DECISION SUPPORT FRAMEWORK FOR THE CONSERVATION TRANSLOCATION OF SARA-LISTED FRESHWATER FISHES AND MUSSELS

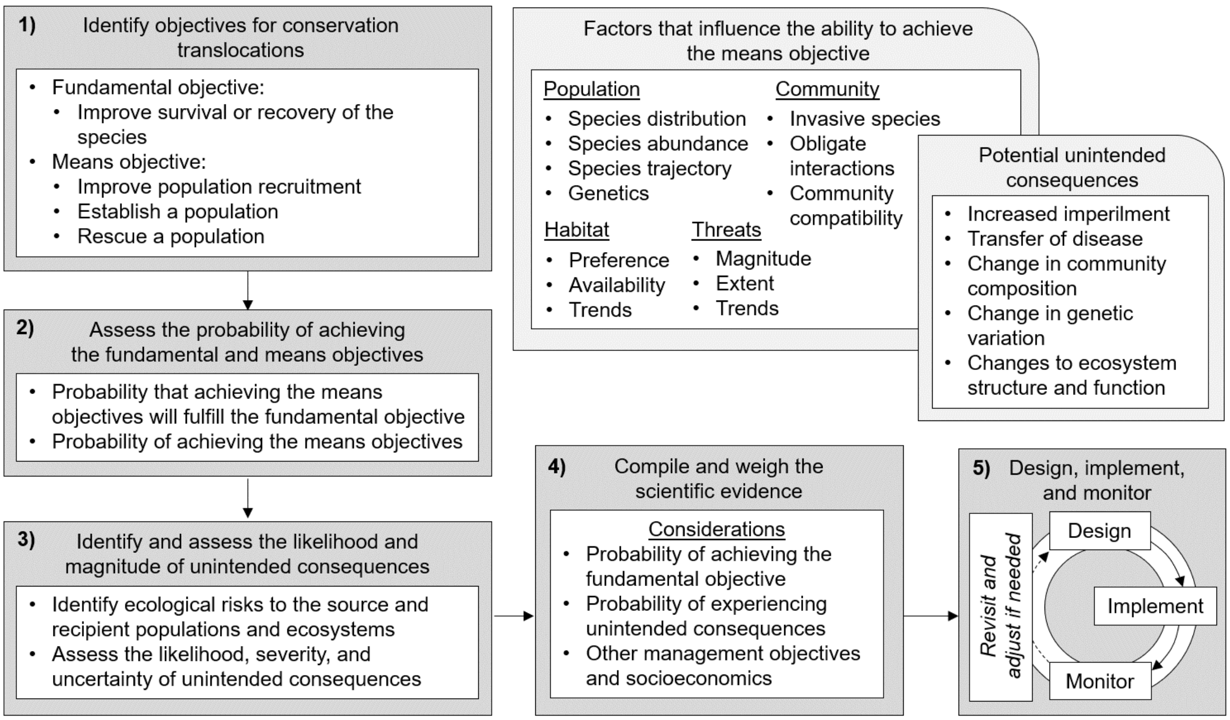

Figure 1. Decision support framework outlining science considerations for the use of conservation translocation as a tool to improve the survival or recovery of freshwater fish or mussel species listed under the Species at Risk Act (SARA 2002). The framework begins at the top left.

Context:

Under the Species at Risk Act (SARA), Fisheries and Oceans Canada must produce management plans and recovery strategies that describe the actions needed to protect SARA-listed aquatic species. For many SARA-listed species, conservation translocation has been identified in their management plans and recovery strategies as a potential action to improve survival or recovery. Science advice was requested to establish scientific guidelines for initiating conservation translocations in support of freshwater SARA-listed species management and recovery targets. Two objectives were identified for the meeting: 1) Identify and evaluate the potential benefits and risks of conservation translocation as a tool for improving the survival, recovery, or management of SARA-listed freshwater fish and mussel species; and, 2) Identify science-based considerations and methods for determining when conservation translocation could improve the survival, recovery, or management of SARA-listed freshwater fishes and mussels. The advice generated from this meeting will be used to help determine when conservation translocation is a suitable action for improving the survival or recovery of SARA-listed freshwater species.

This Science Advisory Report is from the October 19–22, 2021 National Peer Review meeting on Conservation translocations of SARA-listed freshwater fishes and mussels. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Conservation translocations are identified in many management plans and recovery strategies as potential tools for improving the survival or recovery of freshwater fish and mussel species listed under the *Species at Risk Act* (SARA). This document provides a general science-based decision support framework to help inform the potential use of conservation translocations in recovery planning.
- Conservation translocations include supplementation, reintroduction, mitigation translocation, and assisted colonization. They have been defined here as the act of intentionally moving individuals of a species with the aim of improving survival or recovery of a focal species.
- Increasing population recruitment, establishing a population, or rescuing a population from immediate extirpation are the three primary mechanisms by which conservation translocations may achieve improved survival or recovery of SARA-listed species.
- The decision support framework considers the potential ecological benefits to the focal species and the ability to achieve those benefits, relative to the ecological risks to the source and recipient populations of the focal species, as well as broader ecosystem components and processes.
- The five step decision support framework consists of:
    - Identification of objectives;
    - Assessing the probability of achieving the means and fundamental objectives;
    - Assessing the ecological risks;
    - Compiling and weighing scientific evidence to inform the decision; and,
    - Implementing and monitoring the effects.
- Conservation translocations can pose ecological risks to the focal species and broader ecosystem components in both the source and recipient habitats that include:
    - The loss of population persistence;
    - Loss or alteration of genetic variation;
    - Changes in community and ecosystem dynamics; and,
    - The potential for transmitting disease.
- Increased knowledge of population characteristics, species ecology, species habitat requirements and availability, community composition, and potential threats in, or to, the source and recipient locations reduces uncertainty and risk about the outcomes of conservation translocation.
- The science-based rationale for initiating conservation translocations should be informed by the potential ecological benefits and risks to SARA-listed freshwater fishes and mussels, relative to the risks to other ecosystem components.
- Given the uncertainties and limited implementation in Canada, when conservation translocations are pursued they should be considered in a long-term experimental context

and will require adaptability in implementation and robust monitoring to detect both intended and unintended outcomes, and modify or discontinue the translocation program, if needed.

- Context-specific protocols that consider the focal species and ecosystems under consideration must be established prior to implementing and monitoring conservation translocations, and remain flexible and adaptable both within the short-term and long-term for the duration of the program.
- This advice focuses on the ecological considerations for conservation translocations; given the experimental nature of these projects, a socio-economic analysis would also be required before implementation.

BACKGROUND

Federal recovery strategies and management plans for freshwater fish and mussel species listed under the *Species at Risk Act* (SARA) often identify conservation translocation as a potential approach for improving survival and/or recovery. Conservation translocations are defined here as the intentional movement of individuals of a species in an effort to achieve improved survival or recovery of a species, and include four primary approaches:

1. Species reintroduction is the intentional movement and release of an organism to a location inside its native range from which it has disappeared (IUCN/SSC 2013).
2. Supplementation is the intentional release of individuals of a focal species to an area presently occupied by conspecifics (Seddon et al. 2012).
3. Mitigation translocation is the human-mediated, intentional movement of individuals from an occupied location with the objective of reducing the inevitable effects of a development project on local biota (Germano et al. 2015).
4. Assisted colonization is the translocation of a species to favourable habitat beyond its native range to protect it from human-induced threats such as climate change (Ricciardi and Simberloff 2009).

Across all four conservation translocation approaches, individuals are intentionally moved from a source population to a recipient location within or outside the species' native range (Figure 2).

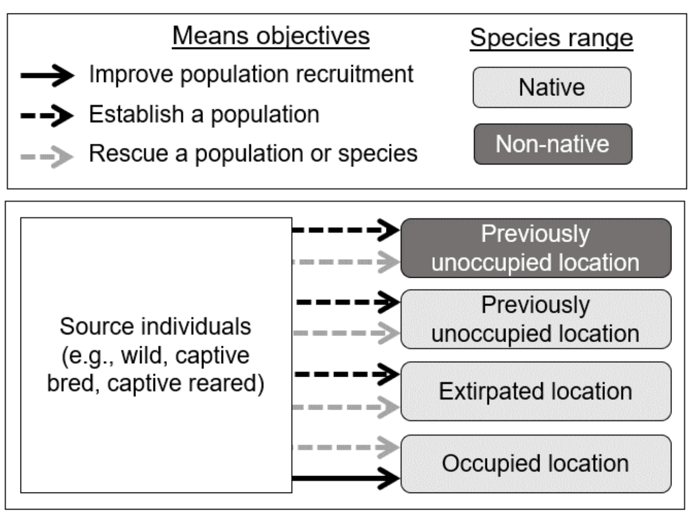

Figure 2. Means for conducting conservation translocations depending on the objective (means objective; arrow shade, type) and scale of intended movement (species range; box shade).

Although conservation translocation, specifically reintroduction or supplementation, are identified in approximately one-quarter of SARA-listed freshwater fish and mussel recovery strategies, management plans, or action plans, only a few species have been the subject of translocations (Lamothe and Drake 2019). Poor progress towards initiating conservation translocations has been partially the result of basic information gaps and concern that such gaps may limit translocation success, as certain SARA-listed species have only recently been the focus of dedicated monitoring and research (Drake et al. 2021). Adding to the lack of standard ecological information, limited progress has been driven by uncertainty about how to assess the potential ecological benefits and risks of proposed conservation translocation efforts.

In the absence of clear policy advice on when to initiate conservation translocation actions, decisions about whether conservation translocations should occur will be made on an ad-hoc, case-by-case basis. Such an approach may fail to identify situations in which conservation translocations would provide meaningful benefit to SARA-listed wildlife species, or alternatively, identify situations where a net benefit to the focal species is unlikely to be achieved. As such, two primary objectives are addressed:

1. Identify and evaluate the potential benefits and risks of conservation translocation as a tool for improving the survival, recovery, or management of SARA-listed freshwater fish and mussel species; and,
2. Identify science-based considerations and methods for determining when conservation translocation would be expected to improve the survival, recovery, or management of SARA-listed freshwater fishes and mussels.

These objectives are intended to help persons involved in species recovery planning and implementation make more robust and consistent decisions around the situations in which conservation translocations would be expected to improve the survival or recovery of SARA-listed species. Thus, information contained in this document will be useful at several stages of recovery planning, from drafting recovery strategies to identifying the information needed to implement translocations.

ASSESSMENT

Identifying the potential ecological benefits for species and ecosystems, as well the risks of negative ecological consequences, is needed when considering conservation translocation as a recovery measure. Figure 1 outlines a five-step decision support framework for evaluating whether conservation translocation would be expected to improve the survival or recovery of SARA-listed freshwater fishes and mussels while considering the risks to the focal species and broader ecosystem components. Below is a summary of each step to describe the process of identifying suitable candidate species, weighing the potential ecological benefits and risks, and implementing recovery actions.

Step 1) Identify objectives for conservation translocation

Determining whether a species should be considered for conservation translocation requires understanding the underlying motivations for the demand-driven action. The development of a problem statement, fundamental objective, and means objective(s) is the first step for using the decision support framework.

A problem statement is a concise description of the issue, setting the context for the decision-making process. This includes identifying the intended taxon for management and the temporal and spatial scale of management efforts.

Fundamental objectives reflect the broadest objectives that decision-makers and stakeholders value most. For all SARA-listed freshwater fishes and mussels, the fundamental objective of recovery actions under SARA (2002) is to improve the survival or recovery of the species.

There are three primary mechanisms, or means, by which the fundamental objective of improved survival or recovery can be achieved using conservation translocation. Described as the means objectives, three mechanisms for improving survival or recovery of species using conservation translocation are to:

1. Improve recruitment of extant populations;
2. Establish a population; or,
3. Rescue individuals or populations at imminent risk of extirpation.

Fulfilling the means objectives will have unique benefits for SARA-listed species that are dependent on the context of the species and its imperilment. A series of high-level questions are presented in Figure 3 that can help decide which means may be relevant to the focal species. For each path through the decision framework presented in Figure 3, more in-depth consideration of the ecological benefits and risks is required.

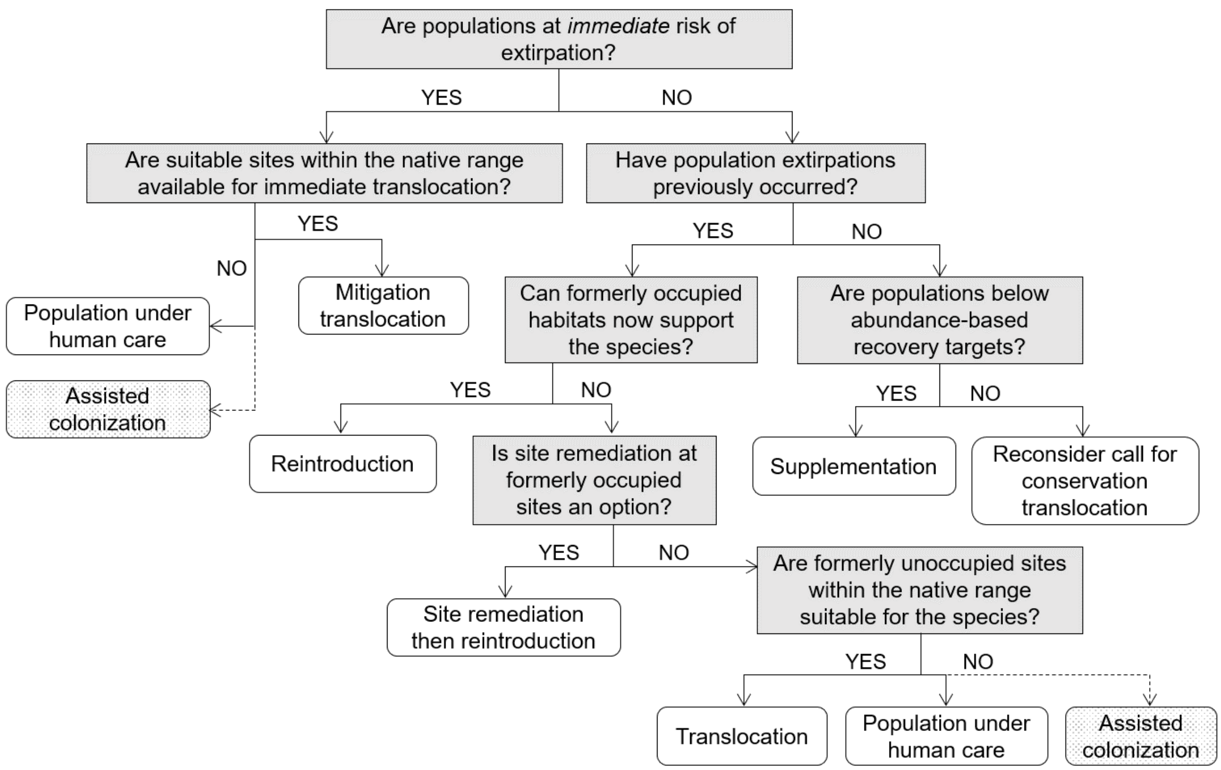

Figure 3. High-level decision framework for initial consideration of means objectives. Management actions are identified in white boxes and questions for the user are identified in grey boxes. Assisted colonization is hashed to identify this as a last resort option owing to greater potential for ecological risks. Note that each path through the decision framework requires extensive consideration of ecological benefits and risks.

Step 2) Assess the probability of achieving the fundamental objective

After describing the context of imperilment and identifying the fundamental and means objectives for the focal species, the next steps are to assess the probability that achieving the means objective will improve survival or recovery of the species and to assess the probability of achieving the means objective. Assessing the probability that achieving the means objective will fulfill the fundamental objective requires identifying how removals will change the viability of source populations, the degree to which translocated individuals will improve species viability at the recipient location, and the degree to which the establishment of a new population or improved recruitment of an existing population will improve the viability of species relative to the change in viability from removals from the source population(s).

2.1) Assessing the probability that achieving the means objective will fulfill the fundamental objective

Improving survival or recovery of SARA-listed species using conservation translocation can be achieved in multiple ways (i.e., three means objectives), but ultimately, each approach can be broadly linked to the need to attain long-term viability of the species in the wild (Figure 4). Developing this quantitative understanding is difficult for SARA-listed freshwater fishes and mussels and requires species and habitat data, which can come from laboratory or field studies, along with simulations and modelling approaches.

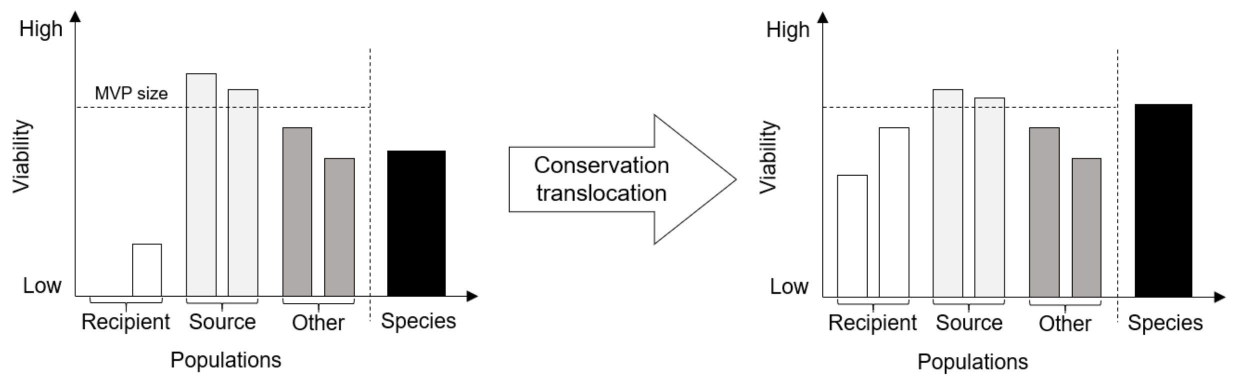

Figure 4. Conceptual assessment of the ability of the means objective to fulfill the fundamental objective of improved survival or recovery of the species. Metrics for assessing viability are measured before and after translocations for the recipient, source, and other (e.g., reference) remaining populations. MVP = minimum viable population. In this example, reintroduction and supplementation are performed for two recipient populations from two source populations.

Simulations can demonstrate how the number of populations, and the persistence of those populations, affects overall long-term species viability. For example, the probability of species extinction (P_{Sp}) can be estimated as a function of the total number of populations (n), the persistence of each population ($P_{pop,i}$; extirpation probability for population i), and the correlation matrix between the persistence of populations ($\boldsymbol{\rho}$):

$$P_{Sp} = \prod_{i=1}^{n} P_{pop,i}^{\frac{n}{\mathbf{d}^{\mathsf{T}}\boldsymbol{\rho}\mathbf{d}}}$$

(Figure 5; van der Lee and Koops 2020). For a species with 10 populations, where each population has a 5% probability of extirpation that is independent from other populations, the probability of species extinction is calculated as the product of the 10 probabilities; reduce the number of populations to two and the probability of species extinction drastically increases (Figure 5a). Incorporating correlation structure in the probability of extirpation among populations increases the probability of species extinction relative to independent populations (Figure 5b, c). Populations typically share sensitivities to particular threats or may be geographically close and, therefore, if a threat were to cause extirpation in one population, a positively correlated extirpation probability would suggest that a second population is now more likely to be extirpated than originally estimated based on the hypothesis of independence. An assessment of current and future threats, geographic proximity, and environmental stochasticity among populations can help inform the most suitable correlation structure for the focal species.

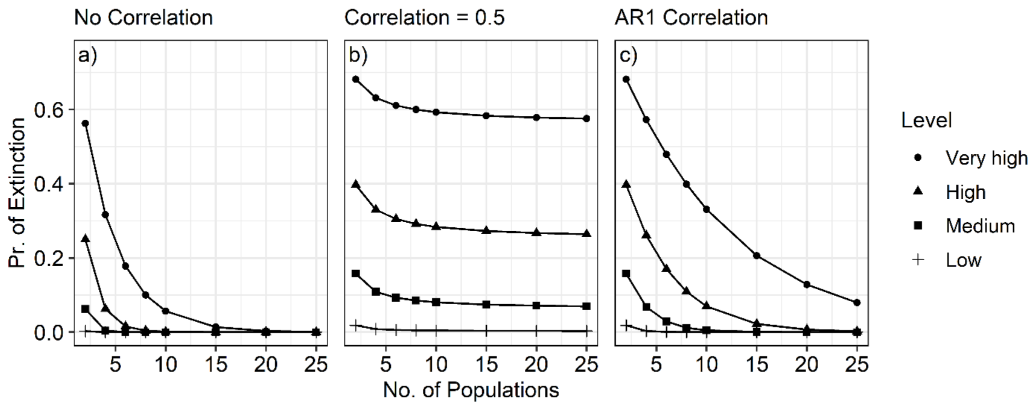

Figure 5. Hypothetical probabilities of species extinction (y-axis). Individual plots represent different correlation structures of extirpation probabilities across populations, including a) no correlation, b) correlation = 0.5, and c) spatial correlation (first-order autoregressive model; AR1). Population-level extirpation probabilities are depicted as low (P_{pop} = 0.05), medium (P_{pop} = 0.25), high (P_{pop} = 0.50), and very high (P_{pop} = 0.75). The true shape of this relationship and correlation structure is typically unknown and will vary among species.

Along with simulations, population viability analysis is a tool that can be used to estimate the effects of adding or removing individuals on recipient and source populations. A study by Fisheries and Oceans Canada (Lamothe et al. 2021) used population viability analysis to evaluate scenarios for re-establishing an Eastern Sand Darter (*Ammocrypta pellucida*) population in Ontario. Each scenario was considered based on its risk of causing source population extirpation against the probability of success, where success was defined as the persistence of a reintroduced population with an abundance greater than the estimated minimum viable population size over the last 15 years of the simulation. For example, considering a high rate of translocation mortality (70%), the potential for Allee effects, and a population growth rate in the recipient habitat of 2.13, it was estimated that approximately 550 individuals would need to be removed and translocated pre-spawn for five years from a source population of 20,000 individuals to achieve reintroduction success with a low probability of source population extirpation (≤ 1%). If population growth rate in the recipient habitat was equal to 1.56, 863 individuals would need to be removed annually and translocated for five years from a source population of nearly 50,000 individuals to achieve the thresholds of ≥ 90% probability of successful establishment and ≤ 1% probability of extirpation of the source population.

2.2) Factors influencing the ability to achieve the means objectives

There are many factors that can influence the ability to achieve the means objectives and, therefore, fulfill the fundamental objective of improved survival and recovery for the species.

These factors can be broadly grouped into four categories: population, habitat, community, and threat considerations.

Populations can have unique responses to conservation translocations, which can therefore affect the ability to achieve the means objectives. In some instances, there will be few, or only one, option for selecting a source population(s), whereas in other scenarios, there may be several. When multiple populations are available, consideration is needed regarding the potentially unique responses to conservation translocations that individual populations may have. Three related, high-level approaches have been suggested for selecting source populations that require knowledge of species habitat requirements: ancestry matching, environmental matching, and the use of adaptive potential (Figure 6; Houde et al. 2015). Ancestry matching, which is generally the most preferred approach, describes the selection of source populations that share genetic similarity to the extant or historically present population. Ancestry matching is the most commonly recommended approach in the species restoration literature (Krueger et al. 1981; Meffe 1995; Houde et al 2015), and relies on the assumption that recent shared ancestry also infers similar adaptations (Moritz 1999). Environmental matching describes the selection of a source population(s) based on the similarity of habitat conditions between recipient and source locations, following a similar logic as the ancestry matching approach. Finally, the adaptive potential approach seeks to translocate individuals from multiple populations to provide the best potential to adapt to conditions at the recipient site. Generally, an ancestry matching approach is considered the most likely to succeed with the least uncertainty, whereas environmental matching and the use of adaptive potential should only be considered when an ancestral match no longer exists (Figure 6).

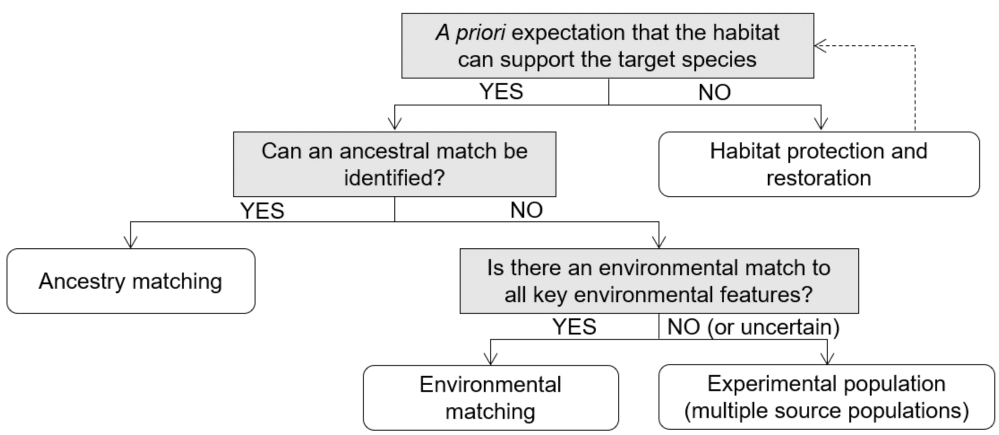

Figure 6. A source population selection framework for conservation translocation that requires knowledge of abiotic and biotic requirements for the species being considered for translocation.

A sufficient quantity of productive habitat for a species is needed when considering conservation translocation efforts. Failing to translocate individuals to areas with optimal habitat reduces the probability of survival for translocated individuals and, therefore, reduces the likelihood of achieving the means objective. As defined under SARA (2002), habitat for aquatic species includes all spawning grounds, areas for nursery, rearing, food supply, migration, and any other areas on which aquatic species depend directly or indirectly to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced. Moreover, microhabitats are an important consideration for SARA-listed freshwater fish and mussel species, and for their obligate host species, which may rely on particular microhabitat features. Improvements in data availability and computing technology over the last few decades have led to the development of predictive models for estimating species distributions based on multiple measured and projected spatial and environmental predictors (Elith and Leathwick 2009) that can be used for evaluating the availability of suitable sites for translocation, how site conditions and distributions might change over time, or, potentially, areas where the species has yet to be detected.

The biotic composition of recipient ecosystems can influence the likelihood that conservation translocations achieve their intended outcomes of improved survival or recovery (i.e., Figure 4). Understanding the significant biotic interactions for candidate species can help ensure that recipient sites meet biotic expectations. Interactions between species can broadly be described as negative, including parasitism, competition, predation, amensalism, or hybridization, or positive, including mutualism or commensalism. The probability of achieving the means objectives should be informed by the potential effects of interspecific biotic interactions, particularly when considering reintroduction, mitigation translocation, or assisted colonization. The goal of exploring species interactions is to rationalize the suitability of the biotic community for the translocation of individuals. There is an increased probability of achieving the means objective at recipient sites when species composition reflects expectations from extant, thriving populations or suspected biotic composition prior to species reduction or extirpation. Alternatively, a heightened presence of negatively associated species, or the lack of obligate or beneficial interactions, can restrict the ability to achieve improvements in recruitment, establish a population, or rescue the species, therefore limiting the ability to achieve the fundamental objective.

The most frequently cited reason for unsuccessful conservation translocations is failure to reduce or eliminate the original cause of species reduction or extirpation (Armstrong and Seddon 2008; Cochran-Biederman et al. 2014). There is a need to assess how current and future threats could influence the viability of source and translocated individuals, and therefore, how threats may affect the probability of achieving the means objectives for the species (Figure 4). Threats to the survival and recovery of freshwater fishes and mussels in Canada have been well-described and include habitat degradation and destruction, flow modifications, invasive species, and pollution, among others (Dextrase and Mandrak 2006; Dudgeon et al. 2006; Reid et al. 2019). Threat summaries in species recovery strategies, recovery potential assessments, management plans, and COSEWIC (Committee on the Status of Endangered Wildlife in Canada) reports can provide information on the relative influence of stressors on populations and species.

2.3) Estimate the ability to achieve the means objectives

In this step, the potential influence of confounding factors on the likelihood of achieving the means objectives is assessed based on best available data and knowledge (i.e., evidence). Sources of evidence include observations from monitoring programs, field and laboratory experiments, the scientific literature, management and recovery documents, existing assessments, and expert opinion (Karasov-Olson et al. 2021).

Table 1 provides a series of considerations that can each be assigned a likelihood for achieving the means objective. Given the general data limitations for SARA-listed freshwater fishes and mussels, a qualitative approach for scoring the influence (or likelihood) of factors on achieving the means objective is presented that considers the uncertainty associated with a factor based on the available evidence. The likelihood of achieving the means objective can be categorized as low, medium, high, or unknown for each row in Table 1. The definitions of each level will depend on the factor being considered. For example, the likelihood of achieving the means objective when considering Row 1, “*abundance of the source population is suitable to achieve the means objective*,” might be characterized as:

- **Low**: There are few reproducing adults in the source population. Removing individuals could threaten the persistence of the source population, and given the few individuals, may not be successful in achieving the means objective at the recipient location;
- **Medium**: Source population abundance is coarsely described, but suggests enough removals can be performed to achieve the means objective in the recipient habitat;
- **High**: Source population abundance is well-described with a sufficient number of breeding individuals and is capable of withstanding removals for translocations; or,
- **Unknown:** Information on source population abundance is insufficient for informing likelihood estimates.

Table 2. Considerations for evaluating the ability to achieve the means objective using conservation translocation. For each row, a likelihood of achieving the means objective is assigned (low, medium, high, unknown) and the evidence strength (limited, medium, robust), agreement between evidence sources (low, medium, high), and overall confidence in that likelihood assignment are scored. Confidence is the outcome of the evidence strength and agreement scores.

***Focal species**:*
***Problem statement**:*
***Fundamental objective**:*
***Means objective**:*

Category	*Factors*	*Likelihood*	*Evidence Strength*	*Agreement*	*Confidence*	*References*	*Additional considerations*
Population considerations	Abundance of the source population is suitable to achieve the means objective	-	-	-	-	-	-
	Age-structure of the source population is suitable to achieve the means objective	-	-	-	-	-	-
	Genetic diversity and variation of the source population is suitable to achieve the means objective	-	-	-	-	-	-
	Genetic diversity and variation of the recipient population is suitable to achieve the means objective	-	-	-	-	-	-
	Life-history strategy of the source population is suitable to achieve the means objective	-	-	-	-	-	-
	Captive breeding or captive rearing techniques are available to achieve the means objective	-	-	-	-	-	-
Habitat	Habitat in the recipient site(s) reflect species requirements (e.g., water clarity, water velocity, depth, vegetation, substrate)	-	-	-	-	-	-
	A sufficient quantity of habitat exists in the recipient location to support all life-stages	-	-	-	-	-	-
	Sufficient connectivity exists in the recipient habitat to support all life-stages	-	-	-	-	-	-
Community considerations	Obligate, facultative, or parasitic species dependencies limit the ability to achieve the means objective	-	-	-	-	-	-
Threats	Pertinent threats limit the ability to achieve the means objective, including:	-	-	-	-	-	-
	Invasive species	-	-	-	-	-	-
	Residential and commercial development	-	-	-	-	-	-
	Agriculture and aquaculture	-	-	-	-	-	-
	Energy production and mining	-	-	-	-	-	-
	Biological resource use	-	-	-	-	-	-
	Transportation and service corridors	-	-	-	-	-	-
	Human intrusions and disturbance	-	-	-	-	-	-

Category	*Factors*	*Likelihood*	*Evidence Strength*	*Agreement*	*Confidence*	*References*	*Additional considerations*
Threats (cont.)	Natural systems modification	-	-	-	-	-	-
	Pollution	-	-	-	-	-	-
	Geological events	-	-	-	-	-	-
	Parasites or disease transfer	-	-	-	-	-	-
	Future habitat modification or degradation	-	-	-	-	-	-
	Climate change	-	-	-	-	-	-
	Other factors	-	-	-	-	-	-

Confidence in the anticipated effects of the factors outlined in each row of Table 1 is based on the type, quality, and quantity of evidence sources and the agreement between sources (Figure 7). Evidence can be described as limited, medium, or robust, where sources of information are in low, medium, or high agreement (Figure 7). Confidence in the influence of a factor on achieving the means objective increases with increasing quality and quantity of evidence and agreement between sources of evidence (Figure 7).

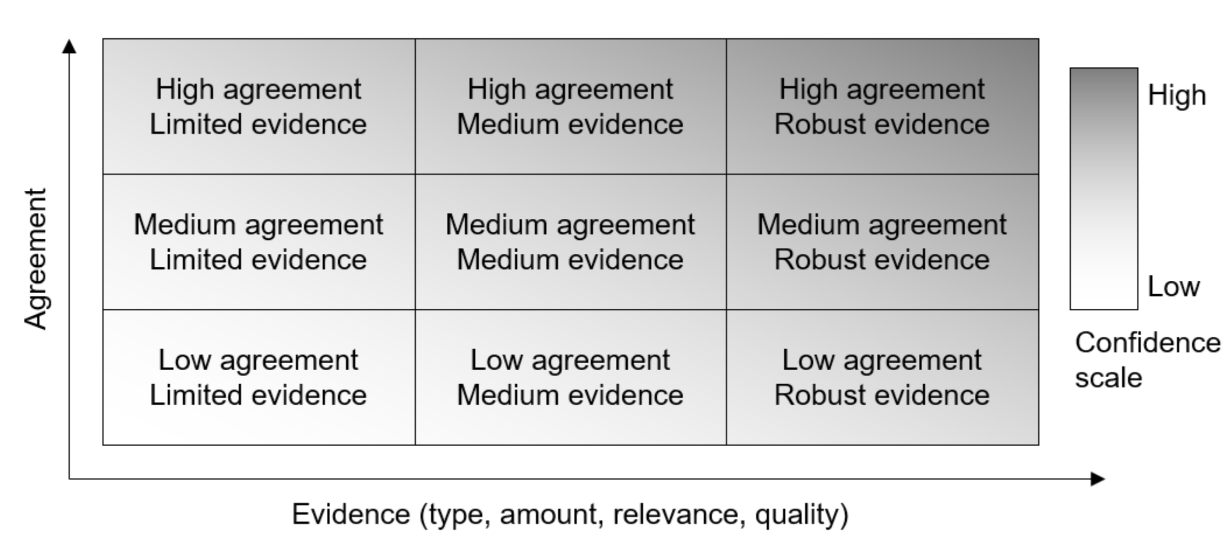

Figure 7. Conceptual framework describing confidence in the evidence for predicting the potential effects of risk factors when performing conservation translocations. Confidence increases with the quality and quantity of evidence and the agreement of that evidence. Modified figure originally presented in IPCC (2013) and later adapted in Karasov-Olson et al. (2021).

Continuing with the example, evidence for assessing if "*abundance of the source population is suitable to achieve the means objective*" could be described as:

- **Limited**: No primary literature or data from local monitoring efforts on population abundance;
- **Medium**: Some data available on population abundance from local monitoring or experiments. Data could be outdated; or,
- **Robust**: Recent data from monitoring efforts and several scientific articles in the primary and grey literature.

The agreement between sources of information can be then be characterized as:

- **Low**: Sources describe contradictory findings;
- **Medium**: Sources describe similar findings, but with differing magnitudes of effects; or,
- **High**: Sources are consistent with findings.

For each row in Table 1, evidence is compiled, reviewed, evaluated, and a likelihood is assigned. Ultimately, Table 1 should be used to qualify the potential improvement in survival or recovery when performing conservation translocations. This evaluation of the ability to achieve the means objective will be used in Step 4 for making a decision, where the potential benefits of achieving the means and fundamental objectives are weighed against the potential risks of unintended consequences.

Step 3) Assess the ecological risks of performing conservation translocations

Although conservation translocation is intended to benefit SARA-listed freshwater fishes and mussels, translocation could result in negative consequences (i.e., ecological risks) on the focal species or other ecosystem components. The scale of the potential consequences can vary from short-term, or systemically minor, to systemically transformative with consequences occurring within or beyond the site of translocation. Moreover, unintended negative consequences of conservation translocations could be experienced by other ecosystem components even when the fundamental objective of improved survival or recovery of the SARA-listed species is achieved.

3.1) Identify the ecological risks of performing conservation translocations

The ecological risks of conservation translocations include:

- The potential reduction in source population persistence;
- Change in source population genetic variation;
- Change in recipient population genetic variation and persistence;
- Change in short- and long-term community and ecosystem dynamics in the source and recipient ecosystems; and,
- The transfer of disease between populations and ecosystems.

3.1.1) Reduction in source population persistence

The worst possible outcome of a conservation translocation for the source population is extirpation. Therefore, understanding how the number and frequency of individuals removed from source populations will affect population persistence is a critical step prior to initiating translocation efforts. Consistent with advice regarding allowable harm of species (DFO 2004; Vélez-Espino and Koops 2009), removals of individuals to supplement populations should not jeopardize the survival or recovery of the SARA-listed species and, therefore, should only occur from robust (i.e., growing or large) populations. Removing too many individuals from a source population could immediately threaten long-term source population persistence. Moreover, a small population size resulting from excessive removals for translocations increases the potential for genetic effects, potentially reducing adaptive potential of wild source populations (expanded in the next section). Removing too few individuals from a source population, however, could lead to failed translocations in the recipient habitat while imposing unnecessary harm to the source population and, by extension, the species. If significant removals are expected to harm the source population, captive breeding or rearing can be considered to reduce impacts of removals on source populations.

3.1.2) Change in source population genetic variation

Maintaining or enhancing local genetic diversity and quality is a priority for conservation translocation efforts. Sourcing individuals from the wild for conservation translocations risks the loss of source genetic variation, particularly when important breeding individuals or large numbers of individuals are removed from relatively small populations (a concern for most SARA-listed species). Rates of mating between closely related individuals can become elevated if too many individuals are removed from the wild, threatening inbreeding depression among the individuals remaining in the source habitat, and possibly reducing long-term adaptive potential. Inbreeding depression describes the relative reduction in fitness of offspring resulting from the mating of closely related individuals compared to those of randomly mated individuals (Hedrick and Kalinowski 2000). Inbreeding can increase the probability of potentially deleterious mutations being present together within populations, thus resulting in reduced fitness. A literature on the effects of inbreeding and how to avoid these effects has been developed (e.g., Ryman and Laikre 1991; Wang et al. 2002; Neff et al. 2011; Rollinson et al. 2014). This literature is particularly relevant when considering the use of captive breeding for sourcing conservation translocations. Overall, it is unlikely that removals of individuals from the source population will lead to inbreeding unless source population abundance or genetic variation is low, emphasizing the need to assess population abundance and genetic diversity prior to removals.

3.1.3) Change in recipient population genetic variation and persistence

Genetic concerns for recipient populations are primarily related to the issues with a small founding population when performing reintroductions or assisted colonization, and the mixing of previously disconnected gene pools when performing supplementation or if the introduced individuals disperse from the site of introduction. The founder effect describes the reduction in genetic variation incurred as a result of re-establishing a population with a small number of individuals unrepresentative of the species pool. Multiple small translocations of randomly selected (or stratified random selection), unrelated individuals with sufficient genetic diversity from the source to recipient location can reduce the likelihood of experiencing founder effects.

Supplementation can lead to other genetic consequences such as outbreeding depression, and demographic and genetic swamping, resulting from the crossing of individuals from two genetically distinct populations. This is likely to reduce fitness for the recipient population. The probability of experiencing outbreeding depression increases with divergence of parental populations and when individuals are translocated to environments with conditions dissimilar to the source habitat. Based on species generation times and the glacial history of Canada, outbreeding depression is unlikely to occur when translocating wild freshwater fish or mussels (in contrast to certain anadromous fishes), but is of particular concern when wild individuals mate with individuals bred in captivity. Domestication selection is a common and particularly challenging problem when raising animals in captivity, with supplemented populations often demonstrating reductions in effective population size (Lennox et al. 2021; Milla et al. 2021). Although genetic diversity can often be maintained for species bred in captivity (e.g., DFO 2018; Vachon et al. 2019), phenotypic variation can lead to observed differences between wild and captive-bred individuals in reproduction and survival post-translocation. These observed differences highlight the urgency of conserving wild populations to avoid the need for captive breeding and release.

3.1.4) Change in community and ecosystem dynamics in source and recipient ecosystems

All species play a functional role in local ecosystem conditions, and the removal or introduction of individuals could lead to alterations in community and ecosystem dynamics. For example, the effects of predator removal from an ecosystem are well-documented, including changes in the dominant species (Stantial et al. 2021) and shifts in food webs (Sieben et al. 2011). Similarly, many studies have documented the effects of recreational or commercial freshwater fish introductions to formerly unoccupied areas (e.g., Sundlund et al. 2013), which tend to be top predators. The likelihood of changes to the source and recipient community will partly be influenced by the magnitude of removals for translocation and the ecological naivety of the recipient community to the translocated species.

3.1.5) Transfer of disease to between populations and ecosystems

Recipient and source locations involved in conservation translocations could be at risk of the accidental introduction of non-native parasites and pathogens. The Government of Canada (2017) has a National Code on Introductions and Transfers of Aquatic Organisms that provides an "*objective decision-making framework and consistent national process for assessing and managing the potential ecological, disease, and genetic risks associated with intentionally moving live aquatic organisms into, between, or within Canadian watersheds and fish rearing facilities*" and requires a risk assessment of disease transfer. As a general rule, risk assessments should begin early and be reviewed periodically (IUCN/SSC 2013).

3.2) Estimate the risk of performing conservation translocations

In the present step, the potential risks of conservation translocations to focal and non-focal species and ecosystems are evaluated and scored based on their expected probability and magnitude of effects in the source and recipient habitat. Similar to the approach for assessing the likelihood of factors influencing the ability to achieve the means objective (i.e., Table 1), a qualitative approach is recommended in data-limited situations for assessing the likelihood and magnitude of risk to source and recipient populations and ecosystems. Such an approach can incorporate qualitative evidence or can be fully quantitative when suitable information is available. Table 2 provides an overview of the risks that should be evaluated for a given conservation translocation based on their expected likelihood and magnitude of effects in the source and recipient habitats (*sensu* Karasov-Olson et al. 2021).

Table 1. Ecological risk considerations for the focal taxa and other ecosystem components in source and recipient habitats of proposed conservation translocations. For each row, the likelihood and magnitude of risk (low, medium, high, unknown), evidence strength (limited, medium, robust), agreement between evidence sources (low, medium, high), and overall confidence are scored. Focal = focal taxa being considered for conservation translocation. Other = other ecosystem components.

Subject	*Location*	*Risk category*	*Risk outcome*	*Risk likelihood*	*Risk magnitude*	*Evidence strength*	*Agreement*	*Confidence*	*References*	*Additional considerations*
Focal	Source	Population persistence	Reduced or altered population abundance	-	-	-	-	-	-	-
Focal	Source	Genetic variation	Altered genetic variation	-	-	-	-	-	-	-
Focal	Source	Genetic variation	Inbreeding depression	-	-	-	-	-	-	-
Focal	Recipient	Population persistence	Individual mortality	-	-	-	-	-	-	-
Focal	Recipient	Genetic variation	Founder effect	-	-	-	-	-	-	-
Focal	Recipient	Genetic variation	Outbreeding depression	-	-	-	-	-	-	-
Focal	Recipient	Genetic variation	Hybridization	-	-	-	-	-	-	-
Other	Source	Community and ecosystem dynamics	Increased negative interactions	-	-	-	-	-	-	-
Other	Source	Community and ecosystem dynamics	Reduced positive interactions	-	-	-	-	-	-	-
Other	Source	Community and ecosystem dynamics	Reduced habitat availability	-	-	-	-	-	-	-
Other	Source	Community and ecosystem dynamics	Altered ecosystem processes	-	-	-	-	-	-	-
Other	Recipient	Community and ecosystem dynamics	Enhanced negative interactions	-	-	-	-	-	-	-
Other	Recipient	Community and ecosystem dynamics	Reduced positive interactions	-	-	-	-	-	-	-
Other	Recipient	Community and ecosystem dynamics	Transformative changes within site of introduction	-	-	-	-	-	-	-

Subject	*Location*	*Risk category*	*Risk outcome*	*Risk likelihood*	*Risk magnitude*	*Evidence strength*	*Agreement*	*Confidence*	*References*	*Additional considerations*
Other	Recipient	Community and ecosystem dynamics	Transformative changes beyond site of introduction	-	-	-	-	-	-	-
Other	Recipient	Community and ecosystem dynamics	Reduced habitat availability	-	-	-	-	-	-	-
All	Both	Disease transfer	Individual mortality / reductions in fitness	-	-	-	-	-	-	-

Risk likelihood and magnitude can be categorized as low, medium, high, or unknown, with definitions based on the risk factor being considered (Table 2). For example, the likelihood associated with "*reduced population abundance*" for the source population might be characterized as:

- **Low**: Low probability of reducing source population abundance. No risk of source population extirpation;
- **Medium**: Medium probability of reducing source population abundance. Low probability of source population extirpation;
- **High**: High probability of reducing source population abundance. Moderate probability of source population extirpation; or,
- **Unknown**: No information available on the potential for reducing source population abundance.

Similarly, the magnitude associated with "*reduced population abundance*" for the source population might be characterized as:

- **Low**: Small reduction in abundance. No risk of source population extirpation;
- **Medium**: Medium reduction in abundance. Small increase in the probability of source population extirpation;
- **High**: Large reduction in abundance. Moderate increase in the probability of source population extirpation; or,
- **Unknown**: No information available on the potential magnitude of reduced source population abundance.

Continuing with the example, evidence for the likelihood and magnitude of "*reduced population abundance*" for the source population could be characterized as:

- **Limited**: No primary literature or data from local monitoring efforts. Evidence available from related species and expert opinion;
- **Medium**: A few correlative scientific articles in the primary literature relevant to the species. Limited data available from local monitoring or experiments; or,
- **Robust**: Several scientific articles in the primary literature as well as a thorough grey literature. Data from local monitoring programs and experiments are available.

The agreement between sources of information can then be characterized as:

- **Low**: Sources describe contradictory findings;
- **Medium**: Sources describe similar findings, but with differing magnitudes of effects; or,
- **High**: Sources are consistent with findings.

Finally, confidence can be assessed for each ecological risk outcome (Figure 7). Ultimately, for each row in the risk table, evidence is compiled, reviewed, and evaluated, with risk levels assigned. However, a final step is to consider the expected improvement in survival or recovery of the species against the potential risks, other fishery and ecosystem management objectives, and a parallel socioeconomic assessment, which are described in Step 4.

Step 4) Compile and weigh scientific evidence to inform the conservation translocation decision

In Step 4, the compiled evidence is used to decide whether the anticipated improvement in survival or recovery of the SARA-listed freshwater fish or mussel species resulting from conservation translocation (Figure 1; Table 1), outweighs the ecological risks to the focal species and other ecosystem components (Table 2). A three-step process is recommended for making this decision that sequentially considers risks to 1) the focal species, 2) other ecosystem components, 3) and other management objectives.

First, a decision should be made on whether the benefits of conservation translocation, which are evaluated as the probability that achieving the means objective fulfills the fundamental objective, and the probability of achieving the means objective, outweigh the risks to the SARA-listed freshwater fish or mussel species (Table 2). Certain risks, for example the removal of individuals from a source population, directly influence the ability to improve survival and recovery of the focal species, and thus can be evaluated in terms of the net expected outcome for the species. Other factors, such as genetic considerations, may be more difficult to evaluate in terms of their role in achieving a short- or long-term net benefit for the species. Only once the anticipated benefits of conservation translocation have been recognized as outweighing the potential risks to the focal species should the risks to other ecosystem components be considered (Table 2). The completion of Tables 1 and 2 will provide important summary information to aid the evaluation of net benefit to the SARA-listed species.

Quantifying risks to other ecosystem components and processes and weighing those risks against the anticipated improvement in survival or recovery of the focal species resulting from conservation translocations requires a careful evaluation of other management objectives that are potentially influenced by the conservation translocation, and the perceived importance of those management objectives relative to the goal of improved survival or recovery of the SARA-listed species. It may be the case that the improvement in survival or recovery of SARA-listed species occurs with little influence on other management objectives, resulting in relatively clear ecological outcomes and straightforward management decisions. Alternatively, achieving improved survival or recovery of SARA-listed species may result in reduced ability to achieve other management goals, implying that weighting of all pertinent management goals and potential outcomes (SARA-related and otherwise) is needed before a decision on the conservation translocation can be made. In such cases, structured decision-making approaches can help identify the perceived importance of each objective, the relevant uncertainties, and, when competing objectives exist, provide clearer opportunities for decision-making.

Ultimately, an understanding of 1) whether fulfilling the means objective will achieve the fundamental objective, 2) the probability of achieving the means objective (Table 1), and 3) the probability of unintended consequences (Table 2), coupled with broader approaches for evaluating multiple management objectives (i.e., structured decision-making), can inform the decision of whether to move forward with conservation translocation as a recovery strategy for SARA-listed freshwater fishes or mussels.

Step 5) Implement and monitor the effects of conservation translocations

If the decision is made to perform conservation translocations, protocols must be established for how they will be implemented and for the monitoring programs designed to document changes to the focal species, non-focal species, and other ecosystem components (Figure 1). Given the early identification of the means objectives, source population selection, and the number and frequency of translocations needed to improve survival or recovery estimated in Step 2, protocols can be confirmed as feasible and implemented, while considering any logistical constraints.

Conservation translocations of SARA-listed freshwater fish and mussel species are long-term ecosystem restoration experiments that must be carefully designed, documented, and monitored. Experimentation describes the process of using the scientific method to test hypotheses and learn from the results. Taking an adaptive approach to the experimental design and implementation of conservation translocation can be beneficial as it requires recurring (e.g., annual) evaluation of translocation protocols and allows experimental design to be revisited, or terminated, when implementation is not producing the expected results. Identifying when to stop translocation efforts is an important decision when planning conservation translocations, as the risk of unintended consequences increases over time (IUCN/SSC 2013). Although monitoring of the effects of conservation translocations must continue over long time frames (i.e., multiple generations; many years to decades), supplementing or reintroducing wildlife species should be considered relatively short-term actions.

For any species recovery action, monitoring of outcomes (intended and unintended) and documenting decisions related to implementation are critical. Well-designed monitoring programs for measuring the effects of conservation translocations must ensure an adequate number of sampling sites and frequency of sampling in source and recipient locations to ensure conclusions are made with sufficient statistical power. There are many attributes of conservation translocations that can be measured to define success, but all should relate back to the intended means objective and fundamental objective of improved survival or recovery. Common metrics for evaluating the effects of conservation translocations include changes in population abundance and genetic variation, changes in size-structure or physiological metrics, or increased rates of survival, spawning, and (or) recruitment at the recipient site. Ultimately, metrics for evaluating conservation translocation actions should consider the outcome of a conservation translocation over time for the recipient population, the source population, and the overall species (Figure 6) relative to some historical information (i.e., before-after), reference location (i.e., control-impact), or ideally both (i.e., before-after control-impact).

There are inevitable complications and logistical constraints when implementing field-oriented restoration or management actions. Logistical constraints can range from the ability to acquire a sufficient number of individuals to implement the translocation to the methods available for transporting individuals between source and recipient locations. In some instances, such as when source populations are very small, captive breeding or rearing approaches will be needed to supply an adequate number of individuals for translocation, which requires significant investment in infrastructure. For example, there are only a few facilities in Canada that can support the propagation and rearing of warm-water SARA-listed fishes. Moreover, captive breeding requires significant expertise about species reproductive strategies and husbandry. Further science advice will be needed on key science considerations for the species-specific implementation and experimental design of conservation translocations (e.g., release schedule, state variables for monitoring, stopping points for translocations).

Sources of Uncertainty

This national peer review meeting is the first formal advisory process to support the development of national operational guidelines for performing conservation translocations in support of the broader implementation of the *Species at Risk Act*. The conservation translocation decision support framework was designed to be flexible, as opposed to prescriptive, to guide decisions for species that may benefit from conservation translocations.

Given the experimental nature of conservation translocations, additional science advice is anticipated to address scientific and logistical uncertainties related to implementation.

Data scarcity presents a challenge for implementing conservation translocations. For example, coarse estimates of species abundance are often unavailable for SARA-listed freshwater fishes and mussels. This limitation can increase the level of uncertainty for how removals or translocations of individuals will affect focal and non-focal species and ecosystems. Similarly, a lack of knowledge on the genetic structure of SARA-listed species can create challenges when considering source population selection, including the role of captive breeding or rearing, and risk future harm if left unconsidered. However, data limitations do not prevent the application of the decision support framework; instead, application of the decision support framework for data-limited species will help identify areas of uncertainty or conflicting information necessary for further inquiry.

In addition to filling in the knowledge gaps related to species biology and ecology, additional work is needed on translocation protocols (i.e., experimental design and logistical constraints) and monitoring program design before implementing species-specific translocation efforts. Included in this design process is the need to identify key indicators of success and failure, and stopping points for the management actions when success or failure is reached. As well, there are many logistical challenges to performing conservation translocations that were not considered in the decision support framework that need to be considered prior to implementation such as the methods for removal and translocation (e.g., timing and release methods), transport of species considerations, and approaches to disease screening.

Future refinement of the decision support framework would benefit from several worked case studies. This includes the use of the framework to guide decisions on single and multiple species translocations. There is a trend outside of Canada of performing conservation translocations for multiple species simultaneously. In theory, such actions align with an ecosystem approach to management and may ultimately reduce operating costs by consolidating resources across multiple species. Originally designed to guide decisions on a single species, future efforts to apply the conservation translocation decision support framework to multiple species could benefit SARA-listed species management and recovery.

CONCLUSIONS

This science advice provides a structured, science-based decision support framework for identifying and evaluating the potential ecological benefits and risks of performing conservation translocations and determining the scientific considerations and methods for determining if and when conservation translocation could improve the survival or recovery of SARA-listed freshwater fishes and mussels (Figure 1). The decision support framework followed five general steps:

1. Identify objectives for conservation translocations;
2. Assess the probability of achieving the fundamental and means objectives;
3. Identify and assess the likelihood and magnitude of unintended consequences;
4. Compile and weigh scientific evidence to inform the translocation decision; and,
5. Implement and monitor the conservation translocation.

Like most recovery actions, conservation translocations are experiments that come with risks and uncertainties, which must be weighed against the potential benefits. Included in this consideration is the risk of inaction. In some cases, the fundamental objective for SARA-listed freshwater fishes or mussels may never be achieved without the use of conservation translocation (e.g., reintroduction). In other cases, however, alternative strategies may be justified. In addition to guiding decisions on conservation translocation, Steps 1–5 of the decision support framework could be modified to evaluate the ecological benefits and risks of alternative recovery actions. Ultimately, using the decision support framework presented here can help determine if and when the ecological benefits of recovery actions outweigh the uncertainties and risks of unintended consequences when aiming to improve survival and recovery of SARA-listed freshwater fishes and mussels. Future refinement of the decision support framework would benefit from several worked case studies.

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