Best practices, errors and perspectives of half a century of plant translocation in Italy

Abstract

Conservation translocations are becoming common conservation practice, so there is an increasing need of understanding the drivers of plant translocation performance through reviews of cases at global and regional levels. The establishment of the Italian Database of Plant Translocation (IDPlanT) provides the opportunity to review the techniques used in 186 plant translocation cases performed in the last fifty years in the heart of the Mediterranean Biodiversity Hotspot.

In this study, we describe techniques and information available in IDPlantT and use these data to identify drivers of translocation outcomes. To this end, we tested the effect of 15 variables on survival translocated propagules at the last monitoring date, using Binary Logistic Mixed Effect Models.

The analysis revealed that 11 variables significantly affected survival of transplants, namely: life form, site protection, material source, number of source populations, propagation methods, propagule life stage, planting methods, habitat suitability assessment, site preparation, aftercare and costs.

Plant translocations in Italy and in the Mediterranean area should consider the complexity of speciation, gene flow and plant migrations that has led to local adaptations with important implications on the choice and constitution of source material. The integration of vegetation studies for the selection of suitable planting sites can significantly increase the success of translocation efforts. Whilst post-translocation watering has a general positive effects on traslocation outcome, other aftercare techniques do not always increase transplant survival. Finally, we found that how funds are spent appears to be more important than their actual amount.

Introduction

Conservation translocations (translocation hereafter) are intentional movements of plant and animal individuals for conservation purposes including population reinforcement (augmentation of an existing population), reintroduction (release of an organism in a site from which it has disappeared) and conservation introduction (release of an organisms outside its natural range; IUCN, 2013). Whilst translocations remain high-risk and high-cost conservation practices (Fenu et al., 2016), their importance in conservation biology is increasing worldwide, as demonstrated by some successful projects (Maunder et al., 2000; Colas et al., 2008; Draper Munt et al., 2016; Holzapfel et al., 2016; Soorae, 2021).

With translocation becoming a common conservation practice (Swan et al., 2018), reviews are important to define the drivers of performance in plant translocation and the future advances in the field. However, most translocation cases are not published in the scientific literature, either because they are confined to the grey literature or because they are not published at all; recent studies on both animals and plants have provided interesting information on drivers of performance in translocation (Brichieri-Colombi & Moehrenschlager, 2016; Bubac et al., 2019; Silcock et al., 2019; Diallo et al., 2023). In plants, translocation success in terms of transplant survival and recruitment is typically related to the planting of a high number of juvenile or adult individuals from mixed source populations with stable demographic trends (Godefroid et al., 2011; Dalrymple et al., 2012). Site preparation, management and protection also increase the chance of better performance (Godefroid et al., 2011; Whitehead et al., 2023).

In addition, reviews at the regional or national level have highlighted additional cues of translocation success that could be useful to design specific guidelines and best practices. For instance, Liu et al. (2015) showed that plant translocation performance in China was related to the plant life form and to the type of plant materials used, with herbs and juvenile plants best performing in terms of percentage survival. Moreover, higher flowering and fruiting performance was observed among herbs propagated vegetatively, and for introductions compared to reinforcements and reintroductions (Liu et al., 2015). Silcock et al. (2019) found that species life form and habitat could affect translocation performance in Australia.

Italy is placed in the Mediterranean mega-hotspot and hosts a rich native flora of 8,249 vascular plant species and subspecies, including 1,739 endemic taxa (Cañadas et al., 2014; Peruzzi et al., 2014; Bartolucci et al., 2018; Bartolucci et al., 2021) and high evolutionary distinct taxa (Carta et al., 2019). A recent red listing initiative on about 2,400 taxa (incl. vascular and non-vascular plants and lichens) highlighted that 24.3% of the assessed taxa are listed in one of the IUCN threat categories (i.e., Vulnerable, Endangered or Critically Endangered; Orsenigo et al., 2021), and 22.4% of the threatened taxa are Italian endemic taxa (Orsenigo et al., 2018), with 54 taxa already extinct or possibly extinct in the wild (Orsenigo et al., 2021). Moreover, the IV Italian report on the conservation status of the 115 Italian plants listed in the European Union Directive 92/43/EEC “Habitats” showed that 54% are in an “unfavourable – inadequate” or “unfavourable – bad” status (Fenu et al., 2021). Overall, a considerable proportion of the Italian flora requires conservation action and translocations represent an effective tool to halt or reduce the risk of extinction of threatened plant species.

In Italy the first documented plant translocation involved the iconic species *Pinus heldreichii* subsp. *leucodermis* (Antoine) E.Murray in the Pollino National Park (Calabria; Brogi, 1960). This translocation is a success story and likely the longest plant translocation activity ever performed, as the reinforcement and reintroduction of this species are still ongoing after 64 years. Since the first reinforcement of *P. heldreichii* subsp. *leucodermis*, many other plant translocations have been performed in Italy, most of them (*c.* 98%) in the last two decades. Unfortunately, only a small number of Italian translocation cases has been published in the scientific literature (Fenu et al., 2016, 2019; Paoli et al., 2020) or in dedicated monographies like the IUCN Global Reintroduction Perspectives (Soorae, 2021, 2022). Given the increasing use of translocation by Italian conservation practitioners and scientists, it would be important to draw some recommendations from translocations already performed, to support future activities and increase the probability of positive outcomes. Therefore, in this study, we analyzed the results of plant translocations performed in Italy since the first documented case in 1958.

Data analysed in this article come from the Italian Database on Plant Translocation (IDPlanT; Abeli et al., 2021), a recently developed database that includes also unpublished translocations, and to our knowledge, is the only translocation database that provides data on economic resources used in translocations. This first complete account of plant translocation targeted to the Italian Flora aims to identify best practices, errors made and future directions in plant translocation in the specific Italian contexts which could also apply to other regions of the Mediterranean Basin. Considering the context where the translocation analysed here have been performed, we aim to answer the following questions: 1) How successful are plant translocations in Italy? 2) Are finding from previous global reviews transferable to translocations in Italy? 3) Which factors shape translocation success in Italy? Here we analysed translocation performance in terms of percentage survival of transplants.

Specific hypotheses tested are: i) life form and native habitat affect translocation performance, with trees and shrubs expected to have better performance than herbs; ii) the choice of the planting site in most IDPlanT translocations has been made through expert-based or vegetation studies (Pott, 2011; Biondi, 2011), which we expect to produce lower survival performance than model-based and correlational studies aimed at identifying suitable planting sites; iii) aftercare increases survival performance; iv) the higher the funds allocate to a translocation project, the higher the chance of plant survival.

Methods

This study is based on the Italian Database of Plant Translocation (IDPlanT) created with the aim to collect data on plant translocations in Italy with a standardized format (Abeli et al., 2021). This database includes published and unpublished plant translocation cases, monitored on average for five years after outplanting, so the description and analysis reported below refer to the medium-term. Seven cases were excluded because they referred to multiple-site translocation activities, without providing separate data for each site.

Descriptive analyses

The analysis of IDPlanT was conducted on 178 out of 185 cases listed in the database. Since a single translocation project may imply the planting of a focal species in one or more populations, we considered every single established population separately. This allowed to account for even minor variations between sites and translocated populations (e.g., differences in microsite, number of planted individuals, pre- or post- translocation management, etc.). In the result section, before analysing the drivers of translocation success statistically, we briefly describe IDPlantT by quantifying the types of materials, techniques and information available in the database.

Statistical analyses

Data on post-translocation plant survival were available in about 40% of cases, whilst data on recruitment were available in 25% of cases and was in most cases null.

To understand the factors shaping translocation outcome in Italy, we fitted Binary Logistic Mixed Effect Models with logit link function, using the proportion between planted and survived individuals at the last monitoring date as the response variables. The full list of explanatory variables that we considered is provided in Table 1. When a single translocation case used more than one technique within a group of operations (e.g., more than one site preparation method, more than one aftercare technique, etc.), we treated this as a different “treatment” in the models called “combined techniques”. It means that levels within a variable group are mutually exclusive (Table 1).

Life form, preferred habitat and distribution refer in most cases to Pignatti et al. (2017-2019). Due to the large number of explanatory variables and the relative low number of cases in IDPlanT that provided survival proportion (Table 2 for sample size of each model), we fitted separate models for each variable as reported in Table 1. The cost of translocation was categorized in four groups: unknown, up to 5,000 €, between 5,000 and up to 10,000 €, and more than 10,000 €.

Sequential Bonferroni post-hoc tests were performed for all significant models. Associations between variables were tested with a χ^2 test. All statistical analyses were performed using SPSS 21.0.

Results

Most translocations were population reinforcements (51.9%), followed by reintroduction (36.2%) and, introductions (11.9%). Overall, plant survival was on average 47.39% (± 38.66 S.D.), flowering 30.78% (± 37.49 S.D.), fruiting 21.80% (± 34.54 S.D.), and recruitment 57.08% (± 196.56 S.D.). The most represented life forms were perennials geophytes, trees and shrubs (altogether accounting for about 70% of cases). Woodlands and grasslands were the most represented habitats (about 50% altogether) and 61% of analysed cases targeted Italian or Mediterranean endemics (Figure 1). The high variation in recruitment is because some translocations were highly successful, so the population size at last monitoring date overcame the initial number of translocated propagules. Table S1 reports the associations between the categorical variables used as predictors of transplant survival and fruiting.

Characteristics of the source material for translocation

Whilst most reinforcements used propagated material from the same population, the propagules used for reintroduction and introduction were mainly juvenile or adult plants from the closest population (Figure S1). In five translocations a combination of juveniles and adults (4 cases) and seeds and juveniles was used. Moreover, vegetative propagules were often combined with seeds or spores. In two cases (*Hypericum elodes* L. and *Marsilea quadrifolia* L.) swards containing rhizomes were used as a source of inoculum. In an introduction of *Corynephorus canescens* (L.) P.Beauv., the soil containing the natural soil seed bank of the species was collected and relocated to the selected planting site.

The number of translocated propagules ranged from 1 to 4,800, with 20% (n = 35) of translocations releasing less than 50 propagules, most often from a single population, whose trend was mostly unknown (Figure S1). Source population trend was unknown in 12.5% of cases, increasing or stable in 43% of cases and decreasing in 44.5% of cases. Unfortunately, we do not know for all cases how source population trends were measured, as this information is not included in the database. However, in some cases (e.g., *Isoëtes malinverniana*, *Hieracium australe* subsp. *australe*) a regular monitoring of the population size was performed by counting or estimating the number of individual plants.

Choice of the planting site, planting techniques and site preparation

The most used method to assess habitat suitability was expert based followed by vegetation studiescorrelational studies, and species distribution models (SDMs) (Figure S2a). When more methods were used to determine habitat suitability for target species, vegetation studies and expert-based considerations was the main combination (22 cases). Additional details on planting techniques, e.g., how the material was planted/sown, and acclimation are shown in Figure S2. As for pre-release site preparations, the most frequently used was competition reduction, followed by fencing, no action, top-soil removal, watering and soil loosening (Figure S3). The most common combinations of techniques were fencing + competition reduction (12 cases) and competition reduction + watering (5 cases).

Aftercare

Post-release manipulations (Figure S3) included from the most used to the least applied competition reduction by periodical mowing and alien species control, watering, no action, fencing, and other techniques like shading (*Hypericum elodes* L.) or modification of the water flow to avoid sediment accumulation (*Isoëtes malinverniana* Ces. & De Not). Nutrient enrichment was not carried out in any translocation case. The most common combination of aftercare techniques included watering associated with competition reduction (23 cases).

Cost of translocation

Data on costs of translocation were provided for 96 cases out of 178. About 18% of cases were carried out at no costs, as it involved voluntary staff. For seven cases the full budget of larger project was provided, without any detail on actual costs of translocations. By excluding the abovementioned cases, the cost of a translocation in Italy ranged from 100 € to 30,000 €, with an average cost of 6,890 € per case.

Drivers of performance: survival percentage

Translocation performance in terms of transplant survival percentage at last monitoring date was significantly affected by all considered variables with the exception of species life form, species distribution, type of action, source population trend and planting method (Table 2; Figure 2, 3). Most of these variables were associated with each other (Table S1), which may confound the interpretation of our results. On one hand, site protection and planting methods showed less correlations with other variables, thus unequivocally important for the translocation outcome. On the other hand, pre-planting site preparation, costs, acclimation and propagule life stage were highly correlated to many other variables, which confounds their real contribution to translocation outcomes.

In detail, species habitat affected translocation outcome with grassland and salt marsh species showing low survival (Figure 2). Moreover, transplant survival percentage was increased by the planting of propagules in protected areas, by the use of material from the closest population to the planting site, and by the use of mixed material from two or more populations (Table 2; Figure 2). Among the propagation methods vegetative propagation or combined propagation methods (vegetative + seeds) led to increased survival. Propagule life stage affected the translocation outcome, but results were quite variable: seeds were clearly associated with low survival, but no significant differences were detected between the use of seeds, seedling and juveniles. Survival is clearly increased by propagules of mixed life stages. (Table 2; Figure 2). Acclimation of material in the field or in greenhouse was not associated with higher survival. The most effective method to assess species habitat suitability and in turn to select a suitable planting site was the study of vegetation alone combined with expert-based considerations, that yielded high survival percentage comparable to more sophisticated correlational studies or SDMs, with the latter highly variable in terms of performance (Figure 3). As for site preparation fencing contributed to high survival. On the other hand, the effect of aftercare, though significant, was highly variable and we could not detect any clear pattern. (Figure 3). Higher survival was associated with medium-level expenditure (between 5,000 and 10,000 €) compared to low and high-level of funds allocated to translocation.

Discussion

The establishment of the Italian Database of Plant Translocation, IDPlanT allowed the first overview of the drivers of plant translocation outcomes in Italy (Abeli et al., 2021). Through IDPlanT we collected data on 185 plant translocations (most of them unpublished) performed in Italy since the first recorded case in 1958 (e.g., Fenu et al., 2016; Carra et al., 2019). With most translocations performed in the last two decades, IDPlanT is one of the most important sources of information on recent translocations in the Mediterranean area (Fenu et al., 2023; TransLoc http://translocations.in2p3.fr/).

Effect of life form, preferential habitat and distribution on translocation outcome

The analysis of IDPlanT reveals similarities and differences with other reviews of plant translocation at the global and regional scale (e.g., Godefroid et al., 2011; Liu et al., 2015; Silcock et al., 2019). We did not find any relationship between survival performance and some intrinsic characteristics of the target species, like life form, and distribution, indicating that the techniques adopted to perform a translocation are more crucial than the abovementioned intrinsic species characteristics. This result contrasts with other reviews where life forms significantly affected the outcome of translocations, with herbs showing greater success compared to trees and shrubs (e.g., Liu et al., 2015; Bellis et al., 2023). . However, our results are difficult to be compared with other similar analyses because we have considered much more life forms (eight categories) then other papers (three in Liu et al., 2015; four in Silcock et al., 2019). One explanation for the lack of effects on intrinsic species characteristics on translocation performance may be due to the high variability of outcome within each category and the fact that in IDPlanT most species had a strict Mediterranean distribution being endemic of the peninsular part of Italy or of the Alps, with 36% of widely distributed species (eurasiatic, eurosiberian and circumboreal species; Pignatti et al., 2017-2019). In our study grassland species were associated with lower survival compared to other habitats, similarly to what has been reported by Whitehead et al. (2023) for Australia. Our first hypothesis that translocation performance is affected by species intrinsic characteristics is therefore partially rejected.

Drivers of translocation performance

The highest survival performance was achieved when propagules were obtained from two or more populations close to the planting site compared to further source populations (Figure 2), an indication that in the Mediterranean areas, complex colonization and dispersal patterns are key aspects for translocation, of endemic taxa (Fenu et al., 2020). For instance, Gargano et al. (2022) showed that even geographically close populations of *Dianthus guliae* Janka have very different adaptations to environmental cues and that population artificial crossing may result in maladaptation. Choosing the best performant source populations or deciding whether more source populations can be mixed is made even more difficult in plants with long-distance dispersal patterns like *Stratiotes aloides* L. (Orsenigo et al., 2017). In contrast with other studies (e.g., Godefroid et al., 2011), a stable or increasing demographic trends of source populations did not affect the translocation outcome (Table 2). Vegetative propagation of plant material had a positive effect on transplant survival that likely depends on higher tolerance to stress of adult-like cuttings or vegetative propagules compared to seeds and seedlings that typically show higher mortality when moved in a recipient site (Godefroid et al., 2011; Albrecht and Maschinski, 2012; Silcock et al., 2019). This is obviously mirrored in a lower (though not significant) survival when seeds were used as the only life stage (Figure 2). The poor performance of seeds may be due to predation or dormancy or intrinsic low seed viability (Krauss et al., 2002), and in general a much higher number of propagules is needed when young life stages are used in translocation (Liu et al., 2015; Silcock et al., 2019).

The "combined methods" level to assess habitat suitability for the selection of a planting site groups together the vegetation study (phytosociology) and the expert-based approaches and resulted in significantly greater transplant survival than an expert base approach alone (Figure 2). This suggests that vegetation studies contribute to the higher transplant survival in the "combined methods" level. The study of the vegetation likely captures the habitat complexity that is not identified otherwise, making the study of vegetation a very helpful method to select suitable planting sites. In many Mediterranean countries (e.g., Italy, France, Spain, Greece; Tomaselli et al., 2000; Petraglia & Tomaselli, 2007; Zanzottera et al., 2021) there is a very deep understanding of species associations and their relationships with abiotic factors (Coppi et al., 2015), that make vegetation studies very informative.

Correlational studies and SDMs were associated with lower (not significant) survival and with a high variability of performance compared to other methods for assessing habitat suitability. Correlational studies and SDMs provide important data on how a species respond to selected variables, that may include the most relevant ecological factors for a given species or may not (Paoli et al., 2020). However, they are usually performed at a scale that do not consider microsite variations of ecological factors, that instead are important determinant of translocated plant survival (Jusaitis, 2005; Reiter & Menz, 2022; see also Bianchi et al., 2020 and Di Nuzzo et al., 2022 for the effect of microclimatic factors on lichen growth). Microsites characteristics are even more important in mountain areas (e.g., Casazza et al., 2021), so both the correlational studies and SDMs used for selecting suitable sites for translocation are susceptible of missing key ecological variables shaping the occurrence of a target species, that are intrinsically considered when the plant community is considered. Therefore, also our second hypothesis is rejected.

Role of site preparation, aftercare and amount of allocated funds on translocation outcome

Pre-release fencing significantly increased transplant survival by protecting plants from grazing and/or accidental damages, as shown in other studies (Jusaitis, 2005; Fenu et al., 2016; Whitehead et al., 2023; Monks et al., 2023). Although our models did not detect any significant difference between pre-release fencing and competition reduction, the latter treatment through soil loosening and top-soil removal is associated with a low transplant survival (Tischew et al., 2017). A possible explanation could be the fact that bare soil dries out quickly in the warm of the Mediterranean climate.

This is confirmed by the importance of post-translocation watering that was associated with increased survival. In the Mediterranean area, watering seems crucial in the very initial post-translocation phase. Except for watering there were no differences between "no aftercare" and other post-planting site manipulations like fencing and combined techniques, which is in contrast with recent studies suggesting that fencing and competition reduction are important measures to increase plant survival (Corli et al., 2023). The third hypothesis on the importance of aftercare in translocation is therefore accepted, though with high variability between the tested techniques. Aftercare is reported as a best practice in several plant translocation guidelines as part of adaptive monitoring and implementation of translocation (Maschinski & Albrecht, 2007; Rossi et al., 2013; Commander et al., 2018). However, the contribution of aftercare to plant translocation performance is poorly understood and likely species-specific, with only a few studies reporting the results of experimental long-term post-planting manipulations (e.g., Daws and Koch, 2015; Al Farsi et al., 2017). For this reason, further research is needed to understand the effect of aftercare techniques on translocation performance, and better evaluate the general costs and benefits of aftercare including those cases where translocated populations require continuous management (Adamski et al., 2020; Rumsey & Stroh, 2020).

Finally, IDPlanT is likely the only plant translocation database reporting on the actual costs of translocation and analysing the relationships between costs and outcomes. Although it is difficult to precisely identify actual costs of translocation, especially when they are part of larger projects that include other management activities, costs of translocation in Italy are lower compared for instance to Australia (Zimmer et al., 2019). It is interesting to note that in our analysis medium-level expenditure is associated to higher survival compared to low- and high-level expenditure. Higher costs for fencing a reintroduced population of *Dianthus morisianus* Vals. resulted in higher plant survival compared to a non-fenced (and cheaper) one (Fenu et al., 2016; Cogoni et al., 2013). However, this does not seem to be a general rule and how funds are spent may be more important than their amount.

Conclusion

The analysis of IDPlanT a reference for the translocation of Mediterranean plant species highlights the complexity and multidisciplinary nature of plant translocation (Abeli and Dalrymple, 2023). Once again, the importance of post-translocation monitoring emerges from this study, as we could analyse only 72 cases with survival and fruiting data out of 178 translocations. Ongoing and future plant translocations in Italy and in the Mediterranean area should consider the speciation and colonisation history that has led in many cases to local adaptations with important implications for the provenance and genetic diversity of source material. In IDPlanT, only 24 out of 178 translocations were based on genetically informed decisions, that should become more common also considering that the costs for gathering genetic data are becoming more and more affordable (Rossetto et al., 2023). The integration of vegetation studies into the recipient site selection process is already well applied at the Italian level and should be expanded and transferred to other contexts. More research is needed on post-translocation plant and site manipulations that, when possible, should be carried out with an experimental approach to identify and develop suitable techniques. Finally, understanding the costs of translocations is important to plan a translocation budget and also to assess the credibility and appropriateness of conservation programmes based on translocations; currently there is no standardised methods to properly account for the expenses of translocation, especially when the latter are carried out within larger restoration projects, thus this aspect requires more investigation. The constant implementation and periodical analysis of large translocation datasets will provide additional key insights into successful plant translocation.

References

Abeli, T., D'Agostino, M., Orsenigo, S., Bartolucci, F., Accogli, R., Albani Rocchetti, G., ... & Fenu, G. (2021). IDPlanT: the Italian database of plant translocation. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, 1-4.

Abeli, T. & Dalrymple, S.E. (2023). Advances in plant translocation. *Plant Ecology*, in press.

Adamski, D. J., Chambers, T. J., Akamine, M. D., & Kawelo, K. (2020). Reintroduction approaches and challenges for Cyanea superba (Cham.) A. Gray subsp. *superba*. *Journal for Nature Conservation*, 57, 125873.

Al Farsi, K. A., Lupton, D., Hitchmough, J. D., & Cameron, R. W. (2017). How fast can conifers climb mountains? Investigating the effects of a changing climate on the viability of Juniperus seravschanica within the mountains of Oman, and developing a conservation strategy for this tree species. *Journal of Arid Environments*, 147, 40-53.

Albrecht, M. A., & Maschinski, J. (2012). Influence of founder population size, propagule stages, and life history on the survival of reintroduced plant populations. Plant reintroduction in a changing climate: promises and perils, 171-188.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A. N. M. G., Ardenghi, N. M. G., ... & Conti, F. (2018). An updated checklist of the vascular flora native to Italy. *Plant Biosystems*, 152(2), 179-303.

Bartolucci, F., Galasso, G., Peruzzi, L., & Conti, F. (2021). Report 2020 on plant biodiversity in Italy: Native and alien vascular flora. *Natural History Sciences*, *8*(1), 41-54. doi: 10.4081/nhs.2022.623

Bellis, J., Osazuwa-Peters, O., Maschinski, J., Keir, M. J., Parsons, E. W., Kaye, T. N., ... & Albrecht, M. A. (2023). Identifying predictors of translocation success in rare plant species. *Conservation Biology*, in press. https://doi.org/10.1111/cobi.14190

Bianchi, E., Benesperi, R., Brunialti, G., Di Nuzzo, L., Fačkovcová, Z., Frati, L., Giordani, P., Nascimbene, J., Ravera, S., Vallese, C. & Paoli, L. (2020). Vitality and Growth of the Threatened Lichen *Lobaria pulmonaria* (L.) Hoffm. in Response to Logging and Implications for Its Conservation in Mediterranean Oak Forests. *Forests*, 11, 995.

Biondi, E. (2011). Phytosociology today: Methodological and conceptual evolution. *Plant Biosystems*, 145, Supplement, 19-29.

Brichieri-Colombi, T. A., & Moehrenschlager, A. (2016). Alignment of threat, effort, and perceived success in North American conservation translocations. *Conservation Biology*, *30*(6), 1159-1172.

Brogi, S. (1960). Il pino loricato (*Pinus Heldreichii* Grist., var. *Leucodermis* Ant.) in Calabria e sua possibilità di diffusione. *L'Italia Forestale e Montana* XV(4): 157-163.

Bubac, C.M., Johnson, A.C., Fox, J.A., Cullingham, C.I. (2019). Conservation translocations and post-release monitoring: Identifying trends in failures, biases, and challenges from around the world. *Biological Conservation, 238*, 108239.

Cañadas, E.M., Fenu, G., Peñas, J., Lorite, J., Mattana, E., Bacchetta, G. (2014) Hotspots within hotspots: Endemic plant richness, environmental drivers, and implications for conservation. *Biological Conservation*, 170, 282–291.

Carra, A., Catalano, C., Badalamenti, O., Carimi, F., Pasta, S., Motisi, A., ... & Garfì, G. (2019). Overcoming sexual sterility in conservation of endangered species: the prominent role of biotechnology in the multiplication of Zelkova sicula (Ulmaceae), a relict tree at the brink of extinction. *Plant Cell, Tissue and Organ Culture (PCTOC)*, *137*(1), 139-148.

Carta, A., Gargano, D., Rossi, G., Bacchetta, G., Fenu, G., Montagnani, C., ... & Orsenigo, S. (2019). Phylogenetically informed spatial planning as a tool to prioritise areas for threatened plant conservation within a Mediterranean biodiversity hotspot. *Science of The Total Environment, 665*, 1046-1052.

Casazza, G., Abeli, T., Bacchetta, G., Dagnino, D., Fenu, G., Gargano, D., ... & Rossi, G. (2021). Combining conservation status and species distribution models for planning assisted colonisation under climate change. *Journal of Ecology*, *109*(6), 2284-2295.

Cogoni, D., Fenu, G., Concas, E., & Bacchetta, G. (2013). The effectiveness of plant conservation measures: the *Dianthus morisianus* reintroduction. *Oryx*, 47(2), 203-206.

Colas, B., Kirchner, F., Riba, M., Olivieri, I., Mignot, A., Imbert, E., ... & Fréville, H. (2008). Restoration demography: a 10-year demographic comparison between introduced and natural populations of endemic Centaurea corymbosa (Asteraceae). *Journal of Applied Ecology*, *45*(5), 1468-1476.

Commander, L.E., Coates, D., Broadhurst, L., Offord, C.A., Makinson, R.O. and Matthes, M. (2018) Guidelines for the translocation of threatened plants in Australia. Third Edition. Australian Network for Plant Conservation, Canberra.

Coppi, A., Lastrucci, L., Carta, A., & Foggi, B. (2015). Analysis of genetic structure of Ranunculus baudotii in a Mediterranean wetland. Implications for selection of seeds and seedlings for conservation. *Aquatic Botany*, 126, 25-31.

Dalrymple, S. E., Banks, E., Stewart, G. B., & Pullin, A. S. (2012). A meta-analysis of threatened plant reintroductions from across the globe. In Plant reintroduction in a changing climate (pp. 31-50). Island Press, Washington, DC.

Daws, M.I., Koch, J.M. (2015). Long-term restoration success of re-sprouter understorey species is facilitated by protection from herbivory and a reduction in competition. *Plant Ecology*, 216, 565-576. https://doi.org/10.1007/s11258-015-0459-7

Diallo, M., Mayeur, A., Vassiére, A.-C., Colas, B. (2023). The relevance of plant translocation as a conservation tool in France. *Plant Ecology*, in press. https://doi.org/10.1007/s11258-023-01295-4

Di Nuzzo, L., Giordani, P., Benesperi, R., Brunialti, G., Fačkovcová, Z., Frati, L., Nascimbene, J., Ravera, S., Vallese, C., Paoli, L., Bianchi, E. (2022). Microclimatic Alteration after Logging Affects the Growth of the Endangered Lichen *Lobaria pulmonaria*. *Plants* 11, 295.

Draper Munt, D., Marques, I., & Iriondo, J. M. (2016). Acquiring baseline information for successful plant translocations when there is no time to lose: the case of the neglected Critically Endangered Narcissus cavanillesii (Amaryllidaceae). *Plant ecology*, *217*(2), 193-206.

Ercole, S., Angelini, P., Carnevali, L., Casella, L., Giacanelli, V., Grignetti, A., La Mesa, G., Nardelli, R., Serra, L., Stoch, F., Tunesi, L., Genovesi, P. (ed.) (2021). Rapporti Direttive Natura (2013-2018). Sintesi dello stato di conservazione delle specie e degli habitat di interesse comunitario e delle azioni di contrasto alle specie esotiche di rilevanza unionale in Italia. ISPRA, Serie Rapporti 349/2021.

Fenu, G., Bacchetta, G., Charalambos, S. C., Fournaraki, C., Del Galdo, G. P. G., Gotsiou, P., ... & De Montmollin, B. (2019). An early evaluation of translocation actions for endangered plant species on Mediterranean islands. *Plant diversity*, 41(2), 94-104.

Fenu, G., Bacchetta, G., Christodoulou, C. S., Cogoni, D., Fournaraki, C., Gian Pietro, G. D. G., ... & de Montmollin, B. (2020). A common approach to the conservation of threatened island vascular plants: First results in the Mediterranean Basin. *Diversity*, 12(4), 157.

Fenu, G., Calderisi, G., Boršić, I., Bou Dagher Kharrat, M., García Fernández, A., Kahale, R., Panitsa, M., & Cogoni, D. (2023). Translocations of threatened plants in the Mediterranean Basin: current status and future directions. Plant Ecology, in press. https://doi.org/10.1007/s11258-023-01303-7

Fenu, G., Cogoni, D., & Bacchetta, G. (2016). The role of fencing in the success of threatened plant species translocation. *Plant Ecology*, 217(2), 207-217.

Fenu, G., Siniscalco, C., Bacchetta, G., Cogoni, D., Pinna, M. S., Sarigu, M., ... & Ercole, S. (2021). Conservation status of the Italian flora under the 92/43/EEC 'Habitats' Directive. *Plant Biosystems*, 155(6), 1168-1173.

Gargano, D., Bernardo, L., Rovito, S., Passalacqua, N. G., & Abeli, T. (2022). Do marginal plant populations enhance the fitness of larger core units under ongoing climate change? Empirical insights from a rare carnation. *AoB Plants*, 14(3), plac022.

Godefroid S., Piazza C., Rossi G., Buord S., Stevens A.D., Aguraiuja R., Cowell C., Vanderborght T. (2011). How successful are plant species reintroductions? *Biological Conservation*, 144(2),672-682.

Holzapfel, S. A., Dodgson, J., & Rohan, M. (2016). Successful translocation of the threatened New Zealand root-holoparasite *Dactylanthus taylorii* (Mystropetalaceae). *Plant Ecology*, *217*(2), 127-138.

International Union for Conservation of Nature. (2013). Guidelines for reintroductions and other conservation translocations. *Gland Switz Camb UK IUCNSSC Re-Introd Spec Group*, 57.

Krauss, S. L., Dixon, B., & Dixon, K. W. (2002). Rapid genetic decline in a translocated population of the endangered plant Grevillea scapigera. *Conservation Biology*, 16(4), 986-994.

Jusaitis, M. (2005). Translocation trials confirm specific factors affecting the establishment of three endangered plant species. *Ecological Management & Restoration*, *6*(1), 61-67.

Liu, H., Ren, H., Liu, Q., Wen, X., Maunder, M., & Gao, J. (2015). Translocation of threatened plants as a conservation measure in China. *Conservation Biology*, *29*(6), 1537-1551.

Maschinski, J., & Albrecht, M. A. (2017). Center for Plant Conservation's Best Practice Guidelines for the reintroduction of rare plants. *Plant diversity*, *39*(6), 390-395.

Maunder, M., Culham, A., Alden, B., Zizka, G., Orliac, C., Lobin, W., ... & Glissmann-Gough, S. (2000). Conservation of the Toromiro tree: case study in the management of a plant extinct in the wild. *Conservation Biology*, *14*(5), 1341-1350.

Monks, L., Yen, J., Dillon, R., Standish, R., Coates, D., Byrne, M., & Vesk, P. (2023). Herbivore exclusion and water availability improve success across 76 translocations of 50 threatened plant species in a biodiversity hotspot with a Mediterranean climate. *Plant Ecology*, in press.

Orsenigo, S., Fenu, G., Gargano, D., Montagnani, C., Abeli, T., Alessandrini, A.... & Fenu, G. (2021). Red list of threatened vascular plants in Italy. *Plant Biosystems*, 155, 310-335.

Orsenigo, S., Gentili, R., Smolders, A. J., Efremov, A., Rossi, G., Ardenghi, N. M., Citterio, S., & Abeli, T. (2017). Reintroduction of a dioecious aquatic macrophyte (Stratiotes aloides L.) regionally extinct in the wild. Interesting answers from genetics. Aquatic Conservation: Marine and Freshwater Ecosystems, 27(1), 10-23.

Orsenigo, S., Montagnani, C., Fenu, G., Gargano, D., Peruzzi, L., Abeli, T., ... & Rossi, G. (2018). Red Listing plants under full national responsibility: Extinction risk and threats in the vascular flora endemic to Italy. *Biological Conservation*, 224, 213-222.

Paoli, L., Guttová, A., Sorbo, S., Lackovičová, A., Ravera, S., Landi, S., Landi, M., Basile, A., Sanità di Toppi, L., Vannini, A., Loppi, S. & Fačkovcová, Z. (2020). Does air pollution influence the success of species translocation? Trace elements, ultrastructure and photosynthetic performances in transplants of a threatened forest microlichen. *Ecological Indicators*, 117, 106666.

Peruzzi, L., Conti, F., & Bartolucci, F. (2014). An inventory of vascular plants endemic to Italy. *Phytotaxa*, 168(1), 1-75.

Petraglia, A., & Tomaselli, M. (2007). Phytosociological study of the snowbed vegetation in the Northern Apennines (Northern Italy). *Phytocoenologia*, 37(1), 67.

Pignatti, S., Guarino, R., & La Rosa, M., (2017-2019). Flora d'Italia, 2a edizione. Edagricole di New Business Media, Bologna.

Pott, R. (2011). Phytosociology: A modern geobotanical method. *Plant Biosystems*, 45, Supplement, 9-18.

Reiter, N., & Menz, M. H. (2022). Optimising conservation translocations of threatened Caladenia (Orchidaceae) by identifying adult microsite and germination niche. *Australian Journal of Botany*.

Rossetto, M., Bragg, J., Brown, D., van der Merwe, M., Wilson, T. C., & Yap, J. Y. S. (2023). Applying simple genomic workflows to optimise practical plant translocation outcomes. *Plant Ecology*, in press.

Rossi, G., Amosso, C., Orsenigo, S., & Abeli, T. (2013). Linee guida per la traslocazione di specie vegetali spontanee. *Quaderni di Conservazione della Natura*, 28, MATTM– Ist Sup Protezione e Ricerca Ambientale (ISPRA), Roma ISSN 1592–2901.

Rumsey, F., & Stroh, P. (2020). Will de-extinction be forever? Lessons from the re-introductions of Bromus interruptus (Hack.) Druce. *Journal for Nature Conservation*, 56, 125835.

Silcock JL, Simmons CL, Monks L, Dillon R, Reiter N, Jusaitis M, Coates DJ. 2019. Threatened plant translocation in Australia: A review. *Biological Conservation*, 236: 211-222.

Soorae PS. 2022. Global Reintroduction Perspectives: 2022 Case studies from around the globe. IUCN/SSC Reintroduction Specialist Group, Gland, Switzerland and Environment Agency, Abu Dhabi, UAE.

Soorae PS. 2021. Global Reintroduction Perspectives: 2021 Case studies from around the globe IUCN/SSC Reintroduction Specialist Group, Gland, Switzerland and Environment Agency, Abu Dhabi, UAE.

Swan, K. D., Lloyd, N. A., & Moehrenschlager, A. (2018). Projecting further increases in conservation translocations: A Canadian case study. *Biological Conservation*, 228, 175-182.

Tischew, S., Kommraus, F., Fischer, L. K., & Kowarik, I. (2017). Drastic site-preparation is key for the successful reintroduction of the endangered grassland species Jurinea cyanoides. *Biological Conservation*, *214*, 88-100.

Tomaselli, M., Rossi, G., & Dowgiallo, G. (2000). Phytosociology and ecology of the Festuca puccinellii-grasslands in the northern Apennines (N-Italy). *Botanica Helvetica*, 110(2), 125-149.

Whitehead, M. R., Silcock, J. L., Simmons, C. L., Monks, L., Dillon, R., Reiter, N., Jusaitis, M., Coates, D.J., Birn, M. & Vesk, P. A. (2023). Effects of common management practices on threatened plant translocations. *Biological Conservation*, 281, 110023.

Zanzottera, M., Dalle Fratte, M., Caccianiga, M., Pierce, S., & Cerabolini, B. (2021). Towards a functional phytosociology: the functional ecology of woody diagnostic species and their vegetation classes in Northern Italy. *IFOREST*, 14(6), 522-530.

Zimmer, H. C., Auld, T. D., Cuneo, P., Offord, C. A., & Commander, L. E. (2019). Conservation translocation–an increasingly viable option for managing threatened plant species. *Australian Journal of Botany*, 67(7), 501-509.

Table 1. Explanatory variables used to test the effect of translocation methods on percentage survival and percentage fruiting of translocated propagules at the time of last monitoring. All variables are categorical, with the exception of the number of translocated propagules. * Not included in the model for “habitat suitability assessment” with fruiting percentage as a response variable because only one record was available. ** Not included in the model for “site preparation” with survival percentage as a response variable, because all cases that performed watering and

competition did it in combination with other techniques, so they are all included in "combined methods".

Variable	Levels
Life form	Geophytes, Forbs, Trees, Herbs (Hemicriptophytes), Hydrophytes, Helophytes, Annuals, Lichens
Preferred habitat	Woodlands, grasslands, cliffs, scrublands, freshwater, salt marshes, coastal dunes
Distribution	Mediterranean endemics
	European-Eurasiatic
	Circumboreal
	S-European mountains
Type of action	Reinforcement
	Reintroduction
	Introduction
Site protection status	Protected area
	Not protected area
Material source	Same population
	Closest population
	Not closest population
Number of source populations	One population
	Two populations
	Three or more populations
Source population trends	Decreasing
	Stable
	Increasing
Propagation methods	Vegetative
	Seed/Spore
	In vitro
	Combined methods
Propagule life stage	Seeds
	Seedlings
	Juveniles
	Adults
	Combined life stages
Planting methods	Sowing
	Bare root
	Potting soil
Acclimation	No acclimation
	Greenhouse
	Growth chamber
	Open field
	Combined methods
Habitat suitability assessment	Correlation studies & SDMs
	Vegetation studies*
	Expert-based
	Combined methods
Site preparation	No preparation
	Fencing

	Top-soil removal
	Watering**
	Soil loosening**
	Reducing competition
	Combined methods
Aftercare	No aftercare
	Fencing
	Watering
	Reducing competition
	Combined methods
Translocation costs	

Table 2. Results of the Binary Logistic Mixed Effect Models with survival proportion at the time of last monitoring as explanatory variables. In the main variable life form "terophytes", "circumboreal" and "phytosociology" groups were removed from the main variable "life form", "distribution" and "habitat suitability assessment" respectively because represented by a single case.

Survival percentage				
Variable	**N**	**F**	**df**	***p***
Life Form	63	0.511	6	*0.767*
Habitat	64	3.117	6	***0.010***
Distribution	63	0.130	2	*0.878*
Type of action	64	1.168	2	*0.318*
Site protection	64	4.287	1	***0.043***
Material source	50	6.425	2	***0.003***
N. source populations	64	6.352	2	***0.003***
Source pop. trend	59	2.773	2	*0.071*
Propagation methods	64	8.814	3	***<0.001***
Propagule life stage	60	3.911	4	***0.007***
Planting method	60	0.743	2	*0.480*
Acclimation	63	5.365	3	***0.002***

Habitat suitability assessment	63	3.677	2	***0.031***
Site preparation	63	4.078	3	***0.011***
Aftercare	64	3.208	4	***0.019***
Translocation cost	50	13.102	2	***<0.001***

FIGURE CAPTIONS

Figure 1. Percentage of species life form, preferred habitat and distribution for the 72 translocation cases analysed statistically (i.e., cases for which data on survival percentage of translocated propagules were available). Numbers on the x-axis indicate the actual number of cases for each variable level.

Figure 2. Drivers of transplant survival. Mean survival percentage of translocated propagules as a function of: a) habitat type b) material source; c) source populations; d) propagation method; e) propagule life stage; f) acclimation methods. Numbers beside the panel title indicate the total number of cases available for a given variable. Error bars represent standard error. Different letters indicate statistically significant differences at $p < 0.05$.

Figure 3. Drivers of transplant survival. Mean survival percentage of translocated propagules as a function of: a) Habitat suitability assessment; b) pre-release site preparations; c) post-release site manipulation (aftercare); d) funds allocated to translocation. Numbers beside the panel title indicate the total number of cases available for a given variable. Error bars represent standard error. Different letters indicate statistically significant differences at $p < 0.05$.

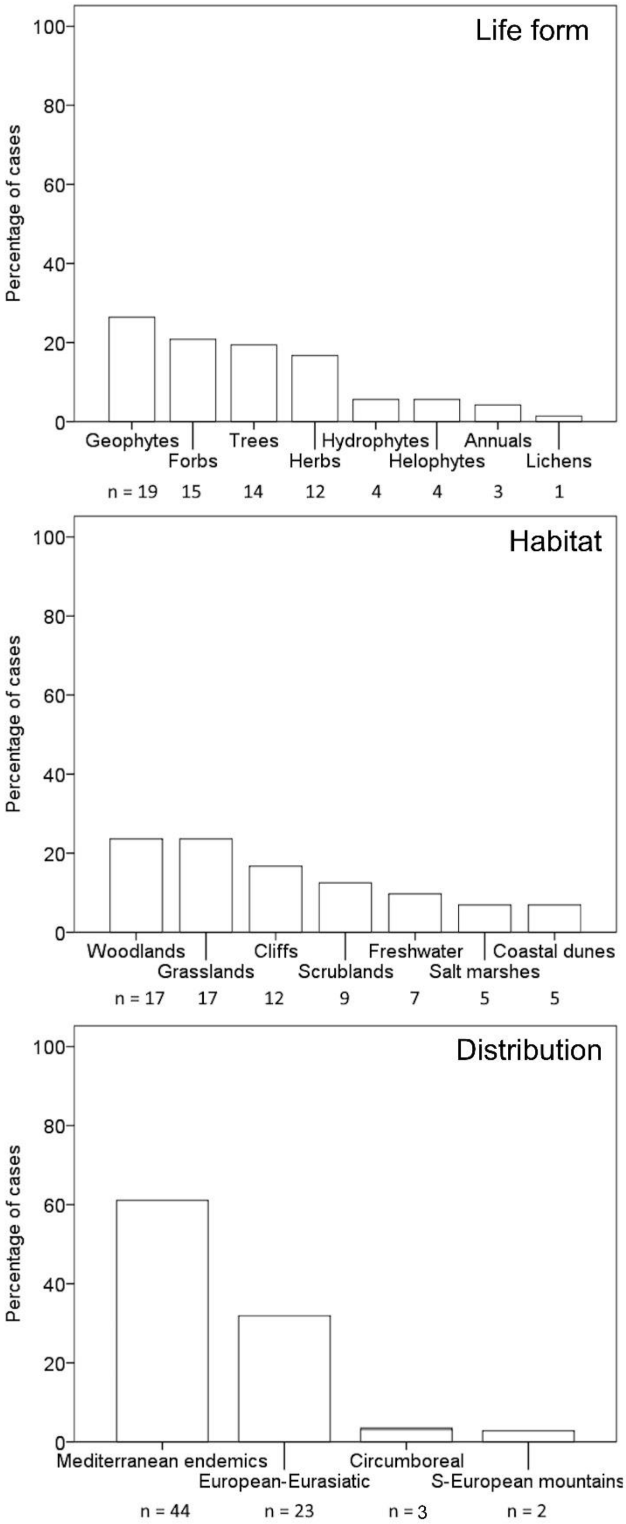

Life form
Percentage of cases
100
80
60
40
20
0
Geophytes
Forbs
Trees
Herbs
Hydrophytes
Helophytes
Annuals
Lichens
n = 19 15 14 12 4 4 3 1
Habitat
Percentage of cases
100
80
60
40
20
0
Woodlands
Grasslands
Cliffs
Scrublands
Freshwater
Salt marshes
Coastal dunes
n = 17 17 12 9 7 5 5
Distribution
Percentage of cases
100
80
60
40
20
0
Mediterranean endemics
European-Eurasiatic
Circumboreal
S-European mountains
n = 44
n = 23
n = 3
n = 2

Figure 1

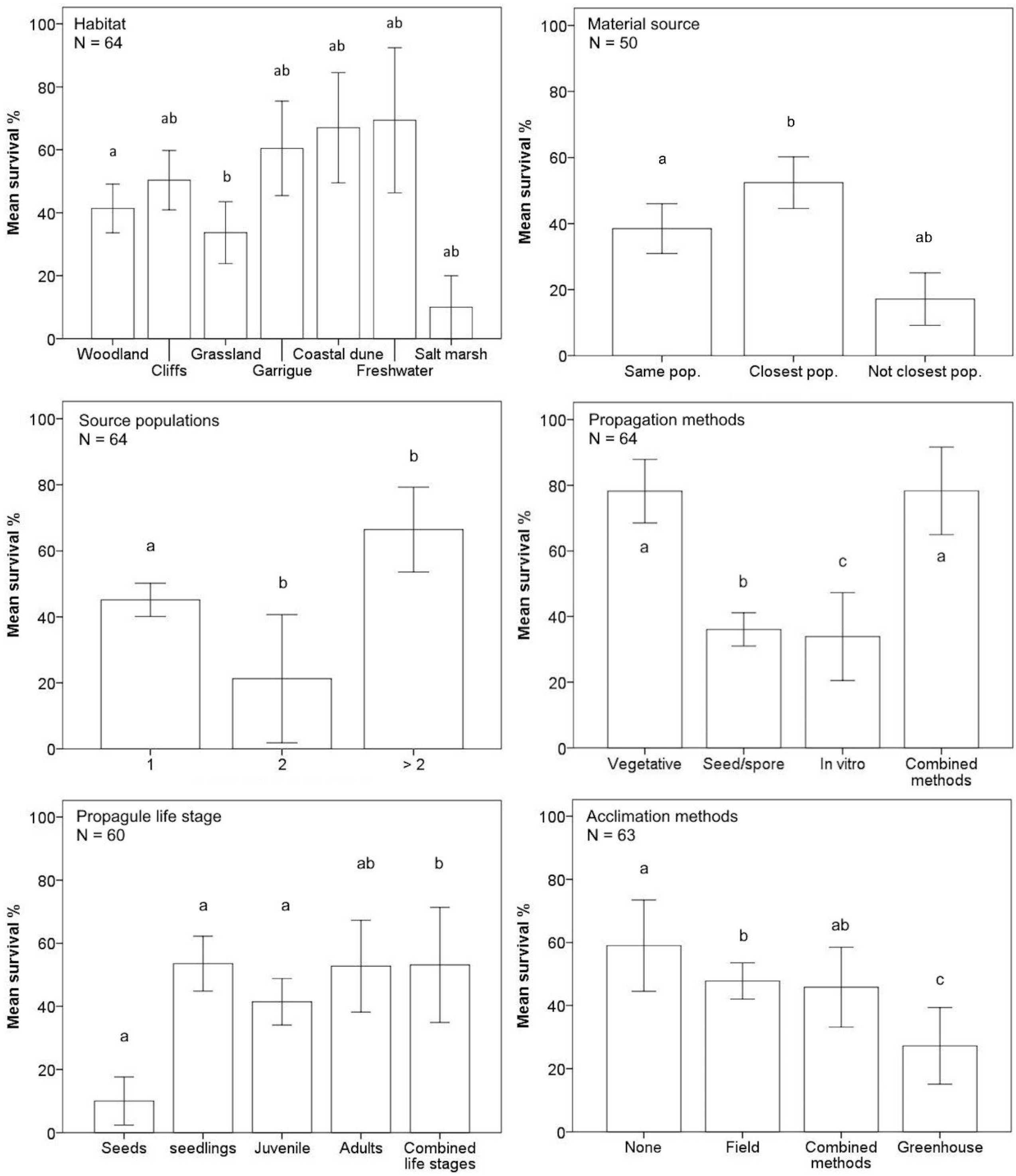
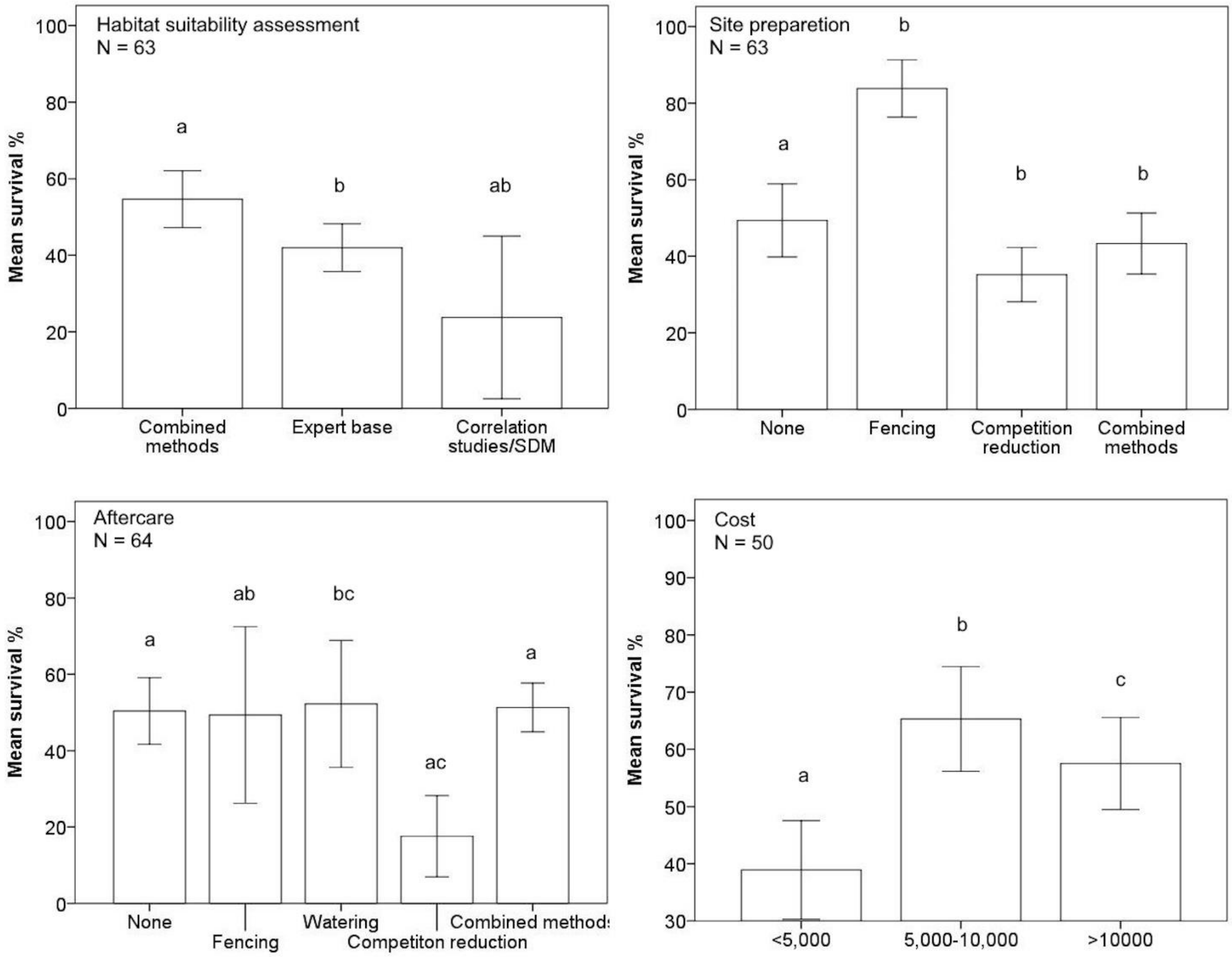

Habitat
N = 64
Mean survival %
a
ab
b
ab
ab
ab
ab
Woodland
Cliffs
Grassland
Garrigue
Coastal dune
Freshwater
Salt marsh
Material source
N = 50
a
b
ab
Same pop.
Closest pop.
Not closest pop.
Source populations
N = 64
a
b
b
1
2
> 2
Propagation methods
N = 64
a
b
c
a
Vegetative
Seed/spore
In vitro
Combined methods
Propagule life stage
N = 60
a
a
a
ab
b
Seeds
seedlings
Juvenile
Adults
Combined life stages
Acclimation methods
N = 63
a
b
ab
c
None
Field
Combined methods
Greenhouse

Figure 2



Habitat suitability assessment
N = 63
Mean survival %
Combined methods
Expert base
Correlation studies/SDM
a
b
ab
Site preparetion
N = 63
Mean survival %
None
Fencing
Competition reduction
Combined methods
a
b
b
b
Aftercare
N = 64
Mean survival %
None
Fencing
Watering
Competiton reduction
Combined methods
a
ab
bc
ac
a
Cost
N = 50
Mean survival %
<5,000
5,000-10,000
>10000
a
b
c

Figure 3