Citizen science-based participatory monitoring is being acknowledged as a credible tool for scientific research and monitoring (Dickinson et al., 2010). In addition, it provides information on distribution and trends in the abundance of species that is regularly updated, being useful for the demands of ecological studies as well as governmental institutions (Jones et al., 2011).

Artportalen (the Swedish Species Observation System) is a system for observations of Sweden's wild plants, animals and fungi. It consists of a database with associated services for reporting, searching and handling the observations. Species data for Artportalen is gathered by private individuals and professionals such as amateurs, researchers and nature conservation consultants (SLU Artdatabanken, 2023a).

The advantage of using this data for studying *G. repens* lies in that it is publicly available, and it includes location and date, among other fields, across a broad geographical region (the whole of Sweden). However, it has limitations arising from it being citizen science data. For instance, the variable ability, experience and type of training of observers, or the sampling biases in the temporal and spatial efforts (e.g., more observations close to populated areas or in protected areas) (Dickinson et al., 2010; Jones et al., 2011).

1.4 Aim and hypothesis

The main aim of this project was to study the relationship between disappearances of the forest orchid *G. repens* and clearcut forest management. This was conducted in two steps. First, all the sites in southern Sweden where *G. repens* had been reported to have disappeared were mapped. Second, the sites were examined in a GIS analysis to find out how many of the sites had been affected by clearcuts before *G. repens'* disappearance report.

For examining this, citizen science reports of presence and disappearance of *G. repens* from Artportalen in southern Sweden from 1997 to 2022 were used, together with information about conducted clearcuts. From this combination of data, the following was obtained: (1) the proportion of disappearance sites with presence reported before which have or have not a clearcut in between, and (2) the percentage of site area that intersects with clearcuts.

The hypothesis is that clearcuts have a negative effect on *G. repens* occurrence, meaning that clearcuts took place in the sites where the orchid has disappeared (i.e., there was a clearcut between the last report of presence and the first report of disappearance).

2. Methods

To find out the relationship between disappearances of *G. repens* and clearcuts, data management and analysis were conducted using the Microsoft software Excel, the ESRI GIS software ArcGIS Pro (Version 3.1) (Esri Inc., 2023) and RStudio (Version 4.1.2). Definitions of commonly used terms can be found in Table 1.

Table 1. Terms used in the text and their definitions.

Term	Definition
Observation	Record of *G. repens* reported in Artportalen. Term is used for both recorded presence and recorded disappearance.
Presence point	Spatial coordinates stored together with a reported observation of presence of *G. repens* in Artportalen.
Disappearance point	Spatial coordinates stored together with a reported observation of disappearance of *G. repens* in Artportalen.
Site / disappearance site	Area that contains one or more disappearance points. In the analyses, areas are used instead of points because of the accuracy values, i.e., the observation is not exact in space, and every report can be of one or several plants in an area of varying size.

2.1 Data collection

Citizen science data of *G. repens* was obtained from Artportalen (the Swedish Species Observation System) (Liljeblad, 2023). When extracting data from Artportalen, the following search parameters were used:

- Species: *Goodyera repens* (L.) R. Br.
- Period: all available records until 31/12/2022
- Provinces: Blekinge, Halland, Skåne, Småland

The initial search, including all available records of *G. repens* until 31/12/2022, resulted in 9,923 observations. After exporting all observations from Artportalen, data was filtered to create two different datasets: one with reported observations of presence ('Not recovered' field = 'false') of *G. repens* (9,498 in total, Fig. 3a) and another one with reported observations of disappearance ('Not recovered' field = 'true') of *G. repens* (425 in total, Fig. 3b).

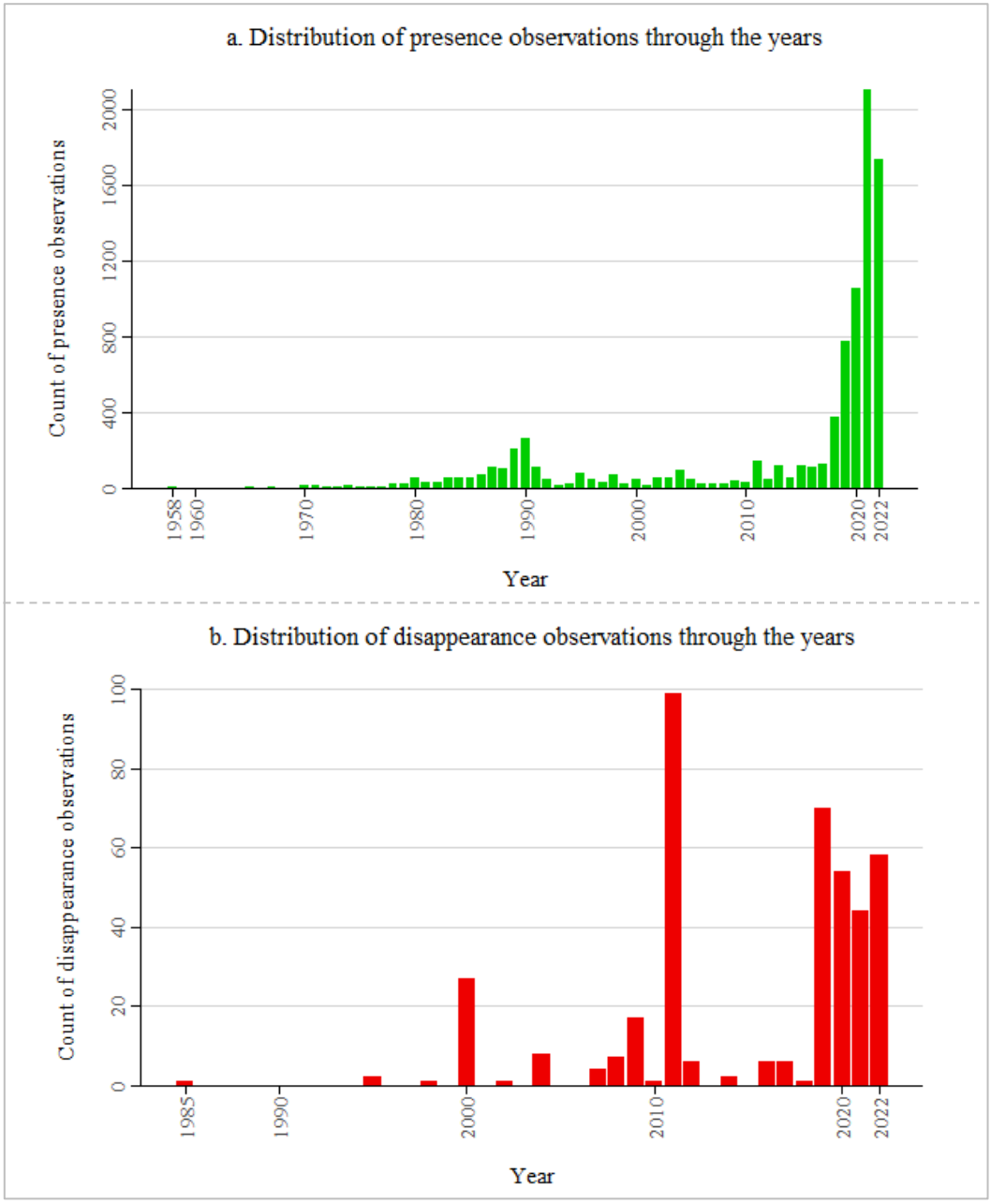


Figure 3. Distribution of the number of a) presence observations of G. repens *reported in Artportalen between the years 1958 (earliest report) and 2022 and b) disappearance observations of* G. repens *reported in Artportalen between the years 1985 (earliest report) and 2022, in the provinces of Blekinge, Halland, Skåne and Småland.*

Because the dataset is a compilation from several different users reporting *G. repens* on Artportalen, there was sometimes overlapping data from different dates in the same location. To solve the problem with repeated observations in sites where *G. repens* had disappeared, only the oldest observation from those with the same coordinates was kept, i.e., the first report of disappearance of *G. repens* in a certain point. This data was then filtered to only keep observations from 1997 to 2022. 1997 was selected as the starting year for observations because the oldest available clearcut data (later used in the analysis) was from that year.

Some observations were reported with a large spatial uncertainty. Observations with more than 100 m of accuracy value (less accuracy) were not considered, as they would generate a too big buffer area and too large uncertainty in the further analysis. This initial filtering of data points (excluding doublets and accuracy of >100 m) resulted in 272 observations of disappearance of *G. repens* (Fig. 4). This data was used for conducting the rest of the analysis.

From the presence dataset, the last observation from points with the same coordinates was obtained, i.e., the most recent presence report. As with the disappearance data, observations where the field 'Accuracy' ≤ 100 m were kept. This resulted in 7,595 last observations of presence.

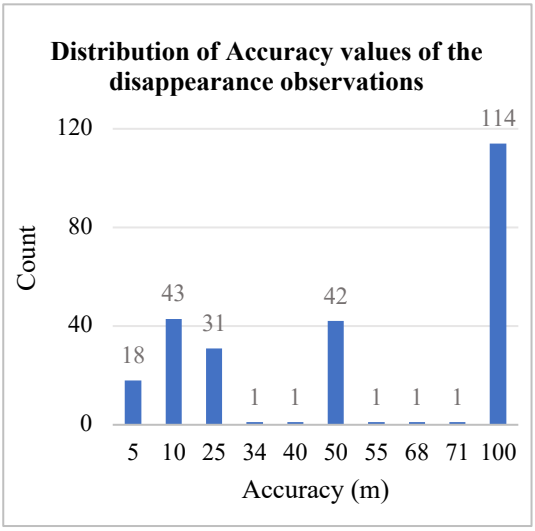


Figure 4. Frequency of the accuracy values (in meters) of the 272 disappearance observations from Artportalen. Here, accuracy values > 100 m have been excluded.

2.2 Definition of the sites

After filtering the observation data of *G. repens* it was noticeable that some points where the species had been reported as disappeared were located close together. To avoid duplicates due to repeated observations of the same population of *G. repens* in the same area, the sites were redefined as clusters of intersecting buffers around the reported coordinates. After the redefinition, only site level (which could include one or several observation points) was considered for the analysis.

The creation of sites from neighbouring individual points was conducted in ArcGIS Pro. The first step was to create buffers from the disappearance points. Due to the uncertain location of the disappearance points from Artportalen (Accuracy values), the expression to create the buffer in the program was: buffer = Accuracy (5-100 m). Then, the boundaries were dissolved to obtain clusters. A visual example of these two steps can be seen in Fig. 5.

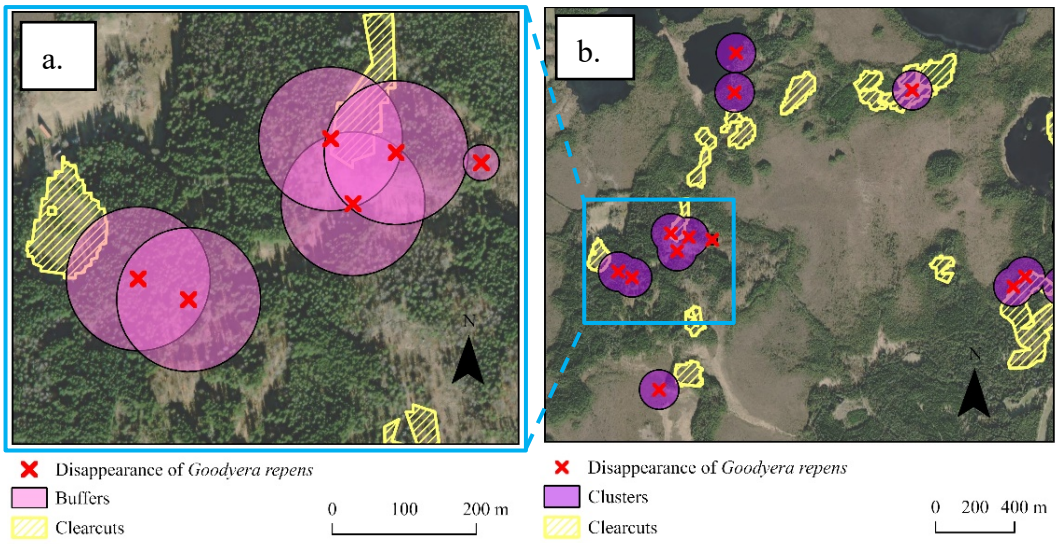


Figure 5. a) Visual example of the creation of buffers (pink polygons) around the disappearance points and b) dissolving the boundaries to obtain clusters (purple polygons). The points where G. repens *was reported as disappeared (red crosses) and clearcuts (yellow polygons) are also represented.*

To define the final sites, new clusters were created considering linear features that crossed the previous clusters. Paths, roads and railways are infrastructures that fragment the habitat. Therefore, if a linear feature (path, road, railway) crossed the cluster, the buffer areas at both sides of the line were considered as different sites (even if they overlapped). The transport networks ('*Fastighetskartan Kommunikation*') geodata was obtained from The Swedish Mapping, Cadastral and Land Registration Authority open data website (Lantmäteriet, 2020). The process of identifying and splitting sites that are crossed by line features can be seen in detail in Appendix I.

After merging nearby observations into sites and splitting sites divided by line objects, the result was a layer with site polygons and a new field in the observation points dataset containing the Site ID of every observation point, i.e., the site that

the disappearance report belongs to. A visual example of these steps can be seen in Fig. 6.

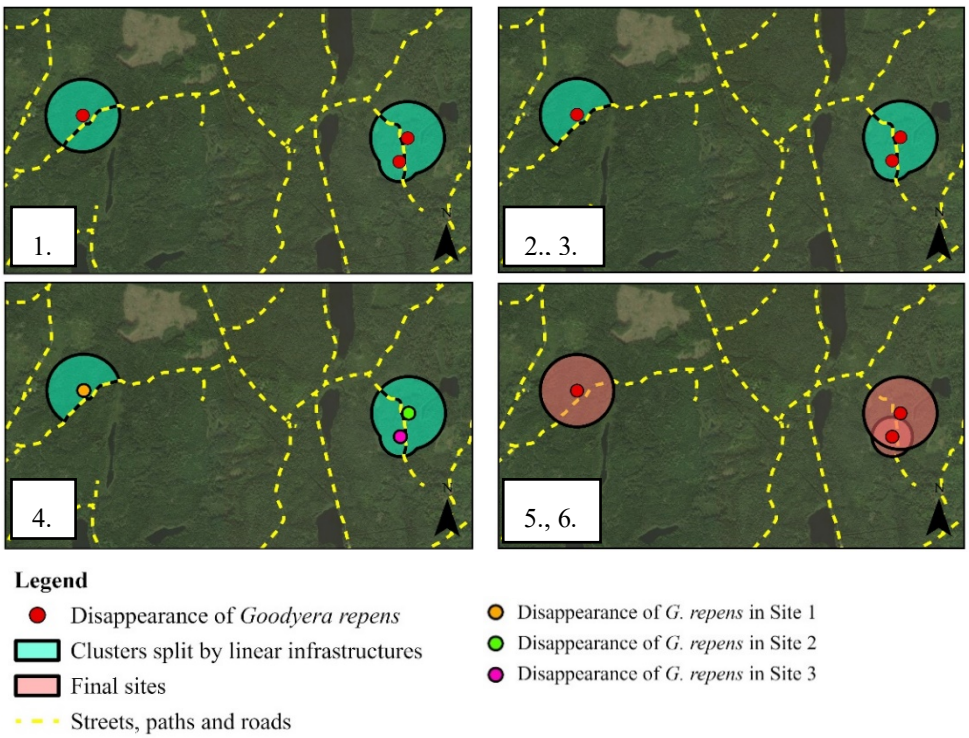


Figure 6. Visual example of the process carried out in GIS to obtain the site areas (pink circles). In the maps are represented the points of disappearance of G. repens *(small circles) and the linear infrastructures considered (yellow dotted lines). 1. split clusters by line features (paths, roads and railways); 2. spatially select split clusters by the disappearance points and 3. and make a new layer; 4. spatial join to give every point a Site ID; 5. create buffers and 6. dissolve boundaries (final result).*

2.3 Analysis of relationships between clearcuts and *G. repens* disappearances

2.3.1 Disappearance sites with presence reported before which have a clearcut in between in their study site

To answer the research questions, the first step was to define the study sites where *G. repens* disappeared in the study area. Here, the main aim was to find out which disappearance sites had experienced a clearcut within their area both after the reported observation of presence and before the observation of disappearance. The time sequence of the concept of the analysis can be seen in Fig. 7.

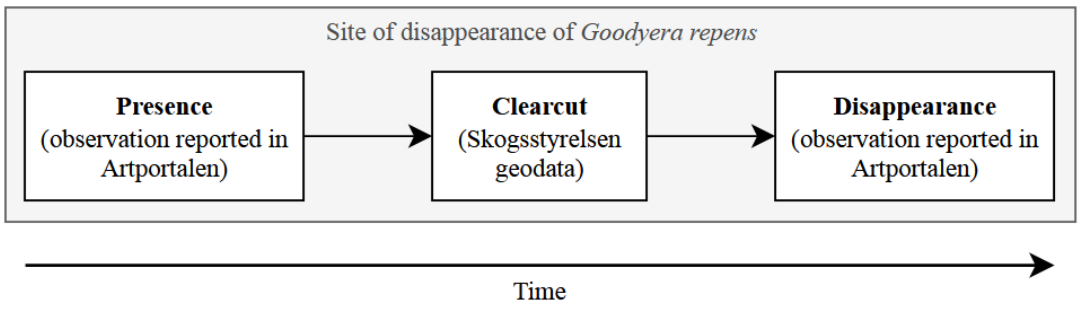


Figure 7. Time sequence of the concept of the analysis. The aim was to know the proportion of disappearance sites with a clearcut between the observation of presence and observation of disappearance.

Clearcut geodata for the time period 1997 – 2022 (‘*Utförda avverkningar’*) for the study area was downloaded from The Swedish Forest Agency (Skogsstyrelsen). The dataset includes the date when the clearcut was conducted together with spatial information about the area where the forest was harvested. This data is openly available on The Swedish Forest Agency website (Skogsstyrelsen, 2023a).

The first step was to identify the disappearance and presence points that were located in the same site. The datasets were processed in R to keep the sites that had at least one presence of *G. repens* reported before at least one disappearance observation (in that same site).

Secondly, in ArcGIS Pro the clearcut polygons were clipped using these sites as clipping feature, and the ID of the sites that intersected with them was joined to the dataset. This resulted in a clearcut dataset with the site ID where they are located and the date of clearcut. This dataset was then processed in R together with the ones with disappearance and presence points (which also included the site ID) to obtain the disappearance sites that had presence reported before disappearance and a clearcut in between. These are the final sites with which the area analysis was conducted.

2.3.2 Area analysis

The aim of the area analysis was to find out the proportion of the final sites (mentioned above) that was occupied by a clearcut.

To calculate the percentage of site area affected by clearcuts, the site polygons were clipped using the clearcuts as clipping feature. The clipped polygons' area was then used to calculate the percentage of the total site area occupied by a clearcut.

3. Results

3.1 Sites where *G. repens* has disappeared

The clustering of observations close to one another (as they are assumed to belong to the same population) resulted in a total of 248 sites where *G. repens* had disappeared from 1997 to 2022. From these 248 sites, 202 had at least one presence observation before at least one disappearance observation (Fig. 8), meaning that someone reported in Artportalen a disappearance of *G. repens* from a site where someone previously had reported an occurrence of *G. repens*.

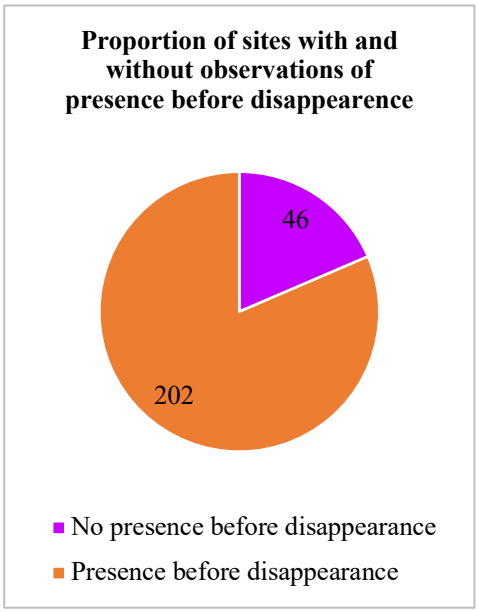


Figure 8. Proportion of disappearance sites (248 in total) with and without at least one presence observation before at least one disappearance observation of G. repens.

When adding the clearcut data to the analysis, there were in total 28 sites where a clearcut occurred between a presence observation and a disappearance observation (Fig. 9, Fig. 10). This corresponds to 11.3% of the total number of sites of reported disappearance of *G. repens* and 13.9% of the sites with presence reported before. A summary of numbers of sites and percentages can be found in Appendix II.

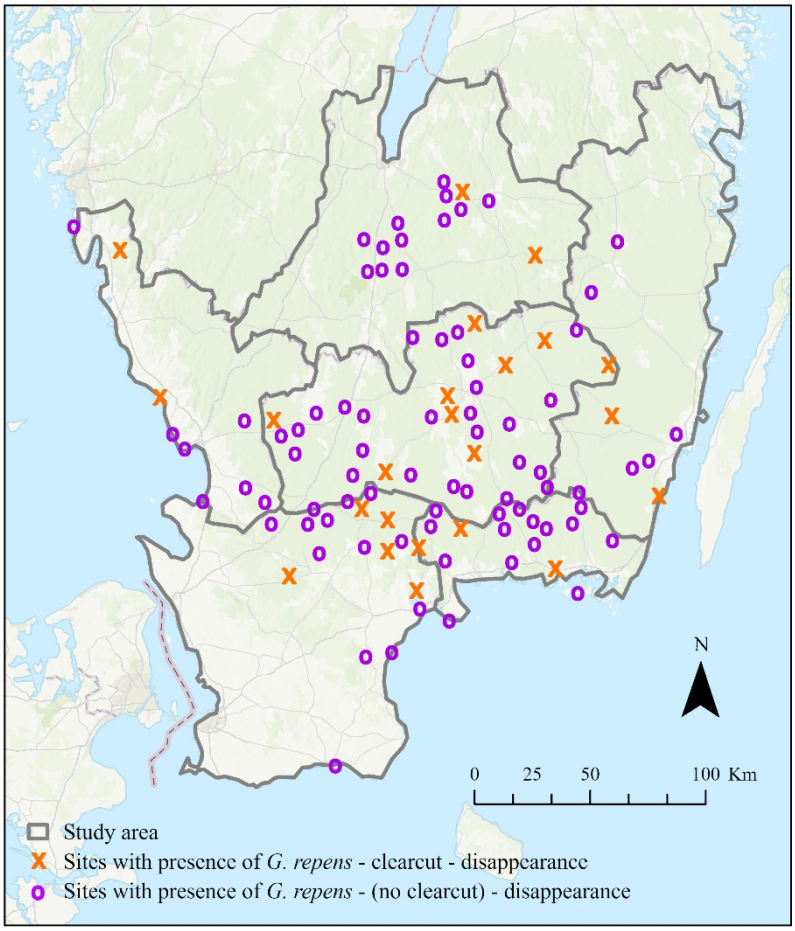


Figure 9. Map of the study area showing the location of the disappearance sites of G. repens *with presence reported before (202 in total). In the map are represented the sites where a clearcut took place between the presence and disappearance observations (28 sites, orange crosses) and the sites where there was no clearcut (174 sites, purple circles).*

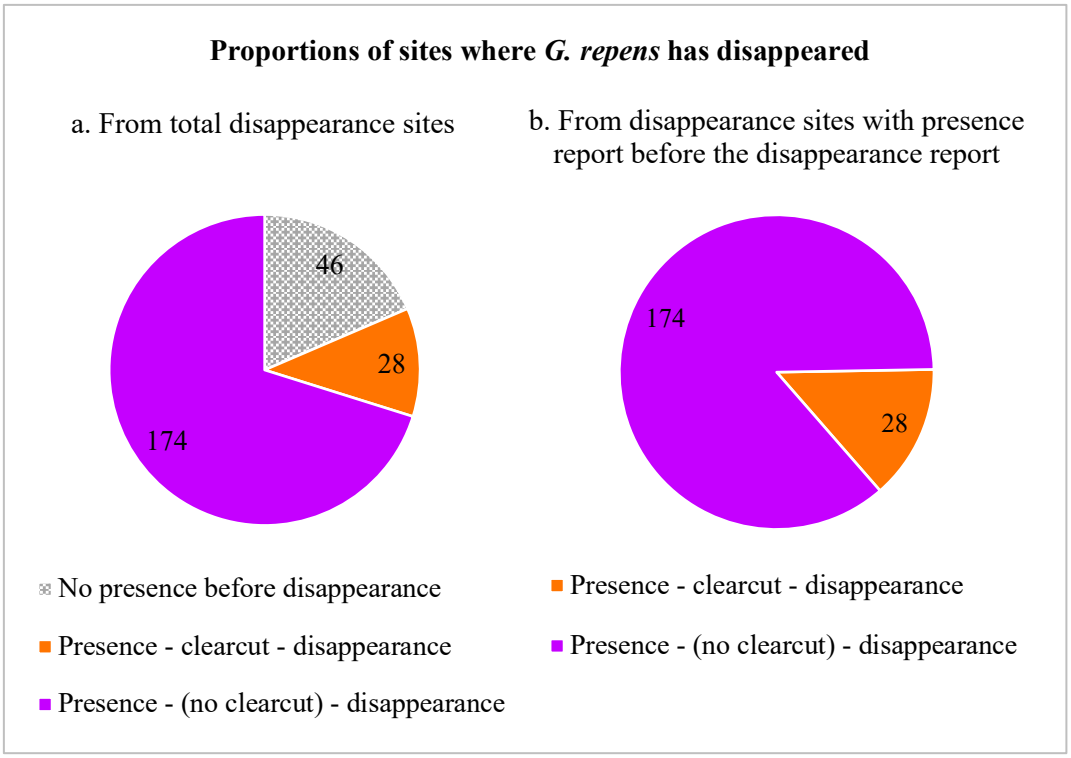


Figure 10. Proportions of different categories of sites where G. repens *has been reported as disappeared. The first category (grey) shows sites without presence reported before. The second category (orange) shows sites with presence reported before and a clearcut in between. The third category (purple) shows sites with presence reported before and no clearcut in between. The numbers inside the chart indicate the number of sites corresponding to each category from a) total disappearance sites and b) disappearance sites with presence observation before disappearance.*

3.2 Area analysis

From the 28 disappearance sites with presence reported before and clearcut in between, the average percentage of area occupied by clearcut was 55.11% with a standard deviation of ±36.47%. The median was 62.19%. From these 28 disappearance sites, 10 of them had less than 33% of their area occupied by clearcuts, 4 had between 33% and 66%, and 14 had more than 66% (Fig. 11).

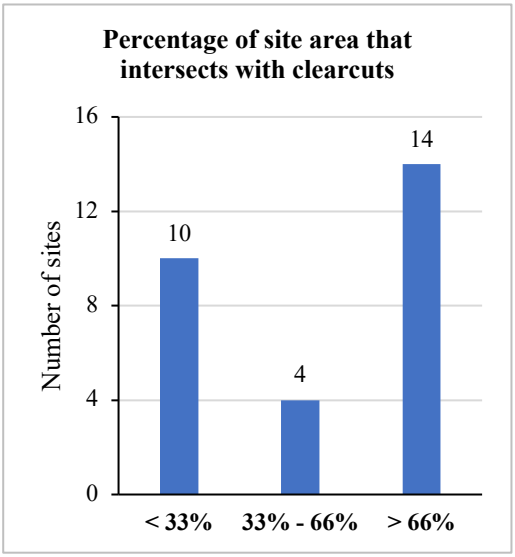


Figure 11. Percentage of the area of disappearance sites of G. repens *with presence reported before and clearcut in between occupied by clearcut.*

5. Discussion

The aim of this project was to investigate the correlation between the disappearance of the forest orchid *G. repens* and the occurrence of forest clearcuts, with a focus on the southern region of Sweden as the study area. In 13.9% of the disappearance sites a clearcut occurred in between presence and disappearance. Half of them had more than 2/3 of their area occupied by clearcut. In the rest of these sites (86.1%), *G. repens* was reported as disappeared even though there was not clearcut occurring.

5.1 Disappearance sites of *G. repens*

The results showed that 13.9% of the defined disappearance sites of *G. repens* had a clearcut occurring there between presence and disappearance observations both reported in Artportalen. This suggests that clearcutting above and close to *G. repens* may have caused the population to disappear from these sites. The fact that clearcuts took place in sites where *G. repens* was later reported to have disappeared is in accordance with the study hypothesis and with the ecology of the species. It is also in line with what has been found in previous studies. Johnson (2014) and Lõhmus and Kull (2011) found *G. repens* absent in clearcuts and present in some mature forests close to those clearcuts, suggesting that clearcuts are not favourable for *G. repens*. However, these studies did not consider the presence of *G. repens* in the plot *before* the clearcut took place.

Forest clearcutting causes changes in the environment where *G. repens* grows. Firstly, when the canopy is removed, air humidity at ground level decreases. This affects the moss layer where the rhizome of *G. repens* grows and which preserves the moisture necessary for the plant and its mycorrhizal fungus (Delin, 1992). Secondly, the clearcut's ground and its surroundings are exposed to a higher light incidence, which favours the growth of fast-growing heliophilous and pioneer plants in the herbaceous layer and understory, i.e., the natural vegetation succession (Tsiftsis et al., 2012). *G. repens* in colder climates tends to colonize clonally with a slow rate more than sexually via seeds (Brzosko et al., 2013), so it can be outcompeted by these plants. Moreover, the mineralisation of organic matter after the cutting would increase the fertility of the soil, allowing the establishment of

more competitive species than both *G. repens* and its fungal partner (Łazarski, 2020; Tsiftsis et al., 2012).

More noticeable than the sites where *G. repens* disappeared after a clearcut, was perhaps the large proportion of sites (86.1%) where *G. repens* had disappeared without being preceded by a clearcut. Even though clearcutting took place between reported presence and disappearance of *G. repens*, this did not happen to a great extent in the study area. This means that there may be other reasons behind *G. repens* disappearance in the majority of the sites, such as:

- The construction of buildings or other infrastructure (including that associated with forestry) could be another cause apart from clearcuts of disappearance of *G. repens* by destroying the habitat. In fact, in the comments of a disappearance observation from Artportalen, someone mentioned a paved road for forestry machinery that was built close to where the orchid was found in the past.
- Other types of forest management apart from clearcutting can also change the environment and disfavour *G. repens*. For instance, cleaning or thinning are activities that open the canopy affecting the light and humidity conditions. Moreover, after a disturbance such as thinning, plant diversity is known to increase due to fast-growing pioneer species colonizing the opened areas (Widenfalk & Weslien, 2009). These could potentially outcompete *G. repens*. The impact of a wider range of forest management operations should preferably be included in future analyses.
- The cyclones Gudrun and Per that took place in 2005 and 2007, respectively, most likely affected *G. repens*'s populations. In fact, the Swedish Forest Agency links them with the disappearance of *G. repens* in many areas (Skogsstyrelsen, 2023b). Both storms affected the south of Sweden, but Gudrun was the most damaging one, with around 75 million m^3 of forest felled by the storm mostly in the same region as the study area (SMHI, 2011).
- The activity of forest fauna, such as wild boars, could cause as well the disappearing of *G. repens* by disturbing the substrate. Wild boar population have increased in Europe and in Sweden in particular in the past few decades (Massei et al., 2015). Their rooting activity creates open soil areas and reduces the cover of herbaceous and moss layers (Pankova et al., 2020). This could affect the finding of the plant and also its persistence if the rooting areas are too big.
- The climate during the last decades might have affected the conditions of the sites where *G. repens* was reported. Since 2001, the running mean temperature in Sweden has increased by 0.72ºC, while the running mean precipitation has decreased by 17 mm (SMHI, 2022a, 2022b). Higher temperature and lower precipitation, specially during summer, may disfavor the humidity requirements of the species. It is not clear how this would have

affected *G. repens*, but severe droughts such as the one from the summer of 2018 are probably not good for the species, and they are more likely to happen under anthropogenic climate change conditions (Wilcke et al., 2020).

5.2 Area analysis

In addition to summarizing the number of sites where *G. repens* had disappeared, it was also analysed which proportion of each site had been affected by a clearcut. Half of the sites (50%) with clearcut between presence and disappearance observations had more than two thirds (>66%) of their surface area occupied by the clearcut. From the other half, most of them had less than 33%, which suggests that it is possible that *G. repens* can be affected even by a small clearcut area in its proximity. This is in accordance with the known ecological needs of shade and humidity of the species. A clearcut in the surroundings would allow more light to penetrate in the understory where *G. repens* grows. In fact, the Swedish Forest Agency recommends a distance of 50 meters from the edge of the clearcut to *G. repens* locations to maintain the local microclimate (Skogsstyrelsen, 2023b). It would be interesting to repeat the analysis carried out in this project using a 50 m buffer added to the accuracy buffer, knowing that this is the estimated distance below which a clearcut would affect the orchid. However, this is just an estimation and would probably vary depending on local conditions.

5.3 Artportalen errors and biases

In relation to the observations reported in Artportalen, there are several situations that could have affected the number of study sites and the proportion of sites with clearcut between presence and disappearance. This could have influenced the results, potentially leading to either an overestimation or underestimation. Some examples are:

- The clearcut analysis was only conducted in those disappearance sites that had a presence of *G. repens* reported after 1997. However, there could be sites where *G. repens* was known before but where it wasn't reported in Artportalen, or it was reported prior to 1997. By excluding these sites from the analyses, some important data may have been missed.
- The number of disappearance sites could have been overestimated due to the possibility of some disappearance reports being erroneous, as a result of the observer's inability to find the plant (for instance, due to its small size and unnoticeability when it does not have flowers).

- Some observers report as one observation a great number of individuals in a big area (lower Accuracy value), while others report individual observations of less individuals in a small area (higher Accuracy value). This would result in different amounts and sizes of disappearance sites. In addition, when filtering the Artportalen data to prepare it for the analysis, reports with low Accuracy were discarded (value higher than 100 m).
- The analysis used data from Artportalen from all available years. However, the distribution of observations through the years, as previously shown in the methods (Fig. 3), is irregular. Most of the observations used for this study are from the last few years, which makes it less probable to have sites with a clearcut happening between reported presence and disappearance. This more recent increase in observations is probably due to citizen science becoming more popular and accessible, and projects having more diffusion because of the internet (Bonney et al., 2014; Silvertown, 2009). It is noticeable a peak of observations in 2011, which coincides with the year that *G. repens* was declared "Plant of the year" ("Årets växt") by the Svenska Botaniska Föreningen (the Swedish Botanical Society), which encouraged people to report the species in Artportalen (Svenska Botaniska Föreningen, 2011).

It is also important to mention that the comments section of the Artportalen database contained information about the observations that was not considered due to time limitations and inconsistency of that information. A quick reading of some of the comments revealed that, on some occasions, observers mention the possibility of not having seen the orchid even if it was there, or they admit the inaccuracy of the coordinates. Some observers also give information about what happened in the area where *G. repens* disappeared (clearcut, thinning, increase of shrub layer density, or road construction). This issue with the comments was as well noticed and brought up by Ståhl (2012). It would be ideal to standardize the way in which this information is uploaded to Artportalen.

When working with citizen science data, one must acknowledge the errors and biases that come with using this method to collect data (Dickinson et al., 2010). First, the skills, experience and type of training of the observers can be different. In this case, this could have led to an erroneous report of disappearance, as mentioned previously. Moreover, there can be a sampling bias in the temporal effort, meaning in this case that some people could have spent more or less time looking for *G. repens*. In the comment field of the Artportalen dataset, some observers mentioned that they could have missed the plant, or maybe found it if they had spent more time looking. There can also be a sampling bias in the spatial effort, meaning that the visited sites can be more likely to be close to populated areas, more accessible or in protected or sensitive areas.

However, around half of the observations of disappearance were part of the Floraväktarna citizen science project ("the Flora Guardians", coordinated by the

Swedish Botanical Society), “a network of nature-interested people who actively monitor species and increase knowledge about threatened Swedish vascular plants” (Svenska Botaniska Föreningen, 2023). Following a standardized methodology, volunteers revisit the sites of interest regularly and report the results of their surveys in Artportalen. Therefore, this data would probably be more reliable to use for assessing species disappearances and future studies could use it.

5.4 Methodology decisions

As mentioned above, irregularities in Artportalen data can have affected the number of study sites and the final result. But the methodology and the analysis conducted, with personal decisions involved, can also have affected the result.

Future studies could test the existence of presence observations after a clearcut (time sequence of presence → clearcut → presence), or presence reported *after* disappearance, indicating that perhaps the disappearance report was erroneous. It would also be interesting to include big water courses and lakes in the process of creating the sites, as they are as well elements that fragment the forest habitat. In addition, the construction of infrastructure may be another cause of disappearance of *G. repens* by destroying the habitat, so they could be included in the analysis too.

5.5 Conservation of *G. repens* and management implications

Considering the conservation of *G. repens*, administrations and forest managers already have the possibility to access information about sites of presence of the orchid and about where it is disappearing through Artportalen. However, this study has shown that clearcutting has been conducted also in locations where *G. repens* is known to occur.

The most obvious recommendation for the conservation of *G. repens* is to avoid clearcut harvesting in known locations of presence of the species. This should be achieved by improved controls when administrating harvesting permissions, and by informing landowners and persuade them to take considerations for the species into account (SLU Artdatabanken, 2023b). Protection of habitats with *G. repens* would also benefit other species adapted to closed forests. Today, the Swedish Forest Agency recommends leaving a protection zone of at least 50 m from the edge of the clearcut to *G. repens*, to avoid desiccation (Johnson, 2014; Skogsstyrelsen, 2023b). This is probably a good idea, as this study indicated that the presence of a nearby clearcut may affect *G. repens*. When it is not possible to avoid the clearcut, translocation of specimens could be a successful measure (Johnson, 2014), but it is

not clear if, in the new forest location, there would be suitable fungal partners for the establishment in a short time (Skogsstyrelsen, 2023b).

In a larger temporal scale, prolonging the rotation time of the managed forests to at least 120 years would be favourable. The slow rate of colonization and reestablishment of the species makes the current rotation time of 45 to 100 years (SFS 1979:429) too short (Johnson, 2014; Skogsstyrelsen, 2023b).

Perhaps one key to the conservation of *G. repens* would be a transition to other forest management models as an alternative to the even aged monoculture system that involves clearcutting, although it is a complex subject. For instance, the Swedish Forest Agency defines continuous cover forestry (CCF) or non-clearcut forestry as a production system where "the forest is managed in such a way that the land always has a tree cover, without any larger clear-cut areas" (Skogsstyrelsen, 2022). However, in Sweden CCF has been facing several barriers to be adopted (Hertog et al., 2022). This type of management, among other benefits for biodiversity, would allow habitat continuity for species adapted to shade and closed forest. More research about how other silvicultural practices such as CCF could benefit or not *G. repens* would be needed.

Nonetheless, while all these conservation efforts focus on how clearcutting affects *G. repens*, the results of this study suggest that other factors may have negatively affected the species to a great extent.

6. Conclusions

The purpose of the study was to analyze the correlation between the disappearance of the forest orchid *G. repens* and clearcutting in forests of southern Sweden. Clearcuts took place between reported presence and disappearance in 13.9% of the sites, suggesting that clearcuts can affect *G. repens* negatively by modifying the environment to which it is adapted. Therefore, the conservation of this red-listed species should consider measures such as avoiding clearcutting where it grows. However, in a large proportion of the sites *G. repens* disappeared without a clearcut occurring, so further research is needed on what other factors can have an effect on the disappearance of *G. repens*, e.g., other forestry practices, wild animal's activities or climate change. By studying these factors, the conservation work on *G. repens* could be improved. In addition, improving the monitoring method of the species and continuing the effort in the future would provide more reliable data to better understand different threats to the species and its trends.

Moreover, it would be interesting to expand the study area to the whole of Sweden, to increase the sample size and making it more representative of the species in the country. Data of disappearance from the Swedish National Forest Inventory's permanent plots could complement data from Artportalen, as *G. repens* is a target species of the vegetation surveys. A study of this scale would serve as well as an example of how the combination of citizen science data with land management data (such as carried-out clearcuts and results from vegetation surveys) can give an insight on possible threats to species of interest.

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Popular science summary

The creeping lady's tresses is a forest orchid protected in Sweden, but the Swedish Forest Agency estimates that its populations declined by 50% in the end of the 20th century. What can be the reason for the disappearance of this orchid? Perhaps forestry and clearcut logging are affecting it? In this master thesis, I studied the relationship between the disappearance of the creeping lady's tresses and conducted clearcuts in the south of Sweden.

Habitat transformation is one of the main threats to biodiversity, and forestry is an important cause of transformation of the boreal forest. In Sweden, many old forests have been replaced by plantations of the same age that are harvested mainly by clearcutting. This is a logging practice in which all or almost all of the trees in an area are cut down and then replanted. The creeping lady's tresses grows in pine and spruce forests and is thought to be affected by clearcuts in a negative way. Why? It needs a stable environment of humidity and shade provided by the moss layer where it grows and the canopy of the trees in closed forests. If the forest is cut down, these conditions are changed. The specific aim of my study was to know to which extend the disappearance of the creeping lady's tresses has happened in a place where a clearcut occurred.

To analyze this, I used citizen science reports to obtain sites in southern Sweden where people reported that the orchid disappeared. Then, I examined those sites to find out in how many of them someone found the orchid in the past, and then a clearcut took place before the creeping lady's tresses disappeared. This happened in 13.9% of the sites, suggesting that clearcuts indeed affect the orchid in a negative way. Administrations and forests managers have accessible information of presence of the orchid, but clearcuts were conducted anyway. Almost half of the sites had a small area occupied by a clearcut, which implies that they affect the orchid even if it's a small area close to it. This is why today's conservation efforts focus on avoiding clearcutting where the orchid grows and close to it. However, in most of the sites the plant disappeared without a clearcut happening, meaning that there are other mysterious factors causing the creeping lady's tresses to decline, maybe other forestry operations, wild boar's activity, or big storms. This result highlights that we need more research about why the creeping lady's tresses is declining apart from clearcutting to truly protect it and improve its conservation work.

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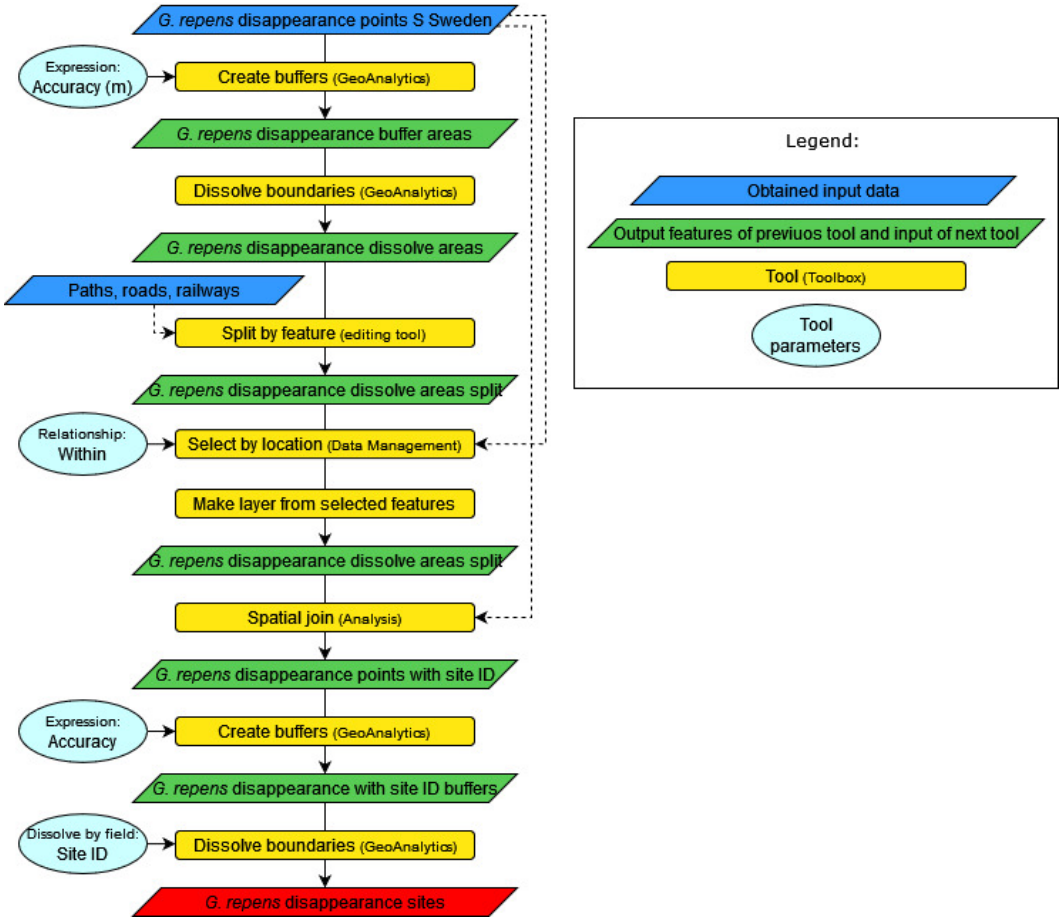
Appendix

I. Diagram showing the process carried out in ArcGIS Pro -to obtain the study sites. In red is the final result, the feature class containing the sites.



II. Count and proportions of disappearance sites with and without presence reported before disappearance, with presence reported before disappearance and clearcut in between, and without clearcut in between. The total number of sites is 248.

	Total	***No* presence ↓ disappearance**	**Presence ↓ disappearance**	**Presence ↓ clearcut ↓ disappearance**	**Presence ↓ (*no* clearcut) ↓ disappearance**
Number of sites	248	46	202	28	174
% from total number of sites	100%	18.5%	81.5%	11.3%	70.2%
% from sites with presence before disappearance			100%	13.9%	86.1%

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