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Practical conservation action on a Critically Endangered lichen species

Torbjørg Bjelland

Museum of Archaeology, University of Stavanger, Stavanger, Norway

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ABSTRACT

To save a species on the verge of extinction, an urgent practical conservation action was performed on the Critically Endangered lichen species *Leptogium hibernicum* in Norway. A transplantation experiment at two localities was carried out in close cooperation with the responsible authorities. An alarming problem for *L. hibernicum* is the imminent challenge of a habitat under threat. A parallel experiment with a comparable yet common species, *Leptogium saturninum*, was performed to exclude variables related to the experimental method. Four years after transplantation of lichen fragments, the rate of survival has levelled off to about 12% for *L. hibernicum* and 19% for *L. saturninum*. The decrease in surviving material is largest one year after transplantation, while the amount of surviving material stabilises over the following three years. Transplantation is here shown as a promising tool for the practical conservation of red-listed lichens.

1. Introduction

To preserve red-listed species, urgent practical conservation action may be necessary to guarantee short-term survival. However, there is a substantial risk involved in working with Critically Endangered (CR) species, as the number of individuals is small, and the action has the potential to lead to a further population decline. Reasonable action assumes scientific knowledge both about the specific target species, e.g., its dispersal limitations, ecology, habitat, as well as about its ecosystem (Hilmo, 2002; Scheidegger & Werth, 2009). Unfortunately, this information rarely exists, and responsible management are often faced with a dilemma. The option is either to wait in performing the conservation action until the relevant scientific knowledge is available, and hope it is not too late, or take the risk and act based on existing knowledge, even if the outcome is uncertain and could fail. According to the Convention on Biological Diversity, the responsible authorities are obliged to do what is possible to avoid letting the number of threatened and extinct species increase. This project is an example of taking a risk by testing an urgent practical conservation method. The target species *Leptogium hibernicum* is a Critically Endangered lichen, the method is transplantation, and the ecosystem is a forest.

Forests represents one of the richest biological areas on earth, an ecosystem with several red-listed species (CBD, 2010). A prominent threat to species diversity in the forest is land-use change driven by human activity, thereby causing habitat loss or degradation (CBD, 2010; Groom et al., 2006, Haugan et al., 2021). Lichens contribute to the overall species richness in the forest (Ellis, 2012), but are only rarely mentioned in ecological restoration programmes (de Lange et al., 2012). Furthermore, a single lichen species is a multi-species symbiosis (Spribille et al., 2016), thus making the required biological conservation action even more complicated since several species are involved in one unit.

Even if transplantation of lichens is a tried method in conservation biology, there exists no universal recipe (Smith, 2014). An optimization of the methodology must be adapted to the ecological knowledge existing about each species (Scheidegger & Werth, 2009). Experiments involving artificial dispersal of lichens have been tried using several species with variable degrees of success (e.g., Hallingbäck 1990; Scheidegger et al., 1995; Hilmo & Såstad, 2001; Walser & Scheidegger, 2002; Lidén, 2009; Hilmo et al., 2011; Gauslaa & Goward, 2012; Gustafsson et al., 2013; Kon & Ohmura, 2014; Smith, 2014; Leddy et al., 2019; Mallen-Cooper & Cornwell 2020). The slow growth rate (1–5 mm yr^{-1}, Armstrong & Bradwell, 2011) of lichens makes transplantation experiments even more complicated, and the lack of long-term results remains a drawback for these experiments.

The global population of *L. hibernicum* for the next 90 years is estimated to be reduced by 30–70%, and it was recently listed as globally Endangered (EN) in the IUCN Red List (Anderson & Yahr, 2021). Approximately 11% of all records are from Norway, but the recent decline in number of populations has led to *L. hibernicum* being recognized as Critically Endangered (CR) by the Norwegian Red List (Haugan et al., 2021). *Leptogium hibernicum* is under pressure as it is scarce, only known to reproduce asexually, and at the same time the main substrate pollarded ash (*Fraxinus excelsior*) is threatened (Haugan et al., 2021).

E-mail address: torbjorg.bjelland@uis.no.

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The pollarding tradition ended around 1950 and many of these trees have a big crown, leading to them being easily uprooted by the wind, and newly pollarded trees seems to be more susceptible to the fungal disease ash-dieback (*Hymenoscyphus fraxineus*) (Bengtsson et al., 2021). Without continuity of suitable substrates, *L. hibernicum*'s population will soon become extinct. This motivates an urgent need in making individual populations more robust. A technique for doing so is transplantation of fragments to new substrates locally. Similar discouraging predictions are estimated for several other lichen species (Hanski, 1999; Thomas, 2000; Snäll et al., 2003; Hanski, 2011) and transplantation technique will be a possibility for lichen species in similar situations as *L. hibernicum*.

In Norway, the responsible authorities have taken an initiative to avoid letting the number of threatened and extinct species increase, by implementing this as the national aim for biodiversity (St. Meld. 14 (2015–2016)). Through a controlled small-scale experiment performed as a cooperation between scientists and the responsible authorities, the main aims of the present study were (1) to provide new valuable knowledge for management of Critically Endangered lichen species, (2) test if transplantation is a useful tool for immediate practical conservation of red-listed lichens, (3) to increase the Norwegian population of *L. hibernicum,* and (4) to compare the transplant procedures and results with those of a common closely related species, *L. saturninum*.

2. Materials and methods

2.1. Study areas

The study areas are situated on the southwestern coast of Norway (Fig. 1). Two of the nine known localities for *L. hibernicum* were chosen in the experiment. The northernmost locality, Sævareidberget, is a Landscape Protection Area along Åkrafjorden, south of Bergen, in Vestland (59°45′56″ N; 6°7′55″ E, 0–200 m a.s.l.). The second locality is Årdal, which is situated north of Stavanger, and close to Årdalsfjorden in Rogaland (59°9′53″ N; 6°11′32″ E, 50–150 m a.s.l.). Both localities have an oceanic climate and are dominated by a broad-leaved deciduous forest with ash, lime (*Tilia cordata*), elm (*Ulmus glabra*), hazel (*Corylus avellana*), and grey alder (*Alnus incana*). The older trees of ash, lime and elm have previously been pollarded. Today, both areas are characterized by a mixture of dense forest and partly open woodland, including areas with grazing land and boulder fields (Fig. 1). The areas have in the past been more open because of more intense management. Ash-dieback has been registered in both localities.

2.2. Species

Leptogium hibernicum (Fig. 2a) is a foliose lichen with a cyanobacterial photobiont (*Nostoc*), with asexual reproduction, dispersal being by isidia and thallus fragments. There is a tomentum composed of spherical hyphal cells on the lower surface of the thallus (Bjelland et al., 2017). *Leptogium hibernicum* is restricted to oceanic/montane regions of western Europe, the islands of the North Atlantic, eastern North America, and

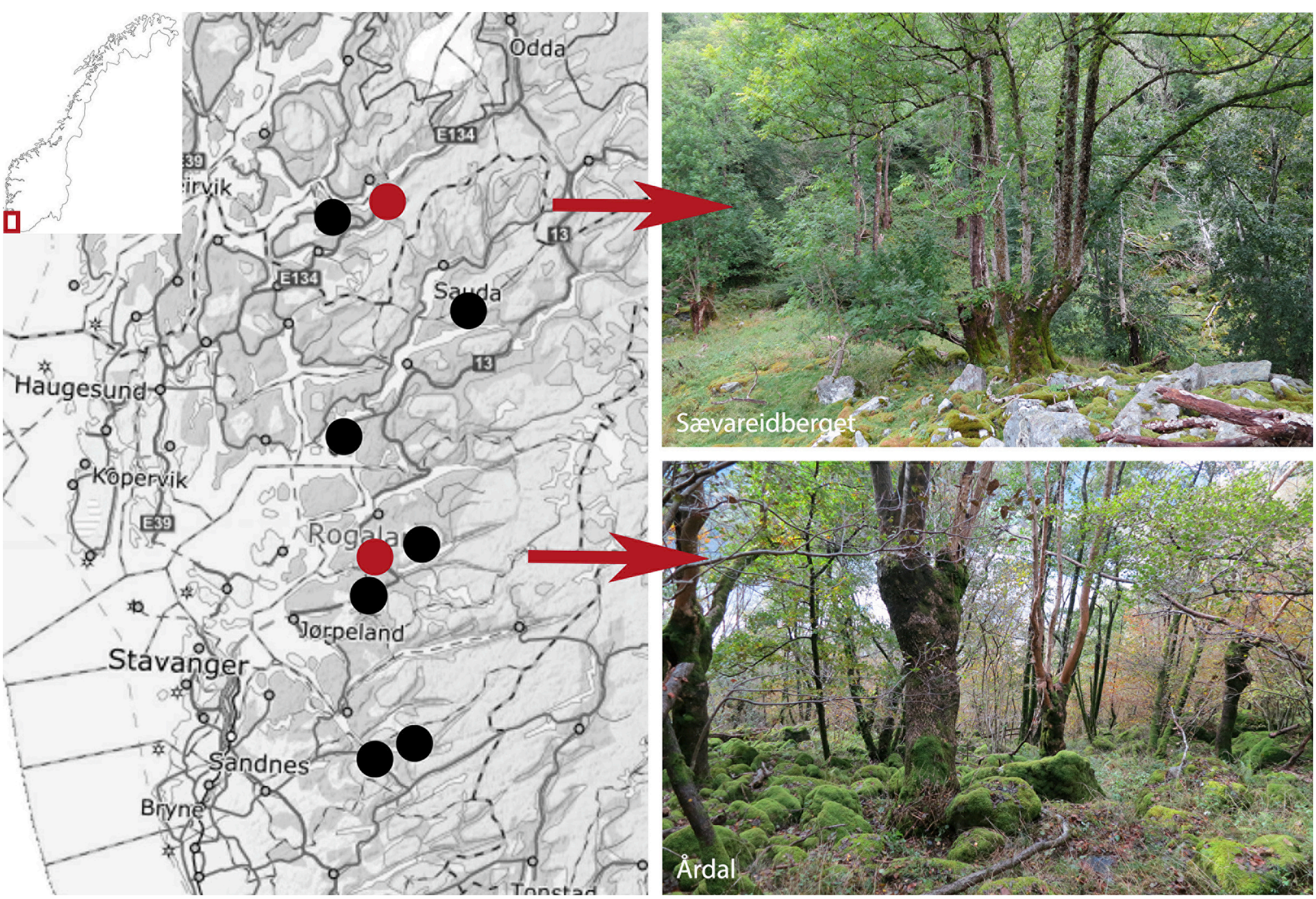

Fig. 1. Distribution of *Leptogium hibernicum* in Norway. Transplantation experiments are performed at two of the nine Norwegian localities, Sævareidberget and Årdal (red dots). Both localities are dominated by broad-leaved deciduous forest with pollarded ash. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

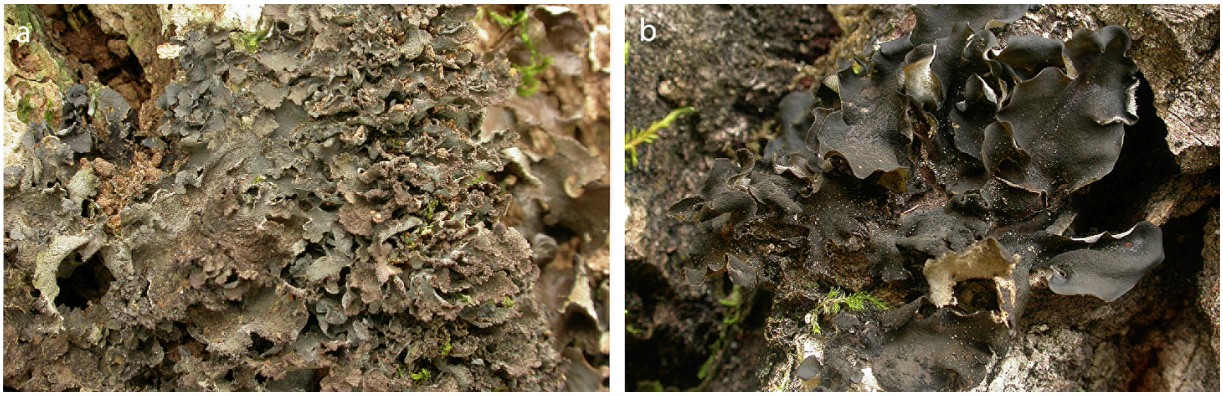

Fig. 2. *Leptogium hibernicum* (a) and *L. saturninum* (b). Photo: Einar Timdal.

Caucasus Mountains near the Black Sea (Anderson & Yahr, 2021). In Scandinavia it is only present in the most oceanic part, southwestern Norway. It is absent in Sweden, Denmark, and Finland. It is frost sensitive and has preferences for high moisture (Bjelland, 2001).

To assess if the selected transplantation method was suitable, a common *Leptogium* species reported from all counties of Norway (GBIF, 2023), *L. saturninum*, was chosen for a parallel experiment (Fig. 2b). *Leptogium saturninum* is a foliose cyanolichen, this species rarely has apothecia, and disperses by isidia and thalli fragments. The tomentum on the lower surface is composed of cylindrical cells that are longer than in *L. hibernicum*. In Norway, *L. saturninum* is epiphytic on deciduous trees, but occasionally it also grows on rocks among mosses.

2.3. Transplantation method

After settling on the transplantation method and finding suitable localities, the responsible authorities gave permission to perform the experiment. Subsequently, the landowner also granted approval for the experiment on his property. The transplantation experiment was conducted during the autumn of 2018 at Sævareidberget (September) and in Årdal (October). At both localities, the transplantation was performed after several days with rainfall. It was decided to perform the experiment at this time of the year when precipitation is highest (https://senorge.no), as there is consequently less possibility for the transplanted material to desiccate in the early experimental phase.

The method employed in this experiment consists of four steps (Fig. 3):

(I) **Selection of representative trees.** It was difficult to find representative trees in accordance with *L. hibernicum*'s ecological niche (Bjelland, 2001), within each locality. In the UK and Ireland *L. hibernicum* is reported on birch (*Betula* sp.), hazel, oak (*Quercus* sp.), sycamore (*Acer pseudoplatanus*), and ash (GBIF). Old trees of elm (*Ulmus glabra)*, lime (*Tilia cordata*), grey alder (*Alnus incana*)*,* aspen (*Populus tremula*) or goat willow (*Salix caprea*) within the localities were considered as possible habitats, but these were either not possible to reach, or in extreme shade. The lichens were thus transplanted to hazel, as well as to pollarded and unpollarded old ash.

(II) **Selection of transplantation spot.** The transplantation spot on each tree was chosen after a) identifying a free spot not already densely coved by lichens or mosses, b) using the same exposure and similar shade regime as for the spot from which the collected transplantation material was derived from, and c) considering practical positioning of the spot on the tree regarding ease of performing the transplantation and the following-up observations in the experiment. Lichens and mosses were removed from the substrate approximately 2–3 cm around the selected transplantation spot.

(III) **Collection and preparation of material.** The lichen material used for the experiments was collected from the same locality as it was transplanted to. Only one thallus fragment from each species was used in the experiment at each locality. For the *L. hibernicum* material, a small piece of a living partly attached thallus was selected with a razor blade and a tweezer. The size of the collected *L. hibernicum* fragment used for the experiment was approximately 1 cm by 2 cm in size. A bigger piece of the thallus was collected from *L. saturninum*, approximately 2 cm by 2 cm in size. A stereo microscope (20 × magnification) and tweezers were used to remove all remnants of any other species of lichens and mosses attached to the fragment. The lichen material was cut into small pieces, 2 mm by 5 mm in size, to be used for the experiment, and then stored in a petri dish to retain humid conditions until transplantation (Fig. 3). Separate tweezers and scalpel were used for each species.

Initially it was planned to use both isidia and thallus fragments in the experiment, but as the selected thallus had few large isidia, it proved too complicated to cut them from the selected fragment in field conditions. It was thus decided only to use small (mostly, 2 mm by 5 mm), and some larger (7 mm by 10 mm in size) thallus fragments in the experiment (Table 1-2).

(IV) **Transplantation.** The material was transplanted either the same day or the day after it was collected. A droplet of carboxy methyl cellulose (CMC), 2% (high viscosity) was used as glue. CMC has previously been used with success in transplantation experiments with lichens (Lidén 2009; Leddy et al., 2019). CMC was placed in a depression or crack, in the transplantation spot on the bark, which had been cleaned beforehand (Fig. 3). This was to prevent the droplet from sliding. Using tweezers, each thallus fragment was attached to the glue by the lower tomentum side. *Leptogium hibernicum* grows either directly on the bark or in between mosses on the trunks. To test if fragments could establish among mosses, six larger *L. hibernicum* fragments (10 mm by 15 mm in size) were added in between mosses together with a droplet of carboxy methyl cellulose, on one tree at Sævareidberget (Table 1).

An alternative method which has often been used to attach transplanted lichen fragments to bark involves a stapler to attach gauze to the selected trees (Scheidegger, 1995; Scheidegger et al., 1995; Walser & Scheidegger, 2002). Due to fragile (old, and especially pollarded trees), or very hard (younger trees) bark, a stapler was not considered for this experiment.

Both species were transplanted to each of the selected trees. Approximately five fragments of each species were transplanted to each tree on a horizontal line. The distance between the fragments was about 1 to 2 cm. The species were put on two separate lines, one above the other, with a distance between 5 and 10 cm. On some trees, 2 × 5 fragments of each species were transplanted, at two different positions on the same tree (Table 1-2).

At Sævareidberget, the trunks of 11 trees were used in the transplantation experiment, two hazels, two unpollarded and seven pollarded ash trees. In total, 86 thalli fragments of *L. hibernicum* and 70 thalli fragments of *L. saturninum* were transplanted (Table 1).

At Årdal the trunks of six trees were used in the experiment, two hazel, two unpollarded and two pollarded ash trees. In total, 39 thalli

Fig. 3. The method used in this transplantation experiment involves four steps: preparing selected material for transplantation in the field, cutting thallus into smaller fragments, adding glue to the substrate, and finally adhering the material to the glue on the substrate.

fragments of *L. hibernicum* and 30 thalli fragments of *L. saturninum* were transplanted (Table 2).

2.4. Following up the experiment

Once a year, every year since the transplantation in 2018, the two localities were visited to register the amount of material which has survived. Foliose lichen species and mosses on the way to overgrow the transplanted material were removed.

3. Results

3.1. Survival of material

Four years after transplantation of *L. hibernicum* and *L. saturninum* fragments, survival was quite high for both species at both localities. The survival rate of *L. hibernicum* was 12% (15 of 225 fragments) and for *L. saturninum* 19% (19 of 100 fragments). The loss in the number of surviving transplants was greatest one year after transplantation. In the subsequent three years, there were fewer losses of surviving material (Fig. 4, Table 1 and 2).

None of the six large *L. hibernicum* fragments (10—15 mm) transplanted among mosses survived (Table 1). Very few of the larger thallus fragments (7–15 mm) have survived (Table 1 and 2). There is a higher survival of small fragments (2–5 mm). Several thallus fragments of both species have developed small lobes (Fig. 5). In addition, the hairs from the lower cortex in the fragments have grown and have attached the fragment to the substrate. All remaining fragments on the bark appears vital.

Table 1
Number of thalli fragments, of *Leptogium hibernicum* and the control species *L. saturninum*, transplanted at Sævareidberget in 2018, and number of fragments found in 2019, 2020, 2021 and 2022. Number of tree trunk, substrate type, aspect of trunk and size of fragment used are indicated for each species.

		Leptogium hibernicum							*Leptogium saturninum*						
				Number of transplanted fragments							Number of transplanted fragments				
Tree	**Substrate**	**Aspect**	**Size**	**2018**	**2019**	**2020**	**2021**	**2022**	**Aspect**	**Size**	**2018**	**2019**	**2020**	**2021**	**2022**
S3	Hazel	W	2–5 mm	5					W	2–5 mm	5				
		S	2–5 mm	5					S	2–5 mm	5				
S4	Hazel	S	2–5 mm	5					W	2–5 mm	5				
S5	Ash	E	2–5 mm	5	1	1			E	2–5 mm	5	3	3	2	2
S6	Pollarded ash	N	2–5 mm	5					N	2–5 mm	5				
		S	2–5 mm	5					S	2–5 mm	5				
S7	Pollarded ash	N	2–5 mm	5	2	2	2	1	N	2–5 mm	5	1	1	1	1
S8	Pollarded ash	N	2–5 mm	5	3	3	3	3	N	2–5 mm	5	2	2	2	2
S9	Pollarded ash	N	2–5 mm	5					N	2–5 mm	5				
S10	Ash	E	2–5 mm	5	1	1	1	1	E	2–5 mm	5				
S11	Pollarded ash	N	2–5 mm	5					N	2–5 mm	5				
		S	2–5 mm	5	2	2	2	2	S	2–5 mm	5	2	2	2	2
S12	Ash	S	2–5 mm	5	6*	4	4	4	S	2–5 mm	5	2	2	2	2
S13	Pollarded ash	NNE	7–10 mm	5	1				NNE	7–10 mm	5	2	2	2	2
		NNE	10–15 mm	6**											
		NNE	2–5 mm	10	1	1									
Total number of thalli fragments				**86**	**16**	**14**	**12**	**11**			**70**	**12**	**12**	**11**	**11**

*One of the fragments divided into two pieces after the first year. ** Transplanted among mosses.

Table 2
Number of thalli fragments, of *Leptogium hibernicum* and the control species *L. saturninum*, transplanted at Årdal in 2018, and number of fragments found in 2019, 2020, 2021 and 2022. Number of tree trunk, substrate type, aspect of trunk and size of fragment used are indicated for each species.

		Leptogium hibernicum							*Leptogium saturninum*						
				Number of transplanted fragments							Number of transplanted fragments				
Tree	**Substrate**	**Aspect**	**Size**	**2018**	**2019**	**2020**	**2021**	**2022**	**Aspect**	**Size**	**2018**	**2019**	**2020**	**2021**	**2022**
R3	Pollarded ash	N	2–5 mm	5					N	2–5 mm	5				
R4	Hazel	Top of branch	2–5 mm	5					Top of branch	2–5 mm	5				
R5	Hazel	SW	2–5 mm	5					SWW	2–5 mm	5				
R6	Ash	SEE	2–5 mm	5	1	1	1	1	SWW	2–5 mm	5	3	3	3	3
R7	Ash		2–5 mm	5					SEE	2–5 mm	5	3	3	3	3
R8	Pollarded ash	SE	2–5 mm	10	5	5	3	3	SE	2–5 mm	5	2	2	2	2
		SSE	10–15 mm	4											
Total number of thalli fragments				**39**	**6**	**6**	**4**	**4**			**30**	**8**	**8**	**8**	**8**

3.2. Relevance of substrate and aspect

After four years, all remaining living transplanted fragments (34) are growing on ash (Table 1 and 2). *Leptogium hibernicum* have survived on five pollarded ash trunks, while *L. saturninum* have survived on five pollarded and on four unpollarded trunks of ash (Table 1 and 2). All fragments from both species (of the total of 40) disappeared from the four hazel trees during the first year after transplantation (Table 1 and 2).

Fragments of both species have survived on different aspects on the trunks. At Sævareidberget both species are surviving at a northern, southern, and easters aspects of the trunks, while at Årdal both species are surviving at a southeast eastern and south-eastern aspects (Table 1 and 2).

4. Discussion

Four years after transplantation, the population of *L. hibernicum* has increased in two localities. The experiment was also successful for the common species *L. saturninum*. Transplantation of red-listed lichens can improve the conservation status and sustain the population. As in our case, it is recommended to consider practical conservation action if it can reduce the probability of a species local extinction, and when local extinction will influence the regional extent. In our case there are nine known locations of *L. hibernicum* and a local extinction will decrease the extent by 11%. Hence, increasing the number of individuals in local populations will make the population more robust and less likely to suffer from stochastic extinction events. In an even longer perspective, another concern regarding *L. hibernicum* is that at present only infertile specimens have been recorded worldwide (Bjelland et al., 2017). This could be a challenge for *L. hibernicum* as regards adaption to meet the forthcoming environmental changes.

Despite a potential high number of offspring (isidia), which even include both main partners of the symbiosis and therefore have a higher probability of establishment, survival is not guaranteed. Evidently the first challenge for the diaspore is to be dispersed to a suitable habitat, then secondly successfully anchored to an applicable substrate. In this experiment only the ability of establishment after an artificial dispersal was evaluated, and each single transplanted offspring has a low chance of survival, of about 12 to 19%. The most critical part, for both common and Critically Endangered (CR) species, is obviously the great loss of material during the first year after transplantation. There are minor differences between the two *Leptogium* species, indicating that this stage in the lifecycle is decisive regardless of niche width, which is the main difference between the two species. This is in accordance with other studies indicating that in epiphytic lichens, the establishment on the substrate is a critical stage of their lifecycle (Hilmo & Såstad, 2001).

As regards survival rate of transplanted material, there are few

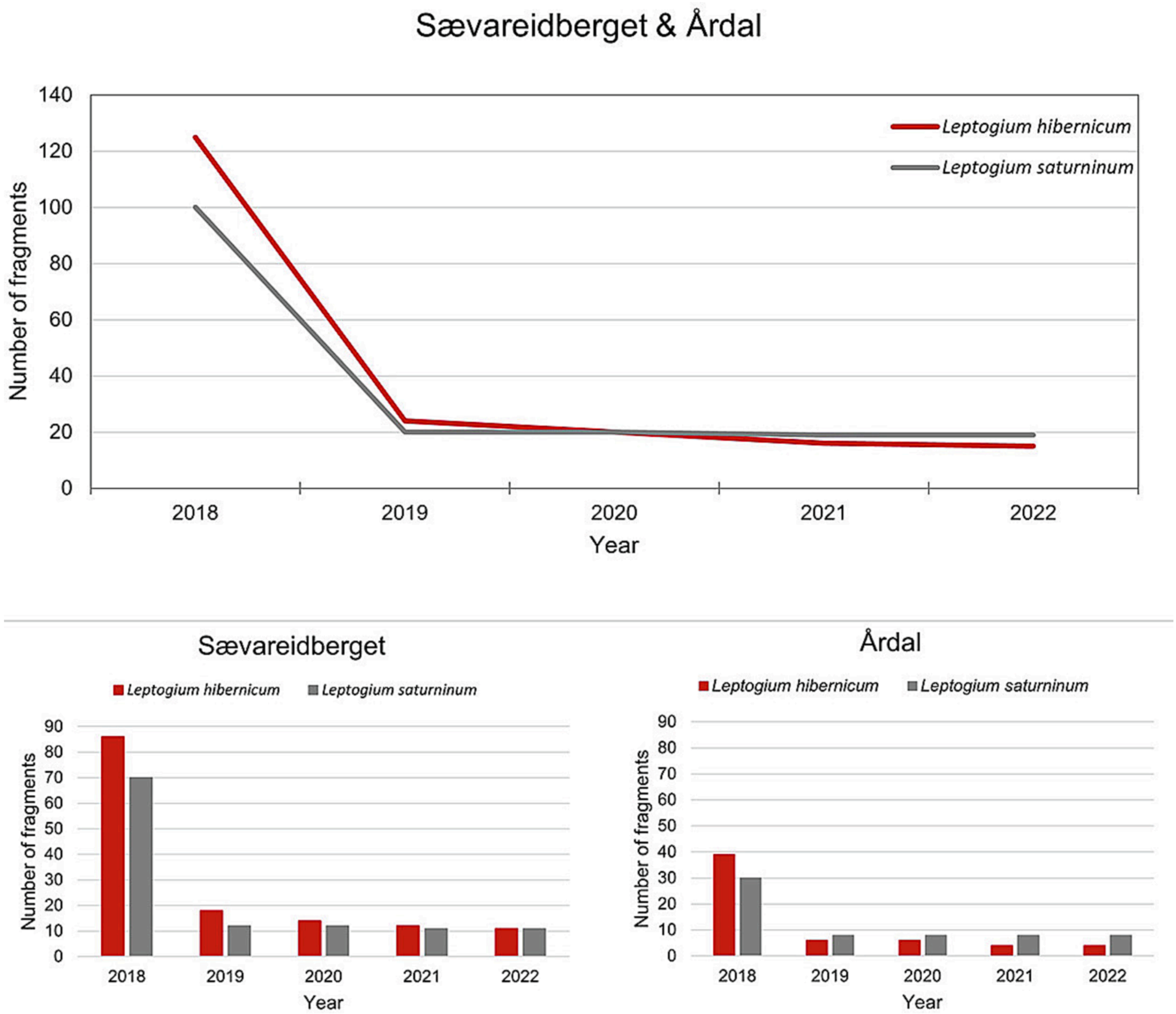

Fig. 4. Number of *Leptogium hibernicum* and *L. saturninum* thalli fragments transplanted at two Norwegian localities in 2018, and number of fragments found in 2019, 2020, 2021 and 2022.

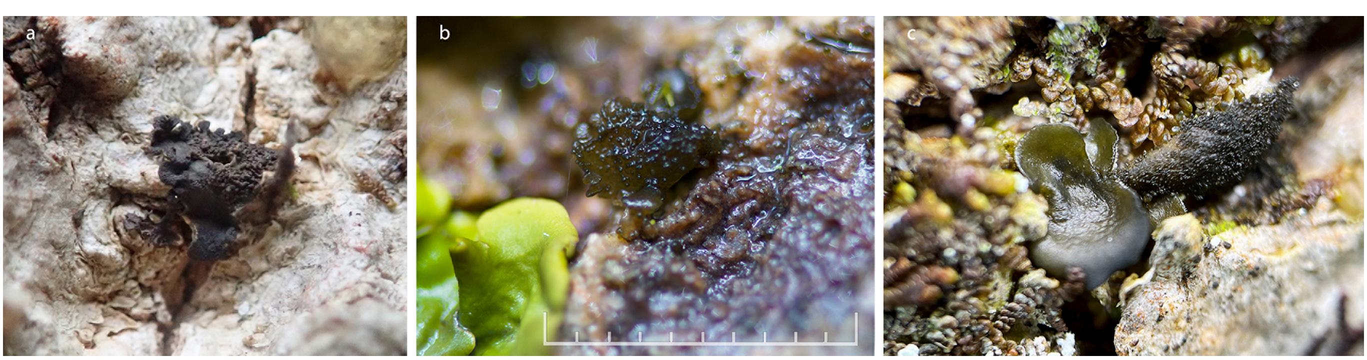

Fig. 5. Two *Leptogium hibernicum* thalli fragments, one three (a) and one four (b) years after transplantation. Scale 10 mm. (c) *Leptogium saturninum* thallus fragment with new lobe, four years after transplantation. Photo 5b and 5c: Annette Græsli Øvrelid.

directly comparable results with our experiment due to different initial settings. After one year, Lidén et al., (2004) reports a survival of fragments between 85 and 98%, while 23% of the fragments remained after 14 years in the experiment of Gustafsson et al., (2013). This high survival rate could be due to the different fragment size and or the method used to attach the fragment to the tree. We used fragments between 5 and 10 mm^2 and attached them directly to the bark without a protection/cover. Lidén et al., (2014) used a fragment size between 35 and 340 mm^2 and attached them to trees with either a nylon thread or sheltering cocoon. Gustafsson et al. (2013) used a plastic net to attach the 6 cm^2 large fragments to the trees.

4.1. Substratum

The success of the experiment is linked to the type of substrate. Transplanted materials of both species have survived on ash, both pollarded and unpollarded trees. The unpollarded trees used had developed a rough bark, but not as rough as the pollarded trees which are presumedly older. One important reason as to why *L. hibernicum* is not currently found growing on unpollarded ash could be that there are only few old unpollarded trees in their habitats. It could indicate a relevance of microclimate and the continuity of the trees, and not necessarily an adaption to a specific substrate (Bjelland, 2001).

Transplanting the two *Leptogium* species to hazel trees resulted in failure. It is worth noting that some *Lobarion* species were already growing on the selected hazel stems, and that *L. saturninum* has been documented as epiphyte on hazel in Norway (GBIF, 2023). In the UK and Ireland, which is the closest population to the Norwegian population, *L. hibernicum* is reported on birch (*Betula sp.*), hazel (*Corylus avellana*), oak (*Quercus sp.*), sycamore (*Acer sp.*), and ash (GBIF, 2023).

4.2. The transplantation method

It would be an advantage to use asexual propagules instead of lichen fragments in a transplantation experiment, as this would disturb the existing populations less (Scheidegger, 1995; Scheidegger et al., 1995; Lidén, 2009; Brooker et al., 2011; Kon & Ohmura, 2014). Due to practical challenges arising in the field, thallus fragments were transplanted instead of asexual propagules. Only thalli from dead trees or thalli partially attached to the substrate were selected.

Different aspects of the methodology could influence the successful outcome in an experiment. The transplantation was performed in the autumn when it is assumed to be less possibility for the material to desiccate in the early phase. However, it is unknown if the outcome of the same experiment would have been different if the experiments were performed at another time of the year. Previous experiments indicate that the time of the year when the material is transplanted is of significant relevance (Smith, 2014). This is at least significant in regions with great seasonal climatical variation. E.g., experiments observed faster establishment of propagules in autumn compared to spring for the development of basal tissue (Ott, 1987), and asexual propagule germination is probably slower in a cold climate (Hilmo & Ott, 2002).

One practical challenge is predicting where and how to place the transplantation fragment (Brooker et al., 2018). Due to the low number of parallels, it is not possible to tell if aspect of the tree trunk, or transplanting fragments among mosses, was relevant for the outcome of this experiment. The amount, and or the consistency of the glue might have had an influence on the duration the fragment was in contact with the smooth bark of both hazel and some of the ash trees, making it challenging for propagules to anchor and or establish. The fragments were attached in a crack or furrow painted with glue on the stem. Previous transplantation experiments have observed that lichen propagules must be in contact with the bark for one to three months before the hyphal development starts (Ott, 1987; Scheidegger et al., 1995; Lidén, 2009; Leddy et al., 2019).

4.3. Invertebrates

One cannot exclude a negative influence of invertebrates soon after transplantation. In this and similar studies, evidence of invertebrate frass and tracks like slime on trees and lichen thalli, suggest grazing and or unintentional removal of the transplanted lichen fragment (Leddy et al., 2019). Carboxy methyl cellulose was used as glue in this experiment. The cellulose content in the glue may attract herbivores grazing lichens, and consequently the procedure may experience higher mortality than by chance alone.

4.4. Management plan

The study indicates that a management plan should at least include four sections: (1) A **pre-transplantation investigation** of the target species. Before the experiment is implemented, all relevant knowledge about the species, its ecological needs including substrate requirements, and different potential transplantation techniques, should be obtained to design the experiment optimal for the species. (2) An **administrative plan** for responsible authorities' approval. Depending on the law in each country, the plan of the experiment must always be approved by the responsible authorities, and sometimes the landowner. For the success of the project, it is important to continuously involve them before, during and after the experiment. A successful experiment can have consequences for a landowner. Having a Critically Endangered species on the property usually results in restrictions regarding many types of actions for the landowner. It is therefore important that the landowner is well informed and approves the transplantation.

(3) A **follow-up plan for the species.** After the transplantation has been performed, the material can be affected by changes related to abiotic and biotic factors in the habitat, e.g. factors related to light, humidity, competition with other epiphytes, predators (Scheidegger et al., 1995; Boudreault et al., 2013; Gustafsson et al., 2013; Leddy et al., 2019). The strategy in the management plan needs to be continuously evaluated. If the experiment is successful more material can be considered for transplantation at a later stage.

(4) A **plan for habitat management** including monitoring habitats and possibly creating new habitats. A species has an advantage if the amount of suitable habitat increases, or if the quality of the existing habitat increases (Öckinger et al., 2005). It is decisive to restore the locality by securing sufficient potential suitable habitats, which in this case involves having a plan for protecting ash trees so they can develop to old trees and start to pollard young ash trees so they develop a rough bark earlier. However, for such actions one need also to consider the negative impact of ash dieback on pollarded trees. One recent study in Sweden indicates that trees pollarded in recent times might have a higher mortality (Bengtsson et al., 2021). It is important to be aware of this dilemma and have a plan for minimising the risk of the disease outbreak by e.g., only pollarding some trees at the time, and subsequently evaluate the ash dieback. The outcome will determine subsequent action, such as pollarding regularly and or continuing with pollarding additional young trees.

If possible, the distance between the potential suitable trees should be considered in the management plan. Thallus fragments or large symbiotic propagules transported by wind typically do not disperse far due to their size, probably no more than 100 m (Dettki et al., 2000; Ronnås et al., 2017).

4.5. Collaboration in nature conservation

Close collaboration with the responsible management agency and the landowners made an immediate practical conservation action for *L. hibernicum* possible. It was successfully achieved by linking scientific knowledge, both regarding the target species and the habitat, with a plan for further habitat restoration and practice. An advantage is that the method employed proved to not be too costly, as it is highly feasible with regards to practical realization and economical expenses. This emphasises the importance of combining scientific knowledge and decision-making processes as regards nature conservation (Török & Helm, 2017; Plaza & Lambertucci, 2021).

This is a small-scale experiment due to the critical status of the species. Regardless, important practical experience and observations have been achieved according to the aims. One limitation of the experiment is still the uncertainty of the long-term result. In foliose lichens it can take between 15 months and four years until it is possible to identify the juvenile stage (Armstrong & Bradwell, 2011), and eight to 12 months before lobes are formed in soredia (Scheidegger, 1995; Zoller et al., 2000; Leddy et al., 2019). Due to this slow growth rate and the life span of many lichens, it is suggested that there is need for a management plan to follow up these transplantation experiments for ten to 30 years after transplantation (Gilbert, 1991; 2002; Allen, 2017). The time needed will vary by species and region, but this is an important yet challenging aspect both with regards to the results and the funding of a long-lasting transplantation project.

If nothing had been done, the story of this species might have been an example of a worst-case scenario in nature, a Critically Endangered habitat specific sterile species, growing on a red-listed substrate, going extinct. Unfortunately, similar cases will most probably increase in the near future in Norway as well as globally. Recently, a similar critical situation was found to be the case for several *Leptogium* species in East African montane ecosystems (Kaasalainen et al., 2021). In the last hundred years there has been a great loss of diversity of epiphytic lichens in temperate broad-leaved forests, thus it is required to act as regards conservation of these species (Hauck et al., 2013).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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