Climate Change and Species Conservation

Introduction

A primary purpose of wilderness and protected areas is the conservation of biodiversity. This entails not only diversity in general, but the well being of specific species found within their boundaries, especially those which are rare or endangered, or that are characteristic of the region, ecosystem, or location. Historically, conservation of species of interest has been based upon a set of static determinants – habitat size and quality, population size, the ability of individuals to move from one area to another. However, under the range of climate change scenarios wilderness and protected areas worldwide now face, these baseline conditions are subject to change, and continued biodiversity conservation may in many cases require active management that takes into account these changing conditions.

The balance of scientific evidence shows that changes in temperature and precipitation regimes will affect species in multiple ways. A 2006 review of research on this topic confirms that a "significant impact from recent climatic warming is discernable in the form of long-term, large-scale alteration of animal and plant populations" (Parmesan 2006). A 2003 review of research from around the world found that 59% of 15,989 studied species showed measurable changes in climate-related variables over the past century (Parmesan and Yohe 2003). In addition climate change interacts with other drivers, such as habitat fragmentation, pollution, and changes to water regimes or nutrient cycling in often-unpredictable ways.

Researchers are attempting to predict the ways in which species will respond to these interacting forces, and the outcomes of these studies will be used to inform management options and decisions. However, strategies for species conservation in a changing environment will involve a significant measure of uncertainty, and incorporating this uncertainty into management plans is crucial to successful adaptation.

Impacts of climate change on species

Range shifts

Species have ranges that are limited by environmental conditions, geographical barriers, food source and pollination requirements, and predation or competition. It is not always evident what limits species ranges, but in many species, high latitude and high altitude boundaries are correlated with environmental conditions, such as temperature, precipitation, or length of growing season.

There is accumulating evidence that recent climate change is leading to changes in the distributions of species. These can be movements of species into areas where they were not previously found, the disappearance of species from a region where they once were, or a shift in the abundance and location of individuals within a species range (Parmesan 2006). A 2003 review of such research found that the majority of current ongoing range shifts are in the direction of the poles; in the northern hemisphere species' northern boundaries are moving north at an average of 6.1 km/decade (Parmesan and Yohe 2003). These movements are seen across all taxa studied, but are most pronounced in species which are highly mobile, such as birds and butterflies. The endangered Edith Checkerspot butterfly in California, for example, has apparently shifted its range 92 km northward in the past decade (Parmesan 1996). In addition to movement toward the poles, many species are moving steadily upward in elevation, and an average rate of 6.1 m per decade (Parmesan and Yohe 2003). This trend has been seen in birds in

Costa Rica, herbaceous plants in the alps, and treelines in the Canadian Rockies (Pounds 1999, Pauli 196, Luckman 2000). A 2008 study in the Santa Rosa mountains of California found that average elevation of dominant plant species rose by approximately 65 meters over a 30 year period, linked to no other forces except local warming trends (Kelly 2008).

These direct effects of climate on species distributions are compounded with the indirect effects of species interactions. Species not directly affected by climate may be affected by predators, prey, pollinators, and competitors whose ranges do experience climate-induced shifts (Thomas 2010). Species have widely varying responses to changes in temperature and precipitation, shifting ranges at different paces or along different pathways (Preston 2008). This has the potential to disrupt species interactions of all kinds. Finally, changes in species distribution depend on the ability of a species to move into new territory. This process may be slowed or halted by poor dispersal and colonization abilities inherent to the species, as well as by habitat fragmentation and land-use change in the areas surrounding its current range (Root and Schneider 2006).

A primary concern for the conservation community is that many species are likely in the process of moving out of the reserves, parks, and wilderness areas designed to protect them. A 2003 study predicted that US national parks may lose up to 20% of the mammal species currently within their boundaries (Burns 2003). The model predicts that while some of the most northern and heterogeneous parks, such as Yellowstone, may gain additional species, national parks as a whole will lose an average of 8.3 mammal species per park.

Phenological shifts

Specific temperature or precipitation cues are essential for breeding, reproduction, and other behavioral traits in many plant and animal species. In plants, timing of spring events such as budding and flowering are often cued by temperature, and occasionally by precipitation. In animals, food availability, timing and rates of reproduction, and migratory patterns are often driven by climatic cues. In the majority of cases, increased temperature has the potential to accelerate these processes.

Recent warming effects phenology in many species worldwide. An analysis of 143 studies found that, on average, species are beginning spring events earlier in the year at a rate of 5.1 days per decade, with many bird species shifting their schedule by as many as 24 days per decade (Root 2003). Migratory birds in particular face challenges in this respect, as the timing of migrations is dependent on water, food, and habitat availability at specific times along migration routes (Inkley 2004). Studies have shown that spring migrations among many species have shifted 1.3-4.4 days earlier per decade (Inouye 2000). Warmer temperatures also result in a lengthened growing season; a 2006 review of 866 studies found that, in the northern hemisphere, the growing season (measured as the time between the last spring and first fall frosts), has grown longer at a rate of 1 to 5 days per decade since 1951 (Parmesan 2006). This will have effects on ecosystem productivity, competitive abilities of plant species, and fluctuations in population growth rates and abundances of animal species.

Evolution

The question arises of whether species can themselves adapt to new conditions through genetic processes of evolution. Estimates vary widely on the extent of species' ability to evolve to keep pace with rapid climate change. There is some evidence that evolutionary changes are already occurring, most noticeably the higher frequencies of already-existing heat-tolerant genotypes in the core of species ranges, and a trend toward greater dispersal distances (Parmesan 2006). However, there is mounting belief that evolution to climate related traits may be slow or difficult. In many cases the genetic variability necessary for evolution may not be present within a species, if new conditions are outside of that species' 'experience.' For example, the range of budburst dates in beech and pine tree populations was recently found to be too narrow to allow these species to track changes in climate (Billington and Pelham 1991, Savolainen 2004). Species with small population sizes, isolated or fragmented ranges, or long generation times are poorly suited toward rapid climate-induced evolution (Jump 2005, Skelly 2007).

Extinction

A 2004 model of the associations between climate and species distributions worldwide found that, under many climate change scenarios, 21-52% of species would completely lose their habitat (Thomas 2004). As species experience environmental change, altered species interactions, and habitat change across their historic ranges, they will be faced with the pressures of moving (range shifts) or adapting (evolution). If a species is unable to do either of these well or quickly, there is a likelihood that it will face extinction. Especially at risk are narrowly endemic species, those with small ranges or specific habitat requirements, populations on the edges of species ranges, species in fragmented landscapes, and poor dispersers (Griffith 2009). A recent model predicts that, worldwide, every degree of warming will lead to an increase in bird extinctions of 100–500 species (Sekercioglu 2008), and a model of climate change effects on vertebrate species in the Americas predicts 11-X% species loss (Lawler 2009). Researchers have already noted the disappearance of local populations or severe population reduction in a number of charismatic or endangered species, including white-tailed ptarmigans in Rocky Mountain National Park, and bighorn sheep in parks and preserves in California and the southwest (Saunders 2007). In addition, climate change has the potential to compound extinction risk from numerous other factors, from pollution to habitat destruction (Brook 2008).

Outcomes for species in the absence of active management

The cumulative effects of climate change will have drastic effects on species of conservation concern. Under current management strategies, without adopting specific climate-change focused management techniques, the species composition of many protected areas will begin to look markedly different. Many species, especially those with strong dispersal and colonization abilities, will shift their ranges out of existing reserves, parks, and wilderness areas. In some reserves, new species will migrate into existing boundaries, with potentially disruptive effects on existing biota. Species that are unable to move their ranges, due either to poor dispersal abilities or landscape fragmentation, may be able to adapt to changing conditions, but a significant percentage will likely face extinction. Increasing mismatches between predators and prey, timing of food supply and reproduction, or novel competing species, will lead to a further set of migrations, adaptations, or extinctions. As a result of these shifts, wilderness and protected areas will contain a set of plants and animals largely different from historical communities. They will include more species from lower latitudes and elevations, and will favor species with high dispersal and colonization abilities, and those with wide ranges and environmental tolerances. In some cases, entire biomes will transform into alternate states, characterized by new suites of vegetation and fauna.

Management for climate change adaptation

Given a changing climate, and increasingly threatened species and populations, land managers and policy makers are faced with a complex set of decisions. They can choose to accept these changes as a set of natural processes, and accept the possibility of extinctions and major shifts in biota, while maintaining a dedication to hands-off management that minimizes human interference. Or they can choose to interfere, and exert human intention on a landscape in order to protect and retain species and ecosystems which they believe are valuable and irreplaceable, while accepting any unintended consequences of their actions. In addition, since processes such as extinction can happen rapidly and unexpectedly, decision-makers must balance the necessity of caution and deliberation with the risk of sudden and irreversible ecological change. In each case, decisions by land managers, policy-makers, and conservationists are set amidst a dense landscape of political and economic concerns, in which stakeholders have competing values and interests, and different metrics for weighing the risks and benefits of conservation strategies and management approaches. The decision of when, and how, to actively manage for climate change adaptation must be made with acceptance of the risk and uncertainty inherent in our ability to understand and manage complex systems, and must take into account both political and economic feasibility. This section outlines a number of adaptation strategies suggested and discussed in the scientific and conservation literature.

Select and design new protect areas to account for changing conditions

The consensus among studies on species conservation under climate change is that the creation of more and bigger parks, reserves, and wilderness areas will increase the ability of species to move, adapt, and find appropriate habitat for survival and reproduction (Heller 2009). The establishment of new protected areas can protect many of the species predicted to go extinct under various climate change scenarios (Peterson 2003) and, while chances of complete habitat loss for a given species within a protected area are high, a network of large protected areas will be likely to provide habitat for more than 90% of species (Hole 2009).

The location of new land acquisitions is critical to the successful protection of species, and research offers a suite of tools and guidelines for selecting the most appropriate locations. There are two main strategies recommended. The first is to use models of the predicted distributions of key species to situate new land acquisitions in places where species *will* be in the future. Such models use both predicted climate change scenarios and information on the climatic tolerances and life history information of species to predict future species distributions. For many species, predicted ranges show large overlap with current ranges and protected areas, suggesting increased conservation focus on those regions of overlap (Vos 2008). Other species are predicted move outside of current reserve boundaries, necessitating the formation of new reserves.

The question arises of which species are selected for modeling upon which to base land acquisition and the design of reserves. Possibilities are specifically charismatic or endangered species, or species which play a strong ecological role in the community. However, a number of studies suggest that such ‘umbrella species’ approaches, in which one species is used for planning purposes in the hope that strategies for its conservation will protect other species as well, may be ineffective under a climate-change future in which species respond in individual ways to complex environmental change (Carroll 2010).

A second approach to the question of where and how to designate protected areas in a changing climate is to focus on the landscape itself, rather than species (Beier 2010). Regions with high variability in elevation, slope, aspect, vegetation, soil type, and moisture levels will provide more possibilities for habitat even as conditions change, and allow species and populations to maintain habitat within the landscape (Halpin 1997, Lawler 2009). Land acquisition along altitudinal or environmental gradients would do more to maintain habitat for a number of species under a range of conditions than general extension of reserve boundaries. Other landscape features to prioritize in conservation are those that moderate local climate, such as forests and riparian areas, regions that are predicted to change very little under global warming projections, known as climate refugia, and transition zones between different vegetation types (Hansen 2009). Regions of high productivity, key water sources, and important migration corridors are also identified as priorities for landscape-based reserve design (Olson 2009). It is generally noted, however, that conservation approaches based on preserving landscape heterogeneity are not necessarily effective when dealing with very rare or locally endemic species; in such cases species-based and landscape-based approaches are best used in coordination (Beier 2010).

In addition to species-driven and landscape-driven strategies for determining where to focus efforts in an uncertain future, a new conversation is arising about dynamic protected areas, in which boundaries are flexible and moveable over space and time. Proposals for dynamic reserves include a combination of fixed and dynamic spatial elements (Hannah and Hansen 2005). The core of the reserve is fixed, and managed traditionally, while dynamic elements may vary in land use history and current use patterns and may involve conservation easements or concessions, with sets of restrictions that can be reassessed, triggered, or removed over time (Hannah 2008).

Dynamic regions may shift in land use, from plantation to natural forest, or low intensity agriculture to pasture, or may change in ownership through land trades (Halpin 1997). In order to be relevant to climate change planning, these landowner agreements much be coordinated over large areas, and involve numerous agencies and stakeholders.

A final point of interest in the discussion of reserve design is the issue of connectivity between protected areas. Traditionally, large scale connectivity via corridors or chains of reserves at regional or continental scales have been viewed as a crucial aspect of species conservation. However, under various climate change scenarios, many researchers believe that the unpredictable and uncoordinated ways in which species will shift and migrate create such a high level of uncertainty about the design of corridors, that such large-scale strategies may be less effective and cost-efficient than focusing on habitat preservation within reserves and between nearby reserves (Hannah 2008).

Encourage compatible land use outside protected areas

As described above, many species will respond to climate change by shifting their ranges over long distances. In many cases, species will move between protected areas, through many different land-use types. Scientists, land managers, and policy-makers are involved in active discussion on ways to make the landscape surrounding resources more hospitable for species of concern. Strategies include the protection of riparian corridors, railway lines, and hedgerows in farmlands, as well as maintaining water sources and minimizing construction of new roadways in key areas (Heller 2009). Possible initiatives involve cooperation between conservation agencies and landowners to adapt agricultural and forestry practices in areas between reserves to be more conducive to the movement of key species, through buffers, rotational land use, and less-intensive production strategies (Lindenmayer 2010). Another focus is on opportunistic restoration of degraded areas and abandoned fields.

Initiatives to manage landscapes outside of the boundaries of parks and wilderness areas require coordination with various stakeholders and the public, as well as actions at local, regional, and national levels. In this cooperative effort, land managers play crucial roles by identifying areas of specific concern, facilitating forums for discussion and debate, and building relationships with stakeholders and local and regional scales. Implementation of landscape-level initiatives requires information and monitoring, not simply of ecological data, but of socioeconomic data regarding the competing values of the land in question.

Minimize compounding stressors

Studies investigating strategies for conserving species in the face of climate change are near-unanimous in their assertion that, in the majority of cases, direct effects of climate change are exacerbated by numerous other environmental stressors, including land fragmentation, pollution, habitat destruction, and changes in the abundance of predators, prey, or competitors. Mitigating these stressors provides species with a far greater ability to maintain populations under historical conditions as well as to adapt to environmental change.

There are a number of actions that can be taking to lessen the effects of climate change on ecosystems and species. These include maintaining or restoring forests and riparian areas which have cooling effects on local microclimates (Heller 2009), and maintaining water availability and fire regimes (Lindenmayer 2010). Such interventions also provide connectivity for wildlife migrations (Mulholland 1997).

Landscape fragmentation can greatly increase the severity of warming effects on populations, and decreasing habitat loss and encroachment on natural areas will allow many populations to retain abundances and range enough to be more robust to change (Lawler 2009). Regulation of pollutants in air, water, and soil will also allow populations to maintain healthy abundances and distributions, allowing them to better weather environmental changes.

Actively manage populations

Species that are unable to migrate or adapt to rapidly changing conditions face a high risk of extinction. In light of the rapid pace of climate change and fragmented nature of wilderness and protected landscapes, intensive management of habitat and populations may be necessary to maintain the presence of valuable or endangered species in their current or historic locations. This raises the perpetual and delicate questions of the balance between minimizing human interference in wilderness, and addressing the danger of losing the species within them. A number of strategies have been proposed to maintain species in current locations and abundances in a changing climate.

The most prevalent suggestions involve the maintenance and supplementation of waterways and water sources. Riparian restoration has potential to moderate local temperatures and improve landscape connectivity (Griffith 2009). This may include stream channel reconfiguration or dam removal to improve habitat for aquatic and riparian species (Lawler 2009). Suggestions also include providing watering holes or irrigation for impacted species, such as migratory songbirds or endemic vegetation (Cole chp 11).

Other possible interventions include habitat and vegetation management. Managed burns can be used to promote regeneration and adaptation of desired and representative tree species

(Frelich 2009). Forest thinning, grazing exclosures, and snow fences can create conditions necessary to maintain species of concern (Lawler 2009). A 2009 study on boreal forests in northern Minnesota found that, in models, managing deer browsing could buffer a number of tree species from climate change impacts (Frelich 2009).

A third set of management prescriptions involve direct management of population levels through feeding or culling individuals. A 2009 report on the National Wildlife Reserve System suggested the propagation of supplementary vegetation to provide a food source for migrants whose timing of migration and food availability is disrupted by climate change (Griffith 2009). Others suggest providing supplemental forage for endangered species and to encourage dispersal along corridors. In other cases, populations may need to be decreased to maintain appropriate resources and habitat. A 2002 study in Rocky Mountain National Park predicts a drastic increase in elk populations under warming scenarios, and suggests that culling these populations may be necessary to protect vegetation and other species dependant on it (Wang 2002).

A final set of recommendations involve the direct management of species' genepools through breeding programs. Broadening the genetic variability within populations of a species by bringing together individuals from different portions of the species' range has the potential to make that species better able to adapt to changing conditions (Lawler 2009). There is, however, a great deal of uncertainty surrounding the issue of which populations have the most value for the conservation of genetic diversity. Many identify the core of the species range, where the greatest genetic variability is likely to be located (Heller 2009). Others focus on the northern or 'leading' edges of species ranges, where the first waves of range expansion will occur, populations are potentially better adapted for dispersal, and more cold-weather adapted populations are at risk (Gibson 2009). Still others identify trailing, or southern range boundary populations, as these populations are more likely have the genetic adaptations necessary to cope with a warming climate (Hampe 2005). However, these researchers are in agreement that maintaining population sizes above an acceptable minimum remains a necessity for successful adaptation (Hannah 2002).

Assisted migration; species relocation

Rising to the forefront of the discussion on adaptation strategies for species conservation in the face of a changing climate is the controversial issue of actively moving species from one place to another, known as assisted migration, assisted colonization, or managed relocation. This concept again strikes at the issue of whether to actively manage wilderness and protected areas to maintain populations in a changing world or to accept ongoing processes of migration and extinction. In addition to broad concerns about human interference in landscapes which are designed to be free of human intention, there are more specific concerns about negative effects on existing plant and animal communities in the region to which species are moved, the introduction of aggressive invasive species, and disruption of ecosystem functions such as nutrient cycling, fire, and erosion (Riccardi and Simberloff 2009a). However, many believe that, due to the rapid pace of current environmental change, compounded with landscape fragmentation which may prevent natural range shifts, assisted migration may be the only option to prevent extinction in some cases.

The first question in the decision-making process is whether the focal species is an acceptable candidate. Candidates for relocation should be at a high risk for extinction under do-nothing scenarios, and this extinction risk should be tied specifically to climate change, rather than to pollution, habitat destruction, or other forces (Hunter 2007). Prime candidates are species with limited natural dispersal and colonization ability, and those whose natural habitat is becoming rare or fragmented (Hoegh-Guldberg 2008). Candidate species are those which do not play strong ecological roles in their communities, as such species likely to have major disruptive effects on the biota of the receiving site (Mclachlan 2002). Successful relocation candidates are those that will cope well with climate change, such as those that are genetically variable and have broad ecological tolerances and adaptable behaviors (Vitt 2010).

Even if these characteristics are met, there is uncertainty involved in relocating a species. A 2000 review of ongoing relocation projects looked at 180 studies of specific relocation projects, largely involving birds and mammals (Fischer 2000). The review found that about quarter were considered successful and a quarter were classified as failures. The remainder of the studies had not yet reached a conclusive position, but these data suggest that roughly half of relocations do not achieve stated objectives. However, success rates were considerably higher for species relocated from wild populations than for those from captive populations (Fischer 2000), suggesting this as another criterion for selecting populations to relocate.

The second consideration is whether the site to which relocated species are moved is acceptable for the project. The level of human disturbance of the relocation site is a primary consideration. Moving species into another wilderness area is a risky and often unpopular proposition, as the effects on the existing biota are unknown. At the other end of the spectrum, moving species into highly disturbed areas may be more palatable, however it is less likely that a species would successfully establish there (Hunter 2007). Some practitioners are designing relocations as part of restoration projects, for example including ‘migrating’ species into replanting efforts after fires (West 2009). In addition, the geographic location and isolation of the site is an important factor. Moving species from one fragmented site to another is of limited long-term utility; relocation sites are most effective if they are well connected and include variable habitat. The potential for the introduced species to become invasive in the new site is another consideration, and research has shown that this is less likely to be problematic if the initial and receiving sites are relatively short distance from one another, and if the receiving site is large and variable (Vitt 2010). Finally, of course, evidence that a site will lie within the species’ predicted range under climate change scenarios is a necessary factor, and relies on extensive modeling and predictive methods.

Multiple parties, including land managers, government and private agencies, legislators, and the scientific community are all necessary participants in a relocation project, and the risks, costs, and benefits must be weighed and agreed upon by all parties (Richardson 2009). This is inevitably a slow and complex process, and one prevalent suggestion is, while project planning is ongoing, to take advantage of the roles of seed banks, botanical gardens, and zoos to provide populations for relocation in a last-resort scenario (Vitt 2010).

Sources:

Beier, P. and B. Brost (2010). "Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors." Conservation Biology **24**(3): 701-710.

Billington, H. and P. J (1991). "Genetic variation in the date of budburst in Scottish birch populations - implications for climate change." Functional Ecology **5**(3): 403-409.

Brook, B. W., N. S. Sodhi, et al. (2008). "Synergies among extinction drivers under global change." Trends in Ecology & Evolution **23**(8): 453-460.

Burns, C. E., K. M. Johnston, et al. (2003). "Global climate change and mammalian species diversity in US national parks." Proceedings of the National Academy of Sciences of the United States of America **100**(20): 11474-11477.

Carroll, C., J. R. Dunk, et al. (2010). "Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA." Global Change Biology **16**(3): 891-904.

Fischer, J. and D. B. Lindenmayer (2000). "An assessment of the published results of animal relocations." Biological Conservation **96**(1): 1-11.

Frelich, L. E. and P. B. Reich (2009). "Wilderness Conservation in an Era of Global Warming and Invasive Species: a Case Study from Minnesota's Boundary Waters Canoe Area Wilderness." Natural Areas Journal **29**(4): 385-393.

Gibson, S. Y., R. C. Van der Marel, et al. (2009). "Climate Change and Conservation of Leading-Edge Peripheral Populations." Conservation Biology **23**(6): 1369-1373.

Griffith, B., J. M. Scott, et al. (2009). "Climate Change Adaptation for the US National Wildlife Refuge System." Environmental Management **44**(6): 1043-1052.

Halpin, P. N. (1997). "Global climate change and natural-area protection: Management responses and research directions." Ecological Applications **7**(3): 828-843.

Hampe, A. and R. J. Petit (2005). "Conserving biodiversity under climate change: the rear edge matters." Ecology Letters **8**(5): 461-467.

Hannah, L. (2008). Protected areas and climate change. Year in Ecology and Conservation Biology 2008. **1134:** 201-212.

Hannah, L. and L. Hansen (2005). Designing Landscapes and Seascapes for Change. Climate Change and Biodiversity. L. Hannah and T. E. Lovejoy. New Haven, Yale University Press.

Hannah, L., G. F. Midgley, et al. (2002). "Climate change-integrated conservation strategies." Global Ecology and Biogeography **11**(6): 485-495.

Hansen, L., J. Hoffman, et al. "Designing Climate-Smart Conservation: Guidance and Case Studies." Conservation Biology **24**(1): 63-69.

Heller, N. E. and E. S. Zavaleta (2009). "Biodiversity management in the face of climate change: A review of 22 years of recommendations." Biological Conservation **142**(1): 14-32.

Hoegh-Guldberg, O., L. Hughes, et al. (2008). "Assisted colonization and rapid climate change." Science **321**(5887): 345-346.

Hole, D. G., S. G. Willis, et al. (2009). "Projected impacts of climate change on a continent-wide protected area network." Ecology Letters **12**(5): 420-431.

Hunter, M. L. (2007). "Climate change and moving species: Furthering the debate on assisted colonization." Conservation Biology **21**(5): 1356-1358.

Inkley, D., M. G. Anderson, et al. (2004). Global climate change and wildlife in North America. K. E. M. Galley. Bethesda Maryland, The Wildlife Society.

Inouye, D. (2000). "Climate change is affecting altitudinal migrants and hibernating species." Proceedings of the National Academy of Sciences of the United States of America **97**: 1630-33.

Jump, A. S. and J. Penuelas (2005). "Running to stand still: adaptation and the response of plants to rapid climate change." Ecology Letters **8**(9): 1010-1020.

Kelly, A. E. and M. L. Goulden (2008). "Rapid shifts in plant distribution with recent climate change." Proceedings of the National Academy of Sciences of the United States of America **105**(33): 11823-11826.

Lawler, J. J. (2009). Climate Change Adaptation Strategies for Resource Management and Conservation Planning. Year in Ecology and Conservation Biology 2009. **1162:** 79-98.

Lawler, J. J., S. L. Shafer, et al. (2009). "Projected climate-induced faunal change in the Western Hemisphere." Ecology **90**(3): 588-597.

Lindenmayer, D. B., W. Steffen, et al. (2010). "Conservation strategies in response to rapid climate change: Australia as a case study." Biological Conservation **143**(7): 1587-1593.

Luckman, B. and T. Kavanagh (2000). "Impact of climate fluctuations on mountain environments in the Canadian Rockies." Ambio **29**: 371-80.

McLachlan, J. S., J. J. Hellmann, et al. (2007). "A frmework for debate of assisted migration in an era of climate change." Conservation Biology **21**(2): 297-302.

Mulholland, P. J., G. R. Best, et al. (1997). "Effects of climate change on freshwater ecosystems of the south-eastern United States and the gulf coast of Mexico." Hydrological Processes **11**: 949-970.

Olson, D., M. O'Connell, et al. (2009). "Managing for Climate Change within Protected Area Landscapes." Natural Areas Journal **29**(4): 394-399.

Parmesan, C. (1996). "Climate and species' range." Nature **382**(6594): 765-766.

Parmesan, C. (2006). "Ecological and evolutionary responses to recent climate change." Annual Review of Ecology Evolution and Systematics **37**: 637-669.

Parmesan, C. and G. Yohe (2003). "A globally coherent fingerprint of climate change impacts across natural systems." Nature **421**(6918): 37-42.

Pauli, H., M. Gottfried, et al. (1996). "Effects of climate change on mountain ecosystems: upward shifting of mountain plants." World Res. Rev. **8**: 382-90.

Peterson, A. T. (2003). "Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences." Global Change Biology **9**(5): 647-655.

Pounds, J., M. Fogden, et al. (1999). "Biological response to climate change on a tropical mountain." Nature **398**: 611-615.

Preston, K., J. T. Rotenberry, et al. (2008). "Habitat shifts of endangered species under altered climate conditions: importance of biotic interactions." Global Change Biology **14**(11): 2501-2515.

Ricciardi, A. and D. Simberloff (2009). "Assisted colonization is not a viable conservation strategy." Trends in Ecology & Evolution **24**(5): 248-253.

Richardson, D. M., J. J. Hellmann, et al. (2009). "Multidimensional evaluation of managed relocation." Proceedings of the National Academy of Sciences of the United States of America **106**(24): 9721-9724.

Root, T. L., J. T. Price, et al. (2003). "Fingerprints of global warming on wild animals and plants." Nature **421**(6918): 57-60.

Root, T. L. and S. H. Schneider (2006). "Conservation and climate change: The challenges ahead." Conservation Biology **20**(3): 706-708.

Saunders, S., T. Easley, et al. (2007). "Losing ground: western national parks endangered by climate disruption." The George Wright Forum **24**(1): 41-81.

Savolainen, O., F. Bokema, et al. (2004). "Genetic variation in cessation of growth and frost hardiness and consequences for adaptation of *Pinus sylvestris* to climatic changes." Forest Ecology and Management **179**: 79-89.

Sekercioglu, C. H., S. H. Schneider, et al. (2008). "Climate change, elevational range shifts, and bird extinctions." Conservation Biology **22**(1): 140-150.

Skelly, D. K., L. N. Joseph, et al. (2007). "Evolutionary responses to climate change." Conservation

Biology **21**(5): 1353-1355.

Thomas, C. D. (2010). "Climate, climate change and range boundaries." Diversity and Distributions **16**(3): 488-495.

Thomas, C. D., A. Cameron, et al. (2004). "Extinction risk from climate change." Nature **427**(6970): 145-148.

Vitt, P., K. Havens, et al. (2010). "Assisted migration of plants: Changes in latitudes, changes in attitudes." Biological Conservation **143**(1): 18-27.

Vos, C. C., P. Berry, et al. (2008). "Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones." Journal of Applied Ecology **45**(6): 1722-1731.

Wang, G. M., N. T. Hobbs, et al. (2002). "Impacts of climate changes on elk population dynamics in Rocky Mountain National Park, Colorado, USA." Climatic Change **54**(1-2): 205-223.

West, J. M., S. H. Julius, et al. (2009). "US Natural Resources and Climate Change: Concepts and Approaches for Management Adaptation." Environmental Management **44**(6): 1001-1021.