CORRESPONDENCE

RESPONSE TO COMMENT: CLIMATIC CHANGE AND THE BROAD-SCALE DISTRIBUTION OF TERRESTRIAL ECOSYSTEM COMPLEXES[1, 2]

In order to clarify the importance of seasonality, an analysis was made of changes in the distribution of Holdridge (1947) life zones with biotemperature incremented by monthly average temperature changes simulated for a doubling of atmospheric CO_2 concentration (Manabe and Stouffer, 1980). As Rowntree's sample calculations imply, changes at higher latitudes are much less substantial when monthly changes are used to calculate biotemperature then when annual average temperature changes are used.

Values of monthly average temperature and monthly precipitation at each 0.5° latitude x 0.5° longitude cell on the world land surface between 80° N and 60° S latitude were interpolated from 7000 long-term meteorological records, and the Holdridge classification was mapped.

Simulated temperature changes for each 0.5° cell were interpolated from contour maps for June, July, and August and for December, January, and February for the CO_2 sensitivity test reported by Manabe and Stouffer (1980). Averages of summer and winter values were assumed to apply to the intermediate months. The montly average temperatures for each 0.5° cell were incremented by these values, the biotemperature was recalculated, and the Holdridge classification was remapped. Changes in precipitation were not considered.

The extents of Holdridge life zones for the base case and for the case with incremented biotemperature are summarized in Table I. Meteorological stations with incomplete temperature or precipitation records were dropped from the analysis. Removing these stations caused slight differences in base-case values.

When seasonality is considered in incrementing the biotemperature index, the most noticeable decreases in life-zone extents are for boreal forests (37% decrease) and tundra (32% decrease), as was the case when only an annual average temperature increment was considered; however, these decreases are much less substantial. Boreal moist forest is replaced by cool temperate steppe or, in limited areas, by cool temperate forest or by boreal dry bush. Boreal wet forest is replaced by cool temperate forest or boreal moist forest. The boreal forest zone shifts north, replacing about 42% of the 0.5° cells designated tundra in the base case. The northern extent of tundra also increases, but this boundary is probably poorly characterized because of inadequate meteorological data.

As expected, smaller changes occur in tropical life zones; however, the extents of sub-

[1] Research sponsored jointly by the National Science Foundation's Ecosystem Studies Program under Interagency Agreement No. BSR-8417923 and the Carbon Dioxide Research Division, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

[2] Publication No. 2549, Environmental Sciences Division, Oak Ridge National Laboratory.

Climatic Change 7 (1985) 457–460. 0165–0009/85.15.

TABLE I: Summary of Changes in Life-Zone Extents (10^6 km^2)

Life Zone	Area	
	Base case	Elevated CO_2
Forests		
Tropical:		
Rain	0.003	0.003
Wet	0.384	0.410
Moist	8.647	9.888
Dry	9.992	14.033
	19.025	24.334
Subtropical:		
Rain	0.014	0.020
Wet	0.496	0.261
Moist	7.947	5.767
Dry	3.506	3.329
	11.963	9.377
Warm Temperate:		
Rain	0.029	0.021
Wet	0.562	0.494
Moist	7.766	5.990
Dry	7.456	8.185
	15.813	14.690
Cool Temperate:		
Rain	0.252	0.200
Wet	1.618	1.319
Moist	9.418	10.108
	11.287	11.627
Boreal:		
Rain	0.343	0.062
Wet	4.266	1.437
Moist	12.654	9.381
	17.263	10.880
	75.351	70.908
Grasslands		
Tropical:		
Very Dry Forest	4.715	6.045
Thorn Woodland	2.351	3.144
	7.066	9.189
Subtropical Thorn Woodland	1.649	2.256
Warm Temperate Thorn Steppe	5.135	5.157
Cool Temperate Steppe	8.931	11.922
	22.780	28.524

Table I (continued)

Deserts		
Tropical:		
Desert Bush	2.321	3.110
Desert	8.419	9.521
	10.740	12.631
Subtropical:		
Desert Bush	1.532	2.549
Desert	1.382	1.109
	2.914	3.659
Warm Temperate:		
Desert Bush	4.863	4.166
Desert	1.886	1.243
	6.748	5.410
Cool Temperate:		
Desert Bush	3.586	3.170
Desert	1.256	0.875
	4.842	4.044
Boreal:		
Dry Bush	1.282	2.576
Desert	0.027	0.015
	1.309	2.591
	26.554	28.334
Tundra		
Rain	0.063	0.000
Wet	1.770	0.472
Moist	2.636	2.504
Dry	0.000	0.058
	4.470	3.034
Ice	2.218	0.567
Total	131.372	131.368

tropical life zones are significantly altered. The areal extent of subtropical forest life zones decreases 22% while the extents of subtropical thorn woodland and subtropical deserts increase 37% and 26%, respectively. Taken together, the extents of subtropical and tropical forest life zones increase by 8%.

Although the changes in life-zone distributions are substantially less when seasonal temperature changes rather than annual averages are considered, the shifts are still quite large on the world scale. The life-zone designations of 34% of the 0.5° cells on the land surface are altered.

The Holdridge classification does not incorporate a detailed treatment of seasonality. Biotemperature provides only a weak indication of the length of the growing season. Small changes in the length or timing of the growing season, which might be recorded by an index such as growing degree-days, can have a pronounced effect on the character of vegetation in a region.

Again, it is important to note that changes in precipitation associated with increasing CO_2 levels in the atmosphere can substantially alter the pattern of changes in life-zone distribution. The timing of precipitation can be as important as that of temperature variations, but its influence on large-scale natural vegetation distribution is understood less clearly.

As more detailed and more reliable seasonal results become available from climate models, it is very important, as Rowntree's comments illustrate, to extend the treatment of seasonality in schemes such as the Holdridge classification in order to improve our understanding of the potential impacts of CO_2-induced climatic change.

Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831, U.S.A.
WILLIAM R. EMANUEL

Department of Environmental Sciences
University of Virginia
Charlottesville, VA 22903, U.S.A.
HERMAN H. SHUGART

and

Science Applications International Corp.
Oak Ridge, TN 37830, U.S.A.
MARY STEVENSON

References

Holdridge, L. R.: 1947, 'Determination of World Plant Formations from Simple Climatic Data', *Science* **105**, 367–368.

Manabe, S. and Stouffer, R. J.: 1980, 'Sensitivity of a Global Climate Model to an Increase of CO_2 Concentration in the Atmosphere', *J. Geophys. Res.* **85**, 5529–5554.