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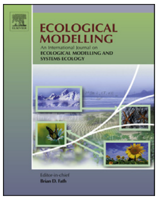

Assessing potential climate change effects on vegetation using a linked model approach

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ABSTRACT

We developed a process that links the mechanistic power of dynamic global vegetation models with the detailed vegetation dynamics of state-and-transition models to project local vegetation shifts driven by projected climate change. We applied our approach to central Oregon (USA) ecosystems using three climate change scenarios to assess potential future changes in species composition and community structure. Our results suggest that: (1) legacy effects incorporated in state-and-transition models realistically dampen climate change effects on vegetation; (2) species-specific response to fire built into state-and-transition models can result in increased resistance to climate change, as was the case for ponderosa pine (*Pinus ponderosa*) forests, or increased sensitivity to climate change, as was the case for some shrublands and grasslands in the study area; and (3) vegetation could remain relatively stable in the short term, then shift rapidly as a consequence of increased disturbance such as wildfire and altered environmental conditions. Managers and other land stewards can use results from our linked models to better anticipate potential climate-induced shifts in local vegetation and resulting effects on wildlife habitat.

1. Introduction

Climate, in concert with local topoedaphic factors, dictates vegetation distribution through thermal and water constraints on plant regeneration, establishment, growth, and mortality. Global vegetation patterns are already shifting in response to observed increases in temperature and changing precipitation patterns (Parmesan, 2006; Allen et al., 2010). Anticipating potential shifts in local vegetation is critical for land managers to develop adaptive strategies. However, predicting vegetation response to climate change requires consideration of interacting physical and biological processes at multiple spatial and temporal scales. Dynamic global vegetation models (DGVMs) are currently considered to be among the most advanced tools to assess climate change effects on ecosystems (Fischlin et al., 2007). DGVMs integrate state-of-the-art knowledge of plant physiology, biogeography, biogeochemistry, and biophysics, with climate model projections to simulate changes in vegetation structure and composition (biogeography) as well as ecosystem function (biogeochemistry) through time (Prentice et al., 1989, 2007; Foley et al., 1998; Cramer et al., 2001). MC1 (Daly et al., 2000; Bachelet et al., 2001) is a DGVM that integrates biogeography, biogeochemistry, and fire into a single modeling environment and has been used for regional- to global-scale assessments of potential climate change effects on ecosystems (e.g., Bachelet et al., 2000, 2003; Lenihan et al., 2008a,b; Gonzalez et al., 2010; Rogers et al., 2011; Shaw et al., 2011). DGVMs simulate broad plant functional types that combine numerous species into single entities (e.g., evergreen needleleaf trees), and thus they are incapable of simulating community- and species-level changes at the landscape scale (Hickler et al., 2004). However, because they focus on mechanisms, their projections of future outcomes are more reliable than simple correlations of location with current climate conditions. To take full advantage of their strength, their results can be translated into directions and magnitude of change applicable to community- and species-level dynamics, making output more useful for sub-regional management and planning efforts (e.g., Halofsky et al., 2011).

State-and-transition models (STMs) simulate trends in vegetation community response to a variety of local disturbances and management strategies by explicitly incorporating landscape legacy, succession rules and species-specific sensitivity to disturbance. STMs are based on transition matrix methods that simulate

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vegetation dynamics using transition probabilities between vegetation states (e.g., Horn, 1975; Noble and Slatyer, 1980; Westoby et al., 1989; Laycock, 1991). The landscape is divided into states representing combinations of cover type (dominant species) and structural stage (e.g., diameter class, canopy density, and number of canopy layers) within a particular biophysical environment. For example, a state could represent dry ponderosa pine forest in the 25–38 cm diameter class with closed tree canopy and a single canopy layer. States are linked by transitions that represent natural disturbances, management actions, or successional processes. For example, high-severity fire could drive a ponderosa pine forest, 25–38 cm diameter class, closed-canopy state to an open grassland state. STMs are run at scales appropriate for management and planning efforts (units typically range from 10 s to 1000 s of ha in size). They have been extensively used for regional to sub-regional assessments (e.g., Hemstrom et al., 2001, 2002, 2007; Merzenich et al., 2003; Forbis et al., 2006; Weisz et al., 2009). However, with the exception of some very recent developments (Provencher and Anderson, 2011), STMs have not incorporated the effects of climate change.

Here we present results from a novel modeling approach that links the mechanistic power of a DGVM with the community-specific control of state-and-transition models to project local vegetation shifts. We linked a DGVM (MC1) with a set of eight STMs, each representing a major vegetation type in a study area in central Oregon, to assess potential changes in species composition and community structure under different climate change scenarios. Our objectives are to (1) describe the approach we used to link the DGVM with STMs; and (2) project potential future changes in species composition and community structure for the central Oregon study area.

2. Materials and methods

2.1. Study area

The study area is a landscape of forests, woodlands, shrublands, and grasslands that is 1,023,808 ha in size, located in central Oregon, USA (Fig. 1). Elevations vary from about 1200 m to above 2400 m. The climate is transitional between moist, maritime conditions west of the Cascade Mountains (which are oriented north to south; Fig. 1) and continental conditions to the east. Annual precipitation varies from over 2000 mm along the Cascade Crest to less than 350 mm along lower treeline and 250 mm at the lowest elevations in shrub-steppe environments (PRISM Group, 2012). Most of the precipitation falls as rain and snow during the winter months, with snow packs of more than 2 m common in upper elevations. Summers are warm and dry, often with several weeks of very low or no precipitation and warmest temperatures at lower elevations exceeding 30 °C.

2.2. The MC1 model

MC1 (Bachelet et al., 2001) is a DGVM that simulates: life-form mixtures, classifying them into potential vegetation classes (PVCs); the fluxes and pools of carbon, nitrogen, and water through ecosystems; and natural fire occurrence and effects. MC1 routinely generates century-long, local to global-scale simulations (e.g., Bachelet et al., 2003; Daly et al., 2000; Lenihan et al., 2003, 2008a; Hayhoe et al., 2005; Rogers et al., 2011). The model reads soil and monthly climate data, and calls interacting modules that simulate biogeography, biogeochemistry, and fire disturbance.

The biogeography module, which was developed using some of the biogeography rules from the MAPSS model (Neilson, 1995), simulates life-form mixtures of evergreen needleleaf or broadleaf, and deciduous needleleaf or broadleaf trees, as well as temperate (C3) and warm-season (C4) grasses. An algorithm is used to determine life-form mixture at each annual time-step as a function of annual average minimum monthly temperature and growing season precipitation (see Bachelet et al., 2001; Daly et al., 2000). Tree and grass life-form mixtures, their biomass simulated by the biogeochemistry module, as well as climate indices are used to determine which of several dozen possible PVCs occurs in each simulated grid cell each year (see Bachelet et al., 2001; Daly et al., 2000).

The biogeochemistry module is a modified version of the CENTURY model (Parton et al., 1993), which simulates plant growth, organic matter decomposition, and the movement of water and nutrients through ecosystems. The biomass and hydrology algorithms from CENTURY were retained and linked to the dynamic biogeography driver. Life-form specific parameters (e.g., maximum production rate of evergreen trees) are determined annually by modifying their original values as a function of their dominance along the two-dimensional climatic gradient defined by growing season precipitation and annual average minimum monthly temperature (Bachelet et al., 2001). In this study, plant growth was assumed not to be limited by nutrient availability; the nitrogen

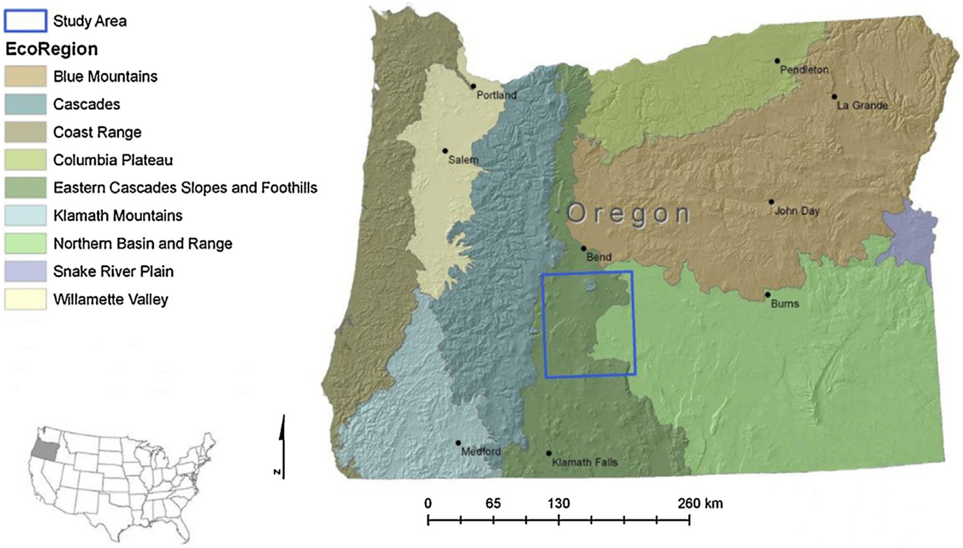

Fig. 1. Study area in central Oregon, USA. Ecoregions shown are Omernik Level III Ecoregions (Omernik, 1987).