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Reconstructing a deconstructed concept: Policy tools for implementing assisted migration for species and ecosystem management

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ABSTRACT

Assisted migration (AM) is increasingly proposed to limit the impacts of climate change on vulnerable plant and animal populations. However, interpretations of AM as a purely precautionary action along with multiple definitions have hampered the development of precise policy frameworks. Here, our main objective is to identify what type of policy tools are needed for implementing AM programs as part of broader environmental policies. First, we argue that policy frameworks for translocations of endangered species that are subject to climatic stress are fundamentally different from translocations to reinforce climatically exposed ecosystems because the former are risky and stranded in strict regulations while the latter are open to merges with general landscape management. AM implementation can be based on a series of phases where policies should provide appropriate grounds closely related to extant environmental principles. During a ''Triggering phase'', AM is clearly a prevention approach as considered by the Rio Declaration, if unambiguously based on evidence that population decline is mainly caused by climate change. During an ''Operational phase'', we suggest that policies should enforce experimentation and be explicit on transparent coordination approaches for collating all available knowledge and ensure multi-actor participation prior to any large scale AM program. In addition, precautionary approaches are needed to minimize risks of translocation failures (maladaptation) that can be reduced through redundancy of multiple target sites. Lastly, monitoring and learning policies during an ''Adaptive phase'' would promote using flexible management rules to react and adjust to any early alerts, positive or negative, as hybridization with local individuals may represent an evolutionary chance. Our analysis of study cases indicates that except for two programs of productive forests in Canada, current AM programs are predominantly small-scale, experimental and applied to endangered species isolated from general environmental management. As the effects of climate change accumulate, policies could include AM as part of larger environmental programs like habitat restoration with common species seeking to provide stable ecosystems in the future.

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1. Introduction

The impact of climate change on biodiversity and ecosystems presents new challenges for the scientific community, managers and policymakers, obliging them to adapt research agendas, conservation practices and regulations to these changes. Among the many conservation strategies developed to lessen the impacts of climate change on plant and animals assisted migration (AM) is one of the options receiving increased attention. The rationale behind is a compensation for the dispersal limitations and potential lack of adaptive capacity of a given species resulting from the speed of current climate change. This concept encompasses several overlapping definitions (Ste-Marie et al., 2011) generating a great deal of debate (Hunter, 2007; McLachlan et al., 2007). Most of the time, AM refers to the movement within or outside the natural species range to mitigate the impacts of climate change (Aitken and Whitlock, 2013). In addition to this general notion, we find two other closely related concepts: assisted colonization (AC) which describes a movement beyond the range of species to limit human-induced threats (Seddon, 2010), and recently, assisted gene flow (AGF) which describes a movement of individuals (genes) inside the range of species to facilitate adaptation to anticipated local conditions (Aitken and Whitlock, 2013). Here, we consider AM to be a general technique corresponding to a human-assisted movement of biological entities (seeds, other propagules, individuals or populations) from a region where their survival is mostly threatened by climate change to a region where they could survive and maintain ecosystem services under current and expected future climates. On a more general perspective, AM would belong to actions seeking to repair the environment and ecosystems like in restoration or ecological engineering programs that have been recently dubbed ''manipulative ecology'' (Hobbs et al., 2011).

Despite the fierce debate that AM has recently produced between opposing actors who see more risks than benefits in AM initiatives and those seeking to act in the face of climate change threats (see Neff and Larson, 2014 and references therein), AM could be nevertheless seen simply as an extension of the practices of translocation and reintroduction of endangered species. In fact, the distinction between translocations and AM is becoming increasingly artificial because climate change makes parts of the historic ranges of many species unsuitable as reintroduction recipient sites (Dalrymple et al., 2011). Critics of AM invoke the high failure rate of translocation programs (Fischer and Lindenmayer, 2000) as a counter-argument. Translocations can fail for many reasons including when supposedly 'core habitat' is in fact marginal for the translocated population (Dalrymple and Broome, 2010) suggesting that lack of ecological knowledge and not the fact of translocating individuals itself is a frequent limiting factor. Nevertheless, AM is developing gradually in public policies of various institutions and countries more as a general objective than as structured programs with precise policies, methods and funding. For instance, preliminary AM considerations have recently been included carefully by the International Union for Conservation and Nature (IUCN) in its latest translocation guidelines for endangered species (IUCN & SSC [Species Survival Commission] 2013). Likewise, the Scottish government (Brooker et al., 2011), the Australian authorities (NCCARF National Climate Change Adaptation Research Facility, 1990), the European Union LIFE program (Silva et al., 2011) and Canadian forest seed planting regulations in Ontario (Eskelin et al., 2011), among others, have all included some sort of AM in their texts.

If AM is deemed necessary by a panel of experts its application requires not only sound ecological knowledge but also clearly identified policy frameworks (Schwartz et al., 2012; Shirey and Lamberti, 2010) that still need to be fully developed. AM policies do not need to start from scratch but can be built upon major principles of environmental law or ecosystem management. Here, our goal is to answer the main question of what kind of policy frameworks are needed for implementing AM programs. Our specific questions are: (1) what are the definitions, scale and risk issues related to AM actions that need to be clearly identified in environmental policies? (2) If AM is an extension of environmental management and translocation programs, what pre-existing regulations and policies can help its implementation? And (3) what can be learned from known cases of AM? To conclude, we provide some recommendations for policymakers when AM is implemented as an option within larger biodiversity and ecosystem management programs in response to climate change.

2. Definitions, scale and risks issues in assisted migration policies

At least three main factors are essential to consider before designing any policy framework for AM: establishing a clear definition of the main objective of the action, assessing as precisely as possible the scale of the proposed action, and assessing the risks related to the action (Fazey and Fischer, 2009; Hewitt et al., 2011; McLachlan et al., 2007; Richardson et al., 2009).

AM has been used as a generic concept describing multiple related actions that can be placed along a continuum (Aubin et al., 2011; Ste-Marie et al., 2011) each requiring different policy frameworks. At the extremes of this continuum, however, two contrasting ideas emerge: whether the migration is to protect by translocation a target population from climate related risks, or to maintain or restore the ecosystem function of a target site. The first case corresponds to what Pedlar et al. (2012) termed 'species rescue AM' where the unit moved is the same to be protected. Here we call this type of AM as 'species-centered AM'. In the latter case, migrations are made *into* a target ecosystem to reinforce ecosystem processes with local, neighboring or even exotic species. Thus, an ecosystem that we want to protect will not be moved obviously, but other genetic units supposed more robust are brought in. We call this process 'ecosystem-centered AM'. Species-centered AM could be implemented where endangered species represent have a low invasion risk, have few migration possibilities in low-connectivity landscapes, low migration rates, low adaptation potential, low population size and well documented life history traits (Loss et al., 2011; Vitt et al., 2010). In contrast, ecosystem-centered AM would be appropriate for managed ecosystems such as productive forests (Pedlar et al., 2012), urban parks, water basins (Kreyling et al., 2011), managed prairies and other semi-natural landscapes, which consist mostly of a few common species without endangered status that have already been managed for many years.

Once the objective of the translocation has been identified, choosing the scale of action (biological, geographical and institutional) conditions the policies needed for AM, many of which already exist, in principle, in the regulations of most countries. The biological scale of the unit to be moved (seed, juveniles, individuals, population, etc.) must be determined first because the movement of propagules, for example, does not require the same sanitary controls as those required for adult plants or animals, and probably not the same economic resources either. Next, the geographical scale of the action needs to be identified, i.e., within, to the margin of, or beyond the current and historical range of the target species, because the risk of invasion is considered lower for sites closer to the historical range. The institutional scale (local, regional, national, bi-national, etc.) at which the AM action would be performed also needs to be determined because the authorizations involved in moving individuals within a reserve network are very different from those involved between countries.

On the contrary, handling the major risks associated with AM may require new suitably structured policies. First, the introduction of potentially invasive species in target ecosystems when the scale of the action is beyond the current and historical range of the species concerned (Aubin et al., 2011; Mueller and Hellmann, 2008; Ricciardi and Simberloff, 2009a; Winder et al., 2011) would be minimized if policies allow small scale experimental introductions to test for invasiveness prior to any large scale migration program; second, the risk of genetic pollution of native populations already present in the recipient ecosystem if species are moved into an area where there might be closely related taxa (Aubin et al., 2011; Frascaria-Lacoste and Fernández-Manjarrés, 2012; Minteer and Collins, 2010; Ricciardi and Simberloff, 2009b; Vitt et al., 2010) could be evaluated at experimental sites provided that molecular markers are available for a first monitoring, for example. In stark contrast, some researchers propose that AM could represent an "evolutionary opportunity" in the context of climate change, if bringing new genetic material into threatened areas (Aitken and Whitlock, 2013). AM can create artificial gene flow to maintain and increase genetic diversity of species by using genetically diverse populations potentially with genes pre-adapted to new conditions. The potential hybridization (genetic introgression) that may result from AM could be an opportunity for future rapid adaptations in changing environmental conditions (Scriber, 2014). These ideas are developed further in the section where we discuss the operational and management aspects of AM.

3. Specific policy frameworks for different types of AM

In the species-centered case, target species predominantly have endangered status (see examples in Table 2), so the application of AM programs is *de facto* difficult. In general, the more critical the status of a population, the more it will be regulated. Furthermore, the greater the translocation distance the more difficult the application of AM programs will be. In the USA, the Endangered Species Act (ESA) includes the 'experimental population' status to translocate populations beyond their range provided that local authorities see no risk for the recipient ecosystem (Shirey and Lamberti, 2010). Likewise, the relatively recent 'Habitats Directive' (92/43/CEE) regulation of the European Union provides a framework close to the ESA of North America. This directive and the programs derived from it are highly constraining and conservationist making many regions in Europe restrictive for AM. As with ESA, however, the Habitats Directive and the French Environmental Code (articles L411-1, 2, 3, 4 and 5) for instance, allow to eventually obtain derogations for small-scale experimentation for the movement of endangered species, as would be the case for other European countries.

On the other hand, new policy frameworks for ecosystem-centered AM should include awareness on the current and future potential ecological interactions (positive and negative) considering the connectivity of the landscapes. Here, the focus is on common biodiversity translocated to reinforce ecosystems so there are a priori small or no legal constraints for this kind of action. Ecosystem-centered AM implies a wider set of actions because of the multiplicity of species and interactions at the landscape level. However, risks exist related to permanent changes in the landscapes because of productivity arguments (Fernández-Manjarrés and Tschanz, 2010). Highly managed ecosystems (e.g., urban parks, productive forests, managed water sheds, etc.) benefit from several characteristics such as regular monitoring of good quality, management plans, and economic significance, making them very good candidates for this type of AM. Bearing in mind these two types of AM and their specific features, we examine next what extant environmental principles and tools could provide a basis for managing natural systems through AM through a series of steps.

4. Policy foundations for assisted migration: extant tools and their timing

4.1. *The triggering phase*

In our opinion, the biggest source of disagreement surrounding the debate of AM is the notion that such actions pertain solely to the realm of anticipation. In addition, the uncertainty about climate change and their impacts on biodiversity led scholars to reach first for principles focusing on uncertainty issues which are extremely difficult to implement in real situations. In this section, we argue that the innovative combination of two founding international environmental principles can provide policy grounds for a triggering phase of AM not substantially different from other environmental practices.

In the literature discussing the convenience of AM, the "precautionary principle" (PP) (Table 1) or "precautionary approach" appears as the main legal tool used to justify or argue against AM programs responding to climate change

Table 1 – Definitions and interpretations of the precautionary and prevention principles.

	Rio principle	Type of risks	Type of action	Interpretation/utilization
The Precautionary Principle (PP)	15	Hypothetical	Anticipation	Extension of the PvP. Most common approach is the identification of minimum risk.
The Prevention Principle (PvP)	17	Proven	Remedial	Originally proposed for environmental assessment now present in most environmental legislations. Never cited in the AM debate, it is overshadowed by the most ambitious PP.

(Camacho, 2010; Lurman Joly and Fuller, 2009; Ricciardi and Simberloff, 2009a,b; Sax et al., 2009; Schwartz et al., 2009; Shirey and Lamberti, 2010). However, it is well known in the legal literature that the PP is not an effective decision-making tool and was never intended as such (Cooney, 2004; Hahn and Sunstein, 2005; IUCN (International Union for Conservation and Nature) Council, 2007; Peterson, 2007; Weier and Loke, 2007). Because most definitions of the PP remain vague its application is not straightforward allowing different actors to appropriate the PP to their own ends. It is therefore not surprising that the PP is invoked legitimately both to justify the application of AM to avoid biodiversity loss (Sax et al., 2009; Schwartz et al., 2009), and at the same time to oppose to AM because of uncertainties regarding the possible introduction of invasive species (Ricciardi and Simberloff, 2009b) or the manipulation of already weakened populations in their source site (Kreyling et al., 2011). Like all principles, the PP states only a general truth (Sands and Peel, 2012; Tridimas, 2007) and does not prescribe any specific actions. Besides, its legally non-binding character does not imply any implementation or regulation strategy. So, even if a degree of uncertainty is inherent in the PP, in reality too many uncertainties block its interpretation and therefore its application, as observed currently with the AM debate. In sum, the PP role is not to be used as an initial decision-making tool, but as a means of raising awareness for future risks and their management implications.

So, if precautionary approaches are not necessarily at the crux of AM, what principles would provide the necessary grounds for triggering it? In AM decision-making frameworks (Hoegh-Guldberg et al., 2008; Winder et al., 2011) the initial stage always questions whether the population considered for translocation is clearly declining because of climate change (climate vulnerability) and not if there are potential negative effects of climate change on a population. So, the presence of clear proof of population decline and/or its exacerbation by climate change fits the purpose of another international environmental principle, often overlooked, namely the ''prevention principle'' (PvP) (Table 1). By definition, the PvP addresses environmental issues where there is relatively little uncertainty on damages but clear evidence that environmental risk has been proved (soil pollution, habitat fragmentation, resource overuse, and so on). In the ecological disciplines, the PvP is akin to the concepts of ecological remediation or ecological restoration.

The PP differs in a subtle but fundamental way from the PvP and the difference lies in the characterization of environmental risk. In the case of prevention approaches, risk has been proved unequivocally and the uncertainty only involves the magnitude of the risk. For precautionary approaches, however, risk is hypothetical but plausible, so uncertainty not only relates to magnitude, but also to the occurrence of the risk in question. The PvP applies in the case of the existence of proven risks, i.e., population decay or ecosystem function decay caused by current climate change, and the PP applies to supposed risks, i.e., the likelihood of negative future climate impacts. In action planning, the PvP triggers the action at time t and the PP allows integrating the future uncertainty to act today for conditions at time $t + 1$.

If we have proof of population decline or ecosystem malfunction because of climate change in biodiversity management, the next question is whether we have enough knowledge about the species ecology to decide upon the appropriate remedial action: to preserve in situ, ex situ, or to move and compensate for current and expected climate change (i.e., AM). For the case of ecosystem-centered AM, it will be necessary to decide if we have good enough knowledge about the history and function of the ecosystem concerned and to identify translocation candidates of well-known keystones species. In traditional biodiversity management, evidence of population decay or ecosystem dysfunction calls for ecological remediation or restoration (Fig. 1, upper left). When ecological modeling suggest high climatic vulnerability for a population, species or ecosystem, awareness of risk based on the PP calls for population and ecosystem monitoring to be able to react rapidly and preliminary research to accumulate knowledge (Fig. 1, lower right). In the context of AM implementation for species-centered AM or ecosystem-centered AM, the PP and the PvP will necessarily overlap (Fig. 1, upper right). The PvP provides grounds to start an action where there is proven vulnerability (population decline or ecosystem dysfunction) and the PP converges with the PvP to anticipate the uncertainty of climate change when vulnerability is supposed (Fig. 1, upper right).

4.2. *The operational phase*

We have seen that precautionary and preventive approaches play primary roles in the implementation of AM and as such should be clearly identified in policies regarding translocations. Whereas the ''triggering phase'' relies on a certain degree of political commitment, this phase relies on ecological knowledge and past empirical experience of translocation programs. Translocation practices have been conducted for many years generating a wealth of methods and recommendations and the most well-known are probably those of the IUCN. These guidelines are permanently updated and provided as reports that support the implementation of translocations by giving step-by-step guidance on feasibility, risk assessment and monitoring (IUCN and SSC, 2013). However, 'traditional' translocations based on a principle of 'equivalent

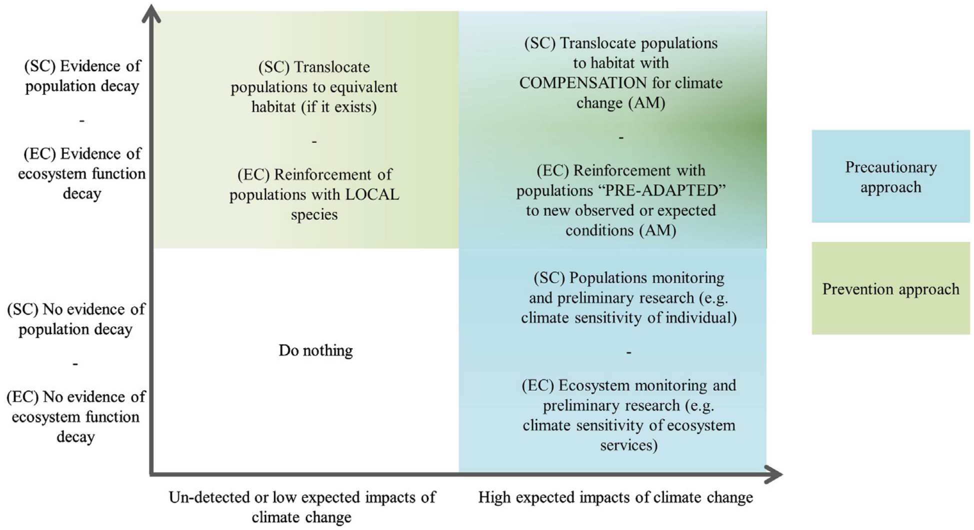

Fig. 1 – Conceptual approach depicting how AM action accounts for both the precautionary and prevention approaches for Species-Centered AM (SC) and Ecosystem-Centered AM (EC).

habitat availability' will be more difficult to apply with ongoing global changes and innovations in translocations practices are needed to increase the probability of success of translocated populations.

The notions of multilevel collaboration and consultation are central to the operational phase of translocations, and by extension, to AM. These notions are well-known in international environmental legislation as the ''coordination principle'' in the United Nations Declarations (The United Nations, 2002, 1992, 1972), the Convention on Biological Diversity (CBD) ecosystem management guidelines and widely acknowledged by the scientific community (Heller and Zavaleta, 2009; Hulme, 2005; McLachlan et al., 2007; Mueller and Hellmann, 2008). In the same way, the IUCN/SSC guidelines (IUCN and SSC, 2013) introduced the notion of multi-disciplinary and multi-scale set of skills alongside biological, ecological, social, economic or technical expertise with a wide approach to limit biodiversity management risks including those related to translocating species (IUCN (International Union for Conservation and Nature) and SSC (Species Survival Commission), 2013; Secretariat of the Convention on Biological Diversity, 2004). This approach will help bridging the gap between current translocations practices and the approach needed for complex programs as AM. In the case of AM, coordination and consultation are particularly important for two main reasons. First, isolated experimental cases of AM as currently implemented (see Table 2) may be forgotten if the short-term grants that financed the action are not renewed, as is often the case. Second, consultation and coordination in AM programs increases their transparency and in consequence, their acceptance by social and expert audiences. Lessons from past translocations show often that social acceptance play an important role in the implementation of these programs (Michaels and Tyre, 2012). For instance, coordination has played an essential role in the AM program for *Abies nebrodensis* in Sicily, Italy, a mountain species threatened by increased drought and fires with less than 50 trees left in the wild. This program has been realized with the participation of the agricultural ministry, university, conservationists, national park and local organizations, thus facilitating its social acceptance and allowing the implementation of continual monitoring of populations at the target site and at the introduction orchards in the main land (F. Ducci, pers. comm).

Finally, risks of failure during the operational phase could be minimized by spreading risks with redundancy approaches. This step is different from experiments to assess the climatic niche of a target species, like provenance tests which provide very valuable information about adaptation, invasions or pest resistance. Redundancy follows any experimental stage and provides the maximum of chances for translocated species in the face of uncertain climate change. The idea of ''bet-hedging'' or spreading the same population across different climates has been suggested to preserve the variety of forest genetic resources under changing climates and in ecological restoration (Lawler, 2009; Millar et al., 2007; Society for Ecological Restoration International, 2009). The choice of future habitat for populations in AM is usually based on statistical models (species distributions or niche models) but the real suitability of the habitat for the translocated population remains uncertain until tested. One way of dealing with this inherent uncertainty is to include redundancy in translocation practices. Redundancy is a well-established principle in safety design in which different components perform the same task providing robustness to a system. Here, redundancy is understood in two ways: for species-centered AM, by placing translocated populations on multiple sites selected along and across a climatic gradient instead of concentrating them in one habitat that may have been predicted to be the most suitable; and for ecosystem-centered AM, by bringing multiple species with different climatic tolerances. The use of redundancy can be understood as a way of implementing precautionary approaches in the field (Fig. 1, upper right) and it merits explicit inclusion in any new regulation concerning AM.

Table 2 – Comparative analysis of known assisted migration study cases.

Project references	Species	Species status (IUCN)	Localization	Climate vulnerability (low/medium/high)	Demographic vulnerability (low/medium/high)	Main threat	Distance between source site and target site	Location of target site (inside or outside actual distribution of species)	Policy context	PP/PvP
Conservation (Species-centered assisted migration)										
(McLane and Aitken, 2012)	*Pinus albicaullis*	Endangered	Canada (British Columbia/USA	High	High	Beetle (linked to climate change)	Between 700 and 1800 km	Inside for the most southerly population and outside for most northerly population	Experimental population	PvP and PP
(Willis et al., 2009)	*Melanargia galathea* and *Thymelicus sylvestris*	Endangered	United Kingdom	High	High	Combination of habitat fragmentation and climate change	Between 50 and 100 km	Beyond the northern border	Experimental population	PvP and PP
(Ducci, 2011)	*Abies nebrodensis*	Endangered	Italy	High	High	Climate change/ habitat destruction	~750 km (Sicilia to Italy)	Outside	Experimental population. In collaboration with ministry, local organization, natural park, conservatories, and university	PvP and PP
(Shirey and Lamberti, 2010)	*Neonympha mitchellii*	Endangered	USA	Medium	High	Combination of habitat fragmentation and climate change	Hypothetically ~200 km	Outside	Theoretical analysis of AM programs in ESA. Use of experimental population status.	PvP and PP
(Pedersen et al., 2014)	*Liatris ligulistylis* and *Houstonia longifolia*	Regionally vulnerable	Canada (Alberta)	Unknown	High	Small population size/climate change (?)	450 km south and 500 km north	Outside	Experimental populations	PP
(Liu et al., 2012)	Several Asiatic orchids	Endangered	China	Unknown	High	Destruction of habitat	Less than 30 km	Outside	Experimental populations – ecological compensation	PvP and PP
Torreya Guardians (www.torreyaguardians.org)	*Torreya taxifolia*	Endangered	USA	Unknown	High	Weakness in reproductive success	~1600 km	Outside the actual distribution but inside the paleo-ecologic distribution	Independent social movement	PvP
Integrity of ecosystems (Ecosystem-centered assisted migration)										
(O'Neill et al., 2008)	15 common tree species of Canadian forest	Least concern	Canada (British Columbia)/USA	Medium	Low	Climate change	~1000 km	Outside	Experimental trials in agreement with provincial and federal ministry.	PP
Beardmore team (www.rncan.gc.ca/forests/climate-change/13121)	6 hardwood tree species	Least concern	Canada (New Brunswick and Ontario)/USA	Medium	Low	Climate change	Between 500 and 1400 km	Outside	Experimental trials in agreement with provincial and federal ministry	PP

4.3. *The adaptive phase*

The adaptive phase is based on monitoring, learning and adapting management that should be reflected in any new AM policies. This last phase does not mark the end of AM actions because it is essential to see translocations and introductions as an iterative process of species and landscape management. Monitoring is essential in all biodiversity and ecosystem management programs, but even more so when a certain degree of risk is involved, as in AM where monitoring has multiple advantages. First, it allows the collection of data to understand how well suited recipient habitats are in compensating for climate change and it is therefore helpful in the design of future translocation programs (Dalrymple et al., 2011; Godefroid et al., 2011; Heller and Zavaleta, 2009; Piazza et al., 2011). For instance, *Abies nebrodensis* seedlings are followed every year in Italy and in the translocated populations using paternity analysis to monitor the reproductive success of different grafted individuals (F. Ducci, pers. comm.).

More importantly, detailed monitoring allows a rapid response in case of early warnings of maladaptation at the early stages of population establishment (Benito-Garzón et al., 2013; IUCN, 2013). In fact, we should always expect some level of maladaptation in AM because latitudinal and altitudinal changes cannot compensate exactly for climate change and also because expected climates cannot be compared with either 20th century conditions (Williams et al., 2007) or other climates in the recent geological past (Benito-Garzón et al., 2014). The question remains open of what level of maladaptation would be acceptable for the translocation to be considered acceptable.

5. From theory to practice: analysis of study cases

In this section, we analyzed a subset of cases from the scientific literature and from non-published sources that clearly state the use of the concept of AM. Several ecological interventions can be assimilated to one type of AM, but we selected cases where the AM terms are clearly mentioned to avoid confusion with ecological restoration programs or reanalysis of already existing tree provenance tests. For each case we considered the status of the focus species, the main threat and the main motivation for the AM program (Table 2). Two cases were in Europe, six in North America, and one in Asia. Translocation distances vary from as little as 30 km to as much as 1800 km.

From current projects explicitly stating AM or AC, we can observe more species-oriented AM cases (cases 1–7 in Table 2) than ecosystem-centered AM (cases 8 and 9 in Table 2) despite the very strict legal context of endangered species. In fact, proofs of demographic decline seem to be an essential step to start AM programs and the application of PvP approaches appears as a common sense decision for managers. Consciously or unconsciously, managers in the field follow the procedure described in the Section 4.1, highlighting the adequacy of our proposed implementation framework (Fig. 1). In general, to override constraints on endangered species manipulations, actors used a variation of the ‘experimental populations’ status to conduct their AM programs. Thus, this experimental population status found in many current regulations appears to represent an adequate solution, albeit a temporary one.

In contrast, for the last study cases (cases 8 and 9 in Table 2), the motivations are clearly different from conservation of a particular endangered species. These cases with common Canadian trees species closely match the first steps of an ecosystem-centered AM. In fact, these are mixed cases of AM experimental research and forestry improvement with common and commercially important North American species. Their motivation is based on economical concerns to find the best provenances and to maintain the productivity of forests despite climate change. These cases with common species potentially vulnerable to climate change correspond to the lower right box in Fig. 1 or strict precautionary approach. They are not yet a complete ecosystem-centered AM as we defined it previously, but they do represent the first research steps for future ecosystem-centered AM in the field. These programs involve the selection of the best genetic material for reinforcing ecosystems through extreme testing of populations for a ten-year or so period in order to understand the functional climatic limits of the species and obtain rules for population translocation distances.

Surprisingly, climate vulnerability does not seem to be a condition to implement AM programs. We found three cases with clear evidence of population threat or decline but where climate vulnerability has not been explicitly shown to be the cause of the current decline and even as a potential future threat of the species (cases 5, 6 and 7 in Table 2). For these three cases the motivations are context-specific. First, the AM program in Alberta represents a case where researchers test simultaneously the climate vulnerability of two regionally endangered species and conduct an AM program in a typical proactive and purely precautionary management. Second, the justification of the Chinese case was the threat of direct habitat destruction by urban expansion. In fact, this action is closer to an ecological compensation program to avoid biodiversity loss. Lastly, the well-known case of the Torreya guardians that have translocated seedlings of *Torreya taxifolia* to more northerly latitudes in North America represents an independent citizen action of very involved and proactive people. These three cases highlight that in different contexts, proofs of population decline or habitat destruction threat are sufficient to start AM programs even without climatic vulnerability evidence. We do not know if the number of such cases will increase or remain anecdotic in the future.

All these cases show that proven demographic decline is a powerful incentive to promote AM programs, whether climatically justified or not. Even if we have few and preliminary AM cases, the pragmatic approach seen here when dealing with clearly climatically endangered species points out that policies based on PvP approaches (demographic vulnerability) are probably more easily accepted than those based only on precautionary thinking that nevertheless is needed for the correct implementation of AM.

6. Implications for policymakers

Our study cases analysis highlight that current actions self-claimed as AM are mainly small-scale programs for endangered species, mostly adapting the 'experimental status' option, making them isolated from general environmental management policies. The inclusion of AM as an explicit climate adaptation option in environmental policies will involve integrating clearly climate change constrains in regulations and by consequence allowing for increased flexibility (Camacho, 2010), while improving at the same time the management of associated risks. This means that the risks of invasiveness, for example, would be considered not more important than the risks of extinction, so regulations could open windows to experimental translocations under controlled semi-natural environments. Here, the complexity is that policy-makers should implement regulations for two-fold precautionary actions, for extinction risks and AM risks. Probable extinctions could be avoided by facilitating appropriate management actions even if risky, and management risks should be decreased by a responsible, reactive and reasonable biodiversity management. Thus, experimentation must remain a first essential step to be able to measure the real extent of the risks involved. Concerning the risk of genetic pollution, management guidelines must consider integrating new ecological and genetic interactions because of the translocations. Even if genetic pollution could damage ecosystems it could also represent an opportunity for adaptation. Policy-makers and managers must accept that some degree of maladaptation could be the first step before natural selection adjusts populations to the new environmental conditions (Aitken and Whitlock, 2013).

Current policies for ecosystem management focus in providing and promoting adaptability, survival, resources provision, ecosystem services, and encouraging biodiversity conservation and recreational aspects. However, this multidimensional component may be more and more difficult to achieve in a changing environment. One option is to reconsider management goals and prioritize according to wider land use planning objectives with potential trade-offs between robustness (seen as the global perpetuation of a healthy ecosystem) and optimality (seen as the maximization of *certain* ecosystem services) of ecosystems. For example, degraded forests could be used as an experimental opportunity for AM by bringing new genetic material from lower latitudes and/or altitudes to reinforce local populations. This type of forest restored through AM would be managed for optimality in biomass production or carbon sequestration while other better conserved areas would be managed for biodiversity conservation. In turn, people using plants for restoring different habitats can follow the experimental approach example from the forestry community and set up seed certification schemes based on networks of reciprocal transplant tests to understand the functional limits of common species used in restoration.

Regulations should clearly address a transparent cross-sectorial coordination between science (researchers), local and national authorities (policymakers and implementation agencies) and technical support (managers and communications officers) where each have a key role in programs that manage living entities and ecosystems. Cooperative research initiatives like the "Ouranos" program created in 2001 in Québec (www.ouranos.ca) involving more than 450 researchers from different disciplines can bridge the gap between research policy and management. This type of program could serve as an example to conceive the implementation of AM, as they are capable of providing stakeholders with data, knowledge and a set of realistic options compatible with what is required in the field.

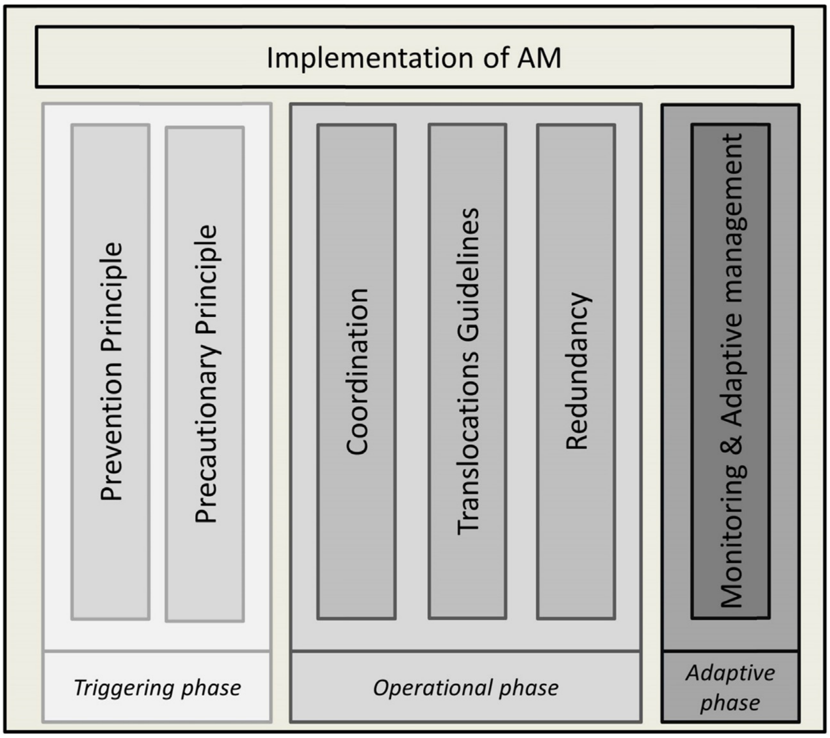

Fig. 2 – Conceptual framework for the implementation of AM programs showing the three action phases.

7. Concluding remarks

Today, AM is still barely used in environmental management because its associated risks have hampered its implementation. Nevertheless, we have seen that there are already legal norms and environmental principles (Fig. 2) providing grounds for its implementation as a climate change adaptation strategy. In any case, both types of AM as defined here should have an experimental stage before engaging in larger scale programs including redundancy and coordination approaches since the offset, as exemplified by the forestry sector. Besides, during this experimental stage, invasiveness, genetic pollution and enhanced evolutionary potential can be strictly monitored. Due to the costs involved, this sort of experimentation can only be done by large networks probably involving both the private and the public sector, and as mentioned earlier, should focus on familiar managed species.

It is essential that policymakers write regulations that provide a clear distinction between the PP and the PvP and interpret them for local applications (Cooney, 2004). Of course, implementing precautionary measures engenders higher political and economic costs than preventive actions and AM is no exception to this. As the legal context for ‘classic’ translocations depends on endangered species regulations – that we doubt will be relaxed soon – species-centered AM will remain inextricably attached to endangered species restrictions. Hence, it is likely that we will see in the future more cases of AM similar to that of the *Pinus albicaullis*, *Abies nebrodensis*, *Melanargia galathea* and *Thymelicus sylvestris*. These cases merged prevention approaches from factual evidence and precautionary approaches to anticipate for increased climatic risks in the future providing legitimacy and reassuring justifications to act. For other species for which few studies exist, or those that we simply do not realize are endangered due to climate change, managing and preserving local habitats and their interconnectivity may be the sole remaining option.

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