Reliability of Remote Sensing for Assessing Planktonic Algal Chlorophyll in NJ Nearshore water of NY Bight

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ABSTRACT

Eutrophication--enrichment of the natural water in New Jersey coastal waters has an adverse impact on the economic welfare of the state. Since shipboard sampling is not cost effective for providing data on coastal/estuarine water processes and materials, satellite remote sensing with its synoptic repetitive coverage is used to obtain some of the data for eutrophication related water quality analysis. This paper represents an initial effort in the development of a methodology for planktonic algal chlorophyll assessment in which the remote sensing data will serve as a valuable complementory data sources. Such study is considered to be vital in assessing the magnitude and duration of short-lived phenomenon--algal blooms as well as potential sources of nutrients which lead to bloom formation. For the purpose of this study, existing imageries such as Coastal Zone Color Scanner, Landsat Multispectral Scanner/Thematic Mapper and Advanced Very High Resolution Radiometer were investigated. On the basis of this comparison, TM digital data of the study area acquired August 25, 1985 was obtained for quantitative analysis. The examination of previous remote sensing water quality studies was also carried out in order to identify the optimum course of the analyses of planktonic algal chlorophyll based on the technology of remote sensing. The goal was to establish a correlation between total plankton content and remote sensing signals indicating relative degree of eutrophy and productivity in the New Jersey coastal waters.

INTRODUCTION

Chlorophyll-a is the pigment present in living plants responsible for photosynthesis. In productivity studies chlorophyll-a is usually taken as a measure of phytoplankton biomass (Gordon,1983). Elevated chlorophyll-a concentrations, associated with algae, most often result from high levels of water borne nutrients which can generate foul smelling and even toxic water conditions. Conversely, abnormally low production of algae, indicated by low chlorophyll-a concentrations, may result from the presence of substances toxic to algae and possibly to higher life forms, including man. While the measurement of the chlorophyll content of surface waters is well established, the reliability of making measurement of optical proper ties and the effects due to the scattering and absorption by organic and inorganic particles in the water column in turbid nearshore (case two) water such as along the NJ Coast has not been established. The thrust of this preliminary investigation is to provide basis for the future more intense analysis of such parameters along NJ coasts based on the technology of remote sensing. For the purpose of this study different bands of information were examined in order to select the optimum band of data to measure planktonic algal chlorophyll concentra tion in NJ nearshore waters. Individual concentration measurement of chlorophyll-a as a measure of productivity and sensor radiance were used to generate regression model of relationship and assist in management project dealing with eutrophication of NJ coastal waters. The final product is a georeferanced level sliced map depicting the spatial distribution of chlorophyll-a concentration during the peak formation of the bloom in NJ nearshore waters of the NY Bight.

LOCATION AND REGIONAL CHARACTERISTICS OF THE STUDY AREA

The study area is the Inner New York Bight extending from eastern Rockaway Beach, Long Island southwest to Sandy Hook and south to Long Branch, New Jersey (fig. 1). This region is an extremely complex system involving the interaction of tidal and wind driven currents modified by fresh water discharge from Hudson, Raritan, Navesink and Shrewsbury Rivers. The Hudson River is the largest of the four originating in the foothill of Adirondack Mountains and flows southward discharging into Lower New York Bay. The second major river is the Raritan with its headwater in Northern New Jersey meandering south of Watchung Mountains discharging into Raritan Bay. The Navesink and Shrewsbury Rivers parallel each other in Atlantic Highlands of New Jersey. They trend northeast and divert northward into Sandy Hook Bay (US Army Corps of Engineers,1971). New Jersey neashore region, enriched by coastal upwelling of high nitrate, coastal sewage outfalls and anthropogenic and non-point source loading from Hudson/Raritan Estuary, is characterized by frequent summer phytoplankton blooms (Warsh, 1986). The technology of remote sensing may provide a valuable tool for monitoring these conditions more effectively and economically.

METHODOLOGY

The research follows two separate but integrated tasks. The first phase of the study which this paper encompasses deals with the comparison of the existing remotely sensed datasets (AVHRR, CZCS, MSS AND TM) and the correlation of the selected scene with the existing sea truth data. In order to achieve the goal of the research the photographic products of various bands of multidate imageries acquired by different sensors were obtained for visual inspection and the selection of the optimum dataset--TM data acquired September 1, 1985. These selections were limited based on the availability of sea truth data for quantitative analysis. The sea truth observations obtained by NOAA Sandy Hook Laboratory at its Long Branch transect August 28, 1985 were found to be the most comparable dataset with the chosen TM data. The laboratory analysis of chlorophyll-a includes correction for Phaeopigment, a degradation product of chlorophyll-a upon acidification, but provides no data on concentration of inorganic materials for this study. The time interval between the sea truth data which were taken from a depth of one meter and the satellite overpass was four days. The data analysis involved three procedures. First was the geometric and radimetric correction of the data followed by the enhancement techniques and finally the production of the output results. The geometric correction was accomplished using several ERDAS programs where the ground control points in the image and reference map were identified and distortion was removed through mathematical modeling using the least squares criteria. The nearest neighbor resampling technique was chosen as the last step in rectification process in order to assign the brightness values to the pixels in the output image. Representative DN values corresponding to seatruth measurements were determined by digitizing and locating the sampling stations on the rectified imagery. The DNs for each individual band were then converted to radiance values in MW. CM^{-2}. SR^{-1} (NASA,1984 and EOSAT Landsat Technical Notes, 1986). The sea truth measurements of chlorophyll-a along with corresponding radiance values in TM bands are listed in table 1. Based on the literature search and inspection of the data TM bands 5 and 7 were not considered in the analysis due to low water depth penetration of these wavelengths (Lathrop et.al.,1986). Using multiple regression techniques--SAE by J. Wesley Barnes the surface measured chlorophyll-a values were input as a dependent variable while the radiance values were used as independent variables (Khoram, 1985 and 1986). The model for chlorophyll-a concentration is a linear one:

$$Y=B_o+B_1X_1+B_2X_2+B_3X_3+B_4X_4$$

where the subscripts of X denote the bands used for the radiance values. As analyzed by Lathrop et. al., 1986, an alternative model was studied of the following form

$$\ln Y=B_o+B_k \ln X_k \quad \text{for} \quad K=1,2,3,4$$

and it was observed that the correlation coefficients were slightly higher for the corresponding individual band regression. It was observed that in the reduced one independent variable regression models, band one showed the highest correlation to chlorophyll_a concentration followed by the band 2 correlation value. Since band one values are more subject to atmospheric effects (leading to lower data validity) the researchers feel band 2 is a better variable for estimating chlorophyll-a concentration. Viewing the vector $[|B_1||B_2||B_3||B_4|]$ (Table 4) as weights for the contributing effects of the components' corresponding bands, one sees that band 1 has the highest contribution followed far behind by bands 3 and 4. Although band 2 has the second highest correlation for the single value regression studies, it has the lowest contributing effect for estimating chlorophyll-a concentration in the multivariable model. The summary of regression model is given in table 2,3,4 and 5. Based on the regression model which translates the radiance values to the predicted level of chlorophyll-a concentration, the entire study area was divided to 4 levels. Figure 2 is a georeferenced level sliced map of the study area depicting spatial distribution of the chlorophyll-a concentration during peak bloom. Data analysis indicates that the high concentration of chlorophyll-a occurs in the poorly flushed nearshore areas of the study site and away from the fresh water inflow from the Hudson and Raritan rivers.

CONCLUSION

The major benefit of this study is to determine the trophic state of the NJ coastal waters producing a data set that was not readily available. The result of this work will be valuable as it provides: a) further development of water quality parameters modeling of the NY Bight b) bring together a variety of data and some unique information for analysis of water quality and c) foster cooperation among several groups interested in water resource application of remote sensing. Future work will be based on the simultaneous acquisition of satellite data and surface water measurements.

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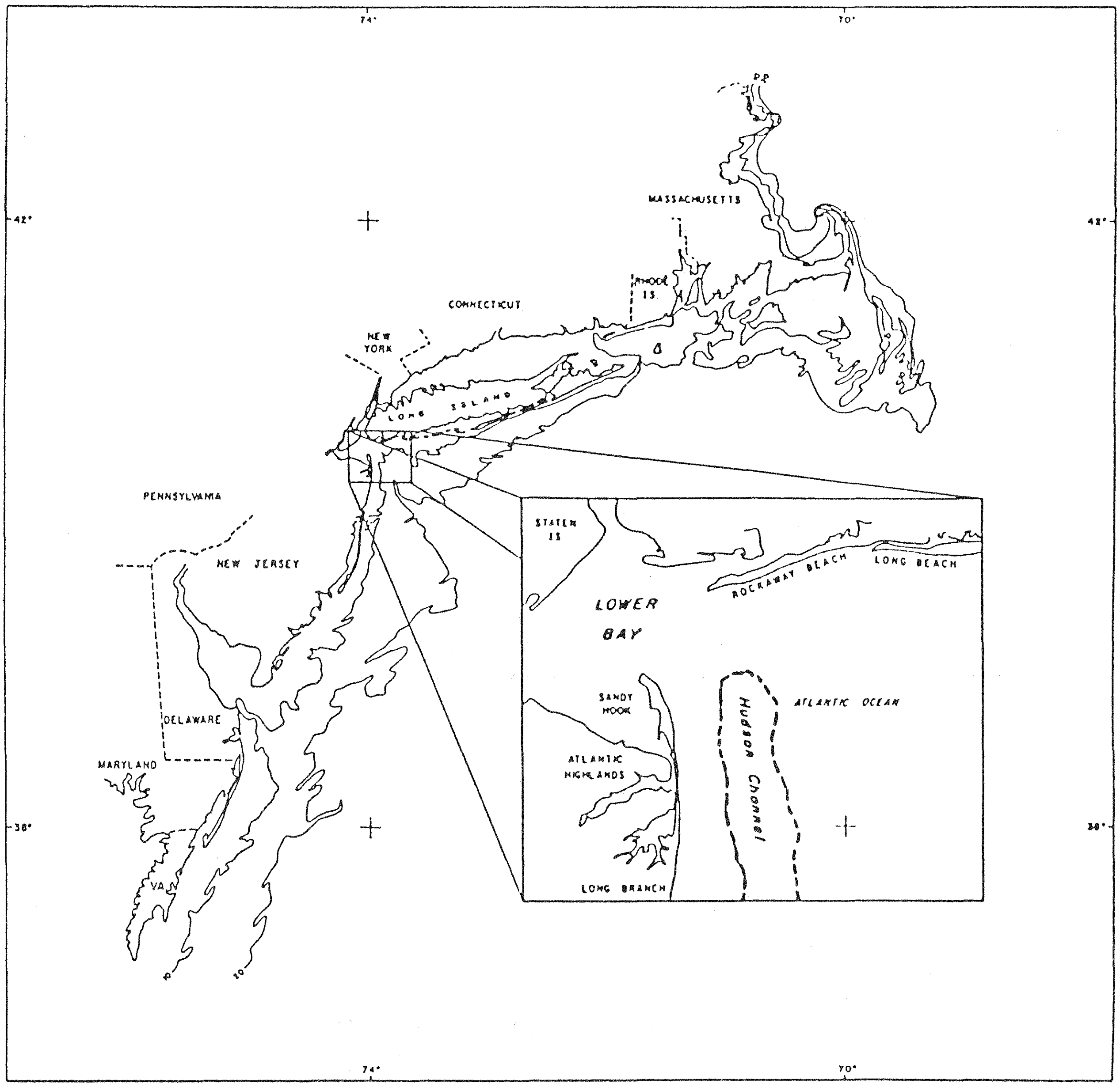

Figure 1. Location map of the Inner New York Bight study area. Map shows the geographic relationship with the northeastern Atlantic coast.

TABLE 1

Chlorophyll-a concentrations and TM radiance data($MW.CM^{-2}.SR^{-1}$)

"Sandy Hook to Long Branch Transect"

	X 1	X 2	X 3	X 4	Chlor-a(ug/l)
1	+0.070	+0.194	+0.326	+0.070	+6.900
2	+0.074	+0.194	+0.346	+0.082	+7.720
3	+0.078	+0.213	+0.346	+0.070	+10.730
4	+0.061	+0.203	+0.341	+0.082	+9.840
5	+0.065	+0.184	+0.336	+0.093	+8.900
6	+0.070	+0.175	+0.341	+0.059	+5.830
7	+0.070	+0.194	+0.341	+0.082	+6.600
8	+0.078	+0.203	+0.336	+0.070	+5.450
9	+0.082	+0.203	+0.360	+0.082	+6.100
10	+0.082	+0.203	+0.355	+0.059	+1.600
11	+0.078	+0.213	+0.360	+0.104	+3.880
12	+0.061	+0.194	+0.331	+0.070	+14.360
13	+0.065	+0.203	+0.331	+0.059	+19.020
14	+0.065	+0.194	+0.351	+0.070	+16.560
15	+0.082	+0.203	+0.370	+0.059	+14.090
16	+0.065	+0.184	+0.336	+0.082	+14.260
17	+0.061	+0.175	+0.336	+0.070	+20.890
18	+0.057	+0.175	+0.322	+0.059	+16.030
19	+0.057	+0.166	+0.326	+0.070	+13.380
20	+0.057	+0.166	+0.322	+0.070	+16.010
21	+0.057	+0.184	+0.336	+0.070	+17.160

TABLE 2

Correlation Matrix for Regression Coefficients

Coe	B 0	B 1	B 2	B 3	B 4
B 0	+1.000	+0.644	-0.198	-0.912	+0.081
B 1	+0.644	+1.000	-0.499	-0.627	+0.190
B 2	-0.198	-0.499	+1.000	-0.118	-0.203
B 3	-0.912	-0.627	-0.118	+1.000	-0.176
B 4	+0.081	+0.190	-0.203	-0.176	+1.000

TABLE 3

Coe.	Value	Std. Dev.	t	Prob>t	Std. Coeff
B 0	-7.522	+28.832	-0.261	+0.604	+0.0000
B 1	-689.279	+177.556	-3.882	+0.999	-1.1398
B 2	+72.039	+89.942	+0.801	+0.220	+0.1885
B 3	+188.242	+108.331	+1.738	+0.049	+0.4524
B 4	-164.773	+73.202	-2.251	+0.981	-0.3608

TABLE 4

Multiple Correlation Coefficient R-Squared = .6262432

F Statistic = 6.702148
with 4 and 16 Degrees of Freedom

Probability (X < F) by chance = 2.421218E-03

Standard Deviation of error = 3.715564

Variance of error = 13.80542
With 16 Degrees of Freedom

Error Sum of Squares = 220.8867

Total Sum of Squares = 590.9905

C(P) = 5 and P = 5

TABLE 5

Observed	Fitted	Residual	Std. Residual
+6.900	+8.341	-1.441	-0.388
+7.720	+7.219	+0.501	+0.135
+10.730	+7.488	+3.242	+0.873
+9.840	+15.678	-5.838	-1.571
+8.900	+8.628	+0.272	+0.073
+5.830	+11.613	-5.783	-1.556
+6.600	+9.211	-2.611	-0.703
+5.450	+4.985	+0.465	+0.125
+6.100	+4.767	+1.333	+0.359
+1.600	+7.601	-6.001	-1.615
+3.880	+4.582	-0.702	-0.189
+14.360	+15.053	-0.693	-0.187
+19.020	+14.714	+4.306	+1.159
+16.560	+15.791	+0.769	+0.207
+14.090	+10.350	+3.740	+1.007
+14.260	+10.506	+3.754	+1.010
+20.890	+14.602	+6.288	+1.692
+16.030	+16.715	-0.685	-0.184
+13.380	+15.063	-1.683	-0.453
+16.010	+14.159	+1.851	+0.498
+17.160	+18.243	-1.083	-0.292

SCALE = 1:300000

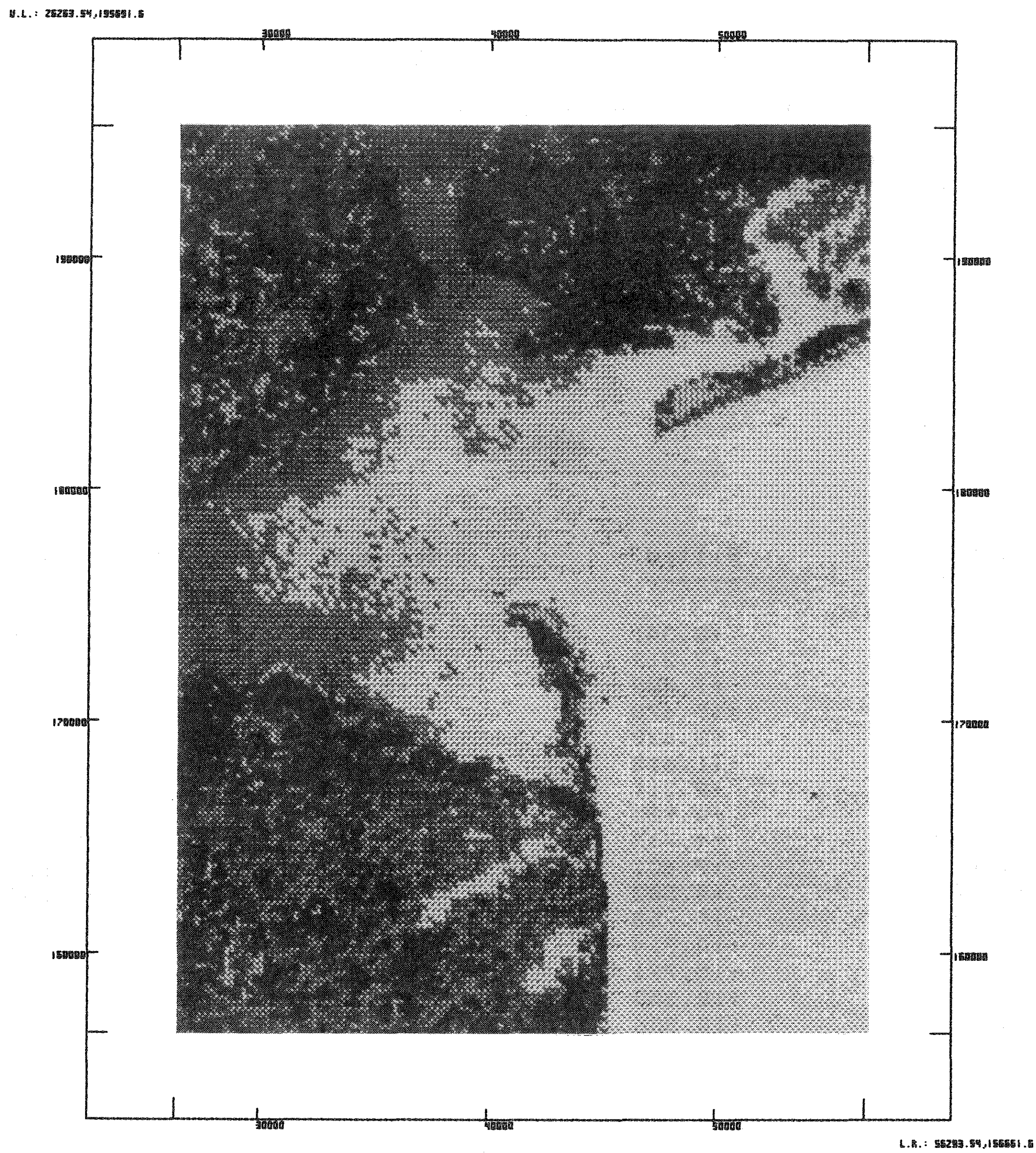

Fig 2. Level sliced map of chlorophyll-a concentration

	estimated chlorophyll-a (ug/l)*
light	0-4.9
	5-10.9
	11-17.9
dark	>18

*Data derived from table 5