POLICY PERSPECTIVE

Assisted colonization under the U.S. Endangered Species Act

Patrick D. Shirey & Gary A. Lamberti

Department of Biological Sciences, Galvin Life Sciences Building, University of Notre Dame, Notre Dame, IN 46556-0369, USA

Keywords
Assisted colonization; assisted migration; climate change; Endangered Species Act; endangered species policy; experimental population provision; managed relocation; Mitchell's satyr butterfly; *Neonympha mitchellii mitchellii*; translocation.

Correspondence
Patrick D. Shirey, Department of Biological Sciences, Galvin Life Sciences Building, University of Notre Dame, Notre Dame, IN 46556-0369, USA. Tel: 574-631-0580; fax: 574-631-7413. E-mail: pshirey@nd.edu

Received: 1 July 2009; accepted 21 October 2009.

doi: 10.1111/j.1755-263X.2009.00083.x

Abstract

Assisted colonization could help prevent the extinction of threatened and endangered species by intentionally moving a species to a region where it has not occurred in the recent past, but should survive under future climate scenarios. Where species are naturally localized and confined to patchy habitats, assisted colonization might be the only means for population dispersal across human landscape barriers such as urban and agriculture areas. The major risk associated with assisted colonization is introducing ecologically harmful species. Previous policy papers have described management options for deciding when to move a species to mitigate for climate change. We build on this previous work by examining management options and policy solutions for assisted colonization under the U.S. Endangered Species Act (ESA). On its surface, the ESA statutory language appears to provide the legal framework for allowing assisted colonization, as the U.S. Congress gave the U.S. Fish and Wildlife Service (USFWS) broad discretion to manage populations of endangered species. However, current USFWS regulations are an impediment to assisted colonization for many endangered animal species, whereas regulations do not necessarily restrict assisted colonization of endangered plants. Because of this discrepancy, we recommend a review of the regulatory language governing movements of endangered species.

Introduction

Human-assisted movement of organisms has been proposed as a conservation strategy for species with poor dispersal abilities in highly modified landscapes subject to the effects of climate change (Willis *et al.* 2009). The human-assisted movement of a species inside a historic range is translocation (Griffith *et al.* 1989), whereas movement to a site outside of the historic range is often termed assisted colonization (Hunter 2007; Hoegh-Guldberg *et al.* 2008; Ricciardi & Simberloff 2009; Willis *et al.* 2009), assisted migration (McLachlan *et al.* 2007), or managed relocation (Richardson *et al.* 2009). Previous policy papers have described the management options for deciding when to move a species to mitigate for climate change (Hulme 2005; Hunter 2007; McLachlan *et al.* 2007; Hoegh-Guldberg *et al.* 2008; Richardson *et al.* 2009). Based on the literature, we define assisted colonization as the intentional movement of a species or subspecies to a region where it has not occurred in the recent past, but could occupy under climate change.

We examine management options and policy solutions for assisted colonization of endangered species, because natural resource agencies and nongovernment organizations might consider management strategies to mitigate for the impact of climate change and fragmented habitat. While several legal options exist for moving species, our legal analysis is limited to assisted colonization of species listed under the U.S. Endangered Species Act (ESA). We are not advocating for assisted colonization of any particular species. Rather, we ask whether assisted colonization would be possible as a management option under the ESA.

Many at-risk species are already listed as endangered because habitat destruction and fragmentation have reduced their populations (Lande 1998; Kerr & Cihlar 2004; Kerr & Deguise 2004; Fischer & Lindenmayer 2007). For example, populations of the threatened Bay checkerspot

Figure 1 *Neonympha mitchellii mitchellii* (Mitchell's satyr) (photo credit: John Shuey, The Nature Conservancy).

butterfly (*Euphydryas editha bayensis*) in California went extinct due to population isolation by habitat fragmentation and increased variability in precipitation (McLaughlin *et al.* 2002). For threatened and endangered species with limited dispersal ability, climate change might be the final push toward extinction in fragmented habitats because shifts in species distributions are projected to cause extinctions even under minimal climate change (Thomas *et al.* 2004).

Mitchell's satyr butterfly case study

We focus on the endangered Mitchell's satyr butterfly (*Neonympha mitchellii mitchellii*) (Figure 1) as a case study because, like the Bay checkerspot, Mitchell's satyr persisted through historical climate change with limited dispersal ability. Climate change since the last glacial maximum allowed for northward expansion of Mitchell's satyr populations, which colonized previously glaciated regions while southern populations were extirpated (Shuey 1997). Mitchell's satyr was originally found in more than 30 healthy populations in the mid-United States, but fewer than 20 populations now persist in sedge-dominated, peat soil wetlands called fens, or in wetlands impounded by beaver (*Castor canadensis*) in forested landscapes (Shuey 1997). Mitchell's satyr has now been extirpated from Ohio and New Jersey, and from all but one site in Indiana (Figure 2).

Mitchell's satyr is single-brooded (univoltine) throughout sites in Michigan and Indiana, but can be double-brooded in captivity (Shuey 1997). Adults are typically active during a 4-week period from late June to mid-July with peak flight occurring in the first 2 weeks of July (Shuey 1997; Szymanski *et al.* 2004; Barton & Bach 2005). Field observations indicate that behavior and activity are strongly influenced by ambient temperature and solar radiation (Shuey 1997; Szymanski *et al.* 2004). Shuey (1997) observed that Mitchell's satyr is most active on warm (26–32°C), overcast days but rarely active on hot (>32°C), sunny days. Due to its short adult lifespan, the reproductive success of Mitchell's satyr could be diminished by extremes of temperature and precipitation (Szymanski *et al.* 2004).

Despite a short generation time that would typically favor adaptation to a changing climate (Pörtner & Farrell 2008), Mitchell's satyr could be vulnerable due to its limited dispersal ability (Szymanski *et al.* 2004; Barton & Bach 2005). Populations of Mitchell's satyr were likely always disjunct, but have been further fragmented by "(1) (habitat) destruction due to development, (2) changes in (wetland) hydrology, (3) invasion by aggressive native and nonnative plant species, and (4) suppression of historical disturbance events important to maintain fen habitat such as fire and beaver activity" (Barton & Bach 2005). In describing dispersal of Mitchell's satyr, Shuey (1997) noted that "recolonization of isolated fens by such a weakly flying insect may have been uncommon historically and has become nearly impossible in today's landscape." While Mitchell's satyr has survived glaciations and climate change in the past, a human-altered landscape inhibits population dispersal and isolates populations (Szymanski *et al.* 2004; Barton & Bach 2005).

An altered landscape complicates the threats associated with anthropogenic climate change, as shown for other butterflies with limited dispersal ability (McLaughlin *et al.* 2002). The historical importance of emigration during times of climate change is demonstrated by Mitchell's satyr populations in previously glaciated regions in the northern portion of its range. While Mitchell's satyr populations moved northward after the last glacial maximum, all of the intermediate populations and all but two of the southern populations that existed during the glacial maximum are extinct (Shuey 1997). These patterns suggest that dispersal corridors are important for the movement of populations between primary habitat sites during periods of climate change.

Management options

The Toledo (Ohio) Zoo protects and breeds a captive population of Mitchell's satyr with the hope of reintroducing individuals to the wild. The population was acquired through a permit from the U.S. Fish and Wildlife Service

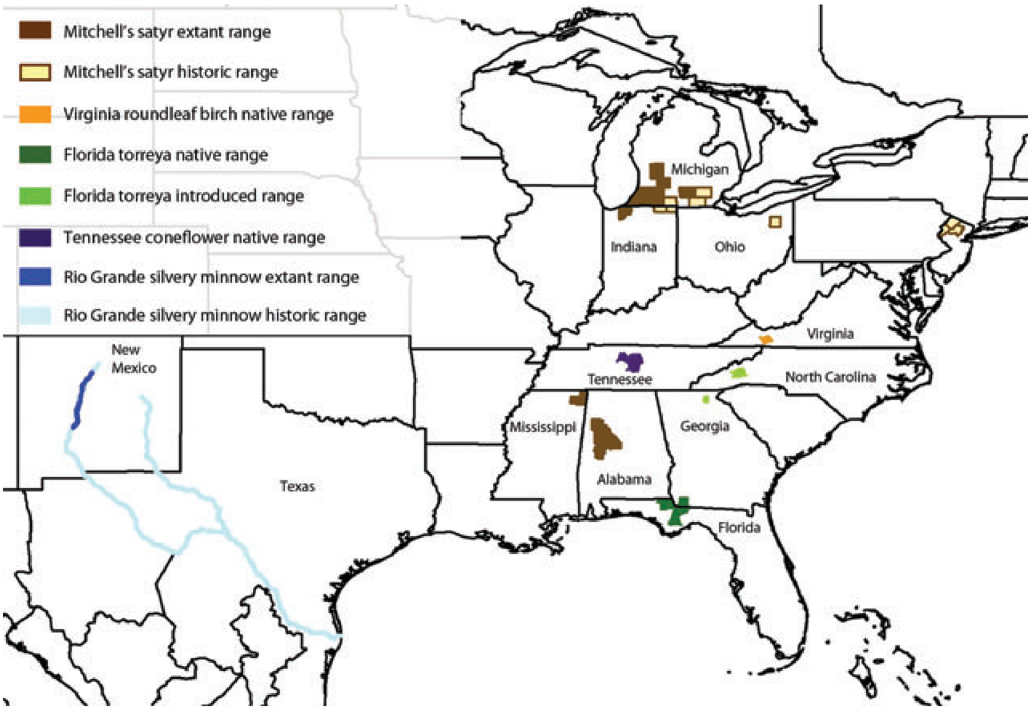

Figure 2 Map of the United States with species ranges for Mitchell's satyr, Virginia roundleaf birch, Florida torreya, Tennessee coneflower, and Rio Grande silvery minnow. Locations determined by county distribution records from citations in the text.

(USFWS), which allowed capture of individuals from two wild populations for captive breeding. Our interpretation is that the Toledo Zoo and the USFWS have five management options for this captive population: (1) return the captive population to the original location of capture, (2) release the captive population to an unoccupied site within the probable historic range, (3) keep the population in captivity indefinitely, (4) release the captive population to a site outside of the historic range, or (5) manage the captive population with any combination of options, 1 to 4, such as releasing part of the captive population.

Legal framework and analysis

In the language of the ESA, the U.S. Congress gave the USFWS broad discretion to manage populations of endangered species. For example, the statutory language of the ESA includes the power to transplant species (16 U.S.C. §1532(3)). However, current agency regulations impede alternative strategies such as assisted colonization for endangered animals, but do not impede assisted colonization of endangered plants. We address this discrepancy by examining the language of the ESA and agency regulations governing species movement. In addition, we provide examples of endangered species moved outside their historic ranges.

Experimental populations

On its surface, the statutory language of the ESA appears to provide the legal framework for allowing assisted colonization of endangered populations to new habitats primarily under Section 10(j), the *experimental population provision* (16 U.S.C. §1539(j); Ruhl 2008). Congress added the provision in 1982 in response to claims by private landowners and local governments that the ESA was too burdensome due to the politically unpopular restrictions on human actions that come with the presence of endangered species (Wolok 2001). Furthermore, the provision was meant to encourage voluntary introduction of species on private property (Doremus 1999; Goble 2001). Recent criticism of the diminished protections of Section 10(j) for managing endangered species under climate change (Chapron & Samelius 2008), disregarded the political importance of private property rights (Raymond & Olive 2008).

The experimental population provision is beneficial for moving endangered species because it encourages the introduction of populations into formerly occupied or new habitat without the full array of legal restrictions that accompany a listed endangered species (Doremus 1999; Wolok 2001). This provision has allowed well-known and controversial experimental introductions, including the gray wolf (*Canis lupis*) and Aplomado falcon

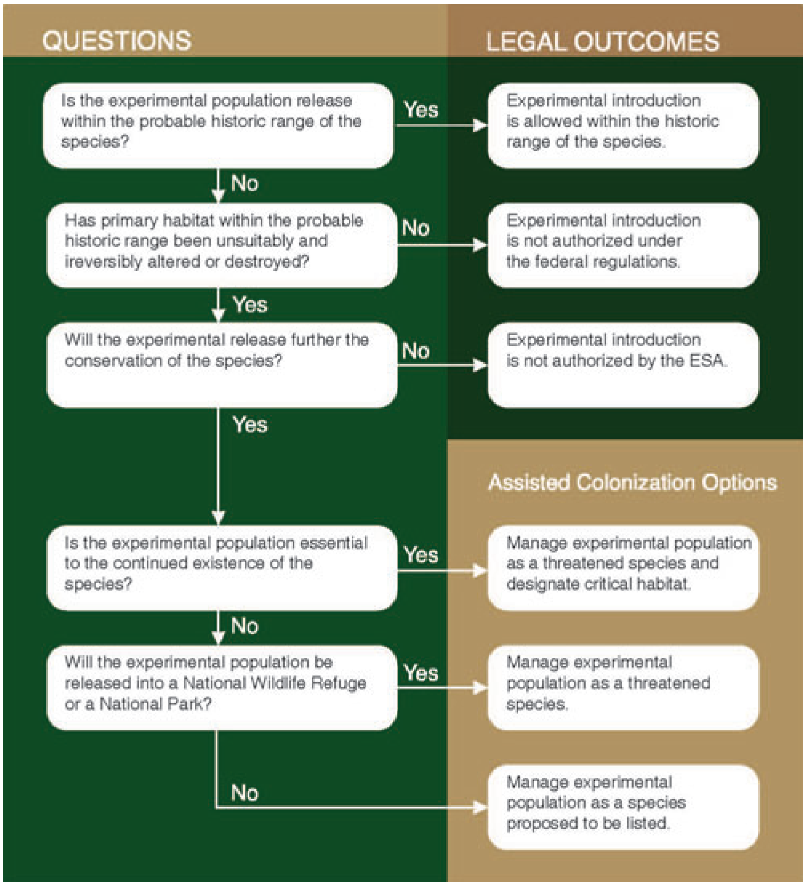

Figure 3 Current legal framework for assisted colonization of an experimental population under Section 10(j) of the Endangered Species Act (16 U.S.C. §1539(j)) and the Department of the Interior regulations pertaining to experimental populations (50 C.F.R. §17.81).

(*Falco femoralis*). Most experimental introductions are from species bred in captivity or species limited to isolated populations (Goble 2001). However, the USFWS has not yet officially used the experimental population provision as a management tool for species threatened by climate change. To understand how the ESA could be used for assisted colonization, we must examine the statutory language pertaining to experimental populations (16 U.S.C. §1539(j)) as well as the regulatory restrictions promulgated by the Department of the Interior (50 C.F.R. §17.81).

Under Section 10(j) of the ESA, an experimental population can be designated as essential or nonessential depending on whether the loss of the experimental population would reduce the likelihood of species survival (Wolok 2001). Management requirements differ depending on this designation (Figure 3). For example, a population designated as *essential* must be treated as a threatened species, which requires a critical habitat designation, prohibits "taking" individuals of the population, and requires USFWS consultation for government agency action within its range (16 U.S.C. §1539(j)(2)(C)). Conversely, a *nonessential* population has fewer management restrictions because the population is treated as a species proposed to be listed; the population is released without a critical habitat designation, without the taking prohibitions and without the USFWS consultation requirement for government action (16 U.S.C. §1539(j)(2)(C)).

The USFWS has avoided designating experimental populations as essential because of the restrictions that are placed on management and land use along with political resistance to introducing an endangered species to unoccupied habitat. Therefore, any release of a species inside or outside of its historic range under Section 10(j) is likely to be designated a nonessential experimental population by the USFWS. In addition, a nonessential designation could allow for an unobstructed option for eradication if an introduced endangered species becomes ecologically harmful in its new location (Lurman Joly & Fuller 2009). An essential designation, in contrast, provides more protection because the experimental population must be managed as a threatened species.

Section 10(j) is not mandatory for translocations (Griffith *et al.* 1989; Doremus 1999; Goble 2001; Wolok 2001) because the ESA definition of "conserve" includes "transplantation" as a tool for recovering listed species (16 U.S.C. §1532(3)). The authority granted to the USFWS is not explicitly limited to where a species might be transplanted. Therefore, transplantation can be used in instances where the administrative flexibility of Section 10(j) is not required (49 FR 33888). For example, before changes to the ESA in 1982, snail darters (*Percina tanasi*) were moved outside of the known range for the species (Etnier & Starnes 1993). For Mitchell's satyr, translocation to unoccupied sites within its historical range is a viable management option because the recovery plan requires 25 distinct populations to delist the species (USFWS 1997).

Restrictions on assisted colonization

In 1982 additions to the ESA, Congress sought to restrict the use of the experimental population provision as a means of removing protection from species and thus imposed procedural limits. Those limits, however, did not restrict the power of the agency to release species into suitable areas without considering historical distribution. The USFWS can authorize release outside the current range if "release will further the conservation of such species" (16 U.S.C. §1539(j)). However, in promulgating regulations to implement the experimental population provisions, the USFWS added a geographic restriction in 1984 that prohibits an experimental population from being introduced outside the historic range, "absent a finding... in the extreme case that the primary habitat of the species has been unsuitably and irreversibly altered or destroyed" (50 C.F.R. §17.81(a)).

The USFWS added the primary habitat restriction because the agency's position provided "that the relocation or transplantation of native listed species outside their historic range will not be authorized as a conservation measure" in cases of (1) the threat of exotic species, (2) the ESA directive "to conserve species in native ecosystems", (3) the risk of subjecting introduced populations to reduced survival chances, and (4) the contrary nature of "the spirit of Executive Order 11987, which prohibits the introduction of exotic, foreign species into the natural ecosystems of the United States" (49 FR 33890). During the comment period for the proposed rule, the National Wildlife Federation and the U.S. Bureau of Reclamation questioned the addition of the primary habitat restriction, suggesting that it was an unnecessary constraint when Congress placed no such restrictions in the ESA (49 FR 33890).

The challenge inherent to the primary habitat standard is determining the degree of change required to result in an "unsuitable and irreversible alteration." The classic example of an experimental population release outside a historic range is the nonessential experimental release of the endangered Guam rail (*Gallirallus owstoni*) (Lurman Joly & Fuller 2009). In 1989, the USFWS declared the rail's habitat indefinitely altered by the nonnative brown tree snake (*Boiga irregularis*) and a nonessential experimental population of Guam rail was introduced to the island of Rota (Goble 2001; Wolok 2001). In this case, the argument could be made that primary habitat had been unsuitably and irreversibly altered because it no longer supported a viable population.

The clear-cut impact of a nonnative, invasive predator like the brown tree snake is unlike the more diffuse impact of climate change within a fragmented landscape. Mitchell's satyr has survived because its primary habitat has not been irreversibly altered or destroyed in its totality; unoccupied wetlands and fens of high-quality exist within its historic range (Shuey 1997), although corridors for dispersal to unoccupied sites have been lost (Szymanski *et al.* 2004). The unfortunate reality under climate change is that unsuitable and irreversible alteration of primary habitat might not be observed until species extinction. The primary habitat standard does not account for climate change and inhibited dispersal within a fragmented landscape. Translocation will likely be necessary to recover Mitchell's satyr within its historic range (USFWS 1997). While assisted colonization of Mitchell's satyr is not probable under current regulatory restrictions, it could be considered due to the threat of climate change.

When assisted colonization is not restricted

Our analysis of the primary habitat restriction contains an important caveat. Currently, 613 animal species and 747 plant species are listed as threatened or endangered in the United States. Although Section 10(j) seems to be the mandatory route for introductions of these 1,360 species, it is not always applied (Doremus 1999). The endangered Florida torreya (*Torreya taxifolia*) provides an example of a species moved without the application of Section 10(j). The conifer has been planted in the southern Appalachian Mountains by some members of the Torreya Guardians (www.torreyaguardians.org) because habitat in the Florida panhandle no longer supports a viable population (McLachlan *et al.* 2007; Ricciardi & Simberloff 2009). The ESA does not restrict individuals from planting these trees outside of their native range if the seeds are acquired legally.

The Tennessee coneflower (*Echinacea tennesseensis*) is another example of moving an endangered species without using Section 10(j) (Walck *et al.* 2002). Once thought to be extinct, the species is known from only five sites in Tennessee (Walck *et al.* 2002). Nurseries are allowed to propagate and sell the coneflower through interstate commerce permitted by the USFWS (61 FR 3943; 73 FR 64628). Allowing the propagation and transport of endangered plants is counter to the rationale for adding the primary habitat restriction in 1984, which included preventing the spread of exotics and conserving species in their native ecosystems (49 FR 33890). Like the Tennessee coneflower, many garden plants already have a head start on climate change because of private cultivation (Van der Veken *et al.* 2008).

Perhaps the most successful case of assisted colonization of a plant listed under the ESA is the Virginia round-leaf birch (*Betula uber*). The first translocation of round-leaf birch occurred after the species was rediscovered in 1975 as a population of 41 trees (59 FR 59173). After the round-leaf birch was listed in 1978, the USFWS encouraged its distribution to conservation organizations and individuals (59 FR 59173). Despite protection of its habitat by agencies and landowners, the natural population of round-leaf birch declined to eight trees in 2003 (www.fws.gov/northeast/pdf/vabirch.pdf). However, because assisted colonization established 20 populations on U.S. Forest Service land, the USFWS reclassified round-leaf birch from endangered to threatened in 1994 (59 FR 59173).

Some species might be poor candidates for assisted colonization, but could benefit from translocation within historic ranges to reduce their vulnerability to catastrophic events associated with climate change, such as drought. An example is the endangered Rio Grande silvery minnow (*Hybognathus amarus*) (RGSM), once one of the most abundant fish in the Rio Grande drainage (Bestgen & Platania 1991; Cowley *et al.* 2006). The RGSM declined primarily because dams changed the Rio Grande ecosystem, fragmenting RGSM populations and reducing adult lifespan (Cowley *et al.* 2006, Dudley & Platania 2007, Shirey *et al.* 2008). The RGSM was recently introduced within its historical range as a nonessential experimental population in Big Bend National Park, Texas, as part of a recovery plan to delist the species by establishing three self-sustaining populations for a period of 10 years (73 FR 74357). While translocation is necessary for recovery, RGSM is likely a poor candidate for assisted colonization to neighboring drainages because of potential impacts on similar *Hybognathus* species. For example, the RGSM was extirpated from the Pecos River in New Mexico and Texas, within 10 years of the introduction and invasion of the congeneric plains minnow (*Hybognathus placitus*) (Cowley 2006).

Policy options and implications

Regulatory restrictions placed on assisted colonization might be lesser obstacles to overcome than political and scientific resistance. Political opposition can include concern over costs of managing populations, resistance of landowners and local governments to introducing endangered species, and concern over species invasiveness. The threat of invasive species, in particular, raises legitimate scientific concern about assisted colonization. Ricciardi and Simberloff (2009) argue that assisted colonization is not viable as a conservation strategy because (1) species translocations can erode biodiversity and disrupt ecosystems, (2) planned introductions carry high risks, (3) risk assessments and decision frameworks are unreliable, and (4) the lack of power in predicting species invasiveness suggests that assisted colonization is ecological gambling and should be avoided as the precautionary principle. Assisted colonization contains risks, but it seems ironic that the species meant to be protected by the ESA could be harmed by its restrictions, whereas species that are not listed or are privately owned (e.g., plants) can often be moved freely with few exceptions. Because private organizations are already moving species to plan for climate change, a comprehensive approach is needed for dealing with translocation and assisted colonization, regardless of whether moving species is viable as a conservation strategy.

The harsh reality for endangered species is that interactions between habitat loss and climate change will likely cause extinctions and range contractions within this century (Parmesan 1996; McLaughlin *et al.* 2002; Thomas *et al.* 2004; Mortiz *et al.* 2008; Ohlemüller *et al.* 2008). In a review of range shifts of 35-nonmigratory European butterfly species in the past century, Parmesan *et al.* (1999) showed that 63% shifted northwards by 35–240 km, with 29% remaining stable at northern and southern boundaries, 6% shifted southwards, and 3% extending at both boundaries. Even though assisted colonization might only be a bandage for species with well-studied life histories, these examples demonstrate the need for reviewing environmental legislation in the context of climate change. Natural resource managers are facing the near-term prospect that anthropogenic climate change will substantially alter ecosystems.

In the United States, elected representatives have recognized the impact that climate change will have on species. In 2007, members of the 110th U.S. Congress introduced bills in the House and Senate titled “Global Warming Wildlife Survival Act” (HR 2338; S 2204). The purpose of the proposed act was to require the Department of the Interior to develop a national strategy to assist wildlife populations and their habitats in adapting to climate change. As lawmakers consider new legislation, management agencies can work within the current legal frameworks to plan for the impacts of climate change. For example, the USFWS might wish to reexamine the regulation that restricts assisted colonization to species whose primary habitat has been unsuitably and irreversibly altered or destroyed; indeed, the USFWS has the power to remove that restriction. In assessing regulations on assisted colonization, lawmakers and management agencies should consider (1) whether assisted colonization is biologically desirable, (2) whether it is politically palatable, and (3) under what conditions it should be implemented.

Assisted colonization could be a viable management option to offset the human-caused and inseparable problems of habitat fragmentation and rapid climate change. Recent attempts at assisted colonization for two butterflies in the United Kingdom have been successful; marbled white (*Melanargia galathea*) and small skipper (*Thymelicus sylvestris*) populations persist 7 years after initial introduction within 65 km of historic ranges (Willis *et al.* 2009). However, we advocate careful consideration before government agencies or conservation groups move endangered species affected by climate change because of the threat of species becoming invasive (Lodge & Shrader-Frechette 2003; Mueller & Hellmann 2008; Ricciardi & Simberloff 2009). Movement of endangered species to areas outside of current and historic distributions should not occur without thorough risk assessment for the habitat where introduction is planned (Hoegh-Guldberg *et al.* 2008). Population introductions on the periphery or outside of a species range have lower success rates than when a population is introduced in the core of its historic range (Griffith *et al.* 1989). Therefore, if assisted colonization is deemed acceptable for an endangered species, it should be considered long before it becomes a last resort for species survival.

Acknowledgements

We thank C.J.A. Bradshaw, M.A. Brueseke, A.J. Fowler, J.J. Hellmann, J.S. McLachlan, J.C. Nagle, J.L. Nishimura, S.B. Pralle, J.A. Shuey, and three anonymous referees for useful comments on previous versions of this manuscript. F.T. Conroy assisted with graphic design. P.D.S. was supported by fellowships from the National Science Foundation (IGERT) and the UND Center for Aquatic Conservation.

References

Barton, B.J., Bach C.E. (2005) Habitat use by the federally endangered Mitchell's satyr butterfly (*Neonympha mitchellii mitchellii*) in a Michigan Prairie Fen. *Am Midl Nat* **153**, 41–51.

Bestgen, K.R., Platania S.P. (1991) Status and conservation of the Rio Grande silvery minnow, *Hybognathus amarus*. *Southwest Nat* **36**, 225–232.

Chapron, G., Samelius G. (2008) Where species go, legal protections must follow. *Science* **322**, 1049–1050.

Cowley, D.E. (2006) Strategies for ecological restoration of the middle Rio Grande in New Mexico and recovery of the endangered Rio Grande silvery minnow. *Rev Fish Sci* **14**, 169–186.

Cowley, D.E., Shirey P.D., Hatch M.D. (2006) Ecology of the Rio Grande silvery minnow (Cyprinidae: *Hybognathus amarus*) inferred from specimens collected in 1874. *Rev Fish Sci* **14**, 111–125.

Doremus, H. (1999) Restoring endangered species: the importance of being wild. *Harv Envtl L Rev* **23**, 1–92.

Dudley, R.K., Platania S.P. (2007) Flow regulation and fragmentation imperil pelagic-spawning riverine fishes. *Ecol Appl* **17**, 2074–2086.

Etnier, D.A., Starnes W.C. (1993) *The fishes of Tennessee*. The University of Tennessee Press, Knoxville, Tennessee.

Fischer, J., Lindenmayer D.B. (2007) Landscape modification and habitat fragmentation: a synthesis. *Global Ecol Biogeogr* **16**, 265–280.

Goble, D.D. (2001) Experimental populations: reintroducing the missing parts. Page 379–399 in D.C. Baur & W.M.R. Irvin, editor. *The Endangered Species Act: law, policy, and perspectives*. ABA Publishing, Chicago, Illinois.

Griffith, B., Scott J.M., Carpenter J.W., Reed C. (1989) Translocation as a species conservation tool: status and strategy. *Science* **245**, 477–480.

Hoegh-Guldberg, O., Hughes L., McIntyre S. *et al*. (2008) Assisted colonization and rapid climate change. *Science* **321**, 345–346.

Hulme, P.E. (2005) Adapting to climate change: is there scope for ecological management in the face of a global threat? *J Appl Ecol* **42**, 784–794.

Hunter, M.L. Jr. (2007) Climate change and moving species: furthering the debate on assisted colonization. *Conserv Biol* **21**, 1356–1358.

Kerr, J.T., Cihlar J. (2004) Patterns and causes of species endangerment in Canada. *Ecol Appl* **14**, 743–753.

Kerr, J.T., Deguise I. (2004) Habitat loss and the limits to endangered species recovery. *Ecol Lett* **7**, 1163–1169.

Lande, R. (1998) Anthropogenic, ecological and genetic factors in extinction and conservation. *Res Popul Ecol* **40**, 259–269.

Lodge, D.M., Shrader-Frechette K. (2003) Nonindigenous species: ecological explanation, environmental ethics, and public policy. *Conserv Biol* **17**, 31–37.

Lurman Joly, J., Fuller F. (2009) Advising Noah: a legal analysis of assisted migration. *Envtl L Rep News Anal* **39**, 10413–10425.

McLachlan, J.S., Hellmann J.J., Schwartz M.W. (2007) A framework for debate of assisted migration in an era of climate change. *Conserv Biol* **21**, 297–302.

McLaughlin, J.F., Hellmann J.J., Boggs C.L., Ehrlich P.R. (2002) Climate change hastens population extinctions. *Proc Natl Acad Sci USA* **99**, 6070–6074.

Moritz, C., Patton J.L., Conroy C.J., Parra J.L., White G.C., Beissinger S.R. (2008) Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. *Science* **322**, 261–264.

Mueller, J.M., Hellmann J.J. (2008) An assessment of invasion risk from assisted colonization. *Conserv Biol* **22**, 562–567.

Ohlemüller, R., Anderson B.J., Araújo M.B. *et al.* (2008) The coincidence of climatic and species rarity: high risk to small-range species from climate change. *Biol Lett* **4**, 568–572.

Parmesan, C. (1996). Climate and species range. *Nature* **382**, 765–766.

Parmesan, C., Ryrholm N., Stefanescu C. *et al*. (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature* **399**, 579–583.

Pörtner, H.O., Farrell A.P. (2008) Physiology and climate change. *Science* **322**, 690–692.

Raymond, L., Olive A. (2008) Landowner beliefs regarding biodiversity protection on private property: an Indiana case study. *Soc Nat Resour* **21**, 483–497.

Ricciardi, A., Simberloff D. (2009) Assisted colonization is not a viable conservation strategy. *TREE* **24**, 248–253.

Richardson, D.M., Hellmann J.J., McLachlan J.S. *et al*. (2009) Multidimensional evaluation of managed relocation. *Proc Natl Acad Sci USA* **106**, 9721–9724.

Ruhl, J.B. (2008) Climate change and the Endangered Species Act: building bridges to the no-analog future. *Boston Univ Law Rev* **88**, 1–62.

Shirey, P.D., Cowley D.E., Sallenave R. (2008) Diatoms from gut contents of museum specimens of an endangered minnow suggest long-term ecological changes in the Rio Grande (US). *J Paleolimnol* **40**, 263–272.

Shuey, J.A. (1997) Conservation status and natural history of Mitchell's satyr, *Neonympha mitchellii mitchellii* French (Insecta: Lepidoptera: Nymphalidae). *Nat Areas J* **17**, 153–163.

Szymanski, J., Shuey J.A., Oberhauser K. (2004) Population structure of the endangered Mitchell's satyr, Neonympha mitchellii mitchellii (French): implications for conservation. *Am Midl Nat* **152**, 304–322.

Thomas, C.D. *et al*. (2004) Extinction risk from climate change. *Nature* **427**, 145–148.

U.S. Fish and Wildlife Service. (1997) *Recovery plan for Mitchell's satyr butterfly (Neonympha mitchellii mitchellii French)*. Ft. Snelling, MN.

Van Der Veken, S., Hermy M., Vellend M., Knapen A., Verheyen K. (2008) Garden plants get a head start on climate change. *Front Ecol Environ* **6**, 212–216.

Walck, J.L., Hemmerly T.E., Hidayati S.N. (2002) The endangered Tennessee purple coneflower, *Echinacea tennesseensis* (Asteraceae): its ecology and conservation. *Native Plants J* **3**, 54–64.

Willis, S.G., Hill J.K., Thomas C.D. *et al.* (2009) Assisted colonization in a changing climate: a test-study using two U.K. butterflies. *Conserv Lett* **2**, 45–51.

Wolok, M.S. (2001) Experimenting with experimental populations. Pages 359–377 in D.C. Baur & W.M.R. Irvin, editor. *The Endangered Species Act: law, policy, and perspectives*. ABA Publishing, Chicago, Illinois.

Editor: Ms. Sarah Pralle

