6 Assessment of Regional Productivity in North Carolina

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One goal of productivity research is to present and analyze patterns of actual and potential primary productivity of landscapes. The data available for such determinations have greatly increased since initiation of the International Biological Program (IBP); and models developed from these studies will be used eventually to predict production for almost any ecosystem. At present, however, productivity data from intensive site studies are of limited value for estimating landscape productivity patterns. No matter how careful the production measurements, the values obtained are in the strict sense valid only for the particular sites and time periods of investigation. For a proper assessment of landscape production patterns we need numerous measurements that can be related to the pattern of the landscape itself. Various agricultural and forestry statistics are readily available and can be used to demonstrate landscape production patterns. Most of these data express primary production for the commercially usable portion of each land-use category (e.g., seed production for crops and mercantile lumber for forests). The data can be converted, however, to estimates of total primary production through the use of appropriate conversion factors—the ratios of total primary production to the commercial yield. Similar analyses can be performed on any land-use category if the production–yield ratios are known. This chapter summarizes 2 years of research in North Carolina, which included the utilization of U. S. Forest Service and state agricultural and land-use data for estimating rates of net primary productivity for all land-use categories in the state's 100 counties. Additional estimates were made of total net primary production for each county, an estimated net primary production rate for the entire state, and an estimate of the state's total net primary production. More complete documentation is available in Whigham *et al.* (1971) and Sharp (1973).

KEYWORDS: Primary productivity; plants, agriculture; North Carolina; forestry.

Primary Productivity of the Biosphere, edited by Helmut Lieth and Robert H. Whittaker.

Table 6–1 Sources of data used to determine county coverage and commercial yield statistics for each land-use category[a]

I. Forests
- a. *North Carolina's Timber.* 1966. U.S. Forest Service Bulletin SE-5.
- b. *Forest Statistics for the Southern Coastal Plain of North Carolina.* 1952. U.S. Forest Service, Forest Survey Release No. 41.
- c. *Forest Statistics for the Mountain Regions of North Carolina.* 1955. U.S. Forest Service, Forest Survey Release No. 46.
- d. *Forest Statistics for the Northern Coastal Plain of North Carolina.* 1955. U.S. Forest Service, Forest Survey Release No. 45.
- e. *Forest Statistics for the Piedmont of North Carolina.* 1956. U.S. Forest Service, Forest Survey Release No. 48.
- f. *Preliminary Forest Survey Statistics for the Southern Coastal Plain of North Carolina.* 1962. U.S. Forest Service publication by the Division of Forest Economics Research.
- g. *Preliminary Forest Survey Statistics for the Northern Coastal Plain of North Carolina.* 1963. U.S. Forest Service publication by the Division of Forest Economics Research.
- h. *Preliminary Forest Survey Statistics for the Piedmont of North Carolina.* 1964. U.S. Forest Service publication by the Division of Forest Economic Research.
- i. *Preliminary Forest Survey Statistics for the Mountain Regions of North Carolina.* 1964. U. S. Forest Service publication by the Division of Forest Economic Research.

II. Land-use categories
U.S. Department of Agriculture, Soil Conservation Service:
Form S-1: *State Land Use Summary (Acres)*
Form S-2a: *Summary—Land by Land Capability Classes*

III. Crop statistics
North Carolina Agricultural Statistics. 1967–1973. Available through the Federal Crop Reporting Service. Raleigh, North Carolina.

IV. Water acreages
Profile, North Carolina Counties. 1970. Statistical Services Section, Budget Division, Department of Administration, Raleigh, North Carolina.

[a] See Table 6–2.

History

Filzer (1951) was the first to evaluate production patterns for a large region. With detailed statistics available from pre-World War I Germany he used agricultural yield as an indicator. This treatment did not include forestry statistics nor did Filzer attempt to calculate total primary production. Further attempts to utilize statistical data for mapping production patterns were made by Weck (1955) for forest yield in Germany, and by Paterson (1956) for forests of the world. Their data were presented as yield in lumber and not as total primary production. Because lumber production and total production occur in predictable ratios to one another, it was possible for Lieth (1964), to use Paterson's data to construct his first world primary productivity map. Whittaker (1961, 1966), Lieth (1964), Monsi (1968), Whittaker and Woodwell (1968, 1969), Kira

State North Carolina — Orange — County Name
68 — County Number
Investigator Douglas Sharp — 36.0 N 79.1 W — Geographic Coordinates of County Center

Data Sources 1: Yield information — Timber in N.C. N.C. Farm — Summary
2: Acerage data — Timber in N.C. N.C. Farm — Summary, USDA S.C.S.
3: Other

Land-use category	1 Hectares	2 Comm. yield (t/ha)	3 Conver. factor[a]	4 Water content	5 Corr. conver. factor[b]	6 Adjusted product. rate[c]	7 Total prod.[d]	
Softwood Forests	62526	.63	2.0	0	2.0	1.26	78783	e 12.90
Hardwood Forests		.81	2.0	0	2.0	1.62	101292	f 80658
Corn	2711	3.32	2.62	.12	2.31	7.67	20793.37	
Soy Bean	627	1.28	4.52	.12	3.98	5.09	3191.43	
Tobacco	991	2.16	2.03	.12	1.79	3.87	3835.17	
Wheat	1153	3.03	3.69	.12	3.25	9.85	11357.05	
Oats (Winter)	910	1.69	5.30	.12	4.66	7.88	7170.80	
Peanut	0	0	2.00	.12	1.76	0	0	
Cotton	0	0	2.08	0	2.08	0	0	
Irish Potato	8	11.77	2.47	.75	.62	7.30	58.40	
Sweet Potato	4	17.93	2.47	.75	.62	11.70	44.68	
Hay	2286	3.47	1.30	.14	1.12	3.89	8892.54	
Urban areas	5972	.50	.50	0	.50	.25	1495	
Water	81	5.00	1.00	0	1.00	5.00	405	
Pasture–Range	10164	3.47	.60	0	.60	2.08	21141.12	
Orchards–Vinyards	176	.81	2.00	0	2.00	1.62	285.12	
Open land	1753	3.47	.60	0	.60	2.08	3646.24	
Tillage rotation	6944	3.47	.60	0	.60	2.08	14443.52	
Other								
Oats (Spring)	0	0	5.22	.12	4.59	0	0	
Total Land Area	96306						276834 Total County Production	g 90334

Actual = 103077

[a]Total prod./yield
[b]Column 3 times (1.00 – Column 4)
[c]Column 5 times Column 2
[d]Column 6 times Column 1
[e]Potential forest prod. rate
[f]Potential total forest prod. (t/ha/year)
[g]Potential total county prod. (t/ha/year)

Weighted county production rate: (Total production/Total area) (t/ha/year) 2.87

Potential weighted county prod. rate: 9.38 (t/ha/year)

FIGURE 6–1. Tally sheet for calculating net primary production for counties by land-use categories. See text for explanation.

et al. (1969), and Satoo (1970) all have shown the feasibility of calculating total productivity figures from partial production values. These authors worked independently during the same period; from their work and that of others has come the essential knowledge of production ratios by which agricultural and forestry statistics can be used for productivity mapping.

Table 6–2 Summary of state net primary production data by region (in grams and tons dry matter)

North Carolina productivity profile (year)	Region	Area (10^3 ha)	% total	Rate of net productivity ($g/m^2/year$)	Area net production (10^3 t/year)	% total
1971	Mountains	2,175	16.0	251	5,454	13.9
	Piedmont	4,018	29.5	259	10,411	26.5
	N.E. Coastal Plain	4,067	29.9	321	13,076	33.2
	S.E. Coastal Plain	3,350	24.6	310	10,384	26.4
	Totals:	13,609	100.0		39,325	100.0
1972 Without adjustments to forest production data	Mountains	2,160	16.6	260	5,623	13.7
	Piedmont	3,988	30.7	277	11,029	27.0
	N.E. Coastal Plain	3,446	26.6	391	13,483	32.9
	S.E. Coastal Plain	3,391	26.1	318	10,793	26.4
	Totals:	12,984	100.0		40,928	100.0
With adjustments to forest production data	Mountains	2,160	16.64	628	13,564	13.0
	Piedmont	3,988	30.17	592	23,593	22.6
	N.E. Coastal Plain	3,446	26.54	927	31,949	30.6
	S.E. Coastal Plain	3,391	26.11	1046	35,453	33.9
	Totals:	12,984	100.0	$805 = \overline{X}$	104,559	100.0

Table 6–3 Comparison of crop conversion factors used in 1971 and 1972

Land-use category	Conversion factor[a]	
	1971	1972
Corn	2.03	2.31
Soybeans	3.92	3.92
Tobacco	2.68	1.79[b]
Wheat	2.15	5.24[b]; 3.25[c]
Oats	2.64	
Winter	—	5.49[b]; 4.66[c]
Spring	—	5.41[b]; 4.59[c]
Peanuts	2.64	2.64
Cotton	2.08	2.08
Irish potato	0.60	0.60
Sweet potato	0.60	0.60
Hay	1.12	1.12

[a] Dry weight productivity/wet weight yield.
[b] Experimentally derived conversion factors.
[c] These conversion factors were utilized in the 1972 report.

Methods

Various sources (Table 6–1 and references cited therein) were used to determine county coverage and commercial yield statistics for each land-use category shown in Figure 6–1. Using Figure 6–1 as a model, computational procedures were as follows. To estimate primary productivity rates for each land-use category, commercial yield data (column 2) were multiplied by appropriate conversion factors (column 3). For each land-use category, the conversion factor represents the ratio of estimated total primary production to commercial yield.

Conversion factors used in 1971 were determined from a literature review and through the cooperation of Dr. Ray Noggle and Dr. Douglas Gross of North Carolina State University (Whigham *et al.*, 1971). For several crops conversion factors were verified by actual sampling at several North Carolina agricultural experiment stations. Conversion factors used in 1972 were somewhat different and are discussed subsequently in more detail.

Commercial yield statistics for crop types were based upon wet-weight figures, and it was necessary to adjust the conversion factors to their dry-weight equivalents (column 5) using an estimated water content (column 4). Commercial yield statistics taken from Dorman *et al.* (1970) (column 2) then were multiplied by the corrected conversion factors (column 5). To determine total county production for each land-use category, the adjusted productivity rates (column 6) were multiplied by the coverage data (column 1). Total primary production estimates for each land-use category were summed, and a weighted county productivity rate (total production/total area) was determined. Computer maps

Table 6–4 Computation of conversion ratio used in estimating net forest production from merchantable timber data in North Carolina

Measurements	Mountains	Piedmont		Coastal Plain	
Merchantable timber growth, U.S. Forest Service survey data, $g/m^2/year$	Mean for N. C. mountain Counties	Alamance County	265	Beaufort County	250
		Orange County	287	Washington County	307
		Durham County	247	Pitt County	319
Means:	266		266		292
Forest net production, Plantation survey data, $g/m^2/year$	Mean of the production rate of Tennessee mountain counties (DeSelm *et al.*, 1971)	Duke Forest[a]		Beaufort County Plantations[b]	
		Pinus echinata (18 stands)	564	(*Pinus taeda*, 28 stands)	
				Trees aged 10 and 11 years	2230
		Pinus taeda (47 stands)	998	Trees aged 12 years	1840
				Trees aged 4 years	430
Means:	765		781		1500
Conversion ratio (forest net production/merchantable timber growth)	2.88[c]	2.94		5.14	
Mean conversion ratio:		3.65 (used in all regions)			

[a] Ralston, C. W., and C. F. Korstian (1957–1958), *Piedmont Plantation Data* (*unpublished*).

[b] Nemeth, J. C. (1971). *Dry-Matter Production in Young Loblolly* (*Pinus taeda*) and *Slash Pine* (*Pinus elliottii*) *Plantations*, Doctoral dissertation. Raleigh, North Carolina: North Carolina State Univ.

[c] Based on the premise that green volume growth rates of trees in the mountains are similar to those rates for the Piedmont or stated in De Selm *et al.*, (1971) *Tennessee Productivity Profiles*. (Mountain counties only.)

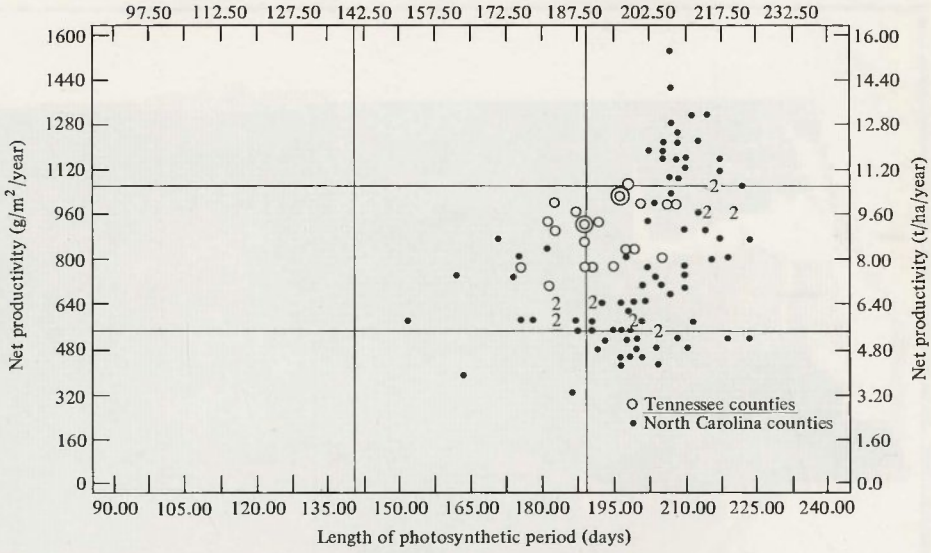


FIGURE 6–2. Net primary productivity rates of North Carolina and Tennessee counties compared to growing season length. Abscissa: photosynthetic period in days; ordinate: net primary productivity ($100g/m^2 = 1^t/_{ha}$). The number 2 is inserted in places where two North Carolina points occupy the same position; double circles indicate the same for Tennessee.

(Reader, 1972) were used to compare graphically weighted county primary productivity rates and rates for each land-use category.

Results

Table 6–2 summarizes the 1971 primary production estimates for the state's four regions. The average regional production rates were lower than might be predicted for a humid temperate climate (Art and Marks, 1971; Whittaker, 1970; Bray and Dudkiewicz,1963; Duvigneaud and Denaeyer-DeSmet, 1967; Satoo, 1967; Madgwick, 1968; Post, 1970; Woodwell and Whittaker, 1970; Odum, 1971). Based on the assumption that the low 1971 estimates were due to inaccuracies in the original set of conversion factors, 1972 efforts focused on a reassessment of the latter. Five crops (Table 6–3) were intensively sampled at agricultural experiment stations throughout the state and, to some degree, all of the 1971 crop conversion factors were changed (Sharp, 1973). When the 1972 conversion factors were used for crops, estimated production rates for the four regions, were increased but still lower than might be anticipated (Table 6–2). Because changes in the crop conversion factors did not significantly alter the estimates of county primary productivity rates, forest-yield conversion factors were examined and changed significantly in 1972 (Table 6–4).

The changes were based upon comparison between Forest Service statistics

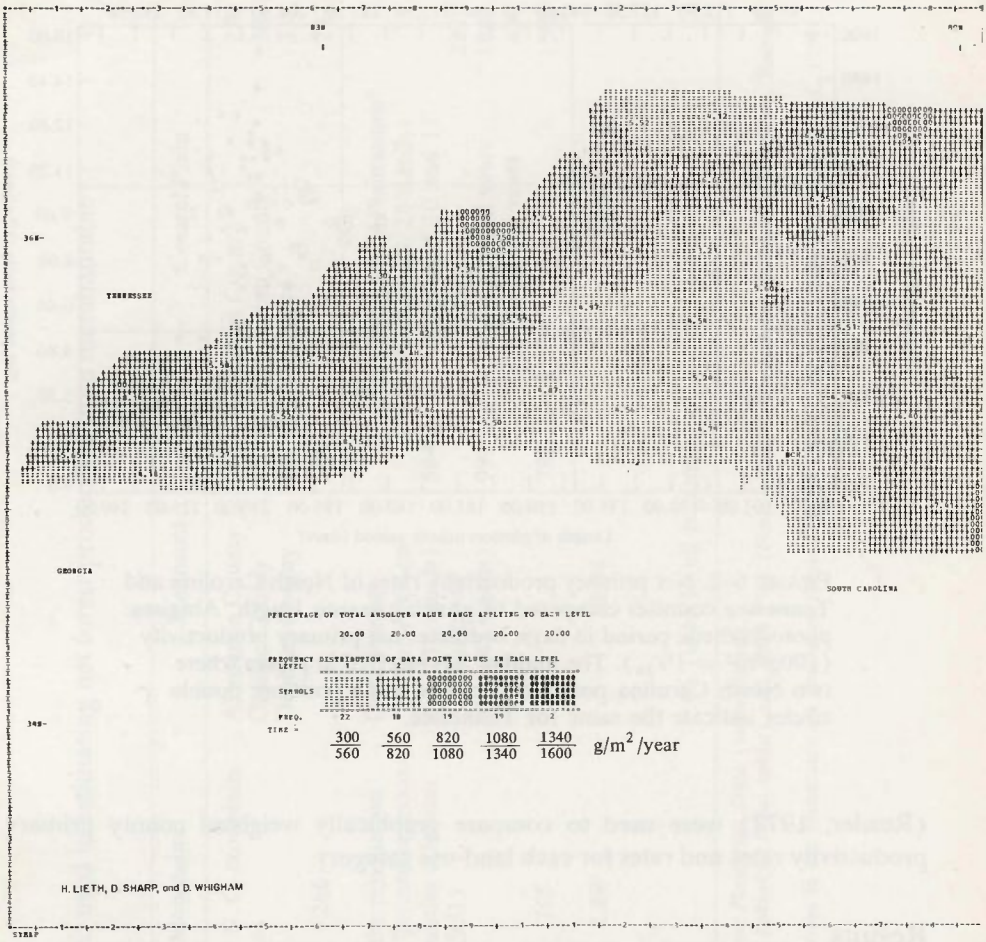
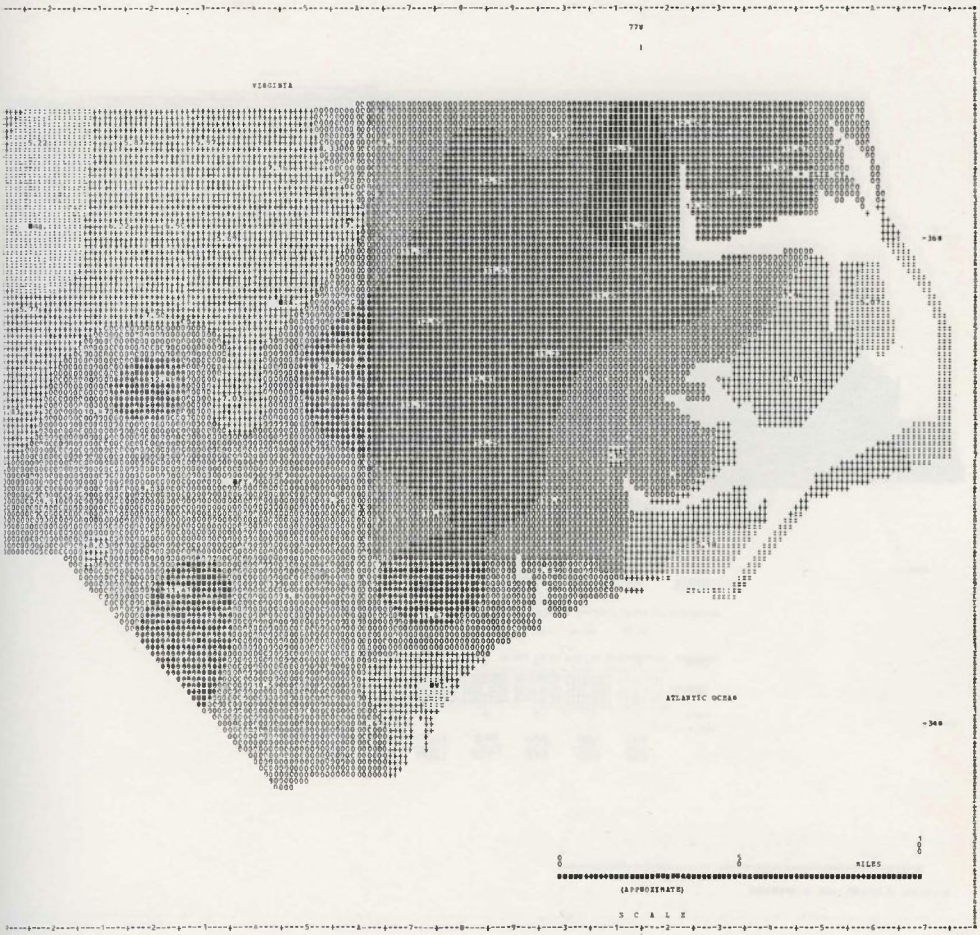


FIGURE 6–3. Map shows distribution of estimated county net primary productivity rates in North Carolina in 1972. Datum points on map represent production rates for each county. Values are based on three distinct mean conversion ratios determined for each region of state. $1^{t}/_{ha} = 100 g/m^2$.

and results of two previous productivity studies. Selecting three counties in the coastal plain region, Forest Service statistics showed a mean production rate for merchantable lumber of 292 g/m^2/year (2.92 t/ha/year). Nemeth (1971) demonstrated a mean production rate of 1500 g/m^2/year for mixed stands of *Pinus taeda* and *P. elliotii* in one of those counties (Beaufort). An earlier study by Ralston and Korstian (*unpublished*) in the Piedmont permitted further comparisons with Forest Service data. For Alamance, Orange, and Durham counties, the Forest Service estimates indicate an average productivity of 266 g/m^2/year (Table 6–4). For stands of *Pinus taeda* and *P. echinata* in the same counties, Ralston and Korstian estimates yield a forest productivity rate of 781



g/m²/year. The higher production values were determined for managed plantations, and it was assumed that most unmanaged forests had somewhat lower production rates. On that assumption, mean conversion ratios (Snedecor and Cochran, 1967; Lieth, 1972) were determined for each region (Table 6–4). Based on DeSelm *et al.* (1971) and on the premise that growth rates of trees in the mountains are similar to those in the Piedmont, similar mean conversion ratios were used for those two regions of the state. Distinct, mean conversion ratios computed for each physiographic province and the average mean conversion ratio of 3.65 for the entire state (Table 6–4) were then used to estimate forest production for each county (county forest production based on Forest Survey data times the mean conversion ratio for each province or the average mean conversion ratio for the state). Using the adjusted forestry conversion factors, Table 6–2 shows that the estimated production rates for the four regions were greatly increased. Figure 6–2 shows that these county estimates agree with county primary production estimates made in Tennessee (DeSelm *et al.* 1971).

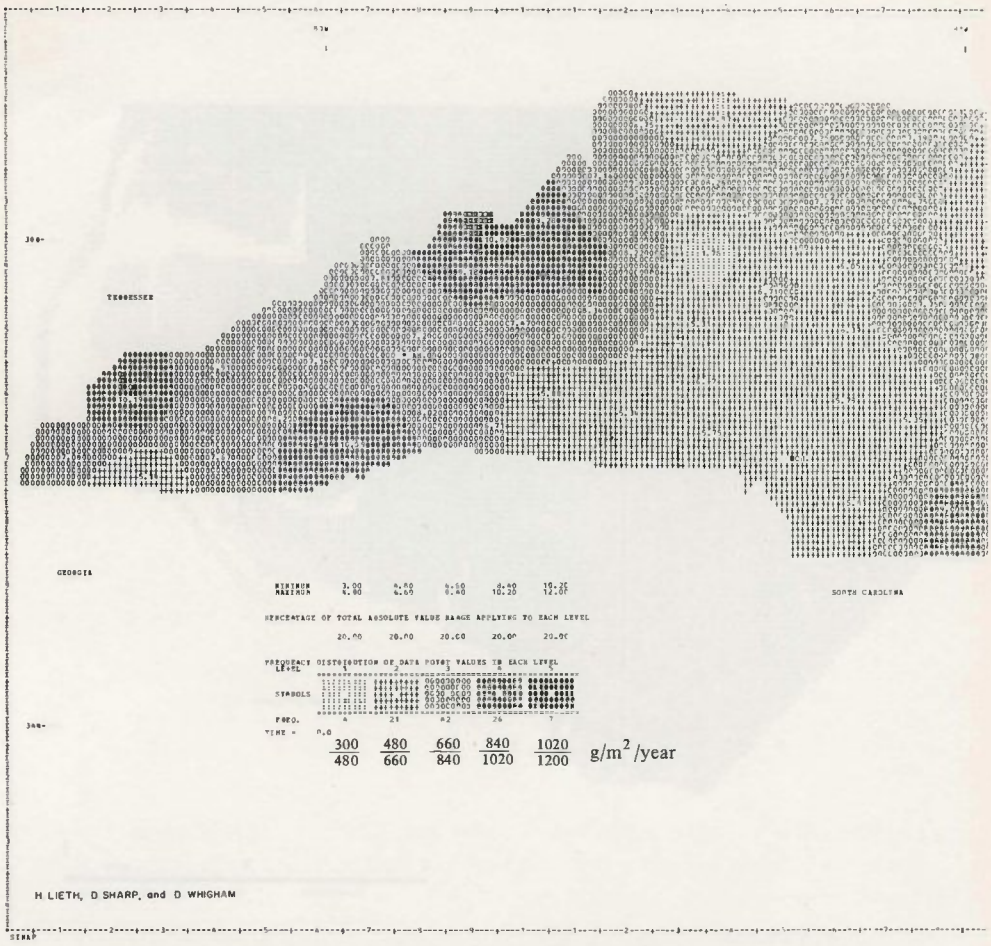
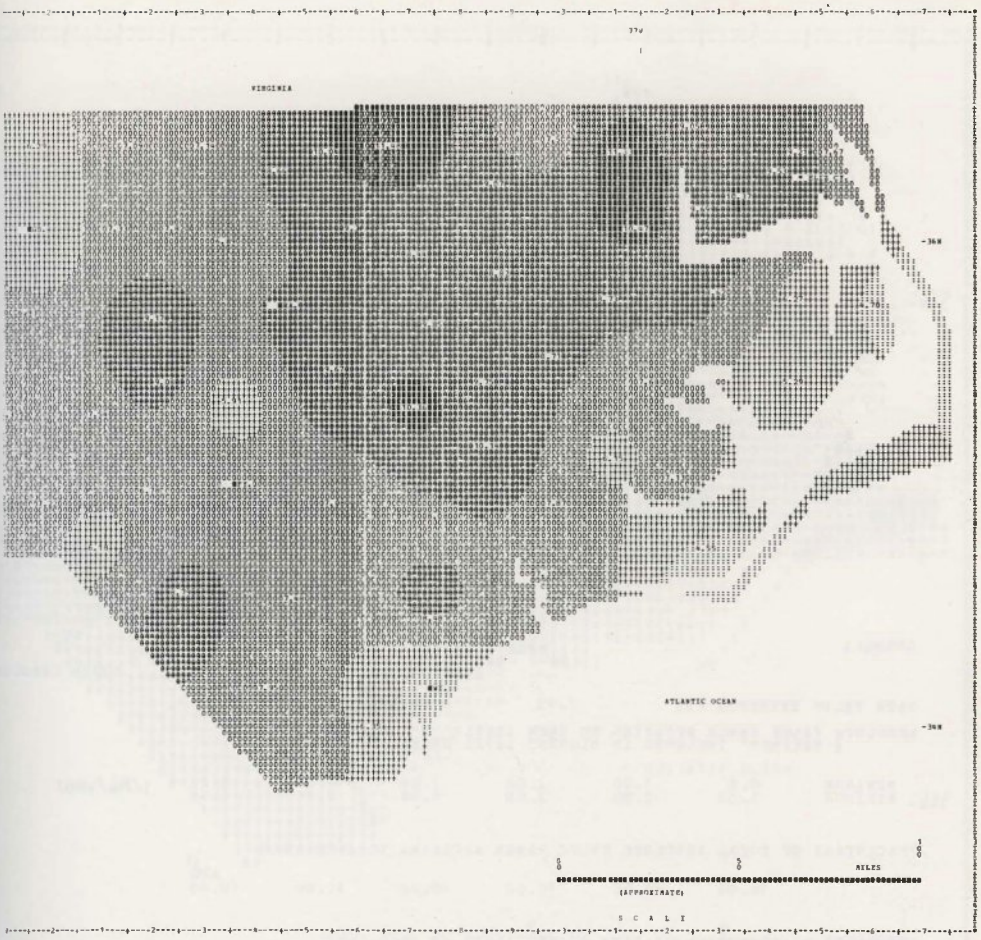


FIGURE 6–4. Map shows distribution of estimated county net primary productivity rates in North Carolina in 1972. Datum point values were determined through use of average mean conversion ratio applied throughout all regions of state. $1^t/_{ha} = 100 g/m^2$.

Patterns of Productivity in North Carolina

The range of estimated net primary productivity was 400 g/m^2/year (Alexander County, Piedmont) to 1538 g/m^2/year (Hertford County, Coastal Plain) utilizing distinct, mean conversion ratios for each province of North Carolina. Most counties were estimated to have productivity rates between 600 and 1200 g/m^2/year (Fig. 6–3). The average rate of primary production for the state was 805 g/m^2/year. The average mean conversion ratio, tabulated for use throughout the entire state, produced the image presented in Figure 6–4. For most crops (Fig. 6–5 is an example), productivity was highest in the eastern counties and lower in the Piedmont and Mountain counties. In the 1971 study,



a distinct east–west productivity gradient occurred when all land-use categories were considered (Lieth, 1972). When the 1972 conversion factors were used, the east–west pattern was still present but was less distinct (cf. Figures 6–3 and 6–4). This was caused by doubling to tripling the adjusted productivity rates for counties in the mountain region. This result was expected because of the extremely high percentage of forested lands in the mountain counties. It might also be concluded that the higher productivity estimates for mountain counties are the result of more favorable edaphic, climatic, and topographic factors.

Control of Productivity Rates by Environmental Factors

Productivity rates of natural and man-influenced vegetation units are controlled by a complex of edaphic, climatic, topographic, and time-related factors. Man's utilization also influences the range of primary productivity values for an area. It has been assumed that for most land-use categories in a humid climate the total net primary productivity is most highly correlated to the onset and

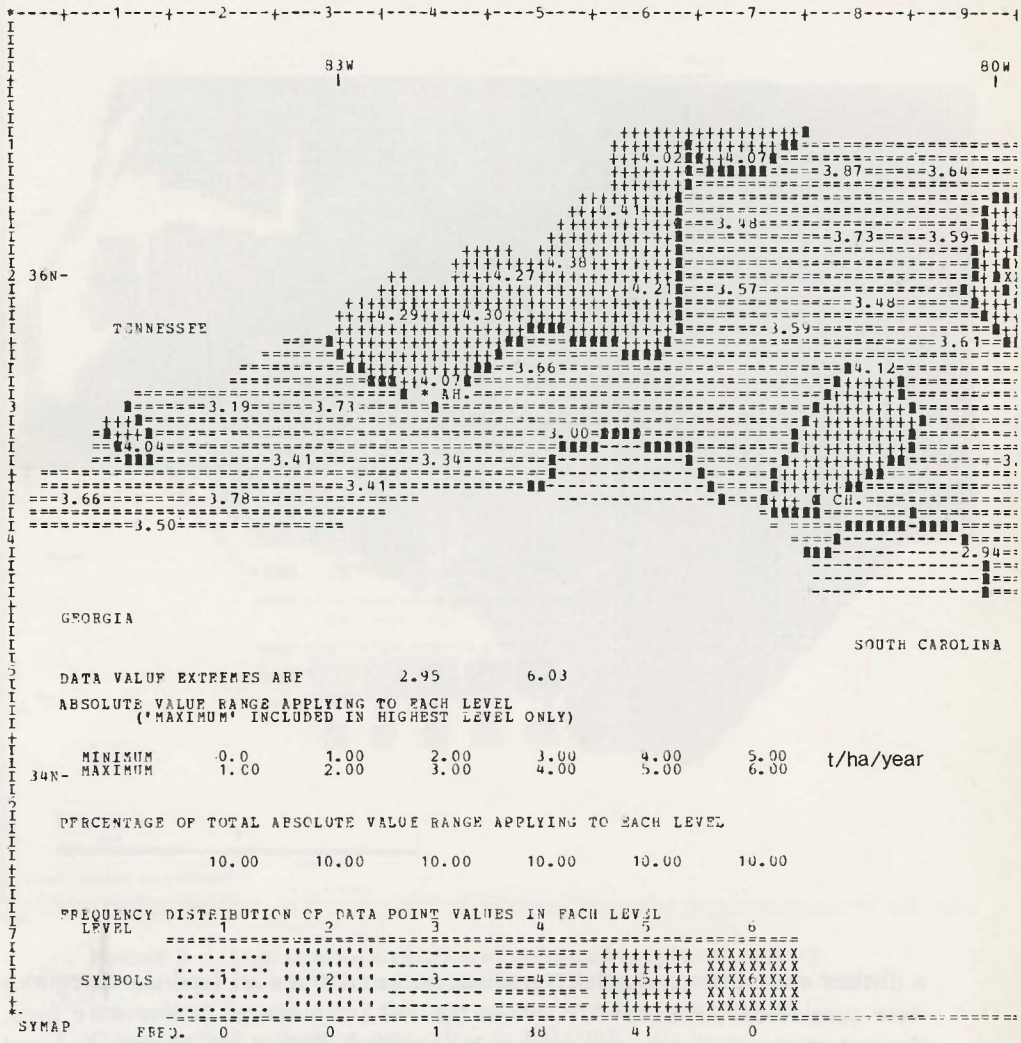
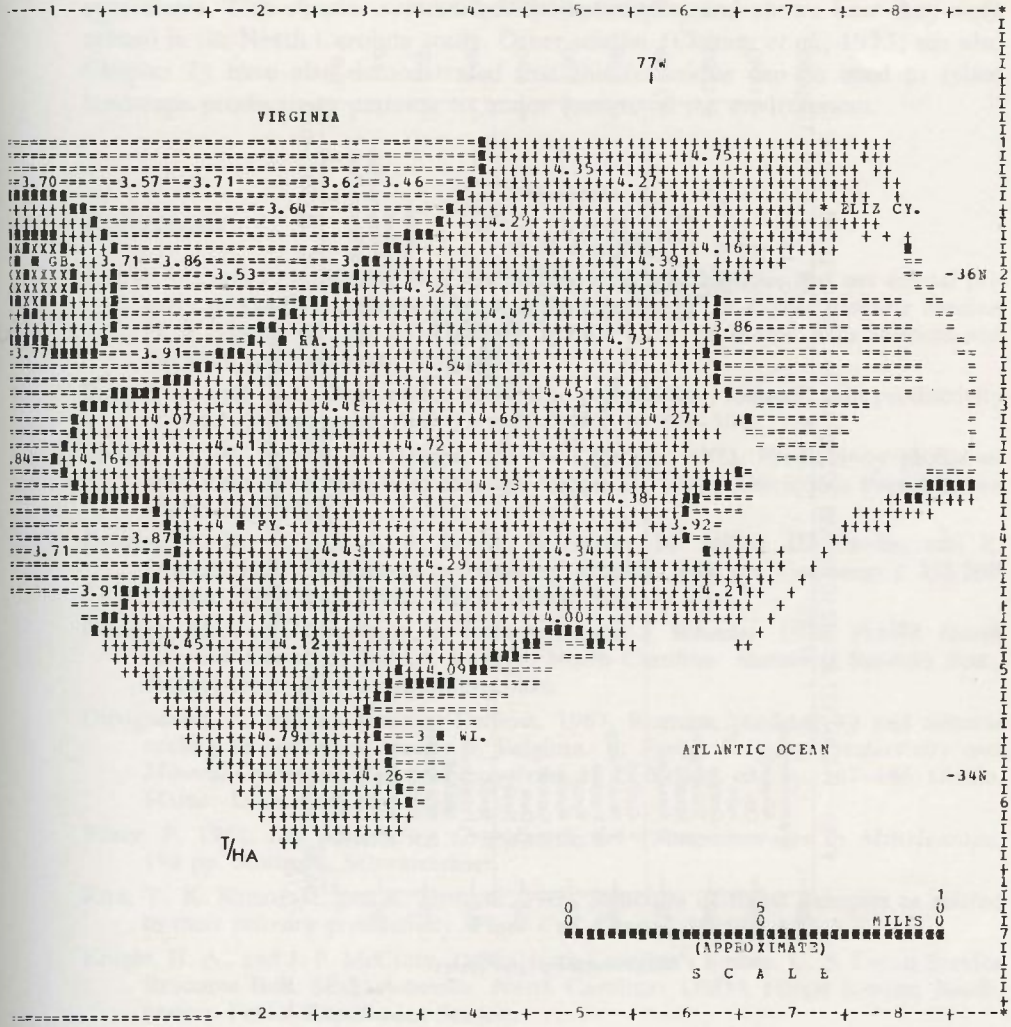


FIGURE 6–5. Map shows distribution of county productivity rates for tobacco in 1972. $1^t/_{ha} = 100g/m^2$.

length of favorable growing conditions. In North Carolina, phenologic studies have shown that the growing season begins earlier and lasts longer in the eastern counties than in the western counties (Radford, 1971). One might expect that there is a relationship between the length of the growing season and rates of primary production throughout the state. Figure 6–6 shows that the correlation between the two factors is limited. Several Mountain counties (Mitchell, Transylvania, Avery, and Graham) have high estimated primary production rates even though the length of the growing season is short. Furthermore, the Coastal Plain counties of Dare, Carteret, and New Hanover exhibit low rates of production under long growing-season conditions. In essence, a clear correlation



between the productivity rate and the length of the growing season cannot be demonstrated by the relationship shown for an area the size of North Carolina. Reader (1973) has shown, however, that the controlling effects of climate over the primary productivity of a large area (biome) can clearly be delineated, and that there exists a correlation between the length of the growing period and rate of net primary production. This correlation is evaluated in Chapter 12.

Conclusions

Since the initial investigation, the techniques for using extant data sources to predict the patterns of landscape primary productivity have much improved. The most critical part of such an analysis is the determination of conversion factors to translate agricultural and forestry statistics into total net primary production

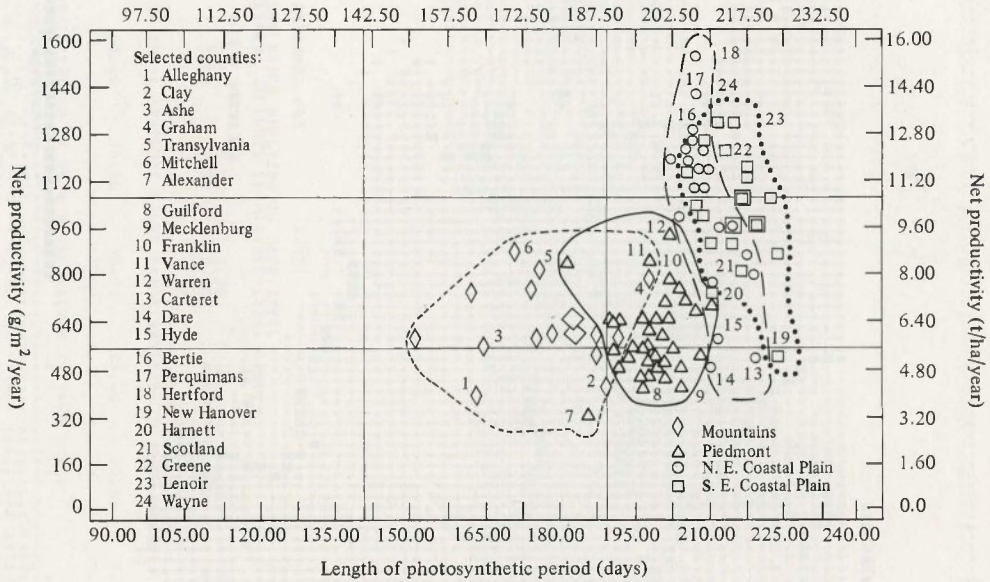


FIGURE 6–6. Estimated productivity rates of North Carolina counties compared to length of growing season. The counties are grouped into physiographic regions. Abscissa: length of vegetation period in days; ordinate: net primary productivity ($1^t/_{ha} = 100g/m^2$).

equivalents. This chapter summarizes the techniques and shows how they were refined in the North Carolina study. Other studies (Cottam *et al.*, 1973; see also Chapter 7) have also demonstrated that this technique can be used to relate landscape productivity patterns to major factors of the environment.

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