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Analysis

An updated biodiversity nonuse value function for use in climate change integrated assessment models ☆

Wesley R. Brooks [a], Stephen C. Newbold [b,]*

[a] Dept. of Ecology, Evolution, and Natural Resources, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901, USA
[b] U.S. EPA National Center for Environmental Economics, Washington, DC, USA

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ABSTRACT

The impacts on biodiversity and ecosystems are among the key reasons for concern about climate change. Integrated assessment models are the main tools used to estimate the global economic benefits of policies that would address climate change, but these models typically include only a partial accounting and idiosyncratic treatment of ecosystem impacts. Here, we review several recent studies of the impacts of climate change on biodiversity and show that the biodiversity value function in the FUND integrated assessment model is insensitive to predicted biodiversity loss, instead depending almost entirely on temperature changes per se. We use quantitative estimates of the influence of global warming on species extinction rates to re-calibrate the biodiversity loss function in FUND, and develop a new global biodiversity nonuse value function calibrated using results from two previous studies of people's willingness to pay to prevent the loss of tropical rainforests and to protect endangered species in the U.S. In contrast to the ecosystem damages function in FUND, our biodiversity value function depends on temperature only indirectly through its influence on biodiversity loss. Finally, we highlight areas where further research is needed for developing more comprehensive and reliable forecasts of ecosystem damages related to climate change.

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1. Introduction

The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report indicated a likely global average surface warming of 0.3–4.8 °C by the end of this century relative to average temperatures between 1986 and 2005. The impacts on biodiversity and ecosystems are among the key reasons for concern about climate change (Smith et al., 2009). Thus, understanding the effects of temperature increases on patterns of biodiversity is of fundamental importance to quantifying the ecological and economic risks of climate change. To date, most ecological research in this area has focused on the effects of climate change on species range sizes and extinction risks, with very little quantitative research on the subsequent effects of species movements and extinctions on ecosystem functions and services. Meanwhile, from an economics perspective, integrated assessment models (IAMs) are the main tools used to estimate the global economic benefits of policies that would address climate change (Kelly and Kolstad, 2000), but these models include only a partial accounting and idiosyncratic treatment of ecosystem impacts.

In this paper, we review recent ecological research on the potential impacts of global average temperature changes on biodiversity, and we develop a modified biodiversity loss function that could be used in a simplified global integrated assessment model of climate change. Additionally, we draw from two previous ecosystem valuation studies to develop a new value function that is designed to capture the "nonuse" value of global biodiversity loss. In the language of the Millennium Ecosystem Assessment, this includes some of the "cultural services" of ecosystems and the "supporting services" that would underpin these, but excludes "provisioning" and "regulating" ecosystem services. The "use" values that arise through species' contributions to these other classes of ecosystem services would need to be assessed separately. Our exclusive focus on nonuse value in this paper follows from the fact that the two biodiversity valuation studies we use to calibrate our value function were stated preference studies, and so we assume that these studies predominantly capture the nonuse value of biodiversity. Finally, we highlight areas where further research is needed for developing more comprehensive and reliable forecasts of ecosystem damages that may be caused by climate change.

This paper is structured as follows. In Section 2 we review the projected impacts of climate change on ecosystems. We focus mainly on global species loss and draw heavily on the IPCC reports and several more recent studies. The main aims of this section are to describe the key mechanisms by which climate change is expected to impact biodiversity, briefly explain the approaches that ecologists use to examine the potential effects of climate changes on species, and summarize the range of projected impacts that can be found in the literature. In

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* Corresponding author.
E-mail addresses: wrbrooks@gmail.com (W.R. Brooks), newbold.steve@epa.gov (S.C. Newbold).

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Section 3 we discuss the ecosystem damage estimates in three simple integrated assessment models of climate change: PAGE, DICE, and FUND. The limited representation of ecosystem damages in these models is understandable in light of the relatively sparse research on people's willingness to pay for biodiversity protection at the global scale; however, it stands in contrast to the growing body of scientific studies that point to potentially severe impacts on biodiversity and ecosystems (Pereira et al., 2010). In Section 4 we examine the ecosystem damage function in FUND and update some of its key parameters based on more recent research. We also develop a new biodiversity nonuse value function that could serve as a replacement for the ecosystem damage function currently used in FUND or in other simple IAMs. We conclude in Section 5 with a brief summary and discussion of areas where more research is needed. An appendix provides additional background information and model details that could not be included in the main body of the paper due to space constraints.

2. Impacts of climate change on ecosystems

The IPCC's Fourth Assessment Report identified several direct and indirect impacts of climate change on biodiversity and ecosystem processes. Much of the research in this area has focused on impacts at the level of species' populations, and a variety of morphological, physiological, behavioral, and reproductive changes in plant and animal populations have been linked to climate change (e.g., Hughes, 2000; Parmesan, 2006; Walther et al., 2002). Other studies have examined the impacts of climate change on evolutionary processes and genetic changes in populations (e.g., Bradshaw and Holzapfel, 2006; Thomas, 2005; Thomas et al., 2001). A growing body of research has implicated climate change in species- and community-level changes as well, including geographical shifts in species distributions and abundances (e.g., Grabherr et al., 2001; Thomas et al., 2001; Walther et al., 2005), changes in phenology (e.g., Parmesan and Yohe, 2003; Root and Hughes, 2005; Root et al., 2003), and altered biotic interactions (Kerr and Kharouba 2007).

2.1. Species responses to climate change

Though many uncertainties remain, a framework for understanding species' responses to climate change has emerged from the developing field of global change ecology (see the Appendix for a more detailed review). As the effects of climate change will vary over different locales, different populations of each species will be affected by varying conditions. In some locales, the effects of climate change may be slight and some organisms with high phenotypic plasticity (see Chevin et al., 2010) may be able to tolerate new environmental conditions with minimal impact on their physiological states and overall rates of reproduction and survival. However, populations with limited phenotypic plasticity or those that reside in areas with more dramatic climate changes may not tolerate these changes as easily. The net result of these population responses to varied climate impacts across a species' range is manifested in the species' response to climate change. Ultimately, species, as aggregated populations of similar organisms, will react to increasing global temperatures with three basic responses: adaptation, migration, or extinction. Most research to date has focused on range adjustments due to migration and extinction as species' primary responses to temperature increases (e.g., Chen et al., 2011; Warren et al., 2011).

2.2. Projections of species losses due to climate change

Three recent studies have examined the potential loss of species diversity caused by climate change at the global scale. First, Thomas et al. (2004) combined the results of six previous studies that used “climate envelope modeling” to predict the effects of climate change on species extinction rates. Based on a variety of sensitivity analyses, including three different CO_2 scenarios and three alternative applications of the species–area relationship (SAR), Thomas et al. estimated that 9–52% of species may be “committed to extinction” by 2050. Under the most rapid climate change scenario examined, with atmospheric CO_2 concentrations exceeding 550 ppm by 2050, Thomas et al.'s extinction estimates ranged from 21% to 52%, with a scenario mean of 35%. Second, Malcolm et al. (2006) used two dynamic global vegetation models (DGVMs) and seven general circulation models to project changes in the distribution of major biome types and associated extinctions of endemic plant and vertebrate species in 25 current biodiversity hotspots under a climate scenario with a doubling of CO_2 in 100 years. Malcolm et al. estimated that between <1% and 43% of species would be “threatened with extinction” under a scenario with doubled atmospheric CO_2 concentration by 2100, with an overall mean estimate of 11.6%. Third, Warren et al. (2011) conducted a meta-analysis whereby they employed up-scaling techniques to reference all of the studies utilized to a common pre-industrial baseline for temperature. Their projections suggest significant range losses and extinctions at less than a 2 °C global mean temperature increase that ramp up quickly as temperatures rise above 2 °C. See the Appendix for more details on these three studies.

Realized extinction rates in the short and medium run likely will be lower than estimates of the number of species “committed to extinction” within those time frames (Pereira et al., 2010), and SAR has been demonstrated to overestimate extinction rates, sometimes significantly (He and Hubbell, 2011). Nevertheless, the projections of Thomas et al., Malcolm et al., and Warren et al., represent the best currently available predictions of the effects of rising temperatures on global species richness.

2.3. Implications for ecosystem services

The relationships between biodiversity, ecosystem functioning, and the maintenance of ecosystem goods and services is a growing focus of inquiry among ecologists and other environmental and social scientists (Diaz et al., 2006; Hooper et al., 2005; MEA, 2005a). Species losses may diminish the availability of ecosystem goods and services through changes in ecosystem structures and functions (MEA, 2005a,b; NRC, 1999). However, the cumulative changes in ecosystems brought about by species turnover, migrations, and the development of novel communities may be more significant to the provision of ecosystem goods and services than species extinctions. Ecosystem services have been linked to human well-being through a variety of direct and indirect channels, so the accelerated degradation of ecosystem service flows could have important economic and social consequences (MEA, 2005a).

Ecological changes and the associated impacts on ecosystem service flows and human well-being are mostly absent from economic integrated assessment models (IAMs) of climate change due, in part, to a lack of reliable quantitative estimates. Climate change may affect a wide variety of ecosystem goods and services, such as pest control, pollination, seed dispersal, decomposition and soil maintenance, subsistence hunting, outdoor recreation, ecotourism, cultural and religious symbols, and more (IPCC, 2001, pp. 276–278). Because many of these goods and services have indirect-use and nonuse (existence) values, they are difficult to quantify using traditional economic valuation methods (Freeman, 2003, pp. 457–460). In the next section, we review the treatment of ecosystem damages in three of the most widely used IAMs in the climate economics literature.

3. Ecosystem damages in integrated assessment models

There are many integrated assessment models designed to examine climate change, but only a subset of these focus on the economic damages from climate change impacts at a global scale. Three of the most prominent IAMs in this category are PAGE, DICE, and FUND. Because these models are designed to estimate the aggregated economic damages of climate change impacts at a global scale over a long time horizon (200 years or more), they are necessarily highly simplified in many respects. Moreover, there is wide variation in the detail with which