world development report 2010

Development and Climate Change

BACKGROUND NOTE

ECOSYSTEM INTEGRITY CHANGE AS MEASURED BY BIOME CHANGE

by

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Ecosystem integrity change as measured by biome change

Background note to the World Development Report 2010

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Natural and extensively used ecosystems regulate regional climate and water cycles, store carbon and provide a range of other goods and services to human societies. Disruption of their functioning may have severe impacts on regional agriculture. Under the combined pressures of human land use and changing climate, ecosystem functioning (or ecosystem integrity) is threatened if the rate of change exceeds natural adaptation potential. Ecosystem conserving management could concentrate on regions with a high risk of catastrophic change, if they were known. However, as ecosystems are complex systems and some processes determining system behaviour are poorly understood, predictions of future ecosystem dynamics and composition are highly uncertain. Our approach to estimating ecosystem integrity change under climate change is therefore derived from macroscopic system properties: Vegetation structure, carbon storage potential and net primary production (NPP) as key ecosystem properties are simulated with the dynamic global vegetation model LPJmL (Sitch et al. 2003, Gerten et al. 2004, Bondeau et al. 2007). We assume a higher need for adaptation and hence a higher probability of exceeding an ecosystem's adaptation potential if the simulated changes in natural ecosystems over the 21st century are strong.

Based on 17 IPCC AR4 climate projections for the SRES A2 emission scenario (Randall et al. 2007), for each 1° grid cell a "mean change" climate trajectory over the 21st century (model mean), and a "high change" and "low change" trajectory (model mean ± inter-model standard-deviation) were created to drive the impact model LPJmL.

Vegetation structure change is measured with the ΔV-metric of Sykes et al. (1999), which characterises ecosystem dissimilarity between present and future conditions and ranges between 0 (identical vegetation) and 1 (completely different structure, e.g. a desert vs. a forest). The main factor determining ΔV is the proportion of vegetation life forms (grass/tree). Secondarily, ecologically important traits such as leaf strategy (needles vs. broadleaf, deciduous vs. evergreen) contribute to ΔV. Carbon storage potential is calculated as the sum of soil carbon, vegetation carbon and litter carbon. NPP is the rate of carbon fixation by plants and an important indicator of energy available to higher trophic levels.

Figure 2.5.1 shows projected changes in vegetation structure over the 21st century. Severe changes can be expected in the boreal zone of Siberia, Scandinavia and Canada and in the Himalayas, where the tree line moves northwards and uphill with increasingly benign temperatures. Vegetation may also change strongly at the trailing edge of boreal species range (although this is more uncertain than changes at the leading edge): rising temperatures can lead to heat and drought stress of cold-adapted species in central Asia and North America, making them more susceptible to catastrophic, large scale insect outbreaks and diseases (Fischlin et al., 2007, Lucht et al. 2006). Ultimately, temperate species will migrate to those regions and replace the current vegetation, but natural succession may take centuries. The strong vegetation changes in savannah regions can be explained by the beneficial effects of CO_2: high CO_2-concentrations increase water-use efficiency of plants, allowing spreading of vegetation and possibly tree growth in dry areas. Figure 2.5.2 shows aggregated results for 10 world regions.

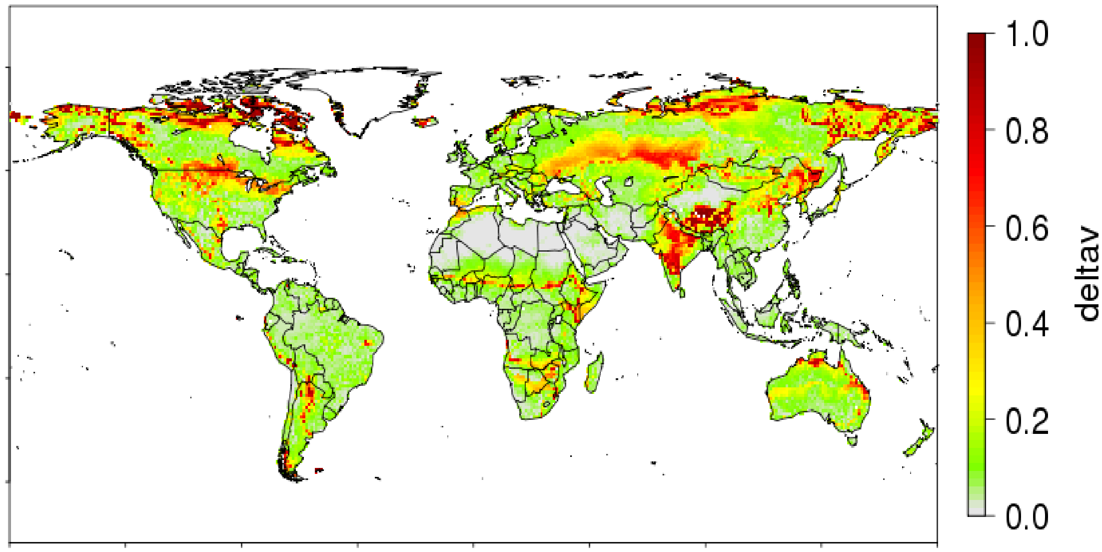

Figure 2.5.1: Change in vegetation structure ΔV (1969-1998 – 2069-2098) under mean projected climate change. Values of 1 indicate completely different structure; values of 0 indicate identical vegetation

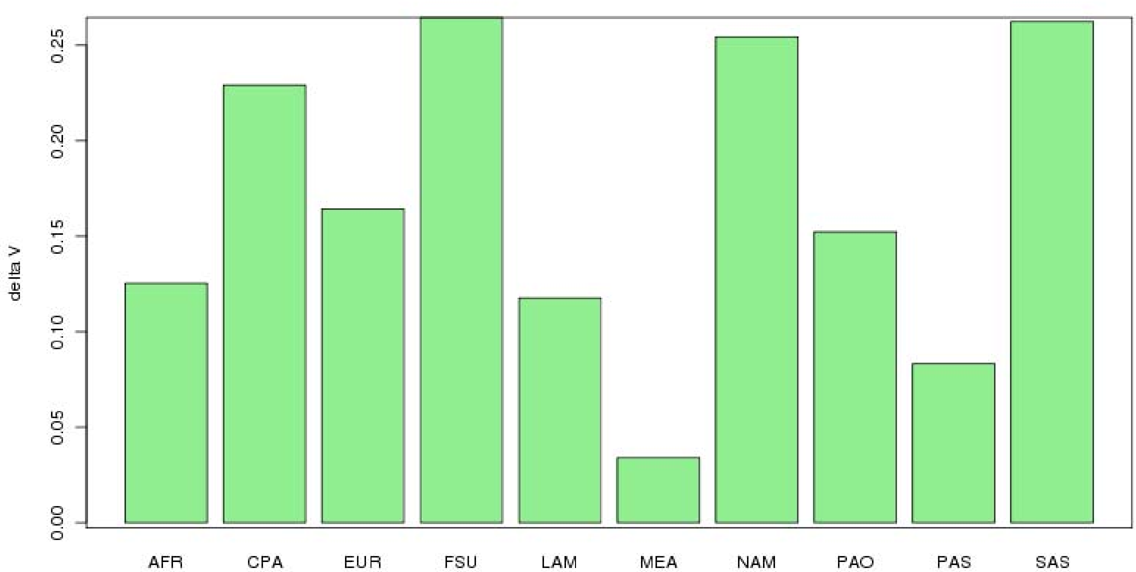

Figure 2.5.2: Vegetation structural change, aggregated for world regions

CO_2-fertilization is also the main cause of the strong increase in NPP throughout the world (Table 2.5.1). The magnitude of LPJmL's CO_2-fertilization effect for natural vegetation is within the range of observations from free-air CO_2-enrichment (FACE) experiments (Gerten et al. 2005, Hickler et al. 2008). However, in many regions nitrogen or phosphorus deficiencies may diminish this response, which is currently not included in the model. In forested areas with stable vegetation, vegetation carbon stocks will most likely increase over the 21st century (Table 2.5.1), but soil carbon stocks in cold regions may be reduced by warming, especially in today's permafrost regions.

	Mean - σ	Mean	Mean + σ
NPP [gC/m2/year]	+ 128.1	+ 165.7	+ 183.7
Carbon storage [gC/m2]	+ 1991.4	+ 2106.6	+ 2025.44
ΔV	0.14	0.17	0.21

Table 2.5.1: global mean changes under a low change (left), medium change (middle) and high change (right) climate trajectory

In many regions of the world projected changes in undisturbed ecosystem seem to move into a positive direction: CO_2 is a plant nutrient in itself, and in addition to direct fertilization, CO_2 increases a plant's water use efficiency, allowing higher productivity in water limited regions and often even overcompensating for reduced plant water availability by changing rainfall patterns and higher temperature. In cold areas, rising temperatures allow plants to colonize previously hostile areas. However, with drastically changed boundary conditions of ecosystems, competitive structures between species will be unbalanced, potentially destabilizing an ecosystem for a considerable time. Human dominated landscapes retard migration of better adapted species, increasing time lags in natural succession and ecosystem recovery. Individual climate models vary widely in their projections of precipitation patterns (Randall et al. 2007) and in some cases produce large scale vegetation dieback in LPJmL (e.g. of the Amazon rainforest, Fischlin et al. 2007). To our current knowledge, such extreme climate projections and extreme vegetation responses cannot be ruled out and should be taken as a serious risk to ecosystem functioning.

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Appendix

Country-to-region mapping for regional aggregation of results

AFR	CPA	EUR	FSU	LAM
Sub-Saharan Africa	**Centrally-Planned Asia**	**Europe**	**Former Soviet Union**	**Latin America**
Angola	Cambodia	Albania	Azerbaijan, Republic of	Argentina
Benin	China	Austria	Belarus	Belize
Botswana	Laos	Belgium-Luxembourg	Georgia	Bolivia
Burkina Faso	Mongolia	Bosnia and Herzegovina	Kazakhstan	Brazil
Burundi	Viet Nam	Bulgaria	Kyrgyzstan	Chile
Cameroon		Croatia	Moldova, Republic of	Colombia
Central African Republic		Czech Republic	Russian Federation	Costa Rica
Chad		Denmark	Tajikistan	Cuba
Congo, Dem Republic of		Estonia	Turkmenistan	Dominican Republic
Congo, Republic of		Finland	Ukraine	Ecuador
Côte d'Ivoire		France	Uzbekistan	El Salvador
Djibouti		Germany		French Guiana
Equatorial Guinea		Greece		Guatemala
Eritrea		Hungary		Guyana
Ethiopia		Iceland		Haiti
Gabon		Ireland		Honduras
Ghana		Italy		Mexico
Guinea		Latvia		Nicaragua
Guinea-Bissau		Lithuania		Panama
Kenya		Macedonia,The Fmr Yug Rp		Paraguay
Lesotho		Netherlands		Peru
Liberia		Norway		Suriname
Madagascar		Poland		Uruguay
Malawi		Portugal		Venezuela
Mali		Romania		
Mauritania		Slovakia		
Mozambique		Slovenia		
Namibia		Spain		
Niger		Sweden		
Nigeria		Switzerland		
Rwanda		Turkey		
Senegal		United Kingdom		
Sierra Leone		Yugoslavia, Fed Rep of		
Somalia				
South Africa				
Sudan				
Swaziland				
Tanzania, United Rep of				
Togo				
Uganda				
Western Sahara				
Zambia				
Zimbabwe				

MEA	NAM	PAO	PAS	SAS
Middle East/North Africa	**North America**	**Pacific OECD**	**Pacific Asia**	**South Asia**
Algeria	Canada	Australia	Indonesia	Afghanistan
Egypt	United States of America	Japan	Korea, Dem People's Rep	Bangladesh
Iran, Islamic Rep of		New Zealand	Korea, Republic of	Bhutan
Iraq			Malaysia	India
Israel			Papua New Guinea	Myanmar
Jordan			Philippines	Nepal
Kuwait			Solomon Islands	Pakistan
Libyan Arab Jamahiriya			Thailand	Sri Lanka
Morocco				
Oman				
Saudi Arabia				
Syrian Arab Republic				
Tunisia				
United Arab Emirates				
Yemen				