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REVIEW PAPER

# The role of aftercare in plant translocation

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## Abstract

Plant translocation can increase the chances of long-term survival of threatened plant species; nevertheless, can be costly and challenging, with unknowns in the pre- and post-release phases, limiting success. Methodological advances have been made in the pre-release phase but long-term monitoring and post-release site management (i.e., "aftercare") are not always applied and almost neglected in the literature despite being frequently effective for identifying and mitigating unexpected threats (e.g., interspecific competition, herbivory) to outplant survival.

Aiming to fill this gap, we reviewed published and gray literature on 296 translocations to shed light on the importance of aftercare on translocation outcome. We identified the most common aftercare techniques, then we performed a meta-analysis on a subset of studies that were specifically designed to test the effect of aftercare against a control (i.e., no aftercare).

The most common aftercare techniques were competition reduction, water irrigation and plant protection. Aftercare significantly increased the percentage of survival of plants when herbivory reduction and other understorey species were enhanced. Aftercare reported also a positive trend toward improved qualitative outcome when plants were protected or competition was mitigated. Nevertheless, more evidence is needed on the importance and effectiveness of aftercare techniques.

Long-term monitoring and post-release site management should be the post-translocation standard in plant translocations when ethical and possible, with plant protection, competition limitation and water irrigation being applied when needed to reduce transplant mortality. To provide statistically supported data on the effect of aftercare on translocation outcome, aftercare should be tested against a control when feasible.

**Keywords** Adaptive management · Long-term monitoring · Plant protection · Competition reduction · Water irrigation · Post-release site management

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## Introduction

Plant translocation (i.e., the deliberate transfer of species from one site to another for conservation purposes; IUCN 2013), is a widely accepted conservation tool (e.g., Maunder et al. 2000; Munt et al. 2016) that has been largely used to increase the chances of long-term survival of threatened plant species in a changing world (Guerrant and Kaye 2007; Godefroid et al. 2011). Hundreds of plant translocations have already been performed and are currently ongoing worldwide (Godefroid et al. 2011; Dalrymple et al. 2012; Silcock et al. 2019; Abeli et al. 2021; see also IUCN Global Reintroduction Perspective series, https://portals.iucn.org/library/sites/library/files/documents/2018-006-En.pdf) supported by guidelines rooted in best conservation practices and experimental evidences (e.g., IUCN 2013; Rossi et al. 2013; Commander et al. 2018; CPC 2019). However, translocations remain high-cost and challenging actions (Drayton and Primack 2012; Monks et al. 2012; CPC 2019; Possley et al. 2022), requiring careful planning both in pre-release and post-release phase.

Important aspects of the pre-release phase include the understanding of species-specific biological and ecological traits of the target plant as well as the accurate selection of suitable recipient sites (Abeli and Dixon 2016). Among the many steps of this stage, the understanding and the consequent removal or mitigation of primary threats together with the selection of the donor sources for propagation are also crucial to guarantee the survival and establishment of the species (Maschinski et al. 2012; Godefroid et al. 2016; Reiter et al. 2017). However, a recent survey among conservationists involved in translocation programs found that almost half of them did not have sufficient knowledge in the pre-translocation phase, with a specific lack of information on both ecological requirements and breeding system of the translocated species (49% and 43%, respectively; Godefroid et al. 2016), leading to high rate of failure.

At the same time, persistence of a translocated population often depends upon the post-translocation phase that includes monitoring and temporary plant and/or site management (with the latter referred to as “aftercare”, hereafter; CPC 2019). Monitoring is crucial for documenting the outcome of translocations because an initially high transplant survival is frequently followed by increased mortality over time (Drayton and Primack 2012). Moreover, monitoring is necessary for identifying unexpected threats that may reduce transplant survival. Interspecific competition, herbivory, climate stochasticity, alien species and human disturbance are examples of unexpected issues that may require mitigation in a translocation recipient site through aftercare (Bontrager et al. 2014; Daws and Koch 2015; Fenu et al. 2016).

Several reviews on plant translocations suggest that aftercare is correlated with increased plant survival (Godefroid et al. 2011; Guerrant 2012; Silcock et al. 2019). For example, fences were demonstrated to be a simple yet highly effective aftercare strategy to reduce the impact of herbivory and human disturbance in the translocated population of *Dianthus morisianus* (Fenu et al. 2016). In other studies, plant watering (Barrett et al. 2011) and the control of competing native and non-native species (Bontrager et al. 2014; Daws and Koch 2015; Commander et al. 2018) were shown to be particularly effective. Moreover, since some species require fire or physical disturbance to promote recruitment, prescribed burns have been demonstrated to positively affect the survival of translocated species i.e., *Acacia attenuata* (Dufourq and Shapcott 2019).

However, although important methodological advances have been made in both pre- and post-translocation phases thanks to several recent studies and guidelines (IUCN 2013; Rossi et al. 2013; Godefroid et al. 2016; Commander et al. 2018, CPC 2019), both at global (Menges 2008; Godefroid et al. 2011; Dalrymple et al. 2012) and sub-global scope (Liu et al. 2015; Brichieri-Colombi and Moehrenschlager 2016; Reiter et al. 2016; Albrecht et al. 2019), the contribution of aftercare to translocated plant survival is poorly reported, preventing a clear understanding of its role in overall translocation performance, and the development of common standards and methodologies.

Therefore, we reviewed published and gray literature and solicited responses from an original survey on plant translocation with the aim to produce the first overview of aftercare effects on plant translocation. We first identified the most common aftercare techniques applied in the reviewed studies. We then tested the hypothesis that aftercare increases the success of translocations in terms of transplant survival percentage compared to a no-aftercare scenario. To do so, we conducted a meta-analysis on those studies that were specifically designed to test one or more aftercare techniques against a control treatment (i.e., no aftercare). The final goal of this review is to provide practical suggestions for practitioners designing plant translocations, aiming at reducing post-planting stress and increasing the chances of transplant survival in the recipient site.

## Materials and methods

### Literature review

We reviewed literature through a search of the online ISI Web of Science database (Clarivate Analytics, https://clarivate.com/webofsciencegroup/solutions/webofscience-platform/), Scopus (Elsevier, https://www.scopus.com/home.uri) and Google Scholar (Google, https://scholar.google.com/), using different queries and cross references with published articles (last check was conducted in March 2022). Queries were as follows: reintroduction OR translocation OR outplanting OR post-translocation OR transplant OR aftercare OR management actions OR adaptive management AND plant. Moreover we checked the LIFE Projects from the LIFE Public Database of European Commission (https://webgate.ec.europa.eu/life/publicWebsite/search), published reports and websites on plants translocation and conservation available online. To be included in the review, the following basic data on the translocation must have been provided: year or duration of the translocation activities, country, species name. In addition, studies had to report the aftercare technique (or techniques, when more than one) and the time of intervention (i.e., proactive, before any issue was detected, or reactive, to mitigate an unpredicted issue after outplanting). Results had to be expressed either as quantitative survival of transplants (i.e., the percentage of surviving individuals at the last monitoring survey) or as qualitative perceived outcome (i.e., either positive or negative).

### Survey

Since several translocation cases are not published in the scientific literature (Godefroid et al. 2011) and some cases found through the abovementioned literature review lacked basic data, we conducted a survey among conservation institutions to solicit reports on unpublished cases and to gather more information on those that were published with missing or incomplete data on aftercare.

We constructed the survey and shared it using a Google Form (Google, https://docs.google.com/forms/u/0/); as for the information needed for the inclusion criteria from the literature review, the survey consisted of 26 fields grouped in five categories to be filled in with seven multiple-choices or 19 open-ended questions (Online Resource 1). We distributed the survey to the members of the Ecological Restoration Alliance of Botanic Gardens and the management committee of the Cost Action “Conserve Plants” (CA18201).

### Data analysis

We grouped the aftercare techniques described in the literature and in the survey into six categories according to their main objective as follows: plant protection, water irrigation, competition reduction, soil properties amelioration, assisted reproduction, and other types of plant manipulations (see a detailed description of each type of aftercare in Table 1). We classified aftercare based on the time of intervention as “proactive,” i.e., when aftercare was performed before any issue was detected, and “reactive,” i.e., when aftercare was put in place as a measure to mitigate an unpredicted issue after outplanting.

We then performed a meta-analysis using data from a subset of studies (23 cases, 8%, in bold in Online Resource 2) that were specifically designed to test the effect of aftercare techniques against a control (i.e., no aftercare). For studies that expressed the outcome of translocation quantitatively as the percentage of survived plants out of number of released plants (i.e., 61% of translocations), we ran a generalized linear model (*glm*) with a binomial distribution, logit-link function and binomial error structure where the effect of aftercare (i.e., presence/absence) was tested against the percentage of survival. Cases were treated individually even in studies that applied more than one aftercare technique, since results were always reported for each type of aftercare, without taking into account the possible interactive effect of multiple techniques. Odds ratio was calculated for explaining the effect size of the aftercare on translocation outcome. Then, within every type of aftercare applied (i.e., plant protection, water irrigation, competition reduction), we ran a *glm* to evaluate the effect of the different aftercare techniques on translocation outcome; odds ratio was calculated for each type of aftercare tested. Statistical analysis was not performed in the case of water irrigation, as a single study with quantitative data was available. For the remaining 39% of translocation cases which reported qualitative outcomes (i.e., positive, negative, not significant), statistical analyses were not applied; instead, we provided an extended description of the results. Statistical analyses were performed with R 3.3.0 (R Core Team 2022) using the *questionr* and *lmer* R package (Bates et al. 2015).

## Results

### Outcome of the literature review and survey

From the literature review we found 95 papers that could be included in the analysis, yielding 214 plant translocations of 205 species performed in 22 countries between 1978 and

**Table 1** Six categories of aftercare techniques identified in this study according to their main scope; threats are provided, including details of the aftercare applied. The number of aftercare techniques basing on the time of intervention (i.e., proactive – Pr, reactive – Re, proactive and reactive jointly – Pr-Re) and the final number of aftercare (Tot) per each sub-category is reported

| Scope | Threats | Details | Pr | Re | Pr-Re | Tot |
|---|---|---|---|---|---|---|
| Competition reduction | Light, space, soil moisture competition; interspecific competition | Mechanical plant removal (manual removal, mowing, rotary tillage, skimming, clipping) | 134 | 10 | 27 | 171 |
| | Interspecific competition, plant disease | Herbicides (glyphosate and other non-selective herbicides; methylated spirits) | 8 | 1 | 3 | 12 |
| | Interspecific competition | Mulching (biodegradable mats; oak mulch) | 1 | 0 | 0 | 1 |
| | Root competition | Root exclusion (holes lined with paper) | 1 | 0 | 0 | 1 |
| | Interspecific competition, limited propagation of fire-dependent species | Burning (ignition at the plot boundaries with drip torches) | 0 | 7 | 1 | 8 |
| | Missing natural management of vegetation | Use of grazers (tortoises and ungulates) | 82 | 0 | 0 | 82 |
| | Biological control of pests | Use of insects | 0 | 1 | 0 | 1 |
| | No information available | Use of animals | 0 | 3 | 0 | 3 |
| | | | **226** | **22** | **31** | **279** |
| Water irrigation | Drought events, reduced plant growth, plant mortality | Manual watering | 77 | 21 | 8 | 106 |
| | Drought events, reduced plant growth, plant mortality | Irrigation system (automated drip irrigation; gravity fed irrigation system; trickle irrigation system) | 90 | 1 | 1 | 92 |
| | Drought events, reduced plant growth, plant mortality | Hydrogel (hydrated hydrogel or water holding crystals) | 3 | 1 | 0 | 4 |
| | | | **170** | **23** | **9** | **202** |
| Plant protection | Grazing, browsing, trampling, illegal collection, soil disturbance | Area fencing (enclosures, wire and netting fences, metal fences, barbed wire fences) | 51 | 6 | 7 | 65 |
| | Grazing, trampling, soil erosion, moisture loss | Plant caging (cloth cages, circular wire baskets, shrub tubes, fine mesh cages, transparent plastic sleeves) | 23 | 5 | 6 | 33 |
| | Grazing, trampling | Not specified (fencing or caging) | 4 | 1 | 11 | 16 |
| | Herbivory, plant disease, pests | Herbivore, disease, pest control (snap traps, automatic resetting traps, chemicals, biological control) | 0 | 1 | 0 | 1 |
| | | | **78** | **13** | **24** | **115** |

**Table 1** (continued)

| Scope | Threats | Details | Pr | Re | Pr-Re | Tot |
|---|---|---|---|---|---|---|
| Soil properties amelioration | Low soil fertility | Soil preparation (rotary tillage) | 3 | 3 | 12 | 18 |
| | Low soil fertility | Fertilization (slow-release fertilizers, organic matter) | 10 | 1 | 0 | 11 |
| | Limited biotic relations | Restoring biotic relations (mycorrhiza-containing soil) | 1 | 0 | 0 | 1 |
| | Accumulation of soil and sediment | Reducing soil/sediment accumulation (soil removal, woody barriers to increase water velocity) | 0 | 0 | 1 | 1 |
| | | | **14** | **4** | **13** | **31** |
| Assisted reproduction | Limited reproduction | Assisted fertilization (hand-pollination) | 0 | 0 | 1 | 1 |
| | Limited reproduction | Assisted seed dispersal and germination (collection and dispersal of part of the produced seed, application of aerosol smoke to stimulate the soil seedbank) | 1 | 1 | 0 | 2 |
| | | | **1** | **1** | **1** | **3** |
| Other plant manipulations | High evapotranspiration | Plant manipulation (leaf tips cut) | 0 | 0 | 1 | 1 |
| | High level of stress | Application of chemicals (aspirin solution) | 1 | 0 | 0 | 1 |
| | No information available | Flowering stem removal | 0 | 1 | 0 | 1 |
| | | | **1** | **1** | **1** | **3** |

2022 (Online Resource 2). The literature review also included two studies on two species (*Ceratodon conicus* and *Ranunculus ophioglossifolius*) obtained from the website https://www.ardeola-environmental.com/research-and-conservation (accessed on 16 July 2022). As for the survey, we reached 116 members across 57 countries and we received answer from 13 institutions (11% feedback) from 10 countries; moreover, we obtained nine responses from other botanists who received surveys forwarded by the members of either Ecological Restoration Alliance of Botanic Gardens or of the management committee of the Cost Action "Conserve Plants"). Totally, we obtained 22 responses; 10 forms were correctly filled and were included in the analysis, yielding 79 translocation studies in eight countries involving a total of 47 plant species (Online Resource 2).

Altogether our study included 295 translocations (of which 45 taxa were translocated more than once in different countries or sites) of plants belonging to 82 families (Online Resource 2); 79% (234 studies) translocation cases were completed whereas 21% (62 studies) are still ongoing. Translocations occurred in 26 countries, with more than half (57%, 170 studies) performed in the USA, followed by Australia (13%, 38 studies), Italy (7%, 22 studies) and Israel (3%, nine studies), with the remaining (20%) covering other countries around the globe.

## Aftercare techniques

From our review, it emerged that the most common aftercare techniques applied in plant translocations were competition reduction (279 cases), water irrigation (202 cases) and plant protection (115 cases; Fig. 1). In 78% of cases (229 studies) aftercare was proactive,

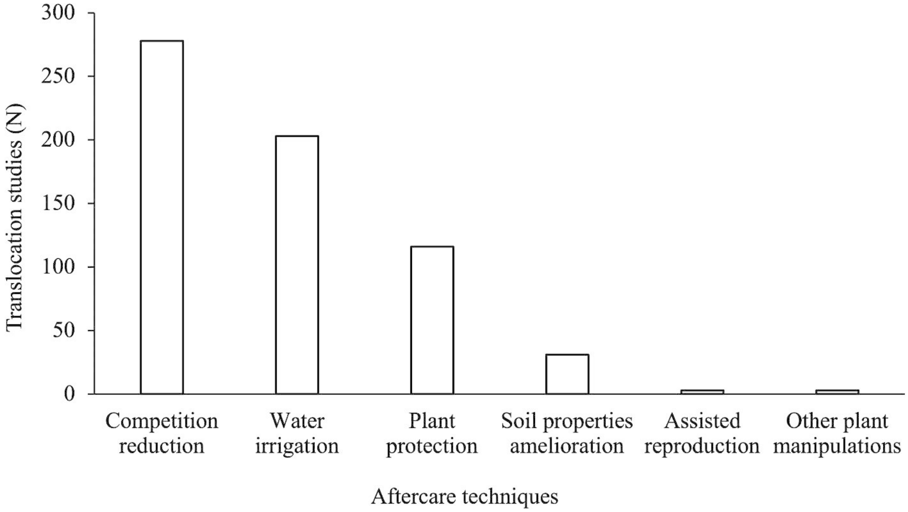

**Fig. 1** Number of translocation studies reported on y axis which applied different aftercare techniques (x axis), grouped according to their main scope

in 13% (38 cases) was reactive and in the remaining 9% (28 cases) aftercare was applied both before and after a threat was detected. Below we provide detailed information on the different aftercare techniques applied in the reviewed cases.

## Competition reduction

Aftercare techniques aiming at reducing competition for light, space, or soil moisture were applied in 279 studies and involved the control of native or non-native invasive species (Fig. 1). In 185 cases, several mechanical and chemical techniques were used to reduce competition with native or non-native species (Table 1); herbicides (e.g., glyphosate; Jusaitis and Soresen 2007) and other chemicals (e.g., phosphoric acid; Dixon 2010) were also applied by spot spraying to control vegetation and diseases. Mechanical and chemical weeding was also used in combination (e.g., Jusaitis and Soresen 2007). Weed removal was done once, regularly or in specific periods. Mulching with biodegradable mats was used to reduce the growth of other species in the translocation plots (Garfì et al. 2021). In one study, translocated species were planted in holes partially lined with paper to decrease root competition; however, data are not available on the effects of this technique (Pence et al. 2008). Overall, in 81% of translocations aftercare techniques aimed at reducing competition were proactive, in 8% were reactive and in 11% were both proactive and reactive (Table 1).

Among the techniques applied to reduce competition, burning and the use of native or non-native animals for grazing or biocontrol were also applied. Burning was applied in eight cases to remove or limit the growth of understory species and invasive species, or to trigger the propagation of fire-dependent species (Dunwiddie and Martin 2016; Dufourq and Shapcott 2019; Fant J, Chicago Botanic Garden, USA, personal communication) and consisted in the ignition at the translocation plot boundaries with drip torches (Dufourq and Shapcott 2019). Burning was reactive in seven cases and in one case this aftercare technique was both proactive and reactive (Table 1).

Use of animals was reported in 86 cases of translocations reported the use of animals as aftercare. Grazing animals were introduced in 82 cases related to a single restoration event at Makauwahi Cave Reserve, Kauaʻi, where the African spurred tortoise *Centrochelys sulcata* and the leopard tortoise *Stigmochelys pardalis* were introduced as an ecological replacement to restore grazing after the extinction of native herbivores (Burney and Burney 2016). In another case, the release of the ladybug *Rodolia cardinalis* (Coleoptera) was performed as a biological control of *Medicago arborea* subsp. *citrina* against the pest *Icerya-purchasi* (Hemiptera; Laguna 2011). The use of animals was also applied in other three translocations of *Pulsatilla patens*, *Dianthus arenarius* subsp. *bohemicus*, *Gentianella praecox* subsp. *bohemica* (Vit P, Institute of Botany, Prague, CH, personal communication). In Burney and Burney (2016) and Laguna (2011) aftercare was proactive whereas in the other cases it was reactive (Table 1).

## Water irrigation

Water irrigation was applied in 202 translocations and differed in type and timing (e.g., Barrett et al. 2011; Cypher et al. 2013; Fig. 1; Table 1). Irrigation was used to reduce plant mortality and to increase plant growth during drought events. Irrigation was performed by hand, using cans, drippers, tanks, by gravity fed systems controlled by a solar-powered electronic valve (Dillon et al. 2018) or by battery operated trickle irrigation system (Dixon and Krauss 2008). In four cases, water irrigation was performed during transplant with water holding crystals (hydrogel; Jusaitis 2016; Garfì et al. 2021). Hydrogel was tested as a potential tool to improve establishment and survival of translocated species such as *Acacia cretacea* (Jusaitis 2016) and was effective for improving early survival and growth of species, particularly over the first four years of establishment. Water irrigation was applied mostly (84% cases) on a weekly basis during the first weeks or months after release, during the dry season or drought periods, or at irregular intervals depending on rainfall (Robichaux et al. 2017); in 23 cases (11%) water irrigation was reactive whereas in 5% of translocations was both proactive and reactive (Table 1).

## Plant protection

Plant protection was applied in 115 translocations (Fig. 1); the most commonly used techniques were fencing (56%) (i.e., installation of netting fences or enclosures around translocation sites, plots or plants; Fenu et al. 2016; Dillon et al. 2018) and caging (38%) (i.e., installation of up-ended hardware cloth cages - metallic mesh either woven or welded to form square or rectangular openings - or wire baskets plant guards around each translocated plant; e.g., Barrett et al. 2011; Daws and Koch 2015; Table 1). Three translocations simultaneously applied fencing and caging (e.g., to protect plants both against cattle and rodents; Skopec et al. 2018). Of note, 16 translocations did not provide information on the type of plant protection.

Fencing was used to delimit the translocated area, to exclude animals from the outplanting site, to reduce grazing, browsing, and trampling or to protect plants from anthropogenic threats (e.g., illegal collection, soil disturbance). Fencing materials included netting and wire mesh. In the translocation of *Cyanea superba*, the control of animals was applied through the use of rodenticide, snap traps and automatic resetting traps (Adamski et al. 2020).

Caging was applied to prevent grazing and trampling, to stabilize the soil around plants, to prevent moisture loss or to facilitate counting of the outplanted individuals. Cages differed in size and shape according to the target species and were usually staked into the ground with metal landscape pins to deter burrowing by small rodents. Over time, cages were either maintained, removed (e.g., when plants grew taller and cages could possibly inhibit future growth and reproduction; e.g., Albrecht and McCue 2010) or replaced with larger cages to ensure access to pollinators while excluding larger animals (e.g., Albrecht and Long 2019).

In most translocations (68%) plant protection was proactive, in 11% was reactive and in 21% was both proactive and reactive (Table 1).

## Soil properties amelioration

Soil properties amelioration was applied in 31 cases (Fig. 1) to improve soil fertility (with chemical fertilizers or organic matter; Daws and Koch 2015; Burney and Burney 2016), to restore biotic relations (e.g., with mycorrhiza-containing soil; Tao and Xiaoya 2021) and to reduce sediment accumulation in a stream through the creation of a woody barrier to increase water velocity (Abeli et al. 2018; Table 1). In 45% of translocations aftercare was proactive, in 13% was reactive and in 42% was both proactive and reactive (Table 1).

## Assisted reproduction

Assisted reproduction was applied in three cases to boost reproductive performance in translocated populations (Fig. 1). Assisted fertilization through hand pollination (Adamski et al. 2020) was applied both proactively and reactively whereas manual seed dispersal in *Argyroxiphium kauense* (Robichaux et al. 2017) was reactive. Aerosol smoke was applied before the release of *Grevillea scapigera* to stimulate the soil seed bank, hastening seedling production compared to fire treatment (Dixon and Krauss 2008; Table 1).

## Other plant manipulations

Other types of plant manipulations were applied in three cases (Fig. 1). Leaf tips were cut to reduce evapotranspiration (Langlois and Pellerin 2016) both proactively and reactively, however information on whether this technique worked as expected is not provided. Aspirin solution was applied to transplants as an anti-stress agent right after the release of the species, without any benefits in terms of plant performance (Turner et al. 2021). Flowering stems were removed in the first season after outplanting, without any additional information on the aim of this action or on the effects on plant performance (Alley and Affolter 2004; Table 1).

## Effect of aftercare on translocation outcome

Overall, 44 aftercare techniques were tested, of which 22 evaluated the outcome through the percentage of survival and 22 provided a qualitative outcome (Online Resource 2); in detail,

**Table 2** Results from the *glm* applied to test the effect of aftercare, plant protection and competition reduction on translocation outcome, considering the presence (aftercare) or absence (control) of management techniques. Estimate, standard error, p-value, log(odds ratio) and 95% of confidence interval are reported. (Marginally) significant values (p<0.1) are indicated in bold characters

| | | Estimate | Standard Error | P-value | Log (Odds Ratio) | 95% Confidence Interval |
|---|---|---|---|---|---|---|
| Aftercare | Aftercare | 0.561 | 0.044 | <**0.001** | 1.753 | (1.607, 1.912) |
| | Control | -0.957 | 0.062 | <**0.001** | 0.382 | (0.339, 0.433) |
| Plant protection | Aftercare | 1.40 | 0.385 | <**0.001** | 4.070 | (1.941, 8.820) |
| | Control | -0.489 | 0.262 | **0.074** | 0.613 | (0.361, 1.017) |
| Competition reduction | Aftercare | 0.298 | 0.348 | 0.406 | 1.347 | (0.682, 2.681) |
| | Control | -0.348 | 0.248 | 0.182 | 0.705 | (0.429, 1.143) |

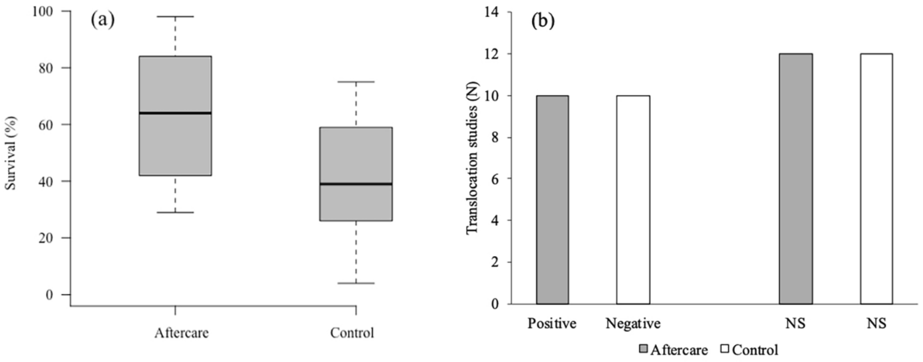

**Fig. 2** Effect of aftercare (i.e., presence/absence = “aftercare/control”) on translocations: (**a**) quantitative outcome expressed as percentage of survival. Boxplots show the median per group (solid line), boxes represent the 25th and 75th quantile, whiskers depict the normal data range; (**b**) number of translocation studies which express the outcome through a qualitative assessment. On the left side studies that recorded positive/negative effect of aftercare, on the right side studies that recorded not significant (NS) effect

21 translocations tested the effect of plant protection (e.g., Daws and Koch 2015), 16 tested the effect of competition reduction (e.g., Tischew et al. 2017) and seven tested the effect of water irrigation (e.g., Al Farsi et al. 2017).

The meta-analysis on the effect of aftercare on translocation outcome suggested that the application of aftercare (plant protection, competition reduction and water irrigation) improved the translocation outcome in terms of transplants survival percentage (mean “aftercare”: 63.7±4.9%; mean “control”: 40.2±3.9%; Table 2; Fig. 2a). In detail, plant protection reported a significant increase in percentage of survival (mean “aftercare”: 71.4±6.4%; mean “control”: 48.7±5.9; Table 2; Fig. 3a). Competition reduction did not significantly affect the outcome of translocations, although there was a trend toward increased survival when this technique was applied (mean “aftercare”: 48.7±5.9; mean “control”: 41.4±6.1; Table 2; Fig. 3b). Although water irrigation resulted in 83% of survival compared to 60% of survival in a no-aftercare scenario, we did not include this information in the analysis since it was tested in just one study.

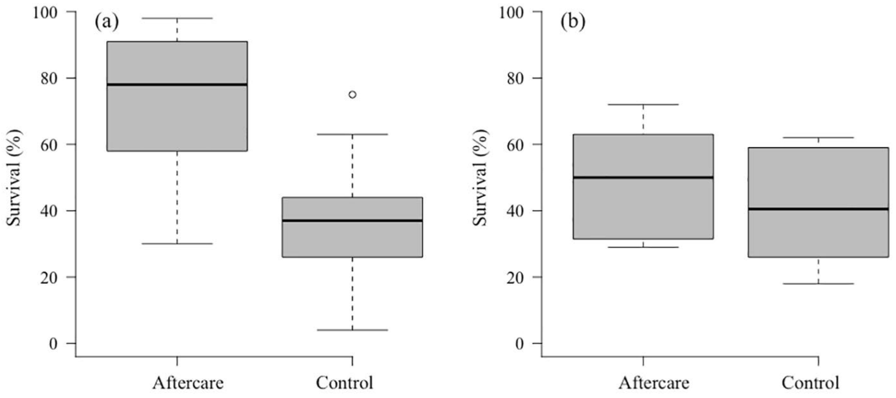

**Fig. 3** Effect of aftercare (i.e., presence/absence = "aftercare/control") expressed through percentage of survival for (**a**) plant protection and (**b**) competition reduction. Boxplots show the median per group (solid line), boxes represent the 25th and 75th quantile, whiskers depict the normal data range, dots are outliers

With regard to the effect of aftercare on translocation expressed through qualitative outcome, 10 cases reported a positive effect of aftercare compared to a condition of no management actions, and in 12 cases the effect of aftercare was considered not significant by the authors (Fig. 2b). Specifically, an improved outcome was observed when plants were protected (eight positive effects out of eight study case) and when competition was limited through aftercare (eight study case; two positive effects, six not significant effect; Online Resource 2). The effect of water irrigation was not considered to be significant by the authors in the translocations (six cases) where it was evaluated (Online Resource 2).

## Discussion

With translocations becoming more and more common as plant conservation tools, synthesis based on critical analysis of multiple cases is key to further improving techniques and protocols. Many aspects affecting plant translocation outcomes have already been analyzed in recent studies and collected in reviews (e.g., Liu et al. 2015; Albrecht et al. 2019; Silcock et al. 2019), however, the role of aftercare in plant translocations across a global range has never been comprehensively studied. Hence, this review aimed to fill this gap, providing a summary of results on post-release site management, including data and suggestions useful for conservation practitioners to evaluate whether and what aftercare techniques should be applied and the time of intervention.

Aftercare techniques were context-dependent and varied among species and sites in line with the threats identified at the translocation sites: the most common aftercare techniques applied across different contexts were aimed at limiting competition with native or non-native organisms (Jusaitis and Soresen 2007; Dixon 2010; Garfi et al. 2021), providing water to transplants (Barrett et al. 2011; Cypher et al. 2013; Dillon et al. 2018) and protecting plants through fencing or caging (Daws and Koch 2015; Fenu et al. 2016; Dillon et al. 2018). Competition reduction and plant protection were mainly applied to limit interspecific competition between the translocated species and the surrounding community in the translocated sites (e.g., invasive plants and grazers), with aftercare applied following a "cause and consequence" relationship. On the other side, water irrigation was influenced by several factors, both environmental- (e.g., climate, amount of precipitation, drought condition) and biotic factors intrinsic to a given species (e.g., acclimatation in the nursery before outplanting). On one side, watering may not be necessary if plants are acclimated and hardened in the nursery before outplanting, on the other side watering can be reactive and part of an adaptive management if unexpected drought conditions happen. In the latter case, it could be useful to define which threshold of drought (e.g., measured in terms of precipitation, soil humidity, soil water potential) or plant stress (e.g., in terms of chlorosis, water use efficiency, photosynthetic efficiency) trigger the need of watering.

Other techniques related to soil properties amelioration, assisted reproduction, and plant manipulations were applied in a few cases for mitigating specific constraints that translocated species may face in the release site. Those were either species-specific, as in the case of hand pollination in *Cyanea superba* (Adamski et al. 2020), or site-specific, as in the reduction of sediment accumulation to guarantee the survival of *Isoëtes malinverniana* with an increased water velocity (Abeli et al. 2018). Fire as a means to control competition was also site-specific, because it could be applied only in areas where it has an ecological role in shaping vegetation dynamics, like in fire-prone temperate and Mediterranean-type ecosystems (Dufourq and Shapcott 2019). It should be noted that the effects of post-planting management can vary, depending upon the context, so that in case of a rare species, there may not be an optimal, universal management regime for all habitats, as highlighted in some translocation studies (e.g., Bontrager et al. 2014).

In most cases, aftercare was performed proactively based on predicted (and predictable) issues that could happen after the release of a target species (Table 1). While this denotes accurate translocation planning, it also suggests that translocations are still characterized by a poor post-release monitoring phase, with adaptive management of translocated populations being performed rarely (Albrecht and Long 2019). Poor and short-term monitoring of transplants is a problem because it prevents practitioners from identifying unpredicted issues as soon as they happen, when reactive remediation is possible (e.g., Abeli et al. 2018).

In cases where continued aftercare is necessary for the long-term survival of the species, it suggests that the recipient site for outplanting may not be suitable. However, continued aftercare may still be justified for species that are currently extinct in the wild and that could be maintained in a condition of quasi-in-situ cultivation to overcome some disadvantage of long-term ex situ cultivation (Adamski et al. 2020; Smith et al. 2023).

By pooling data together on translocation outcome where the effect of aftercare was tested against a control, it emerged that aftercare significantly increased the percentage of transplant survival (Fig. 2). For example, survival and growth of plants were enhanced by reducing herbivory and removing other understorey species (Daws and Koch 2015). Plant protection and competition reduction had a positive effect on translocation outcome (Fig. 3), which was correlated with increased rosette diameter, height, vigor, number of leaves, and inflorescence (e.g., Skopec et al. 2018); however other translocations reporting both quantitative (e.g., Jusaitis 2012; Al Farsi et al. 2017) and qualitative outcome (e.g., Bontrager et al. 2014) did not provide a link between the increased plant survival (or performance) and plant traits. Less than 10% of the reviewed translocations specifically addressed the effect of aftercare on translocation outcome, highlighting a general undervaluation of aftercare in translocation practice and literature and making it difficult to generalize conclusions.

Although our work clearly demonstrates the link between aftercare and success of translocations evaluated qualitatively or quantitatively, it should be considered that aftercare can also increase the cost of translocation programs. Indeed, we found only a single study reporting the cost of aftercare (Fenu et al. 2016), with a ca. 15-times higher costs for fencing for the reintroduced population of *Dianthus morisianus* in Sardinia compared to a second non-fenced population. The higher costs derive from the fence itself, the transport and the greater number of staff working hours needed to install the fence. In this case, fencing significantly increased the costs, but allowed the survival and recruitment of the fenced population after five years (at last monitoring), while the unprotected one disappeared after three years.

## Practical suggestions for designing translocations

Translocation outcome can be often improved through better planning (Godefroid et al. 2016), and through post-release adaptive monitoring and management (Lindenmayer and Likens 2009), including aftercare (this study). Consequently, we recommend that existing and future translocation projects are monitored at regular intervals over several years or even decades and that an adaptive management approach has to be considered an opportunity to increase the outplant survival, when possible. Plant protection and watering are the most common aftercare techniques that have already been applied broadly and shown to reduce transplant mortality in the early post-release phase of most translocations.

Similar to other aspects of translocations, aftercare should be tested against a control when practical and the amount of source material allows to do so, without further threatening the species to provide statistically supported data on its effect on translocation outcome (i.e., translocation should be designed as experiments; CPC 2019). The latter is of key importance, because our study suggested that aftercare significantly improved the translocation outcome, however only a few studies have specifically tested this aspect and even fewer studies directly linked aftercare to increased plant performance and plant traits. It may not always be ethical to include an experimental component in aftercare (if, for example, it is known that outplants will die without frequent watering during establishment), but practitioners should include an experimental component when practical. Lastly, economic evaluation of aftercare should be included in translocation planning and the account of expenditure in cases where aftercare techniques are taken should be published, as there could be important trade-offs between the benefit of aftercare and its costs. Improved aftercare techniques and standards may in the future reduce these costs.

Finally, we suggest that aftercare applied for a short period of time after translocation is a good practice, because it can reduce post-planting stress and may increase the chances of transplant survival in the recipient site. In our study, significant benefits of aftercare for plant protection, competition limitation and watering emerged, but more published evidence is needed to further assess the importance and effect of aftercare techniques listed herein, as well as others.

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## Declarations

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