Forest Ecology and Management 262 (2011) 1460–1472

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history-factors

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ARTICLE INFO

Article history:
Received 29 April 2011
Received in revised form 22 June 2011
Accepted 26 June 2011
Available online 23 July 2011

Keywords:
Climate change adaptation
Eastern United States
Trees
Species distribution models
Disturbance
Model uncertainty

ABSTRACT

Species distribution models (SDMs) to evaluate trees' potential responses to climate change are essential for developing appropriate forest management strategies. However, there is a great need to better understand these models' limitations and evaluate their uncertainties. We have previously developed statistical models of suitable habitat, based on both species' range and abundance, to better understand potential changes of 134 tree species habitats in the eastern United States (http://www.nrs.fs.fed.us/atlas). Our focus here is to build on these results via a more robust assessment framework called modification factors (ModFacs) that is made up of five components. ModFac 1 addresses nine biological characteristics (e.g., shade tolerance and seedling establishment) that quantify the influence of species life-history traits. ModFac 2 considers 12 disturbance characteristics (e.g., insect pests, drought, and fire topkill) which address the capacity of a species to tolerate and respond to climate-induced changes in habitat. ModFac 3–5 distill the tree SDM results and facilitate communication of model uncertainty; we quantified the variability in projected change for General Circulation Models (GCM) and emissions scenarios (ModFac 3), the extent to which each species' habitat intersects novel climate conditions (ModFac4), and accounted for long-distance extrapolations beyond a species' current range (ModFac5). The life-history components of ModFacs 1 and 2 demonstrate the marked variability among species in terms of biological and disturbance characteristics, suggesting diverse abilities to adapt to climate change. ModFacs 3–5 show that the information from the SDMs can be enhanced by quantifying the variability associated with specific GCM/emission scenarios, the emergence of novel climates for particular tree species, and the distances of species habitat shifts with climate change. The ModFacs framework has high interpretive value when considered in conjunction with the outputs of species habitat models for this century. Importantly, the intention of this assessment was not to create a static scoring system, but to broadly assess species characteristics that likely will play an important role in adaptation to climate change. We believe these scores based on biological, disturbance, and model synthesis factors provide an important expansion of interpretive and practical value to habitat model projections.

1. Introduction

Climate change has disrupted ecological systems worldwide, and is predicted to intensify by mid-century (Intergovernmental Panel on Climate Change [IPCC], 2007). Management decisions made in the face of climate change will play a critical role in how forests and individual tree species will respond. Managing natural systems with high uncertainty of future conditions requires adaptive management approaches, yet we first need to understand how species and ecological communities may react to changing climates (Aitken et al., 2008). Models and simulations are the primary tools for evaluating potential responses of biota to changing and uncertain climates (Guisan and Thuiller, 2005). Major modeling efforts have been undertaken worldwide to identify possible trends for forests and tree species, and much of this work relies on species distribution models (SDMs) (Franklin, 2009).

All models are, of course, only approximations of reality and must be treated with caution, especially when projecting into an uncertain future and into new locations. Most SDMs have been built with statistical/empirical approaches and carry numerous assumptions. These assumptions have been reviewed by critics and SDM modelers alike, and include (1) unlimited dispersal capability, (2) equilibrium with environment, (3) biotic interactions, (4) CO_2 effects, (5) key environmental variables unidentified or unsupported by data, (6) adaptation, (7) inability to incorporate disturbance, (8) uncertainties in General Circulation Models (GCM) projections, and (9) variations associated with SDM algorithms

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doi:10.1016/j.foreco.2011.06.047

(Pearson and Dawson, 2003; Hampe, 2004; Iverson et al., 2011; Franklin, 2009; Wiens et al., 2009). Some of these assumptions have been addressed with process-based or hybrid approaches (Morin et al., 2008; Scheller and Mladenoff, 2008; Kearney and Porter, 2009; Keenan et al., 2011), in which temporal stochasticity and individual physiological mechanisms can be better simulated and interpreted. For example with tree species, the main barriers to mechanistic approaches are an inadequate understanding of ecophysiological processes across a species' entire range and then a lack of sufficient data, resources, and time to appropriately parameterize such models for multiple species (Lawler et al., 2006) across these broad geographic extents. Several applications, however, warrant the extra time and effort: (1) developing hypotheses about particular species' limits, (2) modeling invasive or other species markedly out of equilibrium, (3) assessing physiological constraints to future novel environments, and (4) assessing suitability of potential translocation sites (Kearney and Porter, 2009).

Ultimately, all models suffer from insufficient knowledge on how multiple species will respond to and interact in an uncertain future. Nonetheless, managers considering model uncertainties around projected species' responses must keep in mind (1) the risks of taking no action or the wrong action, and (2) the reality that ignoring potential future outcomes is not an option (Wiens et al., 2009). Therefore, to increase the usefulness of projected impacts of climate change, managers should be equipped with a toolbox that provides more specific indications of possible outcomes in light of site-specific and local management decisions.

Many researchers have been using SDMs with statistical methods to better understand the potential future distributions of different organisms in the face of climate change (e.g., Franklin (2009) and citations within). Our assessment framework first uses the DISTRIB model (Iverson et al., 2008c), a decision-tree based ensemble model using the randomForest approach (Breiman, 2001), in conjunction with current and future climate data, environmental data (e.g., soil properties), and tree species abundance data, to create potential suitable habitat maps under three GCMs and two emission scenarios for the eastern United States. Outputs from this effort are detailed on our website http://www.nrs.fs.fed.us/atlas, and published elsewhere (Iverson et al., 2008b,c). Next, the SHIFT migration model is used to assess the potential for tree species to colonize the newly derived habitat by considering Holocene tree migration rates and the current fragmented state of the landscape (Iverson et al., 1999, 2004a,b; Schwartz et al., 2001). The combination of DISTRIB and SHIFT outputs indicate how suitable tree habitats may shift, and the potential of individual species to colonize newly available habitats within about 100 years. Lessons learned from this research of 16 years are detailed in a recent paper (Iverson et al., 2011).

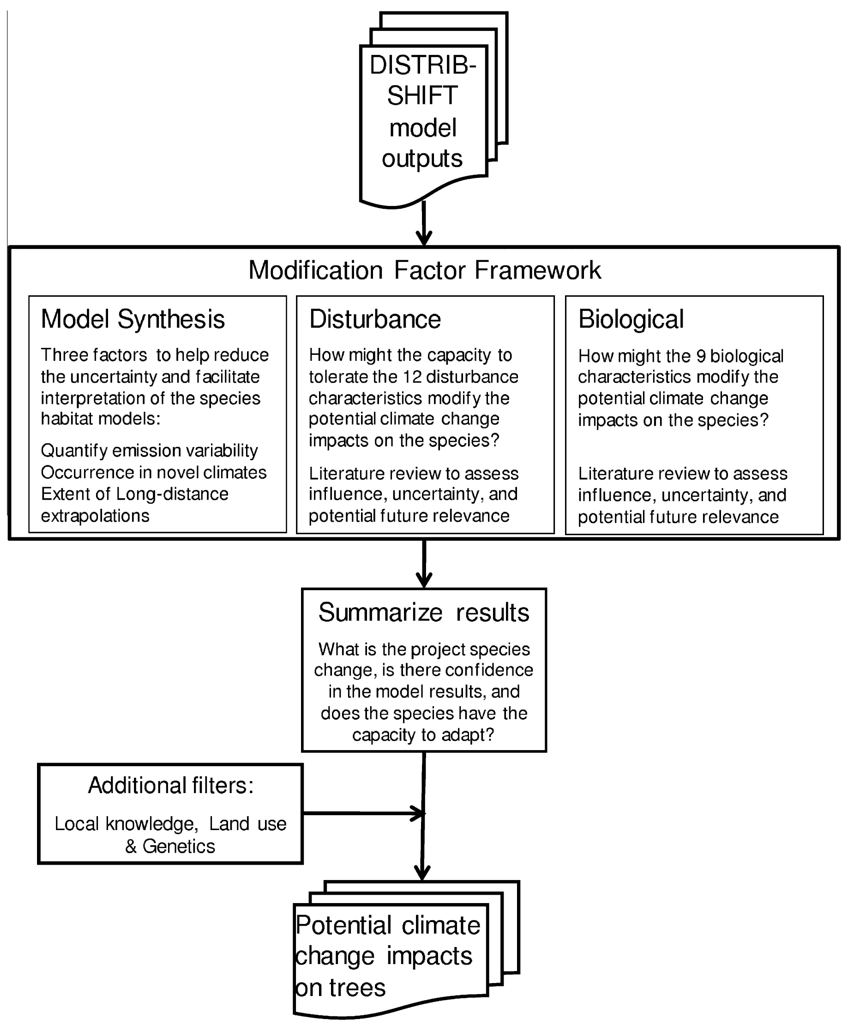

Fig. 1. Graphic depicting the ModFacs framework. The results presented here reflect the main pathway of incorporating the modification factors with the habitat models to provide a broad-scale assessment of species vulnerabilities. However, biological and disturbance factors can be changed to reflect local knowledge and specific management strategies.