Climate Change and Invasive Species

Impacts of Invasive Species on Ecosystems

Invasive species are species whose populations tend to grow and spread, and cause harm to native biodiversity, the economy, or human health (USDA 1999). They are generally non-native, that is, species that have historically been located elsewhere, and have moved into a new region where they are released from predators or competitors which may have controlled their spread in their native region. Invasive species have the potential to alter ecosystem processes such as water or nutrient cycling or fire frequency. Classic examples include cheatgrass (*Bromus tectorum*), which has established in all 50 states and is highly invasive in arid western landscapes. Cheatgrass dramatically increases fire frequency in the landscapes, creating a positive feedback loop which favors further invasion, and is largely unpalatable for livestock and many wild species (Crowl 2008). Invasive species can also radically change community composition and structure by out-competing or preying upon key native species, and by utilizing available light, water, or nutrient resources (Mainka 2010). For example, zebra mussels have invaded the Great Lakes and other freshwater systems in North America, and have devastated native aquatic communities. They can also have genetic effects on closely related local populations, by hybridizing with them or genetically out-competing them. Introduced brook trout are currently a threat to the genetic integrity of native bull trout in much of the American West, and several species of ducks around the world are threatened by hybridization with introduced North American Mallard (Simberloff 2001). In some cases, invasions can lead to species extinctions, such as in the case of Asian chestnut blight virtually eliminating the American Chestnut in the US.

Invasive species represent a massive threat to protected ecosystems, and were considered one of the five major threats to ecosystem integrity in the 2005 Millennium ecosystem assessment. More than twenty-five thousand non-native plant species have been introduced into the United States in the last two centuries, and 5000 have become established in native ecosystems, including both highly disturbed urban areas and protected wilderness areas (Pimentel 2000, Dickens 2004). The economic cost of non-native species in the US has been estimated at over $120 billion each year (Pimentel *et al*. 2005). Prevention, eradication, and control of invasive species is a major environmental, political, and economic challenge (Lodge 2006).
While reserves, parks, and wilderness areas tend to have far fewer invasive species than non-protected areas (Lonsdale 1999), they are increasingly expanding into reserves, an in 2009 they were cited as a problem in 60% of Nature Conservancy projects (Randall 2010).

Relationship between climate change and invasive species

Effects of climate change on ecosystems are difficult to predict, due to both our uncertainty in climate change scenarios (the direction and magnitude of temperature and precipitation) and our uncertainty in understanding how species will respond to those changes. However, there are multiple reasons to believe that most climate change scenarios will have the effect of increasing the extent, frequency, and severity of invasive species, as well as facilitating a shift toward invasion in species that have not historically been invasive.

First, climate change will almost certainly lead to changes in the distributions of species (Parmesan 2006). The removal of temperature or moisture constraints to dispersal and survival

will allow species to move into and successfully invade new areas (Hellmann 2008). For example, warmer nighttime temperatures have lead to increased flight activity of winter pine processionary moth, an important pest of pine trees, rainfall may be increasing the distribution of the Argentine ant in California, and the invasive plant kudzu is likely to expand its range northward and westward by several hundred miles (Walther 2009, Bradley 2010).

Species range shifts will also lead to species moving out of their current distribution, or becoming more rare. This creates ecological space for other species to increase in abundance and become invasive, or for non-native invasive species to move in. It will also create the potential for species that are not currently invasive to become invasive in new environments.

Second, invasive species are inherently well suited to succeed in environments with high resource availability, predicted under climate change scenarios. Climate change will in many cases lead to a future of warmer temperatures, increased CO_2 availability, and increased Nitrogen deposition from cars and agriculture (Bradley 2009a). This increase in resource availability allows species to invade arid environments such as western shrublands and resource-limited environments such as serpentine grasslands (Dukes and Mooney 1999). Research has shown that some invasive species show a greater response to increased CO_2 than non-invaders; examples include invasive red brome in the Sonoaran desert (Weltzin 2003). In addition, invasive species have short generation times, strong dispersal abilities, and broad environmental tolerances, which will allow them to cope with rapid changes.

Third, an increase in extreme storm events, a likely outcome of a changing climate, has the potential to disperse invasive plants and insects through air or water farther and in different patterns (Hellmann 2008). Extreme weather events will also lead to increased disturbance, and invasive species generally thrive in disturbed landscapes with high light availability and fragmented native communities (Bradely 2009a).

Assessment and management implications for climate change and invasive species

In a context of a changing climate, managers more than ever face a host of uncertainties in determining what species may become invasive, which invasions may become more severe, and which species and ecosystems are most vulnerable to invasion. Species are not simply invasive or noninvasive, and being invasive is not necessarily associated with being outside of historical ranges. Decisions regarding tolerance, control, or eradication of invasive species depend on identifying and understanding these dynamics. In this framework, there are four categories of species which may be affected by changes in invasion dynamics under climate change scenarios:

	Non-invasive	Invasive
Native	Native Non-invaders	Native Invaders
Non-native	Non-native Non-invaders	Non-native Invaders

Native / Non-native

Non-invasive / Invasive

Each of these groups requires certain considerations for land managers, and they are discussed in turn below:

1) *Native non-invaders*

The first category of species contains those which are located within their historical range, and which do not have the potential to become invasive. The main area of concern is the potential of these species to be harmed or out-competed by invasions. Species most vulnerable to climate change – such as habitat specialists and poor dispersers – are also vulnerable to being overrun by invasive species as conditions change (Mainka 2010).

A key management objective for these species is to identify areas where invasions are most likely to increase, and work to prevent the introduction of new invasive species in the region, through land-use regulations, careful monitoring for early detection of invasion, buffer zones around un-invaded regions, and control of invasive species populations near the area's boundaries. These native species can also be used in restoration efforts, and can be reintroduced into the same area, or new regions as part of assisted migration programs (Frelich 2009).

2) *Native invaders*

The second category of species contains those which are located within their historical range, but which may increase in abundance and become invasive as the climate changes. This may be due relaxation of abiotic constraints, such as temperature, or through the release of competition or predation by another species whose range or competitive ability shifts. Though it is impossible to truly predict which species will become invasive, there are sets of traits characteristic of invaders which provide guidance.

Species which have the potential to become invasive tend to have rapid growth rates, high reproductive rates and capacity, short generation times, wide environmental tolerances, and good dispersal abilities (Mainka 2010, Frelich 2009, Hellmann 2008). Plants photosynthesize using C4 pathways are a group of species with high invasive potential. Many species adapted to warm, dry environments use this more water-efficient method of converting the sun's energy to plant material. These plants, including many invasive grasses are expected to be favored by both warming temperatures and increasing levels of CO_2, and may gain a competitive advantage over other species with which they currently coexist (White 2001).

There are no clear guidelines or suggestions for management of emerging native invaders. Primary recommendations involve regular monitoring of potentially problematic populations for early detection of increases in population growth rates or competitive success. If potential invaders are identified, managers are faced with the existing range of strategies, including tolerating changes in species composition, and actively controlling populations through mechanical, chemical, or biological methods.

Pests and disease: An important subset of invasive species expected to increase and intensify their impact under climate change scenarios are pests and pathogens of plants and animals. While many pests and pathogens will expand their ranges and invade new regions, many current and future outbreaks involve species in their native range. Many pests and pathogens will reproduce more quickly under warmer, wetter, or C02-enriched conditions. In addition, native host species may be put under greater moisture or temperature stress or be subject more intensive disturbance regimes due to fire or storms, which may make them more vulnerable (Ayres 2000).

Insect pests are one group that may be especially sensitive to a warming climate, as temperature greatly affects their survival and reproductive rate and capacity, and they have the

ability to migrate over great distances. Changes have been observed the distribution and frequency and severity of outbreaks in eastern and western spruce budworm, eastern larch beetle, gypsy moths, and mountain pine beetles, among others (Logan 2003). Many bark beetle species use synchronous adult emergence and life-cycle timing to create outbreak conditions, and these are largely temperature-dependent processes (Bentz 2010). Insect pests that have historically reproduced in cycles of one or more years may be able to reproduce more often. Spruce beetle reproduction in one year instead o two is directly correlated with summer temperatures (Hansen and Bentz 2003), and a lung worm of arctic musk ox in Alaska has begun to reproduce in annual rather than biannual cycles, with stark negative repercussions for musk ox populations (Lafferty 2009).

Plant pathogens that attack bark, roots, or leaves have also been seen to be affected by changes in temperature and precipitation. In addition, researchers have identified feedback loops, in which tree populations that have not historically had pine beetle outbreaks are prone to more severe outbreaks than those that have; therefore expanding beetle distribution will likely also mean increased outbreak severity (Cudmore 2010).

3) Non-native non-invaders

The distinction between non-native species and invasive species is the source of a great deal of uncertainty in climate change research and management. As the environment changes, species ranges will shift, and species will establish in regions where they are not currently found. Ecosystems are not static, and 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). These new arrivals, or 'neo-natives' may in initial stages be difficult to distinguish from species which we label as invasive (Walther 2009).

A key role of land managers in this process is to identify species which do not have traits characteristic of invasive species, and either tolerate or work to facilitate their movement into an ecosystem. In many cases, this facilitation is a key step, as the rapid establishment of neo-natives, well-suited to new conditions, may decrease the potential for future invasion, or the emergence of a weedy, simplified ecosystem as native species shift elsewhere (Frelich 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 dominance and community composition, and changing disturbance regimes (Millar 2007).

Accepting new arrivals as native species requires a reassessment of conservation priorities (Botkin 2001). 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).

Examples include ongoing work on management of hardwood forests in the American Midwest, which are likely to become warmer and drier, and lose many key species. Several researchers suggest using restoration and assisted colonization methods to facilitate the transition to oak woodlands and grassland savannahs in protected areas in order to prevent opportunistic invaders from establishing a weedy, unattractive landscape (Galatowitsch 2009).

4) *Non-native invaders*

The final category of species is the focus of the majority of research and management efforts. These are species which expand outside their historical range, and increase dramatically in abundance in new landscapes with negative ecological, aesthetic, or economic consequences. As discussed earlier, there are multiple reasons why species may increasingly invade new areas under climate change scenarios due, such removal of temperature, moisture, or nutrient constraints, CO_2 enrichment, or the disruption of ecosystems due to loss of native species that may make them more easily invaded (Hellman 2008). This trend is expected to occur, and is already occurring, across all types of organisms in all climates. For example, in Europe a number of invasive tree species are expected to move into parks and protected areas (Kleinbauer 2010). Twenty-seven species of fish are predicted to increase their range into some or all of the great lakes, bringing along 83 species of parasites (Rahel 2008). The highly invasive Kudzu vine is predicted to expand its range northward and westward as temperatures change (Jarnevich 2009).

The initial management goal for new invaders, climate-driven or otherwise lies at the stage of prevention of initial invasion, through close monitoring, regulation of human transport, and buffer zones. Complete or near-complete eradication of invasive species is most often an option only when invasions are detected early, and invaded areas are small in size. For example Asian wild rice was found in a less-than-one hectare plot in Everglades National Park, and was successfully eliminated (Simberloff 2001). Prevention and early detection of invasion requires communication between agencies and landowners regarding presence of invasive species.

In parks and wilderness areas, trails and other areas of high human activity should be focal points for monitoring and early detection. In a recent study in the Boundary Waters Wilderness Area, nonnative species richness and cover were closely associated with distance from trails, and all non-native plants occurred on or within 1 meter of a trail (Dickens 2004). In the Flat Tops Wilderness in Colorado, the distribution of invasive yellow toadflax suggests that new infestations in relatively un-invaded areas are most likely to occur along trails (Sutton 2007).

Considerations for control of invaders in the face of climate change

Management options

Given these expanding distributions of known and new invasive species, managers have a suite of management options open to them, though none are ideal or without potentially negative ramifications. National Park Service policy recommends the elimination of invasive species though methods that preserve wilderness qualities, however this policy leaves a great deal of ambiguity in its interpretation (Botkin 2001). In making decisions regarding management and control of invasive species, wilderness managers must balance the goals of maintenance of natural or historical conditions with the goal of minimizing human interference. They must decide where and when control is appropriate, and which control options to employ. These decisions depend on numerous factors in each protected area, including the extent and value of native diversity in the site, the threat posed by the invader in question, and the feasibility of eradication or control (Randall 2010). These decisions should draw from information on baseline conditions, and therefore extensive research and monitoring programs are necessary for appropriate management.

In some cases these two goals can work together; for example, many weedy invasive species thrive in areas of disturbance, either of the soil or of forest cover, and working to minimize disturbance both maintains natural conditions and minimizes human impact (Botkin 2001) In most cases, however, managers may choose between a suite of active management options. Once eradication ceases to be a realistic option, and the goal becomes control of invasive species, managers have four primary avenues open to them: mechanical or hand removal of individuals, chemical treatments, biological control, and landscape or ecosystem management (Simberloff 2001).

Mechanical or hand removal may be a very appropriate strategy for specific and targeted control of new invasions, or invaders which are not yet widespread. Mechanical or hand removal has minimal effects on non-target species, and hand removal especially is largely in keeping with wilderness goals and regulation, as it does not require mechanization and does not introduce new chemical or biological agents into the environment. There is also a potentially important role for public participation in hand-weeding efforts, through volunteer days, citizen science programs, or information materials at trailheads. However, hand removal of invasive species is time and labor intensive, and is largely ineffective for large-scale or well-established invasions.

Chemical control through herbicides, pesticides, or fungicides has the potential to be effective over larger areas. It can be time, labor, and cost-efficient. However, all chemical treatments pose a danger to nontarget species, and introduce toxic elements into an ecosystem, with potentiall long-term effects. Managers employing chemical control methods must consider site accessibility, proximity to water sources and groundwater, and appropriate timing and levels of applications. Chemical control violates many wilderness principles of non-interference; however in many cases negative effects of chemicals may be minimal, and may be outweighed by the resulting decrease in invasive species in the ecosystem.

The third option available is biocontrol, or the use of other organisms as pests, predators, and parasites of invasive species. There are numerous upsides to this approach, as it can be relatively inexpensive, does not introduce toxins into the environment, can potentially provide control indefinitely, and may have minimal negative effects on the wilderness character of a landscape. However, in all biocontrol situations, there is a risk of unforeseen effects on nontarget species and the larger biotic community. Biocontrol agents may themselves become invasive, impact native species, or alter competitive interactions between species. In addition, biocontrol generally does not lead to total eradication, but when successful will maintain low abundances of invasive species.

The final option for control of invasive species is through manipulation of the landscape through burning, grazing, or seeding to disrupt regeneration of invaders. These activities are appealing, as they simulate natural processes and may allow landscapes to be more resilient to future invasion. However, they have the potential to greatly alter ecosystems and biotic communities, and may have the potential to actually increase the abundance of target invaders through unintended feedbacks.

Climate change and management decisions

A changing climate does not imply a radically different set of options, but will likely necessitate changes in the timing or intensity of control mechanisms. (Hellman 2008). For example, weeding or pesticide applications may need to be moved earlier in the spring to account

for shorter winters and earlier spring events (Rahel 2008). Potential increases in storm intensity and other disturbance events could provide opportunities for restoration activities designed to control or prevent invasions (Mainka 2010). In addition, control activities that were effective in one climate regime may become less effective. For example, the removal of an invasive herbivore of an endangered paintbrush in the Santa Rosa islands off California was effective for a number of years; however beginning in 2003 the islands saw a series of warmer summers, and paintbrush abundances declined again as control mechanism became less effective (McEachern 2009). Another consideration is that changes in species composition may lead to reassessment of effects of control on surrounding, non-target species (Hellman 2008).

A primary focus of invasive species management in a changing climate is increased monitoring programs designed to record the spread of invasion across regions, ecosystems, and protected areas, and to provide warning for managers in landscapes that have not yet been invaded. This active monitoring requires information sharing across agencies and regions, and between the public and private sector, in addition to increases in public education and outreach programs (Bradley 2009a).

Sources:

Ayres, M. P. and M. J. Lombardero (2000). "Assessing the consequences of global change for forest disturbance from herbivores and pathogens." Science of the Total Environment **262**(3): 263-286.

Bentz, B. J., J. Regniere, et al. (2010). "Climate change and bark beetles of thes western United States and Canada: direct and indirect effects." Bioscience **60**(8): 602-613.

Botkin, D. B., H. Saxe, et al. (2007). "Forecasting the effects of global warming on biodiversity." Bioscience **57**(3): 227-236.

Bradley, B. A., D. Blumenthal, et al. (2009a). "Predicting plant invasions in an era of global change." Trends in Ecology & Evolution **25**(5).

Bradley, B. A., D. S. Wilcove, et al. (2010). "Climate change increases risk of plant invasion in the Eastern United States " Biological Invasions **12**: 1855-1872.

Crowl, T., T. Crist, et al. (2008). "The spread of invasive species and infectious disease as drivers of ecosystem change." Frontiers in Ecology and the Environment **6**(5): 238-46.

Cudmore, T., N. Bjorklund, et al. (2010). "Climate change and range expansion of an aggressive bark beetle: evidence of higher beetle reproduction in naive host tree populatinos." Journal of Applied Ecology **47**: 1036-1043.

Dickens, S. J., F. Gerhardt, et al. (2004). "Recreational portage trails as corridors facilitating non-native plant invasions of the Boundary Waters Canoe Area Wilderness (USA)." Conservation Biology: 1653-1657.

Dukes, J. S. and H. Mooney (1999). "Does global change increase the success of biological invaders?" Trends in Ecology & Evolution **14**(4).

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.

Galatowitsch, S., L. Frelich, et al. (2009). "Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America." Biological Conservation **142**(10): 2012-2022.

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

Hellmann, J. J., J. E. Byers, et al. (2008). "Five potential consequences of climate change for invasive species." Conservation Biology **22**(3): 534-543.

Hobbs, R. J., E. Higgs, et al. (2009). "Novel ecosystems: implications for conservation and restoration." Trends in Ecology & Evolution **24**(11).

Jackson, S. T. and D. F. Sax "Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover." Trends in Ecology & Evolution **25**(3): 153-160.

Jarnevich, C. S. and T. J. Stohlgren (2009). "Near term climate projections for invasive species distributions." Biological Invasions **11**(6): 1373-1379.

Kleinbauer, I., S. Dullinger, et al. (2010). "Climate change might drive the invasive tree Robinia pseudacacia into natue reserves and endangered habitats." Biological Conservation **143**: 281-290.

Lafferty, K. D. (2009). "The ecology of climate change and infectious disease." Ecology **90**(4): 888-900.

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

Lodge, D. M., S. Williams, et al. (2006). "Biological invasions: recommendations for U.S. policy and management." Ecological Applications **16**(6): 2035-2054.

Logan, J. A., J. Regniere, et al. (2003). "Assessing the impacts of global warming on forest pest dynamics." Frontiers in Ecology and the Environment **1**(3): 130-137.

Lonsdale, W. (1999). "Global patterns of plant invasions and the concept of invasability." Ecology **80**: 1522-1536.

Mainka, S. and G. Howard (2010). "Climate change and invasive species: double jeopardy." Integrative Zoology **5**: 102-111.

Manning, A. D., P. Gibbons, et al. (2009). "Scattered trees: a complementary strategy for facilitating adaptive responses to climate change in modified landscapes?" <u>Journal of Applied Ecology</u> **46**(4): 915-919.

McEarchern, K., D. Thomson, et al. (2009). "Climate alters response of an endemic island plant to removal of invasive herbivores." <u>Ecological Applications</u> **19**(6): 1574-1584.

Millar, C. I., N. L. Stephenson, et al. (2007). "Climate change and forests of the future: Managing in the face of uncertainty." <u>Ecological Applications</u> **17**(8): 2145-2151.

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

Pimentel, D., R. Zuniga, et al. (2000). "Environmental and economic costs of non-indigenous species in the United States." <u>Bioscience</u> **50**: 53-65.

Pimentel, D., R. Zuniga, et al. (2005). "Update on the environmental and economic costs associated with alien-invasive species in the United States." <u>Ecological Economics</u> **52**: 273-288.

Rahel, F. J., B. Bierwagen, et al. (2008). "Managing aquatic species of conservation concern in the face of climate change and invasive species." <u>Conservation Biology</u> **22**(3): 551-561.

Randall, J. (2010). Objectives, priorities, and triage: lessons learned from invasive species management. <u>Beyond Naturalness</u>. D. N. Cole and L. Yung, Island Press.

Simberloff, D. (2001). "Biological invasions: how are they affecting us, and what can we do about them?" <u>Western North American Naturalist</u> **61**(3): 308-315.

Sutton, J., T. J. Stohlgren, et al. (2007). "Predicting yellow toadflax infestations in the Flat Tops Wilderness of Colorado." <u>Biological Invasions</u> **9**: 783-793.

Walther, G. R., A. Roques, et al. (2009). "Alien species in a warmer world: risks and opportunities." <u>Trends in Ecology & Evolution</u> **24**(12).

Weltzin, J., T. Belote, et al. (2003). "Biological invaders in a greenhouse world: will elevated CO_2 fuel plant invasions?" <u>Frontiers in Ecology and the Environment</u> **1**(3): 146-153.

White, P. C. L., A. C. Taylor, et al. (2009). "Wildlife Research in a changing world." <u>Wildlife Research</u> **36**(4): 275-278.