# Literature Review: Linking Climate Change Scenarios to Biodiversity Species Data in Order to Protect Future Distributions

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## Abstract

Growing interest in the link between climate change and biodiversity has lead to many studies in the past decade. We evaluate a variety of biodiversity and climate modeling studies to understand methodogies used. Our goal is to review studies linking biodiversity and climate at the regional and continental scale. We conclude by suggesting common themes and opportunities for future geomatics based investigations of biodiversity and climate change. A synthesized view of the works completed in this field will aid in the convergence of ideas for future research.

## Background and Relevance

The Intergovernmental Panel on Climate Change (IPCC) states that "[p]rojected impacts on biodiversity are significant and of key relevance, since global losses in biodiversity are irreversible" (IPCC, 2007). Many facets of society are concerned about the future of biodiversity because it provides a foundation of goods and services to allow for a healthy functional biosphere (IPCC 2007, Gayton, 2008). In order to protect species diversity, Canada became a member of the Convention on Biodiversity in 1992 and is committed to protecting and managing biodiversity. Canada is therefore required to address any threats to biodiversity such as climate change (Duro et al., 2007).

The use of climate models to predict future biodiversity is a relatively new field of research. Previously scientists did not have the capacity to accurately model climate and its impact on ecosystems but advances in technology have allowed researchers to accurately map future scenarios of biodiversity and climate change (Duro et al., 2007; Nagendra, 2001; Kerr and Ostrovsky, 2003). Methods to research climate and biodiversity vary depending on the scale of the research, landscape structure, time, resources, and desired detail (Kerr and Ostrovsky, 2003). Remote sensing and field data are commonly used as inputs along with climate models to predict long term forecasts of future biodiversity (Xiaoyang et al., 2004). Reviewing the range of research in the field of biodiversity and climate change will consolidate information and aid in the improvement of future research methodologies. In this paper, we provide a literature review of large area, spatially explicit studies that investigate the link between species distributions or biodiversity and climate change.

## Methods and Data

Our interests are in large area biodiversity which requires a great amount of species spatial data. Most spatial biodiversity research falls into three categories: field based data, remote sensing based data, or a combination of the both (Nagendra, 2001).

Field plot data are used by many researches such as Iverson, Thuiller, and Hamman and Wang (Iverson and Prasad, 1998; Iverson et al., 2008; Thuiller, 2003; Guisan and Thiller, 2005; Hamman and Wang, 2006). Field data requires a massive amount of input data that involves physically sampling the vegetation structure of tens of thousands of plots (Hamman and Wang, 2006; Iverson and Prasad, 1998). The spatial and species data are then put through a number of statistical models. Common models include: regression tree analysis (RTA), random forests, bagging, linear models, generalized boosting models (GBM), multivariate adaptive regression splines, and artificial neural networks (Moisen and Frescino, 2002; Prasad et al., 2006; Iverson et al., 2008; Thuiller, 2003; Thuiller and Morin, 2009). There is no one model that prevails at this time. RTA is the most widely used, but even this model has literature that conflicts with its dominance as the best species distribution modeling technique (Moisen and Frescino, 2002). RTA has a non additive behavior because it separates predictor variables making RTA a valuable model in large diverse environments (Iverson and Prasad, 1998). Researchers commonly use a variety of statistical models and or hybrid / ensemble of models. Thuiller and Morin chose the GBM niche based model and the Phenofit process based model, but also suggest that a hybrid model would better reflect reality and therefore improve the accuracy of the results (Thuiller and Morin, 2009). Field plot data provides a detailed and ground truthed look at species interactions and diversity. The drawback to this type of data gathering is that it dates itself in the short to medium term which will require re-sampling every few years (Condes and Milan, 2010). Furthermore, this is an intensive and costly way to research biodiversity (Condes and Millan, 2010; Guisan and Thuiller, 2005). The field plots must represent all bioregions since the data will need to be interpolated; this is difficult in diverse and remote study areas. Field data research is recommended for limited uniform landscapes at the regional to sub regional level with adequate resources (Nagendra, 2001).

Remote sensing is used by biogeographers such as Foody, Duro, and Xiaoyang; to quickly and cheaply research biodiversity (Foody, 2008; Gillispie et al., 2008; Duro et al., 2007; Xiaoyang et al., 2004). Remotely sensed data can be gathered by a number of passive sensor satellites such as the moderate-resolution imaging spectroradiometer (MODIS), Landsat, and SPOT; as well as active sensor satellites such as Radarsat, SRTM, and ASAR (Gillespie et al., 2008; Turner et al., 2003). This satellite data can provide massive amounts of data such as the fraction of light absorbed by vegetation values (fPAR values), digital elevation models, disturbance, land cover, and fragmentation (Ritters et al., 2002, Running et al., 2004; ). This data are provided in a continuous raster format and can cover all scales of research from local to global scales (Duro et al., 2007). Species richness and diversity can be found using the normalized difference vegetation index (NDVI) which is gathered using passive satellite data (Xiaoyang et al., 2004). Although a large amount of information about biodiversity can be gathered quickly, this type of input data can have limited resolution and currently has limited utility at the species level (Gillespie et al., 2008). At this time only a generalized view of biodiversity is attained from these data sets (e.g., Hamann and Wang, 2006). Innovative research is now being conducted that will refine methods for using remote sensing data. Researchers are using derivatives of satellite data such as fragmentation, land cover, disturbance, productivity, and topography to enhance the accuracy and scope of biodiversity research (Foody, 2008; Hamman and Wang, 2006). Future work will use higher resolution data, integrate a variety of biodiversity data sets, and link field data to ground truth results. Remote sensing is currently recommended for regional to global biodiversity analysis that requires repeatable quantitative analysis (Turner et al., 2003). Although field data are being overtaken by remote sensing as a data source, it is important to sustain both types of research to continuously improve and calibrate methodologies (Gillespie et al., 2008).

Climate models and emission scenarios are constantly being updated. Most research is being conducted on IPCC approved models and emission scenarios that give a variety of outcomes from worst case to best case. Common models include the Hadley CM3, GCM, CGCM, and PCM (Iverson et al., 2008; IPCC, 2007; Flato et al., 2000). Emission scenarios are used in climate models to compare possible future CO2 levels in the atmosphere. The most common emission scenarios used are the A series (high $Co^2$), B series (low $Co^2$) and an averaged scenario. Most researchers use a variety of models and scenarios to allow individual interpretation of the data since no one model or scenario can accurately predict the future of these complex systems (Thuiller, 2007; Iverson and Prasad, 1998; Iverson et al., 2008).

Some common goals for biodiversity and climate change forecasting is to find conservation gaps, species niches, invasive species movements, modeling species distributions, and habitat analysis (Hamann et al., 2005; Guisan and Thuiller, 2005; Hannah et al., 2005). There are many applications for this research that will help resource managers make informative decisions; for example: Hamann et al. used geographic information systems to layer biodiversity models with protected areas data to find conservation gaps for particular forest types (Hamann et al., 2005). The fates of many species can be determined by analyzing future species distribution, the climactic stresses put on them, and the amount of conservation efforts existing for those species (Willis et al., 2008; Foody, 2008). Although the methods to create future biodiversity models differ the value of the data are the same.

## Results and Discussion

GIS is an excellent tool to research shifting biodiversity due to climate change in large complex environments (Duro et al., 2007; McDermid et al., 2005). Field plot data are valuable for species specific relationships, but is not practical for large diverse environments. Remote sensing is valuable for regional to global analysis, but until recently has not been applicable to research at the species level.

Biodiversity and climate research has a number of common opportunities and challenges. For instance, the assumption that climate is the main variable for species survival may be problematic (Currie, 2001; Turner et al., 2003). All researchers used climate scenario models and species distribution data in a GIS to predict future biodiversity. There is a consensus that temperature and precipitation are the most important factors in climate models and biodiversity; however, other variables may be important as well (Hamann and Wang 2006; Turner et al., 2003; Negendra, 2001; Iverson et al., 2008; Hannah et al., 2002). Nagendra stated in 2001 that species diversity research in remote sensing was confusing and contradictory. Current literature shows a more directed approach to this type of research (Nagendra, 2001; Hannah et al., 2002, Barnard and Thuiller, 2008). Output data can be linked with parks and protected areas. Studies use biodiversity models to make suggestions about migration corridors, non climactic stressors to ecosystems, and ecosystems where protected areas should be placed (Ritters et al., 2002; Turner et al., 2003; Lemieux and Scott, 2005; Willis et al., 2008). Although biodiversity research has shown to be useful, there are many opportunities that are not being explored. Within the literature there seems to be a lack of integration between data sets, traditional knowledge, and policies perspective that would help synergize conservation efforts into the future.

## Conclusions

We looked at common biodiversity and climate research to find the methodologies used to map biodiversity, choose climate models, and address conservation gaps. Biodiversity research can be done using field data, remote sensing, or both. Given the spatial nature of predicting future geographical distribution of biodiversity, GIS and remote sensing are important technologies to employ in addressing research questions. Biodiversity and climate mapping has limitations but it provides valuable data to make informed decisions about the impact climate change will have on the biosphere.

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