Report Submitted for the Great Lakes Regional Assessment

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I. Current Stresses

The natural ecosystems of the region are characterized by three prominent environmental gradients. First, a southwest to northeast gradient from prairie to forest in Minnesota is largely a function of moisture availability. Second a south to north gradient from Eastern deciduous (oak-hickory) to Northern mixed hardwoods forests (beech, maple, hemlock) in Michigan and Wisconsin is a prominent landscape feature. This transition corresponds to climatic and soil gradients and corresponds with a steep south-north land-use gradient from predominantly agriculture to predominantly forested. Third, the region is at the Southern margin of the boreal forest (spruce-fir) and northern portions of the region include boreal species as locally dominant, especially on wetter sites.

In 1992, the Upper Great Lakes region (Michigan, Minnesota and Wisconsin) was about 42% forest land, or over 50 million acres. Over 90 percent of that forest land is used for commercial forestry, and more than half of the commercial forest land is owned by the non-industrial private sector (USDA Forest Service, 1999). The forestry sector employs over 200,000 people and produces over $24 billion dollars a year in forest products (Pederson and Chappelle 1997). Expectations in the industry are for sustained or increased output of forest products, particularly given increasing national demand for forest products, decreasing supply from the Pacific Northwest, and the already high production from the neighboring southern and southeastern regions of the United States. The second and third-growth forests of the Upper Great Lakes are maturing, and recent forest inventories report an increase in the amount of forested land and in stocking on those lands. The majority of Americans, including those in the region, express a desire for increased emphasis on non-commodity values in forest management (e.g., recreation, aesthetics, and biodiversity). This desire often conflicts with the dependence of rural landowners on forests for employment and community development. While both standing volume and demand for forest products continue to increase in the Upper Great Lakes, the amount of land available for timber production continues to decrease due to conversion to urban and industrial uses, and development of seasonal and retirement homes.

Two trends in land use should be considered and are likely to continue for the short term. Declines in the amount of farmland in Michigan, Minnesota, and Wisconsin (5% decline in area of farmland between 1997 and 1987) have been observed in the Census of Agriculture. Forest cover increased by 3% between 1980 and 1993 according to the USDA Forest Service forest inventory. Although the pressures causing these changes are still in place, i.e., declining agricultural productivity and increasing demand for recreational and aesthetic uses of land, it seems unlikely that the trends can continue long term. Increasing development, coupled with declining rates of agricultural abandonment are likely to lead to declines in forest area in the longer term (Warbach and Norberg 1995). Furthermore, large-scale management of forests on private lands is becoming increasingly difficult as ownership is becoming increasingly fragmented into more and smaller parcels (Norgaard 1994; Brown and Vasievich 1996). During the thirty years between 1960 and 1990, average private parcel sizes declined by an average of 1.2 percent per year across the region. This parcelization process is related to development of recreational and seasonal homes, but doesn’t necessarily result in forest clearing. It does, however, affect the management of forests and, therefore, the ability of foresters to respond to changing climatic conditions.

II. Previous Assessments

Previous modeling efforts that focused on or included our region (especially Solomon, 1986; Solomon and Bartlein, 1992; Jones et al. 1994; VEMAP, 1995; and He et al., 1999) have consistently projected northward shift in species ranges. Most of the models assume a gradually increasing temperature and model the effects on species establishment, growth, and mortality. Models project that species that are at the southern boundaries of their ranges, like boreal species within the region or northern hardwood species in the southern part of the region, experience increased mortality and are eventually replaced by species from the communities to the south. Although there is no general agreement on the time it will take for this replacement to occur (a very important question), the models are in general agreement about the northward shift in ranges.

The timing of replacement is critical because, as the works by Solomon (1986) and Solomon and Bartlein (1992) suggest, it is possible that increased mortality in the species with more northerly ranges, due to heat or drought stress, increased winter damage due to diminished dormancy, increased pest activity, could cause a dieback before the southern species are available for replacement. This raises questions about just how susceptible the forests are to increased mortality, how disturbance regimes will be affected by climate change, and how quickly the southern species can migrate. Other questions relate to possibility that established trees may persist long than shown in the early models. Confounded with these questions is the possibility that CO_2 enrichment, by improving water use efficiency by trees and increasing productivity, could speed the succession process.

Solomon's (1986) assessment assumed a doubling of atmospheric CO_2 within 100 years, roughly comparable to scenarios used in this and other assessments. Beyond 100 years, the scenario assumes that atmospheric CO_2 concentrations continue to increase to 4x present over the subsequent two hundred years, but here we focus on the first 100 years. Four sites, two in Michigan and one each in Minnesota and Wisconsin, within the region were simulated using a forest growth model called FORENA. Because of the simulated "dieback phenomenon" the sites experienced a total biomass reduction of between 15 and 30 percent, with the most dramatic dieback occurring on the Michigan sites. After about 300 years of simulation, and a quadrupling of CO_2 in the atmosphere, biomass returned to original levels or slightly higher. The forest community compositions, however, were modified, generally through replacement of boreal forests by northern hardwoods and southern parts of the northern hardwood forest by eastern deciduous forests.

With recent exceptions (e.g., He et al., 1999), almost none of the work on evaluating the impacts of climate change on natural ecosystems considers the effects of land management on the processes evaluated. Although the region contains substantial and significant forest resources, about 40 percent of the land in the three-state region (MI, MN, and WI) is used for agriculture, according to the 1997 Census of Agriculture, mostly in the south. Further, much of the forest land in the region used in some way for forestry. The successional processes represented in the assessment models are unlikely to capture the full range of possibilities available in a managed landscape for responding to or mitigating climate change impacts, nor the interactions between management and succession. Further, land management activities can modify such ecologically important variables as seed sources and introduction of exotic species (e.g., gypsy moth and Asian longhorn beetle).

III. Current Assessment

The results of simulations of vegetation change from the VEMAP project are summarized here, but in a manner that accounts for the current land use patterns. Land use is represented in a single map of land use (ca. 1980) developed by the U.S. Geological Survey. Although land use is dynamic and the 1980 map is somewhat dated, the general influences of land use on the likely ecosystem response are accounted for in the analysis. This work represents an important attempt, albeit crude, to consider land management in the evaluation of potential impacts of climate change on terrestrial ecosystems.

Three climate scenarios were used, the current climate and output from general circulation models developed at the Goddard Fluid Dynamics Lab (GFDL) and Oregon State University (OSU). For each climate scenario, vegetation patterns were represented using contemporary vegetation and three different vegetation models (BIOME2, DOLY, and MAPSS), creating 12 different vegetation scenarios. For each vegetation scenario, ecosystem productivity was simulated using three biogeochemistry models (BGC, Century, and TEM). The land use map used to subtract out any areas in the output from the vegetation and biogeochemistry models that were not in "non-natural" land uses, defined to include urban and agriculture. Two types of results are presented: (1) changes in the prevalence of seven natural vegetation types as a result of contemporary land use and under climate change scenarios; and (2) changes in net primary productivity (NPP) in these ecosystems as a result of land use and climate change. Appendix III presents more information on the methods and assumptions of this assessment.

Changing Vegetation

The first set of results pertains to the changes in the prevalence of seven vegetation types due to climate change and land use. Table 1 (Appendix I) describes the influence of contemporary land uses and various climate change scenarios on the composition of the region in terms of vegetation types. The first section of Table 1 shows that land uses differentially affect the prevalence of vegetation types. According to my analysis, only nine percent of the Grassland area expected in the region remains in natural state due to the agricultural activities on those lands. The areas of temperate deciduous forest and temperate deciduous savanna are similarly affected by the presence agriculture (only 24 percent and 31 percent remain natural, respectively). The vegetation type least affected by current land use, boreal coniferous forest, is also the rarest of those that occur in the region.

The three sections that follow in Table 1 are summaries of the projected impacts of climate change for each of three different vegetation models and two climate scenarios. Each model was run with the contemporary climate to determine its ability to recreate the current patterns of natural vegetation communities. The percentage areas for each vegetation type in the region are listed. The MAPSS model recreated the ecosystem composition of the region under current climate best, though that does not necessarily mean that it is best in predicting future ecosystem response.

Listed under each climate model are the proportions of each vegetation type remaining under each climate scenario. All three models under both climate scenarios predict the disappearance of the boreal forest from the region. There is a consistent and substantial reduction in the amount of area covered by both the temperate continental coniferous forest and cool temperate mixed forest types as well. This suggests that the northern hardwood forests that sustain the regions forest products industry are projected to undergo substantial conversion to temperate deciduous forest and temperate deciduous savannas. The results for the grasslands were mixed, depending on the moisture projections in the climate scenarios and the assumptions about water use in vegetation models. The BIOME2 and MAPSS models projected expansion of grassland and DOLY projected substantial reductions. The fact is, however, that very little natural grassland remains and the fate of the grasslands has more to do with agricultural policies and economic conditions than climate.

Given the substantial projected expansion of the temperate deciduous forests and savannas (oak and hickory dominant) it is important to consider two limiting factors. First, between two-thirds and three-quarters of these two communities are under active human management for agriculture and/or development. This may affect the availability of seed sources and, therefore, slow the migration of the species northward. This delay may contribute to the "dieback phenomenon" as communities make the transition from one type to another. Second, the northern forests are strongly influenced not only by climate, but also by the soils present, with conifers tending to dominate on the sandy soils. The soils to the north of the region, especially in Michigan, tend to be very sandy and, therefore, droughty. Although the vegetation models considered this influence, the scale of the variation in soil effects is much finer than can be represented in the models. Therefore, soil effects contribute to uncertainties in the projections.

Changing Natural Productivity

The results related to ecosystem productivity are based on three models of biogeochemistry and are presented in Table 2 (Appendix I). To calculate the effects of land use, I compared total regional net primary productivity (NPP) estimates with estimates of "natural NPP" by subtracting out the estimated NPP of land that is used for agriculture or urban activities.

The results suggest two general trends about the level of natural productivity in the region. First, modification of landscapes through land use has a much greater impact on the level of NPP than do projected levels of climate change. Estimates from the biogeochemistry models under changed climate scenarios project changes in productivity between a decrease of 10 percent and an increase of about 50 percent. However, land use, by taking over half the land out of natural production causes a current decrease in NPP of about 50 percent. The changes in natural NPP are going to be restricted to those areas that are not actively managed.

The second trend is that productivity will most likely get to a point at which it is slightly higher than present levels. The "best guess" value, obtained by averaging those obtained from using MAPSS vegetation, is an increase of about 20 percent. This increase comes about due to longer growing seasons and increased water use efficiency. Growth chamber experiments with young aspen in Northern Michigan show between 15 and 30 percent increase in productivity due to elevated CO2 levels alone, depending on site conditions. This estimate does not account for any changes in disturbance regimes, increase in nitrogen deposition, any change in cloudiness, or changes in land use. Rapid rates of land use change could overwhelm changes due to climate change. Given the vegetation scenarios described above, the forests will need to change their mix of species before attaining this increased productivity. The amount of time it will take for this to occur is still debatable. Solomon's (1986) work suggests a time frame on the order of 200 years. So, if mortality increases substantially within the time frame of this assessment (an uncertain possibility) then decreases in productivity are more likely than increases.

IV. Response, Coping and Adaptation Strategies

The following ideas for coping with change came out of the regional assessment workshop. First, a reasonable response strategy within the forestry and land management communities in the Upper Midwest is to monitor the health of the forests in response to their changing environment, which includes climate change, changing air quality, pest and disease outbreaks, and forest fragmentation due to development. Fire and pest management strategies may need re-thinking in a changing climate. Incorporation of integrated pest management and prescribed burning may reduce the indirect effects of these disturbances with a changing climate.

Land use conflicts may occur as we have a more dispersed settlement pattern and as competition among various land uses change with changing climate. Policies, such as land use planning and/or "sprawl" taxes, might be used to minimize land use conflicts. However, we must understand what current strategies are failing. For example, attempts to minimize sprawl (e.g., Subdivision Control Act, zoning) in the past have not met with great success. The political costs of abridging land ownership rights in the region could be high.

Where possible, some attempt should be made to facilitate the migrations of plant species with the shifting of ecological zones. The establishment of migration corridors was suggested as a possible mechanism to reduce the effects of fragmentation. However, maintaining a corridor may not be successful if flowering is limited due to climatic changes. Following harvest, tree species that are better suited to a changed climate might be planted to encourage adaptation of the ecosystem. Species and genetic diversity should also be encouraged to improve natural adaptive capacity.

Finally, and most importantly, a public education program regarding the potential risks and consequences associated with rapid changes in climate should be in place. For example, the potential for increasing fire danger associated with warmer and drier conditions should be communicated to homeowners in high fire-risk ecosystems. The increased potential for flooding with increase in the frequency of large rain events should be communicated to flood plain landowners. With better information, the residents of the region will be better prepared to respond to a more variable and less certain climate.

V. Information Research Needs

Although the regional assessment workshop identified several information needs, two are particularly relevant to the analysis presented here. Probably the most important need that this research points to, is the need to couple models of ecosystem productivity with models of land use change to study change under altered climate. The magnitude of the landscape alterations in the region suggest that land management will continue to be important, perhaps more so, in determining the productivity of the landscape.

Dynamic (“transient”) models of ecosystems, like the gap models used by Solomon (1986) need to be combined with spatially distributed models of landscape function in a manner similar to He et al. (1999). Spatially and temporally explicit models allow for the incorporation of a number of effects not already considered in these assessments. These include the response of disturbance regimes to climate change, the effect of seed dispersal on the rate of species establishment, and the analysis of patchy landscapes (i.e., landscapes that are not completely natural).

APPENDIX I: Tables

Table 1: Proportion of each vegetation type under current conditions and after the effects of land use (LU) and climate change are introduced. The shaded column is the proportion of the regional vegetation map that is in each vegetation type for each scenario. The column labeled LU indicates the proportion of each potential natural vegetation type remaining after areas that are "non-natural" land uses are subtracted out. The columns labeled GFDL and OSU are the proportions of the vegetation types predicted by each vegetation model under contemporary climate remaining after climate change was simulated using the Goddard Fluid Dynamics Lab (GFDL) and Oregon State University (OSU) general circulation models. In the unshaded columns, a value greater than 1 means the vegetation type increased in area; a value less than 1 means that it decreased in area.

Vegetation Scenario	Contemporary		BIOME2			DOLY			MAPSS		
Climate Scenario *Vegetation Types*	Orig %	LU	Cont %	GFDL	OSU	Cont %	GFDL	OSU	Cont %	GFDL	OSU
Boreal Coniferous For.	7.1	0.91	0	.	.	7.5	0	0	7.4	0	0
Temperate Cont. Conif. For.	14.1	0.79	11.4	0	0.31	3.6	0	0	0	#	.
Cool Temperate Mixed For.	23.6	0.74	57.0	0	0.25	20.9	0	0.23	35.0	0	0.01
Temperate Deciduous For.	21.6	0.24	17.0	3.45	0.95	10.4	1.36	0.39	26.2	0.57	1.68
Temperate Deciduous Sav.	12.2	0.31	3.3	9.79	1.56	41.5	2.01	2.07	16.0	4.10	2.03
C_3 Grassland	0	.	4.8	1.39	2.79	8.7	0	0	0	.	.
C_4 Grassland	16.4	0.09	6.4	0	0	7.3	0	0.66	15.4	1.20	1.48

. – did not exist under contemporary climate and did not appear under change scenario
- did not exist under contemporary climate but appeared under change scenario

Table 2: Effects of climate change and land use on estimates of total natural NPP in the region. The TOTAL NPP is the value obtained for the region from the biogeochemistry models in $gCyr^{-1}$. The CC Ratio represents the ratio of the value under the changed climate to that under contemporary climate using the same vegetation model. NPP ADJ is the total level of NPP after subtracting any NPP that is occurring on land that is in a non-natural land use (ca. 1980). LU Ratio is the ratio of NPP ADJ to TOTAL NPP.

Model	Veg	Climate	TOTAL NPP	CC Ratio	NPP ADJ.	LU Ratio
BGC	Contemp	Contemp	1 354 934		733 089	0.54
		GF3	1 609 237	1.19		
		OSU	1 623 922	1.20		
	BIOME2	Contemp	1 476 355		739 228	0.50
		GF3	829 854	0.56	608 591	0.73
		OSU	1 331 949	0.90	717 735	0.54
	DOLY	Contemp	1 205 629		630 356	0.52
		GF3	1 318 279	1.09	654 747	0.50
		OSU	1 085 936	0.90	555 236	0.51
	MAPSS	Contemp	1 304 392		681 815	0.52
		GF3	1 273 476	0.98	641 549	0.50
		OSU	1 342 034	1.03	692 196	0.52
CENTURY	Contemp	Contemp	1 157 300		599 108	0.52
		GF3	1 321 719	1.14		
		OSU	1 342 691	1.16		
	BIOME2	Contemp	1 118 147		535 135	0.48
		GF3	1 479 373	1.32	694 843	0.47
		OSU	1 518 669	1.36	719 585	0.47
	DOLY	Contemp	1 269 645		640 284	0.50
		GF3	1 778 609	1.40	869 513	0.49
		OSU	1 808 128	1.42	871 746	0.48
	MAPSS	Contemp	1 142 532		553 597	0.48
		GF3	1 698 706	1.49	856 416	0.50
		OSU	1 419 270	1.24	710 765	0.50
TEM	Contemp	Contemp	1 057 558		497 108	0.47
		GF3	1 381 028	1.31		
		OSU	1 315 631	1.24		
	BIOME2	Contemp	1 158 249		543 069	0.47
		GF3	1 505 109	1.30	773 756	0.51
		OSU	1 314 335	1.13	648 218	0.49
	DOLY	Contemp	1 005 208		460 967	0.46
		GF3	1 350 081	1.34	647 168	0.48
		OSU	1 298 704	1.29	596 822	0.46
	MAPSS	Contemp	1 102 723		529 611	0.48
		GF3	1 263 057	1.15	633 535	0.50
		OSU	1 384 205	1.26	688 542	0.50

APPENDIX II: References

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APPENDIX III: Assessment Methodology and Assumptions

Climate Scenarios

The climate scenarios used for this analysis were from an earlier generation of general circulation models (GCMs) and were used in phase I of the VEMAP project. The models were developed by the Goddard Fluid Dynamics Lab (GFDL), Oregon State University (OSU), and the United Kingdom Meteorological Office (UKMO). These models are "equilibrium" models, because the assume a given level of CO_2 in the atmosphere and then calculate the average climatic conditions. Attached to this report are maps of seasonally averaged temperature and precipitation predicted under doubled CO_2 conditions from the three GCMs used in VEMAP phase 1. Also attached are maps of similar output from the more recent models developed by the Canadian Centre for Climate Modelling and Analysis (CGCM) and the Hadley Centre for Climate Prediction and Research (HADLEY), which are more recent "transient" models.

Although direct comparisons are complicated by the output of average temperatures from the older models instead of minimum and maximums, which are output for the more recent models, a few patterns emerge from the scenarios. First, the precipitation estimates of all the earlier models project drier summers at $2xCO_2$ than the CGCM and HADLEY models at 2030 (both of which project slightly wetter summers, though they diverge by 2095). The UKMO model is least like the newer models. Second, the earlier models project wetter winters under $2xCO_2$, whereas by 2030 the CGCM and HADLEY models project neutral and drier winters, respectively. However, it is important to note that, by 2095 the projected winters are wetter in CGCM and HADLEY and, therefore, more consistent with the earlier models. Third, all temperature measures increased in all models within the region. Fourth, the seasonal differences in temperature (i.e., more warming in the winter) were not as pronounced in the earlier generation models, which projected substantial warming (3-6 degrees C) in both seasons. Again, the temperature estimates of the newer models were more similar to the older models at $2xCO_2$ by 2095, especially the CGCM model and the UKMO model estimates were much higher than the others.

In summary, the UKMO model projected conditions least consistent with the newer generation models and the conditions by 2095 were more consistent with the $2xCO_2$ climates projected by the early-generation models. Results of the VEMAP project are, therefore, reported using the GFDL and OSU scenarios. These conditions, assuming $2xCO_2$ atmosphere, are similar to the 2095 conditions projected using the CGCM and HADLEY models, with the exceptions noted above.

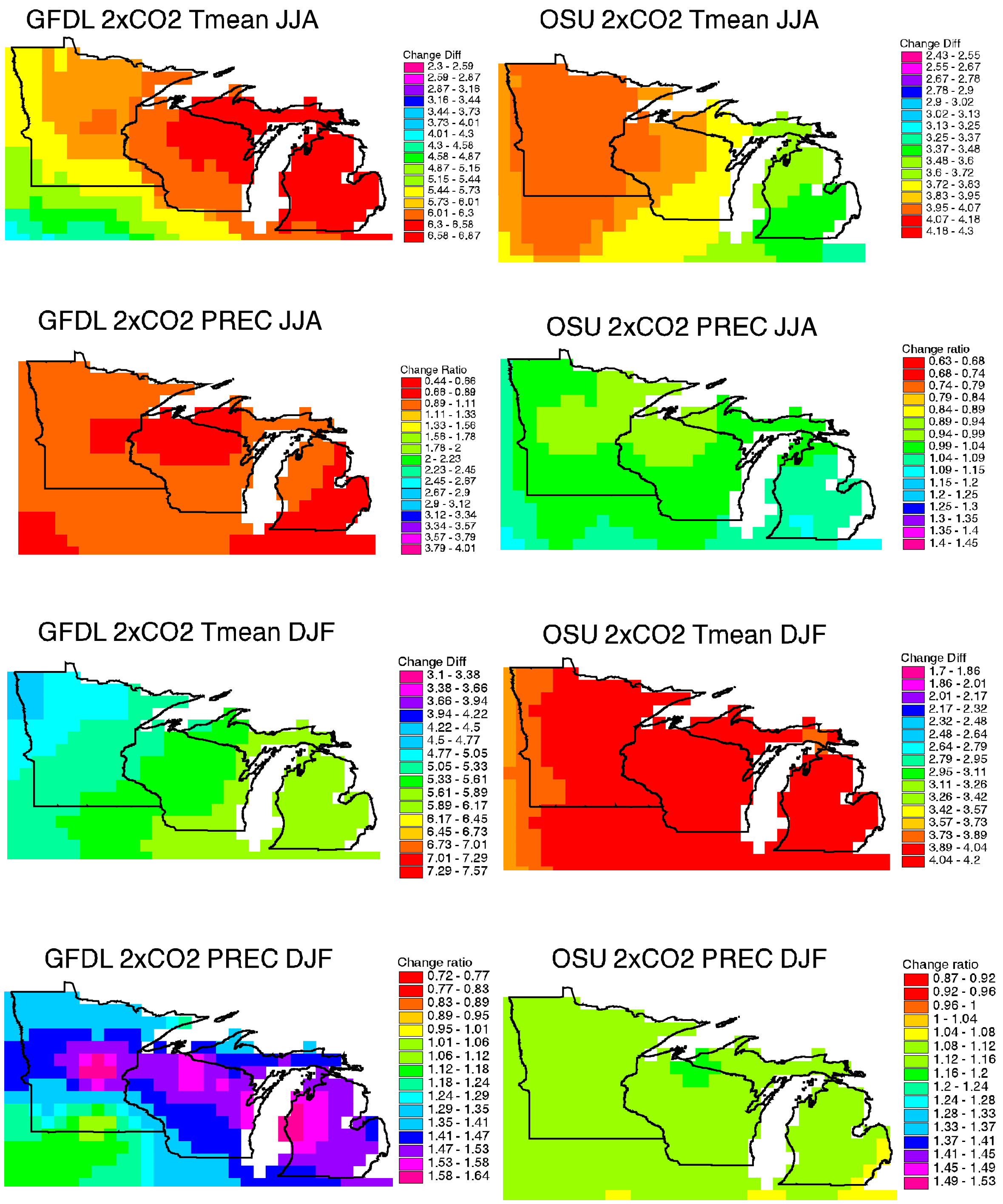
Assumptions

The VEMAP project (VEMAP Members, 1995) used six different models, three models of vegetation geography and three models of biogeochemistry, to project the ecosystem responses to climate change. Because the models assume that all vegetation is in a natural state, the projections are unrealistic in an environment where the land is actively managed for some purpose. In this case we consider the agricultural and developed uses of the land as actively managed and all forest uses as “natural.” Clearly, many forest landscapes are managed for various purposes (e.g., timber production, recreation, ecosystem services). However, because the “natural” condition for the majority of the area, with the exception of the prairies southern and western Minnesota, is forest, I assume that forested areas will respond most like the models predict. How quickly they respond will depend on how actively they are managed and with what goals in mind. Given these assumptions, I interpreted the VEMAP model output using the contemporary land use layer to “subtract out” the areas that are used for agriculture or development from the simulations to provide a more realistic interpretation of the model results. This report presents the results from this exercise.

The biogeography models assume that vegetation is, and will be under a changed climate, in equilibrium with the climate (i.e., the vegetation has developed to its optimum configuration under a given climate). The models take into account the increased water use efficiency afforded by elevated levels of CO_2 in the atmosphere, but ignore changes in disturbance regimes that might result from climate change (e.g., fire, insect outbreaks).

Although I account for agriculture and developed land uses in the analysis, the influences of land use go beyond simply altering the vegetation cover at a location. By altering the vegetation, the availability of seeds, which are required for the establishment of vegetation, is reduced for the species that would have otherwise occupied a location. The reduction of seeds for naturally occurring species is likely to slow the establishment of new species in forested areas as the species composition changes over due to climatic warming. Also, land management in surrounding areas often has the effect of altering disturbance regimes within forests (e.g., through fire suppression or the introduction of exotic species). The work by He et al. (1999) represents a modeling approach that begins to account for these processes in the projection of climate change impacts.

Figure III.1. Average temperature (Tmean) and preciptation (PREC) for winter (DJF) and summer (JJA) seasons predicted by GFDL and OSU models under doubled CO_2 conditions.



GFDL 2xCO2 Tmean JJA

OSU 2xCO2 Tmean JJA

GFDL 2xCO2 PREC JJA

OSU 2xCO2 PREC JJA

GFDL 2xCO2 Tmean DJF

OSU 2xCO2 Tmean DJF

GFDL 2xCO2 PREC DJF

OSU 2xCO2 PREC DJF

Table III.2. Average temperature (Tmean) and preciptation (PREC) for winter (DJF) and summer (JJA) seasons predicted by UKMO model under doubled CO_2 conditions.