Joshua J. Lawler
Assistant Professor, College of Forest Resources, University of Washington
April 17, 2007 “Wildlife and Oceans in a Changing Climate”

Summary

Recent shifts in species ranges have been linked to recent changes in climate. Projected future climatic changes are likely to result in even more drastic shifts in species ranges in the coming century. Research I have conducted in conjunction with colleagues at three other universities and two federal agencies indicates that in many regions of the western hemisphere, climate change will likely result in a wholesale reorganization of vertebrate communities. We modeled the potential effects of 30 different climate-change projections on the geographic ranges of 2,954 vertebrate species. We then identified areas in which the majority (80%) of the climate projections resulted in large predicted changes in animal assemblages. Large portions of both North and South America are projected to experience at least 20-30% species turnover under even the lower B1 greenhouse-gas emissions scenario and at least 30-40% species turnover under the mid-high A2 scenario. Parts of the Andes, Central America, and the far northern boreal forests and tundra are predicted to experience greater than 80% species turnover. Thus, our results indicate that in the coming century, vertebrate communities in many parts of North and South America will likely bear little resemblance to today’s fauna.

Background

Recent shifts in the distribution of plants and animals have been clearly linked to recent changes in climate (Parmesan and Yohe 2003, Root et al. 2003, Parmesan 2006). Most notably, species have shifted their ranges either poleward in latitude or upward in elevation (Parmesan 1996, Parmesan et al. 1999, Thomas and Lennon 1999). These movements have generally occurred at rates that are consistent with rates of recent global warming (Parmesan and Yohe 2003, Root et al. 2003).

Climatic changes for the coming century are projected to exceed those of the past 100 years. For example, global average temperatures have risen approximately 0.7 °C in the past century and are projected to increase between 1.1 and 6.4 °C in the next 100 years (Alley et al. 2007). Given the projected magnitude of future climatic change, we can logically expect even greater shifts in species distributions in the coming century.

Several studies have made projections of potential future shifts in the distribution of both plants and animals (e.g., Peterson et al. 2002, e.g., Thuiller et al. 2005, Araújo et al. 2006). In general, these studies have predicted relatively large changes in local plant or animal assemblages as a consequence of projected changes in climate. For example, Peterson et al. (2002) estimated that changes in some assemblages of animals in Mexico will potentially be as high as 40% by 2055. Thuiller et al. (2005) estimated average changes in plant assemblages across Europe will range from 27-63% by 2080.

Changes in the distribution of species have profound implications for the management of fish and wildlife. Areas that currently provide habitat for a given species may no longer provide habitat in the future. Conversely, areas that are unsuitable today may eventually provide habitat as the climate changes. In addition, the loss of a key species or the addition of a specific species to a community may have profound effects on the other species in the system. Thus, shifts in even small numbers of species have the ability to dramatically alter ecological systems. For example, the climate-induced spread of the mountain pine beetle has increased whitebark pine mortality in parts of the Rocky Mountains resulting in the reduced availability of whitebark pine seed, a primary winter food source for the grizzly bear (Logan and Powell 2001).

Projected climate-induced impacts on animal distributions in the western hemisphere

Here, I present research that my colleagues and I have done to assess the potential effects of climate change on the distribution animals in the western hemisphere. We explored the potential effects of 30 coupled atmosphere-ocean general circulation model (AOGCM) future-climate simulations on the distribution of 2,954 species of birds, mammals, and amphibians for the period of 2071-2100. We then identified areas where animal assemblages are consistently predicted to experience changes.

Study approach

We built individual models for each species in the study based on the relationships between observed species ranges and current climate. This general modeling approach is often called “climate envelope” or “species niche modeling” (Pearson and Dawson 2004). More specifically, we used random forest classifiers (Breiman 2001) a consensus-based ensemble modeling approach that involved building 100 individual models for each of the species in the study and then averaging the predictions from those models to produce one prediction. Random forest classifiers have been shown to outperform other similar modeling approaches (Lawler et al. 2006). We used only highly accurate models our analyses. We tested the models on a reserved set of data that was not used in the model-building process. We then removed any species from the study for which the models were unable to predict at least 90% of the presence data points and at least 80% of the absence data points correctly. This provided us with a set of models that is more accurate than most of those used in previous range-shift studies. After building and selecting the models, we then used the 30 future climate projections as input into the models to generate 30 potential future geographic ranges for each species.

The 30 climate simulations used in the study consisted of projections from 10 AOGCMs (Table 1) run under three different greenhouse-gas emissions scenarios (B1, A1B, and A2) representing the lower, mid, and mid-high range of the scenarios developed for the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000). All 30 simulations have been produced for the IPCC Fourth Assessment Report initiative. For North and South America, these 30 distinct climate simulations produced increases in mean annual temperature ranging from 1.2 to 5.2 °C and changes in mean annual precipitation ranging from -122.5 to 131.9 mm for the 30-year time period relative to 1961-1990. These climate simulations thus represent the uncertainty in both future greenhouse-gas emissions and in the simulated response of the climate system (Cubasch and Meehl 2001).

To summarize the projected range shifts across all species and climate-change scenarios, we used each of the 30 climate-change projections to estimate potential changes in animal assemblages for each of 15,323 50x50-km grid cells in the western hemisphere. As climate changes, species will differ in their ability to track the change and to move into newly created suitable habitat. We calculated potential changes on a cell-by-cell basis assuming no dispersal to new areas with suitable climatic conditions and conversely, assuming unlimited dispersal into new suitable areas. The actual responses of species will likely fall between these two extremes. For the assumption of no dispersal, we calculated “species loss” for a cell as the percentage of all modeled species currently occurring in the cell whose predicted future range did not include the cell. Under the assumption of unlimited dispersal, we calculated “species gains” and “species turnover”. Species gains were calculated as the number of species not in the cell whose future range did include the cell. Like losses, gains were expressed as a percentage of the number of species currently in a cell. Species turnover is a composite measure of both potential species losses and potential species gains and was calculated as 100*((number of species lost from a cell + number of species gained by a cell) / current number of species).

We summarized the 10 predictions of species loss, gain, and turnover for each greenhouse-gas emissions scenario by taking the 20th percentile (80% of the models predicted at least that much change) of the distribution of loss, gain, and turnover values for each grid cell. These values were used to identify areas in which 80% or more (at least 8 out of 10) of the climate projections for each greenhouse-gas emissions scenario predicted high species loss, gain, and turnover.

Findings

Under all three greenhouse-gas emissions scenarios, most of the United States is predicted to experience significant changes in animal communities. Eighty percent of the analyzed climate-change projections predict at least 10-20% species loss over roughly half of the United States under the lower B1 emissions scenario and at least 10-20% loss over most of the United States under the mid-high A2 scenario (Figure 1). Under the A2 scenario, eighty percent of the climate projections result in at least 20-30% species loss for many areas in the central and southwestern United States. In addition, several areas in Central and South America are consistently projected to experience large losses. Eighty percent of the analyzed climate-change projections predict at least 20-30% species loss under the lower B1 emissions scenarios, and at least 50-60% loss under the mid-high A2 scenario in parts of Vera Cruz, the Yucatan Peninsula, and the Andes Mountains.

Several areas are predicted to gain substantial numbers of species as a result of range shifts and expansions (Figure 2). Percentage wise, the largest gains in species are predicted for the northern latitudes and the Andes mountains, where even under the lower B1 emissions scenario, eighty percent of the climate simulations result in at least 60-70% species gains. When losses and gains are both taken into account, the models predict relatively large changes across much of the western hemisphere (Figure 3). Large portions of both North and South America are projected to experience at least 20-30% species turnover for eighty percent of the climate projections under all three greenhouse-gas emissions scenarios and at least 30-40% species turnover under the mid-high A2 scenario. Parts of the Andes, Central America, and the far northern boreal forests and tundra are predicted to experience greater than 80% species turnover, which would mean that the vertebrate communities in those regions would bear almost no resemblance to today's fauna. Due to latitudinal trends in species richness, the largest changes in the absolute number of species are predicted for the tropics. For the tropics, the maximum projected changes in the numbers of species across scenarios are 352 and 465 species, for no-dispersal and full-dispersal scenarios, respectively.

There are several reasons why these analyses provide a conservative estimate of the future climate-driven changes in biodiversity. First, because the approach we used does not directly model interactions between species, it is likely that shifts in the ranges of other species and particularly in the distributions of diseases and pathogens (Pounds et al. 2006) will further alter ecological communities. Second, our models also do not account for land-use change, which could cause many species to disappear from a region or prevent them from occupying newly created suitable climates. Third, we only include in our analyses those species for which we were able to build models that accurately predicted current ranges. Although this restriction improved the accuracy of our analyses over those in previous studies, it generally biased us towards including species with larger, more contiguous ranges. Many of the species that were not modeled had small or highly fragmented ranges. These species are likely to be more susceptible to climate-induced range loss and range contraction due to their restrictive habitat requirements. Thus, our estimates of potential faunal change would likely be much greater if these species could have been modeled. Finally, we have modeled changes in species ranges as defined strictly by changes in climate. Climate change is also likely to alter habitat by changing sea level (Meehl et al. 2005, Alley et al. 2007), fire regimes (Westerling et al. 2006), as well as hydrological and other disturbance regimes.

Conclusions

The results of our study indicate that large portions of North and South America are likely to experience major climate-induced changes in animal assemblages in the coming century. Eighty percent of the climate change scenarios we investigated resulted in species turnover rates of at least 20-30% for much of North and South America under even the lower B1 greenhouse-gas emission scenario and at least 30-40% under the mid-high A2 scenario. These are likely to be conservative estimates of change because 1) they do not include many vertebrate species with small or fragmented ranges, 2) they do not account for interactions between species, and 3) they do not take into account many of the other climate-induced factors such as changing disturbance regimes and disease frequency and prevalence that will alter species distributions and animal communities.

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Table 1. Atmosphere-ocean general circulation models from which projections were obtained.

Model Name	Model Vintage	Modeling Group	References
CGCM3.1 (T47)	2005	Canadian Centre for Climate Modeling & Analysis, Canada	(McFarlane et al. 1992, Flato 2005)
CNRM-CM3	2004	Météo-France/Centre National de Recherches Météorologiques, France	(Déqué et al. 1994, Terray et al. 1998)
GFDL-CM2.0	2005	Geophysical Fluid Dynamics Laboratory, USA	(Delworth et al. 2006)
GFDL-CM2.1	2005	Geophysical Fluid Dynamics Laboratory, USA	(Delworth et al. 2006)
GISS-ER	2004	NASA/Goddard Institute for Space Studies, USA	(Schmidt et al. 2006)
INM-CM3.0	2004	Institute for Numerical Mathematics, Russia	(Diansky and Volodin 2002, Galin et al. 2003)
MIROC3.2(medres)	2004	Center for Climate Research, Japan	(K-1 Developers 2004)
MRI-CGCM2.3.2a	2003	Meteorological Research Institute, Japan	(Shibata et al. 1999, Yukimoto and Noda 2003)
CCSM3.0	2005	National Center for Atmospheric Research, USA	(Collins et al. 2006a, Collins et al. 2006b)
UKMO-HadCM3	1997	Hadley Centre for Climate Prediction and Research/Met Office, UK	(Gordon et al. 2000, Pope et al. 2000)

Figure 1. Consistent predictions of climate-induced species range losses for lower B1, mid A1B, and mid-high A2 greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change based on 10 different climate-change projections. Species-loss values assume no dispersal of individuals to newly created suitable climatic environments. Eighty percent of the climate projections (8 of the 10) resulted in losses greater than the values represented in the maps.

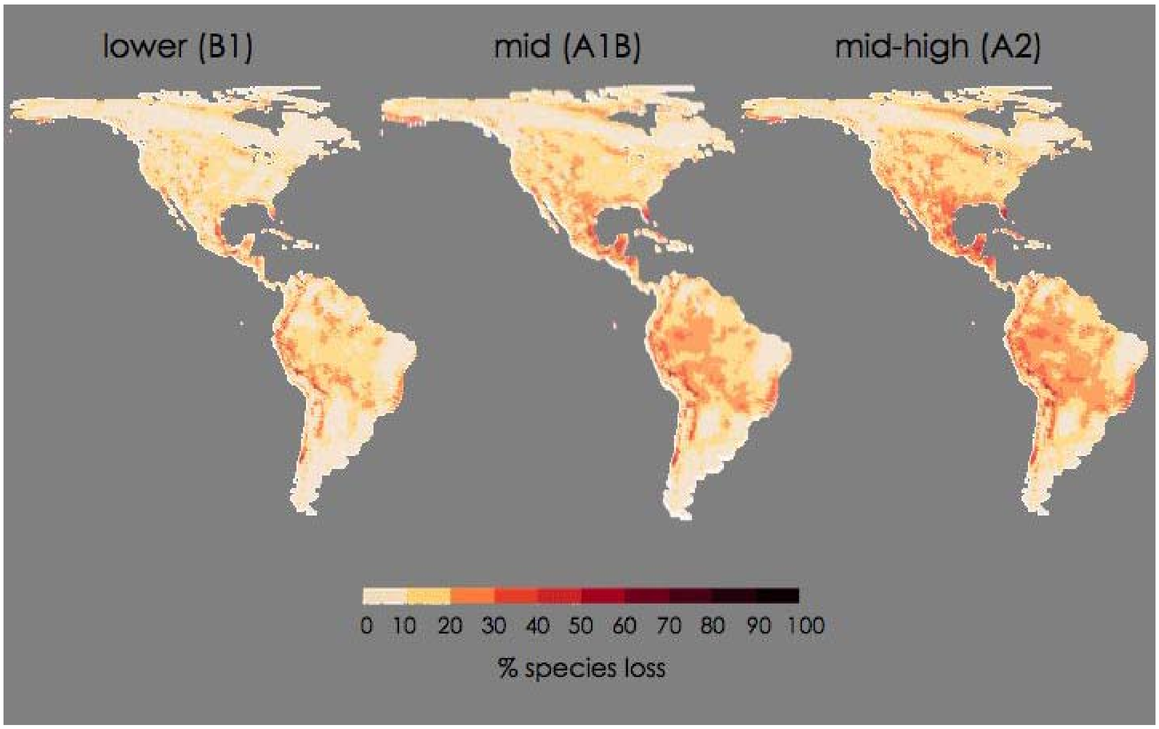

Figure 2. Consistent predictions of climate-induced species gains for lower B1, mid A1B, and mid-high A2 greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change based on 10 different climate-change projections. Eighty percent of the climate projections (8 of the 10) resulted in percent gains greater than the values represented in the maps.

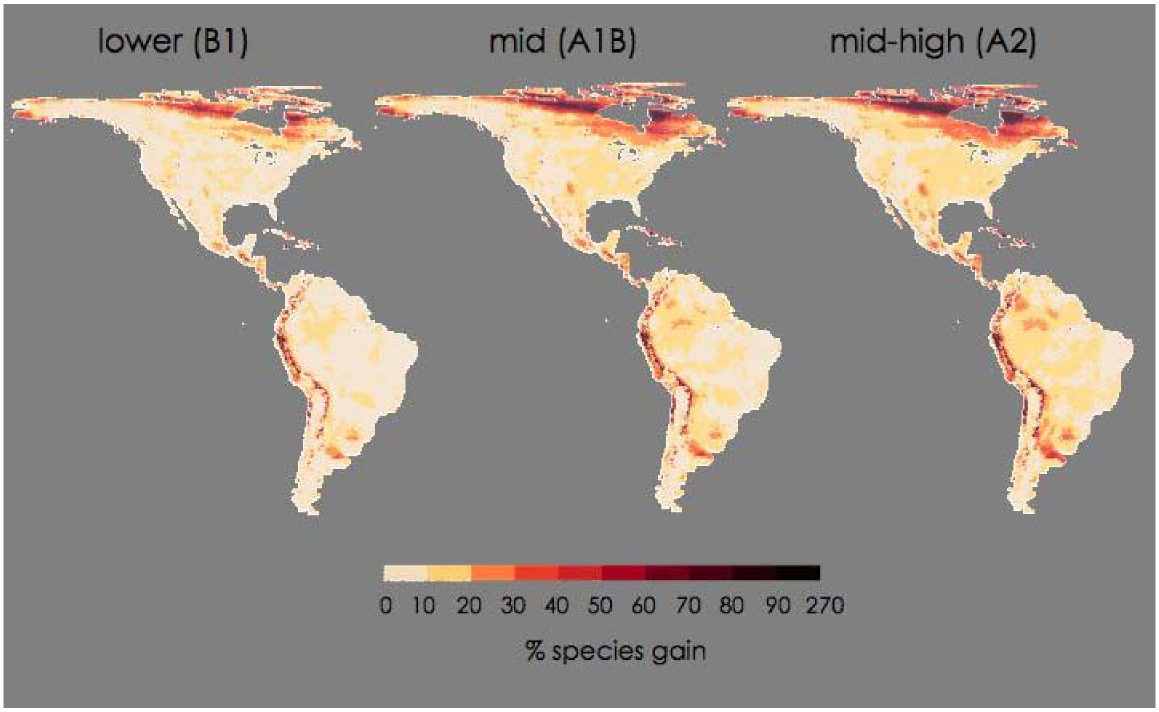

Figure 3. Consistent predictions of climate-induced species turnover for lower B1, mid A1B, and mid-high A2 greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change based on 10 different climate-change projections. Eighty percent of the climate projections (8 of the 10) resulted in percent turnover values greater than the values represented in the maps.