Impacts of Climate Change on Forest Product Markets: Implications for North American Producers

Brent Sohngen
AED Economics
Ohio State University
2120 Fyffe Rd.
Columbus, OH 43210-1067
Sohngen.1@osu.edu
614-688-4640

Roger Sedjo
Resources For the Future
1616 P. St., NW
Washington DC 20036
sedjo@rff.org

**Acknowledgement*: Funding for this research obtained from the US Department of Energy, Climate Change Research Division; US Environmental Protection Agency STAR grant; US Environmental Protection Agency, Climate Analysis Branch.

Impacts of Climate Change on Forest Product Markets: Implications for North American Producers

ABSTRACT

This paper examines potential climate change impacts in North American timber markets. The results indicate that climate change could increase productivity in forests in North America, increase productivity in forests globally, and reduce timber prices. North American consumers generally will gain from the potential changes, but producers could lose welfare. If dieback resulting from additional forest fires, increased pest infestation, or storm damage increases appreciably and has market effects, consumers will gain less and producers will lose more than if climate change simply increases the annual flow of timber products by raising forest productivity. Annual producer welfare losses from climate change in the North American timber sector are estimated to range from $1.4 – $2.1 billion per year on average over the next century, with the higher number resulting from potential large-scale dieback. Within North America, existing studies suggest that producers in northern regions are less susceptible to climate change impacts than producers in southern regions because many climate and ecological models suggest that climate become dryer in the U.S. South.

INTRODUCTION

It is widely recognized that climate change will have substantial impacts upon forested ecosystems during this century (McCarthy et al., 2001). In addition to many existing stresses, such as deforestation, pest infestations, forest fires, and invasive species, climate change is expected to increase stresses upon forested ecosystems. These stresses include potential changes in the distribution of species (i.e., Iverson and Prasad, 2001), positive or negative changes in the productivity of individual species and entire ecosystems (Shugart et al., 2003), potential increases in storm damage or forest fires due to changes in climate and weather patterns (Dale et al., 2001).

The ecological impacts of climate change could have substantial impacts on North American timber markets. The largest temperature changes this century are anticipated to occur in higher latitude regions (McCarthy et al., 2001). A large proportion of forest biomass stock resides in northern Canada, and changes in these stocks could have consequences in markets. Furthermore, some climate change scenarios suggest that productivity in the U.S. South could decline, at least for a time (VEMAP Members, 1995; Joyce et al., 2001). The U.S. south currently produces a large proportion of total timber in the U.S., so any reduction could have large implications for prices.

Forestry is an important component of the North American natural resource base. In regions like the Southern United States, or British Columbia, forestry contributes heavily to the local industrial base. Forest products are also an important export product for Canada in particular. Currently, the value of forest products exports from Canada are around $40 Billion, or 9% of total exports for the country (Statistics Canada, 2005).

Canada supplies approximately 30% of the U.S. lumber market (Haynes, 2003). Any changes in the productivity of forests could have long term consequences for the forest products industry in both countries.

This paper explores the potential economic impacts of climate change upon the forest products industry of Canada and the U.S. We begin with a review of the literature exploring the range of studies that have been conducted to analyze potential impacts. We then present and discuss the results of several analyses of potential climate change impacts estimated for the United States, where most research has been conducted on economic impacts, in more detail. Finally, we examine the results of the global analysis in Sohngen et al. (2001) more closely, presenting specific results for North America. The final section of the paper presents our conclusions.

WHAT ECOLOGICAL IMPACTS ARE IMPORTANT FOR MEASURING THE MARKET IMPACTS?

In order to assess the potential market impacts of climate change in forestry, several important ecological effects must be considered. The ecological effects generally fall into two categories: stock effects and flow effects. Stock effects are those that influence existing timber stands. These include dieback effects that result from storm damage, forest fires, pest infestations, and other disturbances not caused by harvesting trees. Forests have always been susceptible to natural disturbance patterns, and current forest conditions are a result of past disturbances. To the extent that climate change influences the spatial pattern, the pace, or the intensity of future disturbance patterns, the existing stock of forests could be directly susceptible to climate change.

Flow effects are different. For the purposes of this paper, we consider flow effects to be the influence of climate change on the annual growth of trees. Changes in precipitation and temperature, or enhanced CO_2 in the atmosphere are all factors that can affect the annual growth of trees.

It is often difficult to distinguish between stock and flow effects, particularly when moving from smaller spatial scales to more aggregated scales. At the level of a stand, individual tree mortality is a stock effect. At the level of a region, mortality among individual trees can be measured as a reduction in *net* growth, and therefore individual tree mortality can be viewed as a flow effect. Larger events such as catastrophic forest fires, large scale bug infestations, mortality from winter ice storms, etc., however, could be viewed as stock effects. To the extent that these stock effects are large enough to have market implications (i.e. by spurring salvage logging and reducing prices for a time) it is important to account for them as stock effects rather than as flow effects when measuring economic impacts.

From the ecological literature, there is widespread acknowledgement that both stock and flow effects can be important. The recent Canadian National Assessment (Lemmen and Warren, 2004) and U.S. National Assessment (Joyce et al., 2001) of climate change impacts refer widely to the importance of both effects. The Canadian National Assessment, for instance, suggests that growth in forests in northern Ontario and the western part of the country could increase, while growth in the Great Lakes and St.

Lawrence areas could decrease. The U.S. National Assessment by contrast, suggests that forest growth in most regions is likely to increase in the future.

Both the Canadian National Assessment and the U.S. National Assessment report that there could be large increases in most disturbance regimes, including forest fires, insect infestations, and storm damage. Neither of the reports are specific about the actual sizes of changes that might occur in disturbance patterns, or their impacts upon forests, but the U.S. National Assessment report does provide telling detail on projections of potential changes in forest fire regimes. That report suggests that fire severity in the U.S. could increase up to 10% during climate change and that the area burned could increase 25 – 50%. As noted by Dale et al. (2001), the new disturbance regimes introduced by climate change could have substantial and sustained impacts upon forest regimes in the U.S.

When economic models are developed, they often utilize data on tree yields for different age classes to estimate empirical yield functions. These are *net* yield functions that account for historical disturbances within the forests, and historical climate trends. They are the baseline yield functions. Accounting for climate change requires adjusting these functions to incorporate the impact of climate change on forest growth (flow effects), and/or exogenously perturbing the stock of forests to capture potential effects on the forest stock (stock effects).

Within the literature, two basic approaches have been used to model climate change impacts. First, a number of studies have assumed only flow effects (i.e., Joyce et al., 1995; Perez-Garcia et al., 1997; Irland et al, 2001). These studies link projected changes in yields of forest types from ecological models directly to the net yield functions used in the economic model. These models do not assume stock effects are occurring, or at least they assume that the stock effects occur over a small enough area that they have little impact on near term market outcomes. The ecological models may allow for individual tree mortality when calculating changes in annual tree growth, but this individual tree mortality is assumed to be small enough that it does not have market level effects.

Second, some studies have assumed both flow and stock effects (i.e., Sohngen and Mendelsohn, 1998, 2001; Sohngen et al., 2001). These studies link projected changes in yields of forest types directly to net yield functions used in the economic model. They also account for potentially large stock effects that influence forest stands available for harvest in early periods of the model simulation. Since some trees can be marketed even after they have "died" in these scenarios, the modelers usually assume some proportion of the value of the forest is salvaged when dieback occurs.

One of the most important questions remaining in climate change analysis of impacts upon forests is the question of carbon fertilization. Current evidence indicates that additional CO_2 in the atmosphere will improve water use efficiency, but it is unclear whether this will increase overall net ecosystem productivity (Shugart et al. 2003). Some trees could grow more quickly, some more slowly, and others could experience additional mortality. Modeling studies that allow for carbon fertilization through increased water use efficiency tend to show substantial improvements in net primary productivity and overall forest area relative to studies with the same climate change conditions, but without the carbon fertilization effects (i.e. VEMAP Members, 1995). For the most part, the economic studies conducted to date have assumed carbon fertilization occurs and they have used the modeled predictions of carbon fertilization either on net primary productivity or total carbon to assess potential flow, or yield, effects.

Before considering the economic impacts of climate change on markets, it is important to note that while climate change is a global phenomena that clearly requires global action to slow down or prevent, all impacts are local. Estimating economic impacts in forestry requires having information on the regional ecological impacts, at a minimum. Currently, estimates of regional climate change are much more variable across climate models than even the highly variable aggregate estimates of climate sensitivity. Without more refined estimates of climate change impacts at the regional level, it will remain difficult to precisely pin down economic impacts for producers in specific regions. Future research will clearly refine existing results as newer models do a better job of accounting for regional impacts.

REVIEW OF MARKET IMPACT STUDIES IN NORTH AMERICA

A number of studies have been conducted estimating the market impacts of climate change in the U.S. Few economic estimates for Canada have been produced, although the global models examined in the next section do present results for Canada. For the U.S., economic studies indicate that market welfare is likely to increase (Joyce et al., 1995; Sohngen and Mendelsohn, 1998; Irland et al., 2001; Shugart et al., 2003). Consumers gain the most in the scenarios because forest growth is generally expected to increase over the next century, resulting in more timber being available for markets. Producers, however, lose welfare (measured as producer surplus) in most cases because prices decline. While most studies project increased productivity (and hence, yield , in forests), these productivity gains are not strong enough to offset the lower prices.

Within the U.S., the most vulnerable region economically appears to be the Southern U.S. For example, the U.S. study conducted by Sohngen and Mendelsohn (2001) suggests that temperature changes of 1.5º – 5º C for the U.S. could increase economic surplus (consumers' plus producers' surplus) by 13% - 25% for the U.S. as a whole, but that economic surplus in the Southern and Pacific Northwestern U.S. could decline 1% - 20%. Producers in particular could be harmed as producer surplus in these two regions declines by as much as 11% - 43%. This has important market implications since these two regions currently produce the largest share of total timber products in the U.S. By contrast, producer surplus in Northern regions like the Great Lakes and Northeast could increase 16% - 54%.

Results from Irland et al. (2001) suggest smaller overall economic impacts for the U.S.- 0.05% to 0.18% changes in total economic surplus over the coming century- than the results in Sohngen and Mendelsohn (2001). Both studies find that production could decline during the century in the Southern U.S., and increase in the Northern U.S. One reason that the impacts in the Irland et al. (2001) study are smaller than those in Sohngen and Mendelsohn (2001) is that Irland et al. (2001) assume no changes in species distribution. Sohngen and Mendelsohn (2001) allow landowners to adjust species from one type to another when climate changes. Allowing for species changes can boost the total annual production of industrial wood because Southern species tend to have shorter rotation periods. Thus, overall productivity in Northern regions expands in Sohngen and Mendelsohn (2001) not only because productivity has risen, but also because species types change to those that current thrive in the South, allowing for a shorter rotation period.

It may also be important to account for potentially large increases in disturbances. The studies by Sohngen and Mendelsohn (1998; 2001) account for the possibility that large scale dieback effects could occur. The scenarios they examined explore the economic implications of modeling dieback in up to an additional 24% of current forest area. They did not specifically address a particular type of dieback, although all dieback is assumed to kill all trees on sites where it occurs. The largest dieback effects are projected to occur in Northern ecosystems, with up to 45% of existing northern forests undergoing dieback. They implemented the dieback over a 70 year period, and assumed that 75% of the value of the forests could be salvaged. Under these assumptions, their dieback scenarios assume an additional 700,000 hectares of land undergo dieback each year on average. If forest fires are the primary vector for dieback, this results in at least a 41% increase in total area burned each year (assuming 1.7 million hectares are burned in the US each year on average in the baseline).

The results of comparing dieback to other, less intrusive climate change scenarios, have two major implications. First, if dieback occurs and salvage can be accomplished, the dieback can be large enough influence prices in the near term. The loss of stock tends to suppress producer surplus in regions where dieback is largest. Second, to avoid future losses from additional dieback, producers need to adjust the species they plant for the new climate conditions. If producers can regenerate "optimally" for the new and changing climate, they can avoid future damages and avoid additional negative impacts. If, however, they make mistakes in the types of species they plant by planting timber types that are susceptible to additional dieback effects, producer losses will increase (see Sohngen and Mendelsohn, 1998).

One major limitation of all the studies discussed in this section is that they ignore global implications of climate change. That is, they are all U.S. only models. If climate change has relatively larger ecological impacts in other regions of the world, the resulting price changes could cause market impacts in North America. These effects are potentially compounded by emergence of competing timber economies in regions like South America, which have competed successfully with North American producers for market share in recent years. We turn to exploring the implications of international modeling in the next section.

NORTH AMERICAN IMPACTS DERIVED FROM A GLOBAL MODEL

To date, there have been relatively few global market studies of climate change impacts. One study, that of Perez-Garcia et al. (1997), utilized the CINTRAFOR Global Trade Model to estimate impacts of flow effects (productivity changes) in global forests. A separate study, Sohngen et al. (2001) utilized a dynamic optimization model. That study captured both flow and stock effects. This section briefly reviews the results in Perez-Garcia et al. (1997), and then describes several of the implications of the Sohngen et al. (2001) study for North America in more depth.

The ecological model used in Perez-Garcia et al. (1997) suggests that climate change will generally enhance the supply of timber globally due to rising productivity. The model considers only productivity changes and not potential dieback effects. Under the climate and productivity scenarios they examined, nearly all regions experience increased productivity in softwoods and hardwoods, although productivity in some Southeast Asian hardwoods is expected to decline in the scenarios.

The economic results in Perez-Garcia et al. (1997) indicate increasing production in softwood and hardwood products for both the U.S. and Canada. Canada in particular, is projected to obtain substantial increases in softwood production on the order of 20 – 30% over the next 50 years. They estimate that economic welfare increases in both countries as well, although producers lose while consumers gain. The benefits are larger, however, for the U.S.

The study by Sohngen et al. (2001) examines both stock and flow effects by combining the ecological implications of the BIOME3 model (Haxeltine and Prentice, 1996) for two climate scenarios with a dynamic optimization model of global timber markets. Two climate scenarios used in this analysis are the Hamburg T-106 model (Claussen, 1996) and the UIUC model (Schlesinger et al., 1997). Both models project equilibrium climate for a baseline and a scenario with doubled CO_2 conditions. The UIUC model is more sensitive to doubled CO_2, simulating a larger global temperature change of 3.4° C versus 1° C for the Hamburg model. The regional effects in the models differ. For instance, the Hamburg model predicts larger temperature changes in high latitude regions compared to the UIUC model.

The ecological effects derived from the BIOME3 model for these climate scenarios are shown in table 1. The results presented are equilibrium changes that are expected to be realized by 2060. Three effects are shown. First, yield changes, estimated as changes in net primary productivity, are presented. Yield changes are introduced by proportionally adjusting annual growth. For example, the annual growth of timber type i in year X ($AG^{CC}_{X,i}$) is adjusted from the baseline annual growth ($AG^{BS}_{X,i}$) according to the following equation:

$$(1)\ AG^{CC}_{X,i} = AG^{BS}_{X,i}\left(\frac{CEG_i}{60}\right)X$$

where CEG_i is the effect of climate change on the annual growth in the year 2060 and beyond. For the purposes of this study, the transition period from the current climate to the future climate with stabilized concentrations of CO_2 was assumed to take 60 years. As an example, average forest growth in North America is projected to increase by 17-18% under the climate scenarios used in Sohngen et al. (2001). Thus, if forest growth is expected to increase 17% by 2060, then in the 2001, growth only increased 0.28% (0.17*1/60).[1]

Second, the total area of land that potentially dies back by 2060 in each region is shown. Dieback is introduced in one scenario, denoted "dieback". The estimate of the area of land that potentially dies back is based upon the initial area of land in each timber type. To implement the dieback scenario, a fixed proportion of forest stock is assumed to be lost each year (equal losses in each age class). In the scenarios examined, the forest area in North America projected to dieback by 2060 ranges from 28 - 29%. Thus, in 2001, 0.48% of the stock was assumed to dieback.[2]

[1] Note that this example is presented for the average change for North America. Individual timber types in North America were considered in the model, and each timber type had an individual specific change in growth that differed from the average effect for the continent.
[2] As in footnote 1, this estimate is an average for North America. Individual timber types had individual estimates of dieback that differed from this average.

In addition to the dieback scenarios a less intrusive scenario called "regeneration" is also developed. The regeneration scenario allows landowners to choose to adapt by altering the types of species planted. If landowners made the correct assumptions about which species would grow appropriately in the future, the new species planted would be better suited to the new climate they experienced. Landowners would consequently experience no dieback in existing stocks, and therefore no "stock" effects. Both the regeneration and the dieback scenarios are implemented for both climate scenarios, generating four scenarios of potential change – two scenarios with stock effects (dieback) and two scenarios without stock effects (regeneration).

Third, the relative size of the area of forests after climate change is shown. Climate change can cause forest area to expand or contract. Our estimate has been corrected from the original ecological data from BIOME3 such that areas currently in agriculture are prevented from converting to forest. For this analysis, we "mask" out current agricultural areas so that forestland cannot expand onto productive agricultural lands. Thus, all of expansion occurs in regions that are not very productive now (tundra, rangelands, etc.).

Across the two climate scenarios, North American forests undergo more dieback in general than forests in other regions of the world: 28% - 29% compared to 6% - 14% for non-North American regions. The yields of forests also increase less than in other regions (17% versus 32% - 42%), and the net expansion in forests is only 3% - 4% versus 19% - 28% in the rest of the world. While North America appears to gain productivity and forest area, it gains less than the rest of the world. It also possibly could experience more dieback in general if natural disturbance processes increase.

To put some of the estimates into context, under the two dieback scenarios, 28 - 29% of the current forest area in North America is projected to undergo some sort of large scale dieback event over the next 60 years. We implement this over the 60 years such that 0.48% (0.29/60) of the original forest area dies back in the first year. In the second year and over the entire 60 year period, the same total area of land will die back each year. Current estimates suggest that approximately 4.2 million hectares of forestland burn each year in Canada and the U.S. in the baseline (1.7 million hectares per year in the U.S. and 2.5 million hectares per year in Canada). For the dieback scenarios, therefore, the area of forests that burns each year increases by approximately 1.6 million, or 38% relative to the baseline.

For the model developed in Sohngen et al. (2001) Canada and the U.S. are considered together as North America. Timber production for a selection of timber types in North America under the regeneration and dieback scenarios are shown in Figures 1a and 1b. The results shown in the figures are averaged for the two climate scenarios and presented for the dieback and regeneration alternatives. Under the dieback scenarios, the model projects that timber harvests would be suppressed over the first 60-70 years in North America. Although the annual growth of timber is increasing each year during the simulation, dieback eliminates some standing stock.

The economic simulations suggest that average total industrial wood production in North America is projected to decline by approximately 0.14 million m^3 per year in the dieback scenarios during the period 1995 – 2095.[3] The regeneration scenarios, as expected, cause production to increase by approximately 9.02 million m^3 per year. If

[3] Average annual baseline production is expected to be relatively constant over the century in North America, at 530 Million m^3 per year. This change, therefore, represents a very small proportional change in timber production.

dieback occurs, overall production could decline in the near term in North America. In the long term timber production rises by similar amounts in all regions under the dieback and regeneration alternatives.

The global effects of climate change on timber production for several additional timber producing regions of the world are shown in figures 2a and 2b. These regions account for around 90% of global timber production and consumption. As with the results for North America alone, the global results for both dieback and regeneration show that long-term gains in timber production are expected, but dieback can reduce these gains initially. In these scenarios, North America and Russia are the most susceptible regions between 2000 and 2050 because they experience the greatest overall dieback (North America experiences 28 – 29% dieback on average, and Russia experiences 12 – 21% dieback on average, depending on the climate scenario).

Europe, on the other hand, benefits from the dieback scenarios because dieback is not projected to have strong effects there (only 4 – 9% of current forests are projected to dieback in the two climate scenarios). Production in Europe rises relative to the baseline in the period 2010 – 2030, and offsets the reductions in North America and Russia. European production subsequently declines to baseline levels during the period 2040 – 2070 in the dieback scenario as a result of these strong earlier harvests.

Perhaps more importantly for producers in North America, production in South America and Oceania is projected to expand substantially in the period 2000 – 2030 in the dieback scenario. South America shows strong and growing gains in production under dieback throughout the century. Little dieback is projected there, and producers can quickly adjust short rotation species that dominate timber markets as climate changes. As a consequence, these scenarios indicate that producers in emerging industrial forestry regions like South America could potentially benefit substantially during climate change.

When translated into welfare effects, these results imply that producers in North America could lose between $1.4 and $2.1 billion per year over the next century (Table 2). Producers lose welfare under the regeneration scenario because prices decline, but the losses are smaller because existing mature stocks are not lost each year. Losses from dieback in 28% of existing forest areas over the next 60 years, however, could have substantial market impacts, decreasing producer welfare by 30% relative to a scenario with the same general ecological effects, but without dieback effects. Despite the losses to producers in the dieback scenarios, consumer welfare is positive because prices fall. These falling prices result from increases in timber production that occurs in other regions of the world that gain relative to the North America.

Developing countries uniformly fare the best under the climate change scenarios examined in Sohngen et al (2001). Developing countries tend to be in tropical and subtropical regions, and they tend to focus on shorter rotation species. These short rotation species provide multiple opportunities for more rapid adaptation to the ecological and economic effects of climate change, i.e., rising productivity and lower overall prices. As a consequence, the share of global timber production from South America is anticipated to increase 8 – 13% over the next century under climate change.

CONCLUSION

This paper examines the potential economic implications of climate change in North America. Climate change could have substantial impacts on forests by altering the growth of trees, causing dieback in forests, and by causing species to migrate. Given that the largest initial effects of climate change are anticipated to occur in high latitude regions, like Canada, and given the important trade relationship between the two countries in forestry, it is important to carefully assess the implications of climate change impacts for the entire North American region.

The paper begins by examining the potential influence of climate change on forests. The effects of climate change are considered in two categories, flow effects and stock effects. Flow effects adjust the potential future growth of forests due to climate change, and potential carbon fertilization. Stock effects influence current forests through disturbance mechanisms such as forest fires, pest infestations, or windthrow. While flow effects can have potentially large implications for long term economic outcomes by affecting the future growth of forests, stock effects can have potentially important near term impacts by altering supply conditions relatively quickly.

The most extensive analysis of the potential economic impacts of climate change have been conducted in the U.S. to date. The results of these studies suggest that climate change will generally benefit markets in the U.S. because climate change will increase the productivity of forests and enhance the long-term supply of timber. Most of these benefits, however accrue to consumers. Producers tend to lose welfare when prices decline.

The results of analyses conducted in the U.S. also suggest that Northern regions gain at the expense of Southern U.S. Yield changes tend to be larger in Northern areas of the U.S. and some climate scenarios indicate drying in the Southern U.S. The drying leads to near term reductions in forest growth in the South and attendant economic impacts. Since the U.S. South is currently the most productive forestry region within the North American continent, this suggests that producers in Canada could also gain from potential climate change if productivity and forest yields also increase there.

One limitation of many of the studies conducted in the U.S. to date is that they have mostly ignored the ecological and economic implications of global change. That is, they have excluded price effects caused by climate change that occurs in competing regions of the world. The paper reviews recent studies by Perez Garcia et al. (1997) and Sohngen et al (2001) who take a more careful look at these global impacts. The results of the study by Sohngen et al. (2001) for North America are specifically compared and contrasted with results from the same study for different regions.

North America appears to be susceptible to climate change both for ecological and economic reasons. On the ecological side, the ecological model used in the analysis by Sohngen et al. (2001) indicates that North America could experience relatively larger dieback effects under that scenario, leading to losses of production relative to the baseline during the period 2000 – 2050. For the case of North America, the dieback scenarios imply that the area of forests that burns each year increases from 4.2 million hectares to 5.8 million hectares, or a 38% increase. Regions that experienced less dieback tend to gain producer surplus when dieback occurs elsewhere. The absence of dieback however, does not necessarily benefit producers. Lower prices caused by expanding production have broadly negative effects on producers throughout the temperate, developed regions.

In contrast to the developed countries, developing countries mainly appear to benefit from climate change. Many developing countries are located in climates optimally suited to cultivating fast-growing timber plantations. These regions have been gaining global market share in recent years, and these trends are expected to be strengthened during climate change. For example, South American producers are estimated to gain 8 – 13% market share during climate change, with larger gains if dieback occurs in temperate regions.

The review of the literature conducted in this paper and the analysis developed with the results from Sohngen et al. (2001) suggest several important future research directions. First, the economic results are heavily influenced by regional climate change and ecological estimates. Since climate models are still highly aggregated, and methods for regionalizing the large-scale general circulation models are still rudimentary, it will be important to re-assess the economic results as newer data becomes available. Second, the economic results are sensitive to potential dieback effects. Some authors have chosen to ignore potential dieback, or to model dieback by linking modeled yield changes to net changes in ecosystem productivity (i.e. Joyce et al., 1995; Perez-Garcia et al., 1997; Irland et al., 2001). Others have accounted for dieback as a direct stock effect (i.e. Sohngen and Mendelsohn, 1998 and 2001; and Sohngen et al. 2001). Given the potentially important influence of dieback on the results in these last studies, and given the emphasis in recent literature on potential dieback effects (Lemmen and Watson, 2004 and Joyce et al., 2001), more careful integrated ecological-economic analysis of potential stock effects should be conducted.

Third, the results in Perez-Garcia et al. (1997) and Sohngen et al. (2001) demonstrate the importance of capturing global effects when estimating local economic impacts. These studies, while informative, are based on equilibrium climate scenarios conducted in the early to mid 1990's. While numerous new transient climate scenarios have been developed since then, and regional ecological models have been developed to produce ecological impact estimates, the stream of published global ecological analyses that could be used with global economic models has all but disappeared. Strong emphasis has been placed on national assessments in recent years, and while researchers have learned a lot from these exercises, they provide limited information for estimating economic impacts. It will be important in future ecological modeling exercises to develop consistent global analyses of potential climate change impacts for economic modeling purposes.

REFERENCES

Claussen, M. 1996. Variability of Global Biome Patterns as a Function of Initial Boundary Conditions in a Climate Model. *Climate Dynamics*. 12: 371-379.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, and B.M. Wotton. 2001. Climate Change and Forest Disturbances. *BioScience*. 51(9): 723–734.

Haxeltine, A. and I.C. Prentice. 1996. BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition Among Plant Functional Types. *Global Biogeochemical Cycles* 10(4): 693-709.

Haynes, R. 2003. An Analysis of the Timber Situation in the United States: 1952-2050. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report, PNW-GTR-560. Portland, OR.

Irland, L.; D. Adams, R. Alig, C.J. Betz, C. Chen, M. Hutchins, B. A. McCarl, K. Skog, and Brent L. Sohngen. 2001. Assessing Socioeconomic Impacts of Climate Change on U.S. Forest, Wood-Product Markets, and Forest Recreation. *Bioscience*. 51(9): 753- 764.

Iverson,L.R.,and A.M.Prasad. 2001. Potential Changes in Tree Species Richness and Forest Community Types Following Climate Change, Ecosystems. 4(3): 186 – 199.

Joyce, L.A., J.R. Mills, L.S. Heath, A.D. McGuire, R.W. Haynes, and R.A. Birdsey. 1995. Forest sector impacts from changes in forest productivity under climate change. Journal of Biogeography. 22: 703-713.

Joyce, L. J. Aber, S. McNulty, V. Dale, A. Hansen, L. Irland, R. Neilson1, and K. Skog. 2001. Potential Consequences of Climate Variability and Change for the Forests of the United States. Chapter 17 in *Climate Change Impacts in the United States: The Potential Consequences of Climate Variability and Change* by National Assessment Synthesis Team. Cambridge: Cambridge University Press.

Lemmen, D.S. and F.J. Warren. 2004. Climate Change Impacts and Adaptation: A Canadian Perspective. Natural Resources Canada. Canadian National Government.

McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds). 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge, UK: Cambridge University Press.

Perez-Garcia, J., L.A. Joyce, A.D. McGuire, and C.S. Binkley. 1997. Economic impact of climatic change on the global forest sector. In *Economics of Carbon Sequestration in Forestry*, eds. R.A. Sedjo; R.N. Sampson; and J. Wisniewski. Lewis Publishers, Boca Raton.

Schlesinger, M.E., N. Andronova, A. Ghanem, S. Malyshev, T. Reichler, E. Rozano, W. Wang, R. Yang. 1997. Geographical Scenarios of Greehouse-Gas and Anthropogenic-Sulfate-Aerosol Induced Climate Changes. Un-numbered Publication, Climate Research Group, Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign.

Shugart,H. Sedjo,R. Sohngen,B. 2003. Forests and Global Climate Change. Potential Impacts on U.S. Forest Resources. Pew Center on Global Climate Change.

Sohngen, B., R. Mendelsohn, and R. Sedjo. 2001. A Global Model of Climate Change Impacts on Timber Markets. *Journal of Agricultural and Resource Economics.* 26(2): 326-343.

Sohngen, B. and R. Mendelsohn. 2001. “Timber: Ecological-Economic Analysis.” Chapter 4 in Global Warming and the American Economy: A Regional Assessment of Climate Change Impacts. Edited by R. Mendelsohn. Northhampton, MA: Edward Elgar.

Sohngen, B. and R. Mendelsohn. 1998. “Valuing the Market Impact of Large Scale Ecological Change: The Effect of Climate Change on US Timber." American Economic Review. 88(4): 689 - 710.

Statistics Canada. 2005. http://www.statcan.ca/start.html

VEMAP Members. 1995. Vegetation/Ecosystem Modeling and Analysis Project (VEMAP): Comparing Biogeography and Biogeochemistry Models in a Continental Scale Study of Terrestrial Ecosystem Responses to Climate Change and CO_2 Doubling. Global Biogeochemical Cycles. 9: 407-437.

Table 1: Average equilibrium ecological effects estimated from the BIOME3 model using two equilibrium climate scenarios.

	UIUC Climate Model[1]			Hamburg Climate Model[2]		
	% Yield Change	% Dieback	% Change in Forest Area	% Yield Change	% Dieback	% Change in Forest Area
Selected Regions						
North America	17 %	28 %	4 %	17 %	29 %	3 %
South America	23 %	10 %	27 %	46 %	0 %	42 %
Europe	34 %	9 %	7 %	22 %	4 %	16 %
Russia	52 %	21 %	14 %	54 %	12 %	12 %
China	38 %	20 %	20 %	33 %	9 %	41 %
Oceania	13 %	56 %	19 %	-16 %	58 %	-3 %
Rest of World	18 %	6 %	35 %	34 %	1 %	57 %
Non-N. Amer.	32 %	14 %	22 %	42 %	6 %	32 %
World	30 %	16 %	19 %	38 %	10 %	28 %

[1] UIUC Model from Schlesinger et al. (1997)
[2] Hamburg Model from Claussen (1996)

Table 2: Average annual welfare effects during the period 2000 - 2100 from climate change scenarios examined in section 2.

	Dieback			Regeneration		
	CS	PS	NS	CS	PS	NS
	1990 US $$					
Developed						
North America	2.3	(2.1)	0.2	4.4	(1.4)	3.0
Europe	1.3	0.5	1.7	2.4	(0.3)	2.1
Russia	1.0	(0.8)	0.2	2.0	(0.1)	1.9
Oceania	0.1	0.2	0.3	0.2	(0.3)	(0.2)
Developing						
South America	0.5	1.1	1.6	1.0	0.5	1.5
China	0.5	0.4	0.9	0.9	0.2	1.1
India	0.1	0.2	0.4	0.2	0.1	0.4
Asia-Pacific	0.8	0.4	1.2	1.4	(0.1)	1.3
Africa	0.3	0.3	0.6	0.5	0.1	0.6
Global Total	**6.8**	**0.3**	**7.0**	**13.1**	**(1.3)**	**11.8**

Figure 1: Comparison of timber harvests under dieback and regeneration scenarios for North American timber types.

Figure 1a: North American Timber Harvests under the Regeneration Scenario

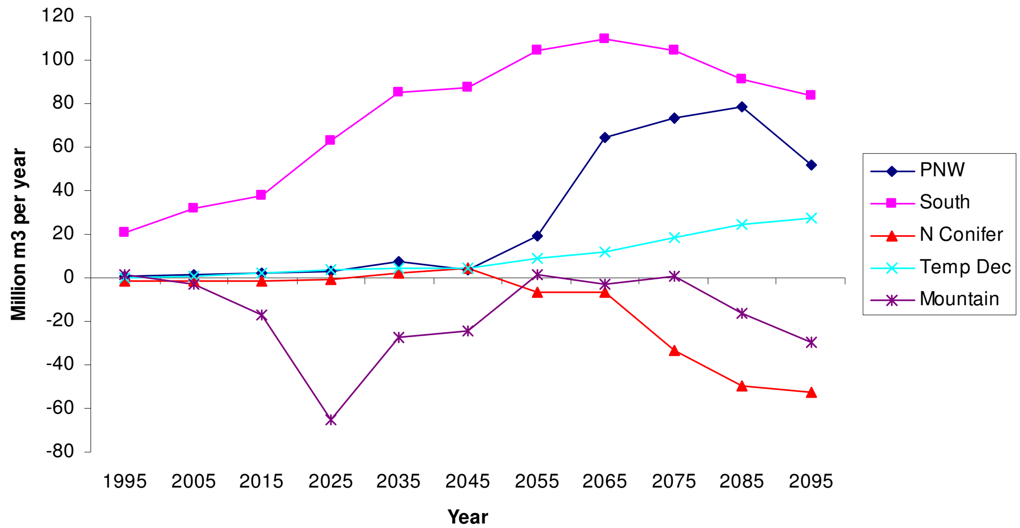

Figure 1b: North American Timber Harvests under the Dieback Scenario

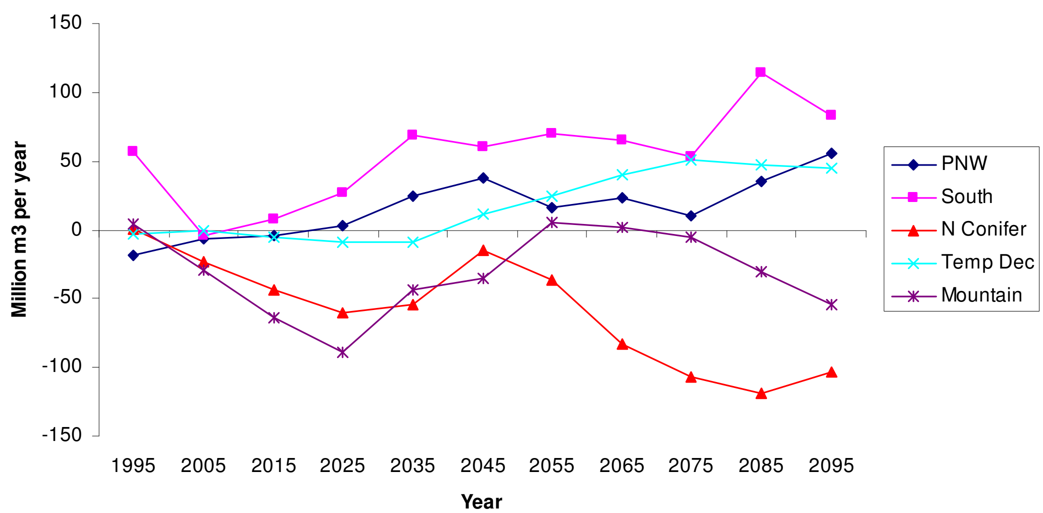

Figure 2: Comparison of timber harvests under dieback and regeneration scenarios for selected regions around the world.

Figure 2a: Proportional change in timber harvests for selected regions under the Regeneration Scenario.

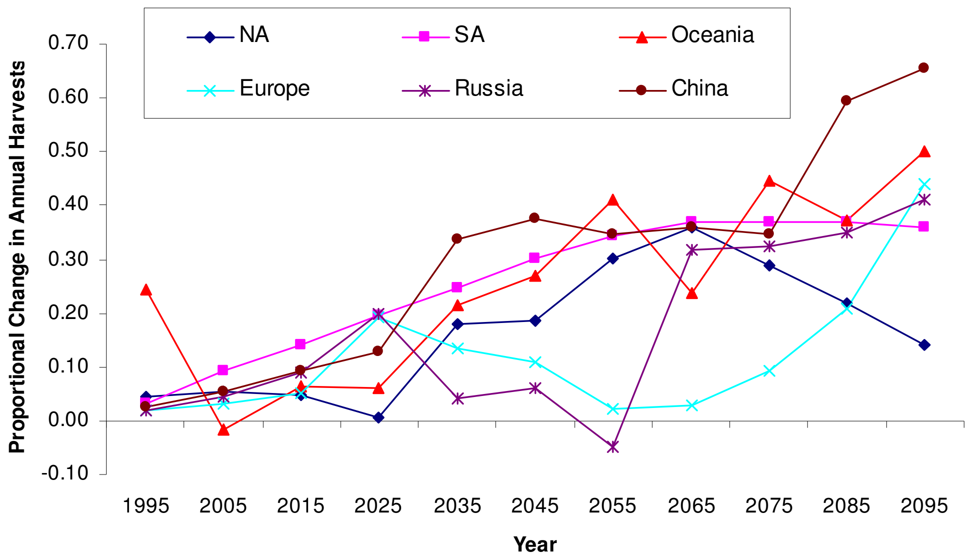

Figure 2b: Proportional change in timber harvests for selected regions under the Dieback Scenario.