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Slow and steady wins the race? Future climate and land use change leaves the imperiled Blanding's turtle (*Emydoidea blandingii*) behind

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ABSTRACT

Climate change is accompanied by shifts in species distributions, as portions of current ranges become less suitable. Maintaining or improving landscape connectivity to facilitate species movements is a primary approach to mitigate the effects of climate change on biodiversity. However, it is not clear how ongoing changes in land use and climate may affect the existing connectivity of landscapes. We evaluated shifts in habitat suitability and connectivity for the imperiled Blanding's turtle (*Emydoidea blandingii*) in Wisconsin using species distribution modeling in combination with different future scenarios of both land use change and climate change for the 2050s. We found that climate change had significant effects on both habitat suitability and connectivity, however, there was little difference in the magnitude of effects among different economic scenarios. Under both our low- and high-CO_2 emissions scenarios, suitable habitat for the Blanding's turtle shifted northward. In the high-emissions scenario, almost no suitable habitat remained for Blanding's turtle in Wisconsin by the 2050s and there was up to a 100,000-fold increase in landscape resistance to turtle movement, suggesting the landscape essentially becomes impassable. Habitat loss and landscape resistance were exponentially greater in southern versus northern Wisconsin, indicating a strong trailing edge effect. Thus, populations at the southern edge of the range are likely to “fall behind” shifts in suitable habitat faster than northern populations. Given its limited dispersal capability, loss of suitable habitat may occur at a rate far faster than the Blanding's turtle can adjust to changing conditions via shifts in range.

1. Introduction

In response to climate change, many species may need to move large distances and colonize new areas when climate conditions within their current range become unsuitable (Chen et al., 2011). However, land use change and landscape fragmentation may limit opportunities for species to reach newly suitable areas (Hamilton et al., 2015). Landscapes can be viewed as a mosaic of habitat and non-habitat patches and, in human-dominated landscapes, many of the non-habitat patches result from human use (Franklin and Lindenmayer, 2009; Lindenmayer et al., 2008). Protected areas are a key conservation tool to maintain biodiversity (Joppa et al., 2008; Rodrigues et al., 2004), although it is not clear how future changes in land use and climate will influence their effectiveness (Fleishman et al., 2011). A commonly proposed strategy for conserving species is to establish habitat corridors and patches that can function as stepping stones to improve connectivity among protected areas (Heller and Zavaleta, 2009; Krosby et al., 2010). The assumption is that a network of connected protected areas will reduce impediments to species dispersal and thereby facilitate movement among resource patches (Griffith et al., 2009; Beier and Brost, 2010). With limited funding available for conservation, it is critical that such investments account for both current and future threats to

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maximize and sustain gains (Mairota et al., 2013; Merenlender et al., 2009).

The majority of the land area of the planet is either used by humans or altered by them (Foley et al., 2005; Sanderson et al., 2002; Vitousek and Mooney, 1997). Land cover outside of protected areas includes a range of cover types, from urban to row crops to areas that include some natural or semi-natural elements. The type of land cover strongly affects potential movement of species through the landscape (Baum et al., 2014; Hamilton et al., 2013). The distribution and arrangement of both natural elements and anthropogenic land use within a landscape matrix affects its ecological function and, therefore, the condition of the matrix must be considered in any planning for habitat connectivity (Franklin and Lindenmayer, 2009; Lindenmayer et al., 2008; Mairota et al., 2013).

To address the consequences of human-induced global change, adaptation strategies such as adjustments to socio-economic and land use practices are often proposed in an adaptive management framework, i.e. the process of adjusting management practices to maximize benefit as we learn about a system (Smith et al., 2000b). Improving habitat connectivity is one of the primary adaptation strategies in this context used for enhancing resilience (i.e., the ability of a system to recover from perturbations) within biological systems (Griffith et al., 2009; Mori et al., 2013). Connectivity reflects the degree to which a landscape facilitates or impedes movements among habitat patches (Taylor et al., 1993), and is an important component of the resilience of ecological systems because high connectivity facilitates species movements among patches (DeFries et al., 2007; Hansen and DeFries, 2007). Connectivity is affected by both habitat loss (i.e., overall reduction in the amount and quality of habitat) and habitat fragmentation (i.e., the breaking apart of habitat). Habitat loss has consistent negative impacts to biodiversity, while habitat fragmentation effects are weaker and more variable (Fahrig, 2003). Connectivity depends on the spatial patterns of habitat, which are affected by land use, and therefore adjustments to land use are the primary method for improving connectivity.

Corridors and stepping stones are, by definition, embedded in a matrix of variably hospitable land cover (Baum et al., 2014; Beier and Noss, 1998). Habitat corridors are linear habitat patches connecting two or more larger blocks of habitat (Beier and Noss, 1998). Stepping stones, on the other hand, are a series of small habitat patches that connect otherwise isolated habitat blocks (Baum et al., 2014). While there has been debate about the effectiveness of corridors, both literature reviews and empirical studies have demonstrated their conservation value (Damschen et al., 2006; Noss, 1987; Simberloff et al., 1992; Beier and Noss, 1998; Gilbert-Norton et al., 2010; Haddad et al., 2003; Haddad and Tewksbury, 2005). Stepping stones tend to have weaker effects but are still useful in many situations (Baum et al., 2014; Leidner and Haddad, 2011), and in some cases may be critical for improving landscape connectivity (Krosby et al., 2010; Saura et al., 2013).

Range shifts driven by climate change have already been documented for a number of species and in the future large changes in species distribution and community composition are anticipated (Chen et al., 2011; Heller and Zavaleta, 2009; Thuiller, 2004), and one of the primary ways to meet the conservation goal is by maintaining and, where needed, improving connectivity. For connectivity assessments to be most valuable for conservation decisions, it is crucial to examine both current functional connectivity - i.e., the amount and spatial arrangement of habitat that a given species uses to move among areas that are permanently occupied - (Crooks and Sanjayan, 2006; Tischendorf and Fahrig, 2000a, 2000b) and likely future changes, potential threats to, and shifts in, connectivity (Mori et al., 2013; Smith et al., 2000a). Incorporating threat into conservation decisions is crucial to maximizing outcomes from the investment of limited funding (Merenlender et al., 2009). Identification of future threats is recognized as a priority by the U.S. Fish and Wildlife Service National Wildlife Refuge System (Griffith et al., 2009) and understanding the potential future effects of matrix land use and climate change on protected areas is essential for guiding conservation policy (Fleishman et al., 2011). Assessing the effects of future change on connectivity among protected areas should thus be an important aspect of conservation planning, yet this has rarely been done (Piquer-Rodríguez et al., 2012; Rouget et al., 2003). However, quantifying future connectivity is critical given its reliance on spatial arrangement of habitat patches, (Fahrig, 2003; Goodwin and Fahrig, 2002). Projections of future conditions can be relatively accurate at estimating proportional change across broad areas, but spatially explicit estimates are far more challenging, owing to the difficulty of identifying which specific parcels of land are likely to undergo changes (Radeloff et al., 2012). In general though, when projecting future conditions, the combination of exploring potential scenarios and constructing predictive models is useful for increasing the value of ecological research for management application (Coreau et al., 2009). The comparison of future scenarios can provide important insights about biodiversity and other ecological resources (Gude et al., 2007; White et al., 1997).

Our goal here was to evaluate current and future potential functional connectivity among protected areas in Wisconsin, U.S., for the Blanding's turtle. We chose Blanding's turtle because it is a widely distributed and declining species that faces similar threats to landscape movement across its entire range. We asked the following four questions:

- Which protected areas are currently important refugia for Blanding's turtle in Wisconsin?
- What is the current pattern of functional connectivity among those protected areas?
- How might climate and land use change affect the importance of those protected areas in the future under different emissions and land use scenarios?
- What is the relative effect of different combinations of economic policy and emissions scenarios on connectivity?

2. Methods

2.1. Study species

We modeled habitat connectivity for the Blanding's turtle, a semi-aquatic species with a center of distribution around the Great Lakes, ranging from Nebraska to Maine and north to Ontario and Nova Scotia (Congdon and Keinath, 2006). The species is listed as threatened or endangered in many states within its range (Mockford et al., 2006), is a 'species of concern' in the U.S. Fish and Wildlife Service Midwest Region (https://www.fws.gov/midwest/es/soc/), and is listed as Endangered on the IUCN Red List (Van Dijk and Rhodin, 2011). Blanding's turtle is a species of special concern in Wisconsin due to observed population declines and habitat vulnerability (Wisconsin Department of Natural Resources, 2014). While Blanding's turtle was removed from the Threatened Species List in Wisconsin in 2014, the species was designated a protected wild animal the following year (Wis. Admin. Code NR. § 10.02(11) ({2015})).

After the Wisconsin glaciation, the Blanding's turtle moved north- and eastward from several potential refugia to occupy its current range (Mockford et al., 2006; Rödder et al., 2013; Schmidt, 1938). Blanding's turtles make use of a wide variety of habitat types, ranging from wetlands and permanent water bodies used for foraging and overwintering, to upland habitats used for movement among wetlands and terrestrial nesting (Congdon and Keinath, 2006). In Wisconsin, these habitats include shallow freshwater ponds, marshes, river backwaters, ditches, and impoundments hosting areas with a mix of open water and dense submergent and emergent vegetation (Ross and Anderson, 1990).