VKM Report 2021: 15

Assessment of possible adverse consequences for biodiversity when planting vascular plants outside their natural range in Norway

Scientific Opinion of the Panel on Alien Organisms and Trade in Endangered species (CITES) of the Norwegian Scientific Committee for Food and Environment

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Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of three VKM members, one external expert and a project leader from the VKM secretariat. Two external referees commented on and reviewed the draft opinion. The VKM Panel on Alien Organisms and Trade in Endangered Species (CITES) evaluated and approved the final opinion.

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The authors have contributed to the opinion in a way that fulfils the authorship principles of VKM (VKM, 2019). The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group and/or the VKM Panel on Alien Organisms and Trade in Endangered Species (CITES).

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Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

VKM highlights that the first author, Anders Nielsen, holds a senior position at the Norwegian Institute of Bioeconomy Research (NIBIO) which is a producer of local seeds for commercial sale. VKM has concluded that there is no conflict of interest in this regard.

Table of Contents

Summary 9
Sammendrag 13
Glossary 16
Background as provided by the Norwegian Environment Agency 20
Terms of reference as provided by the Norwegian Environment Agency 22
1 Introduction 24
1.1 What is 'local' (*stedegen*)? 27
1.1.1 How genetically distinct are local populations? 30
1.2 The choice of local over nonlocal plant populations: consequences for biodiversity 35
1.2.1 Advantages of using local plants and seeds 35
1.3 Composing and producing seed mixes 37
1.3.1 Seeds harvested from local meadows 38
1.3.2 Mix of native seeds from different localities inside or outside the region 38
1.3.3 Seed mixes from seed producers 38
1.3.4 Seeds of alien species 39
1.4 Species found in seed mixes currently available in Norway 39
1.5 Traits affecting the invasiveness of vascular plants 40
1.6 Regulations regarding planting vascular plants outside their natural ranges 42
1.6.1 In Norway 42
1.6.2 In the EU 43
1.6.2.1 EU-specific regulations 43
1.6.2.2 France 44
1.6.2.3 Germany 44
1.6.2.4 Austria 45
1.6.3 Beyond Norway and the EU 45
2 Where, why, and how are vascular plants used? 46
2.1 Revegetation and restoration in rural areas 46

2.1.1 Flower meadows – semi-natural grasslands 46
2.1.2 Flower strips on agricultural land..47
2.1.3 Road verges and airfields 47
2.1.4 Mountain cabin areas 49
2.1.5 Hydroelectric power dams, quarries and military training facilities 51
2.2 In urban areas 52
2.2.1 Storm water retention systems 52
2.2.2 Green roofs 53
2.2.3 Gardens and parks 54
2.3 Restoration, rehabilitation, and revegetation..55
2.3.1 Natural revegetation..56
2.3.2 Reusing local soil 57
2.3.3 Transplantation...58
2.3.4 Seeding and planting..60
2.4 The Norwegian pollinator strategy 62
3 Considerations when planting out vascular plants......................................64
3.1 Reproductive strategy 64
3.1.1 How is the species pollinated? 64
3.1.2 What is the species dispersal strategy?...65
3.1.2.1 Vegetative propagation...67
3.1.2.2 Seed dispersal..68
3.2 Geographic considerations...70
3.3 Biological considerations regarding planting of vascular plants 71
3.3.1 Is the species reported to be invasive, weedy, or otherwise problematic in Norway?.......71
3.3.2 Is the species native to the region? 71
3.3.3 Is the species very patchily distributed within the region?.............................72
3.3.4 Ploidy level variation...72
3.3.5 Known hybridization issues? 73
3.4 Flow chart for identifying potential hazards before planting vascular plants 74

3.4.1 Criteria used on a commercially available seed mix 75
4 Literature and Data 78
5 Conclusions (with answers to the terms of reference) 79
6 Knowledge gaps 82
References 83
Appendix I 93
When is local sourcing not "best"? 93
On seed provenancing strategies 96
Concluding remarks 97

Summary

We sow or plant vascular plant species on a large scale in revegetation and restoration projects in Norway today. Some of the species used are already found in Norway, but many of the species, subspecies or populations used though native are not local, that is, they are *regionally alien*. A regionally alien species is a species that is native to Norway (has been in Norway since 1800) somewhere in the country, but which has been spread by humans to places in Norway where they do not occur. In theory, and according to the Biodiversity Act, it is desirable to use local seeds or plants to preserve local biodiversity.

The aim of this report is to define guidelines that helps prevent the planting of vascular plant species with a high potential for negative effects on local biodiversity. It is assumed that the native or local populations are better adapted to local environmental conditions than populations from other areas or regions, and the risk of harmful genetic changes is therefore considered small when using local plant and seed sources. Arriving at a common definition for the area within which plants are "local" is difficult, though; vascular plant species are numerous (3317 species in mainland Norway, of which more than half are alien species introduced after 1800, Artdatabanken 2015), have different growth forms, different environmental requirements, and different reproductive and dispersal ecology. Even closely related vascular plant species can differ in such characteristics and hence in the extent of the "place" or "area".

The dispersal ecology of a plant species is of great importance for whether the species has genetically distinct populations within its range or not. Different strategies (wind pollination vs. insect pollination, vegetative propagation vs. seed dispersal, large seeds vs. small seeds) have an impact on the degree of gene flow between populations and thus also how locally adapted the species is in different areas. Whether the species has primarily vegetative reproduction or whether it spreads mainly by means of seeds, and whether the seed dispersal takes place ballistically, with wind or water, or by zookori (attached to animals or eaten by animals) determines how far the species can spread and how large gene flow there is between different populations. Whether the species is pollinated by wind or by the help of insects also affects the degree of gene flow differently.

In Norway, there is great variation in many biophysical and ecological conditions (climate, topography, hydrology, and geology) over relatively short distances. This means that species that grow only a few meters apart can grow under different environmental conditions. This large variation in environmental conditions - on different spatial scales - can give rise to local

genetic adaptation. However, plants have been moved around the landscape for several hundred years by our livestock (as seeds in fur and hooves, and in faeces) from lowland pasture to mountain pasture and along traffic arteries across the country due to the extensive transport of animals and people. Over time, this has led to expanded geographical distribution for several species and increased gene flow between populations over relatively large distances.

There are few detailed studies from Norway that document how genetically similar or different various vascular plant species are over different distances in different regions of the country. Jørgensen et al. (2016) divide the mountain areas in Norway into four sectors, based on genetic studies of eight selected mountain plant species. For most other vascular plant species, the degree of gene flow between populations to date is largely unknown. The knowledge base for possibly proposing such regions for most Norwegian plant species is thus not present. Other countries have taken a more pragmatic approach to this challenge. In the United Kingdom, seed collection is defined as "local" if it occurs within a distance of 8 km from the sowing or planting area, while in Western Australia, 15 km is used as the limit for what is considered "local".

Regardless of the purpose and method for planting or sowing, it is desirable that one can readily identify species that can be used without further risk assessment, in order to preserve or restore biodiversity in areas where revegetation or restoration is to be carried out. An identification of species that are "safe" and species that require their own risk assessment must be based on defined criteria, using selected traits such as the plants’ ecological requirements, propagation method and dispersal strategy, traits from which contribute significantly to a species' genetic structure. By using predetermined criteria one can assess the risk that a vascular plant species will have a negative impact on biodiversity locally and regionally at population, species or habitat type level. Unfortunately, these characteristics do not follow the taxonomic classification of plant species to any great extent. Several species that are considered to be problematic in Norway also have characteristics that, objectively speaking, should indicate that they were unlikely to carry a high risk when transplanting. It is therefore not possible to construct a universal set of criteria based on the taxonomic affiliation or on characteristics of the species, such as dispersal ecology. We have therefore chosen to describe a set of properties for plants that can be potentially problematic, based on typical features of invasive plant species. For many species, there is generally available knowledge that can give an indication of whether the species could lead to problems with sowing, transplanting or planting. If this knowledge is lacking, or indicates that the species may be problematic, we have identified aspects that must be risk assessed.

We define five criteria (points 1, 2 and 5 at the species level and points 3 and 4 at the population level) that can be used to determine which species and populations should not be used as a source for sowing or planting, which should be risk assessed and which can be considered acceptable for sowing and planting in a given area:

1. Is the species problematic? It may be that the species is registered as invasive in other countries, or as a regionally alien species that creates problems in ecosystems outside its natural range or in habitats other than where it usually occurs (without creating problems), or that the species is considered a ”weed". These species are not very suitable for use, although they may have desirable properties (e.g., prevent erosion, bind carbon or increase the flower resources of pollinating insects). Examples of such species are cock’s foot or orchard grass (*Dacytlis glomerata*) and couch grass or quack grass (*Elymus repens*).
2. Does the species to be sown or planted occur naturally within a 10 km radius from the intervention site? If the species does not already exist locally, a complete ecological risk assessment must be carried out.
3. Does the species have very dispersed populations within its natural range or distinct ecotypes (local adaptations)? If the species has very dispersed populations at the regional level, it is more likely that it will have a genetic structure that makes it highly locally adapted. In extreme cases, these can be seen as ecotypes or subspecies with distinct local adaptation. A risk assessment must then be made as to whether the introduction of new genes will have a negative impact on the species in the planting area.
4. Are there different ploidy levels within the species? By mixing different ploidy levels, the species can become less locally adapted. If the species has differences in ploidy levels, an ecological risk assessment must be made for the species within the relevant area. Examples of such species are harebell (*Campanula rotundifolia*) and oxyeye daisy (*Leucantemum vulgare*).
5. Is the species known to hybridize with other species? If the species hybridizes with other species, an ecological risk assessment must be made with regard to the negative effects of the hybridization on native species with which it can potentially cross. Common kidneyvetch (*Anthyllis vulneraria*) and Bird’s-foot trefoil (*Lotus corniculatus*) are examples of such species in Norway.

Species that are not defined as invasive or problematic in other ways and that already exist in the region should in principle be considered safe to plant out if you use local individuals or seeds, if the populations are not very dispersed, there is no difference in ploidy levels and there is no danger of hybridization with other species in the area.

Key words:

Climate change · Ecological restoration · Gene flow · Genetic diversity · Habitat fragmentation · Inbreeding · Local seeds · Local adaptation · Native seeds · Outbreeding depression · Plant genetic resources · Regional adaptation · Region of origin · Rehabilitation · Revegetation · Seed biology · Seed collection · Seed mixture · Seed provenance · Seed sourcing strategy · Seed transfer zones · Site-specific seeds

Sammendrag

Vi sår eller planter ut karplantearter i stor skala i revegeterings- og restaureringsprosjekter i Norge i dag. Flere av artene som brukes finnes allerede i Norge, men mange av artene, underartene eller populasjonene som brukes er ikke *stedegne* (*lokale*), dvs. de er *regionalt fremmede*. En regionalt fremmed art er en art som hører hjemme i deler av landet, dvs. at den har vært der siden 1800, men som har blitt spredt av mennesker til andre steder i Norge der de ikke hører hjemme. I teorien, og ifølge Naturmangfoldloven, er det ønskelig å benytte lokale frø eller planter i revegeterings- og restaureringsprosjekter for å bevare det lokale biologiske mangfoldet.

Målet med rapporten er å definere retningslinjer som forhindrer utplanting av karplantearter med høyt potensiale for negative effekter på lokalt biomangfold. Man antar at de stedegne populasjonene er bedre tilpasset lokale miljøforhold enn populasjoner fra andre regioner, og anser derfor at det er liten fare for skadelige genetiske endringer ved bruk av lokale planter og frø. Det finnes 3317 karplantearter i fastlands-Norge, hvorav mer enn halvparten er fremmede arter som er innført etter 1800 (Artsdatabanken 2015). Å definere hva som menes med stedegen for enkeltarter eller grupper av karplanter er vanskelig fordi karplanteartene har ulike vokseformer, ulike krav til miljø og klima, og ulik spredningsøkologi. Selv nært beslektede karplantearter kan ha relativt forskjellige karaktertrekk (f.eks. spredningsformen, vekstformen), som gjør at størrelsen på «stedet» varierer.

Spredningsøkologien til en planteart har stor betydning for om arten har genetisk distinkte populasjoner innenfor sitt utbredelsesområde. Ulike strategier (vindbestøvning vs. insektpollinering, vegetativ formering vs. frøspredning, store frø vs. små frø) har innvirkning på graden av utveksling av gener (genflyt) mellom populasjoner og derved også på hvor lokalt tilpasset arten er i ulike områder. Om arten primært har vegetativ formering eller om den sprer seg hovedsakelig ved hjelp av frø, og om frøspredningen foregår ballistisk, med vind eller vann, eller ved zookori, dvs. festet på dyr eller spist av dyr, avgjør hvor langt arten kan spre seg og hvor stor genflyt det er mellom ulike populasjoner. Om arten pollineres med vind eller ved hjelp av insekter innvirker også på graden av genflyt.

I Norge er det svært stor variasjon i en rekke biofysiske og økologiske forhold (klima, topografi, hydrologi, og geologi) over relativt korte avstander. Dette fører til at arter som vokser kun noen få meter fra hverandre kan vokse under svært ulike miljøforhold. Denne store variasjonen i miljøforhold - på ulike romlige skalaer - kan gi opphav til lokale genetiske

tilpasninger. Planter har imidlertid også, i flere hundre år, blitt transportert rundt i landskapet av våre husdyr (frø i pels, klauver/hover og i avføring) fra lavlandsbeite til fjellbeite og langs ferdselsårer på tvers av landet pga. transport av dyr og folk. Dette har over tid ført til utvidet geografisk utbredelse for flere arter og økt genflyt mellom populasjoner over relativt store avstander.

Det finnes få studier fra Norge som dokumenterer hvor genetisk like eller ulike forskjellige karplantearter er over ulike avstander i forskjellige regioner av landet. Jørgensen m.fl. (2016) deler fjellområdene i Norge i fire sektorer, basert på genetiske studier av åtte utvalgte fjellplantearter. For de fleste andre karplantearter er graden av genflyt mellom populasjoner stort sett ukjent. Kunnskapsgrunnlaget for eventuelt å foreslå slike regioner for de fleste norske planteartene er altså ikke til stede. Andre land har tatt en mer pragmatisk holdning til denne utfordringen. I Storbritannia definerer man frøsamling som "lokal" hvis den skjer innenfor en avstand på 8 km fra utsåings- eller utplantingsområdet, mens i Vest-Australia bruker man 15 km som grense for hva man anser som «lokalt».

Uavhengig av hensikt og metode for utplanting eller utsåing, er det ønskelig at man enkelt kan identifisere arter som kan benyttes uten videre risikovurdering for å bevare eller gjenskape biomangfoldet i områder der inngrep eller restaurering skal utføres. En identifisering av arter som er «trygge» og arter som krever egen risikovurdering må baseres på definerte kriterier (utvalgte planteegenskaper), som plantenes økologiske krav, formeringsmetode, spredningsstrategi samt egenskaper som bidrar til å definere artens genetiske struktur. Ved å bruke forhåndsbestemte kriterier kan man vurdere risikoen om karplantearten vil ha negativ innvirkning på biomangfoldet lokalt og regionalt på populasjons, arts- og naturtypenivå. Dessverre følger disse egenskapene i liten grad den taksonomiske klassifiseringen av plantearter. Flere arter som anses for å være problematiske i Norge innehar også egenskaper som, objektivt sett, skulle tilsi at de har liten sannsynlighet for å medføre høy risiko ved utplanting. Det er derfor ikke mulig å konstruere et universelt kriteriesett som baserer seg på artenes taksonomiske tilhørighet eller egenskaper, som for eksempel spredningsøkologi. Vi har derfor valgt å beskrive et sett med egenskaper for planter som potensielt kan bli problematiske, basert på typiske trekk ved invaderende plantearter. For mange arter finnes det allment tilgjengelig kunnskap som kan gi en indikasjon på om arten vil kunne føre til problemer ved utsåing/utplanting. Hvis denne kunnskapen mangler, eller hvis kunnskapen tilsier at arten kan bli problematisk, har vi identifisert aspekter som må risikovurderes.

Vi definerer fem kriterier (punkt 1, 2 og 5 på artsnivå og punkt 3 og 4 på populasjonsnivå) som kan benyttes for å komme frem til hvilke arter og populasjoner som ikke bør brukes for utplanting, hvilke som bør risikovurderes og hvilke som kan godkjennes for utplanting i et gitt område:

1. *Er arten problematisk?* Det kan være at arten er registrert som invaderende i andre land, eller som en regionalt fremmed art som skaper problemer i økosystemer utenfor sitt naturlige utbredelsesområde eller i andre habitater enn der den vanligvis forekommer (uten å skape problemer), eller at arten regnes som «ugress». Disse artene er det lite hensiktsmessig å benytte selv om de kan ha egenskaper som er ønskelige (f.eks. for å forhindre erosjon, binde karbon eller øke blomsterressursene for pollinerende insekter). Eksempler på slike arter er kveke og hundegress.
2. *Forekommer arten som skal plantes naturlig innenfor en 10 km radius fra utplantingsstedet?* Hvis arten ikke allerede finnes lokalt, må det gjennomføres en fullstendig økologisk risikovurdering.
3. *Har arten veldig spredte populasjoner innenfor sitt naturlige utbredelsesområde eller distinkte økotyper (lokale tilpasninger)?* Om arten har veldig spredte populasjoner på regionalt nivå er det større sannsynlighet for at den vil ha en genetisk struktur som gjør den sterkt lokalt tilpasset. I ekstreme tilfeller kan dette ses som økotyper eller underarter med særskilt lokal tilpasning. Det må da gjøres en risikovurdering på om innføring av nye gener vil ha en negativ innvirkning på arten i utplantingsstedet.
4. *Har arten forskjellige ploidinivå (kromosomtall)?* Ved blanding av ulike ploidinivå kan arten bli mindre lokalt tilpasset. Om arten har forskjeller i ploidinivå må det gjøres en økologisk risikovurdering for arten innenfor det aktuelle området. Eksempler på slike arter er blåklokke og prestekrage.
5. *Er arten kjent for å hybridisere med andre arter?* Om arten hybridiserer med andre arter må det gjøres en økologisk risikovurdering med hensyn på negative effekter av hybridiseringen på stedegne arter den potensielt kan hybridisere med. Rundbelg og tiriltunge er eksempler på slike arter i Norge.

Arter som ikke blir definert som invaderende eller problematiske på andre måter og som allerede finnes i regionen, bør i utgangspunktet kunne betraktes som trygge å plante ut, om man bruker lokale individer eller frø, om populasjonene ikke er veldig spredt, det ikke er forskjell i ploidinivå og det ikke er fare for hybridisering med andre arter i området.

Glossary

Alien species	A species, subspecies, or lower taxon that occurs outside of its natural range (past or present) and dispersal potential (i. e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce (IUCN guidelines for the prevention of biodiversity loss caused by alien invasive species, 2000.) In the context of Norway and Norwegian sites, a species that does not occur naturally in Norway. (Compare: Invasive alien species, Regionally alien.) (Synonyms used by others: non-native, non-indigenous, foreign, exotic)
Anadromous fish	Fish with life cycles that alternate between fresh water (for reproduction) and salt water (mostly for growth), such as shad (e.g., Allis shad, *maisild*) and most species of salmon.
Gene flow	A term from population genetics, referring to the spread of genetic material (genes, chromosomes) from one population to another. In plants, gene flow results from interpopulational spread of either pollen or seeds.
Genetic structure	A term from population genetics, used to refer to the degree of genetic differentiation among populations of a species. The more distinct that populations are from each other, the more genetic structure there is in that species.
Intraspecific hybridisation	Within-species hybridisation between individuals stemming from genetically distinct populations.
Introgression	The spread of genetic material from one species into another via mating of interspecific hybrids with a parent species.
Invasive alien species	Species whose introduction and spread by human action outside their natural distribution threatens biodiversity, food security. "Alien" refers to the species having been introduced outside its natural distribution ("exotic", "non-native" and

	"non-indigenous" are synonyms for "alien" used by others). "Invasive" means tending to expand into and harm ecosystems to which it has been introduced. A species may be alien without being invasive.
Keystone species	A species that has impacts on many species in the ecosystem, impacts that are often far beyond what would be expected based on abundance or biomass of the species.
Local	Local populations are ones that occur or would naturally occur in the immediate vicinity of a site.
Local adaptation	Plants are locally adapted if they have higher fitness in their own environment than would nonlocal plants of the same species. Important adaptations that might differ among populations include phenological characteristics (when a seed germinates, when a plant flowers, and so forth) as well as features affected by soil conditions, climate, or interactions with other organisms—all of which could favour 'local' adaptations that differ from those of distant populations of the same species.
Native species	Indigenous species of animals or plants that naturally occur in a given region or ecosystem. (IPBES Glossary). In the context of Norwegian sites, native species are ones that occur naturally somewhere in Norway, and have done so since at least AD 1800.
Nonlocal	Refers to populations in Norway that are outside of their native range in Norway (see "regionally alien").
Norwegian nature	Includes any part of Norway that is outdoors (including strongly altered nature) as well as native species that occur there. For production species, their production area is not considered Norwegian nature.
Outbreeding	Any mechanism ensuring mating with unrelated individuals.
Outcrossing	Pollination between different individuals of the same species.

Phenotype	The observable traits of an individual organism. Traits of an individual are a product of both genes and environment.
Phenotypic plasticity	A trait that can change adaptively during an individual's lifetime depending on the environmental conditions being faced. For example, leaf shape and leaf size are often influenced by whether a leaf is in the sun or in the shade, and hence exhibit phenotypic plasticity.
Phytoremediation	The use of plants to rehabilitate soils damaged by pollution (such as heavy metal contamination).
Precautionary principle	A principle that enables decision-makers to adopt precautionary measures when scientific evidence about an environmental or human health hazard is uncertain and the stakes are high.
Provenance	Source, as in seed provenance (meaning where the seeds originated)
Plant material(s)	A collective term for any plant parts (or whole plants) that are used for revegetation; in most cases, what is used is seeds or entire plants.
Regionally alien	Regionally alien populations are populations of species that are native to Norway but which have been introduced to novel areas within Norway by humans (Norwegian Biodiversity Information Centre).
Rehabilitation	Rehabilitation refers to restoration activities that move a site towards a natural state baseline in a limited number of components (i.e. soil, water, and/or biodiversity), including natural regeneration, conservation agriculture, and emergent ecosystems. (IPBES glossary)
Restoration	Any intentional activities that initiates or accelerates the recovery of an ecosystem from a degraded state. (IPBES glossary)

Seed transfer zones	A geographic term referring to a region within which it should be safe to transfer seeds (or other plant material) and within which seeds are adapted to climatic and soil conditions.
Ecosystem rehabilitation	Repair and replace the essential or primary ecosystem structures and functions which have been altered or eliminated by disturbance. Repair of an area irrespective of ecological, aesthetical, practical or some other objective.
Ecological restoration	The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.
Restoration ecology	The scientific framework that ecological restoration is based on. Restoration ecology is multi-disciplinary and contains both biological and physical aspects of the ecosystem, as well as conditions related to human social and economic benefit.
Revegetation:	The vegetation phase of an ecological restoration or rehabilitation. Revegetation is most used to describe how a new vegetation cover may be established, often with focus on appearance or form. But the concept is also used about the vegetation part of an ecological restoration.
Weedy plant species:	A weed is a plant considered undesirable in a particular situation, "a plant in the wrong place". The term weed also is applied to any plant that grows or reproduces aggressively, or is invasive outside its native habitat. Taxonomically, the term "weed" has no botanical significance, because a plant that is a weed in one context is not a weed when growing in a situation where it is in fact wanted, and where one species of plant is a valuable crop plant, another species in the same genus might be a serious weed.

Background as provided by the Norwegian Environment Agency

The goal for the management of species under the Nature Diversity Act is that the species and their genetic diversity are preserved in the long term and that the species occurs in viable populations in their natural range of propagation. As far as is necessary to achieve this goal, the species' ecological functional areas and the other ecological conditions on which they depend are also safeguarded. Section 3 (e) of the Nature Diversity Act defines a species or population as alien when it does not occur "naturally" on the site. The word organism, according to the preparations for the provision, is chosen instead of species, because the term is linked to release, i.e., planting or sowing, and not only includes species, but also subspecies, stocks and populations.

The preparations further emphasize that in order to preserve genetic diversity within a species it is often necessary to protect subspecies and genetically diverse populations from introductions of alien organisms of the same species, cf. Section 5 of the Nature Diversity Act which states that "*The objective is to maintain species and their genetic diversity for the long term and to ensure that species occur in viable populations in their natural ranges. To the extent necessary to achieve this objective, areas with specific ecological functions for different species and other ecological conditions on which they are dependent are also to be maintained.*"

Several provisions of the Nature Diversity Act and regulations on alien organisms apply specifically to "alien organisms" as defined above or to an "organism that does not belong to a subspecies, stock or population that occurs naturally in an area". Therefore, in order to apply the provisions to plants that have their natural range in Norway, it is necessary to have knowledge of the plants in question belong to the same population as the one present or not. Where the plants belong to a different population than the one present on the site, one must assess whether there is reason to believe that the planting poses any risk to the population on site.

Understanding the concepts of biodiversity, species and genetic variation etc. must then be in accordance with the use and purpose of Sections 3 and 5 and Chapter IV of the Nature Diversity Act, as well as related regulations.

The Agency will use the results in case management and other measures under the Norwegian national regulation on alien organisms. This will, among other things, be relevant when assessing exemptions on permit requirements and the need for risk assessment, cf. Regulations on alien organisms § 11. This report will further also be relevant with respect to the measures outlined in the proposed Action Plan Against Invasive Alien Organisms and the National Pollinator Strategy.

Terms of reference as provided by the Norwegian Environment Agency

The Norwegian Environment Agency requests VKM to develop criteria for classification by overall assessment of possible adverse effects on biodiversity when planting and sowing vascular plants that occur naturally in Norway, i.e., plants belonging to species, subspecies or populations that do not already occur naturally in the district, into the environment. VKM should develop criteria that make it possible to identify species and higher taxa of vascular plants that occur naturally in Norway that pose little risk to biodiversity when planted in Norway outside the individual species' - or population's range. At the same time, the criteria should be used to identify when risk assessments on species- level or for higher taxa are needed when the individuals to be transplanted from a different stock than the one that occurs naturally at the site of planting.

The criteria should cover groups of vascular plants with different biological properties, including various types of adaptations to pollination (wind, insects etc.), adaptation to seed dispersal, vegetative propagation and different ploidy levels. Considerations to be taken will be relevant to possible risk related to hybridization (outcrossing, outbreeding), a relatively high increase in the competitiveness of hybrid specimens relative to endangered species on site, but also reestablishment measures or measures aimed to prevent inbreeding depression.

The Norwegian Environment Agency further requests VKM to propose suitable documentation for the classification and assessment of risk according to these criteria and to identify a representative selection of species in seed mixtures or similar that are commercially available for various types of use by different sectors. Relevant examples include grass roofs, green roofs/living roofs (stonecrops), transport as well as relevant measures in various protected areas and endangered habitats, and measures relevant to the proposed Action Plan Against Invasive Alien Species and the National Pollinator Strategy (hereafter referred to as the 'pollinator strategy report'). The selection is made in consultation with the Agency.

Demarcation

The study and the criteria shall not include Norwegian tree species, cf. Section 31 of the Nature Diversity Act, which is exempt from the requirement for permission when released pursuant to the Norwegian Regulations on Alien Organisms Section 3, second paragraph, letter b.

1 Introduction

Large scale seeding and planting of vascular plants, other than for the production of food, feed and fibre, usually serve one of two main purposes: revegetation of disturbed land with species which would have been present historically, *restoration*, or planting of species that are best able to revegetate seriously disturbed sites, *rehabilitation* (see Figure 1-1). Certain plants may be introduced to restore endangered nature types or strengthen populations of vulnerable and threatened species (Espeland et al. 2017). Vascular plants are also sown or planted in order to enhance vegetation cover, contribute to water retention, reduce erosion, as food sources for important pollinators, and as shelter for a wide variety of animals—or simply to beautify. Selected species can also be used to rehabilitate polluted or toxic soils through phytoremediation (Yan et al. 2020). The introduction of selected plant species to an area may therefore be conducted for a wide variety of reasons.

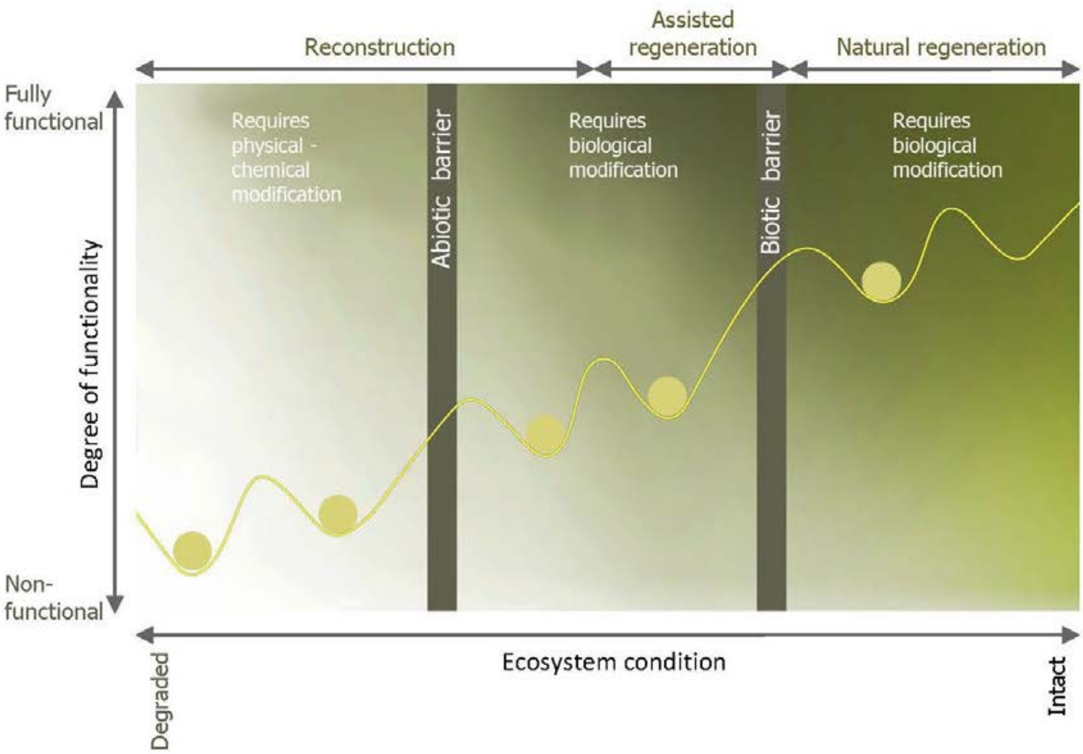


Figure 1-1: Conceptual model of ecosystem degradation and restoration. Redrawn after SERA 2016.

Ecosystems are degraded through conversion, over-exploitation, pollution and other impacts. Restoration efforts are therefore more critical than ever, and we have now entered the U.N. Decade of Ecosystem Restoration (2021–2030). Restoration efforts aim to restore 350 million hectares globally, leading to unprecedented demands for reliable and sustainable supplies of native seeds and plants (Pedrini and Dixon 2020). As most restoration projects require large amounts of seeds, the global push to achieve ecosystem restoration targets has resulted in demands that cannot be met by relying solely on wild resources (Merritt & Dixon 2014), and current production systems are not able to fulfil this need. Sixty-six countries now have seed banks for native plant conservation (Convention on Biological Diversity 2014); nonetheless, the availability of seed material for restoration efforts is limited (Bekessy et al. 2010, Aamlid et al. 2010, Erickson and Halford 2020). Seed farming of native plant species will be crucial to meet restoration goals but may be hampered by the lack of effective policies that regulate native seed production and supply.

Besides the growing demand for plant materials for restoration, there is also a need for plants in ecosystem rehabilitation. According to the Society for Ecological Restoration standards, ecological restoration aims to "achieve ecosystem recovery, insofar as possible and relative to an appropriate local native model (termed here a reference ecosystem)", while rehabilitation focuses on the restoration of ecosystem functions, "without seeking to also recover a substantial proportion of the native biota" (McDonald et al. 2016).

The type of environmental repair efforts and their goals will determine the optimal seed supply criteria (Dupré la Tour et al. 2020). To what degree one should prioritize "local" seed sources can vary depending on whether the overarching goal is restoration (often, "as local as possible") or rehabilitation, where "local" could be subordinate to finding species most effective at providing the desired ecosystem functions.

Our assignment is to develop a method for assessing the risk for adverse effects on biodiversity when planting and sowing Norwegian vascular plants that – as species, subspecies or populations – do not already occur naturally at the target site. Norway's Nature Diversity Act, §3 defines biological diversity as "the diversity of ecosystems, species and genetic variations within the species, and the ecological connections between these components." With respect to species biodiversity, 4,458 plant species are known from Norway (Artsdatabanken 2021a). Roughly ¾ are vascular plants and a little under half of these are flowering plants (angiosperms: Magnoliophyta). However, more than half of the vascular plants that are established in Norway are alien species (Artsdatabanken 2021b).

Nonlocal plant materials are often used for repairing an area by providing plant cover or other ecosystem functions, such as pollination, water retention, erosion control, insolation of buildings with grass roofs or living roofs, or simply visually pleasing scenery. The potential adverse effects of using nonlocal plants for such purposes can be both ecological, such as introducing poorly adapted or overly successful nonlocal plants, and genetic, such as diluting local ecological or genetic adaption of current or nearby native populations when introducing genes from distant populations.

In this report we are concerned with large-scale, non-agricultural plantings of Norwegian species of vascular plants: for seeding or planting bare ground that results from land-use change; for establishing or renewing plant communities on roadsides (verges) and rooftops (living roofs, green roofs); or for creating new flower meadows. Commercially available mixes are commonly used for seeding. Commercially available vegetation mats (*blomsterengmatter*) and *Sedum* (stonecrops, *bergknapp*) are used instead of seeding for purposes, such as living roofs, living walls or flower meadows. In most instances, plant materials used are not from populations in the immediate surroundings (i. e., not 'local') of the restoration or revegetation site. This includes species from "the Norwegian official list of varieties" (Mattilsynet 2020). The list only shows the varieties eligible for certification in Norway, and not whether they are of native, local or foreign origin.

In the remainder of the Introduction, we will address the problem of defining "local" and elaborate on possible adverse effects from using plants from "nonlocal" sources. We finally present a scheme to decide whether risk assessment is needed in regard to different criteria for the use of local or nonlocal plants (also referred to as regionally alien plants in this report). Although a main use of commercial seeds and living plants in Norway is for gardening, the choice of plants or plant sources for private gardens is only indirectly regulated by the government (see 1.6.1 below) in the sense that some species are prohibited (Appendix V in Regulations about alien organisms). Therefore, any risks to biodiversity that might be associated with gardens are outside the scope of this report.

There can be good reason to encourage conservation translocation (for example transplanting of species that will be threatened by climate change or by the hazards of inbreeding due to being in too small populations) or other means of seed provenancing. In the main text of this assessment, we do not discuss in detail whether or not to encourage use of what currently are regionally alien species. This is instead covered in Appendix 1.

1.1 What is 'local' (*stedegen*)?

The 1992 Convention on Biological Diversity marked an institutionalization of biodiversity as a political and a societal issue. Its definition of biodiversity includes genetic diversity, thus establishing diversity within species as a conservation issue separate from the problems of inbreeding depression in that context (Sackville Hamilton 2001, Ralls et al. 2017). Emphasizing genetic diversity in conservation is now a central research agenda in restoration ecology. The idea of favouring plant material of local origin for ecological restoration has developed in this context of institutionalization of the conservation of genetic diversity (Broadhurst et al. 2008; Jones 2013, Breed et al. 2018, Dupré la Tour et al. 2020)

In order to discuss what is "local" we need to place this term in the context of the native and alien dichotomy. Species that occur in Norway, but which are not native, are found on the Alien Species List (2018) of the Norwegian Biodiversity Information Centre (*Artsdatabanken*). Alien species are species that occur outside their natural range, hence, outside the area where the species can spread naturally without the help of humans. This includes all species that have been dispersed outside their natural range by human activity, intentionally or unintentionally.

Data relevant for Norway are largely limited to collections and observations from the beginning of the 19th century (Gederaas et al. 2007). Gederaas et al. (2007) address the problem of classifying species as native or alien, and considered alien species to be those species that have arrived in Norway during the last 200 years: native species, then, being any that have been in Norway for 200 years or more. With this definition, native roughly corresponds to the terms "home-bound species" (*heimlege artar*) in Lid & Lid (2005) and alien to "neophyte" in Fremstad & Elven (1997).

In their risk analysis of invasive alien species in Norway, Gederaas et al. (2007) identified seven groups of species that could be considered alien:

1. Species that were deliberately released into the wild.
2. Species that have spread from captivity, cultivation or commercial activities.
3. Species that have arrived as stowaways during transport of animals, plants, goods, and humans.
4. Species that have spread from wild populations in neighbouring countries where the origin is due to (1), (2) or (3).
5. Species that must have been spread by human activities, but where their history is unknown or uncertain.

6. Norwegian (native) species that have spread to new areas of Norway as a result of human activity.
7. Cultivated native species dispersed by humans within Norway.

With respect to (6), some species are categorized as "regionally alien" in Norway; these occur naturally in parts of the country but have been spread by humans to places in Norway where they do not occur naturally. They are native to Norway but have been introduced to new areas within Norway after 1800, as the term is defined by the Norwegian Biodiversity Information Centre. It follows that occurrences in the distribution area of the species (formerly or present) are registered as regionally native; occurrences outside the species' range and distribution potential are registered as regionally alien. Only in some cases are regionally alien species risk assessed. Which regionally alien species are to be assessed is decided by experts in dialogue with the Norwegian Biodiversity Information Centre and relevant governing bodies. For example, the fish species *Rutilus rutilus* naturally occurs in eastern Norway but has been released into lakes in Trøndelag, where *Rutilus rutilus* is thus considered a regionally alien species. No vascular plant species have been risk assessed so far with regards to being regionally alien and only 12 animal species have been so (Artsdatbanken 2021c).

Defining "local" is problematic. Discussions about suitable seed sources frequently emphasize "local" in a very narrow sense, often based on political boundaries, rather than hard evidence for the scale of adaptation (Broadhurst et al. 2008). Definitions vary from within a set of geographic distances to revegetation or restoration sites, to matching a set of ecological criteria between source and site (Breed et al. 2013, Massatti et al. 2020). Facing this problem in connection with the Endangered Species Act in the USA, conservation biologists approached the problem from a population genetics viewpoint, and have adopted the concept of evolutionary significant unit, where a local population is one that is "substantially reproductively isolated from other conspecific population units…" (Waples 1991), though the concept will not always be easy to apply given the vaguenss of "subtantial".

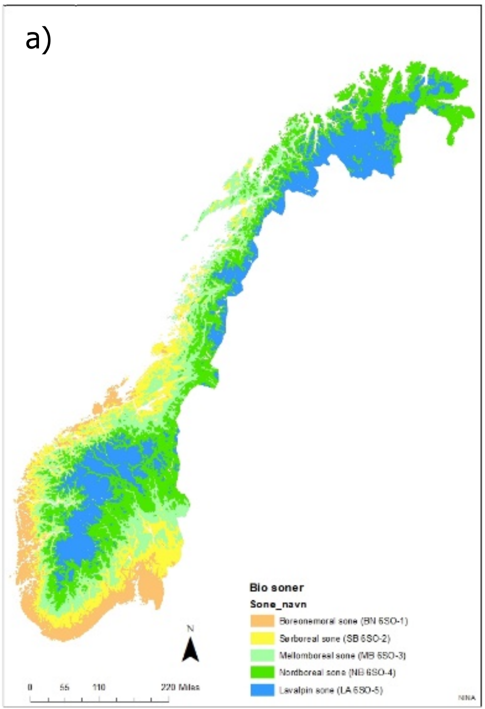
Local source areas delimited ecologically are referred to as "seed zones" or "seed transfer zones". The delineation of Britain into four provenance regions and smaller seed zones is based on accumulated summer heat, mean annual rainfall, ecological and physical boundaries (Hubert & Cundall 2006). The adjustment, within the same region, of seed zone size to account for species differences in scales of adaptation and relationships to climatic factors, such as in the north-west USA (Johnson et al. 2004), is rare. In Australia no such boundaries exist, but application of the precautionary principle regarding seed movement prevails and quarantine regulations limit the unrestricted movement of germplasm between some states. In other instances, set geographic distances (radii) are proposed for seed zones, and seeds (or other plant material) must be collected from within a certain distance from the target site: guidelines from English Nature, for the United Kingdom, recommend that plant material be collected from within 5 miles (8 km) of the revegetation site, while the Western Australian Forest Management Plan 2004–2014 uses a radius of 15 km (Broadhurst et al. 2008). A more relaxed local provenancing prescribes collecting seeds in a fashion that is biased towards certain ecological criteria, e.g., like soil type, altitude and climate, and avoids small population fragments, as done by the Australian FloraBank (Broadhurst et al. 2008).

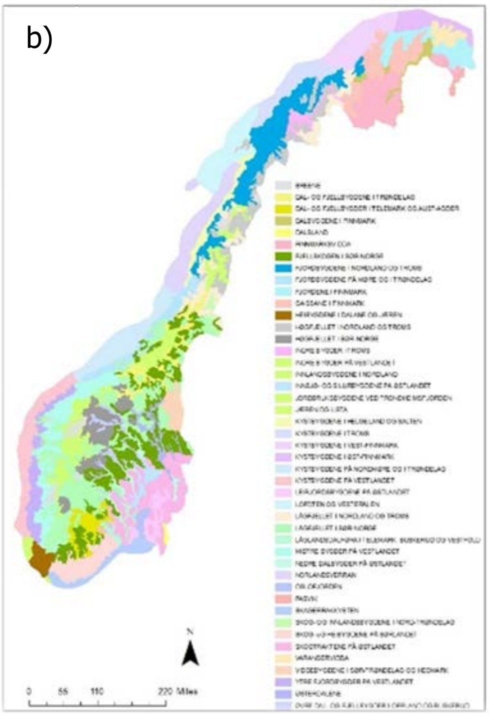
A distance-based approach to defining "local" has great appeal, especially to policy makers and land managers tasked with large-scale restoration projects and guidelines. These projects focus on finding seed sources that are adapted to local climatic conditions, and this has led to the development of the concept of *climate-informed seed transfer zones* (Prasse et al. 2010, Bower et al. 2014, Doherty et al. 2017, Massatti et al. 2020). A system of climate-informed seed transfer zones is currently being applied widely in ecological restoration of public lands in the western USA (Massatti et al. 2020). However, there is a danger of introducing seeds (or other plant material) which will do poorly because they simply are not local enough in terms of genetically determined adaptations (see also 1.2.1 and 1.2.2). Combining genetic data from 13 plant species relevant to ecological restoration in western North America with relevant climate data, Massatti et al. (2020) concluded that 50 km is a safe distance for transferring plant species material, which becomes a suggestion for an operational definition of "local" in the context of ecosystem restoration. In particular, they found that the probability of mixing genetically differentiated individuals (individuals from genetically different populations) was only about 8% when considering locations separated by 50 km but reached nearly 80% by 500 km, which are distances relevant to ecoregionally constrained climate-informed seed transfer zones. Furthermore, climate analyses revealed that geographically proximate locations were likely to have similar environments, regardless of the transfer zone or ecoregion assignment.

In this report, we use "regionally alien" or "nonlocal" in this sense: vascular plant species that occur naturally in Norway but where the target site for planting or sowing is outside of the species' natural range within Norway. We do, however, have to remember that we have little knowledge of what 'native' entails for most of our vascular plant species, and that native species do not follow national or regional borders.

1.1.1 How genetically distinct are local populations?

The anadromous fish populations in Norway form genetically distinct populations that home to their native rivers and streams and have genomes that cope well with local conditions. Each watershed, or even parts of one, forms a local population that remains more or less isolated from others by fish homing behaviour. However, plant species do not readily form such distinct, genetically defined local populations that can be simply identified by distinct geographic features (such as rivers for anadromous fish). As emphasized by Moen et al. (1999), Norwegian topography is riddled with steep gradients in elevation and oceanic influence, both of which influence temperature and precipitation patterns (Fig 1.1.1-1a). These features can result in a large variety of climatic conditions over short distances, with corresponding variation in the composition of local plant communities. As examples are landscape regions (*'landskapregioner'*) (Fig 1.1.1-1b) and landscape subregions (*'Landskap-underregioner'*) (Fig 1.1:1-1c), defined by combinations of six main components: overall form of the landscape, small shapes of the landscape, water and streams, vegetation, agricultural land, and buildings and technical installations (Puschmann 1998). In addition to this, the nature of the bedrock and variation in soil structure and properties affect pH and soil nutrient availability, influencing plant distribution. Due to the fine-grained spatial heterogeneity of climate and soil conditions, we might assume local adaptation of plants in an area. Local adaptation was found in *Trifolium repens* (white clover, *hvitkløver*) where considerable variation between Norwegian populations was observed for winter survival, spring growth, morphological characteristics, dry matter yield, general performance, earliness and seed yield (Finne et al. 2000). Some species, like *Rubus chamaemorus* (cloudberry, *multe*), *Melampyrum sylvaticum* (small cow-wheat, *småmarimjelle*), *Cerastium alpinurn* (alpine mouse-ear, *fjellarve*) and *Elymus alaskanus* (Alaskan wheatgrass, *fjellkveke*), have genetically distinct populations in Norway, which suggests that their populations are effectively isolated from each other (Diaz et al. 1999, Berglund and Westerbergh 2001, Crichton et al. 2016, Leisova-Svobodova et al. 2018). Also, *Agrostis mertensii* (northern bentgrass, *fjellkvein*), *Festuca ovina* (sheep fescue, *sauesvingel*), *Carex bigelowii* (stiff sedge, *stivstarr*), *Poa alpinae* (alpine meadow-gras, *fjellrapp*), *Juncus bulbosus* (bulbous rush, *sumpsiv*) and *Galium aparine* (Goosegrass, Coachweed, Catchweed, Stickywilly, *klengemaure*), showed some differences among populations in Norway (Hubner et al., 2003, Moe et al., 2013, Jørgensen et al., 2016), while *Festuca pratensis* (meadow fescue, *engsvingel*), *Scorzoneroides autumnalis* (autumn hawkbit, *følblom*) and *Avenella flexuosa* (wavy hairgrass, *smyle*) showed little difference among populations in Norway (Fjellheim and Rognli 2005, Jørgensen et al. 2016).





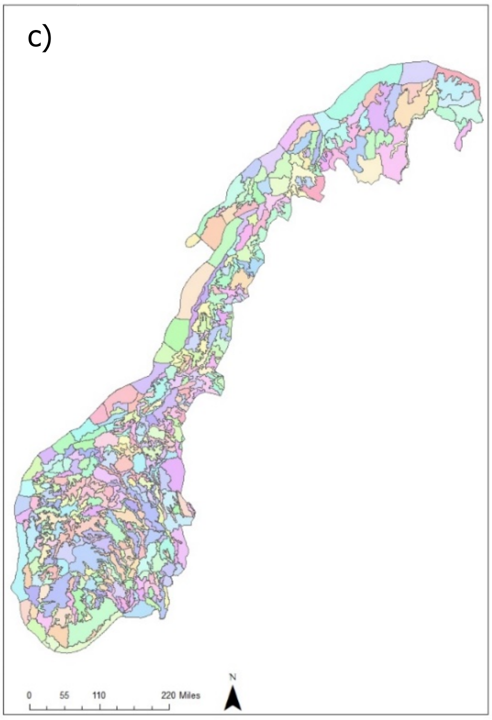


Figure 1.1.1-1: Examples of how Norway can be divided into different zones, by focusing on temperature (a), landscape regions (b) or landscape subregions (c). Maps: Statens Kartverk and Nibio

The above-mentioned studies show that there are contrasting patterns of geographic genetic structure among the few Norwegian plant species for which relevant information exist. These results indicate that it is not straightforward to define the size of the area for which we can assume local adaptation.

Figure 1.1.1-2: Seeds can be transported over long distances attached to animal fur, in this case sheep wool. Photo: Inger Elisabeth Måren

Animals disperse seeds in the landscape on a local, regional or national scale, contributing to spreading plant species across the landscape at various temporal (diurnal, seasonal) and spatial scales (within and among grazing areas)—their movements leading to gene flow among populations (Figures 1.1.1-2 and 1.1.1-3). Studies of seed dispersal via livestock in Scandinavia go back over a century (Heintze 1915). In Norway, seeds and plant parts are dispersed over large distances by both wild animals, such as red deer and moose, and domestic livestock, such as sheep, goats and cattle (Svalheim and Sickel 2017). The traditional Norwegian practice of free-range livestock grazing (summer farming, *beiting i utmark, støling, setring)* dates back hundreds of years and has contributed to long distance seed dispersal over time; extensive movement along old transport routes over long distances including large herds of sheep, cattle and horses, has bound the country together (Svalheim and Sickel 2017). For example, meadow species from lower-lying settlements were spread upwards to higher elevation pasture areas and mountain plants were spread to the settlement areas at lower elevations (Olsson et al. 1995, Jordal & Gaarder 1997, Bryn 1998, Bryn 2001b, Svalheim & Jansen 2002). We can assume that there has been substantial gene flow among populations of certain species in large parts of Norway due to the practice of summer farming and the transport of feed, goods, hay and people among regions. This extensive use of traditional free-range grazing has led to many culturally favoured plant species gaining a wider ecological amplitude and a broader distribution (Svalheim and Sickel 2017).

Figure 1.1.1-3: Sheep, and other livestock, ingest seeds from a variety of plant species which they then discard of through their faeces at shorter or longer distances from the mother plant. Photo: Inger Elisabeth Måren

Even though the practice of seasonal grazing movements has subsided in recent years, we still have 2 million sheep grazing in the countryside in Norway, and an increasing population of red deer spreading eastwards and southwards. This natural and cultural seed re-distribution over the landscape needs to be accounted for in the discussion of what is 'local' (or of what is regionally alien). In addition to this comes the spreading of seeds through human activities, as illustrated in Figure 1.1.1-4.

Figure 1.1.1-4: Seed sprouting on a hiking boot. Photo: Amy Eycott.

1.2 The choice of local over nonlocal plant populations: consequences for biodiversity

As detailed above, the introduction of selected plant species to a site (revegetation) may be conducted for a wide variety of reasons. What are the consequences for biodiversity of opting for local plant materials?

1.2.1 Advantages of using local plants and seeds

Until recently, conservationists have assumed that the goal of restoration should be to establish plant communities similar in species composition to the target site, and similar in genetic composition to populations of present or recently present communities of the traget site—that is, the restored plant communities should be of local origin (see 1.1). The strict use of locally sourced seeds in revegetation and restoration programs is a widespread practice which and is based on the premise that populations are locally adapted (Montalvo et al. 1997; Hufford and Mazer 2003; McKay et al. 2005; O'Brien et al. 2007; Kramer and Havens 2009; Mijnsbrugge et al. 2010; O'Brien and Krauss 2010; Breed et al. 2013).This strategy is commonly referred to as the "local is best paradigm" (Broadhurst et al. 2008; Jones 2013, Breed et al. 2018, Dupré la Tour et al. 2020). The goal of using local sources of seeds or plants is to preserve gene variants or combinations of gene variants that work well in the target site, thereby preserving any local ecological and physiological adaptions (Massatti et al. 2020). Local genotypes are assumed to be better adapted to local conditions, as natural selection over time increases the frequency of genes that improve fitness, selecting for variation that is adaptive (Boshier et al. 2015).

Using seeds or plants from distant populations, from nonlocal subspecies of species already present, or from species native to Norway but not occurring locally (regionally alien species), could pose a risk to local biodiversity (the plant communities in surrounding areas) for one or more of the following reasons (For further discussion and theory on the "local is best" paradigm see Appendix I.):

1) Nonlocal plants with high phenotypic plasticity may outcompete local flora (McKay et al. 2005, Bischoff et al. 2006) or negatively interact with other organisms (Sackville Hamilton 2001, Bucharova et al. 2019). Nonlocal species may shift competitive relationships among species (Kuebbing et al. 2014a,b; Ploughe et al. 2020).
2) Interactions between a given plant species and ectomycorrhizae are sometimes different in different populations of that species, and thus can be disrupted by the introduction of nonlocal conspecifics (Bucharova 2017).

3) Plant material including seeds can have pathogens not present locally (Baker and Smith 1966, Bucharova 2017).
4) The introduction of alien plant material may lead to hybridization with elements of the local flora leading to outbreeding depression (Moore 2000, Sackville Hamilton 2001, Whitlock et al. 2013), where later generations have lower fitness either because the introduction of foreign genes reduces local adaptation (McKay et al. 2005, Keller et al. 2000, Edmands 2007), or because crossings with foreign individuals break up local genetic combinations that work well, so-called co-adapted gene complexes (Maynard Smith 1998, Lynch 1991, Vila et al. 2000, Allendorf and Lundqvist 2003, Ayres et al. 2004, Burgess and Husband 2006, Bleeker et al. 2007, Vinogradova and Galkina 2020).
5) Introduced plant material from other populations may reduce genetic differences among populations (between-population genetic variance), which could negatively affect the species' ability as a whole to respond to future changes in selection pressures (McKay et al. 2005), such as those resulting from the rapid climate change Norway is experiencing (Miljødirektoratet 2017).
6) Introducing alien species may disturb current pollination networks, as aliens might monopolize the pollinator community (Bjerknes et al. 2007).
7) Nonlocal species might alter microclimates (Dukes and Mooney 2004) and alter the physical and biological properties of soils (Kuebbing et al. 2014a; Ward et al. 2019).

In addition to the risk to biodiversity, plants arising from alien plant material might simply grow and reproduce poorly because they are not well attuned to local conditions (Moore 2000, Bischoff et al. 2006, Breed et al. 2018). Local populations are usually adapted to aspects of the physical and biotic environments, such as climate, soil conditions (including the local microorganism community), herbivory, or pollinator availability (Galen 1996, Macel et al. 2007, Durka et al. 2017, Bucharova 2017, Vidaller et al. 2018). The phenology of locally sourced plant material would match conditions of the target site; phenological traits, such as the timing of leafing out or of flowering, can be at least partly genetically determined and hence adapted to local day-length and temperature regimes (Wilczek et al. 2010, Wadgymar et al. 2015).

Given these important potential hazards, choice of local plant material can be justified by the precautionary principle (Moore 2000, Jones 2013). We would point out, though, that there are arguments for adopting other approaches to seed or plant sourcing, based particularly on incorporating climate change considerations when revegetating, or preventing inbreeding depression. These approaches suggest that, in some circumstances, deliberately including nonlocal plant material can have important benefits, such as increasing local genetic diversity or bringing in genotypes better adapted to future environmental conditions. Often, the choice is between using a standard nonlocal seed mixture and not seeding at all, due to deficit of local materials. Our report highlights threats to local plant communities that can arise from using regionally alien plant material, but we summarize counterarguments and discuss various other methods for choosing seed sources in chapter 2.3.4 and Appendix I.

1.3 Composing and producing seed mixes

Efficient and effective use of local native seeds is a cornerstone of ecological restoration (Kirmer et al. 2012, Erickson et al. 2017, Nevill et al. 2018) and the demand is expected to rise as the scale of restoration projects continue to increase . To meet the demand for local seeds there is a push to develop seed supply chains that are reliable, sustainable, and transparent. Standards guiding the collection, production, quality testing, storage, and sale are, however, lacking in most countries, including Norway.

Increasing native seed production is an emerging priority around the world, and significant research and flexible management will be required to refine and enhance current methods for better revegetation and restoration outcomes (Pedrini et al. 2020).

To succeed in producing large amounts of native seeds from wild plant species, some key attributes need to be considered. Seed dormancy is such a key attribute, one that has been removed from the seeds of most crop species. Dormancy refers to a resting state where specific environmental cues are required before the seed can begin to germinate. Suppliers of local seeds are encouraged to define the dormancy condition and give instructions for breaking dormancy. Such dormancy breaking treatments can be applied by the supplier or recommended to end-users as a necessary step for ensuring successful deployment of germination-capable seeds. Also, the seed yields and germination of wild species can be naturally low and variable (Fenner 2000), and while cropping of wild species can facilitate controlled production, some seed ecological traits can determine obstacles to harvesting (Fenner & Thompson 2005). Not all wild species are candidates for commercial production, as variation in seed morphological traits can necessitate the use of a variety of appropriate harvesting and conditioning equipment, the costs of which can be very high if a large number of species are being included in the seed mixes.

Proper seed management from collection to postconditioning storage is essential to maintain seed viability, which is variable between suppliers and can be very low (Marin et al. 2017). These challenges require collaborative efforts between seed suppliers and researchers to fully realize the potential of providing farmed local seeds for ecological restoration. It is also important to acknowledge that any seed harvest activity, whether from natural populations (managed or unmanaged) or under cultivated seed systems, will result in some degree of selection for specific traits, traits which might or might not be beneficial in the wild. In other words, harvesting is implicitly biased. However, several precautions can be taken at each step of seed procurement to limit, as far as practically possible, the impact of this trait selection (see Pedrini et al. 2020).

1.3.1 Seeds harvested from local meadows

In Switzerland for example, meadow seed mixes are usually harvested from donor meadows near the area to be revegetated (Bassignana et al. 2015). Appropriate machinery can extract seed directly from the meadow without harming its development, at least compared to premature mowing. This practice will result in seed mixes that represent the local flora and most of the issues raised in this report will be irrelevant. Seeds or vegetative parts (cuttings) can either be sown directly into the restoration site to germinate and establish, or plants can be grown from seeds or cuttings in a greenhouse. These new plants can then be planted in the restoration site. Mature plants might establish in the restored area, thus avoiding high seedling mortality, and speeding up the revegetation process. This method secures the use of local populations. However, this type of harvest should not be carried out repeatedly over years as not to deplete the harvested species in the source area (meadow). This type of seed mixes reflects the "Local" or "Composite" provenancing in figure 1.2.1-1, depending on the diversity of meadows used for the seed sourcing.

1.3.2 Mix of native seeds from different localities inside or outside the region

Seeds can be sourced from multiple populations within the same region as the target locality and mixed prior to use (see Appendix 1, regional admixture provenancing). The mixing of seeds increases the genetic diversity necessary for future adaptation, while restricting seed origins to a regional scale will maintain regional adaptation and reduce the risk of unintended effects on other biota. This approach is feasible in practice and has recently been implemented in parts of Germany (see Bucharova et al. 2019).

1.3.3 Seed mixes from seed producers

Currently, commercial meadow seed mixes in Norway are grown in dense stands comprising a selection of species that are grown from seeds collected in the wild. Centralized seed production facilities are effective, but a narrow origin of the seeds could lead to low genetic variability and result in inbreeding depression or inability to adapt to changes in the environment (section 1.2). Streamlining the seed production process comes at a cost, namely the difficulties of growing plants in addition to those of producing seeds of local origin. Even if seeds are collected at local scales, the donor plants must be grown in dense stands within manageable distances, posing a risk for interbreeding among plants stemming from seeds (or cuttings) of different origins, or risking plants adapted to nursing rather than field conditions, if the same plant material is used reused for generations.

1.3.4 Seeds of alien species

Alien species are commonly used in restoration projects in Norway and in other countries. Commercial mixes of alien seeds are preferred because they quickly fill in the re-planted area. These seeds are often more readily available and at a much lower price than local or native sourced seeds. The threat posed by introducing alien species that might become invasive are well known, and outside the scope of this report. Invasive alien species are, by definition, species that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment and are not part of our remit[1].

1.4 Species found in seed mixes currently available in Norway

Grass seed mixes are sold in large quantities in stores, such as *Felleskjøpet*, for establishing grasslands for sheep and cattle grazing. The Norwegian Institute for Bioeconomy Research (NIBIO) at Landvik is also producing regional grass seed mixes for the use in alpine areas. Currently, they provide two mixes, stemming from, and to be used in, different mountain ranges: "*Fjellfrø Hardangervidda*" and "*Fjellfrø Rondane/Dovre/Rørosvidda*" ('*fjellfrø'* means seeds from mountains). They also have a grass seed mix for the elevation band 200–600m a.s.l. called "*Naturfrø Telemark*" containing varieties of species local to southeast Norway. The regional definitions of all these mixes are based on a study on the genetic structure of several plant species throughout Norwegian mountain ranges conducted by Jørgensen *et al.* (2016).

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[1]https://ec.europa.eu/environment/nature/invasivealien/index_en.htm, https://www.cbd.int/invasive/WhatareIAS.shtml, https://artsdatabanken.no/fremmedearter and https://www.nina.no/Fremmede-arter

Several producers also sell seed mixes containing flower meadow species, but the quantity and identity of the species in the mixes varies from year to year. The following list is based on our own search for producers and is most likely not including all available seed mixes. Nelson Garden has seed mixes they advertise as "Containing only Norwegian seed types", but the label is in Norwegian, Swedish and Finnish and it is unclear exactly where the seeds are produced or from where they originate. '*Midt-Norsk blomsterengfrø* also produces seed mixes for sale throughout the country but has no emphasis on local seeds. At NIBIO Landvik, several different seed mixes are produced. "*Friskengblanding for Sørøstlandet*" and "*Tørrengblanding for Sørøstlandet*" have been on the market since 2019 and are meant to be used in the lowlands (< 200m a.s.l.) along the coast from Lindesnes to Svinesund on rich and poor soils, respectively. A meadow seed mix for Trøndelag County is available in 2021. Seed mixes for Nordland County, southwestern Norway and two for Innlandet County (mountain and lowland) will be available in 2022 and one for Troms and Finnmark County and two for Vestland County (inner and outer fjord) will be available in 2023. The seeds are harvested from plants growing in the focal area. The species composition of the mixture varies from year to year depending on availability. The Natural History Museum in Oslo sells seeds from meadow species collected in the Oslo area.

Several garden centres sell meadow seeds, but none of the species included are named for many of the seed mixes, or if they are, most of the species are alien to Norway. Some may have species native to Norway, but the actual seeds are produced abroad. Some producers/sellers state that these seeds are for use in gardens only, while most producers do not state anything regarding the origin of the seeds or where they can be used.

1.5 Traits affecting the invasiveness of vascular plants

Biologists often use "invasive" to simply refer to alien species that produce reproductive offspring in areas distant from sites of introduction (Richardson et al. 2000, Simberloff 2013). Here we adopt the definition preferred by policy makers and major conservation organizations, that an invasive species is an alien species that becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biodiversity (IUCN 2000). We use this definition as it is more operational with respect to restoration and rehabilitation efforts in the sense that invasive plants should be avoided.

Many species manage to colonize new areas (with or without human help), but few successfully spread and become invasive. Several attempts have been made to describe specific attributes of plants that increase their likelihood of success in colonizing and spreading within new regions, i. e. becoming invasive. Van Kleunen et al. (2010) compared six performance traits of invasive and non-invasive species in a large meta-analysis comprising 117 field or common-garden experiments. Invasive species had higher values than non-invasive species for all six measures: fitness (seed production), size (plant height), growth rate, shoot allocation, leaf-area allocation, and physiology (see also Moravcová et al. 2015). Nonetheless, it is difficult to find traits that are consistently and strongly associated with invasiveness in all circumstances (Petanidou et al. 2012).

It has long been held that self-compatibility and clonal reproduction facilitate invasiveness in plants, especially in annuals (Baker's Rule, e.g., Baker 1974, Rambuda and Johnson 2004). A large body of research now supports the hypothesis that self-compatibility and apomixis (parthenogenetic seed production) are advantageous for plants colonizing new regions (Petanidou et al. 2012). There are some indications that polyploidy increases invasiveness (te Beest et al. 2011, Rosche et al. 2016, Moura et. al. 2020). Moura et al. (2020) postulate that the inherent greater genetic variation in polyploids has a positive impact on plant competitiveness and hence on the ability to invade new plant communities. However, given that many polyploid plants are apomictic or automictic (regularly self-fertilizing), the increase in invasiveness associated with polyploidy might be at least partly attributable to advantages to those reproductive systems other than being polyploid.

Seed production and dispersal mechanisms are also important plant traits that might affect their invasiveness. In a study of the invasiveness of central European herbaceous alien plants, species producing small seeds that attach to animal fur were especially successful as invaders (Moravcová et al. 2015). They emphasized that it was the number of seeds produced by an invasive herbaceous plant population that most clearly determined the probability of a population becoming invasive: nearly four of five species became invasive if a population produced more than 37,700 propagules per m^2, but only about one in three when it produced fewer propagules.

The above-mentioned studies show that certain plant traits are associated with higher likelihood of the species becoming invasive. There are, however, many exceptions and predicting invasiveness has proven extremely difficult (Pyšek and Richardson 2007, van Kleunen et al. 2010).

1.6 Regulations regarding planting vascular plants outside their natural ranges

Regulations of the use of seed in revegetation projects varies among countries. While the use of alien seeds is often prohibited, using seeds native to the focal country is less controversial or questioned.

1.6.1 In Norway

In the Norwegian Nature Diversity Act of 2009 (in Norwegian: *naturmangfoldsloven*[2]) (LOV-2009-06-19-100) Chapter IV Alien species (*Kapittel IV Fremmede organismer*)[3], , § 30 states that organisms of species and subspecies that do not occur naturally in Norway must not be released into the environment, with the exceptions specified in § 31. However, according to § 31, one does not need special permission to plant Norwegian tree species, plants in private gardens, or plants in parks and other areas, as long as the precautions specified in § 28 are followed. Section 28 cautions that one must attempt to prevent the escape of species that could have unfortunate consequences for biodiversity.

FOR-2015-06-19-716 (In Norwegian: "*Forskrift om fremmede organismer*"[4]; In English "Regulations about alien organisms"[5]) regulates the import or introduction, the trading and release, as well as the unintentional spread of alien organisms. "The purpose of these regulations is to prevent the import, release and spread of alien organisms that have or may have adverse impacts on biological or landscape diversity." The regulation applies to Norwegian land territory, including watercourses, Norwegian territorial waters, and Jan Mayen. The regulations do not apply to Svalbard. Below, we list some of the relevant aspects this regulation establishes.

A permit for release is required for all alien species (Section 10) (§ 10.*Krav om tillatelse ved utsetting) (1) Med mindre utsetting er forbudt etter § 9, eller unntatt fra kravet om tillatelse*

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[2] https://lovdata.no/dokument/NL/lov/2009-06-19-100

[3] https://www.regjeringen.no/en/dokumenter/nature-diversity-act/id570549/

[4] https://lovdata.no/dokument/SF/forskrift/2015-06-19-716

[5] https://www.regjeringen.no/en/dokumenter/forskrift-om-fremmede-organismer/id2479700/

etter § 11, kreves det tillatelse for utsetting av a) vilt av arter, underarter eller bestander som ikke fra før finnes naturlig i distriktet, b) organismer, unntatt av stedegen stamme, i sjø og vassdrag, og c) øvrige organismer som ikke hører til noen art, stamme eller bestand som forekommer naturlig på stedet. ((1) Unless release is prohibited under section 9, or is excepted from the requirement to hold a permit under section 11, a permit under these regulations is required for the release of a) wildlife belonging to species, subspecies or populations that do not already occur naturally in the district; b) organisms, except those belonging to a native population, to the sea or a river system; and c) other organisms that do not belong to a species or population that occurs naturally in an area.) *(2) Ved vurderingen av søknaden, skal det særlig legges vekt på om den omsøkte organismen og eventuelle følgeorganismer kan medføre risiko for uheldige følger for det biologiske mangfold. Det kan ikke gis tillatelse hvis det er grunn til å anta at utsettingen vil medføre vesentlige uheldige følger for det biologiske mangfold*. (2) In assessing the application, special emphasis shall be placed on whether the organism applied for and any accompanying organisms may entail a risk of adverse consequences for biological diversity. Permission cannot be granted if there is reason to believe that the release will have significant adverse consequences for biological diversity.

1.6.2 In the EU

1.6.2.1 EU-specific regulations

According to EU-specific regulations 'Region of origin' is defined as "When a Member State authorises the marketing of a preservation mixture, it shall define the region with which that mixture is naturally associated, hereinafter referred to as 'region of origin'. It shall take into account information from plant genetic resource authorities or organisations recognised for this purpose by the Member States. Where the region of origin is located in more than one Member State, it shall be identified by all Member States concerned by common accord." (European Commision 2010).

The EU directive on the conservation of habitats and species (92/43/European Economic Community [EEC]) covers 502 species of vascular plants with conservation status (EU Commission 1992). These species are prioritized for action under the Natura 2000 European ecological network implementing the goals of the EU Biodiversity Strategy. However, insufficient seeds of these species are commercially available in the EU, and germination data are not freely accessible in comparison with indicator and fodder species (Ladouceur et al. 2017). This may be due to economic reasons (hard to produce) and access (e.g., need for collection permits). Nonetheless, this convergence of factors has resulted in four times more restoration outside than within the Natura 2000 network (Dickie 2016).

A recent study identified 1,122 plant species important for European grasslands of conservation concern and found that only 32% have both fundamental seed germination data available and can be purchased as seed (Ladouceur et al. 2017). The "restoration species pool," or set of species available in practice, may act as a significant biodiversity selection filter for species use in restoration projects.

1.6.2.2 France

In France there is a growing demand for native seeds and trees with certified provenance, but there is only limited native plant material on the market. The French law is non-binding about identification of geographic provenance for wild plants on the market, however, there is now a collective effort to develop standards for wild native seeds, plants and trees by establishing zones in which seed exchanges are compatible with the conservation of genetic diversity (Malaval 2018). In this approach they use a compilation of pre-existing maps (geological, climatic, topographic, vegetation map, woody habitat map, hydro-geographic maps), leading to 40 biogeographic zones. They also considered the economic parameter: in order to grow and to have a sustainable activity, a seed grower needs to have seed zones that are large enough to develop a market, which led to pairing the zones down to a total of 11. (Pers. comm. Malaval 2020).

1.6.2.3 Germany

As a unique example in Europe, Germany has mandated that only native species may be used for all revegetation by 2020 (BNatSchG, Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety 2010). German local native seed production must grow tenfold to meet 2020 targets. In Germany there are concerns about the balance between the genetic local adaption and the need for future genetic adaption in a site. To balance the value of local adaptation with the need for future adaptation potential, they propose 'regional admixture provenancing' as a compromise strategy. Here seeds are sourced from multiple populations within the same region as the target locality and mixed prior to use. The mixing of seeds increases the genetic diversity necessary for future adaptation, while restricting seed origins to a regional scale. This approach will maintain regional adaptation and reduce the risk of unintended effects on other organisms. This approach has been shown to be feasible in practice and has recently been implemented (Bucharova et al. 2019).

1.6.2.4 Austria

In Austria, site-specific is defined in three different categories; species level, community level or vegetation created by humans. (1) A plant species is considered site-specific when it occurs naturally under given site conditions. (2) A plant community is considered site-specific (a) when it is generally and permanently self-supporting or self-stabilizing following extensive use (or non-use), and (b) when the production of agricultural or forestry products is not its main function. (3) Vegetation established by humans is called site–specific if the ecological amplitudes of species used match the environmental site factors where restoration takes place and all plant materials used within the restoration process originate directly from the project area or its vicinity or are obtained from ecologically comparable sites within the natural area, respecting knowledge of local ecological types or subspecies (Krautzer et al. 2012).

1.6.3 Beyond Norway and the EU

In Australia, the United Kingdom, and the United States, there are examples of government, community, or non-profit groups working cooperatively with seed suppliers to enable the inclusion of species that have challenging seed traits in the commercial Retailer, Supplier Partnerships supply chain. The U.S. Native Plant Program (Oldfield & Olwell 2015) contracts production of seed across all available suppliers, to partition demand and market share, then stored in government infrastructure for purchase.

2 Where, why, and how are vascular plants used?

Ecological restoration is used to compensate for land-use change and speed up the process of revegetation in areas subject to human intervention. To ensure the regeneration of plant communities resembling those lost, local soils and plant material (seeds, roots or plants) should be used. Currently, however, nonlocal seeds, seedlings or vegetation mats are the only available commercial options. This raises the issue of the potential effects of introducing vegetation of nonlocal origin in revegetation and restoration projects. Below we list common types of revegetation projects to illustrate the variety of restoration goals, management requirements and spatial scales.

2.1 Revegetation and restoration in rural areas

Many revegetation and restoration projects in rural areas are spatially extensive, making the planting of seedlings or the use of vegetation mats economically unfeasible. Such projects thus typically generate a high demand for seeds if slow natural succession is not a goal in itself. Biodiversity in agricultural landscapes is currently under threat, and policies and management strategies are in place to enable farmers to contribute to biodiversity conservation, either through the maintenance and management of traditional cultural landscapes or through the establishment of, for example, new flower-rich meadows or strips. These incentives are aimed at re-establishing flower-rich habitats and are therefore in need of appropriate seed mixes.

2.1.1 Flower meadows – semi-natural grasslands

Semi-natural grassland is an endangered nature type in Norway due to the abandonment of traditional agricultural practices (Johansen et al. 2019). Semi-natural grasslands usually occur on nutrient-poor and well-managed lands where a few competitive species are unable to dominate, hence providing a great diversity and abundance of wildflowers. The recent increase in awareness and focus on pollinating insects has emphasized the importance of these flower meadows beyond the diversity found in their plant communities. Therefore, flower meadows are established in many places, usually by planting a diversity of seeds and applying management practices resembling traditional management of semi-natural grasslands, mainly mowing of hay meadows.

Figure 2.1.1-1: Two semi-natural meadows, Viken county. Photos: Line Rosef

2.1.2 Flower strips on agricultural land

Current agricultural policies give subsidies to farmers planting flower strips on their agricultural land. Seed mixes are used which increase floral resources for pollinating insects, but these mixes are often of non-Norwegian origin. As opposed to the traditional semi-natural grasslands, flower strips are typically planted in fertile soils and therefore require seeds from other species for successful establishment.

2.1.3 Road verges and airfields

After construction of road verges and airfields, revegetation measures are used to speed up the reestablishment of vegetation in the construction area. The main purpose is to make the areas visually appealing, but also to stabilize soils and decrease erosion. To uphold visibility along roads and across airfields, the vegetation is cut several times a year in order to hamper shrub and tree encroachment. This management regime, if done correctly, can resemble traditional management of hay-meadows and semi-natural grasslands (if the cut biomass is removed), potentially providing floral resource hotspots of high value to pollinators. This would at the same time contribute to the goals of the Norwegian pollinator strategy (see section 1.2.7 below). As grass seed mixes most often are the only available option, other species are left to disperse naturally from the surrounding plant community. Many airfields are placed on what was previously agricultural land and this is reflected in the plant species composition in the vegetation surrounding the airfields. They may include endangered nature types, such as semi-natural meadows. For instance, the company Avinor has conducted botanical surveys on all their airfields and use this information to build management strategies for conserving local biodiversity, in addition to the main purpose of keeping clear visibility for the air traffic (Avinor, pers. comm.).

Figure 2.1.3-1: Re-use of topsoil to restore road verges after road rehabilitation approx. 600 m.a.s.l., Fylkesveg 2208 Engerdal municipality, Innlandet county. Photo: Line Rosef

Figure 2.1.3-2: Flower-rich road verges by Balestrand, Vestland County. Photo: Inger Måren

2.1.4 Mountain cabin areas

In many rural areas of Norway, numerous cabins are built for recreational purposes, both in aggregations in "resorts" or more isolated and dispersed in the landscape. These development projects have increased in numbers over the years, particularly in southern parts of Norway. At higher elevations, natural revegetation after construction takes time and restoration measures are often used to speed up the process. The main purpose of such re-vegetation is to restore nature and make the area surrounding the cabins or resort developments look aesthetically appealing. Grass seed mixes are available for different Norwegian mountain ranges, but also seed mixes with lowland grasses are extensively used. Grass roofs are also popular, and many contain nonlocal, highly productive grasses (NIBIO 2017).

Box 1

The Hjerkinn firing range (165 km^2) is situated in a unique high-mountain ecosystem surrounded by several protected areas (Hjerkinn PRO). After more than 80 years of heavy military use, the Norwegian Parliament decided to close it and restore it as a nature conservation area. By this resolution the largest, most costly, and most ambitious restoration project ever proposed in Norway, or perhaps in any high mountain area, was initiated. Buildings, test fields, target ranges and other military installations, in addition to ca. 90 km of roads were removed. Ecological principles for restoration were formulated, and only local plant material was used. To restore roads, the vegetation and turfs along road verges were used as the basis for the natural recovery of new vegetation. In some large sites, further treatment was applied, as the basis for vegetation establishment was poor, with dense and hard soil, absence of organic material and long distances to surrounding vegetation. Thus, other measures were implemented to improve natural recovery, including the planting of 25,000 willow plants (*Salix glauca, S. lapponum*, and *S. phylicifolia*) propagated from local mother plants and the seeding of *Festuca ovina* sourced from local seed sources. Monitoring in permanent plots show that fertilization and sowing gave rapid development of grass-dominated vegetation cover and had a great short-term effect, but in the slightly longer term (7−16 years) the effect is small. Species diversity was lower in seeded and fertilized plots compared to unseeded plots. Keeping the top gravel (*subbus*) clearly supressed recovery, and vegetation cover is still very low after 16 years.

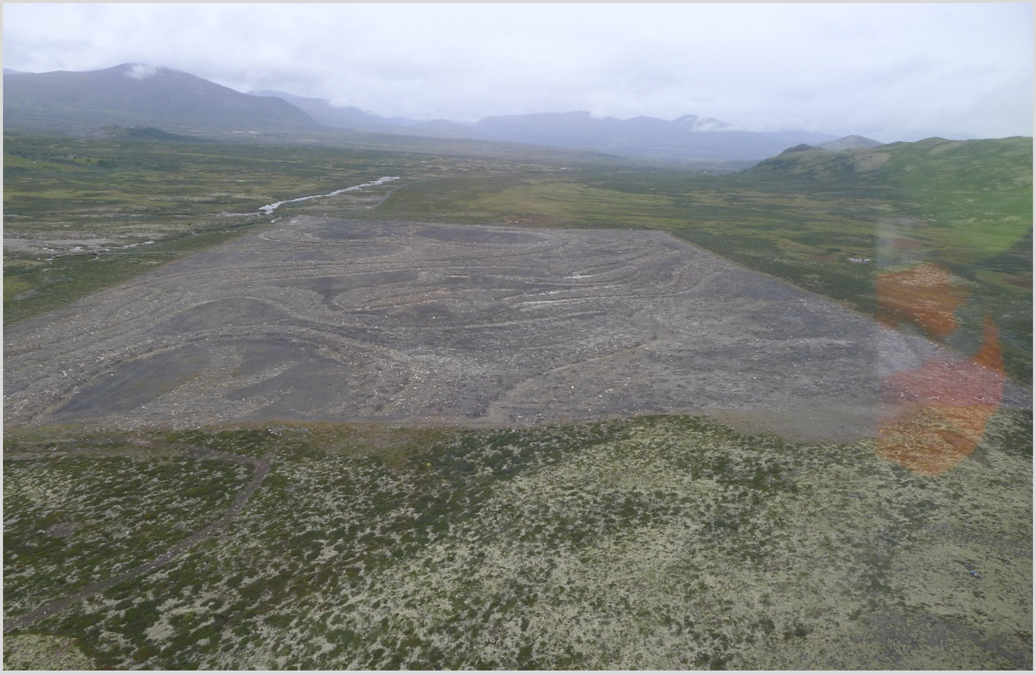


Photo: Forsvarsbygg/S. Solli

2.1.5 Hydroelectric power dams, quarries and military training facilities

The Norwegian Water Resources and Energy Directorate (NVE) requires an Environment and Landscape Plan in projects involving the construction of hydropower dams and quarries (Hagen and Skrindo 2010). After the construction of hydropower dams and quarries, the vegetation must be restored.. In many regulation plans for stone quarries in Norway, the area must be revegetated after the extraction of stone. To our knowledge, the restoration of large-scale military facilities is not regulated in Norway. However, military training activities may have high impacts on ecosystems, highlighting a need for ecological restoration after facilities are abandoned (see Box 1 for an example).

Figure 2.1.5-1: Restoration of landscape and vegetation after hydroelectric power dam rehabilitation approx. 950 m.a.s.l., Bitdalen dam, Vinje municipality, Vestfold and Telemark County. Photo: Line Rosef

Figure 2.1.5-2: Stone quarry for hydroelectric power dam rehabilitation approx. 960 m.a.s.l., Songa dam, Vinje municipality, Vestfold and Telemark County. Photo: Line Rosef

2.2 In urban areas

Revegetation and restoration in urban areas is usually carried out on heavily disturbed areas. In urban areas, the goals of revegetation are rarely to re-establish the vegetation to a former state, as the sites are usually too disturbed. In city centres, space is limited, and vegetation is mostly planted or sown to create gardens or parks for aesthetic and recreational purposes. Re-establishing semi-natural vegetation has, however, become more popular lately, in particular in the outskirts of the cities and in peri-urban settings. Recently, there has also been an increased interest in building vegetation-based stormwater retention systems, both on the ground and on roofs of buildings.

2.2.1 Storm water retention systems

Vegetation-based stormwater retention systems on the ground are based on criteria for soil design and choice of suitable (native) vegetation. The vegetation is usually planted with mature plants and not sown with seeds. With careful design, such green spaces can reduce runoff, increase biodiversity, and provide a range of benefits to society.

Figure 2.2.1-1: Rain-garden in Drammen municipality for retention of water. Photo: Line Rosef

2.2.2 Green roofs

Green roofs are becoming increasingly popular in urban and suburban settings for stormwater retention and to increase biodiversity. Most green roofs consist of pre-grown grass turf or sedum mats, but seed mixes are also used in an increasing number of projects. Designs of roofs using vegetation for both biodiversity and water retention purposes are also being tested (NIBIO 2019).

Figure 2.2.2-1: The roof of Vega Scene in Oslo. Photo: Hans Martin Hanslin.

2.2.3 Gardens and parks

Seed mixes which increase floral resources for pollinating insects are often used in gardens and parks. Due to the limited availability of local seeds, these mixes are mostly of non-Norwegian origin. However, in some parks semi-natural meadows have been established based on the seed bank or seeded with local seeds collected in the vicinity of the planted site.

Figure 2.2.3-1: Flowerbeds in the park at NMBU, Ås municipality. Photo: Line Rosef

2.3 Restoration, rehabilitation, and revegetation

Plants can be used for many purposes, either to restore a specific habitat, rehabilitate a damaged habitat, to revegetate bare ground, or for aesthetic reasons. In some instances, the first critical step in ecological restoration is to re-introduce target plant communities that will successfully establish, persist over time, and provide essential ecosystem functions. Under favourable conditions, restoration can rely on natural succession as a form of "passive restoration", relying on the existing seed bank and vegetative regeneration (Prach et al. 2015a, b, Prach and del Moral 2015, Gilhaus et al. 2015). However, in most cases it is necessary to introduce seeds or other plant materials from other sources, "active restoration", to ensure restoration success (Hölzel et al. 2012). Ecological restoration may also rely on modifying the environmental conditions, e.g., when restoring bogs or coastal heathlands. In bogs, you add water and possibly close drainage canals to change the environment, whereas in coastal heathlands, you clear trees and shrubs, reintroduce grazing animals and use fire as a successional "re-clocking" management strategy. These restoration efforts may not rely on planting or sowing, but rather depend on propagules already present in the system.

It should be noted that the restoration goal is frequently an early successional stage and not a climax community. For example, a meadow-like successional stage is desired for greater overview or as a fire break along roads; in other cases, a meadow-like successional stage might be desired for biodiversity conservation or simply for aesthetics. In many cases, restored landscapes will not be grazed hard enough to prevent the natural encroachment of woody vegetation, so maintaining the desired successional stage in open vegetation types will require active management in the form of regular mowing, cutting and logging, and perhaps even occasional re-seeding.

The goal of rehabilitation is sometimes the formation of novel habitats and the establishment of new vegetation (new for the target site). Creating new vegetation types that have certain key ecological values — flower richness for pollinators, certain food plants for invertebrates, threatened plant species, sparse vegetation for thermophilic insects and digging hymenoptera—may be seen as a type of ecological restoration. This is because such vegetation may provide deficit resources from other vanishing habitats in the landscape, although not necessarily resources that were present at the very spot before the intervention (the construction period).

To restore degraded or modified land and speed up the process of revegetation, several methods of restoration and rehabilitation are commonly used, some of which are listed below.

2.3.1 Natural revegetation

In natural revegetation, the area is left alone after the construction project is complete. Now, the vegetation will re-establish from seeds or vegetative parts already present in the soil or from dispersal from the surrounding areas. Depending on the local climate and environment, e.g., altitude, aspect, slope, organic matter content in the soil, size of the intervention, and the surrounding vegetation—this process may take a long time (>50 years). In particular, higher elevation ecosystems in Norway are characterized by short growing seasons, low temperatures, and poor soil quality, so natural regrowth can require decades (Moen 1999). This method ensures revegetation by local plant populations.

Figure 2.3.1-1: After about 55 years, the area of natural revegetation is still visible in the middle of the picture 1000 m.a.s.l. Songa dam, Vinje municipality, Vestfold and Telemark County. Photo: Line Rosef

2.3.2 Reusing local soil

Soil contains both seeds (the seed bank) and vegetative fragments, such as rhizomes, tubers, and root fragments that can resprout to form new plants. At the onset of construction projects like roadbuilding or hydropower dam construction, local topsoil can be removed and stored in heaps. The removed soil can then be re-introduced in the restoration phase at the end of the project. This method ensures the use of local plant populations for revegetation but may take some time, depending on location, where typically lowland location revegetate faster than high altitude locations.

A problem with re-using soils may be that the soil becomes too nutrient rich for its seed bank flora. For example, the grass sward in an old pasture is poor in nutrients available for plants, which is a key factor for plant species richness. The nutrients, however, are locked up in the living organic matter (mainly roots). When killing the vegetation by scraping, storing and re-using, the nutrients are released through decomposition of organic matter. Such sward soil is no longer nutrient poor, and may not sustain the vegetation composition of the pre-construction flora.

Figure 2.3.2-1: Soil heaps of organic topsoil, approx. 960 m.a.s.l., Songa dam, Vinje municipality, Vestfold and Telemark County. Photo: Line Rosef

2.3.3 Transplantation

Vegetation turfs or individual plants can be dug up at the beginning of the construction phase before the soil is removed. The vegetation turfs or plants might be stored and transplanted back after the construction. The vegetation turfs or plants may be stored for longer or shorter periods, from just hours up to several years as long as the turf is stored in a way that keeps its plants alive and counteracts decomposition and nutrient release. If transplanted vegetation turfs are stored for longer periods or collected from nearby areas, the contractor needs to make sure that the vegetation in the area of concern is not negatively affected. By transplanting intact vegetation turfs or plants, the troublesome establishment phase with typically high seedling mortality can be avoided, and seeds can be spread from the transplanted vegetation immediately, facilitating faster revegetation, and ensuring revegetation by local plant populations.

Figure 2.3.3-1: Vegetation turfs being stored before transplanted into the restoration site. approx. 960 m.a.s.l., Songa dam, Vinje municipality, Vestfold and Telemark County. Photo: Line Rosef

Figure 2.3.3-2: Vegetation turfs transplanted into the restored site, approx. 950 m.a.s.l., Bitdalen dam, Vinje municipality, Vestfold and Telemark County.. Photo: Line Rosef

2.3.4 Seeding and planting

A common way of revegetating or restoring plant communities is to grow desired plants from seeds or cuttings in greenhouses or nurseries and plant these in the restoration area. By planting established plants, the fragile germination and seedling phase is omitted. However, producing plants is more expensive and space- and time consuming than sowing seeds. Seeds and plants can be sourced in various ways, resulting in differing outcomes depending on source.

There are three main approaches for acquiring native or local seeds for restoration projects: (1) seed collection from natural populations, (2) harvest from managed populations (semi-natural habitats), and (3) harvest from cultivated seed production systems (such as native seed farms). These three seed supply strategies lie along a continuum where increasing inputs (labour costs and energy) are required to produce the seeds. The methods present different advantages and limitations, and the sources may be used in complementary and strategic combinations (Pedrini et al. 2020).

In Norway, local provenancing has been almost the only strategy, but provenancing of plant materials can take a variety of forms. In the face of rapid climate change, scaling up restoration efforts in Norway should consider a variety of systems for seed provenancing. The main aim of seed provenancing strategies (Figure 2.3.4-1) with a longer-term perspective is to maximize population performance with an eye towards both population genetics concerns and potential for adaptation to climate change. Possible strategies can be categorized as follows (Breed et al. 2013, Bucharova et al. 2019, see also Gannet et al. 2019):

- Local provenancing: The use of seeds of native plants that originate from wild populations, preferentially from local genotypes. This is the most widespread seed-sourcing practice and has wide support among managers (Sackville Hamilton 2001; Broadhurst et al. 2008). Underlying a local provenancing is the assumption that if local seed is used, the plant will be locally adapted and therefore maladaptation and outbreeding depression will be minimised, thereby increasing establishment success rates (Montalvo et al. 1997; Hufford and Mazer 2003; McKay et al. 2005; O'Brien et al. 2007; Kramer and Havens 2009; Mijnsbrugge et al. 2010; O'Brien and Krauss 2010).
- Predictive provenancing: The use of naturally occurring genotypes from areas that have similar climates as the target locality. This strategy requires data on local adaptation of many populations, e.g., by reciprocal transplant experiments, as well as climate projections for the target species including the revegetation site by, for example, bioclimatic modelling (Breed et al. 2013).
- Climate-adjusted provenancing: The introduction of several nonlocal ecotypes sourced along a climatic gradient to increase genetic diversity; the strategy aims to introduce genotypes better adapted to a future climate.
- Composite provenancing: The use of a mixture of seeds from populations of increasing distance that attempts to mimic natural gene flow patterns (Broadhurst et al. 2008).
- Regional admixture provenancing: In contrast to local provenancing, the seeds are collected from several large populations and mixed to provide high genetic variability (Breed et al. 2013, Havens et al. 2015, Espeland et al. 2017, Bucharova et al. 2019). Collected seeds are mixed before sowing, generating a population with a mixture of genotypes from a wide array of provenances. The key component of regional admixture provenancing is delineating the regions. In principle, the requirements for regions are the same as for seed transfer zones: plants share similar environmental characteristics within a region, so their seeds can be transferred with no or negligible detrimental

effects on mean population fitness (Hufford and Mazer 2003, Durka et al. 2017). Collecting seeds from across different environments is important to build evolutionary resilience into the new plantings, as more additive genetic variation is introduced, which will give more opportunities for the population to successfully adapt to novel conditions (Breed et al. 2013). See also Appendix I for further discussion of problems with relying on "local is best" in seed provenancing.

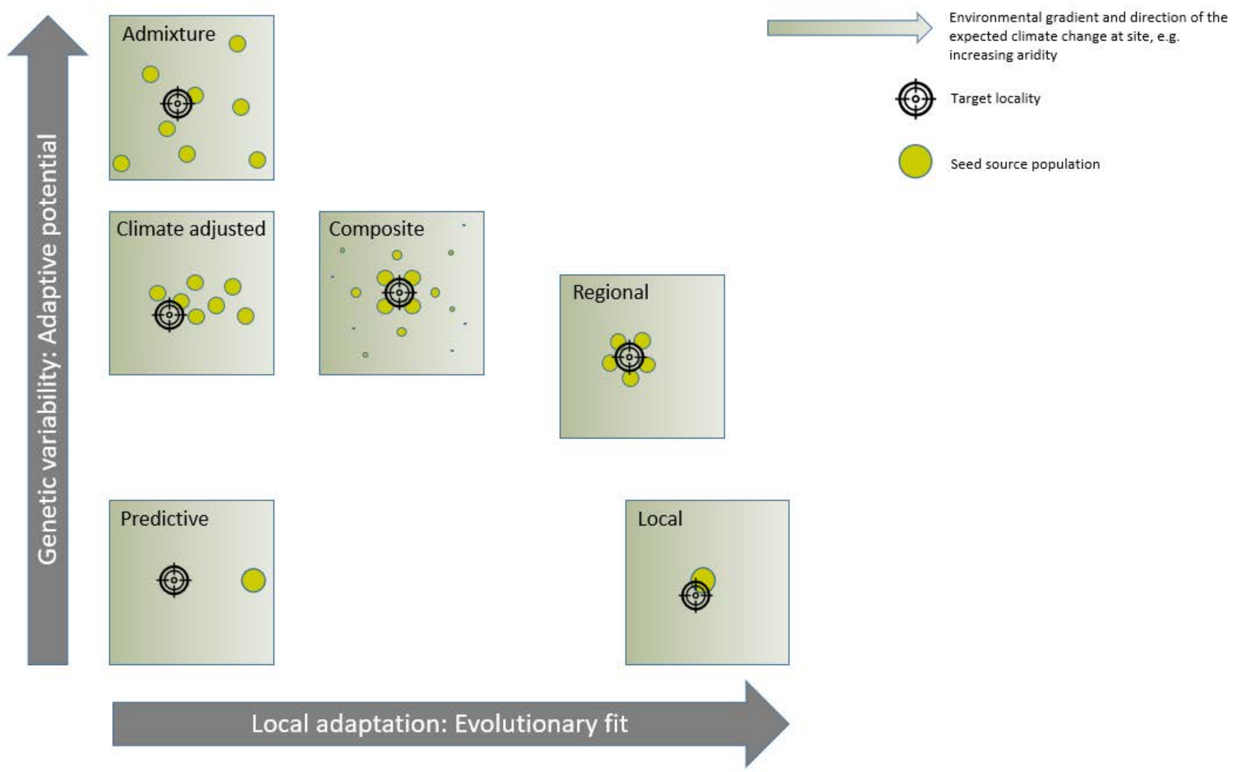


Figure 2.3.4-1. The position of different seed-sourcing strategies in relation to increasing local adaptation (evolutionary fit) on the x-axis and providing genetic variability (adaptive potential) on the y-axis. The differing sizes of seed-source populations reflect their relative contributions. Modified after Prober et al. (2015), McDonald et al. (2016) and Bucharova et al. (2019). See Appendix I for further discussion.

2.4 The Norwegian pollinator strategy

Revegetation measures have been highlighted also in the National pollinator strategy (2018) where any efforts to increase floral abundance and diversity are encouraged. While seed mixes containing only grasses do not have positive effects on pollinators, the use of meadow mixes can provide an abundance and diversity of floral resources for important pollinators. The limited availability, as highlighted in the strategy report, restricts the planting of flower-rich vegetation from Norwegian seed mixes. Subsidies are used to encourage farmers to plant pollinator friendly flower strips on parts of their agricultural land. Currently, most of these flower strips are planted with alien seeds, such as *Phacelia tanacetifolia* (lacy phacelia, *vanlig honningurt*). Planting with lacy phacelia is especially inviting to farmers because it also improves soils and suppresses weeds. Though *Phacelia tanacetifolia* is an alien species in Norway, it has been evaluated by the Norwegian Expert Committee for Seed Plants and found harmless (Artsdatabanken 2018).

3 Considerations when planting out vascular plants

As discussed in chapter 2, vascular plants are planted out as seeds or cultivated plants for different reasons. Regardless of whether the intention is restoration, rehabilitation, development of novel ecosystems or the introduction of species to enhance local biodiversity, several aspects should be considered before deciding whether to plant a given vascular plant species.

3.1 Reproductive strategy

A plant species' reproductive strategy determines how far and how fast the species can spread and introduce its genes to other populations. For a plant species that largely outcrosses, spread will be determined by pollination mode and pollinator resources (as well as by any vegetative propagation) and seed dispersal, germination success and seedling survival. A species that can self-pollinate (or that primarily spreads vegetatively) is less constrained by pollinator availability or pollen dispersal distance, so its rate of spread is determined by the efficiency of seed dispersal or vegetative propagation.

3.1.1 How is the species pollinated?

The reproductive ecology of vascular plant species heavily influences genetic diversity and genetic composition of populations in a given area. Development of local genetic adaptations is determined in part by the transport of pollen among flowers. Gene flow in species that are insect pollinated is limited by the flight distance of their pollinators, as well as by seed dispersal. Although honeybees and bumble bees can search several kilometres for floral resources, they normally forage within a much shorter range. As central place foragers they seek for floral resource hot-spots and then return to their hive or nest. Smaller (solitary) bees have much shorter foraging ranges. Plant species depending on drifting pollinators, such as butterflies, moths or dipterans have a higher probability of receiving, or donating, pollen at longer distances. Wind pollinated species can receive and donate pollen at larger distances. Wind pollination in particular increases the probability of genetic intermixing among local subpopulations (Thiel-Egenter et al. 2008). At the other end of the scale, plant species that depend largely on self-pollination usually exhibit low local genetic diversity but large differences in genetic composition among subpopulations (Charlesworth 2003).

However, it is difficult to use pollination strategy for insect pollinated plants as a separate criterion for evaluating risk associated with planting out various species. This is because most plant species are visited by a variety of pollinators with contrasting foraging behaviours (e.g. flight lengths), i.e. the plants are pollinator generalists (Waser and Ollerton 2006) .

Figure 3.1.1-1: Examples of plants pollinated by insects. *Erica tetralix*, klokkelyng, to the left and *Anthriscus sylvestris*, hundekjeks, to the right. Photos by Inger E. Måren

3.1.2 What is the species dispersal strategy?

Seed dispersal by animals (such as by clinging to fur or by being ingested and later spread through droppings) is especially effective for colonizing and spread (Moravcová et al. 2020). Below, we discuss different means by which species spread.

Figure 3.1.2-1: Sheep spread seeds caught in their fur and by ingesting seeds. Photos by Inger E. Måren

Figure 3.1.2-2: Examples of edible fruits, nuts and berries that promote the spread of seeds via ingestion or intended ingestion. *Fragaria vesca* (wild strawberry, *markjordbær*)*, Empetrum nigrum* (crowberry, *krekling*)*, Vaccinium myrtillus* (bilberry, *blåbær*) and *Corylus avellana* (common hazel, *hassel*)*.* Photos by Inger E. Måren

3.1.2.1 Vegetative propagation

Vegetative reproduction includes any form of asexual reproduction in which a new plant grows from a fragment of the parent plant or from a specialized reproductive structure, such as a stolon, rhizome, tuber, corm, or bulb. Germ cells are not involved, so vegetative reproduction produces a clone, which is genetically identical to the mother plant. Plants spread relatively slowly by vegetative means, slowing genetic mixing within and among local populations. However, alien invasive species, like *Reynoutria japonica* (knotweed, *parkslirekne*) and native species, like *Aegopodium podagraria* (ground elder, *skvallerkål*) and *Elymus repens* (couch grass, *kveke*), are mainly spread vegetatively. As even very small root fragments can produce adult plants, these species can have negative impact on biodiversity in areas where they spread prolifically. Similarly, the recent rapid spread of *Heracleum mantegazzianum* (giant hogweed, *kjempebjørnekjeks*) in Norway may be largely by stem and root fragments in soils moved in relation to construction projects (Artsdatabanken 2018). Dispersal by seeds seems to be relatively ineffective in giant hogweed (Fremstad and Elven 2006).

Figure 3.1.2.1-1: *Calluna vulgaris* (Common heather, *lyng*) resprouting from a stem fragment. Photos by Inger E. Måren

3.1.2.2 Seed dispersal

The distance over which plants disperse seeds depends on plant traits as well as environmental conditions, and can vary greatly in time and space. Seed dispersal mechanisms affect the spread of a species and gene flow among sub-populations. Seeds that are dispersed ballistically (where seeds are expelled forcibly) spread only a short distance from the mother plant, which limits the species dispersal and slows genetic mixing among local populations. This form of seed dispersal does not, however, limit a species ability to spread widely over time. *Impatiens glandulifera* (jewelweed, *kjempespringfrø*) is classified as a species with severe negative ecological impact in The Alien Species List of Norway (Artsdatabanken 2018). Even though it spreads by ballistic seed dispersal, it is one of the most successful invasive alien species in Europe and North America, in part because the seeds float and can be transported long distances by water (Deegan 2012). Wind, water and animals (usually by birds or mammals in Norway) spread seeds further away from the mother plant, thereby increasing the likelihood that local populations are genetically mixed. Hence, the genetic structure across the species' distribution occurs at larger spatial scales.

In a study comparing invasive alien species, Pyšek and Hulme (2005) found 16 species which spread more than 1 km/year by long-distance dispersal, with a maximum of 167 km/yr. They showed that the rate of spread may be similarly high for wind, water or animal dispersed plants. However, the landscape structure and human activity influenced the spreading, with higher dispersal rates in densely inhabited or particularly economically active regions (Williamson et al. 2005). The role of human activity in spreading plants, including invasive alien species, can be considerable (Svalheim and Sickel 2017).

Figure 3.1.2.2-1: Seeds of *Silene dioica* (red campion, *rød jonsokblom*). Seeds are shaken out of this pot-like structure when the stem is vibrated by wind gusts or touching. Photo by Inger E. Måren

Figure 3.1.2.2-2: Left: Seeds of *Galium aparine* (catchweed, *klengemaure*) stick to fur or clothing and can be transported long distances from the mother plant. Right: Seeds of *Taraxacum officinale* (dandelion, *løvetann*) can be transported long distances by wind. Photos by Inger E. Måren

3.2 Geographic considerations

Norway is a geomorphologically and climatically diverse country with ecological niches often in close proximity (see Figure 1.1-1). Within any landscape type there will also be variations in degree of human disturbance, from rural areas with no obvious human influence, to semi-natural landscapes, to more highly disturbed habitats and city centres with high human influence. Variation in human disturbance will affect the possible negative effects of introducing nonlocal plant species or populations. In rural areas with little human influence or semi-natural landscapes, plant species may have genetically distinct populations (see 1.1.1). The possible negative effects when sowing or planting nonlocal species (see 1.2.1) could be high in these areas, because the newly introduced populations might intermix with populations close by. In areas with high human disturbance, the genetic diversity is probably already intermixed, so the negative effect of nonlocal populations or species might be lower. In addition, the sowing/planting of nonlocal species in a city centre might have little negative effect on local species near the city, because the distance to local populations or species is longer than the dispersal ability of the plants. This will thus influence where ecological risk assessments are needed; more stringent assessments will be needed in rural areas and red listen nature types than in highly disturbed habitats and in city centres.

3.3 Biological considerations regarding planting of vascular plants

3.3.1 Is the species reported to be invasive, weedy, or otherwise problematic in Norway?

Invasive alien species have negative impacts on the ecosystems where they are introduced (see 1.5) (IUCN, 2000, definition used in this report). In addition to potential dangers of hybridization between native and alien species (Vila et al. 2000, Allendord and Lundqvist 2003, Ayres et al. 2004, Burgess and Husband 2006, Bleeker et al. 2007, Vinogradova and Galkina 2020) (see section 3.3.5), alien species may disturb current pollination networks (Bjerknes et al. 2007), alter microclimates (Dukes and Mooney 2004), alter the physical and biological properties of soils (Kuebbing et al. 2014a,b; Ward et al. 2020), or shift competitive relationships among species (Kuebbing et al. 2014a,b; Ploughe et al. 2020). Native species which are known to spread prolifically when transplanted should also be avoided (see section 3.2). In addition, native species can be problematic if moved long distances or out of their native range (regionally alien species). Bucharova (2017) cautions that transplanting native species over long distances can disrupt local biotic interactions, leading to unforeseen ecological effects. However, as she emphasizes, research on within-range transplantations (in this context) is largely lacking.

Further, "weedy" species (here understood as any plant that grows or reproduces aggressively, or is invasive outside its native habitat), such as *Anthriscus sylvestris* (cow parsley, *hundekjeks*) or *Chamaenerion angustifolium* (fireweed, *geitrams*) are unsuitable for use in revegetation, regardless of how local they might be. Other common species, such as *Leucantheum vulgare* (oxeye daisy, *prestekrage*), *Silene vulgaris* (bladder campion, *engsmelle*) and *Achillea millefolium* (yarrow, *ryllik*) are only considered weedy in some habitats (often disturbed habitats, such as road verges), and thus pose smaller threat to biodiversity than the above-mentioned species. Thus, species that are reported to be invasive or "weedy", either regionally in Norway or elsewhere, should be considered to pose a high or medium risk and individual ecological risk assessments are needed before use.

3.3.2 Is the species native to the region?

A species may be native to Norway but alien to the region into which it is intended to be introduced. The potential dangers for biodiversity of introducing regionally alien species are detailed in section 1.2.1 and include poor adaption to local conditions; potential for outperforming species in the local area; carry pathogens not locally present; may lead to hybridization with local species. Whether these potential dangers are realized depends on the biology and ecology of the particular regionally alien species. In this report, we use a 10 km radius to delineate the zone for safe seed or plant material collection. This is not based on empirical knowledge (which is largely lacking) but can rather be seen as a rule of thumb, adhering to the cautionary principle. It is similar to current guidelines in the UK and Australia (see section 1.1).

given enough

3.3.3 Is the species very patchily distributed within the region?

Species that are widely distributed in Norway and have large populations are expected to have high levels of genetic diversity, and there should be no genetic problems with moving plant material within their distributions. Conversely, when species are patchily distributed with large distances between populations, they likely have genetically distinct subpopulations, and the need for using local seeds becomes more important.

The genetic structures of plant species populations vary, and it is difficult to predict whether there are important ecological or genetic differences among widely separated populations without thorough study. In cases where a species is patchily distributed, negative consequences for local biodiversity can arise if the plant materials that are used for restoration or rehabilitation belong to species already present locally but originate from distant Norwegian populations, leading to intraspecific hybridization.

Potential negative consequences arising from intraspecific hybridization include reduced local adaption and lower competitive ability. The species most likely to suffer negatively are those with the strongest local adaptation. It should be noted, however, that introducing new genetic material to patchily distributed small populations can also have positive effects (see Appendix I on seed provenancing).

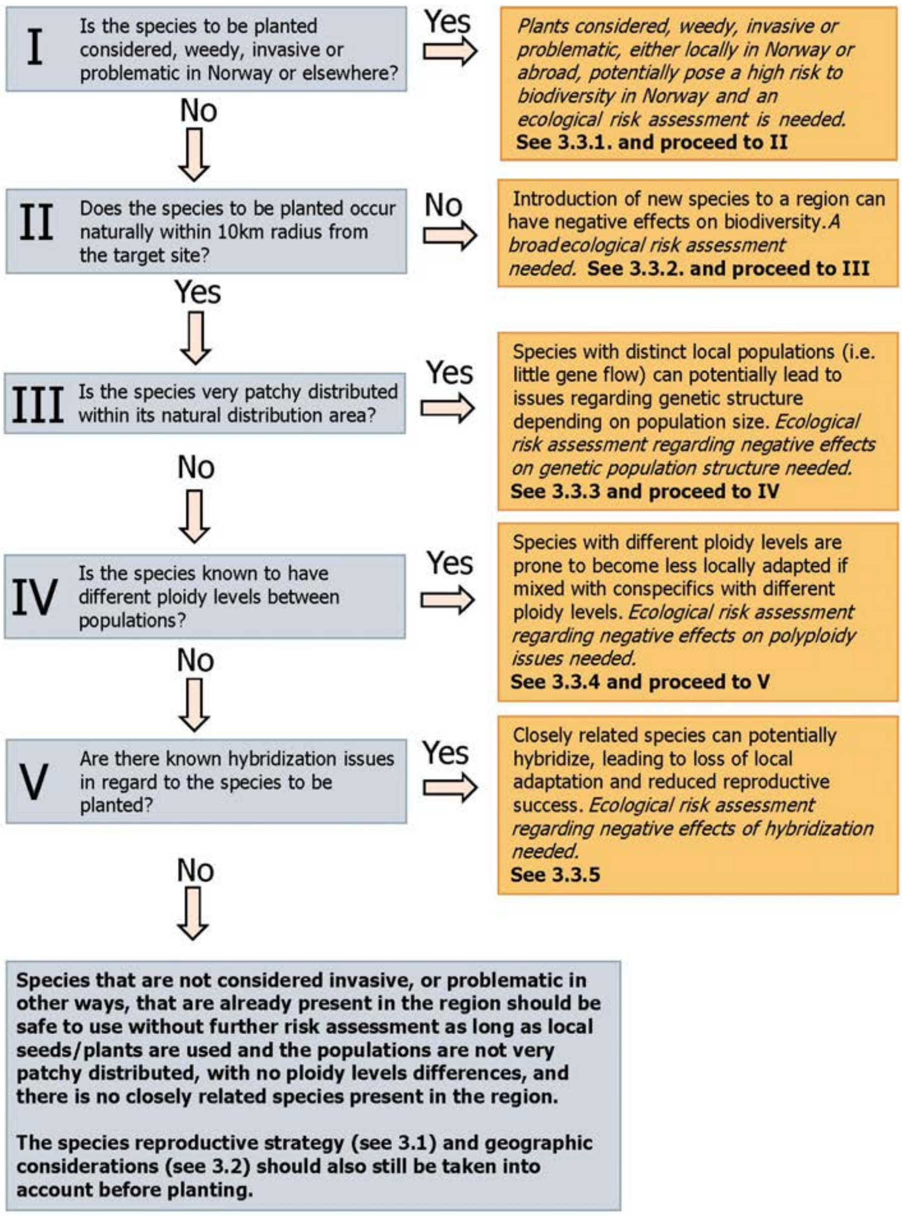
3.3.4 Ploidy level variation

Individuals of a species or species complexes can vary in the number of chromosomes or number of chromosome sets (in ploidy). Care must be taken to avoid mixing plants of different origins that differ in ploidy. Ploidy levels can vary among closely related species, between populations, or even within populations (Buggs and Pannell 2007, Rosche et al. 2016). Otherwise similar individuals that differ in ploidy are often isolated genetically, geographically or ecologically, though hybridization is possible in some cases (Johnson et al. 2003, Castro et al. 2019, Čertner 2020). Individuals resulting from crosses between parent plants differing in chromosome number often have reduced fitness and may even be sterile, posing a risk to mixed populations (Husband et al. 2002, McKay et al. 2005, Buggs and Pannell 2007, Čertner 2020). As pointed out above (1.7), there is some evidence that polyploids are often more invasive than diploids, perhaps because they have greater genetic variability (Moura et al. 2020, but see Buggs and Pannell for an interesting counterexample). Polyploidy is strongly associated with vegetative reproduction and hence polyploids can colonize than outcrossing species that are dependent on pollination (Herben et al. 2017). Some common species in Norway with ploidy differences among populations from different regions include Harebell (*Campanula rotundifolia,* blåklokke*),* Oxeye daisy (*Leucanthemum vulgare,* prestekrage*),* Spotted cat's ear (*Hypochaeris maculate,* flekkgriseøre*)* and Red Clover (*Trifolium pratense,* rødkløver*).*

3.3.5 Known hybridization issues?

Related plant species can, in many cases, interbreed and produce viable, fertile offspring. Therefore, introducing species that are closely related to species in or near the target site could result in hybrids. Hybridization can lead to genetic swamping (loss of local genotypes and hence of any local adaptation) or demographic swamping (lower reproductive rates due to outbreeding depression) (Burgess and Husband 2006, Ellstrand and Riesenberg 2016). Several species in Norway face this potential threat, including common plants, like sticky catchfly (*Viscaria vulgaris,* engtjæreblom) interbreeding with red alpine catchfly (*Silene suecica*, fjelltjæreblom) (Wilson et al. 1995), yarrow (ryllik, *Achillea millefolium*) where species boundaries are still unclear (Guo et al. 2005) and bird's-foot trefoin (tiriltunge, *Lotus cornuculatus*) which seems to have hybridize with *L. stepposus* forming a new species *L ucrainicus* (Kramina et al. 2012).

3.4 Flow chart for identifying potential hazards before planting vascular plants



3.4.1 Criteria used on a commercially available seed mix

In order to evaluate the suggested criteria found in the flow chart in section 3.4, the project group used "Tørrengblanding fra Sørøstlandet" from NIBIO for evaluation, a commercially available native seed mixewhere the origin of each population is listed. This seed mix is sold for use in southeast Norway, and we assessed each of the species according to the flow chart, using Drammen city centre as the focal area for seeding. For information, we used only readily available sources, like Lid's flora (Lid and Lid, 2006) and species distribution maps on the website www.artsdatabanken.no. By following the flow chart, we found that 7 of the 20 species in the seed mix could be planted in Drammen city centre without any further ecological risk assessment. Six of the species are considered weedy in certain environments and this should be given some consideration in relation to what type of habitat they are to be sown in. For seven of the species, we found that there are ploidy differences within populations in Norway. These would therefore require ecological risk assessment. Finally, five species have the potential to hybridize with other closely relates species or subspecies (including some alien species). These also require an ecological risk assessment. The results are summarised in Table 3.4.1-1. A new evaluation of the species according to the flow chart must be done for each new restoration or rehabilitation area.

Table 3.4.1-1: Results from testing each criterion in the flow chart (3.4) for each species in the seed mix from southeast Norway (NIBIO), with Drammen city centre as a focal point. Colour of the squares correspond to the boxes in the flow chart and thus indicate the need for risk assessment on each question. A new test for the species must be done for each new focal area.

Species / Question #	I	II	III	IV	V	Potential hazards
Harebell / blåklokke (*Campanula rotundifolia*)						Ploidy differences among populations and possible hybridization with subspecies.
Sheep's-bit / blåmunke (*Jasione montana*)						There are ploidy differences among populations but not within Norway.
Maiden pink / engnellik (*Dianthus deltoides*)						
Bladder campion / engsmelle (*Silene vulgaris*)						Considered a weed in meadows, road verges and highly disturbed areas.
Sticky Catchfly / engtjæreblom (*Viscaria vulgaris*)						Potential hybridization with *Viscaria alpina*

Species / Question #	I	II	III	IV	V	Potential hazards
Peach-leaved bellflower / fagerklokke (*Campanula persicifolia*)						There are ploidy differences among populations but not within Norway.
Scabious Knapweed / fagerknoppurt (*Centaurea scabosia*)						Considered a weed in meadows, road verges and highly disturbed areas.
Spotted cat's ear / flekkgriseøre (*Hypochaeris maculata*)						Known ploidy differences among populations in Norway.
European goldenrod / gullris (*Solidago vigaurea*)						
Hare's-foot clover / harekløver (*Trifolium arvense*)						Considered a weed in meadows, road verges and highly disturbed areas.
Viper's-bugloss / Ormehode (*Echium vulgare*)						There are ploidy differences among populations but not within Norway.
Oxeye daisy / prestekrage (*Leucanthemum vulgare*)						Considered a weed in meadows, road verges and highly disturbed areas. Unknown ploidy levels.
Perforate St Johns's-worth / prikkperikum (*Hypercium perforatum*)						There are ploidy differences among populations but not within Norway.
Common kidneyvetch / rundbelg (*Anthyllis vulneraria*)						Possible hybridization with alien subspecies.
Yarrow / ryllik (*Achillea millefolium*)						Considered a weed in meadows, road verges and highly disturbed areas. Known ploidy differences among populations in Norway. Possible hybridization with two subspecies.
Field scabious / rødknapp (*Knautia arvensis*)						Considered a weed in meadows, road verges and highly disturbed areas.
Red Clover / vill rødkløver (*Trifolium pratense*)						Known ploidy differences between populations in Norway.

Species / Question #	I	II	III	IV	V	Potential hazards
Ribwort Plantain / smalkjempe (*Plantago lanceolata*)						Known ploidy differences among populations in Norway.
Orpine / smørbukk (*Hylotelephium maximum*)						
Bird's-foot trefoin / tiriltunge (*Lotus corniculatus*)						Possible hybridization between the two native varieties and an alien variety.

4 Literature and Data

We conducted a literature search on Web of Science using the search terms "Ecological restoration"*"native seeds"*"local seeds"*"Europe" to gain an oversight over current literature in our region of the world. This search yielded 52 papers which we browsed for content relevant to this report.

In addition, we used snowball sampling in our literature selection. Snowball sampling or chain-referral sampling is defined as a non-probability sampling technique in which the samples have traits that are rare. This is a sampling technique in which already acquired literature is used to source additional literature to include in our mini review.

We also used snowball sampling in the sense that we contacted people in our networks working on restoration or seed production. They in turn suggested further contacts for gathering information (hence the term "snowballing").

We consulted regularly along the way with the Norwegian Environment Agency about direction and level of detail to be included in this report. Relevant national reports, both written in Norwegian and English, were browsed for relevancy and best practice in relation to terminology applied here.

5 Conclusions (with answers to the terms of reference)

VKM was asked to develop criteria for classification of possible adverse effects on biodiversity when planting and sowing vascular plants that occur naturally in Norway. We have identified two main hazards (possible adverse effects) to biodiversity in Norway with regard to planting or sowing plants in areas where they do not originate:

1. Outcrossing with genetically different individuals at the planting site. These crossings between regionally alien and local individuals can occur both within (cross-pollination) - and across species (cross-hybridisation) and lead to outbreeding depression, loss of local adaptations or the break-up of co-adapted gene complexes.
2. Introducing alien plant material could alter ecosystem structure by shifting dominance within the plant community or by altering species interactions (such as with pollinators or mycorrhiza).

To assess the magnitude of these two hazards, detailed information is needed on the population genetics of the planted species and the resilience of the ecosystem at the target site and in its vicinity. Such information rarely exists and is time consuming and costly to obtain. Given the lack of knowledge of the ecology and population genetics of most species, it could be argued that any introduction of alien plant material to a site might pose at least some risk to local biodiversity. Ideally, an ecological risk assessment should be done for all species to be introduced at any site. However, using the set of criteria outlined in this report would be a pragmatic approach to screening potential species and populations to use and thus selecting species and populations with lower risk of negative impact on biodiversity, while at the same time identifying which aspect of the plant that needs further assessment.

Although several plant traits have been proposed as important for predicting whether a plant species may have adverse effects when introduced to a new ecosystem (i.e., becoming invasive), none of the traits are conclusive, as numerous exceptions exist. It is also hard to use taxonomic relationship as a guidance to what level of risk a plant species might pose, as closely related species might differ in relevant traits.

To identify species that may have negative effects on local biodiversity when planted outside the source population’s range, we have defined a screening method that includes sets of criteria to be assessed: 1. Is the species reported to be invasive, weedy, or otherwise problematic in Norway? 2. Is the species native to the region? 3. Is the species very patchily distributed within the region? 4. Are there ploidy level variations? and 5. Are there known hybridization issues? We have designed a screening method in form of a flow chart that identifies high or low potential risk for target species. Species associated with a high potential risk should undergo a full ecological risk assessment to assess the actual risk, while species associated with a medium risk need only be assessed for the hazard in question. By use of this flow chart species that could be relevant for the Action Plan Against Invasive Alien Species, or species that could pose a threat to protected areas and endangered habitats will be avoided. We also emphasize that the use of flower seed mixes, sourced from local seeds can be of high benefit to pollinators, consequently being a means to fulfil the goals listed in the pollinator strategy report.

We have listed all Norwegian seed producers known to us that produce mainly seed mixes not containing grass seeds. We find that, too often, the geographic sources of seeds are not listed.

Regional plant breeding programs and transport of large quantities of seeds across large distances have most likely diluted local adaptations that might have existed. Currently, NIBIO is the only seed producer that has an emphasis on locally sourced seeds. The current volume produced is limited and the number of regions covered will not span the whole country before 2023. For the time being the volumes available are too small to cover the market demand, especially for larger projects, such as revegetation of long stretches of road verges. The number of species in the available seed mixes are highly variable among years and across regions and will most likely change in the future as new knowledge is gained on the production and the different species' success in revegetation projects. Currently, there are no flower seed mixes targeted at particular sectors. Given the limited production capacity, and high cost, currently seed mixes are only feasible for smaller projects.

Discussions about suitable seed sources often emphasises "local" in a very narrow sense or is based on political boundaries, rather than evidence for the scale of adaptation. Across Europe, countries are divided into provenance regions or seed zones, though the scale and number of zones vary from country to country, rather than directly with variation in climatic factors or the dispersal capabilities of the focal plants.

Over centuries, agricultural practices have facilitated the movement of seeds and other plant material across large distances in Norway. Livestock has been moved on a local scale between farms and summer grazing areas in the mountains (*setra*), on regional scales to trading events and at national scale between western and eastern Norway. Seeds have been moved along these transport routes attached to animal fur or while going through the livestock digestive system, and by the movement of hay. For plants that have been transported by livestock, what is currently "local" in a Norwegian context is most likely relevant only at large spatial scales, as these processes, causing loss of local adaptations and potential negative effect on ecosystems, have been operating for centuries.

6 Knowledge gaps

"Facing significant environmental change, revegetation needs to transition from the status quo to a more scientifically informed practice" (Breed et al. 2013).

There is a knowledge gap pertaining to the balance between benefits and costs of genomic admixture; we need to know more about the topics, such as genetic rescue, adaptation to environmental change and heterosis versus outbreeding depression, and the risks of invasive genotypes or species (Breed et al. 2013). Currently only limited information on population genetic structuring within Norway exists for most plant species used in Norwegian seed mixes. Without this information, it is impossible to define seeds that are local and scientifically grounded "seed zones" cannot be defined.

As many large revegetation and restoration projects are currently being initiated, it is important to integrate an experimental component by developing partnerships between environmental managers and researchers. Generating the scientific evidence required for best-practice restoration under future climatic and environmental conditions is a prerequisite for successful restoration of future landscapes. Projects must move beyond attempting to recreate pre-disturbance ecosystems, as this does not acknowledge that climatic and environmental change are ongoing processes that can occur rapidly with large effects (Thomas 2011, Breed et al. 2013).

Local provenancing is currently the predominant seed-sourcing strategy, but may not be the best approach given the concerns raised in Appendix I. According to Bucharova et al. (2019), we need to find compromise strategies that are based on well-designed and carefully analysed field experiments (Bucharova et al. 2017a; Breed et al. 2018) and genomic analyses (Durka et al. 2017; Williams et al. 2014) to identify the best seed-sourcing strategies for ecosystem restoration in a changing world.

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Appendix I

When is local sourcing not "best"?

For this report we were asked to address the hazards of using regionally alien plant materials for revegetation, assuming that the ideal solution would always be to use local sources. But there is active debate as to which seed sources are best to use for active restoration (Broadhurst et al. 2008, Sgrò et al. 2011, Breed et al. 2013, Havens et al. 2015, Bucharova 2017, Bucharova et al. 2019). Many of the assumptions underlying the "local is best" paradigm are without a strong scientific basis, and failure by scientists to recognize that serves to maintain misconceptions among practitioners (Broadhurst et al. 2008). There are important positive effects of using nonlocal seeds or plants for restoration as well as known potential negative consequences of requiring local sourcing of plant materials. For a variety of reasons, it can be better to use seeds or other plant material from nonlocal populations or from a mix of populations (Keller et al. 2000, Sackville Hamilton 2001, McKay et al. 2005, O'Brien et al. 2007, Bucharova et al. 2019).

When is local sourcing *not* be the best choice? We provide six arguments below.

(1) **Local adaptation cannot be assumed to be present:** if there is no local adaptation, then nonlocal populations from similar environments will not be at any significant ecological disadvantage. Wilkinson (2001) argues on theoretical grounds that locally adapted genotypes will seldom be an important reason to prefer local plant material (see also Weeks et al. 2011). Much of the research that has explored local adaption and natural selection in plant populations concludes that there is a lack of general patterns: species and populations vary in their degree, and spatial scale, of genetic structure, phenotypic plasticity and local adaptation (Jørgensen 2016, Bucharova 2017, Durka et al. 2017, Massatti et al. 2020). Broadhurst et al. (2008) and Leimu and Fisher (2008) argue strongly from empirical studies that local adaptation is less common than usually presumed (see also Frankham et al. 2011, Reiker er al. 2015, Shi et al. 2017; for a cautionary viewpoint see Bucharova 2017). Plant species are highly variable in their genetic structuring, so in most cases there will be a need for detailed species-specific studies to obtain information relevant to the question of whether a population is genetically distinct (and in this sense "local"). However, one cannot assume that finding genetic differences among populations (population genetic structure) equates with there being adaptive differences among

them (Lynch 1996).

(2) **Outbreeding depression may not be a potential problem.** Whether or not local adaptation is apparent, populations can differ enough in genetic composition that hybridization between separated populations of the same species can lead to outbreeding depression, where offspring of interpopulational crosses have lower fitness than do offspring of within-population pairings. Avoiding outbreeding depression is commonly used as one argument for local sourcing of plant materials. A population genetics model developed by Frankham et al. (2011) found that the conditions that would lead to outbreeding depression are fairly restrictive and unlikely to be common in nature. They point out that when outbreeding depression does occur, it would be expected to be short-lived under most circumstances, and they conclude that concerns about outbreeding depression are exaggerated. A slightly more recent meta-analysis (Whitlock et al. 2013) came to similar conclusions: while lower reproductive fitness due to intraspecific hybridization was often detected, it was fleeting, and there was considerable heterogeneity among studies in fitness-related consequences of population outbreeding. They concluded simply that costs to population outbreeding will not always occur.

(3) In specific cases, increasing the availability of pollen and nectar may be **an overriding concern**, one that might sometimes best be met by using species not historically present or by using regionally alien subspecies or ecotypes that better meet this priority. introducing certain alien species can augment nectar and pollen availability in plant communities where these are limiting resources for native insects. Similarly, plants providing key nutrients to insects might be prioritized in the context of insect conservation (Filipiak 2019), whether or not they can be locally sourced.

(4) **Local populations that are small** would benefit from an input of plant material from other populations. Translocation—deliberately introducing individuals of regionally alien populations or species—is an important conservation biology tool for either (a) genetic rescue, countering the effects of inbreeding in small local populations, or (b) improving the adaptive potential of local populations by increasing genetic variation (Weeks et al. 2011). the injection of new genetic material into small, inbred populations can rescue them from extinction and better prepare them for adapting to future changes in the environment precipitated, for example, by rapid climate change (Weeks et al. 2011, Bucharova et al. 2019). There is strong evidence that small, inbred populations can indeed be rescued by crosses with conspecific populations from similar environments (reviewed in Frankham 2015). Maschinski et

al. (2013) worry that many reintroductions of locally extinct species may be doomed to failure by narrow "local is best" policies.

(5) Selected **regionally alien** material—or a mixture of local and selected nonlocal material—**can be better adapted to future environmental conditions** than would local. It is increasingly being argued that local plant communities may often harbour insufficient genetic variability to meet the challenges of a rapidly changing climate. Local plants—particularly long-lived ones—are adapted to past environmental conditions and may lack necessary genetic variation to meet the demands of future, changed conditions (Hoffmann and Sgró 2011, Wilkinson 2001, Bucharova et al. 2019). In a clear example of this, Gross et al. (2017) found that nonlocal seeds of an Australian shrub performed better than did local seeds, when grown under conditions mimicing those expected from climate change (but see Bucharova 2017 for counterexamples). Thus, from an evolutionary management perspective, using well-chosen nonlocal sources for plant material could potentially contribute positively to biodiversity conservation in an era of unprecedentedly rapid climate change (Smith et al. 2014).

(6) A "local is best" attitude is becoming increasingly untenable in the context of inexorable **climate change** in Norway, which takes the form of steady increases in average temperature, regular increases or decreases in annual precipitation, and an increased frequency of extreme weather events. In many parts of Norway, current, "local" mean precipitation and temperature means and annual patterns will be quite different within just a few decades, and many regions are already experiencing increasing frequencies or durations of drought, extreme precipitation, or unusually strong wind storms (https://miljostatus.miljodirektoratet.no/tema/klima/klimaendringer-i-norge/).

Given these genetic, ecological and evolutionary considerations, adhering strictly to "local is best" for guiding revegetation could result in *negative* effects on biodiversity (Maschinski et al. 2013, Albrecht and Edwards 2020). Species likely to benefit most from plantings of foreign-sourced plant material are those in dangerously small populations. However, in the context of climate change, with carefully chosen donor populations (Weeks et al. 2011, Bucharova et al. 2019), many or most locally occurring species could benefit from increased genetic variation and from the introduction of genotypes better adapted to future conditions.

Efforts to re-establish native species should target evolutionary potential as well as ecological processes (Hoffmann and Sgró 2011, Smith et al. 2014, Hufford et al. 2016). Following "local is best" cannot do so. A restoration process should also aim at establishing sufficient genetic variation required to ensure the long-term success of the restored plant community. Simply augmenting or reinforcing (a) current genetic distinctiveness (the current "local" gene pool) or (b) adaptation to current conditions (local adaptation) might not meet the goal of being able to meet future challenges, especially when climate change is accelerating: the ongoing rapid climate change that Norway is now experiencing is creating an evolutionary mismatch between "local" species and their current or near-future environments and is rapidly devaluing any local adaptation that might exist (Smith et al. 2014). Local populations are often small and harbour insufficient genetic variability for the restored populations to be able to adapt to and survive global change (Hoffmann and Sgró 2011). Instead, alternative strategies are proposed, such as mixing seeds from various sources to increase genetic variability and adaptive potential (Hoffmann and Sgró 2011, Weeks 2011) or using seeds from populations that have a similar climate as predicted for the target locality in the future (Bucharova et al. 2019).

With regard to biodiversity or conservation biology concerns, the most important negative effects can be if regionally alien plant materials lead to invasive plant problems, reduce the quality or quantity of ecosystem services, or lead to intraspecific hybridization that lowers the fitness of local populations. However, negative consequences of using nonlocal plants are likely to be of little importance if these effects are isolated to a small target area.

On seed provenancing strategies

An increasing number of studies raise concerns over the suitability of local populations as sources of seeds or other plant materials (Lesica and Allendorf 1999; Wilkinson 2001; Kramer and Havens 2009; Johnson et al. 2010; Mijnsbrugge et al. 2010; O'Brien and Krauss 2010). Additionally, concerns have also been raised relative to local overharvesting or to the possibility that local populations have limited genetic variability (Mortlock 2000; McKay et al. 2005; O'Brien et al. 2007; Broadhurst et al. 2008; Kramer and Havens 2009; Bischoff et al. 2010; O'Brien and Krauss 2010). These concerns have led to the development of a range of alternative seed-sourcing strategies* that aim to more fully capture evolutionary processes to deal with changing environmental conditions and that take into account key genetic issues associated with disturbed landscapes (see 2.3.4).

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* We discuss origins of seeds here, as do most papers dealing with this topic, but the same provenancing arguments apply to other plant materials.

Concluding remarks

If one concludes, on balance, that the default strategy for revegetation should be some mixture of plant materials that is not purely of local origin, then restoration projects can be viewed as opportunities for proactive measures to maintain healthy levels of local biodiversity (prescriptive evolution: Smith et al. 2014). Besides increasing the evolutionary potential of local populations, regional admixture may boost plant performance, when local adaptation is weak or absent, as shown in reciprocal transplant experiments with *Lythrum salicaria* (purple loosestrife, *strandkattehale*; Shi et al. 2017). Such a strategy could be achieved by melding climate-adjusted provenancing and regional provenancing (Bucharova et al. 2019).