

Overview of plant species translocations in Luxembourg

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Abstract. In Luxembourg, 34 % of native plants and archaeophytes are considered threatened or regionally extinct. Species translocations have been implemented in Luxembourg for more than 25 years as a conservation strategy to counteract biodiversity loss. In this overview, we have compiled data on conservation actions implemented between 1997 and 2023. The information collected includes the translocation locations, the plant taxa targeted, the methods used, and the monitoring conducted. For a subset of translocations, we have also included data on the survival of planted juveniles. Examples of translocations from various habitat types were also presented to illustrate different approaches. We found that 585 translocations involving 99 taxa from 26 families were initiated by four main institutions in Luxembourg. The conservation actions mainly targeted Endangered and Critically Endangered, but also Least Concern species. Translocations mainly took place in open land habitats, particularly in grasslands and arable land, with a higher density in the southwestern part of the country. 39 % of the translocations took place in national nature reserves whereas 21 % were in areas without any legal protection status. Planting young plants was the preferred method rather than sowing seeds. In 89 % of the translocations, monitoring was conducted by recording survival of the plants, while natural recruitment of new individuals was rarely recorded. 68 % of the translocations were judged successful by the practitioners, mostly based on transplant survival. Detailed data for the subset of 31 grassland species showed that the survival rate of about half of the species considered successful varied between 25 and 71 %. Translocations are essential for the long-term conservation of plant species, but protection and adaptive management of translocation sites are also essential. Translocations conform to national and European priorities for increasing habitat restorations to counteract species decline. To improve conservation outcomes, actions such as translocations need to be consistently documented, monitoring standardized, and experience needs to be shared among stakeholders.

Keywords. Endangered plant species, establishment, introduction, in-situ, ex-situ, monitoring, restoration, reinforcement, reintroduction, success of translocations.

1. Introduction

Numerous recent studies have shown a global decline in plant biodiversity (Bilz et al. 2011, Meyer et al. 2013, Metzinger et al. 2018, Zehm et al. 2020, Eichenberg et al. 2021, Hochkirch et al. 2023, Härdtle 2024). The loss of plant biodiversity has major impacts on the functioning of ecosystems and overall biodiversity (Eichenberg et al.

2021, Härdtle 2024). The main causes of biodiversity declines are the intensification of agriculture, increasing eutrophication, drainage, use of pesticides as well as land consumption and climate change (Colling 2005, Schneider 2019a, Eichenberg et al. 2021, Hochkirch et al. 2023, Härdtle 2024).

The loss of plant biodiversity is also evident in Luxembourg. About 34 % of native plants

and archaeophytes are threatened (IUCN threat categories Vulnerable (VU), Endangered (EN), Critically Endangered (CR)) and of which 7.6 % are considered extinct (category Regional Extinct, RE) according to the Red List of Vascular Plants of Luxembourg (Colling 2005). Especially plants of the open land habitats, in particular arable land and grassland habitats are threatened. In addition, around half of all species found in bogs, marshes and wet meadows are jeopardized (Colling 2005, Schneider 2019a). Many of the Endangered and Critically Endangered species now only occur in very small or isolated populations (Schneider 2019a, Kempel et al. 2020, IUCN 2024). In addition, an increasing number of local extinction events is taking place. In Luxembourg, 121 species are classified as Critically Endangered and urgent conservation actions are needed to prevent their disappearance (Colling 2005). Additionally, Luxembourg has a particular responsibility for 25 endemic species of Central Europe (Schnittler & Günther 1999). These species have a very small distribution area and occur isolated in Luxembourg, far from their main distribution area. Furthermore, Luxembourg has an obligation to preserve the taxa, which are protected internationally and nationally (JOCE 1992, Appendix II, IV and V; Mémorial 2010). Conservation and protection measures for these species should therefore have the highest priority. Furthermore, studies show that even common and moderately common plant species are experiencing significant losses (Jansen et al. 2019, Eichenberg et al. 2021). These species are often characteristic for a plant community.

The decline of many plant species and their habitats requires conservation actions more urgently than ever. In Luxembourg, habitat restorations, the appropriate management of habitats, the strict protection of sites with remaining populations and species translocations are implemented through the National Plan for the Protection of Nature (MECDD 2023a), species and biotope action plans, the Strategy for the Conservation and Restoration of species-rich Grassland in Luxembourg (MECDD 2020), and

particularly the Plant Conservation Strategy for Luxembourg (Colling et al. 2022).

To prevent genetic impoverishment and an increased extinction risk in rapidly declining populations, translocations may be indispensable (Godefroid et al. 2011, Abeli et al. 2016, Hölzel 2019). Species translocations can be conducted as reinforcements of remnant populations, new introductions within their natural range in areas without any evidence of previous occurrence, or reintroductions in areas where they previously occurred (Diekmann et al. 2016). In-situ measures are particularly effective for species with short-lived seed banks, low dispersal distances or for remnant populations in isolated locations to strengthen their populations (Godefroid et al. 2011, Dalrymple et al. 2012, Diekmann et al. 2015, Breit et al. 2023). Depending on species-specific characteristics, translocations of endangered species are carried out by planting juveniles, direct seed sowing – especially for annual species – or seed propagation in fields. Ideally, the source material used for translocations should be acquired from multiple autochthonous wild populations. To ensure that new populations can thrive in a wide range of environmental conditions, the source material should thereby possess the highest possible genetic diversity (Smulders et al. 2000, Zippel & Lauterbach 2018). Ex-situ conservation material can also provide source material for in-situ conservation actions.

To increase the survival chances of young plants, follow-up care, particularly in the first years after planting, is crucial (Godefroid et al. 2011, Zippel & Lauterbach 2018, Breit et al. 2023). In addition, the appropriate long-term management of the translocation areas must be ensured to guarantee success. The success of translocations largely depends on the targeted species, initial conditions, site suitability, and habitat requirements (Godefroid et al. 2011, Breit et al. 2023). The evaluation of establishment success based on reproduction and fitness is important to estimate the survival of newly established populations and to optimise translocation methods (Menges 2008, Monks et al. 2012, Abeli et al. 2016, Breit et al. 2023). In Lux-

embourg, the first in-situ conservation measures took place over 25 years ago. Since then, hundreds of initiatives have emerged covering a variety of habitats and species.

This paper provides an overview of the translocations for plant species conducted in Luxembourg to date. Additionally, it explores several examples of plant translocations carried out by conservation practitioners to illustrate the variety and complexity of conservation actions within the Grand Duchy. Ultimately, this paper aims to assess the current situation, identify challenges and needs, and propose measures to strengthen and expand the urgently needed plant conservation actions in Luxembourg.

2. Methods

We contributed to the establishment of a European database on conservation actions (CA) of threatened plant species (ConservePlants 2024) implemented during the 'COST Action ConservePlants: An integrated approach to conservation of threatened plants for the 21st century' (Fišer et al. 2021, <https://www.cost.eu/actions/CA18201>) by compiling data from conservation practitioners in Luxembourg. For the whole country, four institutions provided data on the conservation actions they carried out from 2000 until the end of 2020. Moreover, we asked the same institutions in February 2024 to provide data on the CAs they conducted in Luxembourg between 2021 and 2023. Based on this combined list of CAs, we compiled descriptive statistics using Excel and Access (Microsoft Office Professional 2019) and illustrated the results with Sigma-Plot v. 14.5 (Systat Software, Inc.). Measures of grassland habitat restoration such as green hay transfer and sowing directly harvested plant material, were not included.

We collected data on three types of translocations: reinforcements (strengthening) of remnant populations (the transfer of a species to an area where the species still occurs but is threatened by extinction and the population size is to be increased), (new) introductions (the relocation of a species within its natural range to a region for which there is no historical evidence of occurrence),

and reintroductions (the intentional movement of a species to an area where it previously occurred) (IUCN 1987, Diekmann et al. 2016). A translocation was defined as an action that was targeting one species at one site at a particular moment in time.

2.1. Data collection of targeted plant taxa, translocation locations and projects

Information was gathered on the targeted plant taxa, the locations and the projects incorporating the CAs. The targeted plant taxa, their plant family and their conservation status according to the national and global IUCN evaluations were recorded. Taxonomy and nomenclature of plant names and plant families follows Verloove & van Rossum (2024), except for the mosses for which Werner (2003) was used. The national Red List status of the species was retrieved from Colling (2005) and the global status from the IUCN (2024). Latitude and longitude, the surface area, the national and European protection status of the locations and the land property (public or private) of the CAs were noted. The data on the projects encompassing the CAs included the involved institutions, the starting year and funding information. In addition to the data compiled for the COST database, we gathered information on the ecology of the species. Indicator values and life forms were retrieved from Ellenberg & Leuschner (2010). The phytosociological preference of the species was determined using Ellenberg et al. (2001), Ellenberg & Leuschner (2010), and Schneider (2011). Nomenclature of syntaxa follows Mucina et al. (2016). The taxa were also attributed to their main occurring habitat based on the phytosociological preference in Luxembourg and according to our own assessment of the ecological behaviour of species in Luxembourg. In addition, an overlap between the current layers of the protected area categories of Luxembourg and the locations of the CAs was made in ArcGIS Desktop 10.8.1. (ESRI) to infer which translocations were undertaken within protected areas.

2.2. Data collection of in-situ and ex-situ conservation actions methods

Information on the methods used for in- and ex-situ CAs, the monitoring and the evaluation of the success of the CAs was gathered in a survey. We also asked for the type of in-situ translocations carried out, which included re-enforcements, introductions and reintroductions. We did not differentiate between these types in the analyses, because in most cases, the survey participants had not recorded this information; therefore, we used the general term 'translocation'. Relocations due to construction projects were not included.

In addition to the translocations of plant populations, conservation actions reported included population size estimation, removal of competing vegetation (natural, indigenous, or invasive), multispecies management (in cases where more than one species was translocated per site), habitat protection, fence construction and public dissemination efforts. Information on the plant material used was also included (e.g. seeds, juveniles, cuttings). The number of transplants and of source populations was documented as well. Ex-situ conservation measures were recorded if undertaken as part of the in-situ CAs. Since the majority of translocations began with the collection of seeds or vegetative plant material from autochthonous wild populations, the number of seeds or other plant material collected was reported.

2.3. Data collection of monitoring and success evaluation methods

Information on the duration of monitoring and the variables recorded (survival, flowering, fruiting, recruitment or plant size) was documented. The criteria used to evaluate the success and the outcome of the CAs was also indicated.

Data on the success of CAs and detailed survival rates were only available in some cases. Therefore, we also included additional data from a subset of translocations monitored under the project 'reintroductions of endangered plant species' from SICONA up to 2023 in our overview (SICONA 2024a). To

track each planted individual, a high precision positioning sensor (Leica, Type CS15) was used to record their location. This data included information on the total number of transplanted juveniles for 31 species, the years in which translocations occurred, and the survival rates calculated as the number of individuals recorded during the most recent monitoring divided by the total number of transplanted individuals across the various years of translocations. Monitoring took place in the first, second, fifth and tenth year after planting, and was discontinued if none of the transplanted individuals was found in two consecutive monitoring years. The percentage of the total number of transplanted individuals recorded in each monitoring year was categorised into four classes to allow for a quantitative estimation of the proportion of individuals monitored after one, two, five or ten years (I: 0-25 %, II: 26-50 %, III: 51-75 %, IV: 76-100 %).

2.4. Examples of translocations

To illustrate the translocations carried out in Luxembourg, we selected characteristic species for each main habitat type to describe the methods employed. These examples aim to present the motivation behind the translocations, discuss significant outcomes, highlight challenges and lessons learned, and offer recommendations for the translocation and monitoring of these species, serving as inspiration for further CAs.

3. Results

3.1. Overview of translocations

3.1.1. Targeted plant taxa, habitats, locations and projects

The database identified 99 plant taxa for which 585 introductions, reintroductions or reinforcements have been conducted across 228 sites in Luxembourg (Fig. 1, Table 1). These sites were located throughout the country, with the highest frequency in the south-west and west of Luxembourg. The number of sites, which a species was translocated to, ranged from one to 37 with the majority of species introduced at two sites

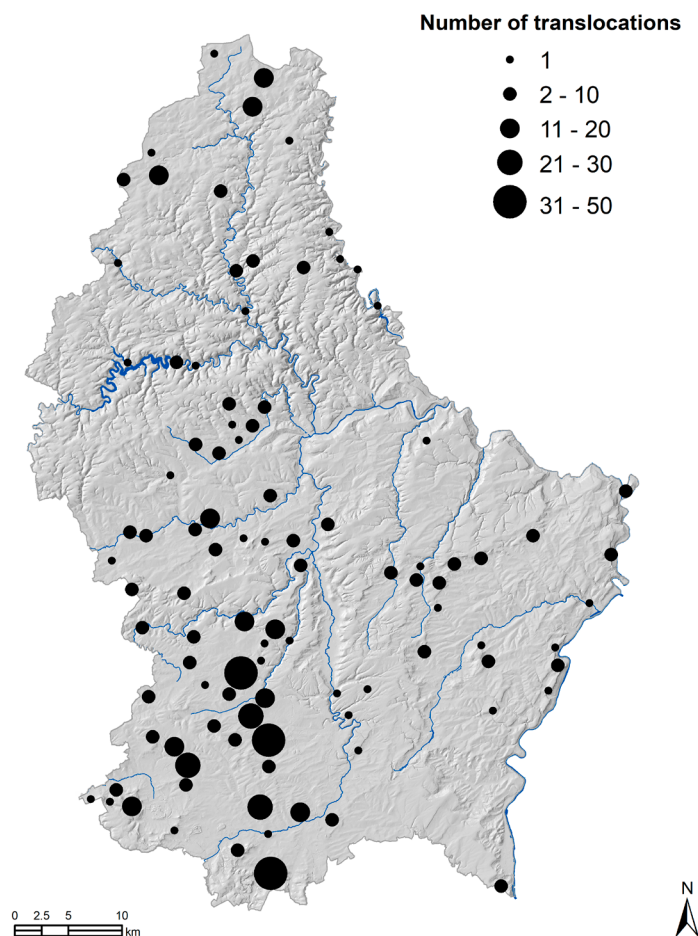


Fig. 1. Translocation sites in Luxembourg. The size of the dots corresponds to the number of translocations undertaken per site with them being grouped into five categories. Map ground: Administration du Cadastre et de la Topographie.

(Fig. 2a). Each site received one translocation per species, except for four sites which had two translocations of the same species six to eleven years apart. In most sites, only one species was targeted; however, multiple taxa were translocated in 39 % of the sites (Fig. 2b). Most of these sites featured multispecies sowings of endangered arable species and four sites were sown with seeds of siliceous grassland and sedge swamps species. Plantings were most common in sites with one to seven translocated species, while sowings were more prevalent in sites with more than seven species.

Most translocations targeted Endangered (EN) and Least Concern (LC) species based on the national Red List assessment, followed by Critically Endangered (CR) and Vulnerable (VU) species (Table 1; Fig. 3a, b).

63 of the 99 species were Not Evaluated (NE) globally by the IUCN, but the evaluated ones were categorized as Least Concern (35) or Near Threatened (NT) (1). This represented 64 % of translocations directed towards NE, 35 % towards LC and 1 % toward NT species.

The 99 translocated species belonged to 26 plant families and were mostly hemicryptophytes and therophytes. Six moss species of the peat moss group were also translocated (Table 1). The plant families most frequently targeted were Asteraceae (17 % of all the translocations), followed by Caprifoliaceae and Lamiaceae (both 12 %) (Fig. 4). The three most targeted families in terms of species number were Asteraceae (12 species), Cyperaceae (10 species) and Poaceae (8 species) (Fig. 4).

Table 1. Translocated species, taxonomic family, Red List status, main habitat type, phytosociological preference (classification based on the phytosociological preference in Luxembourg), main institutions involved in the translocations, first year of project in which translocations were made, number and method of translocations. Nomenclature follows Verloove & van Rossum (2024) and Werner (2003) for mosses. Red list status for vascular plants based on Colling (2005), R: Rare, CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, NE: Not Evaluated. 'Grassland' describes generally anthropogenic managed nutrient-poor pastures and meadows for species with a wide ecological niche. Phytosociological preference classification according to Ellenberg et al. (2001), Ellenberg & Leuschner (2010) and Schneider (2011). Nomenclature of syntaxa follows Mucina et al. (2016), classification of arable weeds only to the class Papaveretea rhoeadis.

Species	Family	Red List Status	Main habitat type	Phytosociological preference	Main Institution	No. of translocations	Material
<i>Anemone pulsatilla</i>	Ranunculaceae	EN	Calcareous grassland	Brachypodietalia pinnati	natur&ëmwelt, MnhnL	15	both
<i>Anthemis arvensis</i>	Asteraceae	LC	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Anthemis cotula</i>	Asteraceae	CR	Arable land	Papaveretea rhoeadis	SICONA	1	seeds
<i>Arnica montana</i>	Asteraceae	CR	Siliceous grassland and heaths	Nardetalia strictae	natur&ëmwelt, MnhnL	18	both
<i>Aster amellus</i>	Asteraceae	CR	Calcareous grassland	Geranion sanguinei	natur&ëmwelt, MnhnL	7	both
<i>Avenula pubescens</i>	Poaceae	NT	Mesophilic grassland	Arrhenatheretalia elatioris	SICONA	1	juveniles
<i>Betonica officinalis</i>	Lamiaceae	LC	Wet grassland	Molinion caeruleae	SICONA	24	juveniles
<i>Bistorta officinalis</i>	Polygonaceae	LC	Wet grassland	Calthion palustris	SICONA	4	juveniles
<i>Briza media</i>	Poaceae	LC	Grassland	Molinio-Arrhenatheretea	SICONA	3	juveniles
<i>Bromus secalinus</i>	Poaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	6	seeds
<i>Buglossoides arvensis</i>	Boraginaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	5	seeds
<i>Calendula arvensis</i>	Asteraceae	CR	Arable land	Papaveretea rhoeadis	MnhnL	1	seeds
<i>Caltha palustris</i>	Ranunculaceae	NT	Wet grassland	Calthion palustris	SICONA	1	juveniles
<i>Campanula glomerata</i>	Campanulaceae	EN	Calcareous grassland	Festuco-Brometea	SICONA	11	juveniles
<i>Cardamine pratensis</i>	Brassicaceae	LC	Grassland	Molinio-Arrhenatheretea	SICONA	1	seeds
<i>Carex demissa</i>	Cyperaceae	LC	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	natur&ëmwelt	2	seeds
<i>Carex echinata</i>	Cyperaceae	VU	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	natur&ëmwelt	2	seeds
<i>Carex hostiana</i>	Cyperaceae	CR	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	natur&ëmwelt	1	seeds

Table 1. (Continued)

Species	Family	Red List Status	Main habitat type	Phytosociological preference	Main Institution	No. of translocations	Material
<i>Carex leporina</i>	Cyperaceae	LC	Siliceous grassland and heaths	Nardetalia strictae	SICONA	1	seeds
<i>Carex nigra</i>	Cyperaceae	LC	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	SICONA, natur&ëmwelt	5	seeds
<i>Carex pallescens</i>	Cyperaceae	LC	Siliceous grassland and heaths	Nardetalia strictae	natur&ëmwelt	4	seeds
<i>Carex panicea</i>	Cyperaceae	LC	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	natur&ëmwelt	2	seeds
<i>Carex pilulifera</i>	Cyperaceae	LC	Siliceous grassland and heaths	Nardetalia strictae	natur&ëmwelt	2	seeds
<i>Carex pulicaris</i>	Cyperaceae	CR	Sedge swamps	Caricion fuscae	natur&ëmwelt	1	seeds
<i>Centaurea scabiosa</i>	Asteraceae	LC	Calcareous grassland	Festuco-Brometea	SICONA	12	juveniles
<i>Cirsium oleraceum</i>	Asteraceae	LC	Wet grassland	Calthion palustris	SICONA	1	juveniles
<i>Comarum pulstre</i>	Rosaceae	VU	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	SICONA	1	juveniles
<i>Corynephorus canescens</i>	Poaceae	EN	Sandy and rocky grassland	Corynephorion canescentis	SICONA	1	juveniles
<i>Cyanus segetum</i>	Asteraceae	VU	Arable land	Papaveretea rhoeadis	SICONA	6	seeds
<i>Danthonia decumbens</i>	Poaceae	VU	Siliceous grassland and heaths	Nardetea strictae	SICONA, natur&ëmwelt	4	both
<i>Delphinium consolida</i>	Ranunculaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	3	seeds
<i>Dianthus carthusianorum</i>	Caryophyllaceae	VU	Calcareous grassland	Brachypodietalia pinnati	natur&ëmwelt	3	juveniles
<i>Dianthus deltoides</i>	Caryophyllaceae	EN	Sandy and rocky grassland	Violion caninae	SICONA	4	both
<i>Eriophorum angustifolium</i>	Cyperaceae	EN	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	SICONA	2	juveniles
<i>Ervum gracile</i>	Fabaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Fumaria vaillantii</i>	Fumariaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Genista anglica</i>	Fabaceae	CR	Siliceous grassland and heaths	Calluno-Genistion pilosae	natur&ëmwelt	2	both
<i>Geranium pratense</i>	Geraniaceae	EN	Mesophilic grassland	Arrhenatherion elatioris	SICONA	11	juveniles
<i>Geranium sylvaticum</i>	Geraniaceae	VU	Mesophilic grassland	Phyteumato- Trisetion	SICONA	3	juveniles

Table 1. (Continued)

Species	Family	Red List Status	Main habitat type	Phytosociological preference	Main Institution	No. of translocations	Material
<i>Jasione montana</i>	Campanulaceae	VU	Sandy and rocky grassland	Sedo-Scleranthetalia	SICONA	3	both
<i>Juniperus communis</i>	Cupressaceae	EN	Calcareous grassland	Festuco-Brometea	natur&ëmwelt, ANF	33	juveniles
<i>Kickxia elatine</i>	Plantaginaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	10	seeds
<i>Kickxia spuria</i>	Plantaginaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	5	seeds
<i>Knautia arvensis</i>	Caprifoliaceae	LC	Mesophilic grassland	Arrhenatheretalia elatioris	SICONA	2	seeds
<i>Lathyrus nissolia</i>	Fabaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Legousia speculum-veneris</i>	Campanulaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	5	seeds
<i>Lepidium coronopus</i>	Brassicaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Logfia minima</i>	Asteraceae	EN	Sandy and rocky grassland	Thero-Airion	SICONA	2	seeds
<i>Luzula congesta</i>	Juncaceae	NE	Siliceous grassland and heaths	Violion caninae	natur&ëmwelt	2	seeds
<i>Luzula multiflora</i>	Juncaceae	LC	Siliceous grassland and heaths	Nardetalia strictae	natur&ëmwelt	4	seeds
<i>Lysimachia foemina</i>	Primulaceae	VU	Arable land	Papaveretea rhoeadis	SICONA	7	seeds
<i>Lythrum hyssopifolia</i>	Lythraceae	CR	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Melampyrum arvense</i>	Orobanchaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Misopates orontium</i>	Plantaginaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	9	seeds
<i>Molinia caerulea</i>	Poaceae	LC	Wet grassland	Molinion caeruleae	SICONA	7	juveniles
<i>Myosurus minimus</i>	Ranunculaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Nardus stricta</i>	Poaceae	EN	Siliceous grassland and heaths	Nardetalia strictae	natur&ëmwelt	3	seeds
<i>Oenanthe peucedanifolia</i>	Apiaceae	CR	Wet grassland	Molinietalia caeruleae	SICONA	11	juveniles
<i>Papaver argemone</i>	Papaveraceae	EN	Arable land	Papaveretea rhoeadis	SICONA	3	seeds
<i>Papaver dubium</i>	Papaveraceae	VU	Arable land	Papaveretea rhoeadis	SICONA	7	seeds

Table 1. (Continued)

Species	Family	Red List Status	Main habitat type	Phytosociological preference	Main Institution	No. of translocations	Material
<i>Papaver rhoeas</i>	Papaveraceae	NT	Arable land	Papaveretea rhoeadis	SICONA	10	seeds
<i>Pedicularis palustris</i>	Orobanchaceae	EN	Sedge swamps	Scheuchzerio palustris-Caricetea fuscae	MnhnL	2	seeds
<i>Pedicularis sylvatica</i>	Orobanchaceae	CR	Siliceous grassland and heaths	Nardetalia strictae	MnhnL	2	seeds
<i>Petrorhagia prolifera</i>	Caryophyllaceae	LC	Sandy and rocky grassland	Sedo-Scleranthetea	SICONA	4	juveniles
<i>Primula veris</i>	Primulaceae	VU	Grassland	Festuco-Brometea	SICONA	7	both
<i>Ranunculus arvensis</i>	Ranunculaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Ranunculus sardous</i>	Ranunculaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	4	seeds
<i>Rhinanthus alectorolophus</i>	Orobanchaceae	EN	Grassland	Molinio-Arrhenatheretea	SICONA	3	both
<i>Rhinanthus minor</i>	Orobanchaceae	NT	Grassland	Molinio-Arrhenatheretea	SICONA, natur&ëmwelt	6	seeds
<i>Salvia pratensis</i>	Lamiaceae	EN	Calcareous grassland	Festuco-Brometea	SICONA	35	both
<i>Sanguisorba officinalis</i>	Rosaceae	EN	Mesophilic grassland	Phyteumato- Trisetion	SICONA	7	juveniles
<i>Saxifraga rosacea</i> subsp. <i>sponhemica</i>	Saxifragaceae	R	Rocks	Asplenietea trichomanis	NP Our, NP Haute-Sûre, MnhnL	9	both
<i>Scabiosa columbaria</i>	Caprifoliaceae	LC	Calcareous grassland	Brachypodietalia pinnati	SICONA	10	juveniles
<i>Scorzonera humilis</i>	Asteraceae	EN	Wet grassland	Molinion caeruleae	SICONA, MnhnL	24	both
<i>Scutellaria minor</i>	Lamiaceae	CR	Wet grassland	Molinietalia caeruleae	SICONA	4	juveniles
<i>Selinum carvifolia</i>	Apiaceae	VU	Wet grassland	Molinion caeruleae	SICONA	16	juveniles
<i>Serratula tinctoria</i>	Asteraceae	CR	Wet grassland	Molinion caeruleae	SICONA	21	juveniles
<i>Seseli annuum</i>	Apiaceae	CR	Calcareous grassland	Brachypodietalia pinnati	SICONA, CFL	6	juveniles
<i>Setaria pumila</i>	Poaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Sherardia arvensis</i>	Rubiaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	10	seeds
<i>Silene flos-cuculi</i>	Caryophyllaceae	LC	Wet grassland	Molinietalia caeruleae	natur&ëmwelt	3	seeds

Table 1. (Continued)

Species	Family	Red List Status	Main habitat type	Phytosociological preference	Main Institution	No. of translocations	Material
<i>Silene noctiflora</i>	Caryophyllaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	4	seeds
<i>Spergula arvensis</i>	Caryophyllaceae	LC	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Stachys arvensis</i>	Lamiaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	8	seeds
<i>Succisa pratensis</i>	Caprifoliaceae	VU	Wet grassland	Molinion caeruleae	SICONA, natur&ëmwelt	38	both
<i>Thlaspi arvense</i>	Brassicaceae	LC	Arable land	Papaveretea rhoeadis	SICONA	6	seeds
<i>Tragopogon pratensis</i>	Asteraceae	LC	Grassland	Arrhenatheretalia elatioris	SICONA	2	juveniles
<i>Trifolium arvense</i>	Fabaceae	LC	Sandy and rocky grassland	Sedo-Scleranthetea	SICONA	1	seeds
<i>Valeriana dioica</i>	Caprifoliaceae	EN	Wet grassland	Molinietalia caeruleae	SICONA	8	juveniles
<i>Valerianella dentata</i>	Caprifoliaceae	EN	Sandy and rocky grassland	Sedo-Scleranthetea	SICONA	8	seeds
<i>Valerianella rimosa</i>	Caprifoliaceae	EN	Arable land	Papaveretea rhoeadis	SICONA	7	seeds
<i>Veronica triphyllos</i>	Plantaginaceae	CR	Arable land	Papaveretea rhoeadis	SICONA	2	seeds
<i>Vicia lathyroides</i>	Fabaceae	CR	Sandy and rocky grassland	Corynephorretalia canescentis	SICONA	1	seeds
Mosses							
<i>Sphagnum auriculatum</i>	Sphagnaceae	NT	Fens	Scheuchzerio palustris-Caricetea fuscae	SICONA	2	cuttings
<i>Sphagnum fallax/ flexuosum</i>	Sphagnaceae	NT	Fens	Scheuchzerio palustris-Caricetea fuscae	SICONA	2	cuttings
<i>Sphagnum fimbriatum</i>	Sphagnaceae	LC	Fens	Scheuchzerio palustris-Caricetea fuscae	SICONA	1	cuttings
<i>Sphagnum palustre</i>	Sphagnaceae	LC	Fens	Scheuchzerio palustris-Caricetea fuscae	SICONA	2	cuttings
<i>Sphagnum rubellum</i>	Sphagnaceae	VU	Fens	Scheuchzerio palustris-Caricetea fuscae	SICONA	2	cuttings
<i>Sphagnum teres</i>	Sphagnaceae	NT	Fens	Scheuchzerio palustris-Caricetea fuscae	SICONA	2	cuttings
						585	

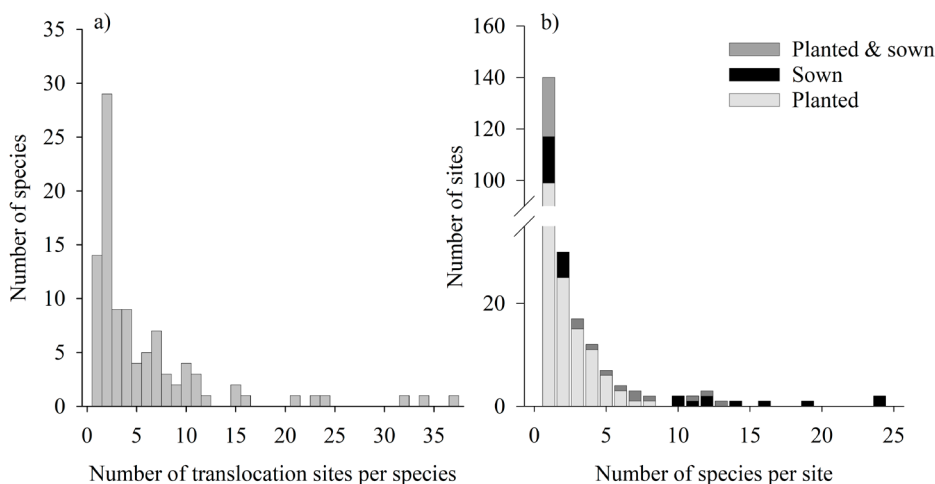


Fig. 2. a) Number of translocation sites per species, and b) number of species planted or sown per site. Note that in four sites, one species was both planted and sown, along with multispecies sowings. Translocations of *Sphagnum* mosses are included into the category 'planted'.

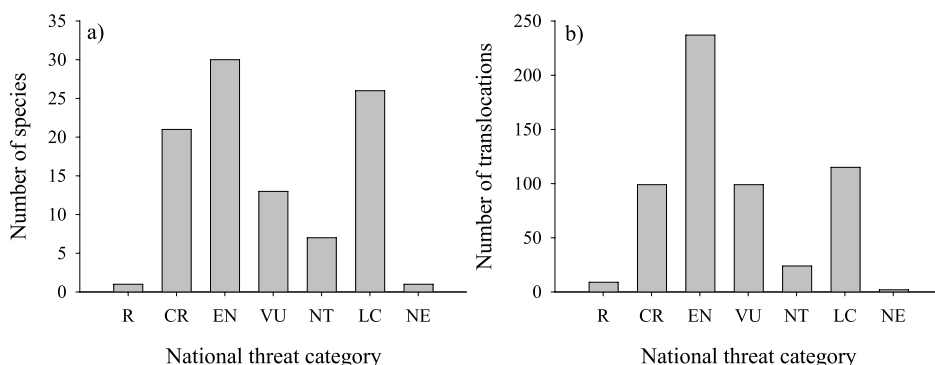


Fig. 3. a) Number of species translocated per threat category, and b) number of translocations per threat category of their target species. We used the threat categories from Colling (2005): R: Rare, CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, NE: Not Evaluated.

So far, the focus of the translocations was primarily put on open land species, especially grassland species: 406 of the 585 translocations were completed with grassland species (siliceous, sandy, calcareous, mesophilic, wet grassland) and 141 with species of arable land according to the main habitat type based on the phytosociological preference of the translocated species (Fig. 5a). Species of fens and sedge swamps as well as rocks were also included. The largest number of species translocated were species of the habitat types arable land, wet grasslands, and siliceous grasslands and heaths (Fig. 5b, Table 1).

The number of species with high Ellenberg indicator values for light confirmed that the majority of the translocations were undertaken on species of open land habitats (Fig. 6a). Most of the species showed lower values of the Ellenberg indicator for soil nitrogen indicating that the translocations were mainly undertaken on species of nutrient-poor habitats (Fig. 6b). Regarding soil moisture and soil pH, a wide array of species was targeted (Fig. 6c, d). Translocations targeted species from both wet and dry sites, as well as species from base-poor and base-rich sites. However, a slight pref-

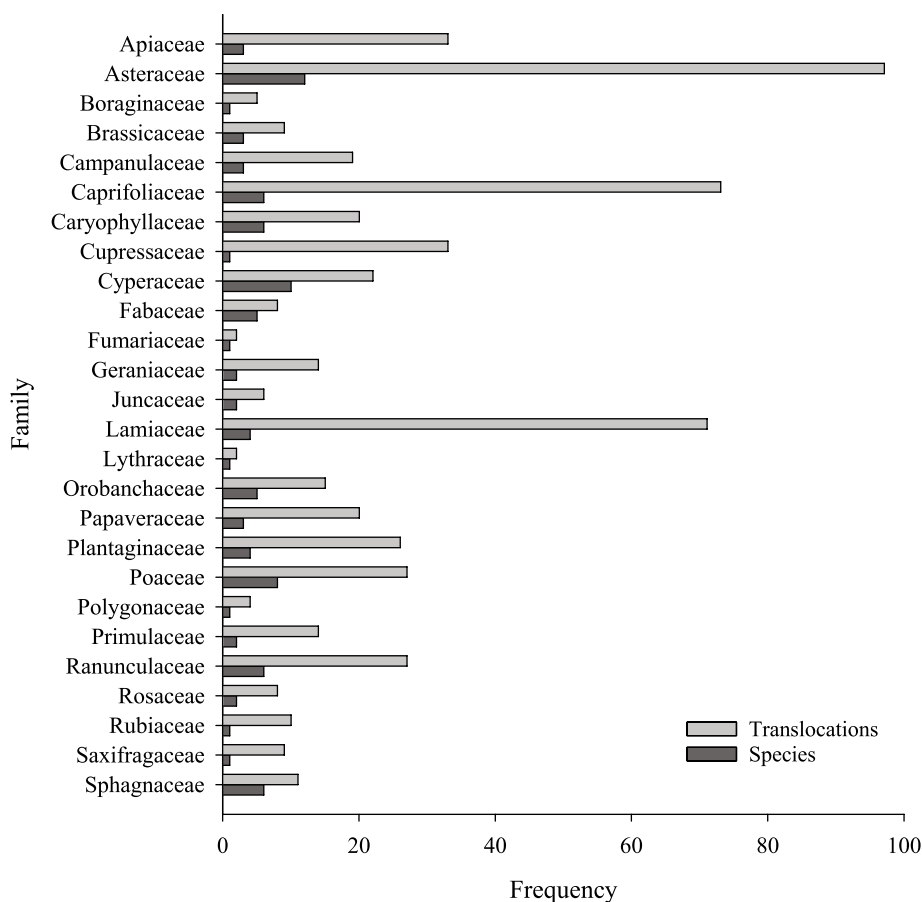


Fig. 4. Number of translocations undertaken per taxonomic family of the target species (light bars) and number of species per taxonomic family for which translocations were undertaken (dark bars).

erence of species from wetland habitats was found (Fig. 6c).

Half of the translocations covered an area between 0.1 and 1 ha, while 35 % covered an area between 1.1 and 10 ha. However, these results should be interpreted with caution as survey participants had different interpretations of the concept of translocation area: some considered it as the area of the plots where plants had been translocated, while others took it as the area of the entire site (utilisation unit). Additionally, 39 % of the translocation sites and actions were situated in national nature reserves. Furthermore, 43 % of the sites (representing 40 % of the translocations) were located in Natura 2000 zones or Biosphere reserves, while 18 % of

the sites (21 % of translocations) were in areas without any legal protection status.

Four primary institutions in Luxembourg initiated translocation projects: three public institutions and one non-governmental organisation. SICONA conducted 75 % of all the translocations in Luxembourg, involving 78 species across 127 sites, followed by natur&ëmwelt - Fondation Hëllef fir d'Natur with 16 % of the translocations involving 21 species across 55 sites. SICONA used 65 % of its sites for multispecies translocations, mainly on grasslands, while natur&ëmwelt translocated multiple species to five grassland sites. Additionally, the National Museum of Natural History (MnhnL) conducted 28 translocations involving eight threatened species, while the

Nature and Forestry Agency (ANF) undertook eleven translocations of one species across nine sites. The MnhnL was the first institute to conduct translocations in the year 1997 as part of a research experiment on a threatened species (*Scorzonera humilis*) in 12 wet meadows, eight of which hosted natural populations of the species (Reckinger et al. 2010). Subsequently, in 2000 and 2003, the MnhnL translocated another species (*Arnica montana*) into two sites as part of the national species action plan (Colling 2009). Ten years later, SICONA began translocating five target species of *Molinia* and dry grassland meadows. In 2014, five additional species of lowland hay meadows were integrated into the project. A total of 78 target species were included in the years since 2013. The majority of all translocations were carried out in the last ten years.

Translocation projects gained momentum between 2011 and 2015 with 323 actions, involving 74 species and 104 sites in mires and fens, mesophilic and wet grasslands, as well as heathlands, other nutrient-poor grassland and rocky habitats. This increase was generated by the launch of the LIFE projects ‘LIFE Orchis’ (LIFE 13NAT/LU/782) by natur&ëmwelt, and ‘LIFE-Natura 2000-Luxembourg’ (LIFE07 NAT/L/000542) and ‘LIFE Grassland’ (LIFE13 NAT/LU/000068)

by SICONA. Additionally, two other SICONA projects aimed to translocate endangered and increasingly rare species of nutrient-poor grassland and arable land – ‘reintroductions of endangered plant species’ and ‘creation of field flora reserves’ – were carried out during this period. These were financed by SICONA member municipalities and co-financed by the project ‘Contribution du secteur communal à la mise en oeuvre du 2^{ème} Plan National concernant la Protection de la Nature dans le sud-ouest et le centre du Grand-Duché’ as part of the National Plan for the Protection of Nature and the Ministry of the Environment, and in addition, some translocations with a co-financing by the EU (LIFE-Projects). Between 2021 and 2023, 104 translocations were conducted. About half of all translocation actions were funded through a combination of national and municipal funds, while 13 % were solely by national funds, and 27 % were partially funded by the European commission.

3.1.2. Methods of in-situ conservation actions

In 88 % of the translocations, participants reported a wide array of supplementary conservation actions, including size estimation of natural populations, habitat protection,

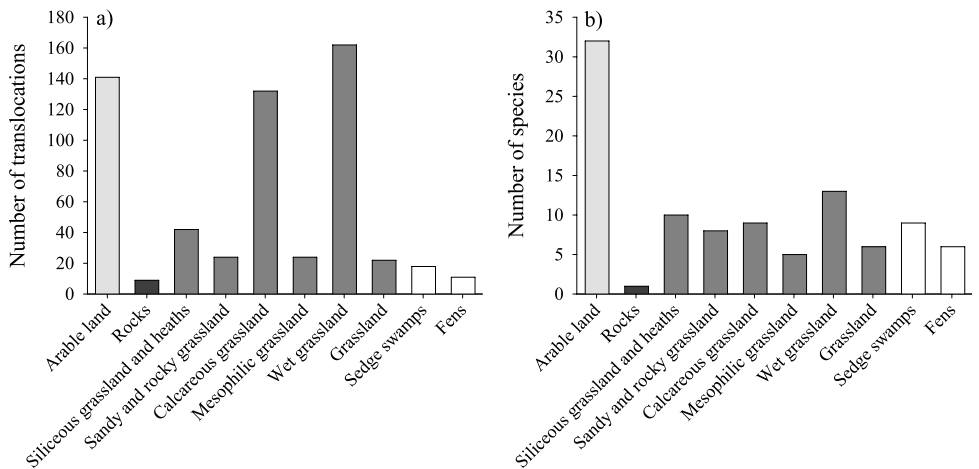


Fig. 5. a) Number of translocations and b) number of target species for which translocations were undertaken according to the main habitat type of the translocated species. Colours represent different habitat groups. ‘Grassland’ describes generally anthropogenic managed nutrient-poor pastures and meadows for species with a wide ecological niche.

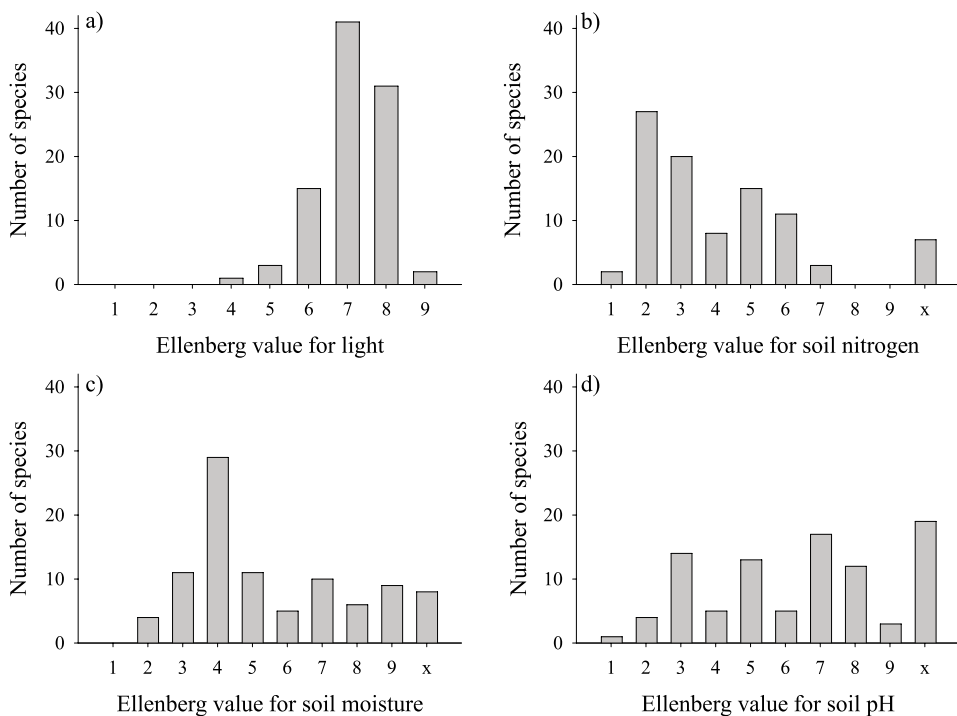


Fig. 6. Number of translocated species per Ellenberg indicator values for a) light, b) soil nitrogen, c) soil moisture and d) soil pH based on Ellenberg et al. (2001). Mosses were excluded.

removal of competing natural vegetation or invasive species, multispecies management, fence construction, and public dissemination.

The most commonly used method for translocations in Luxembourg was the planting of young plants after cultivation. Juvenile plants were used in 327 translocations (including 11 cuttings), seeds in 230 and both types of material in 28 translocations. Since some species were targeted in more than one translocation, we also grouped translocations by species: for 32 species juveniles were used in 207 translocations, for 54 species seeds were used in 198 translocations, and for 13 species both types of material were used in 169 translocations (Table 1). The number of juveniles that were transplanted ranged from 1 to 3'000. In most translocations, between eleven and 100 transplants were used and in only eleven cases more than 500 juveniles were transplanted (Fig. 7). Overall, 39 (6 %) translocations involved a minimum of 200

plants. Only in 22 cases, we could gather information about the number of seeds sown during the translocation. Except for one translocation where only 30 seeds were used, the number of seeds per translocation ranged between 800 and 52'500. The plant material was mostly sourced from three or more source populations. Since 2020 direct sowing has been particularly common for annual arable weeds and for grassland species on restoration sites (see 3.2.5.). In addition to in-situ measures, participants reported collecting seeds for ex-situ storage in a seed bank as part of translocation projects for several species of higher plants.

3.1.3. Monitoring and success evaluation

Monitoring was implemented in 519 translocations (89 %) and lasted for more than five years in 513 instances. Survival was recorded in each monitored translocation. In addition, recruitment of new individuals was documented in 187 cases indicating establishment of the planted individuals

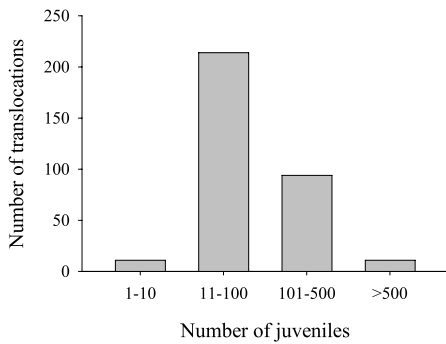


Fig. 7. Number of translocations in which different amounts of juvenile plants were transplanted.

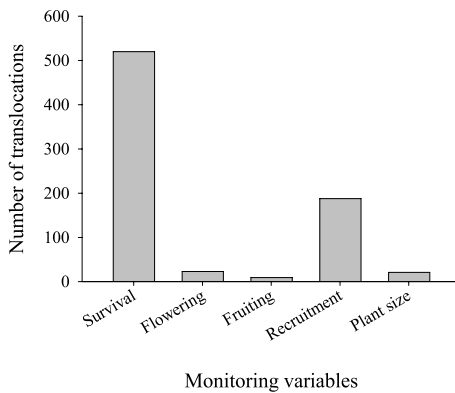


Fig. 8. Number of translocations in which different monitoring variables were used.

(Fig. 8). Flowering plants, fruiting rates or plant size were only rarely recorded.

Success was evaluated in 530 translocations. In each of these cases, survival was used to assess the success. However, the additional assessment of long-term success measured by the flowering or fruiting plants, the recruitment of new individuals and the subsequent establishment of the populations was only considered in a few translocations. Out of the total translocations, 392 (68 %) were evaluated as successful, 75 (13 %) were considered unsuccessful and the outcome was unknown in 106 translocations (19 %).

The analysis of the monitoring data of the project 'reintroductions of endangered plant species' showed that the numbers of juveniles used as starting material varied by species (Table 2). Seven species were planted with individual counts exceeding 1'000 juveniles,

with *Salvia pratensis*, *Betonica officinalis* and *Succisa pratensis* being the most frequently planted. One-third of the species was translocated only once, while the remaining ones were translocated multiple times over several years. For 23 of the 31 species (74 %), data was available for a monitoring period of at least five years. Overall, 61 % of the planted individuals were monitored for five years, and 5 % for ten years. The survival percentage of transplanted individuals after the last monitoring (which occurred between one and ten years after the initial translocation) differed strongly between species, ranging from 0 to 71 % (Table 2). Survival rates above 50 % were recorded for only two species, both characteristic of *Molinia* meadows. Additionally, 42 % of the species exhibited survival percentages between 25 and 50 %, while 52 % of the species had a survival percentage below 25 %. Notably, species in wet habitats showed mostly higher survival rates than those of dry habitats (see 3.2.2.).

3.2. Examples of translocations for different types of habitats

In the following section, we present more detailed information on the translocations conducted in Luxembourg, using species from various vegetation types as examples. We selected both threatened species and those that are in decline but not yet considered threatened, as well as typical species representative of specific vegetation types. Examples are drawn from all institutions involved in translocations. Many of the translocations discussed stem from the reintroductions of 31 rare and endangered species, as well as other species found in oatgrass and golden oatgrass meadows (*Arrhenatherion elatioris*, *Phyteumato-Trisetion*), marsh-marigold wet meadows (*Calthion palustris*) and *Molinia* meadows, fens, and sandy and dry grasslands. Over the past ten years SICONA introduced more than 24'000 juveniles to over 100 sites (Table 1, 2). Although similar translocation methods were often employed, the success and the experiences varied between species.

Table 2. Subset of translocated species, years in which translocations were implemented, number of years after the initial translocation when monitoring took place (time of monitoring), total number of juveniles planted over all the years, and survival percentage after the last year of monitoring (SICONA 2024a). Monitoring took place the first, second, fifth and tenth year after planting. Classes of the proportion of individuals that were monitored after one, two, five and ten years: I: 0-25 %, II: 26-50 %, III: 51-75 %, IV: ≥ 76 %. Data from the monitoring of these species was available until 2023. For calculation of survival rates see 2.3.

Species	Years of translocation	Time of monitoring	No. of juveniles planted	Survival (%)
<i>Avenula pubescens</i>	2020	2 ^{IV}	117	41
<i>Betonica officinalis</i>	2014, 2015, 2018, 2019, 2020, 2021	2 ^{III} , 5 ^{II}	2'266	53
<i>Bistorta officinalis</i>	2016, 2020	2 ^{III} , 5 ^{II}	292	30
<i>Briza media</i>	2017, 2018	5 ^{IV}	269	1
<i>Caltha palustris</i>	2020	2 ^{IV}	45	0
<i>Campanula glomerata</i>	2014, 2015, 2017, 2018, 2019, 2022, 2023	1 ^I , 2 ^{II} , 5 ^{III}	1'213	16
<i>Centaurea scabiosa</i>	2014, 2015, 2016, 2019, 2020	1 ^I , 2 ^{III} , 5 ^{II}	1'121	26
<i>Cirsium oleraceum</i>	2018	5 ^{IV}	30	7
<i>Corynephorus canescens</i>	2021	2 ^{IV}	538	42
<i>Danthonia decumbens</i>	2020	2 ^{IV}	117	43
<i>Dianthus deltoides</i>	2018, 2020	2 ^{III} , 5 ^{II}	216	19
<i>Eriophorum angustifolium</i>	2020, 2022, 2023	1 ^I , 2 ^I	152	29
<i>Geranium pratense</i>	2014, 2015, 2016, 2017, 2018, 2019, 2020, 2023	2 ^{II} , 5 ^{III}	964	42
<i>Geranium sylvaticum</i>	2016, 2017	5 ^{IV}	62	0
<i>Jasione montana</i>	2018	5 ^{IV}	47	38
<i>Molinia caerulea</i>	2015, 2017, 2018	2 ^I , 5 ^{IV}	533	35
<i>Oenanthe peucedanifolia</i>	2015, 2016, 2017, 2018, 2023	2 ^I , 5 ^{IV}	870	71
<i>Petrorragia prolifera</i>	2018	1 ^{IV} , 2 ^I	393	1
<i>Primula veris</i>	2020	2 ^{IV}	199	11
<i>Rhinanthus alectorolophus</i>	2016	5 ^{IV}	2	0
<i>Salvia pratensis</i>	2013, 2014, 2015, 2016, 2017, 2018	2 ^I , 5 ^{IV} , 10 ^I	3'363	8
<i>Sanguisorba officinalis</i>	2014, 2015, 2022, 2023	1 ^I , 5 ^{III}	1'778	25
<i>Scabiosa columbaria</i>	2015, 2016, 2017	1 ^I , 5 ^{IV}	857	11
<i>Scorzonera humilis</i>	2013, 2015, 2016, 2017, 2019, 2020	2 ^I , 5 ^{III} , 10 ^I	991	17
<i>Scutellaria minor</i>	2015, 2016, 2017, 2018	2 ^I , 5 ^{IV}	926	11
<i>Selinum carvifolia</i>	2013, 2014, 2016, 2017, 2019, 2020, 2022	1 ^I , 2 ^{II} , 5 ^{II} , 10 ^I	1'425	33
<i>Serratula tinctoria</i>	2013, 2014, 2015, 2016, 2018	5 ^{III} , 10 ^{II}	943	10
<i>Seseli annuum</i>	2019	2 ^{IV}	563	6
<i>Succisa pratensis</i>	2013, 2014, 2015, 2016, 2018, 2019, 2021, 2023	2 ^I , 5 ^{II} , 10 ^I	3'135	45
<i>Tragopogon pratensis</i>	2018	5 ^{IV}	98	0
<i>Valeriana dioica</i>	2016, 2017, 2018, 2019	2 ^I , 5 ^{IV}	403	34

3.2.1. Translocations of species of nutrient-poor mesophilic and dry grasslands

The once widespread mat grasslands, heaths and dry grasslands (Nardo-Callunetea, Sedo-Scleranthetea, Festuco-Brometea) as well as species-rich oatgrass and golden oatgrass meadows (Arrhenatherion elatioris, Phyteumato-Trisetion) are now among the most endangered habitats (Tischew et al. 2018, Schwabe et al. 2019). As a result of fragmentation, there is a risk for the remaining populations of species in these habitats to lose genetic diversity, as was already demonstrated through population genetic studies on *Arnica montana* and *Anemone pulsatilla* (Luijten et al. 2000, Oostermeijer et al. 2003, Hensen et al. 2005).

Arnica montana is the first species for which translocations were implemented in Luxembourg from the year 2000 on. Populations were reestablished by the MnhnL by reintroducing juveniles to former sites in the north of Luxembourg over several years, natur&emwelt - Fondation Hëllef fir d'Natur continued the translocations for this species in 2011.

Particular attention was also paid to the lack of regeneration of juniper plants (*Juniperus communis*) in juniper heaths. In Luxembourg, until then, larger juniper heaths only existed in two places. Translocations of juniper plants were implemented within the 'LIFE Orchis' project and the juniper project of the ANF, where important efforts were put into their cultivation and more than 900 juveniles were transplanted at extant sites. *Anemone pulsatilla* populations only occurred in a few grasslands on silicate rocks in the Ösling and at one location on limestone in eastern Luxembourg. Sowing seeds on small test plots near extant growth sites was unsuccessful (Frankenberg & Owaller 2020), though the reasons for this are unknown. In contrast, planting cultivated young plants showed success in the east of Luxembourg.

Additionally, ten typical species of oatgrass and golden oatgrass meadows were established using young plants and a few other species were sown. Most of these translocations have been carried out by SICONA since 2013; some of them on restored sites to

enrich the typical species inventory. For this purpose, the conservation actions focused not only on supporting populations of particularly rare species through translocations, but also on improving the habitat conditions to restore declining biotope types and grassland communities.

Other translocations targeted species that were either in decline or characteristic for nutrient-poor mesophilic and dry grasslands types (Table 1). For all these translocations, sites that met the ecological requirements of the target species and for which long-term use for nature conservation purposes was guaranteed were selected. The seed material was collected according to the ENSCONET-Seed Collecting Manual (ENSCONET 2009) which recommends to choose source populations as large as possible. Experienced nurseries were commissioned to propagate wild plants according to ecological standards by either pricking out seeds or directly sowing them in growing trays. One or sometimes two-year-old juveniles were then planted in-situ in late autumn in groups of at least 50, if possible 100 individuals, in rows of ten individuals and with up to five groups per site (Fig. 9; Schneider 2019b, Breit et al. 2023). When planting holes in grassland sites were created, the sward immediately around them was also destroyed. The planted juveniles were protected against wild boars with close-meshed wires during the first months. Each plant was recorded with a high-precision positioning sensor and survival was monitored after one, two, five and ten years. The translocations and the monitoring results were entered into the Recorder LUX database. The origins of the seed material used for sowing or planting juveniles were also recorded (Schneider & Helminger 2019). Depending on the availability of the seed material and the success of cultivation in the nurseries, some species were planted multiple times over several years, thereby spreading out the risk of failure during dry years or when other conditions were less favourable.

With this method, several characteristic species of oatgrass meadows were translocated successfully. Species of dry and nutrient-poor grasslands such as *Centaurea scabiosa*,



Fig. 9. Translocation site of *Primula veris* planted in autumn 2020 (Photo: SICONA, April 2021).



Fig. 10. Established population of *Betonica officinalis* ten years after the initial translocation (Photo: F. Breit, June 2024).

Campanula glomerata and *Scabiosa columbaria* were translocated with approx. 850 to 1'200 young plants in ten to 12 sites. They showed survival rates of 11 to 26 % (Table 2). *Geranium pratense* and *G. sylvaticum* were particularly challenging to grow, as their growth progressed very slowly; therefore, they were mostly planted as two-year-old plants. Around 3'400 young plants of *Salvia pratensis* were planted in 33 sites in 83 plots, mostly in the first years of the translocations (2013 to 2015). On average, 2.6 plots were installed per site; in eight sites only one and in six sites four plots were established. Usually, 50 young plants per plot were planted. Unfortunately, the survival rates of *S. prat-*

ensis were low with only 8 %. Therefore, sowing trials are currently carried out on small plots.

First attempts to translocate species of sandy grasslands were also made. Characteristic species such as *Corynephorus canescens* and *Jasione montana* were planted in few groups of approx. 550 individuals of *C. canescens* and approx. 50 individuals of *J. montana* on each site (Table 2).

3.2.2. Translocations of species of *Molinia* meadows

Molinia meadows are one of the rarest and most endangered grassland types in Luxem-

bourg (Schneider 2011, Schneider 2019b) with only eight hectares left nationwide at present (MDDI 2014). To counteract the decline of this grassland type and its threatened characteristic species, SICONA implemented many translocation measures in this plant community over the last ten years. In addition to the species of *Molinia* meadows, also other characteristic species of nutrient-poor wetlands were translocated, including many other widespread species of wet meadows and endangered species of peatlands (see Table 1 & 3.2.3.). Seeds were collected from extant populations, grown as young plants, and planted to adequate sites in groups of approx. 100 individuals depending on the species and the availability of cultivated plants, like already described for mesophilic species (see 3.2.1.). If there were not enough juveniles available at the first time of translocation, the planting was spread over two or three years. In addition to collecting sufficient donor material for propagations and obtaining good germination rates (especially for *Scorzonera humilis*), the selection of suitable locations was particularly challenging. Characteristic species of *Molinia* meadows mostly show narrow ecological amplitudes and are therefore particularly affected by changes in water and nutrient availability. Various characteristic species of nutrient-poor wetlands were translocated, including *Selinum carvifolia*, *Molinia caerulea* and *Valeriana dioica*. First evaluations of the monitoring of the translocations have shown that five years after the first translocations 33 to 35 % of the planted individuals of these three species have survived (SICONA 2024a, Table 2).

In addition to the systematic monitoring, a recent study (Breit et al. 2023) analyzed the translocations of five characteristic species of *Molinia* meadows to assess their long-term success beyond the survival of the planted individuals. To evaluate the success of the translocations, the survival, the recruitment and various reproductive and generative traits regarding vitality and fitness of translocated and donor populations of the species *Scorzonera humilis*, *Oenanthe peucedanifolia*, *Betonica officinalis*, *Succisa pratensis* and *Serratula tinctoria* were analyzed. The translocated populations were planted between

four and nine years prior to the survey (Breit et al. 2023). Recorded variables included the population size, the proportion of flowering individuals, the number of flower heads per plant and the height of the plant. For *Betonica officinalis* (after 8 years; Fig. 10), *Succisa pratensis* (after 7–9 years) and *Oenanthe peucedanifolia* (after 5–7 years), which were initially translocated with a total of approx. 5'000 juveniles, three to seven times as many individuals as initially planted were recorded. These high establishment rates validate that these translocations were successful. The proportions of flowering individuals were usually significantly lower in the translocated than in the extant populations. Only *Betonica officinalis* and *Succisa pratensis* showed no significant difference when the percentages of flowering individuals between translocated and extant populations were compared. This indicated that the methodology of the translocation (e.g. planting density and site selection) were adequate for the species to establish successfully (Breit et al. 2023). Survival rates for *Serratula tinctoria* were around 23 %, but there was hardly any regeneration (Breit et al. 2023). Nevertheless, there was an increase of population size in three of the six investigated sites of *S. tinctoria*. Although this was an indication of success, demographic monitoring may be necessary to evaluate the long-term sustainability of *S. tinctoria* populations in the future (Breit et al. 2023). For *Serratula tinctoria* the number of individuals available for the translocation was low (on average < 20) due to the scarcity of seeds present in the three remaining large populations of *S. tinctoria* left in Luxembourg that served as source populations, which may have prevented a successful establishment. On the other hand, in the case of *Scorzonera humilis* – which had the lowest establishment rate of the five species –, the number of individuals planted was high, but the reasons for failure may be due to suboptimal habitat conditions or to the donor populations themselves (Breit et al. 2023). Studies on *S. humilis* populations in Luxembourg showed that they were often over-aged and hardly reproduced themselves (Colling et al. 2002, Colling & Matthies 2006, Reckinger et al. 2010, Breit et al. 2023). Godefroid et

al. (2011) demonstrated a relation between the demographic status of the donor population and the success of translocations, finding that stable source populations resulted in more successful translocations. Furthermore, they assumed that the reduced genetic variability of declining populations has a negative impact on the development of translocations and reduces their ability to adapt to changing environmental conditions. Genetic analyses could confirm if that is the case for *S. humilis* populations in Luxembourg.

3.2.3. Translocations of wetland and peat-land species

For species of peat soils and fens it is difficult to find suitable translocation sites, as there are hardly any peat deposits left in Luxembourg (Frankard et al. 2017). Large-scale drainages, measures of agricultural intensification, and other changes in land use have contributed to the decline of wet meadows to a considerable extent. Especially meadows with *Caltha palustris* (*Calthion palustris*) are endangered (Schneider 2019b, Schneider et al. 2023a). Fens and raised bogs are even threatened with extinction in some regions of Europe (Frankard et al. 2017). Only about 1'000 ha of wet meadows, wet fallow land and fens remain in Luxembourg (MDDI 2014). Many of the typical species of fens and wetlands have already disappeared or are threatened by extinction (Colling 2005).

In addition to species of the periodically wet *Molinia* meadows (see 3.2.2.), six species of permanently damp to wet *Calthion palustris* meadows and four species of peatlands were translocated in the last ten years. A small number of individuals of *Eriophorum angustifolium* was planted in a fen nearby Grosbous alongside *Sphagnum rubellum* to assist the colonization of peat mosses (Keightley 2020, Schneider et al. 2023b). Out of around 30 young *E. angustifolium* plants, eight fruiting individuals survived after two years. Additionally, juveniles of *Scutellaria minor* maintained themselves on two out of four restoration sites, but only with 11 % of the total number of transplants surviving after five years. These examples show that some species were more difficult to establish than

others and that large quantities of these species need to be translocated to achieve successful translocations. The translocations were performed by SICONA using the same method as described for the mesophilic species (see 3.2.1.).

In Luxembourg, many moss species are endangered (Werner 2003). Therefore, in addition to flowering plants, peat mosses were also translocated from 2020 onwards on a few fens by cultivating one *Sphagnum* species ex-situ before transplanting and by in-situ translocation of six other *Sphagnum* species from natural populations (Schneider et al. 2023b). The peat mosses including *Sphagnum palustre*, *S. auriculatum*, *S. fimbriatum*, *S. teres*, *S. fallax*, *S. flexuosum*, and the very rare *S. rubellum* were collected from natural peat moss-rich sites (open land and forest). The translocations were carried out in several small plots and in multiple phases over four years by using different methods like inoculations with loosely scattered individual plants, plantings of *Sphagnum* clumps, or spreading *Sphagnum* fragments in agar-agar gel. *S. rubellum* was propagated ex-situ on flooding tables and after rapid growth clumps were translocated (Schneider et al. 2023b). Close-meshed monitoring was used to record the growth of the peat mosses and their surrounding vegetation (estimation of cover) and the variation of the water levels over the years. The translocation and development of the peat mosses was successful when optimal sites with permanently high water levels were chosen and the existing vegetation was removed before the translocation. Further research is crucial to determine which other factors influence the success of the *Sphagnum* translocation. Schneider et al. (2023b) recommend that the combination of ex-situ cultivation and in-situ measures should be continued for the resettlement and restoration of endangered fens.

3.2.4. Translocations of rock species

Inland cliffs are a priority habitat recognized by the EU Habitat directive, where specialized plants can colonize rock fissures containing a small amount of fine soil. These environments can be entirely natural but

may also result from human activities (quarries, road embankments). Siliceous rocks are relatively common in the Ardennes but tend to cover small areas. *Saxifraga rosacea* subsp. *sponhemica* (hereafter referred to by its synonym *S. sponhemica*) is an endemic plant of Central Europe, occurring on siliceous rocks in Luxembourg. It is extremely rare and threatened and is recognised as a species of conservation priority within Europe (Schnittler & Günther 1999). In Luxembourg, populations have become extinct at approximately half of the previously known locations. Extant populations host considerable genetic diversities and are adapted to the regional climate (Walisch et al. 2015a, b). Due to their small size and isolation, they are, however, at risk of genetic erosion (Frankham et al. 2002), which may lead to reduced offspring performance (Keller & Waller 2002). Moreover, the considerable distances between extant populations and suitable new habitats (often several km), hinder the establishment of new populations. To increase the number of viable populations and mitigate the extinction risk of this species, it is recommended to establish new populations in suitable habitats (Walisch 2009, Walisch et al. 2015a). In April 2012, a population was reintroduced to a rock in Kautenbach and subsequently reinforced in May 2015, using seeds from a total of 100 mother plants sourced from various populations nearby. A boom truck with a basket was employed for this purpose. In December 2018, over 30 new plants of varying sizes (1-50 rosettes) were counted with a telescope (Krippel et al. 2019) and by summer 2023, about 185 individuals were recorded appearing vigorous (pers. observation, T. Walisch 2024). Following this successful establishment, a project was initiated to establish new populations at suitable sites (responsible institutions: Nature Parks of the Our and Upper Sure valleys and the MnhnL, funding partner: 'Fonds pour la protection de l'environnement'). From July 2021 to March 2024, either young plants have been planted or a batch of approximately 500 seeds has been sown in at least 160 microsites across each of eight suitable sites. Additionally, moss and other vegetation from half of the microsites were cleared before

planting or sowing and microsite attributes, including size and various types of vegetation cover were documented. The translocations were designed as experimental trials to investigate several factors of translocation success: (1) Does recruitment from seeds differ from establishment from young plants? (2) Do microhabitat characteristics influence the success of plant establishment? (3) Does the removal of vegetation from rock ledges or wall crevices before planting or sowing impact plant establishment?

In the first year, plantings and sowings were carried out in July and were followed by extreme summer drought, resulting in a survival rate of less than 25 %. In the second year, plantings and sowings were done in March and in September to mitigate potential stress from summer droughts. Unfortunately, the survival rate of young plants in cultivation during the summer of 2023 was lower than expected attributed to heat and parasitic infestations in the greenhouse. In response, a fresh batch of plants was cultivated throughout the autumn and winter 2023, and translocated in March 2024.

Each year survival, plant performance, reproduction as well as establishment from new seeds have been recorded. Preliminary results revealed that clearing vegetation from the microsites during translocation events resulted in over twice the early recruitment from seeds and establishment from young plants 3-5 months later (Walisch et al. 2024). In years when more young plants were established, fewer seedlings have been observed, and vice versa, suggesting that recruitment from seeds has different requirements compared to establishment from young plants. Therefore, sowing and planting could complement each other for successful translocations. The mean number of seedlings per microsite was only slightly lower than that of young established plants (2.9 ± 0.5 S.E.) (Walisch et al. 2024). Hence, sowing could serve not only as a complementary method but also a preferable one due to its cost-effectiveness, provided that a sufficient quantity of seeds is available. Nevertheless, continuous monitoring of the plants' long-term survival is essential.

3.2.5. Translocations of arable plants

A strong decline in species of arable fields has been observed in Luxembourg during the last decades (Frankenberg et al. 2022). To protect the species of this habitat type, measures promoting extensive use of fields or field margins without pesticides (within the framework of contractual nature conservation programmes) and the translocations of arable weeds have been implemented. Rare, mostly annual arable weeds can be translocated by hand sowing seeds in small establishment gaps, mechanical sowing mixed with crop seed, or by transferring soil containing diaspores (Bergmeier et al. 2021). While a mix of species was sown in arable fields, in grasslands only one species was usually sown. In Luxembourg, seeds were collected manually during numerous field surveys in species-rich fields. Field mappings conducted over more than 10'000 ha of fields in almost 30 SICONA member municipalities since 2009 are used to identify species that mostly occur in small populations (SICONA 2024b). Since 2012, around 50'000 seeds of 36 characteristic species of arable vegetation, including *Veronica triphyllos*, *Delphinium consolida* and *Misopates orontium*, have been sown in conservation crop fields or field margins in Luxembourg by SICONA (Table 1; SICONA 2024a). Seeds were sown in small plots without cereals to ensure establishment. Monitoring recorded which species survived and in what quantities. First results indicate that not all species were established successfully even though the translocation sites were used extensively to ensure the long-term survival of the translocated species. There is still a significant need for large-scale and rapid conservation measures for the characteristic species of the arable vegetation (Bergmeier et al. 2021).

4. Discussion

4.1. Selection of taxa and habitats for translocations

Translocations in Luxembourg have mainly, but not exclusively targeted threatened species with the aim of conserving endangered

species. While the majority of the translocated species was categorised as Endangered, Critically Endangered or Vulnerable, 25 % of the targeted species were of Least Concern, which were mostly typical species of endangered habitats (see 3.2.1.). The threat status of a species is certainly an important criterion to select target species for conservation actions. However, an analysis by Diekmann et al. (2015) on reintroductions in Germany showed that the national and international threat level of the species is not the only factor determining which species are included in translocation projects. The presence of a species in conservation cultures in botanical gardens, the attractiveness of the species or their habitats often play a decisive role in the selection of target species. This explains why in Germany species of semi-natural grassland and heathland communities were more often translocated than species of other habitats (Diekmann et al. 2015). Similarly, all translocations in Luxembourg targeted open land species, especially grassland species (approx. 70 %). The main reason for this preference is that many translocations were implemented through large-scale projects aiming to restore grassland habitats with an unfavourable conservation status (MECDD 2023a). The urgency concerning these habitats was highlighted in the last national habitat report regarding the Habitats Directive, which showed that the decline and the degradation of lowland hay meadows (Natura 2000 habitat type 6510) and other species-rich grassland habitat types progressed (EIONET 2023). A decision tree by Kienberg et al. (2011) suggests to additionally consider species of special responsibility in order to prioritise species for translocations, similar to the recommendations of the Plant Conservation Strategy for Luxembourg (Colling et al. 2022).

Species translocations by SICONA were part of the large-scale grassland restorations of Natura 2000 habitat types 6510 (lowland hay meadows), 6410 (*Molinia* meadows) and 6210 (limestone semi-dry grasslands) (Biro et al. 2024, Schneider & Breit 2024), while those of natur&ëmwelt Fondation Hëllef fir d'Natur primarily targeted restorations of Natura 2000 habitat type 6210 (Helminger et al. 2019). These restorations play an impor-

tant role in achieving the goals from the National Plan for the Protection of Nature, which aims to restore habitats and species to a favourable conservation status. The objectives are to restore 2'400 ha and to improve 1'600 ha of Natura 2000 habitat type 6510 by 2030 (MECDD 2023a). Such meadow restorations were carried out on numerous sites by transferring mowing material or seed mixtures collected by a seed harvester from suitable donor sites (Schneider & Wolff 2020, Schneider & Breit 2024). However, these restorations, which mostly took place on mesophilic meadows, were not included in this study, which only lists the translocations of species that were individually transferred to complete the characteristic species inventory of the target biotopes. Individual translocations are recommended especially for rare species which are often more difficult to transfer with freshly mown material (Biro et al. 2024).

Most of the translocations targeted species of nutrient-poor habitats because they experience the strongest declines (MECDD 2023b). Nitrogen deposition in Luxembourg strongly exceeds the internationally defined critical load for eutrophication (EEA 2014), which threatens biodiversity in grasslands (Bobbink et al. 1998, Stevens et al. 2004, 2006, 2010). Many species of wetland habitats and fens were also particularly targeted to counteract their decline due to drainage and intensification (Dierschke & Waesch 2004, Janssen et al. 2016, Schneider et al. 2023a). Forest species have not yet been considered in translocation projects. In comparison to grassland species, a lower proportion of woodland species is endangered (Colling 2005, Schneider 2019a). However, due to the ongoing changes and risks for forests (e.g. climate change), the preservation and restoration of woodlands may include species translocations where appropriate.

The high concentration of translocation projects in the south-west and west of Luxembourg is partly due to SICONA being based in this region, with access to a large pool of sites through their numerous member municipalities. Translocations combined with restorations are also among the main priorities of this institution (Schneider &

Breit 2024). A large majority of translocations took place in protected areas, including nature reserves and Natura 2000 areas, which is crucial for ensuring after-care and long-term management to allow for the establishment and sustained protection of the populations. The implementation of translocation projects on public areas (municipal or state), nature conservation foundation land or land with long-term rental agreements guarantees the protection of newly established populations. Most of the projects were financed by public funds (municipal, state or European) to varying degrees, depending on the institution and project. In recent years, the National Plan for the Protection of Nature (MECDD 2023a), the Strategy for the Conservation and Restoration of species-rich Grassland (MECDD 2020) as well as species and biotope conservation plans (e.g. Schneider et al. 2013) have significantly contributed to public financial support for conservation actions aimed at plants.

4.2. Evaluation of translocation methods

Due to the increasing decline of plant species (Colling 2005, Eichenberg et al. 2021, Observatoire de l'environnement naturel 2022, Härdtle 2024) numerous translocations have been carried out in Luxembourg, especially in the last 10 years. Translocations are extensive and complex projects that involve different methods depending on the targeted species or habitat and are often accompanied by additional conservation measures.

Selecting suitable source populations is crucial for ensuring successful translocations. In Luxembourg, more than 75 % of the translocations used seeds from three or more source populations as recommended by several studies (e.g. Smulders et al. 2000, Menges 2008, Lauterbach et al. 2021). It is also recommended to sample source populations with high genetic diversity but limited genetic differentiation (Smulders et al. 2000, Menges 2008, Zippel & Lauterbach 2018, Lauterbach et al. 2021) and to select receiving sites with similar ecological conditions to those of the natural populations (Commander et al. 2018, Maschinski et al.

2023). Even though these guidelines have been considered in many translocations in Luxembourg, they should be applied rigorously and used in any future translocations. Furthermore, the source population's ability to form fertile seeds should be examined (Zippel & Lauterbach 2018, Smulders et al. 2000) by performing germination tests before starting the cultivation or seeding. In Luxembourg, seeds were collected according to the recommendations of the 'ENSCONET-Seed Collecting Manual for Wild Species' (ENSCONET 2009) for the majority of translocations during the past ten years. These recommendations include the number of seeds per plant and of populations to sample, the sampling techniques to use and the documentation to include. Storage in specialised seed banks is also advised to ensure long-term conservation of the collected seeds since seed viability and germination capacity strongly depend on storage conditions (De Vitis et al. 2020). To collect material from protected species or from nature conservation areas it is also necessary that authorisation in accordance with the Nature Conservation Act has been granted by the Ministry of the Environment, Climate and Biodiversity respectively the Nature and Forestry Agency (Mémorial 2018).

The most commonly used method for translocations in Luxembourg is the cultivation of young plants and their subsequent transplantation, followed by direct seeding (see 3.1.2.). Introducing young plants in-situ gives them a competitive advantage over sown seeds, which have to germinate and develop into juveniles first (Dolnik et al. 2020). In grasslands, it is also important to remove the vegetation around the planting hole to reduce competition with existing grasses during the initial growth period (Richter & Grätz 2018). Cultivating plants prior to the translocation is also preferred when there are only limited quantities of seeds available (Menges 2008). While, this method generates higher costs due to propagation in specialised nurseries, it significantly increases the probability of seed germination and successful plant establishment (Albrecht & Maschinski 2012, Olsen 2021).

Sowing seeds is often the most time- and cost-effective method for translocating a species to a site; however, the average germination rate in the wild varies between one and ten per cent, significantly increasing the initial number of seeds required (Menges 2008, Olsen 2021). Using seeds may therefore be suitable for species which produce a lot of seeds, for annual or short-lived species (Olsen 2021) and for those dependent on regular regeneration via seeds. Consequently, this method was primarily used for arable species in Luxembourg. However, when donor populations of rare species are scarce or small and only a limited quantity of seeds is available, the cultivation of young plants may become necessary. Generally, individuals need to be translocated in sufficiently large groups and attention should be paid to small-scale site structure. Taking into account the minimum size of a viable population and possible loss rates, it is recommended to translocate more than 200 individuals when planting or to sow between 1'000 and 50'000 seeds to increase the probability of establishment (Godefroid et al. 2011, Albrecht & Maschinski 2012, Bontrager et al. 2014, Commander et al. 2018, Richter & Grätz 2018, Zippel & Lauterbach 2018). In Luxembourg, only 17 % of the translocation sites received 200 juveniles or more of one species. Practitioners explained it as a result of a lack of seeds, low germination rates and difficulties in propagation for some species. On the other hand, a study on *Melampyrum pratense* in Germany showed good establishment rates even though fewer seeds were used, suggesting that for large seeded, short-lived taxa less seeds may be necessary for a successful translocation (Heinken 2004). Nevertheless, regarding translocations in Luxembourg, more efforts are needed to reach the recommended number of planted individuals.

Propagation is another method to translocate plants and can be done with cuttings or other vegetative propagation units. In Luxembourg, *Bistorta officinalis* was cultivated using rhizomes to serve as a food source for the caterpillars of the endangered butterfly *Lycaena helle*. The plants were dug up, parts of the rhizomes were separated and then planted at the new sites. This type of prop-

agule is particularly suitable for species that reproduce clonally and for which methods to overcome dormancy are unknown (Commander et al. 2018). This invasive method should only be used for species that are not endangered and occur in large populations. Since the cultivation step is not required, it is faster and therefore more cost effective. In contrast, the storage of cuttings can be more expensive than the cultivation of juveniles or the direct sowing of seeds (Commander et al. 2018). In Luxembourg, there is currently limited experience with using cuttings for translocations, having been implemented for only a few species.

Selecting translocation sites with appropriate ecological conditions and suitable established plant communities, is a key factor for the success of translocations (see also 4.4.). Therefore, it is important to consider the site's ecology at a small scale, assess soil and water conditions, and survey the vegetation of the sites. In the case of wetlands for example, water conditions might have to be optimized first to insure successful translocations.

Implementing additional conservation actions alongside the translocations as after-care can be crucial for ensuring success. For instance, installing fences against wild animals can maximize the survival of young transplants. Furthermore, conducting repeated translocations over multiple years, especially during periods of drought or when there are not enough juveniles or seeds available, may be necessary to reach an optimal initial population size (Zippel & Lauterbach 2018, Dolnik et al. 2020). To guarantee long-term establishment, grassland habitats should be used extensively before and after the translocations.

4.3. Monitoring: outcomes and next steps

Our overview showed that in 89 % of the surveyed translocations monitoring was implemented and that when success was evaluated, it was mostly based on the survival of the translocated plant material. How successful translocations are depends on many factors including the species, the initial conditions and the site suitability

(Godefroid et al. 2011, Breit et al. 2023). However, data from monitoring translocations is often missing, making it difficult to evaluate their success (Godefroid et al. 2011). Better reporting on successes and failures can help to learn from conservation actions and to increase acceptance of translocation measures (Koch & Kollmann 2012). Ideally, monitoring comprises recording survival, growth or reproduction, next-generation recruitment, and population expansion (Maschinski et al. 2023). So far, such an extensive monitoring has been executed in only some instances in Luxembourg. While the evaluation of success was based on survival, only in a few cases the recruitment of new plants was recorded. However, the establishment of a species can only be considered successful when the plants can reproduce on-site (Dolnik et al. 2020). Recording the recruitment of new individuals, and thus the regeneration of a new population, is of utmost importance. To establish a second generation in translocated populations, more than five years are usually required (Roncal et al. 2012). Therefore, monitoring the populations for ten years is often recommended (Dalrymple et al. 2012). In accordance with these guidelines, most of the translocations in Luxembourg for which this type of data was available were monitored for over five years. Long-term efforts in monitoring allow management practices to be adjusted during the project and enable the planting of additional juveniles if survival rates are too low (Monks et al. 2012, Maschinski et al. 2023), as was done in some cases in Luxembourg. Furthermore, combining conservation actions with scientific research is recommended as standard practice to enhance our understanding of species translocation science (Commander et al. 2018, Maschinski et al. 2023). In Luxembourg, a few research studies have been conducted as part of translocation projects, as highlighted by some examples presented here. However, research efforts should be undertaken in the future to support ongoing initiatives (see also 4.4.).

To achieve the objectives of the National Plan for the Protection of Nature (MECDD 2023a) and the Nature Restoration law (European Parliament 2024) regarding

habitat restoration, an increasing amount of conservation actions and monitoring will be required. While systematic and regular monitoring of the most important parameters is indispensable, the efforts must remain financially and logistically feasible. In any case, measurements of the position of the planted individuals and those recruited through in-situ reproduction – using a high precision positioning sensor for example – should be carried out (also see 2.3. & 3.2.1.). Identifying areas with low survival rates or where open soil needs to be created to improve germination could help to improve the overall success of the translocations.

Other requirements for the success of translocation projects include the guarantee of long-term funding, as well as the support and engagement of policymakers and the public (Broadhurst & Coates 2017, Maschinski et al. 2023). Project presentations on site and press work to policymakers raise awareness on conservation actions and can help to secure long-term financing. Most translocations in Luxembourg were carried out as part of projects with a limited duration of a few years. However, the follow-up management and monitoring require long-term financing which should ideally be incorporated when planning such projects.

Data concerning translocations in Luxembourg are scattered across various conservation organisations. While the survey which this overview is based on aimed to collect data on past translocations, consolidating detailed information into a standardized, publicly accessible database would facilitate communication between experts and with the broader public (Diekmann et al. 2015). Such a translocation database would allow to assess the success of the translocations but also to document translocation-induced changes to species occurrences for future research and conservation actions (Diekmann et al. 2015). Furthermore, making data readily available to policymakers through tools such as maps, databases and information systems can significantly accelerate decision-making processes.

This overview, along with the database on conservation actions on threatened plant species in Europe (ConservePlants 2024) on

which this work is based, provides a basis for creating a protocol for documenting translocations in Luxembourg. This protocol will include all necessary information to trace back the implemented conservation actions and evaluate the long-term prospects of the populations. In addition to the types and methods of the translocations, information on monitoring needs to be included (Menges 2008, Godefroid & Vanderborght 2011, Richter & Grätz 2018, Commander et al. 2018, Breit et al. 2023). It is advisable to record and document more than just the survival rate, at least for a representative sample of the newly created population. This is especially important when translocations have failed and methods need to be adapted. Furthermore, recording establishment based on reproduction and fitness parameters can be extremely useful for evaluating overall success (Menges 2008, Monks et al. 2012, Abeli et al. 2016, Breit et al. 2023).

4.4. Challenges of translocations

In a cultural landscape predominantly under intensive use, the availability of translocation sites with often very specific habitat requirements for the targeted species is one of today's most limiting factors (Bontrager et al. 2014, Becknell et al. 2021, Breit et al. 2023). Suitable translocation sites must meet the ecological requirements of the species (Diekmann et al. 2015). Unfortunately, many translocations fail due to the lack of knowledge about the biology and ecology of the target species (Godefroid et al. 2011, Maschinski et al. 2012, Zippel & Lauterbach 2018). Abiotic and biotic conditions of habitats can differ on a small scale making it important to analyse the prevailing conditions at translocation sites (Noël et al. 2011, Bontrager et al. 2014). For example, for translocations involving wetland species, ensuring suitable hydrological conditions is crucial; otherwise, the site will need to be restored before the translocation can proceed. Assessing whether the initial site conditions can be restored and maintained is therefore key when selecting the most suitable sites (Breit et al. 2023, Schneider et al. 2023a, b).

With climate change, altered eutrophication and the intensification of agricultural use finding suitable sites for translocations will become increasingly challenging (Koch & Kollmann 2012, Olsen 2021). Thus, it is essential to recognise and protect potential sites early on (Olsen 2021) and long-term management of these areas must be ensured. A complicating factor is that, in the future, sites with suitable conditions may differ significantly from current sites (Maschinski et al. 2023). In Luxembourg, several habitat types are already quite rare making it necessary to engage in international collaborations when implementing assisted migrations of European species.

After a translocation event, follow-up care is essential to enhance the survival chances of young plants (Godefroid et al. 2011, Zippel & Lauterbach 2018, Breit et al. 2023). It is a common observation that most losses occur in the first few years after planting (Godefroid et al. 2011, Dalrymple et al. 2012, Breit et al. 2023). Possible reasons are unsuitable sites, insufficient water supply, slug damage, fungal infestation, low vitality of the juveniles or competition (Godefroid et al. 2011, Guerrant 2012, Roncal et al. 2012, Diekmann et al. 2015, 2016, Schneider & Helminger 2019, Breit et al. 2023).

In the monitoring study by SICONA, the survival of juveniles varied strongly with the species targeted by the translocations (Table 2). This aligns with the findings of Silcock et al. (2019), which determined that 'species' has the greatest influence on the success of translocations. However, the success of translocations also depends on initial conditions, site suitability, and specific habitat requirements (Godefroid et al. 2011, Guerrant 2012, Diekmann et al. 2015, 2016, Schneider & Helminger 2019, Breit et al. 2023), as also illustrated by the examples presented in this overview.

In about half of the studied grassland species the survival rates varied between 25 and 71 % (Table 2). These values are similar to those found in other studies (e.g. Dalrymple et al. 2012, Liu et al. 2015). Part of the variation could be due to different monitoring periods, as shown by other studies that report varying outcomes depending on the

time elapsed after the translocation (Primack et al. 2009, Monks 2012). There are generally few suitable comparative values in the literature, particularly since survival rates may vary significantly with the translocation and evaluation method, as well as the species involved. Additionally, many projects remain unreported or in the grey literature. In a meta-study Godefroid et al. (2011) reported survival percentages of 33 to 78 % for translocated species, with variations depending on whether the data was coming from published studies or from surveyed practitioners. The reasons for this strong variation between documented and perceived survival rates may include the lack of documentation and publication of failed translocations, leading to an overestimation of success (Godefroid et al. 2011, Guerrant 2012). In our study, practitioners based their assessment of translocation success solely on survival without mentioning exact values and specifying which survival percentage was considered as successful. Therefore, we consulted a monitoring subset of 31 species to provide more detailed information. Generally, we recommend using standardised parameters to evaluate success of future translocations.

Other reasons for the failure of translocation can include insufficient vitality of the donor populations or an inadequate number of initially planted juveniles (Breit et al. 2023). It can be difficult to obtain enough material of rare or endangered species with only a few small populations left. For example, only three sufficiently large populations of *Serratula tinctoria* remain in Luxembourg from which seeds can be collected. Unfortunately, due to this limitation, only a small number of individuals of this species has been planted out so far. Consequently, this species will be included in plant cultivation efforts aimed at seed production, and plans are in place to use additional donor material from neighbouring countries. Since most of the grassland species translocated in Luxembourg were established with only a few plants at a few locations or have poor survival rates, further translocations are essential to establish sufficiently large numbers of individuals in the new populations or to strengthen existing declining populations. For some

species where translocation was not successful, e.g. *Campanula glomerata* or *Salvia pratensis*, or for species whose habitats are becoming increasingly rare and endangered, such as lowland hay meadows or wet meadows (Schneider 2019a, b, MECDD 2023a), further translocations are essential to ensure their survival. These translocations should be designed as scientific experiments, particularly in the case of rare species, to improve the outcomes (see 4.3.). Examples of such experiments include those implemented for *Scorzonera humilis* (Reckinger et al. 2010) and for *Saxifraga rosacea* subsp. *sponhemica* (Walisch et al. 2024) in Luxembourg, as well as for three species of steppe-like grasslands (Kienberg et al. 2013), where various parameters that influence translocation success were investigated.

4.5. Other conservation measures

In addition to species translocations, propagating wild plants and producing autochthonous wild plant seeds is a further important contribution to the preservation of plant diversity in Luxembourg. Under the 'Wëllplanzesom Lëtzebuerg' certificate, seeds of autochthonous wild plants of proven origin are propagated on agricultural fields in Luxembourg according to strict quality standards and organic criteria. In this project, rare species as well as more widespread typical species of species-rich grasslands are cultivated. The produced seeds are assembled into seed mixtures that can be used to create wild meadows and urban flowering areas, which in turn contribute significantly to biodiversity (Schneider et al. 2024; <https://wellplanzen.lu>). However, additional conservation measures for species of arable land are urgently needed, as the typical and once common wild herbs of these habitats have declined in recent decades and they lack any protection status compared to other habitat types (Bergmeier et al. 2021, Frankenberg et al. 2022). The establishment of a network of conservation crop fields and arable plant sanctuaries at landscape level as well as the implementation of sufficient field margin strips is essential. These measures will serve as conservation areas for local wild species of arable land and potentially act as sources

for translocations (Bergmeier et al. 2021). They would contribute to achieve the goals outlined in the existing action plans (Naumann 2009a, b) and the Bartringer Declaration on the Protection of Arable Biocenoses in Luxembourg (Anonymous 2017), which have not yet been implemented to any significant extent.

In the conservation actions reported during our survey, ex-situ measures only rarely accompanied the translocations. Using ex-situ conservation cultures from botanical gardens for translocations reduces the risk of negative effects of collecting from small remnant populations (Diekmann et al. 2015). Luxembourg does not have a botanical garden where rare plant species can be taken into conservation culture like in other countries. Ex-situ collections would however be necessary to achieve target four of the Plant Conservation Strategy for Luxembourg (Colling et al. 2022) that aims to conserve at least 75 % of rare, threatened or socio-economically important wild plant species in Luxembourg.

Another method of ex-situ conservation is the collection and long-term storage of seeds. Seeds of rare and increasingly rare species have systematically been collected, preserved and recorded in the seed bank of the National Museum of Natural History. A regional seed bank was also established at the Nature Conservation Syndicate SICONA to store the required material for translocations (Schneider 2019b, Schneider & Breit 2024). Currently, 36.5 Mio seeds from 432 species are recorded in the national seed bank, of which around 30.5 Mio seeds from 220 species are stored by the regional seed bank (MnhnL 2024). The collection of seeds may not have been mentioned by all participants in our study as it was not the primary focus.

Seed banks are very important for the conservation of rare species, however only one third of the species present in the seed banks in Luxembourg are threatened (Critically Endangered: 9 %, Endangered: 13 %, Vulnerable: 9 %). Expanding the existing seed banks to include all high-priority species for Luxembourg would increase the material available for translocations and allow their

ex-situ conservation. Collecting seeds in numerous donor populations and preparing them for storage under adequate conditions is important for maintaining the highest possible germination capacity.

Apart from translocations and other conservation measures, it is crucial to ensure the survival of species and the preservation of remaining wild populations. This can be achieved through various legal measures like the plant species protection regulation (Mémorial 2010), habitat protection within the framework of the Nature Conservation Act (Mémorial 2018) and inclusion in national nature reserves or Natura 2000 areas. The extensive management of open land habitats through nature conservation contracts is another way to conserve populations of species that are endangered by agricultural intensification and fallow land (Wolff et al. 2020). Numerous measures have already been implemented in recent years to achieve the goals laid down by the Plant Conservation Strategy for Luxembourg (Colling et al. 2022), the Strategy for the Conservation and Restoration of species-rich Grassland in Luxembourg (MECDD 2020), the National Plan for the Protection of Nature (MECDD 2023a) and by international guidelines and legal specifications (JOCE 1992, Botanic Gardens Conservation International 2012, Planta Europa Secretariat 2022). Nevertheless, the upcoming assessment of the threat status of plants (update of the Red List of the vascular plants of Luxembourg) will demonstrate that these efforts need to be intensified.

5. Strategies, research needs and collaborations to foster translocations

Based on our survey and detailed examples provided, translocations are a widespread and valuable practice to conserve species in Luxembourg. Conserving the existing populations of endangered species is of the highest priority. Nevertheless, the ongoing decline and loss of species must be actively counteracted through translocations and ex-situ cultivation, to an even higher degree than at present. To achieve this, the participation of all stakeholders is

crucial. A national prioritisation of target species is still lacking but should be developed. So far, translocations have largely focused on threatened species, but Critically Endangered species are underrepresented and should be given high priority in the future to prevent their rapid extinction, particularly those for which Luxembourg holds significant responsibility. The priority list should also include species for which Luxembourg has a particular international responsibility (Schnittler & Günther 1999). In Germany such a prioritisation already exists and is implemented by the ‘WIPsDe project’ (<https://www.wildpflanzenschutz.uni-osnabrueck.de>). Additionally, more widespread species that are characteristic of habitats currently being restored also need to be considered for translocation efforts. To achieve the goals of the national and European targets to restore habitats (MECDD 2023a, European Parliament 2024) and to increase the success of translocations and the long-term conservation of plant species, translocations need to be implemented more frequently and on larger scales. Therefore, a strategic plan and guidelines on the methods of the translocations and their monitoring for Luxembourg are needed, which are currently under discussion and preparation. Based on numerous experiences, the relevant factors for a successful establishment on a species-specific basis should be compiled in an international database and made available to all practitioners (Godefroid & Vanderborght 2011).

Even though more and more translocations are following international guidelines (e.g. IUCN/SSC 2013), a practical guide could help align translocations efforts in Luxembourg with these recommendations, thereby increasing their efficiency and success. For example, the number of plants translocated was often insufficient. It is also crucial to choose suitable sites for the translocations and take small-scale changes in site ecology into account. Testing the germination ability of the seeds produced by the established plants can help to assess the probability of recruitment and the overall success of translocations (Breit et al. 2023).

Furthermore, to provide the needed conservation efforts across the country and conserve species of specific habitats across all natural landscapes, it would be essential to increase translocation efforts in all regions. Thus, so far translocations have occurred to a large extent in the southwest of Luxembourg. A systematic monitoring of transplant survival over at least ten years should ideally be implemented, including recording the recruitment of new plants to assess success. Allocating sufficient budget for comprehensive, long-term monitoring is essential.

In general, understanding the factors behind the success or failure of the translocations is key to improving their success. Designing translocations as experiments to investigate these factors, and to explore fundamental aspects of species ecology and biology could serve this purpose. Ecological research experiments are thus crucial to strengthen the body of knowledge on local conservation actions and translocation science (Maschinski et al. 2023). Further research may also investigate the genetic variations in populations of endangered plants to ensure a high adaptive potential of plant populations and conserve endangered populations. Furthermore, the type of translocation (reinforcement, introduction or reintroduction), the source sites of the seeds or the plant material and the monitoring result should be documented in a national database (Godefroid & Vanderborcht 2011), which currently for Luxembourg is the Recorder LUX database (MnhnL). Seed collection sites also need to be entered in the national database of the seed bank (BGBase of MnhnL).

The Plant Conservation Strategy for Luxembourg presents a variety of measures to contribute to the conservation of plants species (Colling et al. 2022). To achieve its goals, facilitating the transfer of expertise between actors by strengthening the network of translocation practitioners in Luxembourg would be key. Gathering practitioners into a network has proven to be useful to exchange experiences in many cases (e.g. 'Netzwerk Renaturierung', <https://renaweb.standortsanalyse.net>) and to strengthen ecological research during conservation actions (Abeli

& Dixon 2016). Moreover, conservation practitioners should collaborate in a trans-regional network to increase the connectivity of habitats of natural and translocated populations of rare plants at a larger scale. Cooperations within the Greater Region could be highly valuable for using source material from neighbouring regions for nearly extinct species or species whose local populations are not suitable sources for the translocations.

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