***On farm* plant reintroduction: a decision framework for plant conservation translocation in EU agro-ecosystems**

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ABSTRACT

The increased demand of food produced through sustainable agriculture has resulted in localised amelioration of intensive management imposed by agroecosystems. However, these newly available niches are often isolated and plant species may not be able to recolonise fragmented agroecosystems from where they have been extirpated. Plant reintroduction can overcome dispersal limitation in agroecosystems but may also generate conflicts that jeopardise conservation efforts. Conflicts arise when reintroductions are perceived to place constraints on the management and productivity of agroecosystems: the translocated plants may require space sharing with crops, may have negative effects on crop yields, and come with the expectation that farmers must modify their farming practices and accommodate legal obligations deriving from protected species status. Benefits include economic incentives that pay farmers through CAP, the conservation of nature, ecosystem services, an effective marketing strategy and increased aesthetic value that might generate ecotourism.

We discuss the practical implications of the abovementioned issues by reference to two cases of European species in which different approaches to reintroduction resulted in opposite outcomes (i.e., consensus vs. opposition). Coexistence of threatened plants and crops is possible if farmers and local stakeholders are involved in a conservation project from an early stage and if farmers conservation efforts turn into benefits for their income. Based on these considerations, we propose a strategic framework to promote reintroduction of threatened plants in agroecosystems (land sharing) and policy advancement aimed at recognising the role of farmers in maintaining biodiversity on their lands.

KEYWORDS: arable species; EU Common Agricultural Policy; land sharing; organic farming; plant translocation; sustainable farming

INTRODUCTION

Agriculture supports the increasing human population through the production of food and other commodities. Nevertheless, agriculture-related practices are among the most significant threats for wild plant diversity worldwide, with increasing environmental impacts foreseen by 2050 and beyond (Tilman et al., 2011). Land clearing, habitat fragmentation, and excessive use of chemicals and fertilisers are the main factors affecting plant diversity in intensive agricultural landscapes (e.g., White & Boutin, 2007; Meyer et al., 2013).

Recently, national and international regulations, as well as an increased demand of food from sustainable and specially from organic agriculture, have triggered the amelioration of environmental conditions in areas of intensive agriculture, at least in more developed countries (Henle et al., 2008; Tuomisto et al., 2012). Examples of these regulations are the European Union Directives for the reduction of water pollution (Nitrates Directive 91/676/EEC; Water Framework Directive 2000/60/EC), the Directive on the sustainable use of pesticides (e.g., glyphosate; Directive 2009/128/EC), and the Habitats Directive 92/43/EEC, with the latter representing the main legal conservation framework in the EU, through the establishment of an EU wide network of protected areas, including semi-natural habitats worthy of conservation (the Natura 2000 network includes 10.6% of the cultivated lands in EU; Olmeda et al., 2018). More recently, key commitments from the EU Biodiversity Strategy adopted in May 2020 by the European Commission include at least 10% of agricultural area under high-diversity landscape features by 2030.

Despite these measures, in most developed countries threatened plant species have already disappeared from areas of intensive agriculture, in particular arable species (Meyer et al., 2013) and the same is expected in the future in developing countries, following agriculture intensification (Bilz et al., 2011; Zabel et al., 2019). Arable plants have been shaped by farming practices over several millennia, following the movement of human populations and crop seed lots traded in commercial activities, and they have evolved with agricultural practices, e.g., tillage, sowing, or harvest (Gaba et al., 2017). Contrary to weeds that can also inhabit a range of non-cultivated habitats (Munoz et al., 2020), arable plants often have no natural habitat outside of crops, as for instance *Bromus* species of the *grossus-secalinus-bromoideus* complex (Koch et al., 2016). In Europe, 582 arable plant species are listed as rare or threatened (Storkey et al., 2012). Plants strictly linked to agro-ecosystems do not generally recolonise their original habitat after extirpation, and where populations can escape destruction, they remain confined to relict habitats which are fragmented in a crop landscape (on farm). Thus, the recovery of many threatened species to pre-Green Revolution levels is constrained, unless they are intentionally reintroduced in their historic locations.

Reintroduction (IUCN, 2013) of arable plants within agro-ecosystems has been proposed to improve their conservation status (Lang et al., 2016) and is one of the practices implemented in "nature-inclusive agriculture", a recent approach that is at a relatively theoretical stage in development (Oberč & Arroyo Schnell, 2020). However, economic pressures driving farmers in highly productive lands often creates conflicts with conservation biologists and others promoting nature-centric approaches. It also consolidates the firm opposition of local stakeholders and policy makers to the intentional release of threatened and protected plants in agricultural landscapes, species that would often be perceived as potential weeds.

For farmers, perceived issues include potential detrimental effects on crop yields, weed control, legal constraints deriving from protected species, and increased costs associated with threatened plant management. Reintroductions of arable plants are not consistent with the conventional farmer's 'vision' of agriculture that has typically been shaped by economic drivers to increase yield and decrease impurities in crops and seed (Piqueray, pers. comm.).

In this paper, we outline the reasons why farmers are often reticent to agree to the reintroduction of threatened plants on their lands, explain how information and communication strategies can positively or negatively affect the perception of reintroduction among farmers, and describe how the process of reintroducing threatened plant species in agro-ecosystems should involve local stakeholders (i.e., farmers; NGOs) and policy makers. Our aim is to define a framework for facilitating the reintroduction of arable threatened species in agricultural landscapes and contribute to the development of a policy that integrates the conservation needs of species at risk of extinction and the production goals of farmers (e.g., Agenda 2030 Sustainable Development Goals 2, 12, 15; Brussaard et al., 2010). The framework can also be applied to other taxa associated with agricultural landscapes that are not strictly arable plant species.

CONSTRAINTS TO PLANT REINTRODUCTION IN AGRO-ECOSYSTEMS

Plant translocations into protected areas achieve higher success rates than outside protected areas (Godefroid et al., 2011) and reduce the risk of conflictual interactions with humans, a topic well known to wildlife conservation biologists (Pearce et al., 2017). However, some plant species depend on traditional agricultural practices. Vascular plants adapted to arable habitats need regular disturbance to survive. Due to changes in agricultural practices, a decrease in crop diversity and excessive use of chemicals, the arable flora is among the most vulnerable groups in western Europe (Storkey et al., 2012).

Plant reintroduction in areas of agricultural value present several concerns. Firstly, stakeholders' (i.e., farmers, landowners, farmer associations, local policy makers) concerns include space sharing with reintroduced species. Some focal species may require the maintenance of set-aside areas that may limit the full farm operational capacity. Secondly, the reintroduction of plant species into agro-ecosystems implies that threats posed by intensive cultivation practices are removed or significantly reduced. A decrease in the use of chemicals may have negative consequences for the capacity to control weeds; focal species may also become weeds once the chemical control is removed or reduced. A third possible concern is that the modification of farming practices required to maintain favourable conditions for focal species may increase the costs of production or reduce the working efficiency of farms (Table S1). Although it is not a general rule, mechanical weed removal is sometimes more expensive than overall spraying (George & Brennan, 2002; Whiltshire et al., 2003). Finally, legal obligations associated with the reintroduction of protected species and the conservation of biodiversity more generally, are often perceived as a loss of income by farmers. In an era of low prices in agriculture, policy makers are cautious not to introduce constraints to productivity.

Whether perceived or real, such concerns are exacerbated by a typically conservative culture in rural areas and prevent the reintroduction of plant species in a context of intensive agriculture, even when threats due to environmental quality are removed.

TWO OPPOSITE CASE STUDIES

Reintroduction of *Marsilea quadrifolia* in organic rice farms of Italy: a bottom-up approach

Marsilea quadrifolia L. is a widespread aquatic pteridophyte declining in Europe (Bruni et al., 2013; Corli et al., 2021a). Considered to be a weed of rice fields, *M. quadrifolia* has been almost completely extirpated in northern Italy, the main area of rice production in the EU. *M. quadrifolia* begins to die at 0.001% of the recommended dose of the most common combinations of herbicides used in the cultivation of rice (Bruni et al., 2013). In 2017, this information was shared amongst a group of about twenty organic farmers (Orlando et al., 2020) interested in the use of *M. quadrifolia* as an indicator of organic farming. Bioindicators can often provide more reliable information than soil, water or crop chemical analyses that might not detect occasional use of banned products. Three farmers consented to the experimental cultivation of *M. quadrifolia* on their farms to demonstrate that their cultivation methods were compatible with the presence of this plant (Corli et al. 2021b). Interestingly, the group of organic farmers also proposed to use *M. quadrifolia* as a marketing strategy. By developing product labelling that declares the presence of *M. quadrifolia* on their farms, they expect to gain commercial advantages over conventional producers.

This opportunity might be adopted by other organic farmers, or even conventional farmers where the recent use of highly selective chemicals (Ruffner & Barnes, 2010; Lincoln et al., 2018) presents new nature conservation opportunities, once limited to organic farming systems. *M. quadrifolia* may also occur in conventional farming in which selective herbicides or reduced supply of chemicals are applied (Corli et al., 2021).

While the potential to utilise bioindicators presents a win-win situation benefiting both farmers and threatened species, this approach is not without its limitations. In this case, the inclusion of *M. quadrifolia* in the Annex II of EU Directive 92/43/EEC presents obstacles to wider adoption. Populations of species listed in this Directive (including reintroduced ones) should be included in the Natura 2000 network through the establishment of a Special Area of Conservation (SAC), i.e., "*site of Community importance designated by the Member States through a statutory, administrative and/or contractual act where the necessary conservation measures are applied for the maintenance or restoration, at a favourable conservation status, of the natural habitats and/or the populations of the species for which the site is designated*" (Directive Habitat, 1992). Consequently, the experimental cultivation of *M. quadrifolia* is limited to farms included in existing SACs (i.e., "Garzaia della Rinalda" – IT208005; "Boschi del Ticino" IT2080301) that were established to protect Ardeid nesting sites, and not for the presence of suitable ecological conditions for *M. quadrifolia*. The previous inclusion of a farm in a SAC may provide important benefits for farmers, like the opportunity to participate in the LIFE+ funding programme (the rich funding framework dedicated to species and habitats of conservation interest in the EU) whilst avoiding the imposition of additional legal constraints upon reintroduction *M. quadrifolia*. However, the land surface available for the reintroduction of a target species in existing SACs may be limited, especially if SACs were established for the occurrence of other species. For arable species not listed in the Habitats Directive, the reintroduction may be undertaken outside protected areas, so the above constraint is overcome.

Conventional farmers against *Bromus bromoideus* reintroduction in spelt fields in Belgium

Bromus bromoideus (Lej.) Crép. (Poaceae) is an annual species endemic to southern Belgium and northern France, exclusively restricted to spelt fields (de Cugnac, 1954). The species is strictly protected under Appendix 1 of the Bern Convention. From the end of the 19th century, it became progressively rare and, since being observed *in situ* for the last time in 1935, *B. bromoideus* was declared to be extinct in the wild. The progressive replacement of spelt with wheat is the main reason for its extinction but additionally, cultivated fields have been transformed into grasslands due to increasing livestock farming and the growing dairy industry, and improved seed cleaning processes may also have contributed to the extinction of the species (Piqueray et al., 2018). Fortunately, the plant still exists in several *ex situ* collections, and seeds stored for decades at 5% moisture content and -20°C have maintained good viability (Godefroid et al., 2020). Moreover, after the gradual abandonment of spelt a few decades ago, this cereal is currently regaining interest among farmers, with 13,176 ha planted in the southern half of Belgium (SPW, 2019), including a significant part of the historical range of *B. bromoideus*. The possibility of a *B. bromoideus* reintroduction was therefore raised and a feasibility study was carried out by Liège University to assess to what extent the reintroduction of the species would be possible. Next to biological and agronomical aspects, sociological constraints were examined by analysing results from a questionnaire survey intended to farmers and conducted by telephone (Danhieux et al., 2010). The objective of this survey was to collate the views of conventional farmers on the reintroduction of *B. bromoideus* and their willingness to participate in a possible action plan. A list of farmers located in the natural distribution area of *B. bromoideus* has been obtained from the regional authorities. As this list included 9026 contact details of farmers, a random sample resulted in a total of 117 phone calls generating the following results (Danhieux et al., 2010):

- 65% of the interviewed farmers were aware that wild species from cropland are endangered;
- 56% of them have observed a decline in the presence of such species throughout their career;

- 7.5% of them have already heard of *B. bromoideus*;
- 57% of them believe that species reintroduction is a waste of money;
- 20% of them consider reintroduction as being against nature;
- 52.5% of them were indifferent to or little worried by the decline of biodiversity in cropland;
- 57.5% of them consider that the loss of biodiversity in cropland is an inevitable consequence of production necessities;
- 30% of them would not in any way participate in a reintroduction project;
- 27.5% would like financial incentives to offset yield loss;

The results of this survey show that, in general, conventional farmers in the target area do not seem willing to participate in the reintroduction of *B. bromoideus*, thus showing the challenge that such conservation measures can represent in the agricultural landscape. However, where farmers identified a benefit (specifically financial incentives), more than a quarter of farmers may support a reintroduction. Recent contacts with organic farmers in the same region show that they are much more receptive than conventional farmers to the idea of reintroducing wild species into their crops. For a closely related species, *Bromus grossus*, there are now between 30 organic farmers in Belgium who participate in its reintroduction by annually sowing a mixture of cereals "contaminated" with *B. grossus* (Piqueray, pers. com.). One of these has recently started working with regional authorities on the reintroduction of *B. bromoideus*.

FRAMEWORK FOR PLANT REINTRODUCTION IN AGRICULTURE LANDSCAPEs

Premises

The cases reported above are just two examples, but they sit comfortably within emerging theory around stakeholder engagement and participation in environmental management more generally (Reed et al., 2017). These include the very different contexts within which the reintroductions might occur – one being characterised as 'pro-environmental' and therefore receptive to conservation aims, and the other being concerned with efficient farming to maximise yield and apparently therefore, representing an intractable conflict between agriculture and species restoration. These cases also seem to confirm the divergence in opinion and attitudes between two worlds with different approaches, i.e., conventional vs. organic farming.

The opportunities for engagement through possible mechanisms like product-labelling represent a benefit to organic farmers that would not be as attractive to conventional farmers, but the crucial aspect of these mechanisms is that they shift the balance of power and influence to the farmers rather than conservationists – the bioindicator properties of *Marsilea quadrifolia* offer an opportunity which farmers can exploit thereby encouraging farmers to seek out opportunities for reintroducing this plant rather than being passive hosts to a species that someone else has prioritised for restoration. This contrasts with the top-down requirements of legislation for species restoration on agricultural land which removes power from the landowners where it is enacted.

When evaluated against stakeholder participation frameworks (Reed et al., 2017), these case studies suggest that reintroducing threatened plant species in areas characterised by intensive agriculture (which can be classed as one form of land sharing; Balmford et al., 2012) can generate conflicts with local stakeholders. To minimise conflicts, plant translocations to agro-ecosystems might emulate the approach to animal translocation in an urban context (van Heezik & Seddon, 2018), by providing a framework for plant reintroduction in agro-ecosystems that includes a commitment to constructive interactions between farmers, local stakeholders and conservation biologists, and an analysis of whether reintroductions are socially and economically feasible and acceptable aside from considerations around technical feasibility (Figure 1). Social and economic feasibility (IUCN/SSC, 2013) means that the reintroduction of a focal species should not substantially interfere with the farming activity and in return, farmers perceive the benefits of accommodating a focal species and the wider issue of facilitating more biodiverse farmlands (Paracchini et al., 2015). In other words, such a strategy should minimise the conflicts between plants and farmers by balancing potential positive outcomes against the perceived risks. Based on the above considerations we propose a framework to involve farmers in the reintroduction of plant species in areas of intensive agriculture that stands on two main axes: benefits for farmers and policy advancement (Figure 1).

Benefits for farmers

1) Identify potential benefits that a focal species may provide to farmers. This may include several types of ecosystem services, access to funds for biodiversity conservation, more effective marketing strategies, and direct utility of the focal species (Table S2). Examples of ecosystem services provided by arable weeds include reducing soil erosion (e.g., on field edges), enhancing soil organic carbon (Ruiz-Colmenero et al., 2013), and improving yields of pollinator-dependent crop systems (Garibaldi et al., 2016). In intensively-grown cereals, arable weeds can also play an important role in restoring invertebrate populations, provided they cover an area equal to at least 10% of the field (Smith et al., 2020). Mixed crops of cereal and arable species are one of the approaches to maintain and preserve landscapes through agricultural systems like "high nature value farming" (Oberč & Arroyo Schnell, 2020). High biodiversity landscapes provide cultural services through, for instance, the well-being associated with seeing the colourful arable flora, which might also enhance the aesthetic value of a landscape and increase ecotourism. Some weeds can even be used as a food (see Table S2). Focal species that neither provide direct benefits nor generate conflicts may also be considered depending on farmers' commitment to sustainability. Payments for biodiversity achievements in agriculture are already implemented in several countries or regions. In Belgium, farmers receive aid payments of 1,250 EUR/ha to set up strips of arable weeds (12 m wide) located at the field margin (Piqueray et al., 2018) and although uptake of such payments was minimal in the 1990s, there is a now greater appetite for diversifying income streams and benefiting from alternative agricultural practices (Piqueray pers. com.). In the German region of Northeim, farmers are even paid according to the richness of arable weeds present in their fields (Ulber, 2009). The Lombardy Region in Italy provides incentives ranging from 175-500 €/Ha for the conservation of some habitats listed in Directive 92/43/CEE. Arable plants can also become a tracer of ecological practices for the consumer. The current environmental crisis has shown that a growing proportion of the Western European population is favouring small local producers in order to obtain quality food (Feldmann & Hamm, 2015). There is even a growing tendency for these consumers to visit the sites where the products they buy come from. Agricultural plots that have a rich arable flora can therefore represent a guarantee of production quality for the consumer.

2) Promote communication. The benefits of reintroducing a focal species should be communicated to farmers, agriculture-related policy makers and people living near the farms, in a clear but rigorous way. Direct interaction between farmers and conservation biologists is the best strategy to involve local stakeholders in the process, for instance during agriculture-related events. Farmers often learn from their neighbours (Piqueray pers. com.) and may in this way incorporate ecological and biological concepts in their technical background of the farming process (for example, biological control of pests is a typical ecological concept now well understood by farmers). Scientific publications or conferences are less accessible and can be counterproductive due to the jargon used. Importantly, communications should not be directed only towards farmers or policymakers, but also to consumers, that should be made aware of the importance of arable species and other taxa living in an agricultural landscape. Consider for example the case of *M. quadrifolia*: a labelling and marketing strategy would be effective only if consumers have the cultural awareness to recognize the conservation of *M. quadrifolia* as a valuable endeavour. This type of communication relates more with the engagement of the general public into biodiversity conservation matters, but it may also be delivered directly with a product, by using, for instance smart labels with a QRcode and links to further information.

3) Communicate solutions, not uncertainties. The way scientists disseminate their message is often made ineffective by the uncertainties behind their statements. Typical scientific communication styles convey phenomena as probabilities, or might describe ranges of values which are bounded by confidence intervals, but these are inaccessible to many non-scientists and should be avoided. Whilst recognising that predictions are always affected by some degree of uncertainty, scientists should offer precise and certain solutions and take the responsibility for the solutions offered. One way to achieve this is to propose an adaptive approach where different scenarios are matched with exit strategies that can minimise negative impacts to farmers.

4) Involve farmers practically from the very beginning of the process. Reintroduction projects should directly include farmers as beneficiaries of funds (e.g., farmers are eligible to receive funds from the EU LIFE+ funding programme) and allow their involvement in practical operations (e.g., allowing them to plant the first plants, helping with report and monitoring, etc.). While the former can provide financial benefits, the latter increases the emotional investment in the project which also helps in creating a synergy between the production and conservation views. Farmers' involvement in field monitoring is also crucial as this allows them to realise that in most cases only minor impacts are produced by a reintroduction programme. The latter aspect is very important, and one of the primary motivations for joining the projects described above was that they do not fundamentally change the operational capacity of the farm.

5) Train farmers to maintain reintroduced focal species. Farmers and landowners spend much of their time in their fields, so they are the best monitors and managers for the reintroduced populations of a focal species. Training is necessary to adapt farming practices to the presence of a focal species. This may include training in new techniques increasing the efficiency of a farm and have economic returns independently from the management of the focal species. These modifications in practice might be more readily accommodated where there is an appetite for de-intensifying agriculture as a result of younger farmers coming into the sector (Piqueray pers. com.).

Policy advancement

Not surprisingly, the most difficult issues to resolve are the legal constraints associated with species protected at the local or higher levels. Local opposition to the designation of protected areas (including Natura 2000 sites in EU) is based on the fear of restrictions from established agro-environmental practices (Henle et al., 2008). So, policy adjustments are needed to reduce stakeholder perception that maintaining threatened species *on farm* is economically detrimental.

First, in the EU there are already incentives for farmers aimed at “restoring, preserving and enhancing ecosystems related to agriculture and forestry” from the CAP. These include semi-natural habitats like mountain grasslands or wet meadows of conservation importance and the species occurring in such habitats. Specific funds (from the Rural Development Programme (RDP)) for conservation and management measures are available and accessible to farmers for maintaining these habitats in a “favourable” conservation status, according to the principles of the Directive 92/43/EEC.

Second, for species listed in the EU Habitat Directive, there is the opportunity for farmers to participate in the EU LIFE Programme for the conservation of species/habitat of Community Importance. These benefits are not marginal, because Natura 2000 sites contain 10.6% (i.e., 22.2 million ha) of the total EU agricultural land (Olmeda et al., 2018).

Indeed, further policy improvements may help solving plant-farmer conflicts and promote a more general acceptance of reintroduction of threatened species in agro-ecosystems:

- Increase the values of subsidies/incentives: this is justified by the fact that the whole community benefits from farmers that maintain and increase biodiversity in their lands. Incentives should be directed to the conservation of species, not only habitats, and be worth the conservation effort. Higher incentives are expected to increase the interest of farmers in arable species translocation to their farms as highlighted by the result of the survey on *B. bromoideus* (see above);

- Overcome legal constraints for the use of wild protected species as side products of the farming activity. This may also open new opportunities related to social changes (e.g., *M. quadrifolia* is eaten in South East Asia and may become commercially interesting for immigrants; Kosaka et al., 2013). Protected areas (including Natura 2000 areas) should put in place rules and management practices that take into account the role of farmers in the conservation of the landscape, fauna and flora and favouring product trade (e.g., by creating quality brands recognising the conservation efforts of farmers and that compensate potential economic losses).

- Negotiate derogation to the law for those species that can benefit from the reintroduction *on farm*. For instance, derogation to art. 3 of EU Habitat Directive (i.e., “on the designation of sites hosting […] the species listed in Annex II”) may allow the reintroduction of *M. quadrifolia* in paddy fields outside SCIs covering 220,000 Ha (Enterisi, 2018).

- Make plant-related international targets binding, such as Target 6 of the Global Strategy for Plant Conservation: "At least 75 per cent of production lands in each sector managed sustainably, consistent with the conservation of plant diversity" (Convention on Biological Diversity, 2012). These kinds of objectives are unlikely to have absolute priority on international agendas if they are not binding, even if it must be underlined that some countries (e.g., Germany and Belgium) have recently set up permanent reserves for the protection of arable flora.

CONCLUSION

Threatened species from arable lands deserve conservation efforts. These species can provide different benefits to the farmer and the whole society (e.g., indicator species, ecosystem services, attractiveness of the landscape, or in terms of local tourism and economy). For the reintroduction of species strictly associated with agro-ecosystems, the sole option is to negotiate the co-habitation of farming activities and focal species, the latter cultivated alongside crops and subject to the same management as their commercially-exploited counterparts. As with other translocations, and perhaps even more so, on farm translocations have the potential to generate multiple and varied conflicts. A framework for facilitating the reintroduction of plant species in areas of intensive agriculture has been proposed here. A ‘conflict index’ should be developed to assess potential risks of disagreement with farmers for a focal species. We also recommend that good communications are nurtured and facilitate the farmer’s involvement from the very beginning of a reintroduction project. Training aimed at the management of the focal species while ensuring economic returns is also suggested. Large-scale changes toward more sustainable agricultural practices are needed to reduce pressures on threatened species from arable lands and whilst we recommend relatively small adjustments in the EU Common Agricultural Policy, it is the engagement of conservation scientists with the agricultural community that has the potential for making the greatest difference to some of our most threatened plants in the near future.

DECLARATION OF INTEREST

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

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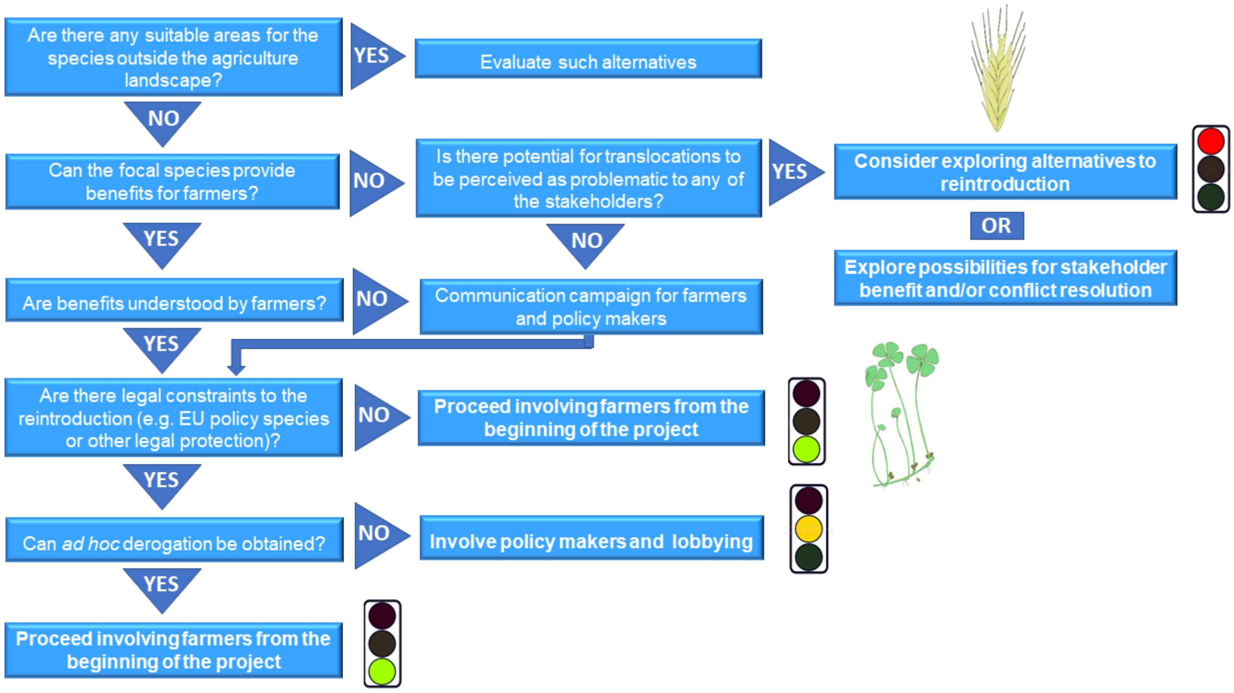

Figure 1. Decision framework to promote reintroduction of arable and threatened plants in European agroecosystems.