ECOLOGY

Assisted Colonization and Rapid Climate Change

Moving species outside their historic ranges may mitigate loss of biodiversity in the face of global climate change.

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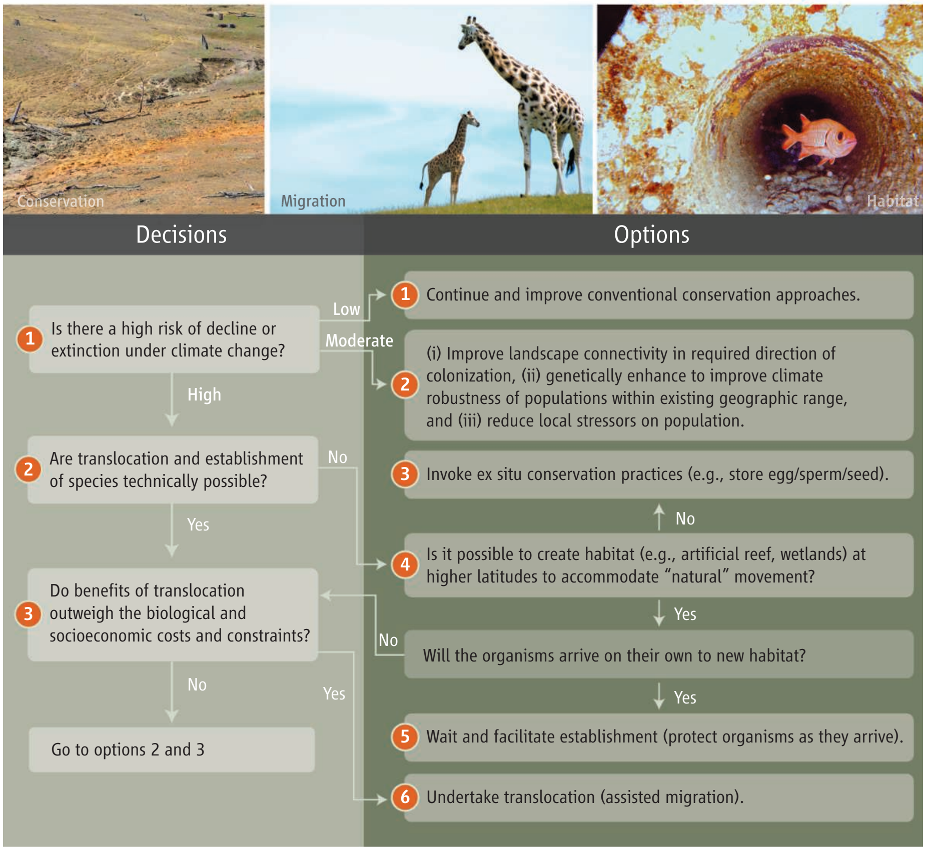
Rapid climatic change has already caused changes to the distributions of many plants and animals, leading to severe range contractions and the extinction of some species (*1*, *2*). The geographic ranges of many species are moving toward the poles or to higher altitudes in response to shifts in the habitats to which these species have adapted over relatively longer periods (*1*–*4*). It already appears that some species are unable to disperse or adapt fast enough to keep up with the high rates of climate change (*5*, *6*). These organisms face increased extinction risk, and, as a result, whole ecosystems, such as cloud forests and coral reefs, may cease to function in their current form (*7*–*9*).

Current conservation practices may not be enough to avert species losses in the face of mid- to upper-level climate projections (>3°C) (*10*), because the extensive clearing and destruction of natural habitats by humans disrupts processes that underpin species dispersal and establishment. Therefore, resource managers and policy-makers must contemplate moving species to sites where they do not currently occur or have not been known to occur in recent history. This strategy flies in the face of conventional conservation approaches. The world is littered with examples where moving species beyond their current range into natural and agricultural landscapes has had negative impacts. Understandably, notions of deliberately moving species are regarded with suspicion. Our contrary view is that an increased understanding of the habitat requirements and distributions of some species allows us to identify low-risk situations where the benefits of such "assisted colonization" can be realized and adverse outcomes minimized.

Previous discussions of conservation responses to climate change have considered assisted colonization as an option (*11*, *12*), but have stopped short of providing a risk assessment and management framework for how to proceed. Such frameworks could assist in identifying circumstances that require moderate action, such as enhancement of conventional conservation measures, or those that require more extreme action, such as assisted colonization. These frameworks need to be robust to a range of uncertain futures (*13*). Uncertainties arise in climate projections and in how species and ecosystems will respond. Hence, calculation of the lower and upper bounds for the probability and cost of a range of possible outcomes may be the best strategy.

With this in mind, we developed a decision framework that can be used to outline potential actions under a suite of possible future climate scenarios (see figure, below). Determining whether a species faces significant risk of decline or extinction under climate change requires an in-depth knowledge of the underlying species' biology as well as the biological, physical, and chemical changes occurring within its environment. The risk of extinction for many widespread, generalist species found across a range of habitats may be low. In this case, the option of moving such species outside their present



Decision framework for assessing possible species translocation. Assessing the feasibility of whether or not to attempt the movement of a species to prevent its extinction or ecosystem collapse.

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ranges would be dismissed. Some species will also disperse sufficiently to maintain large populations and range sizes (for example, highly dispersive insects or birds with generalist life histories) and others may adapt in situ (*14*). Where species are perceived as being at moderate risk from climate change, improvements in connectivity to actual or potential habitat at higher latitudes and altitudes may be sufficient (*15*).

Moving widespread species within their ranges might, nonetheless, be an important conservation option, especially where significant ecotypic differentiation exists. Moving individuals from "warm-adapted" populations to historically colder locations may increase the probability of subsequent adaptation as the climate changes. For example, staghorn corals (Acroporidae) have wide latitudinal ranges, with low-latitude populations having higher temperature tolerances than those at higher latitudes (*15*, *16*). Populations of staghorn (*Acropora*) corals have already been lost from some high-latitude locations because of increasing thermal stress and declining water quality, and hence, introducing lower-latitude, heat-adapted genotypes to these degraded sites may hold little risk (*16*). Latitudinal and altitudinal clines in genetically based thermal adaptation are equally common on land, e.g., in fruit flies (*17*) and butterflies (*18*). Careful introduction of low-latitude forms of a species may help to preserve it at higher latitude and altitude, as the climate changes.

Assisted colonization should also be considered for species whose ranges have become highly fragmented. Movement in the direction required by climate change may be blocked by human-dominated landscapes [e.g., the endangered Quino checkerspot butterfly, *Euphydryas editha quino* (*19*)]. Dispersal processes that have been disrupted by loss of habitat connectivity could be restored by colonization.

Species that are confined to disappearing habitats present the greatest challenge. Many montane species, for example, face elimination of their habitat as suitable climatic conditions migrate upward and off the top of mountain ranges (*7, 9, 20*). In other cases, the shift of environmental envelopes in a poleward direction may be thwarted by natural barriers (e.g., North African species needing to cross the Mediterranean). In both cases, translocation of species to locations outside their historic range where conditions will be suitable in the medium- to long-term may be the only strategy to prevent extinction.

The assisted colonization of species to a new site depends on additional factors. The first is whether the establishment of species at the target location is technically feasible, and whether the biophysical characteristics of the new location match the needs of the species. In cases where translocation is technically impossible or is prohibitively expensive (*21*), it may be possible to respond by constructing suitable habitat at potential sites for natural colonization. The movement of many coral reef species to higher latitudes, for example, may depend on the presence of benthic structure as opposed to an existing biological community. It might be practical, at small scales, to establish artificial, three-dimensional reef structures ahead of migrating coral, fish, and invertebrate species. On land, it may be possible to restore degraded land with habitats not originally present. Clearly, however, there are financial and other logistic constraints, especially at the scale of the world's ecosystems (*10*, *22*).

One of the most serious risks associated with assisted colonization is the potential for creating new pest problems at the target site. Introduced organisms can also carry diseases and parasites or can alter the genetic structure and breeding systems of local populations. However, most major pest problems have been created by continent-to-continent and continent-to-island translocations or by the transfer of organisms between distinct biogeographic regions within continents (e.g., Nile perch to Lake Victoria). Clearly, risks escalate as species are moved across biogeographical boundaries. Introduction of the cane toad, *Bufo marinus*, from its native range in tropical America to Australia and various tropical parts of the world has been disastrous. This is not the scale of translocation that is being proposed here; we are not recommending placing rhino herds in Arizona or polar bears in Antarctica. We are, however, advocating serious consideration of moving populations from areas where species are seriously threatened by climate change to other parts of the same broad biogeographic region (i.e., broad geographic regions that share similar groups of organisms).

In addition to the ecological risks, socioeconomic concerns must be considered in decisions to move threatened species. Financial or human safety constraints, for example, may make a species' introduction undesirable. It is likely to be unacceptable to move threatened large carnivores or toxic plants into regions that are important for grazing livestock. Ex situ conservation (storage of frozen gametes) may be the only practical option for these species until more suitable habitat can be found or developed in the future.

The reality of a rapidly changing climate has caught many natural-resource managers and policy-makers unprepared. In the past, the assisted migration of a species outside its current range was rarely considered to be an acceptable conservation measure, with the exception of moving species to small, predator- or other threat-free islands (*23*). Larger-scale translocations might now be needed. Consequently, the conservation community needs to move beyond the preservation or restoration of species and ecosystems in situ. Assisted colonization will always carry some risk, but these risks must be weighed against those of extinction and ecosystem loss.

We must contemplate the possibility that some regions of the Earth will experience high levels of warming (>4°C) within the next 100 years, as well as altered precipitation (*10*) and ocean acidity (*8*). Under these circumstances, the future for many species and ecosystems is so bleak that assisted colonization might be their best chance. These strategies will, however, require careful thought and will need to be backed up by detailed scientific understanding if they are to succeed. They must also be accompanied by strategies that address the myriad of other threats in addition to climate change that also endanger species and ecosystems.

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