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Climate Change and Invasive Plants in Forests and Rangelands

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Synthesis

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portion of their potentially available habitats; thus they have the potential to spread widely.

There is considerable evidence suggesting that future climate change will further increase the likelihood of invasion of forestlands and rangelands as well as the consequences of those invasions. This is largely because of the potential for complex interactions between (1) the impact of warming and precipitation changes on population dynamics and species distributions, (2) increased ecosystem disturbance (e.g. wildfire, hurricanes), (3) the enhanced competitiveness of some invasive plants due to elevated CO_2, and (4) increased stress to native species and ecosystems [2,3,4,5].

Invasive plants are introductions of nonnative (also referred to as exotic, alien, or non-indigenous) species that are or have the potential to become successfully established or naturalized, and spread into new localized natural habitats or ecoregions with the potential to cause economic or environmental harm [6]. Billions of dollars are spent every year to mitigate invasive plants or control their impacts [1]. Familiar examples include the nonnative annual grass cheatgrass (Figure 1, *Bromus tectorum*) which has invaded significant areas of sagebrush-steppe and dry forests in the western U.S., and the invasion and spread of the non-native vine kudzu (*Pueraria montana* var. *lobata*) in the southeastern U.S. (Figure 2). While most definitions of invasive plants only consider nonnative species, native species may be considered invasive by some [7]. For example, juniper (*Juniperus* spp.) species in the western US have historically expanded their range and are considered invasive in certain ecosystems [8,9]. We limit our discussion largely to nonnative invasive species, referring to these species simply as invasive plants.

In general, the detrimental effects of invasive plants in natural ecosystems may include a reduction in native biodiversity, changes in species composition, loss of habitat for dependent and native species (including wildlife), changes in biogeochemical cycling, and alteration of disturbance regimes. Most of the nonnative species in the United States have been introduced recently and their actual invasiveness and possible future spread are unknown. The spatial extent of many invasive plants at any point in time can be difficult to determine, limiting assessment of their overall consequences. In addition, observed negative environmental effects can be later discovered to be more subtle or complex [10]. Not all consequences associated with invasives are viewed as detrimental. Some species have been found to help preserve ecosystem function or provide ecosystem services [11,12,13].

Table 1. Examples of nonnative plants that have had significant spatial invasions in US forests and woodlands.

Species	*Origin†*	*Form*	*Region of Invasion*	*Common Name*
Acer platanoides	Europe	Tree	Northeast	Norway maple
Ailanthus altissima	China	Tree	Southeast, East, California	tree of heaven
Alliaria petiolata	Europe	Biennial forb	Northeast, Midwest	garlic mustard
Berberis thunbergii	Asia	Shrub	Northeast, East, Midwest	Japanese barberry
Bromus tectorum	Eurasia	Annual grass	West	cheatgrass
Celastrus orbiculatus	Eastern Asia	Vine	Northeast, East	oriental bittersweet
Centaurea solstitialis	Eurasia	Annual forb	West	yellow star-thistle
Centaurea stoebe	Europe	Biennial/ perennial forb	West	spotted knapweed
Cirsium arvense	Europe	Perennial forb	West, Midwest	Canada thistle
Cytisus scoparius	Europe	Shrub	Northwest	Scotch broom
Hedera helix	Europe	Vine	Northwest	English ivy
Imperata cylindrica	East Africa or Southeastern Asia	Grass	Southeast	cogongrass
Ligustrum sinense	Southeast Asia	Shrub	Southeast	Chinese privet
Lonicera japonica	Asia	Vine	Southeast, East	Japanese honeysuckle
Lygodium japonicum	Asia & Australia	Climbing fern	Southeast	Japanese climbing fern
Microstegium vimineum	Eastern Asia	Annual grass	East, Midwest	Japanese stiltgrass, Nepalese browntop
Pueraria montana var. lobata	Asia	Vine	Southeast	kudzu
Triadica sebifera	China	Tree	Southeast	Chinese tallow, tallowtree

Figure 1. Cheatgrass (Bromus tectorum, reddish grass) can invade forested areas after disturbances that remove portions of the overstory canopy. (photo: Becky Kerns)

Cheatgrass | Kudzu

Likely Changes

The success of invasive plants in native plant communities is highly influenced by factors related to environment (e.g., temperature, precipitation, CO_2), disturbance or resource availability, propagule pressure (e.g., seeds), and biotic resistance (how healthy and diverse the native community is) [14,15,5]. While changes to any one of these factors can influence plant invasions, a key issue in the future will be the complex interaction of these factors.

Environment: Scientists have known for over 200 years that enhanced levels of CO_2 stimulate plant growth. Increased photosynthesis as a result of recent and projected increases in CO_2 is one of the most researched aspects of global change [16,4]. There is some evidence that elevated CO_2 may favor weedy plants [17].

In a hypothesized response to warming, several studies have documented the movement of species poleward and/or upward in elevation, [e.g., 18,19] although this trend has not been found universally [20]. Invasives might move faster than native species, since they tend to have higher dispersal ability and genetic flexibility, among other features. Some invasive species may also presently occupy only a portion of their potentially available habitats, thus having the potential to spread widely [21]. Species interactions and species' lag times responding to environmental changes are also important to consider. Species performance such as growth, phenology, and productivity may also change in novel conditions [22]. However, it is unclear how important direct environmental effects such as changes in CO_2, temperature and precipitation will be, compared to other invasion drivers such as disturbance, propagule pressure, and biotic resistance.

Disturbance: Future changes may be more influenced by climate- related shifts in disturbance regimes and altered land-use, rather than changes in a species' environment. Natural and human-caused disturbances such as fire, landslides, volcanic activity, logging, road building, etc., alter resource availability in forests by opening canopies, reducing above- and below-ground competition, exposing mineral soil, or by directly increasing resources via geomorphic or chemical processes. For example, numerous studies have documented the positive relationship between fire, the spread of invasive plants, and the subsequent alteration of future fire regimes [14, 23, 24]. Disturbances do not necessarily lead to successful species invasions, but they can provide an environment conducive to plant invasion. Therefore, post-disturbance invasion may be particularly problematic in areas adjacent to invasive plant seed sources (wildland urban interface areas), and influenced by key pathways (roads), and vectors (e.g. wild animals and recreationists dispersing seeds) as propagule pressure is a key factor in the invasion process.

Propagule pressure: A propagule is the ecologically relevant unit of plant dispersal, defined as a colonizing organism or vegetative structure capable of establishing a self-sustaining population. For example, there is higher propagule pressure when an area already has a significant invasion and there are ample seed sources. Areas that remain largely uninvaded have low propagule pressure. Climate change will alter numerous aspects of propagule supply and pressure. Most invasive species reach new regions by purposeful or accidental human-aided transport (tourism, commerce), and tourism and commerce are likely to be altered by future climate change [25]. Factors associated with human populations and activities (urban areas, roads, recreation) are positively correlated with plant invasions [26, 15, 27]. Atmospheric patterns that transfer seeds, such as hurricanes and wind patterns, will also change in the future. Climate change may also result in increased management actions that cause new disturbances, such as biofuel production or forest thinning.

Biotic resistance: The ability of the native plant community to resist an invasion may also change in the future. For example, invasive plants may be exposed to above- and below-ground biotic interactions different from those in their current range and "enemy release" may occur [28]. In other words, invasive species in the invaded ranges often do not face the "enemies" such as diseases and competitors they have at home in native ranges.

Options for Management

Informing Management Decisions: how do scientists study climate change and invasive plants?
Experimental studies such as CO_2, warming, and water deficit studies, and field and observational studies are used to try to decipher the likely changes that climate change may have on invasive plant population establishment and spread. Scientists also use simulation modeling tools to assess the effects of climate change on invasive plants, including population and spread models, and species distribution models. While tools such as models can be critical for alerting us to the potential magnitude of the effects of climate change, considerable uncertainty remains about what the future may hold.

Fundamental research regarding invasion drivers and invasion biology is still needed, as are new tools that integrate invasion and climate change biology [25].There is only limited data, particularly in field settings, about how plant invasions will be affected by different aspects of climate change. Understanding the responses of the most detrimental invasive plants to climate change is critical. Therefore, much more research, especially with multidisciplinary and collaborative efforts are strongly needed in the future [29].

Management Responses
Early detection and rapid response systems could consider how climate change may alter invasion patterns in the future. Because the window of opportunity for cost-effective and successful responses to plant invasions is small, the greatest chance for action is in the early phase of invasion. Closely monitoring the directional spread of introduced species under climate change could help identify the potential of future spread for the many species with a relatively restricted distribution in their nonnative range [19]. Smart management would include examination of possibilities for protecting and managing 'ports of entry' along forest borders or in wildland urban interface areas, and limiting vector pathways (e.g. equipment care, roads). Presently many higher elevation forest and wilderness areas have some extensive areas of uninvaded land. Keeping these areas uninvaded will require rapid detection, and monitoring [29].

Managers may also consider what level of invasion is low risk (e.g. does not impact management goals or desired future conditions) and what level of invasion is higher risk. Risk assessment processes can assist managers in thinking about the consequences of potential environmental change, and alterations to native biodiversity and productivity. Risk assessment work may need to be done over broader geographic areas than traditionally have been examined in the past [25], and future habitat suitability maps could be used to target areas of potential risk [21].

Management actions to control invasive plants may also have decreased effectiveness in the future. Studies have shown reduced herbicide efficacy in elevated CO_2 environments [30,31]. Managers are also concerned that some biocontrol methods may no longer be effective with climate change [25]. Therefore, new chemical or biological methods may need to be devised.

Ultimately the management options for limiting plant invaders depends on our ability to understand how native ecosystems resist invasion, our ability to limit propagule pressure via early detection, rapid response, development of effective control methods, and the availability of resources to conduct appropriate management activities.

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