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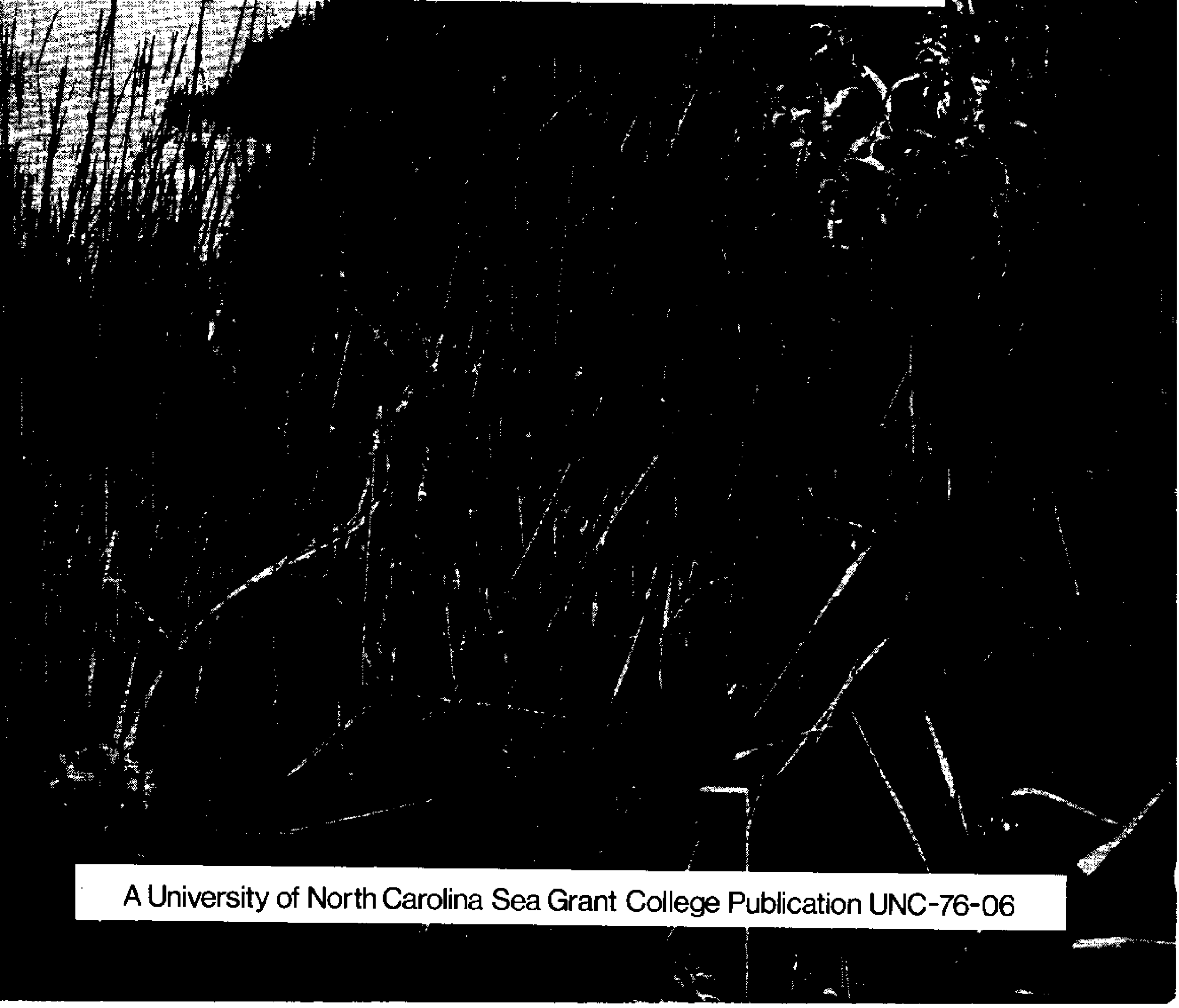

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ABSTRACT

The importance of the extensive areas of North Carolina salt marshes to the productivity of the coastal fisheries is a major question facing those concerned with the fate of the State's coastal resources and the capricious development of coastal wetlands. Knowledge of the variation in net primary productivity of the coastal marshes is meager, but our understanding of the contribution of the decaying marsh grass to estuarine productivity in North Carolina is growing. This report deals with the development of a model based upon known marsh productivity estimates from various East Coast regions, and gives projections from the model of marsh productivities for each North Carolina coastal county. Such productivity information is essential before alternative uses of these extensive marsh lands can be properly determined.

The basic model was developed from 23 estimates of East Coast salt marsh primary productivity that were analyzed by multiple regression procedures. The independent variables included vegetation species, latitude, growing season, temperature range, and mean tidal height. These variables explained 69% of the variation in marsh primary productivity with three of the variables having the greatest effect, growing season, temperature range, and tidal height. The observed primary productivity values and those predicted from the model were generally found to correspond. The model also projected net primary productivity values for salt marshes in the Morehead City region of North Carolina which were found to be consistent with those actually measured in 1974-1975.

Utilizing values of tidal height, latitude, and growing season for a central representative region of each North Carolina coastal county, the

model was then used to compute the potential net primary productivity of Spartina, Juncus, and mixed species marshes for each county. The productivity values for medium Spartina and for Juncus were selected and applied to the known acreages of regularly and irregularly flooded marshes respectively for each coastal county. The total weighted estimated net salt marsh primary productivity was then derived for each coastal county of North Carolina. Values included a high of 145 million kilograms/year for the extensive marshes of Carteret County, 400 thousand kilograms/year for Beaufort, 71 million for Brunswick, and 31 million for Dare County. Based upon the conservative assumption that 30% of the annual regularly flooded marsh vegetation and 10% of the annual irregularly flooded marsh production in North Carolina marshes are carried as decomposing vegetation and detritus to the open estuary, North Carolina's marshes provide approximately 157 million pounds of such vegetation per year to the open waters of the estuaries. Such decomposing vegetation is known to be extremely important to the sustained high production of North Carolina coastal fisheries.

This study and the projected salt marsh primary productivity values for North Carolina coastal counties provide a set of baseline production data that can be used in helping assess the alternative uses of coastal marsh lands, and in computing the possible reduction in the coastal fishery as marsh lands are lost through dredging, filling, and development.

INTRODUCTION

North Carolina possesses almost 150,000 acres of salt marsh distributed among nine coastal counties. Over a third of this acreage has been categorized as regularly flooded *Spartina* dominated marsh which is representative of the most productive kind of salt marsh (Wilson, 1962). While the economic and ecological importance of such marsh lands is difficult to assess, it is generally agreed that the daily tidal action carries substantial amounts of dead and decaying marsh vegetation to the open estuary where it is utilized directly and indirectly by consumer organisms, including commercially important fish and shellfish. Odum (1975) places a conservative annual dollar return value of $2,600 per acre per year for Georgia salt marsh lands based upon (a) their contribution of dead vegetation to estuarine commercial and sport fisheries production and (b) their potential tertiary waste treatment use. Their additional potential use in moderate oyster culture would elevate this figure to $3,230 per acre per year.

While the importance of salt marshes as a source of vegetation energy for estuarine fisheries production is of interest in this report, the assessment of the amount and flow of decaying vegetation to the open estuary is dependent upon a clear knowledge of the levels of marsh primary productivity. Few values exist for North Carolina marshes that permit extrapolation to the extensive marsh areas of the coastal counties. The principal objective of this report, therefore, is the development of a productivity model, derived from existing East Coast data, that can be used to predict average levels of marsh productivity for coastal counties.

There now exist a number of studies that provide estimates of net primary productivity from salt marshes along the East Coast of North America. The number of such studies, although limited, comprises a base of variable productivity information that lends itself to quantitative summarization and interpretation.

In this report we utilize multiple regression analysis to examine the contribution of selected geographical and environmental variables to the known variability of salt marsh primary productivity data. This method of analysis not only provides an indication of the relative importance of these variables to variation in productivity, but also provides a predictive model for assessing primary productivity for East Coast marsh areas where values of the selected environmental variables can be obtained.

Keefe (1972), Keefe and Boynton (1973), and de la Cruz (1973) listed some of the known salt marsh productivity studies for the East Coast of North America that are used in this analysis. In most of these studies net primary productivity was measured by the aerial harvest method which excluded production by the root system. This method involves the clipping of vegetation from randomly selected plots in the marsh throughout the growing season and the estimation of net primary productivity from the increases in weight of living material together with that portion of the vegetation that died during the season. In many of the studies only the biomass or standing crop of the living material was determined at the peak of the growing season. Occasionally, the weight of dead material and that consumed by herbivores was estimated from leaf scars and damaged leaves and added to that of the living biomass.

Most fall standing crop measures are just that and probably underestimate true net primary productivity by 10-15 percent, according to Williams and Murdoch (1969). Variability in the techniques of determining net productivity clearly contributes to the overall variation among estimates. In this report 23 net primary productivity aerial estimates from ten different studies were utilized in the multiple regression analysis.

REGRESSION MODEL AND INPUT VARIABLES

Multiple regression is a statistical technique for studying the relationship between a set of independent variables (X_1, X_2, X_3,....., X_n) and one dependent variable (Y). It not only permits an analysis of the relative importance of the independent variables and their contribution to the variation in the dependent variable, but also provides a predictive equation for estimating values of the dependent variable from known sets of the independent variables. The latter is of principal interest in this report, but must, of course, be carried out with caution since accuracy of prediction is a function of the amount of variation in the dependent variable which is explained by the model. The computer program for this model was adapted from that of Barr and Goodnight found in Service (1972); Statistical Analysis System (SAS) and was run on the Triangle Universities Computation Center, IBM 370/165 computer at Research Triangle Park, North Carolina.

Values of the dependent variable, net primary productivity, (grams of dry matter/meter^2/year) were taken from the 23 selected East Coast salt marsh studies (Table 1). These studies yielded 23 estimates of net productivity for several species and forms of salt marsh vegetation including the tall, medium, and short forms of Spartina alterniflora, Spartina patens, tall and medium forms of Spartina cynosuroides, Spartina patens, Juncus roemerianus, as well as four studies specifying mixed species marsh systems. All selected studies were conducted from 1967 through 1973, and all utilized the aerial harvest method of primary productivity measurement. All productivity values utilized were taken from investigations along the north-south gradient of the East Coast of the United States from Rhode Island to Georgia. Species-specific productivity values were differentiated within the regression model utilizing the dummy variable concept (see Wonnacott and Wonnacott (1970) for a discussion of the use of dummy variables in multiple regression analysis). Net productivity values ranged from a low of 329 grams/m^2/year for short S. alterniflora in North Carolina (Stroud and Cooper, 1969) to a high of 3990 grams/m^2/year for S. cynosuroides in Georgia (Odum and Fanning, 1973).

The independent variables selected included one geographical and three environmental variables. The values of these variables were taken either directly from the study or from other sources, usually the latter. The variables are as follows.

Latitude (X_1): This geographical variable specified the location of each study site as provided by the author or as extracted from maps. Latitude of the investigations ranged from the most northerly Rhode Island study of Nixon and Oviatt (1973) at 41.583 degrees to the most southerly Georgia study of Odum and Fanning (1973) at 31.416 degrees.

Growing Season (X_2): This variable (in days) was extracted from tables in the U.S. Department of Agriculture Yearbook (1941) and applies primarily to agriculture crops near the study site. Growing season is defined as the average number of days from latest spring killing frost to earliest fall killing frost of the same year. The value for each study was selected as that of the nearest site to the actual productivity study site. In many cases the estimated growing season period may actually underestimate actual growing season on the salt marsh since occurrences of frosts may be moderated by the maritime climate.

Temperature Range (X_3): Values for this variable (in ^oF) were also extracted from tables in the U.S. Department of Agriculture Yearbook (1941). It represents the difference between mean annual maximum in July and mean annual minimum temperature in January for a site closest to the actual salt marsh study site. If the mean annual minimum temperature was less than freezing, 32^{o}F was used instead of actual minimum. This variable is related to heat summation on an annual basis; day-degrees would have been more appropriate but such data were unavailable for the study sites.

Mean Tidal Height (X_4): Data for this independent variable were extracted from the U.S. Department of Commerce (NOAA) Tide Tables (1974). Each value again represents that of the actual study marsh or that site closest to the marsh area. Mean annual tidal height expressed in feet varied considerably among the various study areas. Maximum values occurred in the Sapelo Island salt marshes of Georgia (Odum and Fanning, 1973), and minimum values in the Chincoteague Bay region of Maryland-Virginia (Keefe and Boynton, 1973). The variable flushing action and nutrient availability from varying tidal heights appears related to salt marsh productivity (Adams, 1963; Nixon and Oviatt, 1973).

Values for the 23 estimates of net primary productivity and the corresponding four independent variables are given in Table 1. It is clear that several other important independent variables influence vegetation productivity in salt marshes, particularly such nutrients as phosphorus, nitrogen, and iron (Nixon and Oviatt, 1973a; Broome et al., 1973), as well as high concentrations of soil organic matter (Gorham, 1953). Reliable nutrient data for each of the 23 study sites were simply not collected by the respective investigators and are unavailable from other sources.

MULTIPLE REGRESSION ANALYSIS OF PRODUCTIVITY DATA

Logarithmic ($\log_{10}$) transformations of both dependent and independent variables helped linearize relationships between net productivity and each independent variable with the exception of mean tidal height. This variable showed an arithmetic linear relationship with marsh productivity. The following predictive equation represents the overall multiple regression model relating net primary productivity (grams of dry matter/m^2/year) to the four selected independent variables.

$$\log Y = -26.858 + 4.121\ X_1 + 5.271\ X_2 + 6.783\ X_3$$
$$+0.150\ X_4 + C \text{ (species-specific constant)}$$

The constants (C) for each species or form, together with the standardized regression coefficients are given in Table 2. The addition of each constant to the above regression equation provides a prediction of net productivity for that species or form. The standardized regression coefficients (B) are independent of the original units of measurement, and indicate the relative importance of each of the independent variables. For example, the most important numerical variable is X_2 or growing season, with temperature range, mean tidal height, and latitude following in order of importance. Growing season appears to be over twice as important as latitude. The value of the overall multiple correlation coefficient (R^2) was 0.687. This demonstrates that variation in the four independent variables together with the dummy variables (marsh grass species and form) accounted for 69 percent of the variation in the 23 values of net primary productivity. About 31 percent of the variance in Y remains unexplained. This is not an unreasonable amount in view of the small number of available case studies and the wide range of variation in net primary productivity values not only between geographically close areas, but also within any one investigation (although few investigations actually reported variances with their productivity measurements). Nutrient levels, organic content of sediments and other important controllers of net primary productivity probably account for much of the unexplained variation.

The overall analysis of variance of the regression was significant at $P = 0.10$. Analyses of variance of each independent variable utilizing the partial sums of squares, which are adjusted for all other effects and variables in the model, produced the following respective significance probabilities; log latitude 0.272, log growing season 0.048, log temperature range 0.123, and mean tide 0.078. Again we interpret this to indicate that growing season and tidal height are the most important independent variables in the multiple regression model. All selected independent variables were maintained in the model when it was used for predictive purposes.

COMPARISON OF OBSERVED AND PREDICTED VALUES

Predicted net primary productivity values for each of the 23 input values are shown in Table 1. With 69 percent of the variance explained in the regression model, correspondence between predicted and observed values is exceptionally good in many cases, although discrepancies do occur. Some of the authors, such as Nixon and Oviatt (1973a) did present estimates of variation about their mean standing crop values. They indicate an overall coefficient of variation (standard deviation/mean) of 0.38; implying a fairly wide variation in Spartina standing crop within a small coastal area in Rhode Island. This variation about their Spartina average estimate (840 grams/m^2/year) clearly encompasses that predicted by this multiple regression analysis (1075 grams/m^2/year). Some estimates of net productivity are not predicted well, such as the unusually high value of 3990 grams/m^2/year for tall Spartina alterniflora along a creek in Sapelo Island, Georgia by Odum and Fanning (1973). Unfortunately, estimates of variance were not provided by these authors.

The predictive ability of the regression model was also tested against recent primary productivity data (Kuenzler and Stiven, unpublished) from two salt marshes in the Morehead City region of North Carolina. These marshes border Bogue Sound and consist almost entirely of Spartina alterniflora. Tar Landing marsh contains Spartina of short to medium height (average of 50 cm), Causeway marsh contains Spartina of medium height (average of 90 cm). Early fall (September - October) sampling during 1974 and 1975 yielded estimates of net primary productivity (summation of living and dead Spartina biomass) as follows (values are mean grams dry wt/m^2/year $\pm$ 2 S.E.).

Year	Tar Landing Marsh	Causeway Marsh
1974	849 ± 138 (10)	900 ± 192 (10)
1975	664 ± 126 (27)	725 ± 128 (30)

Numbers in brackets represent number of samples. Using values for the four independent variables that correspond to the Morehead City region, the multiple regression model predicted net primary productivity values of 902 and 435 grams/m^2/year for medium and short Spartina respectively. We conclude that these predicted values correspond quite well to those actually measured in the two North Carolina marshes.

SALT MARSH PRIMARY PRODUCTIVITIES FOR N. C. COASTAL COUNTIES

In view of the general satisfactory overall goodness of fit of the regression model to the productivity data, the model can be now used with caution to predict the total annual net productivity of salt marsh vegetation in the coastal counties of North Carolina. Wilson (1962) provided data on the acreages of salt marsh lands for each coastal county of North Carolina. Additionally, he specified how much of the acreage was represented by regularly and irregularly flooded marsh. To compute total county productivities we assume that regularly flood marsh is Spartina dominated (Wilson, 1962) and on the average contains plants of medium height (in contrast to the short or tall forms of Spartina alterniflora). Irregularly flooded marsh lands tend to be dominated by Juncus (Wilson, 1962). These assumptions of marsh vegetation composition in North Carolina are necessary as input data for the model; the actual vegetation composition for North Carolina marshes by county is not known. The values of the independent variables for each county were taken from the sources specified earlier. Specific sites for each county were those closest to the latitudinal midpoint of the county; corresponding temperature range and growing season data were taken from the Department of Agriculture Yearbook, 1941, and the tidal height data from NOAA Tide Tables, 1974. Table 3 depicts the predicted net primary productivities (grams/m^2/year) for the principal species and form of salt marsh vegetation. Only the values for medium height Spartina alterniflora and Juncus are used for calculating the productivities for regular and irregular flooded marshes respectively. Salt marsh acreages (in hectares) for each county (computed from Wilson, 1962) are given in Table 4, along with the weighted predicted total net primary productivities for each county. These latter values were calculated by multiplying acreage by net productivity and summing both marsh types (regularly flooded, irregularly flooded) to give estimates of total primary productivity for each county.

These results suggest, therefore, that a county such as Carteret produces a net average of 145 x 10^6 kilograms of salt marsh vegetation per year. An estimated total for all counties containing salt marsh areas in North Carolina comes to approximately 356 x 10^6 kilograms per year. On a per acre basis these calculations suggest that North Carolina coastal salt marshes are producing approximately an average of 6,213 pounds of dry vegetation matter per acre per year, with values ranging from as low as 2,400 lbs/acre/year in the northern county of Hyde to 10,000 lbs/acre/year in the southern county of Brunswick.

DISCUSSION AND CONCLUSIONS

The validity of any multiple regression model can only be as good as the original data upon which it is based. This multiple regression analysis must be viewed as a first approximation of the analysis of variation in and prediction of salt marsh net productivity among East Coast marshes. As new production data become available, and as more accurate estimates of current and new independent variables occur, the model can be refined and its predictability improved.

The methods of measuring productivity were found to be inconsistent among the various studies with some reporting biomass at peak growing season and others biomass plus standing dead. These differences alone obviously contribute considerably to variation. Data on year to year variation in productivity in any one marsh seems generally unavailable in the literature, and this source of variation among studies remains unknown. Our own data on North Carolina marshes suggest that this variation may be large (a 20% change occurred in two study marshes from 1974 to 1975).

Of the independent variables utilized in the regression analysis, growing season, temperature range, and tidal height were found to be most important. Almost 70% of the variability in net primary productivity was explained by the independent variables. Much of the 30% unexplained variation is probably due to differences in nutrient concentrations, organic content of marsh soils, and other unknowns controlling marsh grass productivity. One must also be cautious in assessing the 70% explanation of variability in the dependent variable since the independent variables are not clearly and completely independent. This is particularly true for growing season and temperature range. Since the model is used primarily as a predictive tool rather than a technique for assessing the relative importance of a series of independent variables, this problem is not considered serious.

Finally, we can now consider the important question of the contribution of marsh vegetation to secondary production in the open estuary. Teal (1962) estimated that 45% of the annual marsh vegetation in Georgia is exported to the open estuary as detritus and contributes significantly to the high levels of secondary production of fish and shell fish. Nixon and Oviatt (1973b) estimated a comparable figure of 10 - 30% in their Rhode Island marsh study. If we conservatively estimate that 30% of the annual regular marsh vegetation production and 10% of the annual irregular marsh production in North Carolina (71 million kilograms/year or 157 million pounds/year) is carried by tidal action to the open estuary as decomposing vegetation or detritus, one can readily appreciate the importance and contribution of coastal marshes to the production of shell fish, crustaceans, and fishes in the adjacent tidal creeks and open estuaries and sounds.

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TABLE 1

Net primary productivity (NPP) values from ten different studies along with corresponding environmental data. Predicted productivity values from the multiple regression model are also shown.

NPP Observed	NPP Predicted	Latitude	Growing Season(days)	Temperature Range (°F)	Mean Tide(ft.)	A	B	C	D	E	F	G	H[1]	Source
560	780	33.900	249	32.5	4.1							*		Foster (1968)
492	374	38.166	185	39.5	0.4		*							Keefe and Boynton (1973)
518	455	38.166	185	39.5	0.4								*	" "
1296	1803	33.900	249	32.5	4.1	*								Stroud & Cooper (1969)
461	1012	33.900	249	32.5	4.1		*							" "
329	488	33.900	249	32.5	4.1			*						" "
796	970	31.416	257	29.7	6.8							*		Odum & Fanning (1973)
2883	1259	31.416	257	29.7	6.8		*							" "
1028	1028	31.316	257	29.7	5.2					*				" "
2092	2092	31.316	257	29.7	5.2						*			" "
3990	2242	31.416	257	29.7	6.8	*								" "
1246	1113	38.416	187	42.3	1.4								*	Johnson (1970)
1207	915	38.416	187	42.3	1.4		*							"
445	621	38.766	183	42.3	0.5		*							Morgan (1961)
985	1276	31.516	256	29.7	6.8		*							Smalley (1959)
840	1075	41.583	176	35.7	3.5	*								Nixon & Oviatt (1973)
432	291	41.583	176	35.7	3.5			*						" "
430	510	41.583	176	35.7	3.5				*					" "
680	734	41.583	176	35.7	3.5								*	" "
754	606	34.766	269	33.3	1.3							*		Williams & Murdoch (1972)
1297	1093	35.850	289	32.1	2.0				*					Waits (1967)
1334	1574	35.850	289	32.1	2.0								*	"
1361	997	35.850	289	32.1	2.0							*		"

[1] A. S. alterniflora (tall)
B. S. alterniflora (medium)
C. S. alterniflora (short)
D. S. patens
E. S. cynosuroides (tall)
F. S. cynosuroides (medium)
G. Juncus roemerianus
H. mixed

TABLE 2

Species constants (C) and standardized regression coefficients (B) for all species and species forms. C is the regression constant added to equation (+) for the prediction of net productivity for each species.

Species and X variables	Dummy variable code	C	B
S. alterniflora (tall)	A	+0.324	
S. alterniflora (medium)	B	+0.073	
S. alterniflora (short)	C	-0.244	
S. patens	D	0.0	
S. cynosuroides (tall)	E	+0.231	
S. cynosuroides (medium)	F	+0.540	
Juncus roemerianus	G	-0.040	
mixed	H	+0.158	
Log Latitude (X_1)			0.659
Log Growing Season (X_2)			1.553
Log Temperature (X_3)			1.279
Mean Tide (X_4)			1.141

TABLE 3

Predicted average net primary productivity (grams/m^2/year)[1] values for each North Carolina coastal county.

County	*S. alterniflora* Tall	Medium	Short	*Juncus*	Mixed
Brunswick	1751	983	474	758	1196
New Hanover	1666	936	451	721	1138
Pender	384	216	104	166	262
Onslow	1122	630	304	486	766
Carteret	1607	902	435	695	1097
Beaufort	479	269	130	208	328
Pamlico[2]	435	244	118	188	297
Hyde	489	275	132	211	334
Dare	1106	621	300	478	756

1 Kilograms/Ha/year x 1.122 = pounds/acre/year. Gram/m^2 = 10 kilogram/Ha.

2 Pamlico County tidal height and growing season data are those of New Bern, N. C. which has the same latitude as Stonewall, Pamlico County.

TABLE 4

Predicted annual net primary productivity (10^6 kilograms/year) for each coastal county in North Carolina.

County	Regular marsh, Ha[1]	Irregular marsh, Ha	Regular flooded marsh, NPP	Irregular flooded marsh, NPP	Total NPP for Co.
Brunswick	7,285	-	71.6	-	71.6
New Hanover	3,177	-	29.7	-	29.7
Pender	3,683	-	8.0	-	8.0
Onslow	4,593	405	28.9	2.0	30.9
Carteret	4,047	15,621	36.5	108.6	145.1
Beaufort	-	182	-	0.4	0.4
Pamlico	-	6,070	-	11.4	11.4
Hyde	647	12,100	1.8	25.5	27.3
Dare	202	6,273	1.3	30.0	31.3

[1] 1 Hectare = 2.471 acres; kilograms/Ha x 1.22 = pounds/acre. Salt marsh acreage data from Wilson (1962).