Trade-offs and synergies between in situ and ex situ taxa conservation to support practical decision-making

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Table of Contents

List of Figures

List of Tables

Executive Summary

Of the 3,700 listed threatened and priority flora in Western Australia, 429 are listed as Threatened. About 70% of the threatened flora (300 taxa) are ranked as either *critically endangered* or *endangered*. Recovery actions for critically endangered and endangered flora involve managing threats *in situ* i.e., at the site of original populations and can include augmentation of extant populations or reintroducing plants into extinct populations. In addition, *ex situ* actions are used to provide insurance against extinction in the wild. These involve deliberate transfer of plant regenerative material from one area to another for the purpose of conservation (Commander et al. 2018). Translocation of threatened species falls into four categories and includes *in situ* and *ex situ* plantings:

- Augmentation - adding more plants to an existing population.
- Reintroduction - re-introducing plants to a site where a population formerly occurred.
- Introduction – introducing plants to appropriate habitat at a new site within the current range of the species. This can include the establishment of a seed orchard (see below).
- Assisted migration - introducing plants outside their current range to novel habitats with climates projected to be suitable under future climate change (Richardson et al., 2009).

As methods have improved, translocations have become more successful and are increasingly important in threatened flora conservation programs. They can, however, be costly. Moreover, there are trade-offs inherent in deciding which conservation actions to invest in. It is particularly relevant in situations where more taxa are likely to benefit from translocation than can be managed with existing resources. Techniques to estimate both cost and recovery actions for large numbers of threatened species are not readily available, creating a barrier to effective use of cost-benefit analysis in operational decision making. Importantly, the decision-making process should ideally include consideration of the uncertainty of costs and benefits of the conservation actions. This has not always been the case in decision-making processes until now.

Here we develop a decision-support process to rapidly identify when translocations are likely to be preferable to the status quo of managing threats *in situ*. This decision process also considers the uncertainty of costs and expected benefits of the management actions. The process is easy to follow and can be quickly applied to a large group of taxa for which conservation intervention is being considered. As an end product, the process produces a ranking of taxa indicating their relative priorities for action. Specifically, our decision support process consists of: (1) a screening (or routing) process to rapidly identify taxa for which translocation would be an appropriate recovery action, (2) an expert elicitation process to estimate ecological benefits (in terms of increase in population size or probability of persistence of the taxa), (3) a cost estimation tool to estimate costs of translocation, including an indication of cost uncertainty, (4) a cost-effectiveness analysis of the conservation goal, and (5) a strategy evaluation to facilitate consideration of trade-offs of ecological benefits and costs. Where an *ex situ* strategy is recommended, the recovery action is either translocation with a goal to establish a new population of 250 mature individuals or a seed orchard (considered an intermediate step) with a goal to establish a population of 50 mature individuals depending on feasibility for the taxa.

We tested our decision-making process to prioritise conservation actions for critically endangered or endangered flora occurring in the Wheatbelt region of Western Australia. Applying the screening process to the 95 critically endangered and endangered taxa in the region resulted in 53 taxa being selected to proceed to a cost-effectiveness analysis. Costs of conducting germplasm conservation and translocation could be estimated for all 53 taxa, but because of time constraints and the need to test the process, expert elicitation was carried out on a subset of 12 species . The ecological benefits in terms of expected increase in populations and probability of persistence together with the cost of recovery actions allowed us to derive the decision support metric (cost-effectiveness ratio) to rank taxa for conservation prioritisation. After adjusting the elicited expected benefits for the likelihood of success of the recovery action, the risk to long-term funding for a taxon, and weighting to account for the threat status of the taxon, the top five taxa to be considered for the implementation of recovery action among the 12 taxa considered in the cost-effectiveness analysis were (from highest priority to lowest): *Daviesia cunderdin*, *Acacia cochlocarpa* subsp*. velutinosa*, *Eremophila verticillata*, *Acacia pharangites*, and *Grevillea scapigera*. We emphasize that this ranking is only for the set of 12 taxa included here. There may be species that would be more highly ranked than some or all of these five if they were put through the expert elicitation process.

We determine the costs and benefits (measured in terms of increased population (number of mature individuals) and increased probability of persistence) of either establishing a population of 250 mature individuals or establishing a seed orchard for a population of 50 mature individuals depending on the taxa in the cost-effectiveness analysis. The development of a rigorous model to rapidly estimate cost provides a means for conservation managers to facilitate cost-benefit analysis for multiple threatened species within their jurisdiction and budget. As germination and translocation techniques improve, the cost model can be readily adaptable to include changes in taxa survival and cost, streamlining the decision-making process. Consideration of cost uncertainty, rarely undertaken in conservation, enables future implementation of techniques to evaluate whether the ranking (i.e. the investment decision) is robust to that cost uncertainty, such as stochastic dominance.

This work could be extended to capture and incorporate social benefits of taxa in developing the ranking list for conservation prioritization, which would allow variation in the value to the community of particular species to be captured – for instance, state emblems, or wildflowers which generate income for communities. The analysis could be extended to evaluate sensitivity of decisions to uncertainty, and to cover all threatened taxa in the Wheatbelt region as well as in other regions of WA. This would help to streamline the state-wide decision making process for flora conservation, and to initiate national conversations around collective priorities.

1. Background

A large number of Australia's plants are in danger of extinction (Broadhurst and Coates, 2017). Population sizes of threatened plants throughout Australia have declined precipitously over the past 20 years (Silcock and Fensham, 2018; TSX, 2020). In Western Australia (WA) nearly 3,700 plant taxa are considered to be of conservation significance; being 'Threatened' and or poorly known 'Priority Flora' (Smith and Jones, 2018). Many of these taxa have conservation significance at national (EPBC Act) and international (IUCN red list) levels (Silcock and Fensham, 2018). Threatened flora include taxa that are considered *critically endangered*, *endangered*, or *vulnerable* that are specially protected under the Biodiversity Conservation Act of 2016. The current list of Threatened, Extinct and Specially Protected flora and fauna have been published under Part 2 of the Biodiversity Conservation Act 2016 (DBCA, 2019). Taxa that do not meet state government survey criteria, or are otherwise data deficient, or which are rare but currently secure, are listed as "Priority Flora" under one of four categories depending on the amount of available information (Brown et al., 1998). Priority Flora under categories 1 to 3 are data deficient species and are more likely to be at risk (Bland et al., 2015).

Of the 3,700 listed Threatened and Priority Flora, 429 are listed as 'Threatened' (i.e., either *critically endangered*, *endangered*, or *vulnerable*). *Critically endangered* taxa are those threatened taxa listed under Part 2 of the Biodiversity Conservation Act 2016 "facing an *extremely high risk of extinction* in the wild in the immediate future, as determined in accordance with criteria set out in the ministerial guidelines" (DBCA, 2019). *Endangered taxa* are those threatened taxa listed under Part 2 of the Biodiversity Conservation Act 2016 considered to be "facing a *very high risk of extinction* in the wild in the near future, as determined in accordance with criteria set out in the ministerial guidelines" (DBCA, 2019). *Vulnerable* taxa are those threatened taxa listed under Part 2 of the Biodiversity Conservation Act 2016 and are considered to be "facing a *high risk of extinction* in the wild in the medium–term future, as determined in accordance with criteria set out in the ministerial guidelines" (DBCA, 2019). This report will focus on conservation actions for taxa listed as *critically endangered* and *endangered*.

Of the 429 Threatened Flora, 300 are ranked as either *critically endangered* or *endangered* (Table 1).

The WA Department of Biodiversity, Conservation and Attractions (DBCA) has divided the state into nine administrative regions for conservation and management purposes. These are Goldfields, Kimberley, Midwest, Pilbara, South Coast, South West, Swan, Warren and Wheatbelt (Figure 1). The greatest number of threatened flora occur in the Wheatbelt region (131) followed by the Midwest region (122) (Table 1). Taxa can occur across multiple regions, but generally, the threatened flora of south-western Australia is characterised by narrow-range endemic taxa associated with landscape features and specific geomorphological features not found in the wider landscape (e.g. granite outcrops) (Gosper et al., 2020a).

Management of such a large number of threatened flora taxa and populations that are affected by a diverse suite of threats is challenging. As resources are limited, not all actions can be implemented, so careful consideration of costs and benefits to identify options likely to yield the greatest ‘bang for the conservation buck’ is required.

Understanding of both the (social/economic/environmental) benefits and costs of species recovery would help in selecting either a particular mode of action or taxa in a given context.

Thus, there is a need for approaches that help to prioritise taxa to be considered for particular conservation actions, specifically the translocation of taxa.

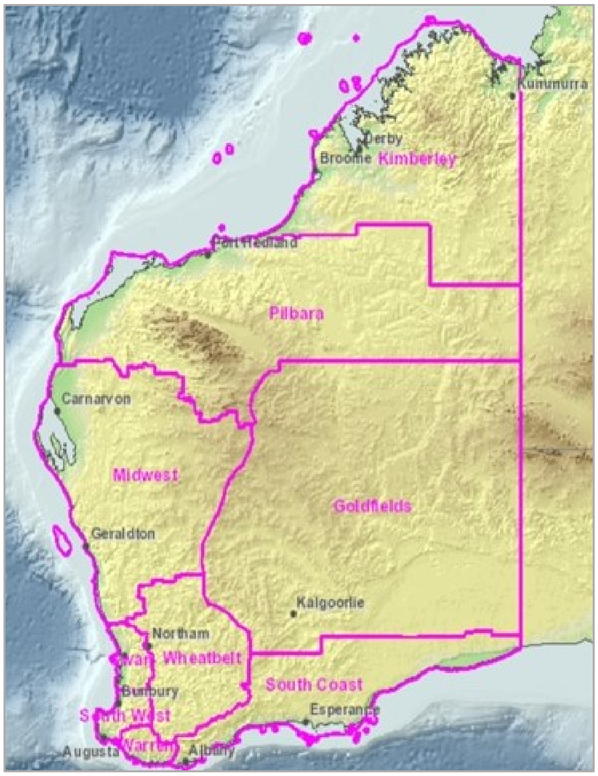

Figure 1: Map showing the nine administrative regions of the Department of Biodiversity, Conservation, and Attractions, Western Australia. Taken from Smith and Jones (2018).

Table 1: Distribution of threatened plant taxa by administrative region.

REGION	NUMBER OF THREATENED TAXA [a]
KIMBERLEY	5
PILBARA	3
SWAN	70
GOLDFIELDS	16
SOUTH COAST	107
WARREN	24
MIDWEST	122
SOUTH WEST	53
WHEATBELT	131
STATE	429

[a] Taxa classified as *critically endangered*, *endangered*, or *vulnerable*. Data taken from Smith and Jones (2018).

2. Recovery actions for threatened flora

2.1. In situ *recovery actions*

Recovery actions for critically endangered and endangered flora are often implemented *in situ* i.e., at the site of original populations. Such actions can include (Burgman et al., 2007; Coates and Atkins, 2001; Monks et al., 2019):

- maintaining critical habitat by
    - implementing weed control, disease (e.g., Phytophthora) control.
    - controlling grazing by rabbits, goats, kangaroos, wallabies etc.
    - implementing fire management
- stimulating the germination of soil-stored seed
- augmenting the population (a type of translocation)
- obtaining biological and ecological information
- acquisition (purchase) of important sites if they are not on Crown land.

Recovery actions also include monitoring existing populations, mapping critical habitat, and surveying for new populations.

2.2. Ex situ *recovery actions*

Ex situ recovery actions are those actions that are undertaken in a site away from the site of original populations. Such actions can include (Monks et al., 2019; Offord and Makinson, 2009; Seaton et al., 2010)

- collecting seed and storage in a seed bank (Offord and Makinson 2009)
- collecting cutting material for propagation and establishment of a living collection (APGA, 2020; Seaton et al., 2010)
- collecting mycorrhizal fungi and storage in a fungal bank (Merritt et al., 2014)

2.3. Translocation

Increasingly threatened species recovery also involves translocation: the deliberate transfer of plant regenerative material from one area to another for the purpose of conservation (Commander et al. 2018). Translocation of threatened species falls into four categories and includes *in situ* and *ex situ* plantings:

- Augmentation - adding more plants to an existing population.
- Reintroduction - re-introducing plants to a site where a population formerly occurred.
- Introduction – introducing plants to appropriate habitat at a new site within the current range of the species. This can include the establishment of a seed orchard (see below).
- Assisted migration - introducing plants outside their current range to novel habitats with climates projected to be suitable under future climate change (Richardson et al., 2009).

Translocations are conducted to meet a range of conservation objectives including increasing focal taxa abundance, genetic management, mitigating stochastic risk through the establishment of new population sites where existing populations are at risk from unmanageable threats. In this study, translocation as a prospective management action for the recovery of threatened plant taxa was considered. Plants are obtained for translocation most commonly either through propagation from seed, cuttings, or tissue culture, however direct removal, and relocation are sometimes used.

Establishing a wild translocation may not initially be a viable option for taxa with low numbers of plants in the wild and where the ability to obtain sufficient propagation material is limited. In such cases, the establishment of a seed orchard can be considered as an intermediate step for such taxa.

2.4. Establishing seed orchards

Some taxa produce very little seed each year. This low fecundity, combined with low numbers of mature plants in the wild, limits the amount of seed that can be collected and stored for germplasm conservation. In addition, seed licencing conditions designed to avoid over-collection of seed limit the amount of seed that may be collected from a population to 20% of the seed produced. Small population size also makes it difficult to collect sufficient material for propagation from cuttings. For such taxa, collecting enough seeds from existing wild plants to facilitate a ‘wild’ translocation may take decades. For these taxa, establishing a more intensively managed site where management is designed to maximise seed yield or generate sufficient material for cuttings (i.e. a seed orchard or seed production area) is an important intermediate step before translocation (Nevill et al., 2016). A site established as a seed orchard may also be designed to eventually lead to the establishment of a viable ‘wild’ population long term, depending on management objectives, but fundamentally differs from translocation in that the new site is primarily managed for the purpose of producing seeds, generally through the intensive management of growth conditions and where all seed produced may be targeted for collection (Commander et al., 2018). Once an adequate number of seeds are produced from a seed orchard they can be propagated to produce sufficient individuals to establish a larger translocation with the aim of establish a viable population, long-term.

3. Prioritisation of taxa to implement recovery actions

3.1. Goal

Budgets for threatened taxa’ recovery are limited, making it necessary to prioritise actions for their conservation (Gerber et al., 2018). The goal of this work, therefore, was to design a decision-making process that can identify taxa for which translocation is a useful management strategy, and among these, identify taxa for which translocation will be most cost-effective. Additionally, it was desired that the taxon identification process aligns well with a process that can simultaneously examine whether translocation is the most cost-effective management action, relative to managing threats *in situ*. This would allow decisions to be made on the most effective use of limited conservation funds for threatened taxa recovery.

3.2. Decision support tools for prioritising recovery actions for taxa

Cost-effectiveness analyses (CEA) have often been used to assist conservation managers with prioritising recovery actions where limited resources prohibit implementing all actions required for all at-risk taxa (Bode et al., 2012; Busch and Cullen, 2009; Cullen et al., 2005; Helmstedt et al., 2014).

A cost-effectiveness analysis compares the present value of costs to implement a conservation project and the ecological outcomes generated by the project measured relative to the baseline project. The metric from a cost-effectiveness analysis ranks conservation actions according to the least cost per unit of recovery outcome, (in this instance the number of plants or probability of persistence) (Table 2 and section 3.3). Metrics based purely on maximising ecological effectiveness are sometime used in ranking conservation actions (Table 2), but they are not generally preferred since they do not consider the cost of implementing recovery actions. Therefore, our work will only focus on decision making through a cost-effectiveness analysis using the metrics described in Table 2. The overall objective of this work, therefore, was to maximise the cost-effectiveness of the investment into the recovery of a given taxon. A CEA is described further in section 3.3 below.

Table 2: Objectives and metrics used in prioritisation of taxa

Objective	Metric
Maximise cost-effectiveness	Cost-effectiveness ratio (Section 3.3)
Maximise ecological benefits	Difference in the number of mature individuals with and without recovery action (Section 7.2) Difference in the probability of persistence of the taxon with and without recovery action (Section 7.2).

3.3. Cost-effectiveness analysis

A CEA compares the present value of costs to implement a recovery action and the ecological outcomes generated by the action measured relative to a baseline (or do-nothing) scenario. Taxa are prioritised for conservation on the basis of the cost-effectiveness ratio (CER), which is the ratio of the expected ecological benefit (*EB*) to the present value of costs *PV(C)* of a recovery action for the taxa/ taxon i.e:

$$CER = \frac{EB_a - EB_b}{PV(C)} \qquad (1)$$

where, EB_a and EB_b denote the expected ecological benefits measured as either the expected increase in taxa population (number of mature individuals) or the increase in the probability of persistence under the recovery **a**ction and the **b**aseline scenario respectively, and *PV(C)* is the present value of costs calculated as:

$$PV(C) = \sum_{y=0}^{Y} \frac{C_{ay} - C_{by}}{(1+r)^y} \qquad (2)$$

where, *Y* is the duration of the recovery action, *y* denotes the year in which the costs (*C*) occur, and *r* is the discount rate.

Recovery actions are prioritised in descending order of cost-effectiveness ratio i.e., actions that deliver the highest ecological benefits per unit cost are preferred over taxa delivering lower ecological benefits per unit cost. This decision rule is reliable if there is no overlap between the different species in the specific conservation actions undertaken, which is usually a reasonable assumption in the case of *ex situ* management. If the ecological benefits are measured in terms of increase in population size (number of mature individuals), then the inverse of the cost-effectiveness ratio (i.e., 1/CER) gives the cost invested for each additional plant.

3.4. Steps in decision support process to prioritise threatened taxa for recovery

The decision support process took place in four steps described below.

1. *Screening (or routing)*: this step was used to rapidly identify the taxa for which translocation would potentially be appropriate, and was based on Gregory et al. (2012) (chapter 3). In this step, taxa were first screened into different groups (which putatively have different optimal recovery actions) using a decision-tree. Taxa belonging to groups that are most likely to benefit from translocation were chosen over those that were viewed as being in less need of such actions at present. The Screening is explained in detail in Section 4.
2. *Eliciting ecological benefits*: The ecological benefits in terms of increased populations for the screened taxa under the recovery action of translocation were obtained from expert elicitation workshops. Benefits were measured as the increase in the number of mature individuals as a result of translocation. In other words, it was the difference in population size with and without recovery action. These estimates were made considering the feasibility of implementing the action, the ecological dynamics of system and target taxon, the probability for threat reduction, the population response of the taxon, and the risk of obtaining long-term funding for the recovery action. Elicitation of ecological benefits is explained in detail in Section 5.
3. *Costing*: Costs for different recovery actions (seed collections and translocations) were obtained by developing a cost model and populating it for the taxa in question. This model was informed by cost data from prior implementations of recovery actions allowing cost uncertainty to be incorporated rapidly and robustly. Details on the development of the cost model and calculations are given in Section 6.
4. *Ranking (or prioritisation)*: was carried out using cost-effectiveness analysis and a strategy evaluation table to facilitate consideration of trade-offs (Section 9.3). The taxa were ranked according to their cost-effectiveness ratios, i.e., the ratio of the cost

to implement the recovery action to the adjected benefits in terms of number of mature individuals.

4. Screening

Of the 429 listed threatened taxa of plants in Western Australia (Table 1[1]), we focused on taxa that were listed as either critically endangered or endangered. This left us with a total of 300 taxa. We implemented the process in the Wheatbelt region as this region had the greatest number of critically endangered and endangered flora in the state (95).

We used a decision tree developed as part of this project (Figure 2, described below) to categorise taxa into groups based on traits and risks to facilitate easier identification of the type and urgency of actions required. Groups ranged from those where taxa are relatively stable (Group A) to those that require immediate action to avoid loss (Group G). The group into which a taxon is routed facilitates identification of appropriate management actions, and the relative importance and urgency of translocation, based on traits, demography and threats. Each management group was assigned to a translocation category (Table 2). For taxa in groups B through G, translocation is considered to be a relatively important part of the management strategy for the taxa (with varying degrees of urgency). Taxa in these groups are progressed to cost-effectiveness analysis.

The decision-tree was programmed in Microsoft Excel to facilitate easy use by managers and practitioners (Supplementary Item S1). The Excel sheet provides available options under each decision node (Figure 2) as a dropdown list, and when populated automatically assigns taxa to a management category.

As the process is generalised, exceptions to the assignment rules may occur, in which case, specific knowledge should be used to reassign taxa among categories. The process is designed to be used on vascular flora only (traits and risks for non-vascular flora are not incorporated). It is also designed to be used at taxon-level, so a taxon should be considered

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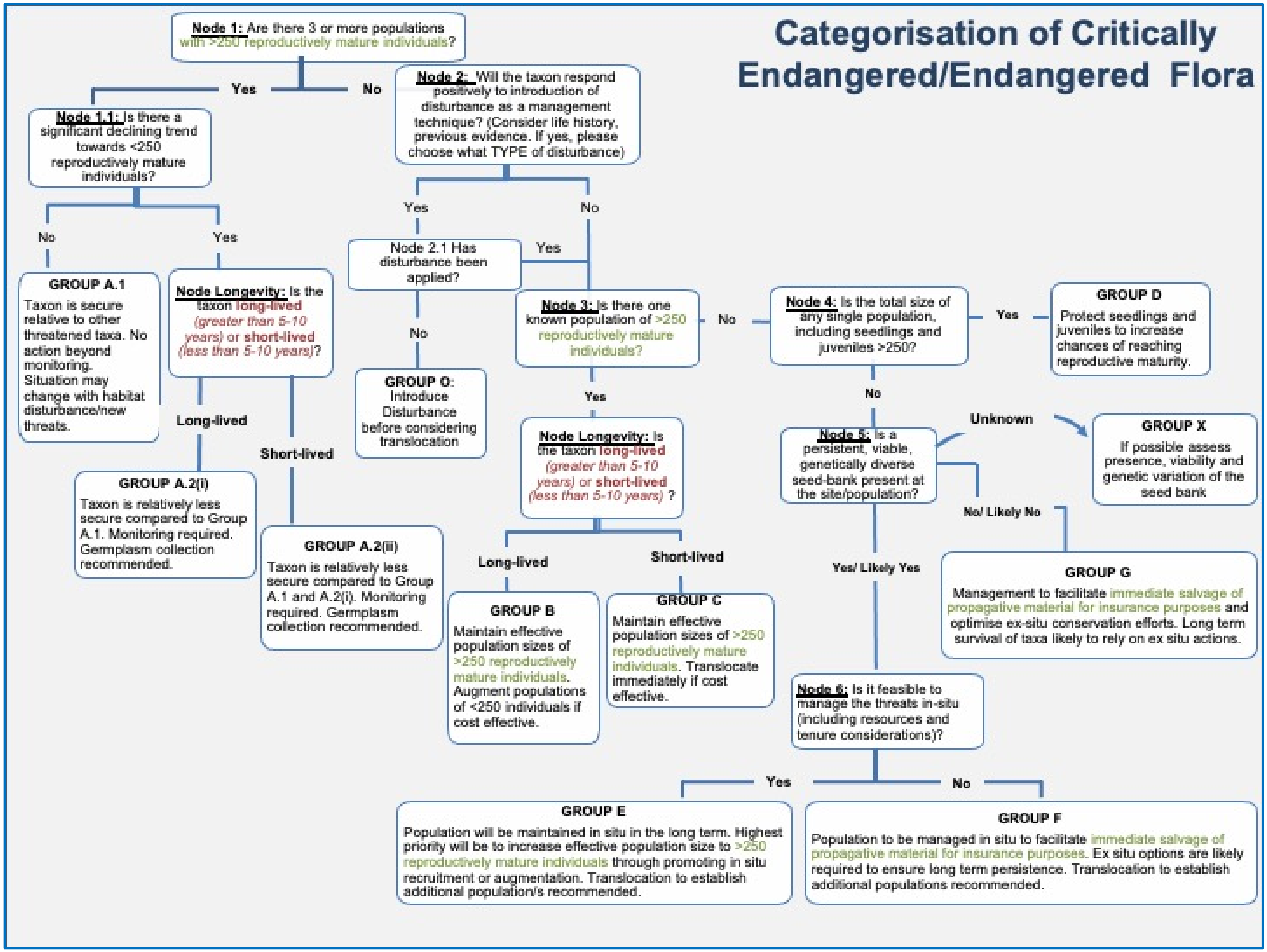
[1] Table 1 does not include taxa that are extinct / extinct in the wild. If such taxa are rediscovered, they can be included for consideration.

across its extent of occurrence when implementing the routing process. Here we apply the process at the sub-species level consistent with state and national management sub-units, but any management-relevant taxonomic unit (e.g., species) could be used.



Categorisation of Critically Endangered/Endangered Flora

Node 1: Are there 3 or more populations with >250 reproductively mature individuals?

Node 1.1: Is there a significant declining trend towards <250 reproductively mature individuals?

Node 2: Will the taxon respond positively to introduction of disturbance as a management technique? (Consider life history, previous evidence. If yes, please choose what TYPE of disturbance)

Node 2.1 Has disturbance been applied?

GROUP A.1
Taxon is secure relative to other threatened taxa. No action beyond monitoring. Situation may change with habitat disturbance/new threats.

Node Longevity: Is the taxon **long-lived** *(greater than 5-10 years)* or **short-lived** *(less than 5-10 years)*?

GROUP O: Introduce Disturbance before considering translocation

Node 3: Is there one known population of >250 reproductively mature individuals?

Node 4: Is the total size of any single population, including seedlings and juveniles >250?

GROUP D
Protect seedlings and juveniles to increase chances of reaching reproductive maturity.

GROUP A.2(i)
Taxon is relatively less secure compared to Group A.1. Monitoring required. Germplasm collection recommended.

GROUP A.2(ii)
Taxon is relatively less secure compared to Group A.1 and A.2(i). Monitoring required. Germplasm collection recommended.

Node Longevity: Is the taxon **long-lived** *(greater than 5-10 years)* or **short-lived** *(less than 5-10 years)* ?

Node 5: Is a persistent, viable, genetically diverse seed-bank present at the site/population?

GROUP X
If possible assess presence, viability and genetic variation of the seed bank

GROUP B
Maintain effective population sizes of >250 reproductively mature individuals. Augment populations of <250 individuals if cost effective.

GROUP C
Maintain effective population sizes of >250 reproductively mature individuals. Translocate immediately if cost effective.

GROUP G
Management to facilitate immediate salvage of propagalive material for insurance purposes and optimise ex-situ conservation efforts. Long term survival of taxa likely to rely on ex situ actions.

Node 6: Is it feasible to manage the threats in-situ (including resources and tenure considerations)?

GROUP E
Population will be maintained in situ in the long term. Highest priority will be to increase effective population size to >250 reproductively mature individuals through promoting in situ recruitment or augmentation. Translocation to establish additional population/s recommended.

GROUP F
Population to be managed in situ to facilitate immediate salvage of propagalive material for insurance purposes. Ex situ options are likely required to ensure long term persistence. Translocation to establish additional populations recommended.

Figure 2: Initial decision tree to categorise critically endangered and endangered flora for putative priority for translocation.

4.1. Justification for decision nodes and additional details

The decision nodes selected reflect generalised characteristics designed to differentiate taxa at greater demographic and stochastic risk, with different ecology and traits that mediate differential susceptibility to threats (Gosper et al., 2020b), how successful *in situ* management is likely to be and whether alternative management opportunities are available. For some taxa, little is known about their ecology. To limit the need to spend time collating information for taxa unlikely to proceed through the screening and reduce the information burden for managers utilising the screening tool, where possible, we automated screening based on widely available information such as IUCN criteria. Since there are 95 endangered or critically endangered taxa in the Wheatbelt alone, the tool is also designed to minimise the amount of information managers are required to provide by filtering based on widely available criteria first, reducing the number of taxa early, and deferring more technical questions to be closer to terminal nodes.

Definitions

Persistent soil seed bank: Taxa are considered to have a persistent soil seed bank if they drop seeds, and those seeds remain viable and germinable until at least the second germination season, but usually much longer due to seed dormancy. For the purposes of understanding whether a seed bank is persistent for management purposes, we further define a persistent seed bank as one which is likely, at the time of germination, to contain viable and germinable seeds (Walck et al., 2005).

Viable seed: A viable seed is one which is capable of germination under suitable conditions (Bradbeer, 1988).

Genetically diverse seed bank: a genetically diverse seed bank is one that is capable of producing an effective population size of 50 (Mace and Lande, 1991). An effective population size of 50 is widely used as the threshold for the smallest viable population (Soulé, 1980). Ideally a more diverse population is desired (Bradshaw and Brooke, but this threshold is applied as a *minimum* standard here.

Mature individuals: Mature individuals are defined following the guidelines for interpreting IUCN criteria 3.1 found in section 4.3 of the Guidelines for Using the IUCN Red List Categories and Criteria (IUCN Standards and Petitions Committee, 2019) as plants that are capable of reproduction. For clonal taxa “philosophically equivalent” units to individuals, such as ramets, or clumps should be considered, these should be defined individually for the specific taxon following the guidelines. Since this assessment is designed to assess likely cost-effectiveness over a short management relevant horizon, we account for management and funding risk in the assessment, and therefore deviate from this definition in one detail, considering translocated individuals which are producing viable seed to be classified as mature individuals.

Probability of persistence: The probability that the taxon will persist for a particular period of time say, 10 years or 100 years. It varies between 0 and 1. A probability or 0 means that the taxa will certainly not persist. 1 means that the taxon will certainly still be extant, even under the worst-case scenario. We define persistence in the region as at least 1M and 1F reproductively mature individuals present in the wild, or at least one clone for clonal species.

4.1.1. Why was a threshold population size set at 250 reproductively mature individuals?

The IUCN population size threshold for listing a taxon as *endangered* is that the “Population size is estimated to number fewer than 250 mature individuals”(IUCN, 2012). The population size (N) of 250 individuals is used as a threshold based on being approximately equivalent to an effective population size of 50 (N_e) (Mace and Lande, 1991). An effective population size of 50 is widely used as the threshold for the smallest viable population (Soulé, 1980). Mace and Lande (1991) propose that based on an average ratio of N_e: N of 0.2, 250 individuals would, on average, secure an effective population size (N_e) of 50.

The IUCN population size criterion for *critically endangered* taxa provides an important and useful threshold for decisions about population persistence, but there is also supporting data for this population size threshold of 250 mature plants from integrated genetic and ecological studies assessing responses of plant taxa to habitat fragmentation in the WA wheatbelt region. Findings from these studies show a range of effects associated with altered population parameters; such as size, shape and isolation (Byrne et al., 2007; Krauss et al., 2007; Llorens et al., 2012; Llorens et al., 2013; Yates et al., 2007a; Yates et al., 2007b); and altered soil nutrients and soil salinity (Llorens et al., 2018; Llorens et al., 2013). Importantly, it was shown that population sizes of less than 200 to 300 mature plants displayed significantly reduced reproductive output in terms of seed production and in some cases reduced seedling fitness. For a number of taxa, this appeared to be associated with genetic effects due to increased inbreeding, smaller effective sizes of paternal pollen pools and altered pollinator behaviour. Studies investigating threatened taxa have also shown that demographic rather than genetic effects in small populations (<200-300) of plants in this region are likely to result in increased extinction risk of populations (Gibson et al., 2012; Yates and Broadhurst, 2002). This is not the case for all taxa, with some finding that the expected genetic impacts of small population size associated with recent habitat fragmentation in relation to inbreeding and population fitness are not evident (Gibson et al., 2012; Sampson et al., 2016; Sampson et al., 2014; Thavornkanlapachai et al., 2019). It is suggested such cases may be associated with long-term adaptations for persistence in small populations on naturally fragmented landscape features, such as are expressed in old, climatically buffered, infertile landscapes (OCBILs) of limited distribution (Hopper, 2009). However, regardless of the genetic effects, demographic risk remains, and recent research suggests 250 may be well below an appropriate population size for many taxa (Frankham et al., 2014). Thus, while we consider the 250 threshold to be a practical indicator of population persistence for the purposes of this process, it does not necessarily indicate that populations below this threshold will not persist. Finally, while it may be a conservative estimate for some taxa from a genetic perspective, demographic and stochastic risks remain, and used in concert with other nodes these risks are captured. It is possible that a small number of taxa may be progressed unnecessarily to benefit-cost assessment, but this approach is conservative and therefore prudent given the risk status of the taxa considered.

We utilise the threshold to rapidly evaluate many taxa. However, the intent is to identify taxa and populations at risk of inbreeding and decline via demographic effects. To that end, as and when taxon or population specific evidence becomes available, the numeric threshold can be altered for a given taxon to operate using a number of individuals more appropriate for that taxon. Alternatively, if desired, a more conservative threshold could be utilised: e.g. 1,000 as suggested in Frankham et al. (2014). In practice, more conservative thresholds, while desirable, are often not possible – few CR and EN flora have anywhere close to such numbers, and adoption of a threshold of 250 individuals is far more practical for the appropriate allocation of resources in these cases.

The screening tool is designed to auto fill this information from IUCN criteria to facilitate rapid assessment and enhance usability of the tool for managers — taxa having less than 250 mature individuals (IUCN criterion C2(a) or criterion D) or those present in only a few locations / having a severely fragmented area of occupancy (IUCN criterion B2(a)) were automatically identified. Use of the IUCN criteria makes it easy for the experts to assess whether the taxa had over 250 mature individuals or not. The automatic assignment can be overridden if the information is not current, or criterion under which a taxon is listed misses the fact that the taxon has greater than 250 individuals by simply over-writing the automatically assigned response at Node 1. For instance, when we tested the process, *Grevillea curviloba* subsp. *curviloba* was reallocated through this process as it was not possible to automatically infer the population size from the IUCN listing status. If an alternative threshold is selected, users can simply provide a response relevant to that threshold selected for that taxon.

4.1.2. Node 1: Why three or more populations?

Taxa with a fewer populations are at higher risk of extinction due to stochastic climactic events such as floods and wildfire, diseases, and predation. Three or more populations are desirable to provide serial redundancy that may ensure the persistence of taxa in the face of increasing threats.

4.1.3. Node 1.1: Is there a significant declining trend towards <250 mature individuals?

While the threshold selected is useful, populations with more than 250 individuals may also face substantial risks, so declining taxa projected to reach this threshold within the next ten years were also progressed.

Populations with three or more populations that are not in decline were considered to be relatively secure, and in the context of the large number of threatened taxa, not considered immediately for translocation, and assigned to group A.1 (Figure 2).

4.1.4. Node 2: Will the taxa respond positively to the introduction of disturbance as a management technique?

Introducing a disturbance event or regime can be used effectively as a management action for those taxa that respond positively to disturbance, especially those with a persistent soil seed bank. A common form of disturbance is fire which can be applied for management purposes by planning and carrying out a prescribed burn on some or all of a population site. Other methods are sometimes used to simulate natural disturbance events These methods include activities such as applying smoke water, scalping, and soil ripping. Past recoveries in response to disturbance events such as fire indicate that there can be large benefits to such taxa from both planned and unplanned disturbance events (Monks et al., 2019). These taxa, for which a positive response to disturbance is likely, are directed to a management stream where management actions that trial and evaluate introduced disturbance prior to translocation should be implemented.

Managers pointed out that for some taxa, although they respond positively to disturbance, it was unlikely to be feasible to appropriately disturb any known sites where seed may occur and therefore assignment to this management category may carry high risk. Examples of this situation include taxa with very few remaining individuals, sites containing co-occurring threatened taxa that do not respond well to disturbance, and sites where other threats, such as weeds and disease, may be exacerbated by fire (Gosper et al., 2011; Hobbs and Yates, 2003; Monks et al., 2019). For these reasons, such taxa were reallocated for consideration of whether translocation may be cost-effective and the screening process re-designed. The re-designed decision tree was not used in the screening of the taxa for this report since the process of expert elicitation had already commenced for the taxa screened using the original decision tree (Figure 2). The revised decision tree (Figure 3), produced subsequent to benefit elicitation will be used for future cost-effectiveness analyses using the process outlined in this report.

Evaluation of the response to disturbance would make sense only once in the decision-making process. It would make more sense from an efficient decision making standpoint to ask about disturbance first and only once, but this is also perhaps the most challenging component to populate in the spreadsheet as disturbance and fire responses are often poorly understood, and the information can be difficult to obtain. Additionally, if a taxon is otherwise secure, this information is not strictly necessary. Therefore, to minimise the information burden and the required time for managers to populate the datasheet, we sacrificed decision-tree efficiency for pragmatism opting to cull many taxa first with readily-available population data in the screening process.

If disturbance has not been applied to taxa that putatively respond positively to disturbance (Node 2.1), the taxon is assigned to group O and disturbance trials are conducted. Once trials have been conducted, the taxon progresses to Node 3 with revised population information based on results of the trials. Taxa assigned to group O with positive responses to disturbance may still require translocation if few populations are extant. Upon expert review of the decision tree classification, it was noted that if disturbance has already been applied and was effective (i.e., post-disturbance recruitment was recorded), the taxon may be best managed through appropriately timed and scaled disturbances, and this needed to be reflected in the screening process and structure of the decision tree. This issue was resolved in the revised decision tree (Figure 3), where the language was also improved.

4.1.5. Node 3: Are there one or more populations with >250 individuals?

The rationale underlying the selection of 250 as a threshold is described in detail in section 4.1.1 above. Here we identify whether ANY populations exceed this critical threshold for self-maintenance. Even if there are a large number of populations, if all are small and subject to potential demographic and genetic decline, then action may be required.

4.1.6. Node *Longevity*: Is the taxon long lived or short lived?

For the purposes of this question, short lived taxa were considered to be those which live less than 5-10 years, and long lived those which live greater than 5-10 years. The intent of this node was to differentiate the relative urgency of action for translocation for short-lived (e.g. *Grammosolen odgersii* subsp *occidentalis*) vs. long-lived taxa (e.g. *Banksia cuneata*, ~30-45 years Lamont et al. (1991), M. Edgley pers. comm). The cut-off on lifespan of taxa is essentially arbitrary, and in reality, lifespan is a distribution with a long right-hand tail. A range was therefore provided, and what short or long lived was based on the life span and ecology of the taxon. Taxa whose average longevity fell between 5-10 years could be assigned to either category and discretion was given to flora experts when answering.

4.1.7. Node 4: Is the total size of any single population, including seedlings and juveniles >250?

While mature individuals are generally considered consistent with IUCN guidelines, where a large number of juveniles are present, their future reproductive potential may be considered. In some cases, it may be better to simply support or enhance seedling/juvenile survival in existing populations, rather than translocation. Group D represents the taxa in this situation.

4.1.8. Node 5: Is a persistent, viable, genetically diverse seed-bank present at the site/population?

All taxa that reach this node have no populations with greater than 250 individuals. However, extant individuals do not capture the total effective population size, therefore at this node we consider the likely contribution of the seed bank to taxon persistence. For taxa with certain life histories, such as disturbance responders with a persistent soil seed bank, it is not necessary to always have a large number of mature individuals above ground. Indeed, frequent management to keep individuals above ground may risk depleting the seed bank or the persistence of co-occurring taxa which require longer intervals between fires (Gosper et al., 2013). Nonetheless, seeds lose viability over time, and the seed bank may become depleted so there is an unavoidable trade-off.

To answer the question at this node, one should compare the genetic variation within the seed bank with the above-ground population. If variation in the seed bank is greater, the effective population size (genetically) may exceed 50. If the variation is equivalent or less, then the population is already genetically compromised/depauperate. For taxa that do not form a persistent seed bank then any seed produced is likely to contain the same genetic material as the remaining reproductively mature plants in the population. However, if the taxon does form a persistent seed bank there is a possibility that seed may contain genetic variability that has been lost from the above-ground population due to senescence and death of reproductive plants. Assessing the presence and viability of the seed bank can be undertaken using quantitative empirical techniques via combinations of a variety of *in situ* and *ex situ* methods such as smoke water treatment, soil cores, glasshouse propagation, seed collection from serotinous taxa, seed fill and viability tests et cetera. However, qualitative methods can also be utilised, such as considering existing and previous population size, time since seeds were last contributed to the seed bank, likely viability periods of seeds and local conditions where these are known. If these elements are not known, it may be necessary to evaluate the condition of the seed bank.

Experts were asked to provide estimates for this node on a four point-scale to reduce assignment to unknown categories thus avoid deferral of action due to uncertainty. For the screening process, ‘likely yes’ and ‘likely no’ responses were recorded; we considered them to be affirmative (yes) and negative (no) respectively.

4.1.9. Node 6: Is it feasible to manage the threats *in situ*?

The intent of this node is to differentiate what type of translocation action is likely to be useful, and where it might be most usefully undertaken. Regardless of the answer here, the taxon progresses to cost-effectiveness analysis, but the response informs the type and location of the *in situ* actions (i.e., augmentation, reintroduction, assisted reproduction), or *ex situ* translocation action (i.e., introduction or assisted migration). If threats cannot be managed *in situ* within feasible cost and tenure constraints, then translocation becomes much more important. Ideally, feasibility would be considered explicitly in the benefit elicitation and cost-effectiveness assessment. However, at this stage, an understanding of how viable the *in situ* conservation may be is essential. The viability of *in situ* conservation depends on key considerations that drive whether a site is manageable in the Wheatbelt region that include tenure security, accessibility, landscape fragmentation, adjacent incompatible land uses, and for many taxa, whether it is logistically and legislatively possible to introduce fire or implement other threat management effectively. For instance, it is almost impossible to keep weeds out of small linear remnants of native vegetation with high edge to area ratios on roadside reserves (Yates and Broadhurst, 2002). If participants are unclear, multiple alternative management strategies can be considered.

Table 3: Characteristics for each group.

		GROUP										
DECISION NODE		A.1	A.2(i)	A.2(ii)	O	B	C	D	E	F	G	X
1	Are there 3 or more populations with over 250 reproductively mature individuals?	Yes	Yes	Yes	No	No	No	No	No	No	No	No
1.1	Is there a significant declining trend towards <250 mature individuals?	No	Yes	Yes	_	_	_	_	_	_	_	_
Longevity	Is the taxa long-lived (greater than 5-10 years)?	_	Yes	No	_	_		_	_	_	_	_
2	Will the taxa respond positively to introduction of disturbance as a management technique?	_	_	_	Yes	Yes/ No	Yes/ No	Yes/ No	Yes/ No	Yes/ No	Yes/ No	Yes/ No
2.1	Has disturbance been applied?	_	_	_	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Is there one known population of >250 reproductively mature individuals?	_	_	_	_	Yes	Yes	No	No	No	No	No
Longevity	Is the taxa long-lived (greater than 5-10 years)?					Yes	No					
4	Is the total size of any single population, including seedlings and juveniles >250?	_	_	_	_	_	_	Yes	No	No	No	No
5	Is a persistent, viable, genetically diverse seed-bank present at the site/population?	_	_	_	_	_	_	-	Yes/ Likely Yes	Yes/ Likely Yes	No/ Likely No	Unknown
6	Is it feasible to manage the threats (includes resources and tenure considerations)?	_	_	_	_	_	_	-	Yes	No	-	-

Table 4: Recommended targeted management actions for flora taxa' recovery based on their categorisation group.

Group	Suggested targeted management action(s)
A.1 (most secure)	Taxon is secure relative to other threatened taxa. No action beyond monitoring. Situation may change with habitat disturbance/ new threats.
A.2(i)	Taxon is relatively less secure compared to Group A.1. Monitoring required. Germplasm collection recommended.
A.2(ii)	Taxon is relatively less secure compared to Groups A.1 and A.2(i). Monitoring required. Germplasm collection recommended.
B	Maintain effective population sizes of >250 reproductively mature individuals. Augment populations of <250 individuals if cost effective.
C	Maintain effective population size of >250 reproductively mature individuals. Translocate immediately if cost effective.
D	Protect seedlings and juveniles to increase chances of reaching reproductive maturity.
E	Population will be maintained *in situ* in the long term. Highest priority to increase effective population size to >250 mature plants through promoting *in situ* recruitment and/or augmentation. Translocation to establish additional population/s recommended.
F	Population to be managed *in situ* to facilitate immediate collection of propagative material for insurance purposes. *Ex situ* options are likely required to enhance long term outcomes. Translocation to establish additional populations recommended.
G (least secure)	Management to facilitate immediate salvage of propagative material for insurance purposes and optimise ex-situ conservation efforts. Long term survival of taxa likely to rely on *ex situ* actions.
O	Introduce disturbance before considering translocation.
X (Unknown)	If possible, assess presence, viability, and genetic variation of the seed bank. If previous count data exists, identify the population size before the decline. This would apply only to taxa with persistent seeds. Failing this contact Biodiversity and Conservation Science Division for advice.

Flora experts populated the spreadsheet for the critically endangered and endangered taxa in the Wheatbelt, resulting in groupings as shown in Table 5 below.

Taxa in Groups A.1, A.2(i), and A.2(ii) were considered to be more secure relative to the other taxa and a translocation was not deemed necessary for these taxa at the present time. Their populations were to be monitored. In case of Group D it was decided that it would be prudent and more cost-effective to protect the seedlings and juveniles *in situ* and allow them to reach reproductive maturity rather than do a translocation (Table 4). Threatened flora screened into Groups B, C, F and G require active intervention, potentially including a translocation. Taxa in Groups B, C, and E were relatively less secure compared to taxa in Groups, A1, A2(i) and A2(ii), and were to be considered for translocation if it was cost-effective. Taxa that were at higher risk included those assigned to Groups F and G and were considered for immediate translocation. After extensive consultation among flora experts the most appropriate translocation action to evaluate the cost-effectiveness of translocation for the taxa under consideration was the establishment of a new viable population at a site where the taxa is not currently present (an 'introduction'), ideally aiming to achieve a population of 250 mature plants.

Some taxa that were initially classified under Group O for which disturbance was the recommended management action were manually reassigned to other groups such as groups C, E, F and G and progressed to the cost-effectiveness analysis. For these taxa several factors rendered application of disturbance to *in situ* populations difficult or high risk, meaning that translocation may form a more effective management approach. These factors included the location of the population on road verges with multiple additional threats. Such was the case for *Acacia volubilis*, where road verge populations are threatened by competition from weeds, lack of recruitment (likely due to lack of fire), herbicide spray drift from adjacent agricultural land and potential for accidental destruction during maintenance of the road verge.

Other factors may include: the location of the population, such as on granite outcrops making it difficult to implement disturbance by fire, as in the case of *Tetratheca deltoideia*; or the presence of one or more other threatened taxa which may be detrimentally impacted if disturbance were to be carried out, such as in Charles Gardner Reserve in the Northern Wheatbelt (Phillips et al., 2016); or where taxa were theoretically likely to respond to disturbance but had very few individuals, making it risky to implement the disturbance should it not be successful, as in the case of *Daviesia cunderdin,* which is currently only known from one population with three individuals.

One taxon in Group G (*Darwinia carnea*) has a disjunct distribution between the Northern and Southern Wheatbelt regions in Mogumber and Narrogin, respectively. These were treated as two distinct conservation management units as taxonomic observations suggest they are likely to be different taxa and require further study (Neville Marchant, pers comm). Thus, the total number of taxa progressed to cost-effectiveness analysis was 53 from the initial 88.

Table 5: Screening results for Wheatbelt flora taxa indicating the relative priority (importance) of translocation to enhance taxon status based on demography, traits, threats, and risk profile. All taxa classified as either moderate or high priority for translocation are progressed to cost-effectiveness analysis.

Group	Number of taxa	Translocation Priority
Group A.1	5	Low Priority
Group A.2(i)	8	Low Priority
Group A.2(ii)	2	Low Priority
Group B	15	Moderate Priority
Group C	4	Moderate Priority
Group D	3	Low Priority
Group E	19	Moderate Priority
Group F	5	High Priority
Group G	8	High Priority
Group O	19	Introduce disturbance and evaluate

The names and classifications of the 53 taxa for which translocation is putatively of greatest benefit (Moderate and High Priority for translocation based on risk profile) that were progressed to the cost-effectiveness analysis phase are listed in Table 6 .

Table 6: Wheatbelt taxa along with their IUCN threat status and rank selected for the cost-effectiveness analysis.

Biodiversity asset	IUCN threat status	IUCN Rank	Translocation Priority	Translocation Group
Acacia cochlocarpa subsp. *velutinosa* *	Critically endangered	B1ab(v)+2ab(v)	High Priority	F
Acacia insolita subsp. *recurva*	Critically endangered	B1ab(ii,iii,v)+2ab(ii.iii.v)	High Priority	G
Acacia pharangites *	Critically endangered	B1ab(v)+2ab(v);C2a(i)	Moderate Priority	E
Acacia sciophanes	Critically endangered	B1ab(iii,v)+2ab(iii,v)	Moderate Priority	B
Acacia subflexuosa subsp. *capillata* *	Critically endangered	D	High Priority	G
Acacia volubilis *	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(i)	High Priority	G
Banksia ionthocarpa subsp. *chrysophoenix*	Critically endangered	B1ab(iii,v)+2ab(iii,v)	High Priority	G
Banksia oligantha	Endangered	B1ab(iii)+2ab(iii)	Moderate Priority	B
Caladenia christineae	Endangered	D	Moderate Priority	B
Caladenia dorrienii	Endangered	B1ab(iii,iv,v)+B2ab(iii,iv,v)	Moderate Priority	B
Caladenia drakeoides	Critically endangered	B2a,b,(ii,iii,iv,v)	Moderate Priority	B
Caladenia graniticola	Endangered	B1ab(iii,v)+2ab(iii,v); C2a(i); D	High Priority	G
Caladenia hopperiana	Endangered	B1ab(iii)+2ab(iii)	Moderate Priority	E
Caladenia luteola	Critically endangered	B1ab(iii,v)+B2ab(iii,v); C2a(ii)	Moderate Priority	E
Caladenia melanema	Critically endangered	B2ab(iii); C2a(ii)	Moderate Priority	E
Caladenia williamsiae	Critically endangered	D	Moderate Priority	E
Conospermum galeatum	Critically endangered	B1ab(iii,iv)+B2ab(iii,iv); D	Moderate Priority	B
Grammosolen odgersii subsp. *occidentalis*	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(ii)	High Priority	F
Darwinia carnea (Mogumber)	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(i)	High Priority	G
Darwinia carnea (Narrogin)	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(i)	High Priority	G
Dasymalla axillaris	Critically endangered	C1+C2a(i)b	Moderate Priority	E

*Daviesia cunderdin **	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(ii); D	High Priority	F
Daviesia euphorbioides	Critically endangered	B2ab(iii,v); C2a(ii); D	Moderate Priority	C
Eremophila pinnatifida	Critically endangered	B1ab(iii)+2ab(iii)	High Priority	F
Eremophila verticillata	Critically endangered	A2c; B1a; b(ii; v)+2a; b(ii; iv); C1	Moderate Priority	C
*Eremophila virens **	Endangered	B1+2Ca	Moderate Priority	E
*Eremophila viscida **	Endangered	A4c; C1	Moderate Priority	E
Frankenia parvula	Endangered	B1ab(iii)+2ab(iii)	Moderate Priority	B
Gastrolobium diabolophyllum	Critically endangered	B1ab(iv); C2a(ii)	Moderate Priority	B
Gastrolobium hamulosum	Critically endangered	B2ab(iii), C1	Moderate Priority	B
Goodenia integerrima	Endangered	D	Moderate Priority	C
Grevillea bracteosa subsp. *bracteosa*	Endangered	B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)	Moderate Priority	B
Grevillea dryandroides subsp. *dryandroides*	Critically endangered	B1ab(iii,v)+B2ab(iii,v); C2a(i)	Moderate Priority	E
Grevillea involucrata	Endangered	C2a; D	Moderate Priority	E
*Grevillea pythara **	Critically endangered	B1ab(iii)+2ab(iii); C2a(ii)	High Priority	G
Grevillea scapigera	Critically endangered	B1ab(i,ii,iii,1v,v)+2ab(i,ii,iii,1v,v); C2a; D	High Priority	G
Grevillea sp. *Gillingarra* (R.J. Cranfield 4087)	Critically endangered	B1ab(iii)+2ab(iii); D	High Priority	G
Guichenotia seorsiflora	Critically endangered	C2a(i); D	Moderate Priority	E
Hemigenia ramosissima	Critically endangered	C2a	Moderate Priority	B
Isopogon robustus	Critically endangered	B2ab(v); C2a(ii)	Moderate Priority	B
*Lasiopetalum moullean **	Critically endangered	B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v); C2a(i); D	Moderate Priority	E
*Lysiosepalum abollatum **	Critically endangered	B1ab(iii; iv; v)+B2ab(iii; iv; v); C2a(ii)	Moderate Priority	E
Melaleuca sciotostyla	Endangered	D1+2	Moderate Priority	B
Philotheca basistyla	Critically endangered	A1c; B1ab(iii)+2ab(iii); C1	High Priority	F

Pityrodia scabra subsp. *scabra* *	Critically endangered	B1ab(iii,v)+2ab(iii,v); C1; D	High Priority	F
Rhizanthella gardneri	Critically endangered	C1+2a(i); D	Moderate Priority	E
Stylidium applanatum	Critically endangered	B1ab(iii)+2ab(iii)	Moderate Priority	B
Symonanthus bancroftii	Critically endangered	A1c; B1ab(iii,v)+2ab(iii,v); C1; D	Moderate Priority	E
Tetratheca deltoidea	Critically endangered	B1ab(iii,v)+2ab(iii,v); D	Moderate Priority	E
Thelymitra stellata	Endangered	D; C2a	Moderate Priority	E
Thomasia sp. Green Hill (S. Paust 1322)	Critically endangered	B1ab(iii)+2ab(iii)	Moderate Priority	E
Verticordia staminosa subsp. *cylindracea* var. *erecta*	Critically endangered	B1+2ab(iii,v)	Moderate Priority	B
Verticordia staminosa subsp. *staminosa**	Critically endangered	B1+2c	Moderate Priority	C

* Taxa that were reallocated from the group with a putatively positive response to disturbance (Group O) have a * by their name.

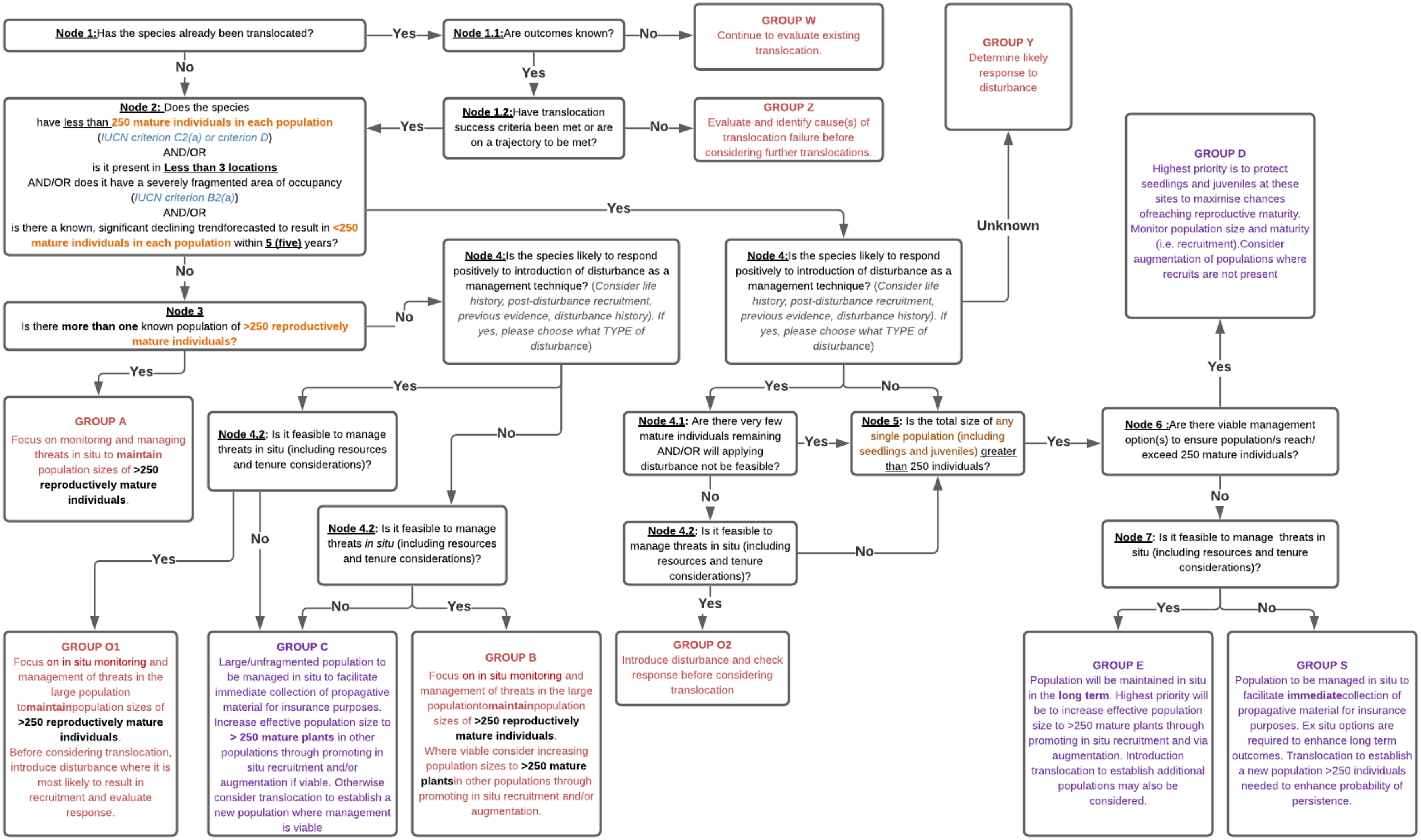


Figure 3: Revised decision tree to categorise critically endangered and endangered flora for putative priority for translocation based on traits, demography, and threats

Additionally, during the workshops to elicit the ecological benefits for the taxa (Section 7) there were extensive discussions among experts regarding categorising taxa. This led to a revision of the initial (Figure 2) decision tree, resulting in the tree shown in Figure 3. The decision tree was revised as experts felt that some of the decision nodes led to taxa that putatively respond positively to disturbance (i.e., showing post disturbance recruitment) being inappropriately categorised under Decision Node O, rather than asking additional questions about whether it was actually feasible to apply the disturbance. This was especially crucial for taxa where there were less than 250 mature individuals in each population (IUCN criteria C2(a) or D) or those present in only a few locations / having a severely fragmented area of occupancy (IUCN criterion B2(a)). Thus, the decision tree was revised to include these considerations and a new disturbance group O.2 was added. Additionally, for efficiency, groups A.1, A.2(i) and A. 2(ii) were consolidated into one group–Group A, and groups F and G were consolidated into one group–Group S (or, the "Salvage" group). As there were very few for which seed bank information could not be inferred, albeit with varying levels of uncertainty, and it was recognised that Groups G, F, and S all may require understanding of the seedbank, Group X (unknown seed bank) was removed.

4.2. Brief summary of changes to nodes and rationale/justification

Nodes 4 (Node 2 in Figure 2, section 4.1.4), 4.2 (Node 6 in Figure 2, section 4.1.9), 5 (Node 4 in Figure 2, section 4.1.7), and 7 (Node 6 in Figure 2, section 4.1.9) are unchanged in terms of their intent and structure and are described in section 4.1 above in the sections denoted in brackets.

Five major changes were introduced to the structure subsequent to the pilot. (1) The most important change was to explicitly redesign the tree to incorporate the need to carefully consider the role of disturbance in the process. To that end, Group O.2 was introduced, and Node 4.1 was introduced (see below) and a process to redirect taxa to/away from group O where relevant was introduced. (2) the second was to implement a process to identify where work was ongoing and it would be prudent to evaluate current translocations first (Nodes 1, 1.1, 1.2, Groups W and Z), (3) The third was to re-design the initial Node 1 (now Node 2) to more clearly identify when a species was likely to remain stable without the need for intervention in the form of *ex situ* intervention, and simultaneously to better align the node with IUCN criteria to improve rapid allocation of species to the Group A, greatly reducing the time required to populate the screening tool, (4) Group X was removed, as it resulted in information bias towards species with long-lived hard coated seeds, and the principle could be usefully incorporated in groups E and F, resulting in a management outcome that incorporated the information or lack thereof available, (5) the longevity node (Figure 2, section 4.1.6) was removed as the final decision was the same, and urgency and timing are considered in the cost: benefit process.

Node 1.1: If a translocation has already occurred it was deemed appropriate to wait until initial outcomes are available prior to further translocations, therefore Node 1.1. was introduced to redirect such taxa to Group W (Wait).

Node 1.2: If a translocation has already occurred but did not meet translocation success criteria (or they are not on a trajectory to be met), it was felt that further consideration should be deferred, and evaluation of the potential reasons for failure conducted first and the taxon is directed to (Group Z). Practically, the node should be implemented such that, if assessment has been conducted to identify the causes of decline and they are either known, or a plausible alternate adaptive strategy is deemed likely to be viable, then taxa should progress as if the answer at node 1.2 is Yes (ideally set up in such a way as to evaluate potential causes of failure).

Node 2: The rationale for the criteria in node 2 are described in sections 4.1.2 (why three populations) and 4.1.3 (why 250 individuals). These criteria were combined into one node to simplify the process, and there was no divergence in the tree when the criteria were considered separately after removing longevity. To address an important concern: that in some cases decline is ongoing and taxa are likely to move into a more tenuous management context in the near future (the next five years), it was deemed prudent to conservatively treat such taxa as if the decline had already occurred.

Node 3: Node 3 was introduced to ensure that all taxa with only one population of greater than 250 reproductively mature individuals were considered for translocation, as such populations are by definition at high risk from catastrophic stochastic events such as bushfire, disease, or extreme drought (Helmstedt et al., 2014).

Node 4: Node 4 was introduced to ensure that the potential benefits of disturbance in increasing population size or increasing the probability of persistence were considered for all taxa prior to allocation to a category in which translocation is considered. The proportion of species known to recruit from seed after fire or other disturbance across south-western Australia is high, often exceeding 80% of species (Clarke et al., 2015; Gosper et al., 2016; Shedley et al., 2018). In the Wheatbelt, fire no longer naturally occurs in many parts of the landscape due to disruption of continuity of fuels, reduced land area susceptible to lightning ignitions, and active fire suppression (Parsons and Gosper, 2011). Planned introduction of fire has successfully led to recruitment of reproductively mature individuals of threatened flora at sites without pre-fire extant individuals via the stimulation of persistent soil-stored seed banks (Monks et al., 2019). For tree simplicity and efficiency, the ideal place to introduce this node would be immediately after node 1, as it applies to all taxa. However, to balance the pragmatic and ideal, it is introduced subsequently, allowing for automatic assignment of species to group A before information about fire response is included (Figure 3).

Node 5 (Node 4 in Figure 2) and *Node 7* (Node 6 in Figure 2) are identical to the initial tree and described in sections 4.1.7 and 4.1.9 above.

Node 6: "*Are there viable management option(s) to ensure population/s reach/ exceed 250 mature individuals?*" was introduced to ensure that feasibility was considered prior to allocation of group D, an oversight in the initial decision tree.

The categorisation of taxa in "translocation categories", and whether they progressed to cost-effectiveness analysis under the revised decision tree (Figure 3), was not expected to greatly differ from the one given in Table 5, but the revised tree reduced bias in assignment to action related categories.

The structured expert elicitation to quantify ecological benefits and the recovery costs of the taxon will focus on the 53 taxa that were selected after categorisation using the decision tree given in Figure 2 and those that were manually reassigned. The revised decision tree (Figure 3) will used be in future management.

4.3. Seed availability assessment

The amount of seed held in conservation storage at the Western Australian Seed Centre (WASC) and available for use for translocation for the CR and EN Wheatbelt taxa was calculated. (See the "Seed in Storage" spreadsheet in Supplementary Item S2.) Where the storage unit for a taxon was fruit rather than seed, estimates of the number of seed in storage was calculated based on actual seed-fill data for a collection, or in the absence of this information, was estimated using seed-fill data for other collections of the same taxon. Seed-collection data was used estimate of the amount of seed of a taxon that could be collected annually, which in turn was used to calculate the number of years it would take to collect a target amount of seed.

The amount of seed available for translocation was based on the quantity of seed in storage and the germination of the seed (germinable seed; where germinable seed = number of seed x germination rate). The WASC's guidelines for access to seed for management actions aim to ensure that a proportion of seed for each taxon is always held in the WASC seed bank. The amount of seed which could be accessed is based on a range of factors including:

- Intended use of the seed
- Number of plants and populations remaining in wild
- Genetic representativeness of collections
- Relationship between plants sampled and current plants in wild
- Potential for recollection

Assessment of available seed in storage for translocation revealed that some of the taxa being considered for translocation had little to no seed in the WASC, and insufficient seed production by mature individuals in the wild to allow sufficient seed collection in the short term (~ 10 years). Consequently, it was estimated that the collection of an adequate amount of seed for translocation was likely to take decades. It was decided that for these taxa (Table 7) an intermediate step of establishing a seed orchard or other high yield translocation from which germplasm could be harvested to support future translocation actions (section 2.3) would be preferable (Table 7). The goal of the seed orchard was to establish a population of 50 reproductively mature plants.

If there are more than 1000 seeds for a given taxon, then up to half of the germinable seed may be accessed for use in translocations. If a taxon is represented by less than 1000 seed then seed would only be able to be accessed for use in a seed orchard as this is considered likely to have a higher chance of success, and a more judicious use for a limited resource.

Table 7: Taxa for which a translocation of 250 individuals is not currently feasible within 8–10 years without the establishment of a seed orchard to collect seeds to support a future translocation.

Biodiversity asset	IUCN threat status	IUCN Rank	Translocation Priority
Acacia insolita subsp. *Recurva*	Critically endangered	B1ab(ii,iii,v)+2ab(ii.iii.v)	High Priority
Acacia volubilis	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(i)	Moderate Priority
Banksia ionthocarpa subsp. Chrysophoenix	Critically endangered	B1ab(iii,v)+2ab(iii,v)	High Priority
Conospermum galeatum	Critically endangered	B1ab(iii,iv)+B2ab(iii,iv); D	Moderate Priority
Grammosolen odgersii subsp. *Occidentalis*	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(ii)	High Priority
Darwinia carnea (Mogumber)	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(i)	High Priority
Darwinia carnea (Narrogin)	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(i)	High Priority
Daviesia cunderdin	Critically endangered	B1ab(iii,v)+2ab(iii,v); C2a(ii); D	High Priority
Daviesia euphorbioides	Critically endangered	B2ab(iii,v); C2a(ii); D	Moderate Priority
Eremophila pinnatifida	Critically endangered	B1ab(iii)+2ab(iii)	High Priority
Eremophila virens	Endangered	B1+2Ca	Moderate Priority
Gastrolobium diabolophyllum	Critically endangered	B1ab(iv); C2a(ii)	Moderate Priority
Gastrolobium hamulosum	Critically endangered	B2ab(iii), C1	Moderate Priority
Grevillea bracteosa subsp. *Bracteosa*	Endangered	B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)	Moderate Priority
Grevillea dryandroides subsp. *Dryandroides*	Critically endangered	B1ab(iii,v)+B2ab(iii,v); C2a(i)	Moderate Priority

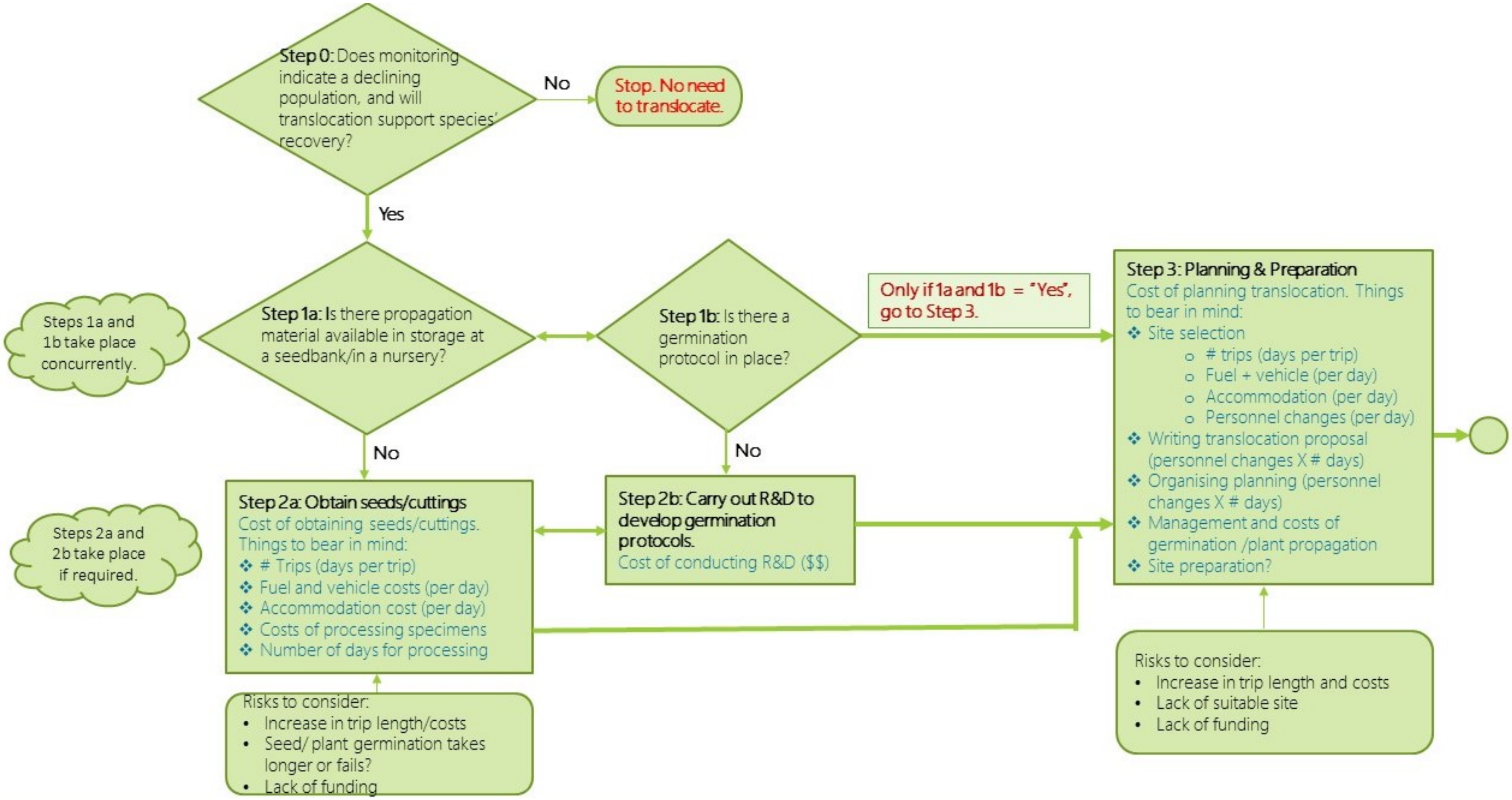
Grevillea involucrata	Endangered	C2a; D	Moderate Priority
Grevillea sp. Gillingarra (R.J. Cranfield 4087)	Critically endangered	B1ab(iii)+2ab(iii); D	High Priority
Lasiopetalum moullean	Critically endangered	B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v); C2a(i); D	Moderate Priority
Philotheca basistyla	Critically endangered	A1c; B1ab(iii)+2ab(iii); C1	High Priority
Pityrodia scabra subsp. *Scabra*	Critically endangered	B1ab(iii,v)+2ab(iii,v); C1; D	High Priority
Stylidium applanatum	Critically endangered	B1ab(iii)+2ab(iii)	Moderate Priority
Tetratheca deltoidea	Critically endangered	B1ab(iii,v)+2ab(iii,v); D	Moderate Priority
Thomasia sp. Green Hill (S. Paust 1322)	Critically endangered	B1ab(iii)+2ab(iii)	High Priority

5. Costing recovery actions

5.1. Conceptual framework of cost model

One of the biggest obstacles to routinely embed cost-effectiveness analysis in decision-making is the time investment burden of undertaking them. Managers have extremely limited time available to them and fully budgeting a large number of actions unlikely to be implemented is a time-consuming task which carries a high opportunity cost, taking time away from monitoring and management.

To assist conservation managers in rapidly calculating the costs incurred in undertaking recovery actions, specifically translocations and the establishment of seed orchards, we constructed a Microsoft Excel based tool for the cost model. This model was informed by cost data from seed collecting and translocations conducted over 20 years (Supplementary Item S2). The conceptual framework of the cost model (Figure 4) was developed based on consultations with flora experts at DBCA. The tool is fully flexible and can be updated with more recent costs as they change or become available. A novelty of the tool is that it also (implicitly) accounts for uncertainty in costing. This is described in more detail in section 6.2.3.



Step 0: Does monitoring indicate a declining population, and will translocation support species' recovery?

No

Stop. No need to translocate.

Yes

Steps 1a and 1b take place concurrently.

Step 1a: Is there propagation material available in storage at a seedbank/in a nursery?

Step 1b: Is there a germination protocol in place?

Only if 1a and 1b = "Yes", go to Step 3.

No

No

Steps 2a and 2b take place if required.

Step 2a: Obtain seeds/cuttings

Cost of obtaining seeds/cuttings. Things to bear in mind:

- # Trips (days per trip)
- Fuel and vehicle costs (per day)
- Accommodation cost (per day)
- Costs of processing specimens
- Number of days for processing

Risks to consider:

- Increase in trip length/costs
- Seed/ plant germination takes longer or fails?
- Lack of funding

Step 2b: Carry out R&D to develop germination protocols.

Cost of conducting R&D ($$)

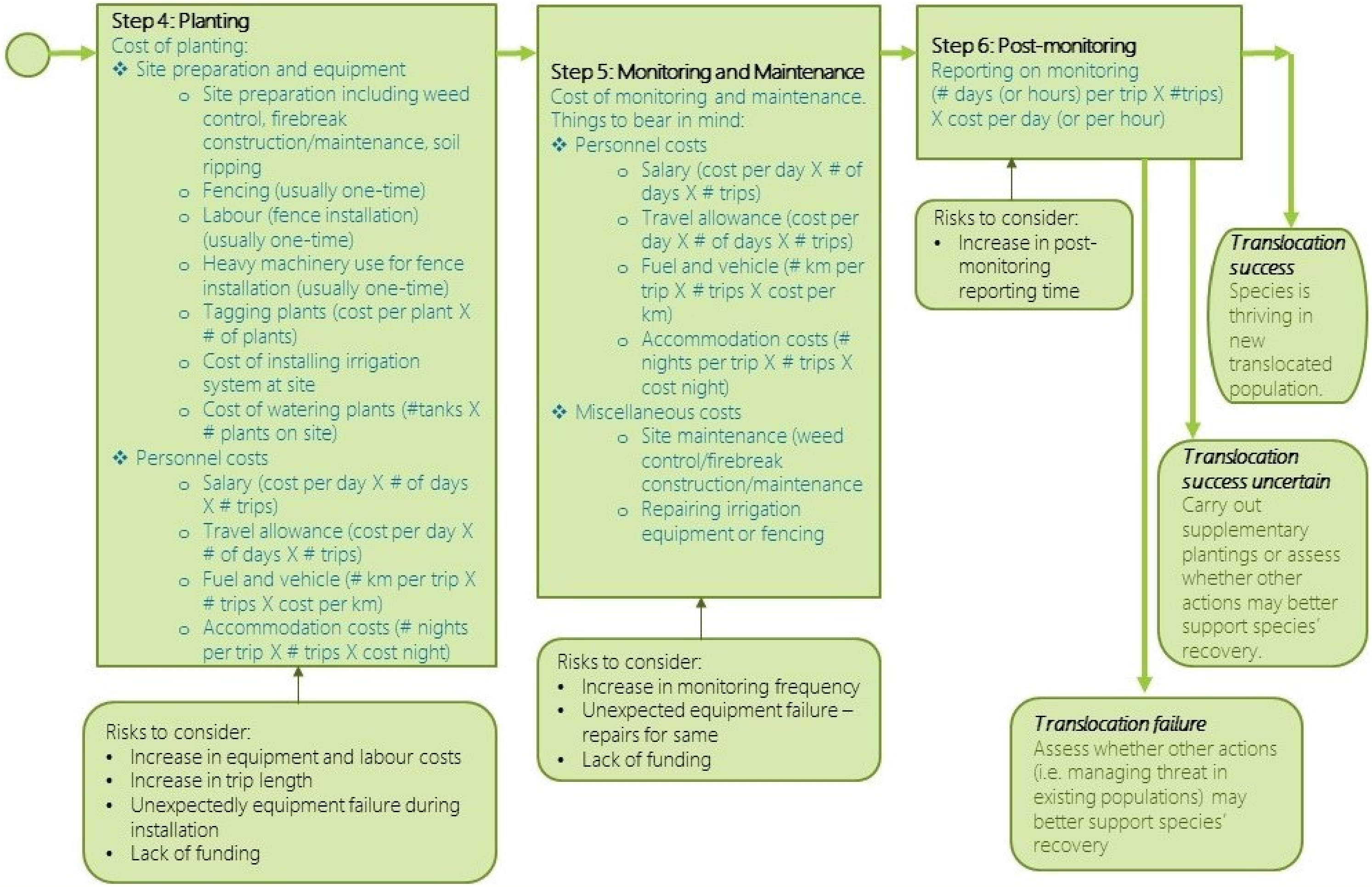
Step 3: Planning & Preparation

Cost of planning translocation. Things to bear in mind:

- Site selection
  - # trips (days per trip)
  - Fuel + vehicle (per day)
  - Accommodation (per day)
  - Personnel changes (per day)
- Writing translocation proposal (personnel changes X # days)
- Organising planning (personnel changes X # days)
- Management and costs of germination /plant propagation
- Site preparation?

Risks to consider:

- Increase in trip length and costs
- Lack of suitable site
- Lack of funding



Step 4: Planting

Cost of planting:

- Site preparation and equipment
  - Site preparation including weed control, firebreak construction/maintenance, soil ripping
  - Fencing (usually one-time)
  - Labour (fence installation) (usually one-time)
  - Heavy machinery use for fence installation (usually one-time)
  - Tagging plants (cost per plant X # of plants)
  - Cost of installing irrigation system at site
  - Cost of watering plants (#tanks X # plants on site)
- Personnel costs
  - Salary (cost per day X # of days X # trips)
  - Travel allowance (cost per day X # of days X # trips)
  - Fuel and vehicle (# km per trip X # trips X cost per km)
  - Accommodation costs (# nights per trip X # trips X cost night)

Risks to consider:

- Increase in equipment and labour costs
- Increase in trip length
- Unexpectedly equipment failure during installation
- Lack of funding

Step 5: Monitoring and Maintenance

Cost of monitoring and maintenance. Things to bear in mind:

- Personnel costs
  - Salary (cost per day X # of days X # trips)
  - Travel allowance (cost per day X # of days X # trips)
  - Fuel and vehicle (# km per trip X # trips X cost per km)
  - Accommodation costs (# nights per trip X # trips X cost night)
- Miscellaneous costs
  - Site maintenance (weed control/firebreak construction/maintenance
  - Repairing irrigation equipment or fencing

Risks to consider:

- Increase in monitoring frequency
- Unexpected equipment failure – repairs for same
- Lack of funding

Step 6: Post-monitoring

Reporting on monitoring

(# days (or hours) per trip X #trips) X cost per day (or per hour)

Risks to consider:

- Increase in post-monitoring reporting time

Translocation success

Species is thriving in new translocated population.

Translocation success uncertain

Carry out supplementary plantings or assess whether other actions may better support species' recovery.

Translocation failure

Assess whether other actions (i.e. managing threat in existing populations) may better support species' recovery

Figure 4: Conceptual framework supporting development of the cost model

The conceptual framework for the cost model includes six broad stages in translocation/establishment of a seed orchard: 1) Collecting seeds/cuttings/propagules, 2) Establishing a germination protocol, 3) Plant propagation and planning, 4) Planting, 5) Monitoring and maintenance, and 6) Post-monitoring. The various stages of translocation in the conceptual framework are detailed in section 6.3.

5.2. Determinants of cost

Costs for translocation vary owing to a range of factors:

- the life-history of taxa
- the survival rate of taxa along the different stages from seed germination to reproductive maturity (Figure 5). This will impact the number of seedlings that need to be planted and the number of plantings required to establish a new population. The impact of survival rate on cost is detailed in section 6.3.1.
- the availability of seed in the WASC seed bank for translocation
- the number of seeds that can be collected annually from the wild populations if seeds are unavailable in the WASC seed bank
- the time taken to collect seeds (number of years, number of annual trips, trip length per trip)
- whether a germination protocol has been established for the taxon
- the ease of establishing a germination protocol if one is not already in place
- if a taxa is clonal and/or sterile, whether new plants can be propagated from vegetative material (e.g., cuttings)
- the distance to the population sites and translocation sites
- the time it takes to find a suitable translocation site (this is especially important for orchids)
- multiple and varied site preparation requirements
- the time required to manage seed germination or the propagation of cuttings
- the time required to organise planting

- the number of plantings required to be carried out
- the number of annual monitoring trips required
- the frequency of watering the translocation site
- the number of staff required for the various stages

5.2.1. Fixed and variable cost parameters

Some parameters to calculate costs were kept fixed (for example, the personnel/staff costs per day, vehicle running costs per kilometre, equipment costs, etc.). The duration over which these costs were incurred (the annual number of trips, the number of days per trip, distance to the site, number of days required to manage seed germination and organise planting etc.) were allowed to vary. Table 8 shows the fixed-cost parameters and their values.

Table 8: Fixed cost parameters and their values

Personnel, travel, and fuel	
Personnel costs (per day)	$581
Travel allowance (including accommodation costs per day)	$209
Travel costs/km	$1
General R&D	
Cost of growth control cabinet (per week)	$13
Glasshouse bench space (per week per m^2) [a]	$13
Consumables (lab chemicals, petri dishes, plastic ware) (per year)	$5,000
R&D [b]	
Average R&D cost for potentially easy orchid taxa	$9,339
Average R&D cost for potentially challenging orchid taxa	$37,356
Average R&D cost for potentially easy non-orchid taxa	$1,822
Average R&D cost for potentially challenging non-orchid taxa	$17,741
Average R&D cost for completely unknown taxa	$125,628
Plant propagation from germinants/cuttings	
Cost per plant–from germinants (non-orchid taxa)	$9
Cost per plant–from cuttings (non-orchid taxa)	$15
Cost per plant–from germinants (orchid taxa)	$20
Site preparation and planting costs	
Staff time for first planting	
Cost of one Perth staff member for first planting [c]	$3,950
Cost of one regional staff member for first planting [c] (WITH overnight stay)	$3,950
Cost of one regional staff member for first planting [c] (WITHOUT overnight stay)	$2,905
Cost of driving to and from accommodation to translocation site each day	$25
Fencing costs	
Fencing (per enclosure to accommodate 250-500 plants)	$3,010

Fabricated goat fencing 1 (per km)	$5,984
Fabricated goat fencing 2 (per km)	$4,780
Rabbit fence (per km)	$5,678
Floppy top fence (per km)	$13,799
Rigid overhang fence (per km)	$14,099
Electric wire overhang fence (per km)	$16,200
Fence installation costs	
Contract labour for installation (2 people per day)	$792
Heavy vehicle running for fence installation (per day)	$210
Irrigation system costs	
Irrigation system per 500 plants	$1,504
Other costs	
Lodgement, processing, and storage costs for each seed collection trip	$626
Regional staff costs for site selection	$781
Reusable equipment (shovels, gloves, hammer, pliers)	$50
Irrigation material per plant	$2.3
Tagging material per plant	$2.8

[a]A taxon would use 14 m^2 of glass house bench space per week; [b] Calculations detailed in Table 10; [c]The first planting is assumed to take five days.

There are several variable parameters that affect the cost of particular recovery/translocation actions. Variable parameters and their variations could include:

- Distance to the
  - population site(s)
  - translocation site
- The number of years for
  - seed collection
  - site selection
  - planting

- The number of annual trips for
    - seed collection
    - site selection
    - planting
    - monitoring
- The trip length of each trip for
    - seed collection
    - site selection
    - planting
    - monitoring
- The time (number of days) required annually for
    - writing the translocation proposal
    - managing seed germination/propagation of cuttings
    - organising planting
- The number of annual water carting trips to the translocation site

The calculation of costs is detailed in the next section.

5.2.2. Calculating present values of costs

All costs were converted to present value terms using a discount rate of 7% (OBPR, 2016) and considering 2019 as the base year (or Year 0). The year for our calculations was assumed to be the same as a financial year (i.e., from July to June). Table 9 below shows a general calculation of costs in present value terms. If, for example, costs C1, C2, C3, C4 and C5 are incurred during different stages of the translocation at different years and for different durations, they are first discounted using the discount rate for the given year and then added to give the total value of discounted costs that occur in a particular year.

Table 9: Present value calculations of cost

Year (y)	Cost	Discount factor = [(1+r)^y] [a]	Total annual discounted cost = Annual Cost/Discount factor
0	\$C1	1.00	\$C1/1
1	\$C2	1.07	\$C2/1.07
2	\$C2, \$C3	1.14	(\$C2 + \$C3)/1.14
3	\$C2, \$C3	1.23	(\$C2 + \$C3)/1.23
4	\$C2, \$C3, \$C4	1.31	(\$C2 + \$C3 + \$C4)/1.31
5	\$C4, \$C5	1.40	(\$C4 + \$C5)/1.40

[a] The discount rate (r) is assumed to be 7%. The discount factors are calculated for a discount rate of 7% and will change depending on the discount rate chosen.

In the example above, let \$C3 denote the annual cost of planting. Then the total present value of planting = sum of discounted annual planting costs in Year 2, Year 3, and Year 4 = (\$C3/1.14) + (\$C3/1.23) + (\$C3/1.31).

Since many costs in the translocation process occur annually (for example, the annual cost of planting), we employed the “PV” function in Excel, to automatically calculate the total present value of a series of the constant costs occurring periodically (in our case, annually). The Excel PV function is a financial function that returns the present value of a series of future payments (costs), assuming periodic, constant payments and a constant interest rate (in this case, the discount rate).

5.2.3. Present value calculation of costs from best estimates and simulations for variable parameters

The expected present value of cost was calculated through the following steps:

1. The cost of the selected strategy for each taxon (either translocation or seed orchard) consisted of a number of component costs. The component costs were identified, and their magnitudes were elicited from experts, including the number of units and the cost per unit. The experts were asked to estimate the lowest and highest plausible values for each aspect of the costs, including separate low and high values for the number of units and the cost per unit (see Supplementary Item S2).

2. 500 random cost variates were generated for each strategy. Each random variate included a random draw for each constituent variable, including the number of units and the cost per unit for each component cost. It was assumed that each of these variables had a uniform probability distribution bounded by the high and low values elicited for that variable.
3. For each random variate of the overall strategy cost, costs was converted to present value terms and aggregated as shown in Table 9 using a discount rate of 7%.
4. The expected value of overall strategy cost was calculated as the average of the resulting distribution, assuming that each of the random draws was equally likely, and that all of the random variables were independently distributed.

5.3. Stages in translocation and calculation of costs

This section gives an overview of the various stages of translocation and the calculation of cost across these stages. Costs for the different stages occur in different years and for varying duration depending on the taxa. The different stages of translocation in the cost model and example cost calculations will be highlighted for different taxa— a relatively easy-to-translocate non-orchid taxon– *Acacia cochlocarpa* subsp. *velutinosa*, a relatively challenging non-orchid taxa– *Philotheca basistyla*, and a challenging orchid taxon – *Rhizanthella gardneri* where necessary.

5.3.1. Seed /cutting collection

This is the first stage in translocation and involves travelling to existing population sites and collecting seeds or cuttings for the purpose of propagating plants. This step does not need to be carried out if there are adequate number of seeds from suitable source populations in *ex situ* storage in the WASC seed bank available for translocation. For our calculations, we assumed that if the number of germinable seeds in the WASC was greater than or equal to 1,000, then half of those seeds could be used for translocation or for a seed orchard. If the number of germinable seeds in the WASC was less than 1,000, then half of those seeds could be used for a seed orchard only but not for a translocation.

The number of seeds to be collected (N_c) was calculated as:

$$N_c = (N_g \times 2) - N_a \quad \mathit{if}\ N_a < N_g \tag{3}$$

$$N_c = 0 \quad \mathit{if}\ N_a > N_g$$

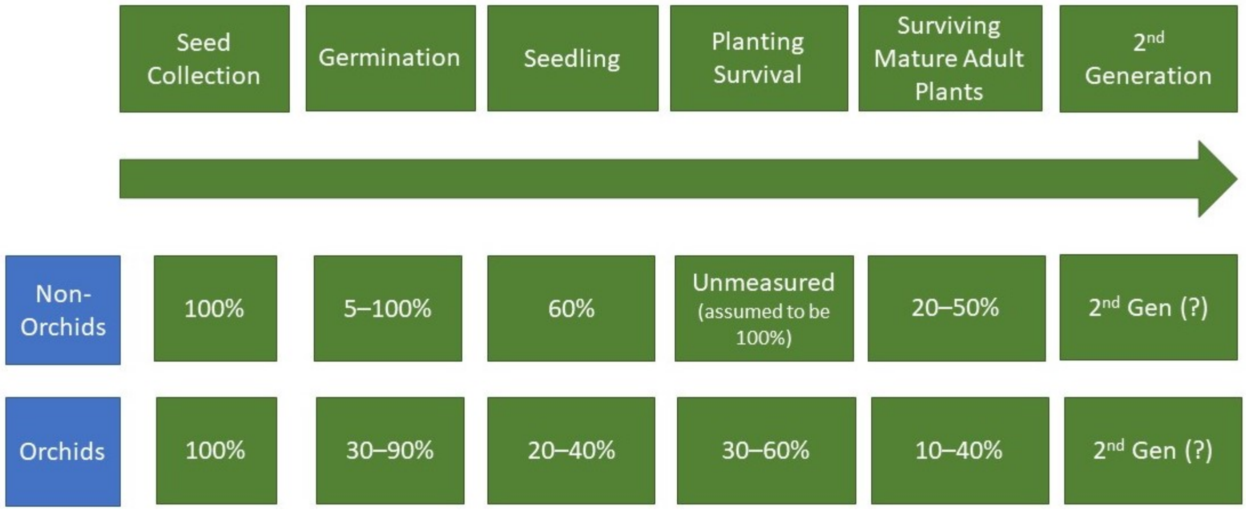
Where, N_g is the number of seeds required for germination, and N_a is the number of seeds available for translocation.

The number of seeds that need to be collected for translocation depends on the goal of the conservation action and the survival rate across the different stages from germination to seedling stage, to planting and to reproductive maturity (Figure 5).

For non-orchid taxa, the proportion of seed germinating (Supplementary Item S2: Survival rate - Anticipated survival rate at the end of germinant stage) was derived from actual germination data, where available, or estimated based on knowledge of similar taxa. Data (unpublished) for survival of seedlings through to establishment of mature plants was available for four taxa. Average survival across the four taxa was used (60% survival from germinant stage to seedling stage and 20% survival of planted seedlings to recruitment (mature plants)). For taxa where a seed orchard was decided to be the most appropriate recovery action, survival of seedlings to mature plants was increased to 50% to account for an anticipated higher survival rate for seedlings grown under seed orchard conditions.

For orchid taxa, the proportion of seed germinating was derived from actual germination data from two taxa (unpublished data), and a review of orchid translocations (Reiter et al., 2016). Ninety per cent of available seed germinates to seedling stage and 66% of the germinants survive transfer to soil and their first dormancy *in situ*. It is assumed that survival would increase in an *ex situ* seed orchard owing to the greater control of growing conditions.

It must be mentioned here that we assumed that the number of seeds required for a translocation or a seed orchard would first need to be collected or obtained from seed storage, and only then would planning for translocation / seed orchard (section 6.3.3) take place. Of course, this assumption can change. However, for the purpose of the model, we assumed that planning for the translocation/ seed orchard establishment would only take place after all the required seed was obtained. We discuss the consequences of this assumption in the discussion (section 10).



	Seed Collection	Germination	Seedling	Planting Survival	Surviving Mature Adult Plants	2nd Generation
Non-Orchids	100%	5–100%	60%	Unmeasured (assumed to be 100%)	20–50%	2nd Gen (?)
Orchids	100%	30–90%	20–40%	30–60%	10–40%	2nd Gen (?)

Figure 5: Anticipated survival rate across various stages of a translocation/ seed orchard establishment for orchid and non- orchid taxa.

5.3.1.1. Example calculations for seed /cutting collection

Consider taxa *Acacia cochlocarpa* subsp*. velutinosa*. For this taxon, only 20% of the seedlings that are planted are estimated to survive to reproductive maturity. Therefore, to achieve the goal of 250 reproductively mature plants, 250/20% = 1,250 seedlings need to be planted. For the same taxon, the survival rate from the germinant to the seedling stage estimated to be 60%. The number of germinants that need to be made available is, therefore, 1,250/60% = 2,083. Finally, the survival rate from the seed to germinant stage is 70% for this taxon. Thus, the total number of seeds that need to be collected are 2083/70% = 2,976. Therefore, about 3,000 seeds will need to be obtained for *Acacia cochlocarpa* subsp*. velutinosa* to achieve the goal of 250 reproductively mature plants (See rows 18 to 33 of Column B in Worksheet “Survival Rate” in Supplementary Item S2 for the calculations explained here). There are currently about 12,300 seeds of *Acacia cochlocarpa* subsp*. velutinosa* in the WASC of which 8,600 are estimated to be germinable. Up to half (i.e., 4,300) may be made available for translocation. Since only about 2,100 germinable seeds will be required for translocation, there is no cost of seed collection for this taxon.

For *Philotheca basistyla* the survival rate at the end of germination, from germinant to seedling, seedling to planting, and planting to reproductive maturity for translocation were assumed[2] to be 20%, 60%, 100%, and 20%, respectively. Establishing a population of 250 mature plants, would require 10,417 seeds. However, since the WASC seed bank only has 205 seeds of which only 40 are likely to be germinable, none would be available for translocation, but up to 20 may be available for use in a seed orchard. The average number of seeds that could be collected annually from wild populations based on prior seed collection data was 34 seeds, implying that it would take about 306 years to collect the seeds necessary for translocation. Since this was impractical, it was decided that a seed orchard with a goal of 50 mature individuals would be the most viable option. Since plants in a seed orchard have a better chance of reaching reproductive maturity, the survival rate from planting to reproductive maturity was increased to 50% for all taxa where seed orchards were the chosen recovery action. Also, for seed orchards, it was assumed that the number of seeds that could be collected annually per plant was three times the number that could be collected from the wild. With these changes, the number of years to collect seeds to establish a seed orchard for *Philotheca basistyla* was reduced to 48 years. See Rows 18 to 33 of Column AS in Worksheet “Survival Rate” in Supplementary Item S2 for these calculations. However, even this time frame of 48 years is very long and impractical over which seeds for a seed orchard need to be collected. It was, therefore, decided not to calculate the cost to establish a seed orchard for *Philotheca basistyla* for the purpose of the report given the present assumption that seeds for translocation or for a seed orchard would first need to be collected and only then a translocation or a seed orchard is established. We discuss this further in the discussion (section 10).

5.3.2. Establishing a germination protocol

This stage takes place concurrently with seed collection. If a taxa does not already have a germination protocol in place, then costs will be incurred to establish a protocol. If a germination

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[2] This is an assumption derived from mean germination and survival rates for four previously translocated taxa (Crawford and Monks, unpublished data).

protocol is not in place then it will not be known whether it is possible to propagate plants successfully and, therefore, carry out a translocation. For this study, taxa that did not have a germination protocol in place were classified as either:

- “Relatively easy” - a germination protocol is available likely to achieve germination close to the potential of a seed lot (where a seed lot is a quantity of seed, collected at a single site at a given time);
- “Relatively challenging” – a germination protocol is not available, but based on existing knowledge it is thought a protocol could be developed with a relatively small amount of research; and
- “Completely unknown” a germination protocol is not available and based on existing knowledge it is thought that considerable research will be required to develop a technique that will germinate seed close to the potential of a seed lot.

The costs incurred for establishing a germination protocol included staff salary for time, and the cost of materials and equipment including the cost of using growth cabinets, glasshouse bench space, and the cost of lab consumables. The more challenging a taxon, the longer the duration to establish a germination protocol, and the higher the costs.

Average costs to establish a germination protocol were supplied by the staff at DBCA based on prior cost information for different taxa (Table 10). The time to establish a germination protocol ranged from 6 hours and around $475 for potentially easy non-orchid taxa to 80 days and about $50,000 for potentially challenging orchid taxa. The cost to establish a germination protocol for a completely unknown taxa was calculated as the cost of funding one fulltime PhD student for a duration of three years, and the cost of using facilities, laboratory equipment, and consumables. For relatively easy and relatively challenging taxa, the cost to establish a germination protocol was fixed as the average of lower bound and upper bound costs given in Table 10.

Table 10: Costs to establish a germination protocol.

Potentially easy orchid taxa		
	Total time (days) [a]	Total (cost) [b]
Lower bound	10	$6,226

Upper bound	20	$12,452
Potentially challenging orchid taxa		
	Total time (days) [a]	Total (cost) [b]
Lower bound	40	$24,904
Upper bound	80	$49,807
Potentially easy non-orchid taxa		
	Total time (hours) [c]	Total (cost) [b]
Lower bound	6	$475
Upper bound	40	$3,168
Potentially challenging non-orchid taxa		
	Total time (hours) [c]	Total (cost) [b]
Lower bound	8	$634
Upper bound	440	$34,848
Completely unknown taxa		
	Total time (years)	Total (cost) [d]
	3	125,630

[a] Includes time for media preparation/sowing, contamination check, transferring to the light, and scoring germination; [b] Calculated as the cost of staff time and the cost of the growth cabinet, glasshouse bench space, and consumables (lab chemicals, petri dishes, plastic ware) for the total time given using the values of these variables given in Table 8; [c] Includes time to assess seed viability, media preparation/sowing, and scoring germination; [d] Calculated as the funding for one fulltime PhD student for 3 years and the cost of the cost of using facilities, equipment and consumables.

For instance, for establishing a germination protocol and assigning assumed germination rates, *Rhizanthella gardneri* was deemed “potentially challenging”. Therefore, establishing a germination protocol for *Rhizanthella gardneri* was assumed to take an average of 60 days and cost $37,350. *Acacia cochlocarpa subsp. velutinosa* already had a germination protocol in place, so there was no cost to establish a germination protocol.

5.3.3. Plant propagation and planning

Once seeds have been collected and a germination protocol is in place, planning can commence for the translocation. This stage has several substages including site selection, writing the translocation proposal, managing seed germination / preparation of cuttings, and organising the planting schedule. Writing the translocation proposal and some of the initial planning takes place in July, August, and September, while seed germination is usually carried out in September, October, and November. Planting for translocation usually takes place over multiple years. Therefore, the substages in the plant propagation and planning stage (except site selection) are also repeated over multiple years depending on the duration of planting.

5.3.3.1. Site selection

This stage involves visiting current population sites and other potential sites to select a suitable site for translocation. It may be a single visit or may involve multiple visits by a DBCA staff member from their main offices in Perth depending on the taxa to be translocated. A staff member from the DBCA regional office usually accompanies the Perth staff member for the initial site visit or sometimes even subsequent site visits. For non-orchid taxa, site selection is usually completed in one to three trips and can usually be completed in one year. For orchid taxa, site selection can take longer as this stage also involves carrying out pollinator surveys. Pollinator presence at a site, along with mycorrhizal presence, are the greatest determinants of success in translocation establishment, and can take several years to establish (Reiter et al., 2016). If the taxa was an orchid, or if seed collection was not necessary, site selection was assumed to commence in Year 0. For non-orchid taxa that required seed to be collected, site selection was assumed to commence in Year 1.

Costing the site selection stage involves considering staff/personnel costs for site visits. This includes the number of annual trips required, the duration (number of days) of each trip and the distance to the different sites. Site selection is assumed to be carried out by one staff member from Perth, who is joined on the first site visit by a regional staff member for one day.

The cost calculations by component (personnel costs, travel allowance, and vehicle running) for *Rhizanthella gardneri* are explained in Table 11 at the best estimates of the number of annual trips for site selection, the number of days per trip, and the round-trip distance to the potential population site(s) for the taxa, which are 4 annual trips, 10 days per trip, and 550 km round-trip distance, respectively. These calculations can be found in Rows 18 to 39 in the “Cost-Prep & Planning” worksheet Column AU in supplementary item S2.

Table 11: Example site selection cost calculations for *Rhizanthella gardneri*

Number of years required for site selection	1
Best estimate of annual number of trips for site selection	4
Best estimate of the duration of each trip for site selection (days)	10
Best estimate of round-trip distance to population site (km)	550
Perth staff costs [a]	
Vehicle running cost per km	$1
Vehicle running cost per trip (cost per km x number of km)	$550
Total annual vehicle running costs (cost per trip x number of trips)	**$2,200**
Personnel costs per day	$581
Personnel costs per trip (cost per day x number of days per trip)	$5,810
Total annual personnel costs (cost per trip x number of annual trips)	**$23,240**
Travel allowance per day [b]	$209
Travel costs per trip [cost per day x (number of days per trip - 0.5 days [c])]	$1,986
Total annual personnel costs (cost per trip x number of annual trips)	**$7,942**
Total annual costs for site selection	**$33,382**
Total costs for site selection for Perth staff (Total annual cost x number of years required for site selection)	**$33,382**
Regional staff costs	
Regional staff costs for site selection [d]	**$781**
Discounting	
Year in which costs occur [e]	0
Discount factor for Year 0 [f]	1
Total discounted cost for site selection for Perth staff (Total cost / discount factor)	$33,382
Discounted regional staff cost for site selection (Total cost / discount factor)	$781
Total cost of site selection (Perth + regional staff)	**$34,163**

[a] Site selection is carried out by one staff from the Perth office; [b] The per day travel allowance includes the cost of accommodation and meals. [c] The number of days over which the travel allowance is calculated is reduced by 0.5 days from the total number of days per trip to account for the fact that breakfast on day 1 and dinner on the last day of the trip will not be covered; [d] Includes personnel cost for one day ($581), and vehicle running cost for a 200 km round-trip distance = $200; [e] The site selection for this taxon is assumed to take place occur in Year 0. This will of course vary by taxa; [f] See Table 9 for a calculation of the discount factor.

Since *Rhizanthella gardneri* is an orchid, the site selection costs include the costs for conducting pollinator surveys as well making it necessary for multiple trips to be carried out annually for site selection (Reiter et al., 2016).

The cost of site selection from simulations is calculated according to the steps listed in section 6.2.3. A total of 500 estimates are simulated for each of the variable parameters– the number of annual trips for site selection, the number of days per trip, and the round-trip distance to the potential population site(s). For each estimate, an annual cost is calculated as shown in Table 11, i.e., the first simulated value of the number of annual trips for site selection, the number of days per trip, and the round-trip distance to the potential population site is used to calculate the first simulated value of cost, and so on. Each annual cost is converted to present value terms and added across the number of years to give the total present value of cost for a given estimate. The average and standard deviations of these total present values are then calculated. These are presented in rows 43 and 44 of the "Cost- Prep & Planning" worksheet in supplementary item S2.

5.3.3.2. Writing translocation proposal

Once a suitable site has been selected, a translocation proposal is written to formally request permission for the translocation / establishment of seed orchard. Translocation proposals are required under the Biodiversity Conservation Act (2016) and must describe and justify benefits to the taxa, impacts on source and recipient populations, and risks to recipient ecosystems, as well as site suitability and how the success of the action is to be assessed, to the satisfaction of DBCA's Executive Director of Biodiversity Conservation Science. Costs include staff time for writing the translocation proposal, for proposal review, and for addressing concerns raised by the review committee. Writing a translocation proposal is a one-time cost and is assumed to be the same across taxa and take about 3 weeks (i.e., 15 working days) and cost $8,715 (15 days x personnel cost of $581 per day) without discounting. Depending on which year, the cost occurs, it is discounted to present value terms based on calculations described in Table 9.

5.3.3.3. Managing seed germination / propagation of cuttings

After translocation has been approved the required number of seeds are germinated by DBCA staff for the purpose of planting. Once the seed are germinated, germinants are transferred to a nursery to raise them to seedling stage after which they will be ready to be planted at the selected translocation site. Costs in this substage include staff time for carrying out seed germination and also the cost of raising germinants to seedling stage. The cost of raising the germinants to seedling stage is based on cost recovery for DBCAs Kings Park nursery.

The total cost of managing seed germination / propagation of cuttings was calculated at the best estimate of the variables and through simulations using their given upper and lower bounds as described in section 6.2.3. The cost of staff time to manage germination annually is calculated by multiplying the annual number of days required (either from best estimate or that generated via a simulation) by the personnel cost per day ($581) to give the annual cost of staff time, which is then converted to present value terms using a discount rate of 7% and for the given year in which this cost occurs. Annual present value costs over multiple years are added to give the total cost of staff time in present value terms.

The cost of raising the germinants to seedling stage is calculated as follows: The expected total number of seedlings to be planted is divided by the number of years that planting will take to give an average number of plants that will be annually planted. The cost of obtaining these seedlings is $9 per plant for non-orchid taxa when germinants are supplied, $15 per plant for non-orchid taxa when cuttings are supplied, and $20 per plant for orchid taxa when seed and mycorrhizal fungi are supplied. It is possible that the number of plants required for planting may not be constant across the years. To simulate this variation in cost, the number of plants to be planted annually was allowed to vary by 20% from the expected number of plants, i.e., the lower and upper bounds of the number of plants annually planted was 20% lower and 20% higher, respectively than the expected number of plants. For these upper and lower bounds, annual cost of plant propagation was calculated from the following steps:

1. 500 estimates of the annual number of plants available for propagation were simulated using the RANDBETWEEN function.

2. For each simulation, the annual cost of plant propagation was calculated by multiplying the number of plants with the cost per plant (either $9, $15, or $20 depending on the type of taxa and whether propagation was carried out by seeds or cuttings)
3. The annual cost was converted to present value terms and added across the years when these costs would occur. Thus, 500 costs of propagation in total present value terms were simulated.
4. The average and standard deviation of the total present value of cost for plant propagation was calculated. These are presented in rows 94 and 95 of the "Cost-Prep & Planning" worksheet in supplementary item S2.

5.3.3.4. Organising planting

This stage involves the organisation that need to be carried out to undertake the planting and establish a translocated population. It includes staff time for monitoring the germinants being raised to a seedling stage at the nursery, time for liaison with staff at the regional office to coordinate planting, and time for regional staff to support logistics and planning, such as through organisation of vehicles, equipment and other materials including fencing and contract labour for fencing, the irrigation system and tagging and other irrigation material for the plants.

The total cost of organising planting was calculated at the best estimate of the variables and through simulations using their given upper and lower bounds as described in section 5.2.3. The cost of staff time to organise planting is calculated by multiplying the annual number of days required (either from best estimate or that generated via a simulation) by the personnel cost per day ($581) to give the annual cost of staff time, which is then converted to present value terms using a discount rate of 7% and for the given year in which this cost occurs. Annual present value costs over multiple years are added to give the total cost of staff time in present value terms.

5.3.4. Planting

Planting for translocation usually takes place over multiple years and is usually carried out in the months of May and June. This stage also has several substages.

5.3.4.1. First Planting

The first planting at the translocation sites usually takes about five days and includes preparing the translocation site (weed control, firebreak construction/maintenance, soil ripping); fence construction (if required) to keep out herbivores which may eat the plants and setting up an irrigation system on the site. At least two regional staff are usually involved in the 1st planting at the translocation site. Costs, therefore, include staff time, travel time, and costs of fencing, fence construction, and the purchase of irrigation system(s) and tagging and other material for the seedlings. It also includes the cost of carting water to fill the irrigation system for two summers after planting. (See lines 14–66 and 98–120 in the “Cost- Planning&Monitoring” worksheet in supplementary item S2 for these calculations).

5.3.4.2. Subsequent Planting(s)

This involves the remaining planting(s) at the translocation site to establish the required population of 250 reproductively mature individuals. While undertaking subsequent plantings, staff monitor the planting(s) from the previous years and carry out any maintenance work required at the translocation site such as firebreak, fence repair, and ensure that the irrigation system is working well. Costs for subsequent planting(s) include staff time, travel time, and costs of purchasing tagging and other materials for planting the seedlings. (See lines 68–96 in the “Cost- Planning&Monitoring” worksheet in supplementary item S2 for these calculations).

5.3.5. Monitoring

For this cost model, it is assumed that monitoring takes place once annually for five years after the last planting has been carried out. Costs for monitoring include staff time and roundtrip travel time to the translocation site (See lines 122–139 in the “Cost- Planning&Monitoring” worksheet in supplementary item S2 for these calculations).

6. Structured expert elicitation to determine the ecological benefits of recovery actions

The ecological benefit of the recovery action of translocation was calculated as the difference in the expected number of mature individuals with and without translocation.

Calculating the expected ecological benefit of a conservation action requires explicit estimation of two elements in the units of a metric that reflects the fundamental objectives:

1. **Business-as-usual**: the expected outcome in terms of the status or condition of the biodiversity asset (in this case, threatened flora population) at the end of the evaluation period in the absence of any proposed action (i.e., should nothing be done); and
2. **If the action is implemented**: the expected outcome in terms of the status or condition of the biodiversity asset at the end of the evaluation period should the proposed action (in this case, translocation) be undertaken.

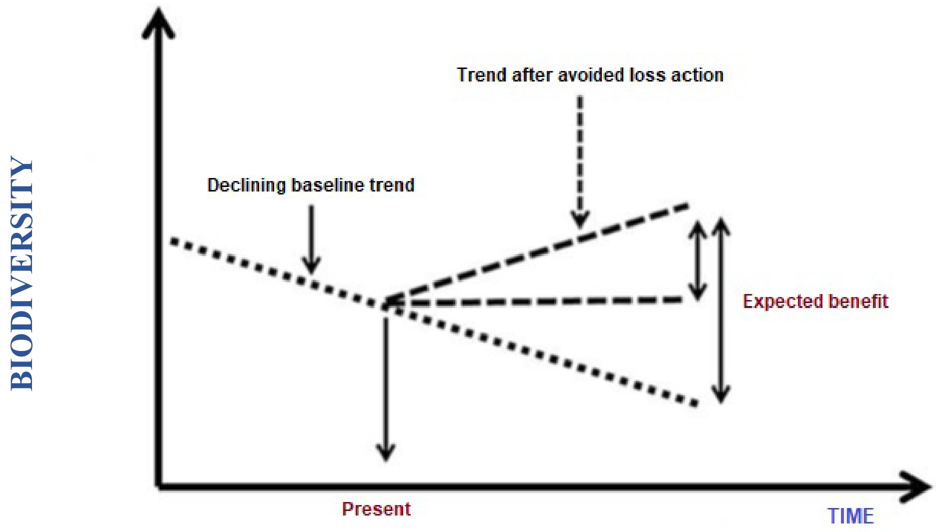

Figure 6: Calculation of ecological benefits

The difference between these two alternative potential future states (i.e., the expected outcome with action minus the expected action without any action produces an estimate of the difference in expected outcomes attributable to the action. This is the expected ecological benefit (*EB*) (Figure 6). If the outcome under the action were expected to be worse than without the action, the expected ecological benefit would be negative.

As given in Table 2, the expected ecological benefit was measured in terms of:

1) ***the number of mature individuals***, where the expected benefit is calculated as the difference in the number of mature individual plants with and without the management action, or
2) ***the probability of persistence*** of the taxa, where the expected benefit is calculated as the difference in the probability of persistence with and without the management action.

6.1. *Structured elicitation of ecological benefits*

Flora experts were asked to participate in the expert elicitation processes. To determine the benefit of each conservation action, experts were asked to determine changes in the relevant metric over a defined time period. The metric chosen for this study was the population of mature individuals and the timeframe chosen was 10 years.

Structured elicitation following the IDEA (“Investigate”, “Discuss”, “Estimate” and “Aggregate”) protocol (Hemming et al., 2018a) was conducted to determine the expected outcome for each asset under:

i. a business-as-usual counterfactual scenario, and
ii. a translocation scenario.

The IDEA protocol combines a four-point elicitation process with an iterative Delphi process. The 4-point elicitation structure requires participants to estimate lowest and highest plausible bounds, and best estimate of the outcome under each action. Additionally, participants are asked to identify how confident they are that the true response was contained within the range they provide for each estimate. The confidence estimate is used to adjust the estimated range to reflect an 80% credibility interval. The Delphi process is a multiple loop process. Experts are initially provided with an information package and presentation describing the process and how to avoid cognitive biases. Individual experts are then asked to complete an initial phase of the structured elicitation independently, not confer with other experts participating in relation to scores and to document any assumptions underpinning their estimates. All participants are provided with contextual information to assist in determining the change in metric. Comments from the experts collated through action development is also shared to provide context where appropriate.

After the initial independent elicitation round, all experts gathered for two discussions. Here, anonymised results from each previous round were visualised and shared with all participants. At this stage, participants discussed the processes and assumptions underlying their estimates and other attributes, with a focus on why estimates are similar/divergent, or low/high among participants. Subsequent to this phase, participants were given the opportunity to adjust their estimates.

For each taxon and its counterfactual status quo situation and its proposed recovery action, which in our case is either translocation or the establishment of a seed orchard, participants are asked to estimate the expected outcome after the time period both in terms of the number of mature individual plants and in terms of the probability of persistence. Participants are also asked as part of this process to provide a score between 0 and 1 for each component of likelihood of success—implementation feasibility success (I), threat reduction success (T), and management outcome success (M), and also to assess the risk to receiving long-term funding (F) for the taxon also measured between 0 and 1. A score of 0 implies that the component of likelihood of success is definitely going to be unsuccessful, while a score of 1 implies that it is definitely going to be successful. A score of 0 for long-term funding risk implies that there is no risk to obtaining long-term funding for the taxon, while a score of 1 implies that the taxon will not receive long-term funding.

Definitions

Implementation feasibility success: Pertains to the likelihood that managers can successfully proceed with implementing the recovery action, given physical, legal, or socio-political constraints (From Brazill-Boast et al. 2018).

Threat outcome success: Pertains to the likelihood that the action will successfully control the threat in terms of extent or severity. (From Brazill-Boast et al. 2018).

Management outcome success: Pertains to the likelihood that the recovery action will lead to a positive population response (via improving survival and/or reproduction) at the site. (From Brazill-Boast et al. 2018).

Long-term funding risk: Is the risk of not obtaining required funding in the long-term to continue conservation management for a taxon after carrying out the recovery action.

6.2. Calculation of ecological benefits

Individual scores were collated and analysed, and the group mean utilised to determine ecological benefit (B) and likelihood of success (L) scores for the proposed recovery action for each taxon. The overall likelihood of success score for translocation for taxon *i* (L_i) is calculated by combining the three dimensions of the likelihood of success following Brazill-Boast et al. (2018):

$$L_i = I_i \times T_i \times M_i \qquad (4)$$

where I_i= implementation feasibility success, T_i = threat reduction success, M_i = management outcome success for the *i*th taxon.

The estimated expert-elicited expected ecological benefit for taxon *i* (EB_i) is adjusted based on the likelihood of success (L_i) to give the adjusted expected ecological benefit or “return” (AEB_i) as:

$$AEB_i = EB_i \times L_i \qquad (5)$$

As stated earlier, this expected benefit can be measured in terms of either (a) the number of mature individuals or (b) the probability of persistence.

If the expected ecological benefit for taxon *i* is negative (i.e., if the outcome under the action were expected to be worse than without the action for the taxon) then the adjusted expected benefit is calculated as:

$$AEB_i = |EB_i| \times L_i \times -1 \qquad (6)$$

We also tested whether the ecological benefit would be affected by the risk to be able to continue funding the recovery action for a given taxon. This was measured on a 4-point scale by asking experts to estimate the lowest and highest plausible bounds, best estimate of the funding risk (as a percentage) and their confidence that the true response was contained within the range. The confidence estimate is used to adjust the estimated range to reflect an 80% credibility interval. The funding risk is a measure of the uncertainty in continued funding for the recovery of a given taxon. This uncertainty may result from one or more of (but is not limited to): diversion of limited conservation funding to taxa requiring immediate attention, increased costs for some actions, expiration of external or temporary funds, budget cuts, or changing priorities of the department and other funding bodies.

The expected benefit adjusted for funding risk for taxon *i* (AEB_{fi}) was calculated as:

$$AEB_{fi} = AEB_i \times (1 - F_i) \qquad (7)$$

where, F_i = funding risk for the *i*th taxon. If the expected benefit is negative, then AEB_i should be calculated as given in Equation (6).

The expected ecological benefit can also be weighted to reflect the extinction risk of a taxa, reflecting a core policy mandate to prevent extinction. Each extinction risk category is assigned a weighting (W) after (Joseph et al., 2009). W is 3 for an endangered taxon and it is 4 for a critically endangered taxon. The expected benefit is adjusted to reflect the relative value of action for each taxon either without considering funding risk (equation 8) or considering funding risk (equation 9):

$$AEB_{wi} = AEB_i \times W \qquad (8)$$

$$AEB_{wfi} = AEB_{fi} \times W \qquad (9)$$

where, AEB_{wi} is the weighted adjusted expected ecological benefit for taxon *i*, and AEB_{wfi} is the weighted adjusted expected ecological benefit considering funding risk. If the expected benefit is negative, then AEB_i should be calculated as given in Equation (6).

Owing to the limited time, the ecological benefits could only be elicited for a subset of 12 taxa considered for the cost-effectiveness analysis. Those results are discussed in section 9.2.

7. Cost-effectiveness calculations

7.1. Cost-effectiveness ratio calculations from the cost model

Recall Equation (1), where the cost-effectiveness ratio for a recovery action is calculated as:

$$CER = \frac{EB_a - EB_b}{PV(C)}$$

where, EB_a and EB_b denote the expected ecological benefits measured as either the expected increase in taxa population (number of mature individuals) or the increase in the probability of persistence under the recovery **a**ction and the **b**aseline scenario respectively, and *PV(C)* is the present value of costs as given in Equation (2).

The baseline scenario for a taxon includes management such as monitoring existing populations, liaising with private landowners or land managers etc. This continues to be carried even when a recovery action (either translocation or establishing a seed orchard) is implemented. Thus, the costs for implementing baseline management actions are also incurred while implementing the recovery action. This implies that any benefits (or the population of reproductive plants) under the baseline scenario are also obtained under the recovery action.

The denominator of Equation (1) includes only those costs that differ between the baseline and recovery actions (i.e., they only include the costs of translocation / establishing a seed orchard). These costs are calculated from the cost model.

The numerator of Equation (1) is the difference in the ecological benefits (increase in the population of a taxon (number of mature individuals) or the increase in the probability of persistence) with and without the recovery action. Since a translocation and a seed orchard are being carried out to establish a new population of 250 and 50 reproductively mature plants respectively, the numerator of Equation (1) = 250 for a translocation and 50 for a seed orchard for cost-effectiveness calculations from the cost model. Thus, for the cost model, the cost-effectiveness ratio for taxon *i* (CER_{Mi}) becomes:

$$CER_{Mi} = \frac{250}{PV(C)} \quad \text{for a translocation (a)}$$

$$CER_{Mi} = \frac{50}{PV(C)} \quad \text{to establish a seed orchard (b)} \qquad (10)$$

where PV(C) is the present value of costs to carry out a translocation for taxon *i*.

The cost-effectiveness ratio can be understood as the additional gain per dollar of investment.

7.2. Cost-effectiveness ratio calculations from expert elicitation

The goal of a translocation or establishing a seed orchard was to establish a new reproductively mature population of 250 and 50 plants, respectively. However, the likelihood of success of a recovery action (as explained in section 7.2) can lead to expected benefits not being achieved. It is for this reason that the cost-effectiveness ratios calculated from Equation (10) can be considered initial or naïve. Including the likelihood of success of a recovery action to reassess the expected benefits ensures that the ranking from those metrics will be more plausible. Thus, the cost-effectiveness ratio for taxon *i* from expert elicitation (CER_{EEi}) can be calculated depending on whether funding risk was considered or whether weighting is applied as either:

$$CER_{EEi} = \frac{AEB_i}{PV(C)} \quad \text{(a) OR}$$

$$CER_{EEi} = \frac{AEB_{fi}}{PV(C)} \quad \text{(b) OR} \qquad (11)$$

$$CER_{EEi} = \frac{AEB_{wfi}}{PV(C)} \quad \text{(c)}$$

where AEB_i, AEB_{fi}, and AEB_{wfi} are as defined and calculated in Equations (5), (7), and (9) respectively, and *PV(C)* is the present value of cost to carry out either a translocation or establish a seed orchard calculated from the cost model.

8. Results

8.1. Cost of recovery action and cost-effectiveness ratio from the cost model

The expected number of years to ensure an established translocated population or seed orchard varied from 7 to 12 years for all taxa considered with an average of 8.5 (± 1) years.

The total present value of cost of undertaking either translocation or the establishment of a seed orchard was found to vary between $124,014 to establish a seed orchard of 50 reproductively mature plants for *Acacia insolita* subsp. *recurva* over a period of 8 years to $643,780 to establish a new (translocated) population of 250 mature plants for *Rhizanthella gardneri* over a period of 12 years with an average value of $178,557 (Table 12). While the average total cost to establish a seed orchard ($151,691) was significantly lower ($p = 0.006$) than the average total cost for translocation ($198,259), in terms of cost per plant, the average cost for each additional plant obtained through translocation ($793) was significantly lower ($p < 0.0001$) than the average cost for each additional plant obtained through the establishment of a seed orchard ($3,034). This result is not surprising because seed orchards in our model had a target of 50 reproductively mature plants whereas translocations were set at a target of 250 reproductively mature plants. Also, the costs are reflective of the more intensive management required to establish seed orchards. It is important to note that a seed orchard is undertaken at a more intensively managed site and is only an intermediate step in the goal to establish a new wild population of the taxa (although in some cases, the seed orchard is set up at the final site for the wild population, and additional management reduced over time). For that reason, the results for translocations should not be directly compared to the results for seed orchards.

The average total cost for translocation/ seed orchard establishment for non-orchid taxa ($161,848) was significantly lower (p= 0.041) compared to the average total cost to translocate orchid taxa ($248,735). One of the reasons for this is that orchid taxa incur significantly higher (p<0.0001) costs for site selection–on average, almost 10 times higher ($61,646) than non-orchid taxa ($6,489) as this stage involves conducting pollinator surveys as well. For example, the total site selection costs for *Caladenia graniticola* alone are about $70,525. (See rows 23 and 24 in the "All Costs" spreadsheet in supplementary item S2). In terms of cost per plant, the average cost for each additional plant of a non-orchid taxon ($1,919) was significantly higher ($p = 0.0006$) than the average cost for each additional plant of an orchid taxon ($995). But this result is because of the conservation action for non-orchid taxa included either translocation (goal = 250 plants) or establishing a seed orchard (goal = 50 plants), whereas the action for orchid taxa included only translocation (goal = 250 plants). When the comparison was made on the same goal of translocation, the average cost for each additional plant of a non-orchid taxa ($692) had a lower mean but was not significantly different ($p = 0.125$) from the average cost for each additional plant of an orchid taxa ($995).

For the cost model, a naïve or initial cost-effectiveness ratio (CER_{Mi}) for taxon i was calculated as the ratio of the expected goal (250 reproductively mature individuals for translocation and 50 reproductively mature individuals for a seed orchard) to the cost of achieving the goal (Equation (10)). This measures the additional gain (in terms of the number of plants) per $1 invested, should the goal be perfectly achieved in full. This is extremely unlikely given variation in survival, feasibility, and delays before implementation can be initialised, and for this reason it is not a recommended metric for decision making but does serve as an indicative naïve comparison and could potentially be considered a theoretical maximum. The naïve cost-effectiveness ratio was found to be between 0.0002 plants per dollar to 0.0018 plants per dollar, or between 2 plants per $10,000 to 18 plants per $10,000 with an average value of 9.4 (± 5.9) plants per $10,000 across all taxa (Table 12). As expected, the additional gain in plants for a translocation (13.9 plants for $10,000) was significantly higher ($p < 0.0001$) than that to establish a seed orchard (3.3 plants for \$10,000). The additional gain in plants per \$10,000 for non-orchid taxa (8.9 plants on average) was significantly lower (p = 0.031) than the additional gain in plants per \$10,000 for orchid taxa (11.5 plants for \$10,000). But this result considers the actions of translocation and seed orchard establishment for non-orchid taxa. When only translocation is considered, the additional gain in plants per \$10,000 for non-orchid taxa for translocation (15.1 plants on average) was significantly higher (p = 0.0023) than the additional gain in plants per \$10,000 for orchid taxa (11.5 plants for \$10,000).

The inverse of the naïve or initial cost-effectiveness ratio measures the cost per additional plant. This varied between \$561 per additional plant for *Melaleuca sciotostyla* and \$4,598 per additional plant for *Lasiopetalum moullean* with an average value of \$1,741 (± 1,197) per additional plant across all taxa (Table 12). As described earlier, the cost per additional plant for a translocation to achieve a goal of 250 mature plants (\$785) was significantly lower (p < 0.0001) than that to establish a seed orchard (\$3,125) of 50 mature plants. However, each \$10,000 spent to establish a seed orchard achieved a significantly higher (p = 0.0004) percentage of the goal of 50 plants (6.8% on average) compared to translocation that only achieved 5.6% on average of the goal of 250 plants. Each \$10,000 spent on non-orchid taxa achieved, on average, a significantly higher (p= 0.0074) proportion of the goal of 250 plants for translocation (6.05%) compared to orchid taxa where on average 4.8% of the goal was met for every \$10,000 spent.

Table 12: Total present value of cost for undertaking a particular recovery action for the 53 taxa. Also given are the additional gain per $10,000 invested, the percentage of the goal achieved for $10,000 invested, and the cost per additional plant.

Biodiversity asset (Taxon)	Goal (number of mature individuals)	Translocate or establish seed orchard?	Expected total number of years for translocation/ seed orchard to achieve the stated goal	Average Total present value of cost (in 2019 AUD)	Standard deviation of Total present value of cost (in 2019 AUD)	Additional gain (plants) per $10,000 dollars invested [cost-effectiveness ratio x 10,000]	% of the goal achieved for $10,000	Cost per additional plant [1/cost-effectiveness ratio] (in 2019 AUD)
Acacia cochlocarpa subsp. *velutinosa*	250	Translocate	8	$143,425	$37,145	17	7%	$574
Acacia insolita subsp. *Recurva*	50	Seed orchard	8	$124,014	$34,507	4	8%	$2,480
Acacia pharangites	250	Translocate	8	$141,103	$36,685	18	7%	$564
Acacia sciophanes	250	Translocate	8	$151,929	$38,762	16	7%	$608
Acacia subflexuosa subsp. *Capillata*	250	Translocate	9	$159,087	$37,194	16	6%	$636
Acacia volubilis	50	Seed orchard	8	$124,865	$35,217	4	8%	$2,497
Banksia ionthocarpa subsp. chrysophoenix	50	Seed orchard	9	$172,798	$50,043	3	6%	$3,456
Banksia oligantha	250	Translocate	8	$145,205	$36,944	17	7%	$581
Caladenia christineae	250	Translocate	7	$216,274	$67,049	12	5%	$865
Caladenia dorrienii	250	Translocate	7	$212,350	$62,445	12	5%	$849
Caladenia drakeoides	250	Translocate	7	$214,354	$63,315	12	5%	$857
Caladenia graniticola	250	Translocate	7	$226,125	$66,470	11	4%	$905
Caladenia hopperiana	250	Translocate	7	$204,969	$61,068	12	5%	$820
Caladenia luteola	250	Translocate	7	$207,865	$62,147	12	5%	$831
Caladenia melanema	250	Translocate	7	$203,844	$63,578	12	5%	$815
Caladenia williamsiae	250	Translocate	7	$205,233	$61,194	12	5%	$821
Conospermum galeatum	50	Seed orchard	9	$134,680	$37,079	4	7%	$2,694
Cyphanthera odgersii subsp. *occidentalis*	50	Seed orchard	8	$129,960	$36,632	4	8%	$2,599

Darwinia carnea (Mogumber)	50	Seed orchard	9	$163,348	$33,230	3	6%	$3,267
Darwinia carnea (Narrogin)	50	Seed orchard	8	$141,323	$30,798	4	7%	$2,826
Dasymalla axillaris	250	Translocate	9	$149,931	$39,749	17	7%	$600
Daviesia cunderdin	50	Seed orchard	10	$145,430	$40,045	3	7%	$2,909
Daviesia euphorbioides	50	Seed orchard	8	$130,745	$38,219	4	8%	$2,615
Eremophila pinnatifida	50	Seed orchard	8	$145,805	$34,285	3	7%	$2,916
Eremophila verticillata	250	Translocate	9	$185,272	$42,462	13	5%	$741
Eremophila virens	50	Seed orchard	8	$155,226	$44,147	3	6%	$3,105
Eremophila viscida	250	Translocate	9	$249,112	$43,823	10	4%	$996
Frankenia parvula	250	Translocate	9	$172,250	$65,510	15	6%	$689
Gastrolobium diabolophyllum	50	Seed orchard	9	$152,420	$36,861	3	7%	$3,048
Gastrolobium hamulosum	50	Seed orchard	8	$127,192	$37,043	4	8%	$2,544
Goodenia integerrima	250	Translocate	9	$217,025	$43,701	12	5%	$868
Grevillea bracteosa subsp. *bracteosa*	50	Seed orchard	9	$162,638	$35,986	3	6%	$3,253
Grevillea dryandroides subsp. *dryandroides*	50	Seed orchard	8	$137,191	$36,861	4	7%	$2,744
Grevillea involucrata	50	Seed orchard	8	$144,057	$40,884	3	7%	$2,881
Grevillea pythara	250	Translocate	9	$158,474	$41,915	16	6%	$634
Grevillea scapigera	250	Translocate	9	$183,395	$38,336	14	5%	$734
Grevillea sp. Gillingarra (R.J. Cranfield 4087)	50	Seed orchard	9	$144,275	$34,326	3	7%	$2,885
Guichenotia seorsiflora	250	Translocate	8	$142,529	$38,942	18	7%	$570
Hemigenia ramosissima	250	Translocate	8	$149,108	$35,797	17	7%	$596
Isopogon robustus	250	Translocate	8	$164,664	$38,764	15	6%	$659
Lasiopetalum moullean	50	Seed orchard	11	$229,895	$54,642	2	4%	$4,598
Lysiosepalum abollatum	250	Translocate	8	$153,038	$34,239	16	7%	$612
Melaleuca sciotostyla	250	Translocate	8	$140,183	$36,529	18	7%	$561
Pityrodia scabra subsp. *scabra*	50	Seed orchard	9	$159,861	$34,245	3	6%	$3,197
Rhizanthella gardneri	250	Translocate	12	$643,779	$162,271	4	2%	$2,575
Stylidium applanatum	50	Seed orchard	9	$150,984	$58,934	3	7%	$3,020

Symonanthus bancroftii	250	Translocate	9	$150,598	$35,616	17	7%	$602
Tetratheca deltoidea	50	Seed orchard	10	$206,732	$61,065	2	5%	$4,135
Thelymitra stellata	250	Translocate	7	$152,560	$28,953	16	7%	$610
Thomasia sp. Green Hill (S. Paust 1322)	50	Seed orchard	9	$153,762	$33,737	3	7%	$3,075
Verticordia staminosa subsp. *cylindracea var. erecta*	250	Translocate	11	$234,135	$61,207	11	4%	$937
Verticordia staminosa subsp. *staminosa*	250	Translocate	11	$269,966	$49,154	9	4%	$1,080

8.2. Ecological benefits from expert elicitation

The probability of implementation success of the recovery action varied between 0.44 for *Grevillea pythara* to 0.80 for *Acacia volubilis*, with an average value of 0.70 (±0.10) (Table 13). Thus, for all of the 12 taxa discussed, experts felt that it was highly probable that the recovery action could be implemented. Probability of threat reduction success owing to the recovery action varied between 0.66 for *Acacia volubilis* and 0.84 for *Lysiosepalum abollatum* with an average value of 0.76 (±0.07). For the 12 taxa discussed with the experts it was highly probable that the recovery action would lead to reduced threat to the survival of these taxa. Similarly, probability of taxa' outcome success varied between 0.63 for *Grevillea pythara* to 0.85 for *Daviesia cunderdin* with an average value of 0.77 (±0.08), representing the view of experts that it was highly probable the recovery action would be successful in achieving the requisite goal in terms of mature individuals. The risk of receiving long-term funding to carry out the intended recovery action was quite similar across taxa and varied between 0.50 for *Acacia cochlocarpa subsp. velutinosa*, and 0.67 for *Grevillea scapigera* with an average value of 0.57 (±0.05) (Table 13).

For the number of mature individuals, the unadjusted benefit for each taxon can be thought of as the average value (across experts) of the number of plants that it would be possible to expect owing to the recovery action without considering the probabilities for implementation success, threat reduction success, taxa' outcome success, and risk of long-term funding (Table 14). For *Grevillea pythara* translocation was expected to lead to 250 plants, but given the clonal nature of the taxon, experts felt that a smaller population of about 50 plants would be more appropriate, and in future additional sites could be considered to spread risk spatially (as the taxon occurs at only one site) (Table 14).

The adjusted expected benefit considering the long-term risk to funding was lower than the adjusted expected benefit when funding risk was not considered. This was true for expected benefit expressed in terms of the number of mature individuals and when expressed in terms of the probability of persistence (Table 14 and Table 15). Thus, although not often considered, it would be important for conservation managers to consider the risk of long-term funding to implement conservation actions else this may lead to benefits being overestimated, especially if the risk is different for different taxa.

To account for the effect of extinction risk on the relative values resulting from conservation, weighting was undertaken such that the expected benefit for critically endangered taxa were multiplied, by *4*, and for endangered by *3* following Butchart et al. (2007) and Joseph et al. (2009).

Table 13: Probabilities of implementation success, threat reduction success, and management outcome success and risk to long-term funding obtained through expert elicitation. The weighting used for adjusting the expected ecological benefits is also given.

Asset	Action	Probability of			Risk to long-term funding	Weighting used
		Implementation Success	Threat Reduction Success	Management Outcome Success		
Daviesia cunderdin	Seed orchard	0.78	0.81	0.85	0.51	4
Eremophila verticillata	Translocate (250 plants)	0.76	0.84	0.84	0.56	4
Acacia cochlocarpa subsp. *velutinosa*	Burn and Translocate (250 plants)	0.63	0.81	0.82	0.50	4
Acacia pharangites	Translocate 250	0.74	0.83	0.84	0.62	4
Grevillea scapigera	Translocate 250	0.76	0.81	0.81	0.67	4
Symonanthus bancroftii	Translocate 250	0.69	0.71	0.71	0.59	4
Lysiosepalum abollatum	Translocate 250	0.72	0.84	0.84	0.60	4
Acacia subflexuosa subsp. *capillata*	Translocate 250	0.69	0.68	0.75	0.55	4
Acacia volubilis	Seed Orchard	0.80	0.66	0.71	0.51	4
Stylidium applanatum	Seed orchard	0.64	0.70	0.64	0.56	4
Eremophila virens	Translocate 250 (Includes burning)	0.74	0.77	0.76	0.62	3
Grevillea pythara	Translocate 250 (Includes disturbance)	0.44	0.73	0.63	0.55	4

It is important to adjust expected benefits to account for the varying success with implementation, threat reduction and taxa' outcome and possibly risk of securing long-term funding, so that they are not overestimated and will provide a more accurate and realistic estimation of the success of conservation outcomes. Therefore, in the discussions ahead, we discuss the taxa ranking only based on the various calculations of adjusted expected benefits and not based on the unadjusted benefit. The rankings based on different calculations of adjusted expected benefits were found to be somewhat different. Including funding risk altered the ranking for some taxa but not all (Table 14 and Table 15). Of course, since the funding risk was almost the same across taxa (0.57 (±0.05)) (Table 13), it may not have made a large difference in ranking. However, if the risk to long-term funding is different, it will make a difference to the ranking of taxa. Weighting to reflect different values (due to different threat statuses) also altered the rankings for some taxa (Table 14 and Table 15). However, it must be remembered that all the taxa discussed here were *critically endangered* except one (Table 13) and would get the same weight (=*4*). This type of weighting will be a more important consideration when taxa with different threat status are being considered for conservation prioritisation.

The probability of persistence measures the probability that the taxon will survive with the implementation of the given conservation action and was measured relative to the baseline action of not doing the conservation action but only monitoring the existing population sites of each taxon. The probability of persistence was very low (< 0.05) for some taxa such as *Grevillea scapigera* and *Lysiosepalum abollatum* (Table 15), implying that carrying out the conservation action was not expected to greatly improve the chances of survival of such taxa relative to the baseline. However, for some taxa, such as *Daviesia cunderdin*, the probability of persistence was about 22% higher when the recovery action was implemented relative to the baseline of not doing so. This value increased to 47% when adjusted for risk to long-term funding and weighting by threat status (Table 15), since the ecological benefits were multiplied by a factor of *4* as the taxon is *critically endangered*.

The change in probability of persistence was negative for some taxa such as *Acacia subflexuosa* subsp. *capillata*, *Eremophila virens,* and *Grevillea pythara* implying that carrying out the recovery action was expected to worsen their chances of survival relative to the baseline scenario of monitoring existing populations, indicates that on average, the proposed strategy was expected to result in worse outcomes than continuation of existing management. However, the negative values were quite small. Often in practice if the value is less than 1-2 % experts intended their estimate to be the same value but set their confidence in such a way that the uncertainty bounds when adjusted resulted in values slightly less than zero. These taxa were therefore excluded from ranking based on the lack on any change in the probability of persistence.

It is interesting to note that the ranking for the taxa whose ecological benefits were elicited by flora experts differ based on what type of ecological benefit was considered (i.e., number of mature individuals (Table 14) or probability of persistence (Table 15)). The top five taxa when ranked according to the adjusted number of mature individuals (that had been weighted and where risk to long-term funding was considered) were (1) *Daviesia cunderdin,*(2) *Eremophila verticillata*, (3) *Acacia cochlocarpa* subsp. *velutinosa*, (4) *Acacia pharangites*, and (5) *Grevillea scapigera* (Table 14). The top five taxa for recovery prioritisation when ranked according to the adjusted probability of persistence (that had been weighted and where risk to long-term funding was considered) were (1) *Daviesia cunderdin*, (2) *Stylidium applanatum*, (3) *Eremophila verticillata* , (4) *Acacia cochlocarpa* subsp. *velutinosa* and (5) *Acacia volubilis* (Table 15). The main difference in the taxa ranks using the two measures of ecological benefit is the much higher rank for *Stylidium applanatum* when considering probability of persistence relative to number of mature individuals. A plausible reason for this outcome is that *Stylidium applanatum* does not have the highly persistent soil-stored seed bank of the other 12 taxa, with the consequence that establishing a new population in a seed orchard substantially reduces stochastic risks to the existing single population. *Stylidium applanatum* only occurs at one location. *Acacia volubilis* may also only occur at one location. *Grevillea scapigera* has seed stored, three translocations and a persistent seed bank protected within the translocation sites so mature plants could be 0 and the species would still persist *in situ*. Long term seed burial trials have shown that seed is still has high viability after 20 years in the soil. *Acacia pharangites* may be similar to *Grevillea scapigera* in the persistence and security of an *in situ* seed bank where mature plants could be 0 and the species will still persist.

Table 14: Overall results obtained through expert elicitation where ecological benefits are measured as the increase in population of mature individuals.

Asset	Action	Expected benefit (in terms of the number of mature individuals)				Rank		
		Unadjusted expected benefit	Adjusted expected benefit (Without funding risk) [a]	Adjusted expected benefit (With funding risk) [b]	Weighted and adjusted expected benefit (With funding risk) [c]	Adjusted expected benefit (Without funding risk)	Adjusted expected benefit (With funding risk)	Weighted and adjusted expected benefit (With funding risk)
Daviesia cunderdin	Seed orchard	167	90	44	176	1	1	1
Eremophila verticillata	Translocate (250 plants)	165	88	39	156	2	2	2
Acacia cochlocarpa subsp. *velutinosa*	Burn and Translocate (250 plants)	186	77	39	155	3	3	3
Acacia pharangites	Translocate 250	131	67	26	103	5	4	4
Grevillea scapigera	Translocate 250	144	72	24	95	4	5	5
Symonanthus bancroftii	Translocate 250	116	40	16	66	7	7	6
Lysiosepalum abollatum	Translocate 250	79	40	16	64	8	8	7
Acacia subflexuosa subsp. *capillata*	Translocate 250	97	34	15	61	9	9	8
Acacia volubilis	Seed Orchard	81	30	15	60	11	10	9
Stylidium applanatum	Seed orchard	108	31	14	55	10	11	10
Eremophila virens	Translocate 250 (Includes burning)	111	48	18	55	6	6	11
Grevillea pythara	Translocate 250 (Includes disturbance)	51	10	5	19	12	12	12

[a] Calculated using equations (4) and (5); [b] Calculated using equations (4),(5) and (7); [c] Calculated using equations (4),(5), (7) and (9).

Table 15: Overall results obtained through expert elicitation where ecological benefits are measured in terms of the probability of persistence.

Asset	Action	Expected benefit (in terms of the probability of persistence)				Rank		
		Unadjusted expected probability of persistence (relative to the baseline)	Adjusted expected probability of persistence (without funding risk) [a]	Adjusted expected probability of persistence (with funding risk) [b]	Adjusted expected probability of persistence (Weighted & with funding risk) [c]	Adjusted expected probability of persistence (without funding risk)	Adjusted expected probability of persistence (with funding risk)	Adjusted expected probability of persistence (Weighted & with funding risk)
Daviesia cunderdin	Seed orchard	0.219	0.117	0.058	0.230	1	1	1
Stylidium applanatum	Seed orchard	0.226	0.065	0.029	0.116	2	2	2
Eremophila verticillata	Translocate (250 plants)	0.089	0.048	0.021	0.084	3	3	3
Acacia cochlocarpa subsp. *velutinosa*	Burn and Translocate (250 plants)	0.078	0.032	0.016	0.065	4	4	4
Acacia volubilis	Seed Orchard	0.075	0.028	0.014	0.055	6	5	5
Acacia pharangites	Translocate 250	0.057	0.029	0.011	0.045	5	6	6
Lysiosepalum abollatum	Translocate 250	0.040	0.020	0.008	0.032	7	7	7
Symonanthus bancroftii	Translocate 250	0.057	0.020	0.008	0.032	8	8	8
Grevillea scapigera	Translocate 250	0.030	0.015	0.005	0.020	9	9	9
Acacia subflexuosa subsp. *capillata*	Translocate 250	-0.006	-0.002	-0.001	-0.004	NR [d]	NR [d]	NR [d]
Grevillea pythara	Translocate 250 (Includes disturbance)	-0.017	-0.003	-0.002	-0.006	NR [d]	NR [d]	NR [d]
Eremophila virens	Translocate 250 (Includes burning)	-0.015	-0.006	-0.002	-0.007	NR [d]	NR [d]	NR [d]

[a] Calculated using equations (4) and (5); [b] Calculated using equations (4),(5) and (7); [c] Calculated using equations (4),(5), (7) and (9); [d] Taxa with a negative adjusted probability of persistence were not ranked since their survival under the recovery action of translocation was expected to be worse than under a baseline scenario of monitoring existing populations.

8.3. Ranking based on cost-effectiveness ratio from expert elicitation

The cost-effectiveness ratio defined as additional gain in plants per dollar invested (or per $10,000 invested) and the cost per additional plant (the inverse of the cost-effectiveness ratio) was calculated for the various adjusted benefits (Table 16).

Allowing for project risk, the additional gain per $10,000 invested varied between 0.6 plants (for *Grevillea pythara*) to 6.2 plants (for *Daviesia cunderdin*) with an average value of 3.3 (±1.6) plants across all taxa when funding risk was not considered in adjusting benefits. When funding risk was considered to adjust benefits, the additional gain per $10,000 invested varied between 0.3 plants (for *Grevillea pythara*) to 3.2 plants (for *Daviesia cunderdin*) with an average value of 1.9 (±0.9) plants across all taxa. Weighting and including altered the additional gain per $10,000 invested to an average of 7.4 (±3.5) benefit units across all taxa[3].

The cost per additional plant varied between $1,617 (for *Daviesia cunderdin*) and $16,578 (for *Grevillea pythara*) with an average value of $4,313 (± $4,015) across all taxa when funding risk was not considered in adjusting benefits. When funding risk was considered to adjust benefits, the cost per additional plant varied between $3,171 (for *Daviesia cunderdin*) to $30,141 (for *Grevillea pythara*) with an average value of $7,678 (± $7,357) across all taxa. Inclusion of weight for threatened status of the taxa and funding risk altered the cost per additional plant between $793 (for *Daviesia cunderdin*) to $7,535 (for *Grevillea pythara*) with an average of $1,960 (± $1,833) across all taxa.

The ranking or the prioritisation for conservation, which was based on the additional gain per $10,000, depended on how the benefits were adjusted. Adjusting benefits to account for long-term funding risk altered the ranking far more than the inclusion of weighting (Table 15) but this was very likely because all the taxa except one[4] were equally weighted since they were all

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[3] The benefit units consist of plant numbers weighted by the factor for the relative value of the taxon reflecting its threat status: *4* for *critically endangered*, *3* for endangered taxa following Butchart et al. (2007) and Joseph et al. (2009).

[4] A weighting of *3* was applied to *Eremophila virens* as it is *endangered* . All other taxa in Table 16 had a weighting of *4* applied to them since they are *critically endangered*.

critically endangered. If the threat status of the taxa were very different then weighting would play an important role in influencing the ranking of the taxa.

Using the cost-effectiveness ratio as the decision metric and adjusting the expert-elicited expected benefits for the likelihood of success, risk to long-term funding and weighting the benefits according to the threat status of the taxa, the top five taxa to be considered for the implementation of recovery action among the 12 taxa considered are (in order of ranking): *Daviesia cunderdin*, *Acacia cochlocarpa* subsp*. velutinosa*, *Eremophila verticillata*, *Acacia pharangites*, and *Grevillea scapigera*.

Table 16: Adjusted expected benefits, total present value of cost of recovery action (*PV(C)*), the additional gain per $10,000, cost per additional plant, and the ranks based on the additional gain per $10,000 obtained through expert elicitation.

Asset	Expected benefit (in terms of the number of mature individuals)			*PV(C)* (2019 AUD)	Additional gain per $10,000 [cost-effectiveness ratio x 10,000]			Cost per additional plant [1/cost-effectiveness ratio]			Rank based on additional gain per $10,000		
	Adjusted expected benefit (without funding risk)	Adjusted expected benefit (with funding risk)	Weighted and adjusted expected benefit (with funding risk)		From adjusted expected benefit (without funding risk)	From adjusted benefit (with funding risk)	From weighted adjusted benefit (with funding risk)	From adjusted expected benefit (without funding risk)	From adjusted benefit (with funding risk)	From weighted adjusted benefit (with funding risk)	From adjusted expected benefit (without funding risk)	From adjusted benefit (with funding risk)	From weighted adjusted benefit (with funding risk)
Daviesia cunderdin	90	44	176	$145,430	6.2	3.0	12.1	$1,617	$3,301	$825	1	1	1
Acacia cochlocarpa subsp. velutinosa	77	39	155	$157,925	4.9	2.4	9.8	$2,041	$4,083	$1,021	2	2	2
Eremophila verticillata	88	39	156	$185,272	4.8	2.1	8.4	$2,098	$4,736	$1,184	3	3	3
Acacia pharangites	67	26	103	$141,103	4.8	1.8	7.3	$2,104	$5,488	$1,372	4	4	4
Grevillea scapigera	72	24	95	$183,395	3.9	1.3	5.2	$2,554	$7,740	$1,935	5	5	5
Acacia volubilis	30	15	60	$124,865	2.4	1.2	4.8	$4,119	$8,379	$2,095	9	6	6
Symonanthus bancroftii	40	16	66	$150,598	2.7	1.1	4.4	$3,743	$9,192	$2,298	7	7	7
Lysiosepalum abollatum	40	16	64	$153,038	2.6	1.0	4.2	$3,823	$9,557	$2,389	8	9	8
Acacia subflexuosa subsp. capillata	34	15	61	$159,087	2.1	1.0	3.8	$4,700	$10,445	$2,611	10	10	9
Stylidium applanatum	31	14	55	$150,984	2.1	0.9	3.7	$4,825	$10,895	$2,724	11	11	10
Eremophila virens	48	18	55	$169,726	2.8	1.1	3.2	$3,551	$9,265	$3,088	6	8	11
Grevillea pythara	10	5	19	$172,974	0.6	0.3	1.1	$16,578	$36,839	$9,210	12	12	12

[a] Recovery action for taxa includes disturbance by fire followed by a translocation to establish a new population with expectedly 250 reproductively mature plants; [b] Recovery action for taxa is a translocation to establish a new population with expectedly 250 reproductively mature plants; [c] Recovery action for taxa includes establishing a seed orchard.

For comparison, we present the rankings of the taxa based on (a) their total cost for recovery, (b) expected benefit based on the number of mature plants, (c) expected benefit based on the probability of persistence, and (d) the cost-effectiveness ratio (Table 17). This demonstrates how the ranking for conservation prioritisation can change based on the metric chosen. We recommend using the cost-effectiveness ratio as the decision metric since it considers the ecological benefits as well as the cost of recovery for prioritising taxa for conservation decision-making.

Table 17: Strategy evaluation table comparing ranks based on a) expected total cost of recovery, b) expected benefit based on number of mature individuals, c) expected benefit based on probability of persistence, d) cost-efficiency. All benefit estimates based on weighted and adjusted expected benefit (With funding risk).

Asset	Rank based on expected total cost	Rank based on expected benefit (number of mature individuals)	Rank based on expected benefit (probability of persistence)	Rank based on cost-effectiveness ratio
Acacia cochlocarpa subsp. velutinosa	7	3	4	2
Acacia pharangites	2	4	6	4
Acacia subflexuosa subsp. capillata	8	8	NR	9
Acacia volubilis	1	9	5	6
Daviesia cunderdin	3	1	1	1
Eremophila verticillata	12	2	3	3
Eremophila virens	9	11	NR	11
Grevillea pythara	10	12	NR	12
Grevillea scapigera	11	5	9	5
Lysiosepalum abollatum	6	7	7	8
Stylidium applanatum	5	10	2	10
Symonanthus bancroftii	4	6	8	7

9. Discussion and future work

9.1. *The approach*

We developed a decision support tool to rapidly identify when translocation may be preferred over status quo *in situ* management and which *ex situ* translocation and seed orchard actions may provide the most cost-effective conservation outcomes. The first step in our decision support tool was to rapidly screen all listed threatened plant taxa to identify those in most urgent need of conservation actions compared to others. Using a combination of taxa ecology and traits such as response to disturbances such as fire, demographic risk factors, and local context, we routed taxa to categories that can identify whether and what types of translocations may be useful for the taxon, including whether disturbance should be considered prior to translocation. The decision-tree could be simplified but was structured to reduce the amount of information needed from the users of the tool - a key consideration with regard to usability.

Ideally for taxa advanced to cost-effectiveness analysis, multiple options would be considered where feasible for each taxon, especially those that are not classified as "in urgent need". A full management strategy evaluation (Gregory et al 2012) for each species that compares the relative utility of translocation to other available options before translocation is implemented would be useful for some species where options other than translocation remain available. Indeed, for some taxa, such a process was initiated. While there is no scope to implement or discuss this here, the expected benefit function (Equation (7)) is broadly applicable and was designed to be compatible with strategy evaluation at both the individual taxa level and portfolio level.

9.2. *Cost risk*

Cost risk[5] is rarely considered and internalised in conservation decisions. Here we made an effort to incorporate it to prioritise threatened plants for translocation. Cost risk refers to risk

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[5] Cost uncertainty refers to potential future situation in which probability of occurrence of factors affecting recovery costs in the future cannot be assigned. On the other hand, cost uncertainty turned into cost risk if we can assign the probability of occurrence of the future events that affect the costs of recovery actions.

incurred as a result of future events with a known or given chance of occurrence which would affect the costs of recovery actions if the event occurred. These events will deviate the realised costs of actions (i.e., the most likely costs) from estimated costs with some probability. We collectively considered potential cost risks, such as changes in funding priority to translocation program, potential increase in translocation costs due to increased input costs (labour or materials etc) or decrease in costs due to technological progress, or funding shortfall due to known reasons even without changes in funding priority. We estimated the probability distribution of costs using Monte Carlo simulation, with 500 random draws for each cost element.

9.3. Measuring benefits

Here we assess only the value of the translocation to the taxon of conservation concern, and the cost-effectiveness of undertaking a translocation for one taxon relative to one another, since these are the biggest barriers to action. However, some actions may be beneficial to more than one taxon (e.g., *Acacia volubilis*, *Daviesia cunderdin* which co-occur at one location). In such cases, if the expected ecological benefit to both taxa (say, T1 and T2) were elicited, it would be reasonable to sum the benefits before dividing by a single shared cost for the recovery action, i.e.

$$CER_{EE\ T1,T2} = \frac{\sum_{i=T1}^{T2} AEB_{wfi}}{PV(C)} \qquad (12)$$

Additionally, the ecosystem benefits of the presence of the taxa within communities are not considered, nor are non-monetary social values such as tourism and aesthetic values. While not addressed here, in cases where cost-efficiencies may be anticipated based on co-occurrence or similar site needs, the design of the benefit metrics are such that the expected benefits for all taxa for mature individuals can be seen as additive if we are willing to assume independence, and the sum of the overall difference with and without the action for both taxa is an appropriate metric.

The numerator in the cost-effectiveness ratio (equation (1)) is the difference in the expected ecological benefits with and without conservation actions. Assume that the ecological benefits are measured in terms of the population of the taxon (number of mature individuals). This treats the value of population increases the same without considering the value of the initial population size of the taxon. For example, consider a hypothetical scenario in which the present value of cost (*PV(C)*) is the same for two taxa. For one of the taxa, the population increases from 500 individuals to 550 individuals (a 10% increase). For another taxa, the population increases from 10 individuals to 60 individuals (a 500% increase). According to equation (1) both would have the same cost-effectiveness ratio (and, therefore, the same rank), whereas in reality, an increase of one plant would have more value for smaller populations compared to larger populations. Currently our weighting for rarity is relatively crude, based only on threat status, not population size. An alternative would be to measure benefits in terms of the percentage change in populations:

$$CER_{adj} = \frac{PV(C)}{\left(\frac{P_a - P_b}{P_b}\right)} \qquad (13)$$

where, CER_{adj} is the adjusted cost-effectiveness ratio, P_a and P_b denote the taxa population (number of mature individuals) under the recovery **a**ction and the **b**aseline scenario respectively, and *PV(C)* is the present value of costs. Using Equation (13) would mean that the two taxa will have very different CER_{adj} values, with the benefit for the latter species being much higher than that of the former. A preference for using equation (1) or equation (13) comes down to deciding which of them better reflects the way values should be measured – a difficult judgement with no objectively correct answer.

Also, while this decision support process has the advantage that it removes individual bias or preferences for particular taxa from the process of ranking other factors such as phylogenetic distinctiveness of taxa may also become important and could be incorporated in adjusting the ecological benefits. One option could be to essentially replace the weighting given currently with a measure of phylogenetic distinctiveness such as an Evolutionarily Distinct and

Globally Endangered (EDGE) score that combines a taxon's evolutionary distinctiveness and its global endangerment level (Isaac et al., 2007). Alternately a preference scaling could be introduced.

9.4. Translocation versus seed orchard

Although the desired goal for all taxa was to establish a new (translocated) population of 250 plants, initial calculations revealed that some taxa being considered had little or no seed in the WASC to support a translocation and insufficient seed production in the wild to allow sufficient seed collection in the short term[6] Consequently, it was decided that for these taxa establishing a seed orchard or other high yield translocation from which germplasm could be harvested would be the fastest and most efficient path to support future translocation actions since it is anticipated that seed yield would increase by using a seed orchard. The quantity of seed able to be collected using good collecting practices (Cochrane et al., 2009) and seed collection licence restrictions in Western Australia is limited to 20% of the available seed. If seed were collected from a seed orchard, then all seed would be available for collection (i.e., five times as much seed). In addition, higher productivity in terms of seed yield can potentially be achieved when plants are grown in a cultivated situation (Pedrini et al., 2020). For the purpose of estimating seed yield from a seed orchard although all seed in a seed orchard would be available for collection (i.e., five times as much as allowable from the wild) a conservative multiplier of three was used to account for other factors that may limit collection of all seed from plants such as: not all plants producing seed; timing; feasibility. The multiplication factor did not consider potential seed production increases that may be possible when plants are grown under cultivated conditions and might be expected to be much higher. Our decision-making process thus became adaptive to suit the specific needs of the taxa being considered for conservation.

For the seed orchard, it must be reiterated that although the goal was set at the minimum number of reproductively mature plants (50) for our analysis, the actual seed orchard size would be case dependent and determined by the availability of parent material with the goal

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[6] For these taxa in our analysis, the number of years required to collect seeds for a translocation of 250 plants was estimated to take eight years and longer – mostly decades.

of capturing the maximum genetic variability still available either in the wild or *ex situ* seed banks.

9.5. Costs

The way the cost model is set up also offers us the opportunity to think about the impact on cost-effectiveness of creative management techniques that are currently perceived as costly, perhaps because an additional capital investment (such as in the case of pre-translocation fire) may be required, or because an additional ongoing cost (such as increased watering) occurs. It is possible that some solutions perceived as costly may be more cost-effective than current practice. The model makes it easy to illustrate this.

While our model costed monitoring effort uniformly for five years after last planting, this may not be sufficient time to reach reproductive maturity in some taxa. It is possible that some taxa will need to be assessed for longer, thus, the length of annual monitoring may need to be extended on a case-by-case basis.

The total present value of cost was found to vary between $124,014 and $643,780 with an average value of $178,557 and depended on whether a translocation or the establishment of a seed orchard was being carried out and on the type of taxa (orchids versus non-orchids, in our case) (Table 12). While the average cost for each additional plant obtained through translocation ($793) was significantly lower ($p < 0.0001$) than the average cost for each additional plant obtained through the establishment of a seed orchard ($3,034), it must be re-iterated that the result was because seed orchards in our cost model had a target of 50 reproductively mature plants whereas translocations were set at a target of 250 reproductively mature plants. However, this can change depending on the actual size of the seed orchard in question, which, as noted earlier, will be decided on a case-by-case basis. Additionally, in some cases, amplification of available seed may be undertaken at a temporarily more intensively managed wild site, while in others the seed orchard may be more similar to an *ex situ* collection and is intensively managed more long term at a location that may be removed from the wild populations. It is also important to note that in some cases, a seed orchard functions as an *ex situ* collection, and is only an intermediate step in the goal to establish a new wild population of the taxa, while in others amplification of available seed may be undertaken by temporarily more intensively managed wild site.

In general, orchid taxa are slightly more expensive to translocate compared to non-orchid taxa when translocation is the sole recovery action. The increased cost is a result of the much greater investment required to establish pollinator presence, ensuring translocated plants have established a fungal symbiosis and matching translocation habitat as closely as possible with natural habitat (Reiter et al., 2016). The two most important factors in establishing a self-sustaining orchid translocation have been identified as ensuring pollinator and fungal mutualisms are present (Reiter et al., 2016). The often obligate mutualisms that orchids possess require translocations, in particular, to be treated holistically in terms of understanding and replicating the ecological interactions necessary to support establishment post-translocation. Perhaps the key to enhancing conservation outcomes for a wider range of taxa would involve a higher level of rigour in site selection, such as the adoption of microhabitat matching or modelling and identification of key ecological drivers of occurrence and persistence.

9.6. Accounting for risks

It is important to adjust the expected ecological benefits derived from recovery actions to account for the likelihood of success in implementation, threat reduction, and in outcome (increase in population). It is for this reason that the adjusted cost-effectiveness ratio (equation (11)) is a more realistic metric to guide the prioritisation of taxa for recovery over metrics where the expected ecological benefits have not been adjusted for likelihood of success (equation (10)). Values derived from equation (10) can be at best considered theoretical maxima. These serve as useful indicative values for naïve comparison but are not recommended for decision making. Also, while the goal of our recovery projects was expected to be the same across all taxa (establishing a new population of 50 or 250 mature plants depending on the recovery action), discussions with experts during the elicitation process showed that this may not be possible for most taxa (Table 14). This makes it important to conduct expert elicitations to adjust the goal (or ecological benefits) and also the probability of success of the recovery action for each taxon individually.

Funding risk was generally high, and relatively similar for all taxa, varying between 0.50 and 0.67 with an average value of 0.57 (±0.05). There was a general pessimism amongst experts that long-term funding would be made available for ongoing monitoring and maintenance and additional planting at translocation site that influenced the similarity of this risk across taxa. This finding highlights inherent uncertainty in the ability to fund long-term conservation programs for a given species, even in relatively secure tenure. Although the funding risk score did change some rankings, anecdotally, the reasons given for variation were linked to high levels of threats and competing needs, community preferences, and the fact that funders prefer to fund ”new” programs rather than supporting ongoing work. To that end, since funding risk is generic and inherent one, it is perhaps not needed in the tool, although preferences perhaps are. Nonetheless, this finding highlights that it is critical that long-term funding security be available for translocation programs.

Adjusting benefits to account for long-term funding risk did alter rankings, and more than the inclusion of weighting for the threat status of taxa, however all but one taxon were critically endangered (the threat status of one was endangered), so the weighting played little role in generating the list in this pilot application. If the threat status of the taxa were very different then weighting would likely play an important role in influencing the ranking of the taxa. If experts felt that the long-term funding risk would be very different across the set of taxa chosen for the cost-effectiveness analysis, then this would affect the ranking of the taxa to a much greater extent.

At present, the group mean is utilised as the estimate of benefit. Use of the group mean works reasonably well (Hemming et al., 2018a) and has been shown to result in estimates much closer to the true estimate in trials where validation of results occurred (Hemming et al., 2018b). However, beta-PERT distributions were specifically developed for the treatment of expert-elicited information to reflect the uneven shape in most expert estimates (Davies et al., 2018; Vose, 2008), and the estimates could be enhanced by incorporating a beta-PERT distribution. In addition, use of such a distribution permits the subsequent application of additional econometric and decision science methods such as stochastic dominance, which can be used to rank alternative conservation actions by comparing the probability distributions of their outcomes, allowing consideration of the best action across the full distributions of outcomes instead of one or two moments of the distribution (Canessa et al., 2016).

The decision-making process we describe here has three key benefits. First, the screening process utilises theory and concepts that identify those taxa most likely to be at risk and therefore highlights taxa at risk (irrespective of cost-benefit). Second, it identifies when and what type of translocation actions are likely to be mostly useful, resulting in rapid identification of key actions across the full management portfolio. Third, it provides a clear path for resolving investment among taxa by focusing on cost-effectiveness, utilising two conservation objectives, resulting in identification of the most cost-effective actions. Using a weighting, we also attempt to account for relative risk of extinction among taxa withing the cost-benefit process, by upweighting benefits to species at higher risk. Finally, consideration of the probability of persistence metric focuses efforts on actions likely to limit the chance of extinction. There remains the challenge that the best actions for all species may not be implemented due to budget limitations, particularly where feasibility at present may be low, or the only available actions are extremely costly. To this end, we suggest that a valuable extension to this work would be to rout such taxa to an alternate process wherein research to identify barriers to success and the potential value of information for are considered.

9.7. Identifying challenging taxa and limiting steps in the translocation process

The cost model provides conservation mangers with information on where best to invest to cost-effectively enhance the state of knowledge for taxa that are challenging to translocate. For example, when the information on survival rates at various stages of a translocation was entered into the cost model, it was found that seed collection to establish a seed orchard for *Philotheca basistyla* was expected to take 48 years at current annual harvest rates from the wild compared to 1.4 (± 2) years for other taxa. The long duration of the seed collection was the limiting step for this taxon and led to it not being considered further in the cost-effectiveness analysis. This resulted in discussions among conservation managers on the right conservation approach for this taxon. From the discussions it became clear that the current rates of survival of *Philotheca basistyla* across the germination stage were based on current germination limitations due to seed dormancy. If the dormancy issue could be solved, or if plants of this taxa were produced via vegetative means this could change (i.e., the survival rate across the germination stage could be increased). For challenging taxa such as *Philotheca basistyla*, the cost model, thus, provides a means of identifying the limiting steps in the translocation process. Addressing these limitations prior to the actual implementation of the translocation will allow for improvements in rates of survival.

Information on survival rates at various stages of a translocation led to two stages being identified as limiting steps for many taxa —germination, and plants surviving to maturity. Germination was found to be the primary limiting step in the translocation process for many taxa (e.g., *Philotheca basistyla*). If germination success could be improved, it would dramatically decrease the number of years required to obtain adequate seed required for a translocation. It would be interesting to compare results with 20% germination – the current estimate on what germination might be able to be achieved for many non-orchid taxa, to 80% germination – germination hoped for if research into how to germinate the taxa was successful. Likewise, survival of planted seedlings to reproductive maturity is a major bottleneck in the process of achieving a successful translocation. The survival rate of planted seedlings until maturity is about 20% currently for many taxa. Improvements in the establishment and plant survival techniques, are therefore, equally important to increase the cost effectiveness of translocations.

Plants surviving to maturity was found to be another key limiting factor on translocation success more broadly and many factors can contribute to whether survival to maturity is achieved (Godefroid et al., 2011; Menges, 2008). These factors can include propagule type, translocation type, genetic variation, and environmental factors at the translocation site such as herbivory, drought stress, environmental extremes, nutrient deficiencies, competition from weeds and native plants, disease, and transplant shock (Guerrant, 2012; Menges, 2008). Management techniques that minimise the negative impact of the environmental factors may be essential in ensuring the translocated plants survive to maturity and the translocation activity is ultimately successful in reducing the extinction risk for the taxa (Dillon et al., 2018). However, some of these additional management techniques place an extra cost on the translocation, so the requirement for these needs to be carefully considered. Evaluating the sensitivity of costs and cost-effectiveness to enhancing each of the steps in the translocation process (Figure 5) would be a useful way to identify for which taxa this would be a good investment.

9.8. Potential seed yield from plants in a fully established seed orchard

We also calculated potential seed yield from plants in a seed orchard that has 50 reproductively mature plants in order to show how having a fully established seed orchard may be used to facilitate the recovery of taxa that are particularly challenging. The calculations were carried out as follows: First, the average seed yield per plant for all the non-orchid taxa considered in the cost-effectiveness analysis was calculated based on available seed collection data for existing wild collections or estimated using data for other similar species. This calculation was not possible for two species (*Banksia ionthocarpa* subsp. *chrysophoenix* and for *Grevillea pythara*) as they are thought to reproduce vegetatively with little to no seed production (George, 2005; Olde and Marriott, 1993). The time for seed collection was estimated from available field data, and a best estimate of the time to collect seeds used for these two taxa for the purpose of this study (three years for *Banksia ionthocarpa* subsp. *chrysophoenix* and one year for *Grevillea pythara*) . A multiplication factor of 3 was then applied to provide a conservative estimate of the increased seed yield which might be possible from a seed orchard. As the goal of the seed orchard was to establish 50 reproductively mature plants the seed yield per plant was multiplied by 50 to account for this plant number. This gives the annual seed yield for 50 mature plants from a seed orchard. These calculations are presented in the worksheet titled “Seed yield from seed orchards” in Supplementary Item S2. Using the annual seed yield from a fully established seed orchard with 50 mature plants, the number of years required to collect seeds for a translocation from such a seed orchard is calculated for various taxa in row 46 of the “Survival Rate” worksheet in Supplementary Item S2. These calculations show that for many taxa, seed collection time falls significantly. For example, seed collection for *Grevillea bracteosa* subsp. *bracteosa* that was expected to take seven years from the wild now would fall to less than 1 year once the plants in the seed orchards are mature. Similarly, for *Philotheca basistyla*, seed collection that was expected to take 48 years from the wild, now falls to 2.2 years if the entire seed is collected from a fully established seed orchard. Of course, such a change to the time required for seed collection is true only if there is a fully established seed orchard available. Seed orchards, however, take time to be established, and that time is not included in these calculations. Nonetheless, the purpose of the calculations of seed yield from a seed orchard are to show how it may be used to facilitate the recovery of taxa that are particularly challenging.

9.9. Limitations and potential avenues to improve the decision support process

We identified some limitations in the process developed to date, and potential avenues where we can invest to improve outcomes. Currently, the assumption in the cost model is that all the seed for a translocation or a seed orchard are first collected and only then the process of propagating the seeds and planting the germinants takes place. While this may hold true for some taxa, it be not necessarily be the case for many other taxa where seed collection is likely to take a few years (say, 5–7 years). In those cases, it is likely that seed collection may be carried out until the point that half the required seed are collected after which the process of propagating the seeds and planting the germinants would take place concurrently as the next annual seed collection. This assumption would hold for the establishment of seed orchards too. In fact, in the case of seed orchards, seed propagation and planting could take place even with a small number of seeds (say 20—25). The seed harvested annually from the plants in the seed orchard could then supplement seed collected from the wild and be propagated and planted until a population of 50 mature plants is reached, although consideration of genetic implications is necessary. Building this assumption into the cost model would make the model more “dynamic” and possibly be a better reflection of how the process would actually take place.

During the elicitation it was felt that additional expertise was required for orchids and therefore no orchid taxa proceed through to the prioritisation in the report, although they were costed, and naïve comparisons undertaken. A follow-up expert elicitation on the orchid taxa chosen through the screening process will be held with orchid experts.

At present the cost model does not include automated costing for disturbance either through fire or other means, although costs not included in the model can be incorporated as part of the initiation cost. It is also set up for either a translocation or to establish a seed orchard but not a seed orchard followed by a translocation. The cost tool can be enhanced over time to incorporate these actions. Also, other costs such as the opportunity cost of personnel time could be captured in an enhanced version of the cost tool.

The model may have some limitations in diagnosing exact benefit and cost, due to currently not capturing how improvements in rate-limiting steps are likely to improve outcomes over time. The challenge is not ignored–increased survival (50% in seed orchard populations that are more intensively managed compared to 20% for translocated populations) is incorporated. However, in reality, increases would scale with the actual number of individuals, and it is possible that in some cases time required to conduct the translocation may be overestimated. Nonetheless, the results hold – as where seed collections are limited and germination success low, if we were to begin now, these would be the anticipated results, and overall, such taxa would be expected to have poorer outcomes.

The assumptions used for the seed orchard, and the subsequent results presented here could change if new information on seed orchard viability and cost becomes available. Indeed, this is true for all the assumptions that have been used in the cost model– while they are based on the best available information to date, we caution that the results presented here could change if new information about taxa comes to light. It must also be noted that the personnel costs in our model were akin to their 'billable hours' for working on a translocation as opposed to funding a position or project. The costs assume that staff and basic infrastructure (such as greenhouses, seed store) are already in place. It would not be possible to "buy" an independent translocation at these prices if starting from zero or managing it externally. In such cases translocation projects would require a staff member to manage activities for their duration, resulting in increased cost. Also, other costs such as opportunity costs of staff time or the cost of not currently undertaking necessary actions, is also not accounted for.

9.10. Future Work

This decision support process will also be expanded to other DBCA administrative regions to aid in flora recovery prioritisation for those regions, or it could be undertaken for the state as a whole.

Future work will also involve quantifying the social benefits of the threatened taxa in monetary terms using non-market valuation surveys specifically, best worst scaling (BWS) surveys. In a BWS survey (Louviere et al., 2015), respondents are presented with several choice questions each having different sets of options (in this case threatened flora taxa). Respondents will be asked to select their most and least preferred taxa for translocation from the options given. This will allow us to elicit the preferences and the social values of the taxa and recalculate the value of the benefits. The survey will be administered to flora experts working with the Department of Biodiversity, Conservation and Attractions on the conservation of threatened flora in the Wheatbelt region. It is possible that the ranking of the taxa might change once the benefits are adjusted to include the social benefits in terms of expert values of the taxa. In future, these BWS surveys may also be administered among the general public to elicit their preferences and values for threatened flora conservation to see how they differ from expert values for the same taxa. Incorporating social values of threatened taxa will allow us to make more informed decisions about prioritising threatened taxa for conservation.

10. Conclusion

The decision support tool developed here provides clear guidance to managers on where to place resources when they are limited, allowing for periodic planning of expenditure (i.e., put off seed orchards or translocations for taxa that are not in immediate need to a later funding cycle). The tool also allows for rapid comparison across all vascular plant taxa, immediate comparisons of benefit-cost which can be updated as data comes in or likely threats change. One additional advantage of the model is that it makes very clear where in the “translocation cycle” rate limiting steps occur. Further evaluation of sensitivity of costs, benefits and cost-effectiveness may allow us to identify where we could best invest in improving knowledge to enhance the likelihood that taxa will survive and improve cost-effectiveness. We caution that the results presented here will change should new information on costs and benefits become available.

11. References

APGA, 2020. CPC Best Plant Conservation Practices to Support Species Survival in the Wild. American Public Gardens Association.

Bland, L.M., Collen, B., Orme, C.D.L., Bielby, J., 2015. Predicting the conservation status of data-deficient species. Conservation Biology 29, 250-259.

Bode, M., Brennan, K.E.C., Morris, K., Burrows, N., Hague, N., 2012. Choosing cost-effective locations for conservation fences in the local landscape. Wildlife Research 39, 192-201.

Bradbeer, J.W., 1988. Seed Viability and Vigour, Seed Dormancy and Germination. Springer US, Boston, MA, pp. 95-109.

Brazill-Boast, J., Williams, M., Rickwood, B., Partridge, T., Bywater, G., Cumbo, B., Shannon, I., Probert, W.J.M., Ravallion, J., Possingham, H., Maloney, R.F., 2018. A large-scale application of project prioritization to threatened species investment by a government agency. PloS one 13, e0201413-e0201413.

Broadhurst, L., Coates, D., 2017. Plant conservation in Australia: Current directions and future challenges. Plant Diversity 39, 348-356.

Brown, A., Thomson-Dans, C., Marchant, N., 1998. Western Australia’s Threatened Flora. Department of Conservation and Land Management, Western Australia.

Burgman, M.A., Keith, D., Hopper, S.D., Widyatmoko, D., Drill, C., 2007. Threat syndromes and conservation of the Australian flora. Biological Conservation 134, 73-82.

Busch, J., Cullen, R., 2009. Effectiveness and cost-effectiveness of yellow-eyed penguin recovery. Ecological Economics 68, 762-776.

Butchart, S.H.M., Resit Akçakaya, H., Chanson, J., Baillie, J.E.M., Collen, B., Quader, S., Turner, W.R., Amin, R., Stuart, S.N., Hilton-Taylor, C., 2007. Improvements to the Red List Index. PLOS ONE 2, e140.

Byrne, M., Elliott, C.P., Yates, C., Coates, D.J., 2007. Extensive pollen dispersal in a bird-pollinated shrub, Calothamnus quadrifidus, in a fragmented landscape. Mol Ecol 16, 1303-1314.

Canessa, S., Ewen, J.G., West, M., McCarthy, M.A., Walshe, T.V., 2016. Stochastic Dominance to Account for Uncertainty and Risk in Conservation Decisions. Conservation Letters 9, 260-266.

Clarke, P.J., Lawes, M.J., Murphy, B.P., Russell-Smith, J., Nano, C.E.M., Bradstock, R., Enright, N.J., Fontaine, J.B., Gosper, C.R., Radford, I., Midgley, J.J., Gunton, R.M., 2015. A synthesis of postfire recovery traits of woody plants in Australian ecosystems. Science of The Total Environment 534, 31-42.

Coates, D.J., Atkins, K.A., 2001. Priority setting and the conservation of Western Australia's diverse and highly endemic flora. Biological Conservation 97, 251-263.

Cochrane, J.A., Crawford, A.D., C.A., O., 2009. Seed and vegetative material collection, in: C.A., O., Meagher, P.F. (Eds.), Plant germplasm conservation in Australia: Strategies and guidelines for developing, managing and utilising ex situ collections. Australian Network for Plant Conservation, Canberra, Australia, pp. 35-62.

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

Cullen, R., Hughey, K.F.D., Fairburn, G., Moran, E., 2005. Economic analyses to aid nature conservation decision making. Oryx 39, 327-334.

Davies, O.A.M., Huggins, A.E., Begue, J.A., Groombridge, J.J., Jones, C., Norfolk, D., Steward, P., Tatayah, V., Zuël, N., Ewen, J.G., 2018. Reintroduction or natural colonization? Using cost-distance analysis to inform decisions about Rodrigues Island Fody and Warbler reintroductions. Animal Conservation 21, 110-119.

DBCA, 2019. Conservation codes for Western Australian Flora and Fauna. Department of Biodiversity, Conservation, and Attractions, Government of Western Australia.

Dillon, R., Monks, L., Coates, D., 2018. Establishment success and persistence of threatened plant translocations in south west Western Australia: an experimental approach. Australian Journal of Botany 66, 338-346.

Frankham, R., Bradshaw, C.J.A., Brook, B.W., 2014. Genetics in conservation management: Revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. Biological Conservation 170, 56-63.

George, A.S., 2005. Further new taxa in Dryandra R.Br. (Proteaceae : Grevilleoideae). Nuytsia 15, 337–346.

Gerber, L.R., Runge, M.C., Maloney, R.F., Iacona, G.D., Drew, C.A., Avery-Gomm, S., Brazill-Boast, J., Crouse, D., Epanchin-Niell, R.S., Hall, S.B., Maguire, L.A., Male, T., Morgan, D., Newman, J., Possingham, H.P., Rumpff, L., Weiss, K.C.B., Wilson, R.S., Zablan, M.A., 2018. Endangered species recovery: A resource allocation problem. Science 362, 284.

Gibson, N., Yates, C., Byrne, M., Langley, M., Thavornkanlapachai, R., 2012. The importance of recruitment patterns versus reproductive output in the persistence of a short-range endemic shrub in a highly fragmented landscape of south-western Australia. Australian Journal of Botany 60, 643-649.

Godefroid, S., Piazza, C., Rossi, G., Buord, S., Stevens, A.-D., Aguraiuja, R., Cowell, C., Weekley, C.W., Vogg, G., Iriondo, J.M., Johnson, I., Dixon, B., Gordon, D., Magnanon, S., Valentin, B., Bjureke, K., Koopman, R., Vicens, M., Virevaire, M., Vanderborght, T., 2011. How successful are plant species reintroductions? Biological Conservation 144, 672-682.

Gosper, C.R., Coates, D.J., Hopper, S.D., Byrne, M., Yates, C.J., 2020a. The role of landscape history in the distribution and conservation of threatened flora in the Southwest Australian Floristic Region. Biological Journal of the Linnean Society.

Gosper, C.R., Kinloch, J., Coates, D.J., Byrne, M., Pitt, G., Yates, C.J., 2020b. Differential exposure and susceptibility to threats based on evolutionary history: how OCBIL theory informs flora conservation. Biological Journal of the Linnean Society.

Gosper, C.R., Prober, S.M., Yates, C.J., 2013. Estimating fire interval bounds using vital attributes: implications of uncertainty and among-population variability. Ecological Applications 23, 924-935.

Gosper, C.R., Prober, S.M., Yates, C.J., 2016. Continental-scale syntheses of Australian pyromes – misclassification of south-western eucalypt woodlands misinforms management. Journal of Biogeography 43, 858-861.

Gosper, C.R., Yates, C.J., Prober, S.M., Williams, M.R., 2011. Fire does not facilitate invasion by alien annual grasses in an infertile Australian agricultural landscape. Biological Invasions 13, 533-544.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., Ohlson, D., 2012. Structured decision making: a practical guide to environmental management choices. . Wiley-Blackwell.

Guerrant, E.O., 2012. Characterizing Two Decades of Rare Plant Reintroductions, in: Maschinski, J., Haskins, K.E., Raven, P.H. (Eds.), Plant Reintroduction in a Changing Climate: Promises and Perils. Island Press/Center for Resource Economics, Washington, DC, pp. 9-29.

Helmstedt, K.J., Possingham, H.P., Brennan, K.E.C., Rhodes, J.R., Bode, M., 2014. Cost-efficient fenced reserves for conservation: single large or two small? Ecological Applications 24, 1780-1792.

Hemming, V., Burgman, M.A., Hanea, A.M., McBride, M.F., Wintle, B.C., 2018a. A practical guide to structured expert elicitation using the IDEA protocol. Methods in Ecology and Evolution 9, 169-180.

Hemming, V., Walshe, T.V., Hanea, A.M., Fidler, F., Burgman, M.A., 2018b. Eliciting improved quantitative judgements using the IDEA protocol: A case study in natural resource management. PLOS ONE 13, e0198468.

Hobbs, R.J., Yates, C.J., 2003. Impacts of ecosystem fragmentation on plant populations: generalising the idiosyncratic. Australian Journal of Botany 51, 471-488.

Hopper, S.D., 2009. OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. Plant and Soil 322, 49-86.

Isaac, N.J.B., Turvey, S.T., Collen, B., Waterman, C., Baillie, J.E.M., 2007. Mammals on the EDGE: Conservation Priorities Based on Threat and Phylogeny. PLOS ONE 2, e296.

IUCN, 2012. IUCN Red List categories and criteria, version 3.1. IUCN Species Survival Commission.

IUCN Standards and Petitions Committee, 2019. Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. Prepared by the Standards and Petitions Committee. Downloadable from http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Joseph, L.N., Maloney, R.F., Possingham, H.P., 2009. Optimal Allocation of Resources among Threatened Species: a Project Prioritization Protocol. Conservation Biology 23, 328-338.

Krauss, S.L., Hermanutz, L., Hopper, S.D., Coates, D.J., 2007. Population-size effects on seeds and seedlings from fragmented eucalypt populations: implications for seed sourcing for ecological restoration. Australian Journal of Botany 55, 390-399.

Lamont, B.B., Connell, S.W., Bergl, S.M., 1991. Seed Bank and Population Dynamics of *Banksia cuneata*: The Role of Time, Fire, and Moisture. Botanical Gazette 152, 114-122.

Llorens, T.M., Byrne, M., Yates, C.J., Nistelberger, H.M., Coates, D.J., 2012. Evaluating the influence of different aspects of habitat fragmentation on mating patterns and pollen dispersal in the bird-pollinated Banksia sphaerocarpa var. caesia. Mol Ecol 21, 314-328.

Llorens, T.M., Yates, C.J., Byrne, M., Elliott, C.P., Sampson, J., Fairman, R., Macdonald, B., Coates, D.J., 2018. Altered Soil Properties Inhibit Fruit Set but Increase Progeny Performance for a Foundation Tree in a Highly Fragmented Landscape. Frontiers in Ecology and Evolution 6.

Llorens, T.M., Yates, C.J., Byrne, M., Nistelberger, H.M., Williams, M.R., Coates, D.J., 2013. Complex interactions between remnant shape and the mating system strongly influence reproductive output and progeny performance in fragmented populations of a bird-pollinated shrub. Biological Conservation 164, 129-139.

Louviere, J.J., Flynn, T.N., Marley, A.A.J., 2015. Best-Worst Scaling: Theory, Methods and Applications. Cambridge University Press, Cambridge.

Mace, G.M., Lande, R., 1991. Assessing Extinction Threats: Toward a Reevaluation of IUCN Threatened Species Categories. Conservation Biology 5, 148-157.

Menges, E.S., 2008. Restoration demography and genetics of plants: when is a translocation successful? Australian Journal of Botany 56, 187-196.

Merritt, D.J., Hay, F.R., Swarts, N.D., Sommerville, K.D., Dixon, K.W., 2014. Ex Situ Conservation and Cryopreservation of Orchid Germplasm. International Journal of Plant Sciences 175, 46-58.

Monks, L., Barrett, S., Beecham, B., Byrne, M., Chant, A., Coates, D., Cochrane, J.A., Crawford, A., Dillon, R., Yates, C., 2019. Recovery of threatened plant species and their habitats in the biodiversity hotspot of the Southwest Australian Floristic Region. Plant Diversity 41, 59-74.

Nevill, P.G., Tomlinson, S., Elliott, C.P., Espeland, E.K., Dixon, K.W., Merritt, D.J., 2016. Seed production areas for the global restoration challenge. Ecology and Evolution 6, 7490-7497.

OBPR, 2016. Guidance Note: Cost-Benefit Analysis. Office of Best Practice Regulation, Department of Prime Minister and Cabinet, Government of Australia.

Offord, C.A., Makinson, R.O., 2009. Options and major considerations for plant germplasm conservation, in: Offord, C.A., Meagher, P.F. (Eds.), Guidelines for germplasm conservation in Australia: Strategies and guidelines for developing, managing and utilising ex situ conservation collections. . Australian Network for Plant Conservation, Canberra, Australia, pp. 11-34.

Olde, P.M., Marriott, N.R., 1993. New species and taxonomic changes in Grevillea (Proteaceae : Grevilleoideae) from south west. Nuytsia 9, 237–304.

Parsons, B.C., Gosper, C.R., 2011. Contemporary fire regimes in a fragmented and an unfragmented landscape: implications for vegetation structure and persistence of the fire-sensitive malleefowl. International Journal of Wildland Fire 20, 184-194.

Pedrini, S., Gibson-Roy, P., Trivedi, C., Gálvez-Ramírez, C., Hardwick, K., Shaw, N., Frischie, S., Laverack, G., Dixon, K., 2020. Collection and production of native seeds for ecological restoration. Restoration Ecology 28, S228-S238.

Phillips, B., Beecham, B., Jolliffe, D., Crawford, A.D., 2016. Fire and the Wongan Hills: Determining fire return intervals for vegetation and Critically Endangered flora, in: Wildlife, D.o.P.a. (Ed.). Department of Parks and Wildlife.

Reiter, N., Whitfield, J., Pollard, G., Bedggood, W., Argall, M., Dixon, K., Davis, B., Swarts, N., 2016. Orchid re-introductions: an evaluation of success and ecological considerations using key comparative studies from Australia. Plant Ecology 217, 81-95.

Richardson, D.M., Hellmann, J.J., McLachlan, J.S., Sax, D.F., Schwartz, M.W., Gonzalez, P., Brennan, E.J., Camacho, A., Root, T.L., Sala, O.E., Schneider, S.H., Ashe, D.M., Clark, J.R., Early, R., Etterson, J.R., Fielder, E.D., Gill, J.L., Minteer, B.A., Polasky, S., Safford, H.D., Thompson, A.R., Vellend, M., 2009. Multidimensional evaluation of managed relocation. Proceedings of the National Academy of Sciences 106, 9721.

Sampson, J.F., Byrne, M., Gibson, N., Yates, C., 2016. Limiting inbreeding in disjunct and isolated populations of a woody shrub. Ecology and evolution 6, 5867-5880.

Sampson, J.F., Byrne, M., Yates, C.J., Gibson, N., Thavornkanlapachai, R., Stankowski, S., MacDonald, B., Bennett, I., 2014. Contemporary pollen-mediated gene immigration reflects the historical isolation of a rare, animal-pollinated shrub in a fragmented landscape. Heredity (Edinb) 112, 172-181.

Seaton, P.T., Hu, H., Perner, H., Pritchard, H.W., 2010. Ex Situ Conservation of Orchids in a Warming World. The Botanical Review 76, 193-203.

Shedley, E., Burrows, N., Yates, C.J., Coates, D.J., 2018. Using bioregional variation in fire history and fire response attributes as a basis for managing threatened flora in a fire-prone Mediterranean climate biodiversity hotspot. Australian Journal of Botany 66, 134-143.

Silcock, J.L., Fensham, R.J., 2018. Using evidence of decline and extinction risk to identify priority regions, habitats and threats for plant conservation in Australia. Australian Journal of Botany 66, 541-555.

Smith, M.G., Jones, A., 2018. Threatened and Priority Flora List, 5 December 2018. Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia.

Soulé, M.E., 1980. Thresholds for Survival: Maintaining Fitness and Evolutionary Potential, in: Soulé, M.E., Wilcox, B.M. (Eds.), Conservation Biology: An Evolutionary-Ecological Perspective. Sinauer Associates Inc., Sunderland, MA, USA, pp. 151-170.

Thavornkanlapachai, R., Mills, H.R., Ottewell, K., Dunlop, J., Sims, C., Morris, K., Donaldson, F., Kennington, W.J., 2019. Mixing Genetically and Morphologically Distinct Populations in Translocations: Asymmetrical Introgression in A Newly Established Population of the Boodie (Bettongia lesueur). Genes (Basel) 10.

TSX, 2020. The first Threatened Plant Index. Threatened Species Recovery Hub- National Environmental Science Programme, St Lucia, QLD, Australia.

Vose, D., 2008. Risk Analysis: A Quantitative Guide, 3rd Edition. John Wiley and Sons, Chichester.

Walck, J.L., Baskin, J.M., Baskin, C.C., Hidayati, S.N., 2005. Defining transient and persistent seed banks in species with pronounced seasonal dormancy and germination patterns. Seed Science Research 15, 189-196.

Yates, C.J., Broadhurst, L.M., 2002. Assessing limitations on population growth in two critically endangered Acacia taxa. Biological Conservation 108, 13-26.

Yates, C.J., Coates, D.J., Elliott, C., Byrne, M., 2007a. Composition of the pollinator community, pollination and the mating system for a shrub in fragments of species rich kwongan in south-west Western Australia. Biodiversity and Conservation 16, 1379-1395.

Yates, C.J., Ladd, P.G., Coates, D.J., McArthur, S., 2007b. Hierarchies of cause: understanding rarity in an endemic shrub Verticordia staminosa (Myrtaceae) with a highly restricted distribution. Australian Journal of Botany 55, 194-205.