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A global assessment of current and future biodiversity vulnerability to habitat loss–climate change interactions

Daniel B. Segan [a,b,*], Kris A. Murray [c], James E.M. Watson [a,d]

[a] Global Conservation Program, Wildlife Conservation Society, Bronx, NY 10460, USA
[b] School of Biological Sciences, University of Queensland, St Lucia QLD 4072, Australia
[c] Grantham Institute – Climate Change and the Environment, Imperial College London, Exhibition Road, London, SW7 2AZ, UK
[d] School of Geography, Planning and Environmental Management, University of Queensland, St Lucia QLD 4072, Australia

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ABSTRACT

Habitat loss is the greatest threat to biodiversity and rapid, human-forced climate change is likely to exacerbate this. Here we present the first global assessment of current and potential future impacts on biodiversity of a habitat loss and fragmentation–climate change (HLF–CC) interaction. A recent meta-analysis demonstrated that the negative impacts of habitat loss and fragmentation have been disproportionately severe in areas with high temperatures in the warmest month and declining rainfall, although impacts also varied across vegetation types. We compiled an integrated global database of past, current and future climate variables and past vegetation loss to identify ecoregions where (i) past climate change is most likely to have exacerbated the impacts of HLF, and (ii) forecasted climate change is most likely to exacerbate the impacts of HLF in the future. We found that recent climate change is likely (probability >66%) to have exacerbated the impacts of HLF in 120 (18.5%) ecoregions. Impacted ecoregions are disproportionately biodiverse, containing over half (54.1%) of all known terrestrial amphibian, bird, mammal, and reptile species. Forecasts from the RCP8.5 emissions scenario suggest that nearly half of ecoregions globally ($n = 283$, 43.5%) will become impacted during the 21st century. To minimize ongoing and future HLF–CC impacts on biodiversity, ecoregions where impacts are most likely must become priorities for proactive conservation actions that avoid loss of native vegetation (e.g., protected area establishment). Highly degraded ecoregions where impacts are most likely should be priorities for restoration and candidates for unconventional conservation actions (e.g. translocation of species).

1. Introduction

Human-forced climate change and ongoing environmental degradation leading to habitat loss and fragmentation threaten the future of the world's biodiversity (Thomas et al., 2004; Hoffmann et al., 2010). The synergy between different

* Corresponding author at: Global Conservation Program, Wildlife Conservation Society, Bronx, NY 10460, USA.
E-mail address: dbsegan@gmail.com (D.B. Segan).

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threatening processes, whereby the presence of one exacerbates the effects of another, has been implicated in past biodiversity declines and extinction events (Lorenzen et al., 2011), yet little is known about how and where the interaction between habitat loss and fragmentation and climate change (hereafter, HLF–CC interaction) will impact ecosystems or species (Brook et al., 2008). This knowledge gap limits the identification of effective conservation responses in regions that have experienced, are experiencing, or are expected to experience both.

Previous spatial ecosystem assessments that have considered climate change have focussed on assessing the varying dimensions of potential exposure to climatic changes, including the temporal pace of climate change (Loarie et al., 2009), the degree of difference between past, current and predicted future climates (Ponce-Reyes et al., 2012; Watson et al., 2013), or the novelty of new climatic environments (Williams et al., 2007). These studies are important first-step assessments that identify those locations where climate change is likely to be most significant and raise awareness about its range of potential impacts. However, little attention has so far been given to potential interactions between climatic changes and other major anthropogenic processes that threaten biodiversity (Mantyka-Pringle et al., 2012; Watson and Segan, 2013). This is problematic because it is well established that most species that are imperilled or in a state of decline are simultaneously impacted by a range of threatening processes (Hilton-Taylor et al., 2009), with the predominant stressor being direct habitat loss and fragmentation (Brook et al., 2008; Hilton-Taylor et al., 2009).

The direct impacts of habitat loss and fragmentation (HLF) on biodiversity have been extensively documented and include extinction, decreased population abundance, reduced genetic diversity, lower reproductive success, lower dispersal ability, increased vulnerability to stochastic events, increased susceptibility to invasive species, simplified trophic structure and altered interspecies interactions (Fahrig, 2003; Fischer and Lindenmayer, 2007). Although already a widely distributed threat, HLF will continue to be a major pressure on species and ecosystem into the future (Newbold et al., 2015). There are several means by which rapid human-forced climate change may exacerbate or limit a species' ability to cope with HLF. For example, climate change induced behavioural changes have been implicated in reduced levels of individual fitness (Arponen et al., 2005), which may limit a species' ability to endure further habitat disruption. Climate change may also increase the distance a species needs to travel to locate suitable habitat in the event of future disturbance or loss (Williams et al., 2007). Climate change is also expected to increase the frequency and intensity of extreme events, such as heat waves, which may push populations already diminished by HLF over a tipping point as has been observed in some avian communities (McKechnie and Wolf, 2010).

Habitat loss and fragmentation may also limit or prevent species' adaptive responses to climate change, again resulting in more severe impacts. Species' adaptive responses to climate change are generally limited to three response mechanisms: a shift in range, a behavioural or physical change, and altered phenology (temporal shift in activity) (Bellard et al., 2012). Habitat loss and fragmentation may prevent or impair these responses. For example, habitat loss compromises a species' capacity for rapid dispersal or refugial retreat (Brook et al., 2008; Opdam and Wascher, 2004), while fragmentation may hinder a species' ability to track shifts in suitable environmental conditions or access remaining suitable habitat (Cushman, 2006). Habitat loss may also destroy microrefugia, localized climatically suitable areas in otherwise unsuitable landscapes, which provide species the opportunity to survive during unfavourable climate periods and locations from which to re-colonize when conditions become more suitable (Dobrowski, 2011; Scherrer and Körner, 2011). Even when there are no physical barriers to dispersal, a species' ability to navigate fragmented landscapes to seek out suitable areas may be lower than in intact landscapes due to reluctance to traverse unsuitable land cover types, leaving suitable habitat unoccupied because of a species failure to locate it (Opdam and Wascher, 2004). Populations whose range has been extensively lost or degraded may also lack the adaptive capacity (e.g. phenotypic plasticity or micro-evolution) to adapt to climate change *in-situ* because both their genetic and phenotypic diversity may have been reduced by declines in population size or connectivity (Jump and Peñuelas, 2005).

While it is clear that there are numerous mechanisms by which climate change and habitat loss and fragmentation could plausibly interact to magnify biodiversity impacts, few studies have documented HLF–CC impacts directly or examined how general or widespread they might be. Recently, however, Mantyka-Pringle et al. (2012) used a meta-analytic approach to detect adverse biodiversity impacts attributable to an HLF–CC interaction. Using a global assessment of 168 published data sets that examined the impacts of HLF on multiple taxa, they modelled the likelihood of observing a negative impact on biodiversity (decline in density, richness, diversity or probability of occurrence) due to HLF as a function of current climate and observed climate change (Mantyka-Pringle et al., 2012). They showed that negative impacts associated with HLF were more likely in landscapes with two key climatic determinants, (i) current high maximum temperatures and (ii) declining precipitation, and that the strength of the impact varied across different vegetation types but, with the exception of arthropods, varied little across taxa (Mantyka-Pringle et al., 2012). This is an important study because for the first time it enables the spatial assessment, and hence preliminary risk assessment, of where the HLF–CC interaction is most likely to impact biodiversity.

Here, we apply the models derived in the Mantyka-Pringle et al. (2012) meta-analysis to an integrated set of global spatial data comprising vegetation loss, current climate, observed climate change, and forecasted climate change (using RCP 4.5 and 8.5 scenarios to both 2055 and 2090 IPCC, 2013) to identify ecoregions where an HLF–CC interaction is most likely to (1) have already impacted biodiversity, and (2) cause biodiversity impacts in the future as a result of future HLF and/or climate changes. Understanding where HLF–CC interactions will most impact biodiversity is an important step towards effectively allocating conservation resources aimed at preventing ongoing biodiversity loss.