



Climate Change and Ecosystem Management

Introduction

The identity of many wilderness areas, parks, and other protected areas is tied to and defined by characteristic ecosystems and landscapes. These diverse and distinct biomes, from alpine tundra and boreal forest to sagebrush steppe and native prairie, are the result of a specific set of plant and animal species in constant interaction with each other and with their environment. As the climate changes, and species move, adapt, or decline, these interactions will change. In many cases, these changes will trigger large scale shifts in species composition, leading to the emergence of ecosystems which may look very different from those which parks and reserves were intended to protect. Management decisions made now and in the near future may greatly affect the extent to which ecosystems shift to new states, as well as the appearance and composition of newly arising ecosystems.

Impacts of climate change on ecosystems

Interacting forces of change

Climate change is predicted to have, and is already having, a profound effect on plant and animal communities in every ecosystem on the planet. A changing climate does not simply mean increased temperatures, but also changing and more variable patterns of precipitation, increases in CO₂ concentrations, and unpredictable feedbacks between these processes. These changes will affect species and communities in diverse ways, leading to the extinction of many species, as well as altered interactions between species, and potentially the creation of new ecosystems and the loss of existing ones.

Initially, a changing climate leads 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). 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 changing distributions of predators, prey, pollinators, and competitors (Thomas 2010). Species have widely varying responses to changes in temperature and precipitation, shifting ranges at different paces or along different pathways (Preston 2008). In addition, specific temperature or precipitation cues are essential for breeding, reproduction, and other behavioral traits in many plant and animal species. In the majority of cases, increased temperature has the potential to accelerate these processes, moving spring events like tree budburst and bird migrations earlier in the season. This will have effects on ecosystem productivity, competitive abilities of plant species, and fluctuations in population growth rates and abundances of animal species. Climate change is also predicted to lead to increasingly variable water availability, especially where water is dependent on snowpack, or where landscapes are likely to be affected by sea level rise or intensification of storm events (Welch 2005). In addition to the effects of warming, studies have shown increased CO₂ to lead to increased growth rates in bristlecone pines and other high elevation conifers (Hughes 2000), though effects will be different for each species (Inkley 2004). In combination with warming, increased CO₂ can have major effects on primary productivity in a number of ecosystems (McCarty 2001), however in many cases this increased productivity is predicted to drop sharply once specific thresholds of warming are reached (Inkley 2004).

Community disassembly, ecosystem shifts

Species will respond to climate change in different ways, on different time scales, and at the ecosystem level the combined responses are likely to be nonlinear, and more than a sum of each species response (Montoya 2010). In a long term forest study, tree budburst advanced only slightly, while caterpillars who ate the leaves, and birds who ate the caterpillars, moved significantly earlier, while hawks who ate the birds did not advance at all (Walther 2010). Species react asynchronously in space as well, as some will shift their ranges more quickly than others, or not at all. Such differential responses among ecologically linked species has the potential to disrupt, and potentially dismantle, ecological relationships and biotic communities. The result of these varied and unpredictable species-level reactions may be the partial or complete transformation of an ecosystem. Decoupling of predator-prey or plant-herbivore interactions may lead to one or both species disappearing or becoming more prevalent (eg Wang 2002, Frelich 2009). Changes in temperature and water regimes may favor increasing dominance of pioneer species, such as weedy plants (Welch 2005). These changes may be gradual, involving slow changes in soil qualities or moisture regimes, or sudden, following disturbances such as fire or storms and thresholds in tolerances for various species (Hagerman 2009).

In many cases, these changes may lead to the emergence of new ecosystems. In the southwest US, several sites have already shifted from grassland to shrubland as a result of changing precipitation patterns, and shortgrass steppe in Colorado is in the process of making this change, as higher temperatures are leading to decreasing productivity of the dominant native grass (McCarty 2001). Models have found that more than 40% of all protected areas in Canada are expected to experience a change in biome type (Lemieux and Scott 2005). In US national parks, models predict that subalpine forests could be replaced by temperate evergreen forests in North Cascades National Park, boreal forests could be replaced by temperate evergreen forests, shrub steppes, and savanna woodlands in Grand Teton, Rocky Mountain, and Yellowstone National Parks, and shrub steppes could largely be replaced by savanna woodlands and grasslands across the Colorado Plateau, including Arches and Bryce Canyon National Parks (Saunders 2007).

In addition to shifts from one ecological community to another, ecosystems have the potential to transition into biomes which are not familiar, and are not seen in existing communities. These ecosystems, referred to as novel or non-analogous communities, can be transitional or stable states, and can arise slowly or at sudden thresholds (Keith 2009). In these emerging ecosystems, historical conditions do not provide any guideline for management, and ecosystem properties and function are unknown and unpredictable.

Outcomes for protected ecosystems in the absence of active management

Protected areas in all climates and regions will experience shifts in the composition of plant and animal communities as climate change alters the environment, and species interactions magnify and propagate those effects. If these processes run their course, wilderness areas and reserves will see new community assemblages, losses of charismatic or rare species, shifts toward different ecosystem states, and the emergence of novel biotic communities. These shifts will in many cases favor fast-growing pioneer species, species that can cope well in variable precipitation regimes, species that are favored by high temperatures, and those with strong long-distance dispersal capabilities. In all cases, there is a high level uncertainty in predicting what

these ecosystem shifts will be, on what time scale they may occur, and what abiotic or biotic thresholds may trigger them.

Management for climate change adaptation

As the climate changes, plant and animal communities will reorganize in diverse and unpredictable ways, and land managers and policy makers will be faced with a complex set of decisions. They can choose to accept these changes as a natural set of 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 ecosystems which they believe are valuable and irreplaceable, while accepting any unintended consequences of their actions. In addition, since ecosystem shifts 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 risks and uncertainty inherent in our ability to understand and manage complex systems, and must take into account both political and economic feasibility.

Our traditional understanding of ecosystems is based on a concept of equilibrium, in which past conditions and processes provide the context and guidance for contemporary management. However, future climate patterns will not only be different, but may be increasingly variable and unpredictable, and successful management strategies must be able to address this variability and uncertainty. (Baron 2009). In addition, changes in ecosystems are likely to be nonlinear, and a crucial part of adaptation plans is to identify thresholds at which sudden changes may occur (Lindenmayer 2008). This section outlines a number of adaptation strategies suggested and discussed in the scientific and conservation literature. They fall into three broad categories: increasing the ability of an ecosystem to resist change, supporting the resilience of an ecosystem through the maintenance of key processes and functions, and facilitating shifts to new and different biotic communities.

Increase resistance to ecosystem change

An initial step in adapting ecosystem management to climate change, in many cases, is to develop strategies that increase the ability of an ecosystem to withstand change, and to retain current or historical plant and animal communities in their current ranges (Heller 2009). This strategy is most appropriate as a short-term approach, or to protect specific species when changes are predicted to be relatively minor (Galatowitsch 2009).

Resistance-based management strategies most often entail intensive management of protected landscapes. Ecosystems may be buffered from rapid environmental changes by reducing undesirable effects of fire, invasive species, or changes in water availability (Millar 2007). Fuel breaks around high risk areas, or other manipulations of fire regimes, can protect ecosystems from large-scale disturbance which may trigger state shifts (Galatowitsch 2009). Models of deciduous forests in Minnesota suggest that active management in the form of logging and harvest will reduce compositional shifts of forest tree species under mild climate change

scenarios, while harvest in combination with planting of desired species is effective under more extreme climate change (Ravenscroft 2010). When possible, reducing synchrony across a landscape, by maintaining a mixture of species, age classes, and landscape components, can be valuable in buffering a landscape from invasion or disturbance.

Management of stream flow to maintain riparian areas and artificially increasing water supplies can buffer ecosystems from increasingly frequent or severe droughts. Intensive removal of invasive species, alteration of grazing regimes, or landscape management such as tree thinning, can prevent pest outbreaks which may trigger shifts to new biotic communities. Direct control of pests through chemical treatment is another common tool. Population management, such as food provision, culling, or breeding can also bolster species which may not be favored under new climate regimes. Another prominent suggestion is the reintroduction of populations that are declining or locally extinct from nearby regions (Frelich 2009).

All of these strategies require management flexibility to account for uncertainty and variability. Representation targets for conservation must be variable, and conservation areas should be dynamic in space and time in order to capture shifting biodiversity patterns (Pressey 2007). Conservation focus should also be placed on regions which are projected to change less, and on landscape features, such as hydrologic or soil regimes, which may drive biodiversity processes.

While management to resist ecosystem change is supported by many scientists and land managers, there is growing consensus this strategy is not effective in the long term, and may actually be harmful (Heller 2009). Resistance-based responses may be ineffective if changes are more rapid than anticipated, and irreversible thresholds such as extinctions are reached (Scott and Lemieux 2005). More problematic still, management to bolster resistance may actually increase the vulnerability of the system, and decrease its ability to adapt to changing conditions (Heller). Resulting managed landscapes may become increasingly poorly adapted to new climate regimes, and sensitive to sudden changes (Millar 2007).

Support resilience of ecosystem processes

In cases in which managing to maintain current plant and animal communities is inappropriate due to ecological realities or economic or political constraints, a second suite of management strategies seek instead to support landscape resilience. Resilience in this context is defined as the capacity of a system to absorb disturbance and environmental change while retaining key ecosystem functions, processes, structure, and identity (Folke 2004). Rather than focusing conservation on species protection, efforts are instead focused on processes which maintain community structure, such as water and nutrient cycling, microclimate regulation, habitat provision, and landscape complexity.

Managing for resilience requires managers to accept a broader range of desirable outcomes, not based on individual species, and to accept new species as potential new 'natives', rather than as unwanted invaders (Heller 2009). Some research suggests that the addition of new species may make an ecosystem better able to adapt to environmental change (Cote 2010).

The majority of strategies for supporting resilience focus on maintaining diversity at all scales. Maintaining or increasing genetic diversity through corridor design or breeding programs, increases the ability of species to adapt to change (Cole 2010). Molecular methods are constantly increasing our ability to understand the genetic structure of populations, and to 'disperse' genes in ways which may improve adaptive capacity or preserve and support already-adapted populations and individuals (Rice 2003).

At the species scale, simplified ecosystems, with too few species or groups of species, are vulnerable to extreme change, as they do not efficiently utilize available resources or create complex interspecies interactions (Folke 2004). Protecting top predators or other keystone species provides stability and maintains diversity for the ecosystem as a whole, and efforts to reintroduce or increase populations of these species can have far-reaching effects for ecosystem resilience. The strength and structure of interspecies interactions affect the ability of populations to recover from disturbance (Montoya 2010). Maintaining complex, multi-linkage interactions, through large and complex reserve systems will improve the ability of species to function in the absence of any one species interaction. Another strategy for increasing ecological resilience is to focus on the maintenance of 'response diversity,' by directing conservation so as to maximize the range of responses among species to environmental change (Elmqvist 2003).

Maintaining habitat and appropriate conditions for diverse communities of dispersers, pollinators, and decomposers can help an ecosystem maintain diverse species compositions at other ecosystem levels in the face of changing conditions (Folke 2004). At the landscape scale, focusing conservation efforts on 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).

Other direct management actions can support ecosystem resilience to specific threats. Fire management can be designed to allow for recruitment of desirable tree species, rather than weedy or simplified communities (Galatowitsch 2009). Restoration efforts such as seed banking or re-vegetation after disturbances can help communities return to their prior states (Millar 2007). In some cases, tree thinning or grazing management can improve resilience to disease and fire, preventing massive burns or outbreaks which are conducive for the establishment of weedy plant communities (West 2009).

Facilitate the emergence of new ecosystems

In some landscapes, attempts to increase the resistance of the ecosystem to change, or support the resilience of the biotic community to adapt to change, are not appropriate or feasible, and managers may choose to instead work to hasten and smooth the transition of the current biotic community into one that better aligns with future climate scenarios. Advantages of this strategy are that proactive management of this type may prevent extinctions of species and populations which have difficulty weathering ecosystem transitions, and may also prevent the emergence of transition states which are weedy and simplified.

A key facet of the discussion of this category of management scenarios is our growing awareness that ecosystems are not static; rather the formation of biotic communities is a dynamic process, and biomes have formed, disassembled, and reformed throughout the history of the planet (Jackson 2009). The transition of an ecosystem into a new state is, therefore, a natural and fluid process (Manning 2009). Management to facilitate ecosystem change may mimic or enable ongoing adaptive processes such as species dispersal and migration, population mortality and colonization, changes in species dominances and community composition, and changing disturbance regimes (Millar 2007).

When maintenance of or restoration to historical conditions is no longer the goal, managers must develop new objectives for ecosystem management. Many of the possible goals focus on ecosystem processes and functions, rather than specific species assemblages (Lawler 2009). Management goals may include ecosystem complexity and stability, high biodiversity,

water and nutrient cycling, and value for recreation or beauty (Hobbs 2009). Another set of goals is to attempt to create and maintain landscapes which may mitigate effects of climate change, both globally, through CO₂ sequestration, or locally, through the formation of microclimates (Harris 2006).

Assisted migration, moving species into new regions where they are not currently present, is already being used in hundreds of cases, and can facilitate the transition to a new biotic community. This strategy includes both the relocation of animal species, and the seeding of desirable plant and tree species, often as part of restoration efforts. Both relocation of animal population and “transformative restoration” with seeds and seedlings from distant biomes, are increasingly suggested as methods for anticipating future climatic conditions in protected areas (Heller 2009). Much of this discussion focuses on ‘ecological analogs’ – species which may fill the ecological role of other species which may be unable to persist in a landscape under climate change (Parker 2010).

Another set of management approaches directly addresses physical characteristics of the landscape (Hobbs 2008). Managers may design or modify wetlands to create habitat or microclimates, or to manage hydrological flows and water tables. Other direct management options include improving soil structure through modifications of topography and water runoff, management of soil and water salinity and pH, and the supplementation of soil nutrients through leguminous plants or other pathways.

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