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UNITED STATES GOVERNMENT

Memorandum

TO : Superintendent Assateague

DATE: March 8, 1972

FROM : J. Robert Stottlemyer, NPS - EROS Coordinator

SUBJECT: Applications of High-Altitude and Satelite Photography to Coastal Marine Ecological Research

The attached is another report in the series of NPS and EROS documents demonstrating the application of remote sensing to the management and preservation of areas within the National Park System.

Bob Stottlemyer

Enclosure

APPLICATIONS OF HIGH-ALTITUDE AND SATELLITE PHOTOGRAPHY
TO COASTAL MARINE ECOLOGICAL RESEARCH

By

Daniel S. Stetka, Research Assistant
December 1971

Submitted as part of the
Ecological Survey of Cape Lookout National Seashore, N. C.
CALO-2

Paul J. Godfrey, Principal Investigator
Department of Botany
University of Massachusetts
Amherst, Massachusetts 01002

to the

Office of Natural Science Studies
National Park Service
U.S. Department of the Interior
Washington, D.C.

and

Superintendent, Cape Hatteras National Seashore
Manteo, North Carolina

Superintendent, Cape Lookout National Seashore
Beaufort, North Carolina

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Introduction

The coastal zone is one of the nation's most valuable geographic regions. Encroachment by man via pollution, landfill operations and the like has demonstrated the need for improved capabilities to treat the multi-disciplinary problems that will arise in the coming decades. It will be important to rapidly scan extensive areas to provide real-time data on environmental changes, human or natural in origin.

This program was designed to consider the feasibility of monitoring physical and ecological changes in the marine environment with remote sensing techniques, specifically high-altitude and satellite photography. The major research objectives are:

a. Evolution of high- and low-altitude aerial photography as a tool for interpreting ecological and geophysical phenomena in the estuarine region of North Carolina's Outer Banks; judging the usefulness of satellite borne cameras based on the results of high-altitude photography.

b. Preparation of a large scale map of the underwater vegetation and major terrestrial communities on the Cape Hatteras and Cape Lookout National Seashore.

c. Preparation of detailed, small scale maps of selected study areas, with relationships between physical processes and vegetation distribution to be correlated.

d. Determination of the most suitable type of imagery (standard Ektachrome, Ektachrome Infrared Aero, or black and white).

e. Sampling of underwater vegetation using underwater photography and quadrat analyses, the results to be correlated with photo-imagery thereby facilitating objectives a through d.

Ecological Background

The maritime environment of the barrier islands is one of rapid change due to oceanic storms. Few terrestrial or shallow water ecosystems face such powerful natural forces. The physical and ecological aspects of this environment are closely related, with each being highly dependent on the other in determining the overall state of the system.

The barrier island system includes offshore zones, beaches, dunes, grasslands, forests, marshes, and lagoons. The latter two are estuarine resources of great value, both being areas of very high productivity. Physical processes that build and mold the islands also affect the estuary. Due to the interaction of these systems a complete understanding of coastal ecology can be realized only if more is learned about the lagoonal ecosystem.

Preliminary Work

In the spring of 1971 a literature search was conducted to evaluate various remote sensing techniques and develop a plan for the summer field survey. Workers such as Conrad (1967), Anderson (1970) and Lattman and Ray (1965) have established the value of aerial photography for biological research, Conrad and Anderson having worked specifically on the coastal marine environment. Three general areas of study were considered: 1) the monitoring of environmental conditions, 2) the delineation of areas to be studied in the field, and 3) the mapping of underwater communities.

Many plants have a narrow-range of environmental tolerance. Successional changes among bottom organisms are affected by nutrient levels and the quality of bottom sediments, and bottom organisms should therefore be good indicators of water quality. Investigators can monitor the effects of pollution, storms, dredging, disease, etc. on a large scale from aerial photography (Conrad, 1968). It is possible to identify and roughly quantify parameters such as salinity, temperature, and pH as well (Anderson, 1970). Monitoring these temporal changes is of considerable importance since these factors may have a profound influence on the fisheries and recreational use of an area.

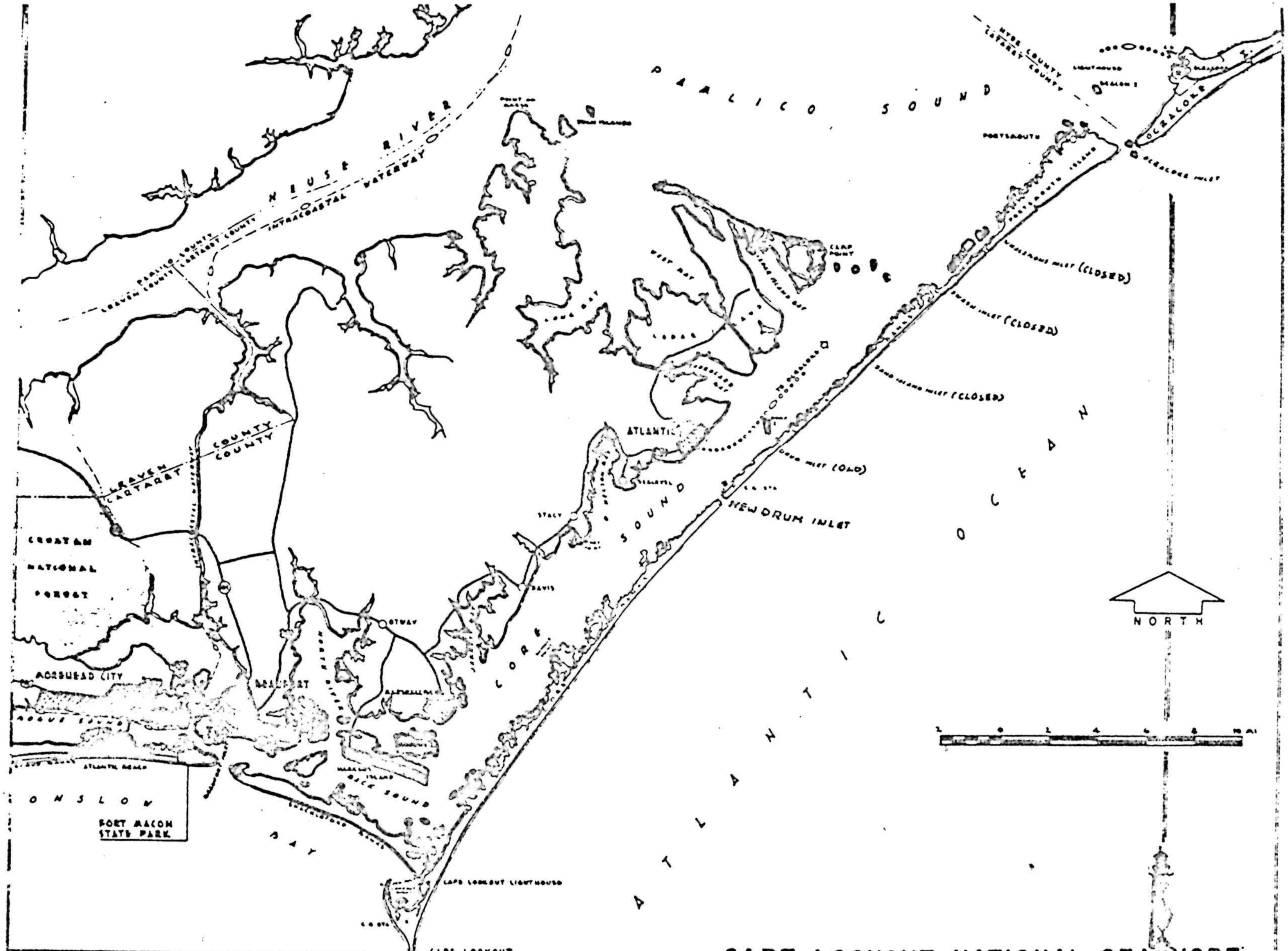
Aerial photography is useful for de-limiting areas to be covered in conventional biological surveys of underwater vegetation. It facilitates the detection of anomalous features that cannot be spotted from the surface due to large scale, unusual occurrence, or low contrast (slight differences in contrast between adjacent areas are hard to detect while diving). Preliminary identification of features and relationships between communities and the environment can be studied by analyzing distribution patterns and geographic variations. Field time may be greatly reduced with aerial photography as it tells the investigators "where to look."

During an investigation of the Bahama Banks, aerial photography was used to locate major communities (Conrad et al., 1968). The organisms present in these communities were then identified by divers, and the zonation, distribution, edges and ecotonal locations between communities were examined. Quadrats were photographed at regular points along transects to examine uniformity and distribution of plant cover in relation to the photography. Areas of current scouring and fish grazing, both of which lack dense plant population development, were also examined after being located using aerial photographs. Large scale distributional features were observed in the photographs but not studied in the field.

It was established by several authors (e.g. Conrad, 1968) that with complementary field work the distributions of communities and changes in plant distributions can be mapped from aerial photographs.

Low-altitude black and white photographs covering Core Banks and Shackleford Banks were initially available from two series, 1963 and 1967. Features such as beaches, marshlands, islands, deeper channels, and tidal creeks were obvious, with their boundaries reasonably well-defined. Other features, including the underwater grasslands, were not so obvious to this investigator at first. Maps were prepared by sketching an overlay (on acetate film) from the photomosaic to delineate tonal differences. This was the the procedure described by Conrad and Short in their report, although they were aided by more precise initial identifications. The communities that comprised the zones on their map were indentified by diving on the underwater areas.

Figure 1. Cape Lookout National Seashore and Vicinity



CAPE LOOKOUT NATIONAL SEASHORE
NORTH CAROLINA

NS-CL-7101 SEPT 1963 (UPDATE 1972)

Site Selection

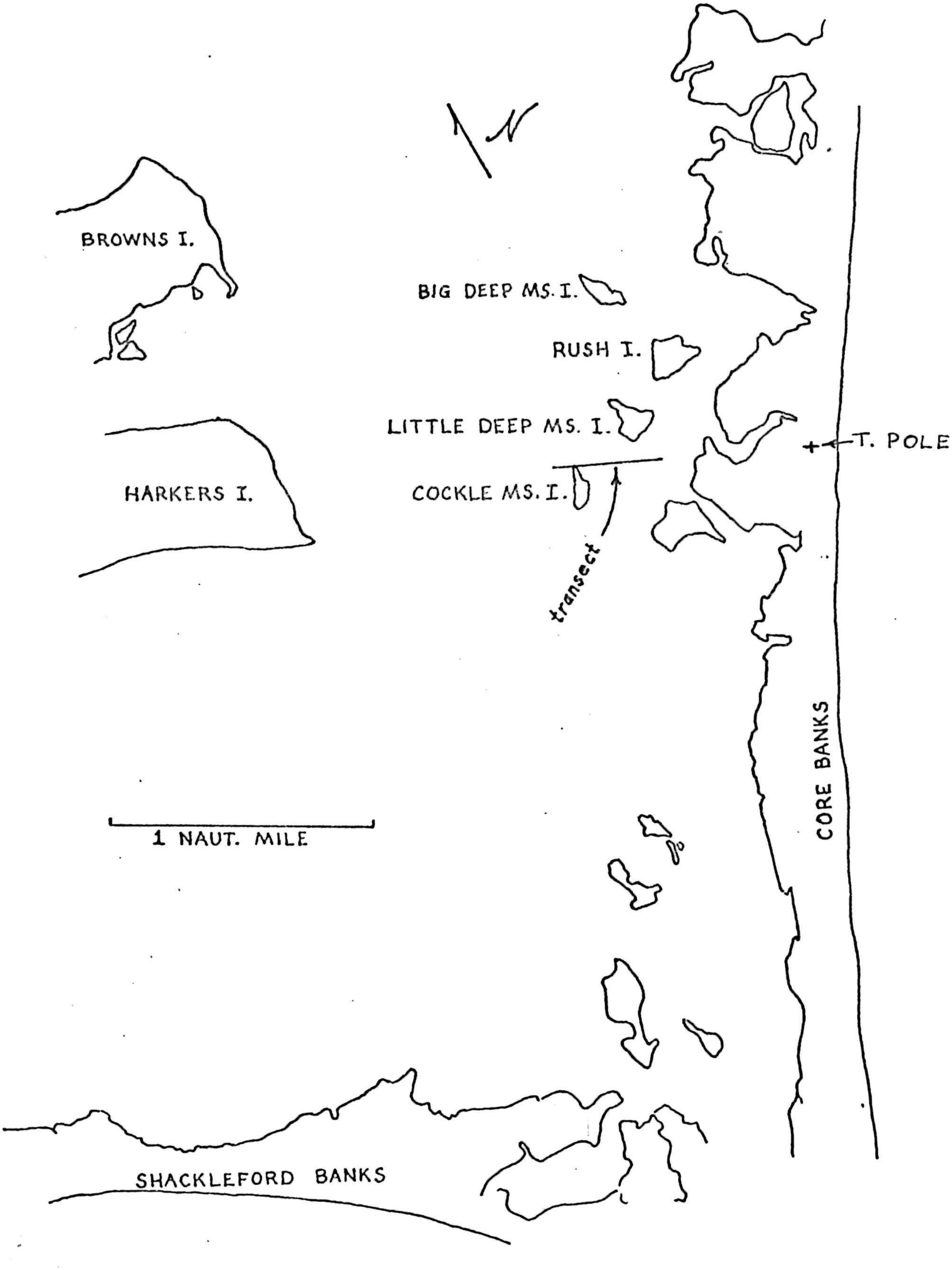
The estuarine region associated with the Cape Lookout National Seashore (Figure 1) is one of the few such regions on the North American coast that has not been dramatically altered by man. With the expressed purpose of maintaining this condition, the National Park Service requires a more complete understanding of estuarine region ecology,as well as a means of monitoring the effects of man's activities in the area. (For a discussion of estuaries and their economic importance see Apendix 1).

Ecological research in the Cape Lookout National Seashore area has been remarkably light, with Core Banks having been virtually bypassed. The marine laboratories in the Beaufort vicinity (Duke Marine Lab, U.S. Bureau of Commercial Fiseries, and Univ. of N.C. Marine Lab) have conducted numerous projects in the estuarine areas, yet little work has been done in the areas behind Core Banks. Williams (1968) of the B.C.F. Lab ran several productivity studies of the Core Sound estuarine region. Godfrey (1970) described the terrestrial ecosystems and environmental factors, primarily overwash, that affect these systems on Core Banks. The underwater region to be surveyed was selected to tie in with some of his terrestrial work.

Field Work

The transect line was laid out by sighting along the northern tip of Cockle Marsh Island to a clearly marked telephone pole on Core Banks (Figure 2). Cockle Marsh Island lies almost due east of Harker's Island.

Figure 2. Cockle Marsh Island Transect Location



BROWNS I.
D
BIG DEEP MS. I.
RUSH I.
LITTLE DEEP MS. I.
T. POLE
COCKLE MS. I.
HARKERS I.
transect
CORE BANKS
1 NAUT. MILE
SHACKLEFORD BANKS

Starting 200 meters west of Cockle Marsh, markers were driven in at 100 meter intervals over a total distance of 800 meters.

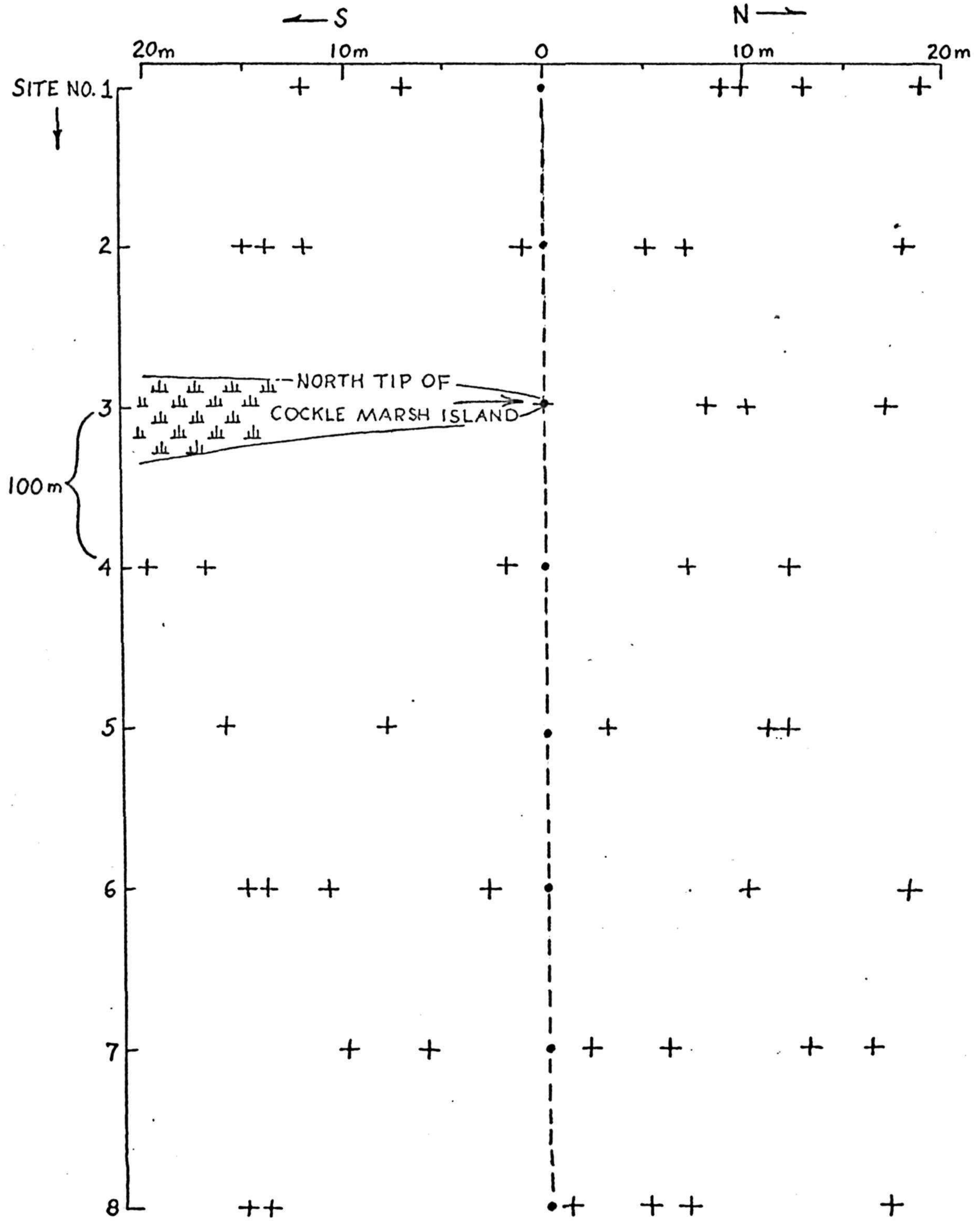
A square metal quadrat, one-half meter on a side, was used for sampling the underwater vegetation. Sites to be sampled were chosen at random with the restriction that they lie along lines perpendicular to the transect at each marker and fall within 20 meters of the markers in either direction (Figure 3).

The quadrat was placed at the chosen sites and living benthic vegetation falling within each 1/4 m^2 area was snipped off at the base and put in a labelled bag. Upon return to shore the day's samples were examined to determine composition and average length. The material from each site was then dried and weighed.

Underwater photographs were taken to evaluate this technique for use in underwater surveys. Photographs of each type of grassbed encountered are included here (Figure 4) and will be referred to later in this report. The quality is poor due to turbidity, lack of a light meter, and poor processing, but, when refined, the technique should prove to be a quick and reliable means of conducting underwater surveys.

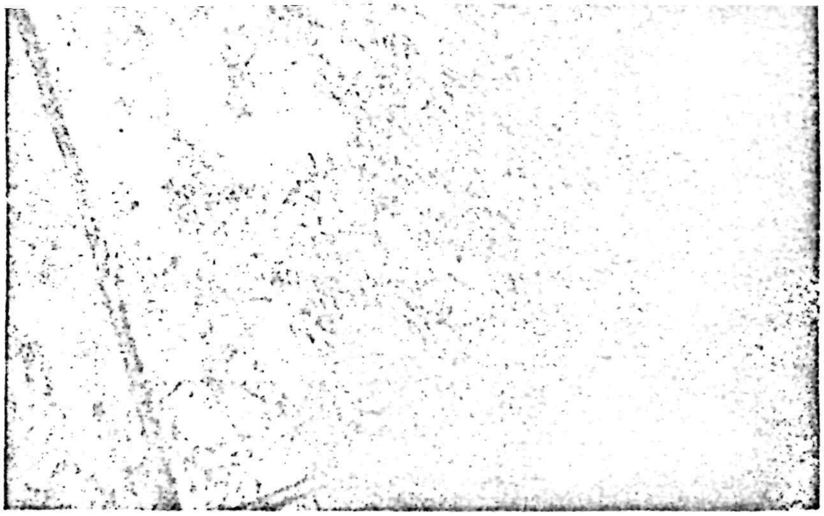
Since in a given region the benthic communities present depend largely on bottom type, whether sand, rock, or mud, bottom samples were taken in the vicinity of each marker in an attempt to correlate mud content with vegetation density. Shifting sand does not provide a stable substrate, yet it may still be fairly well populated by burrowing animals, bacteria and algae. Another group occurs on mud bottoms. Mixed mud and sand is thought to be more favorable than

Figure 3. Sites Sampled During Field Survey



← S
N →
20m
10m
0
10m
20m
SITE NO. 1
2
3
4
5
6
7
8
100m
NORTH TIP OF
COCKLE MARSH ISLAND

Figure 4. Underwater photographs of various areas along the transect.

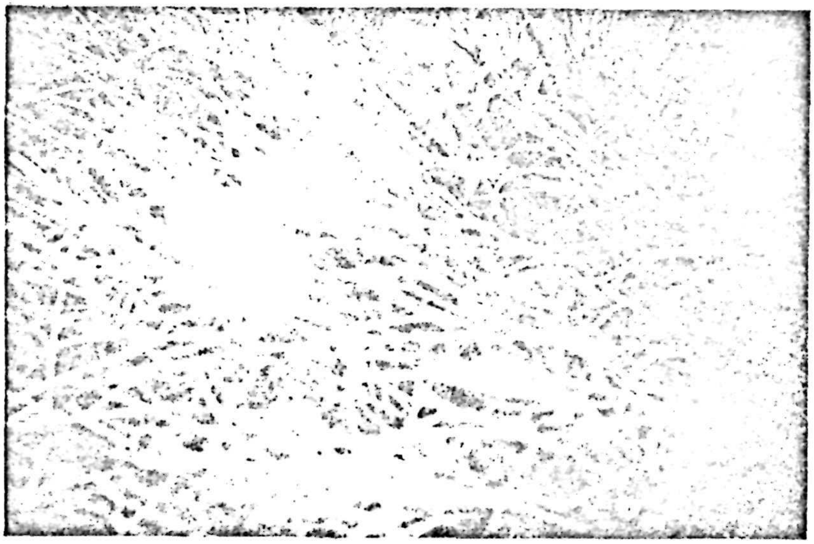


PATCHY BED AT MARKER NO. 1 (NO. 2 SIMILAR)

GRAZED EELGRASS AT MARKER NO. 3

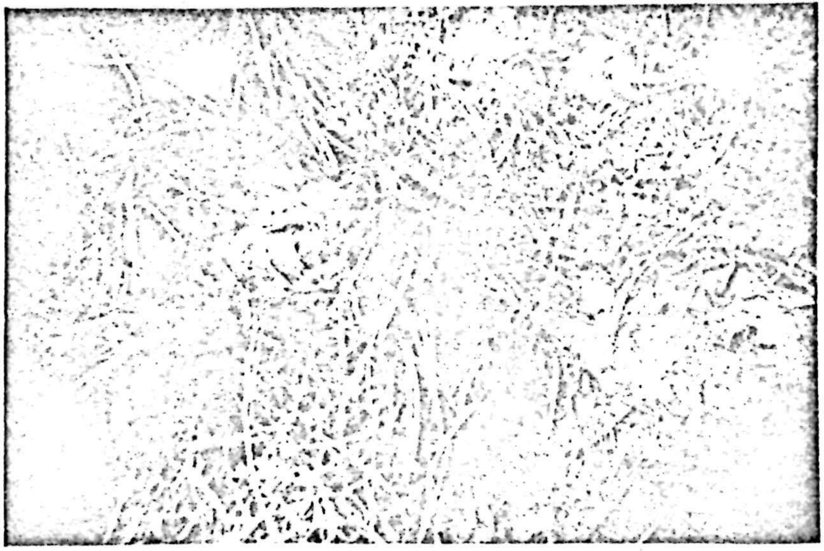
BARNACLE COLONIZATION OF MARKER NO. 4

DENSE MIXED BED AT MARKER NO. 4



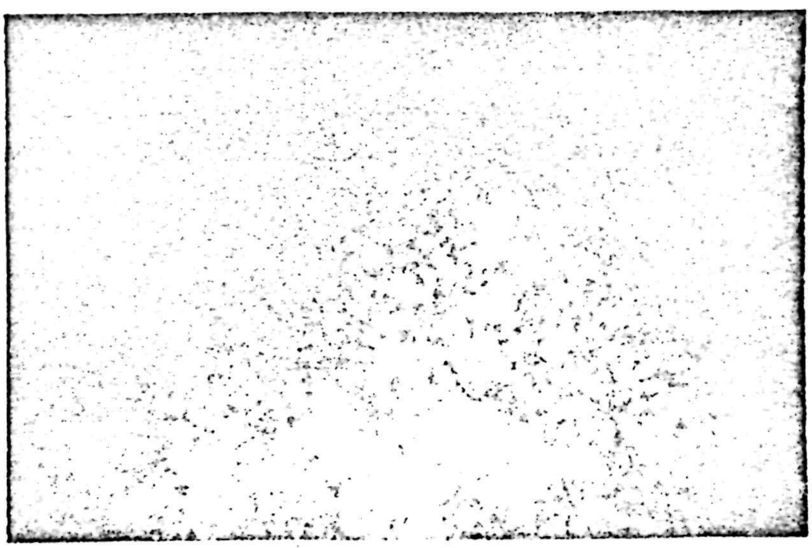
DENSE EELGRASS AT MARKER NO. 5

DENSE EELGRASS AT MARKER NO. 5

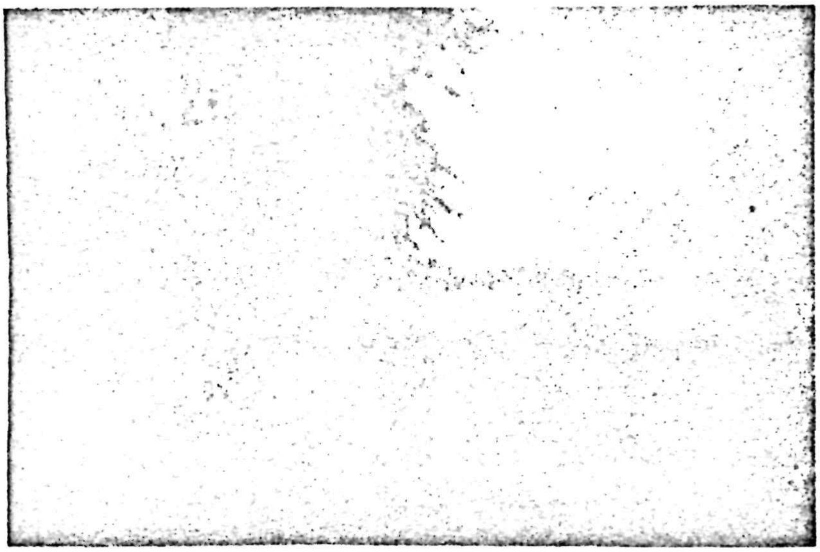


EELGRASS AT MARKER NO. 6

SPARSE MIXTURE AT MARKER NO. 7



CLIPPED QUADRAT OF DENSE RUPPIA
AT MARKER NO. 8



ALGAL COLONIZATION OF MARKER
NO. 8

either alone, showing increased population density. Transition zones often support communities with characteristics additional to those of communities which adjoin the ecotone (Odum, '59). Some niches are likely to be found in the overlap which are not present in either community alone.

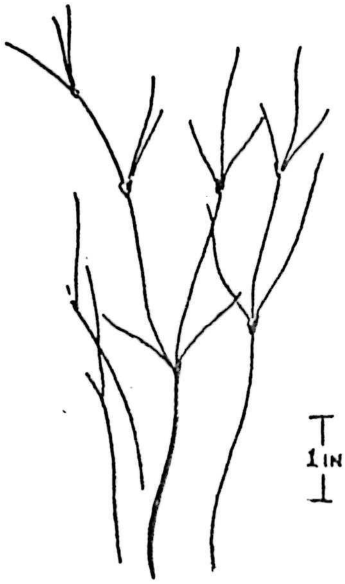
The samples were taken using a screw-top can with the bottom cut off. The open end was inserted to a depth of 5 inches with the top removed. After screwing on the top the can was withdrawn and the core then placed in jars for future interpretation.

Due to time limitations no attempt was made to count or collect animals. The abundance of fish, starfish, scallops, crabs, and periwinkles in the grassbeds was noted, however, as was their virtual absence in bare areas. The grassbeds are obviously highly productive and I hope to study the plant-animal associations in the future.

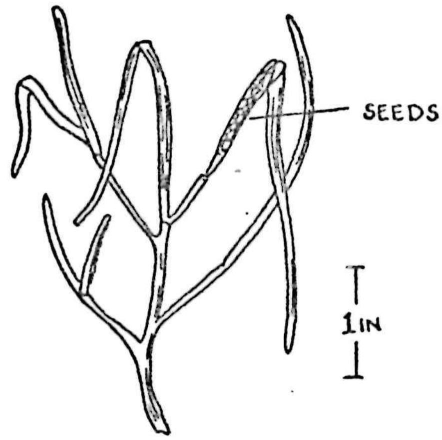
Data Presentation

The grassbeds were essentially of three types 1) *Zostera marina* (eelgrass), 2) *Ruppia marina* (widgeon grass), and 3) mixtures of the two. There were many benthic algal species present, but due to the lack of solid substrates none were found in abundance. A remarkably rapid colonization of several markers by the red alga *Agardhiella sp.* was noted, however. The growth shown in Figure 4(8) occurred within 5 weeks. Figure 5 illustrates the growth habits of the three dominant plants.

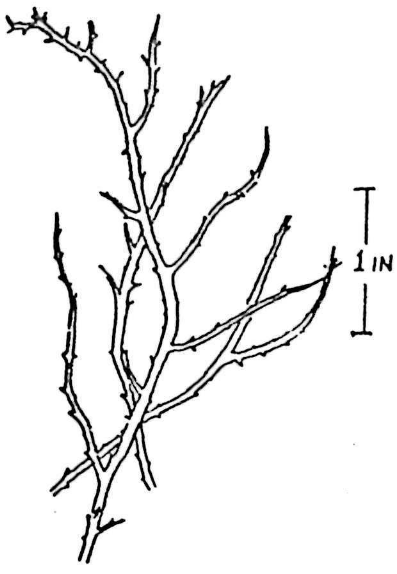
Figure 5. Growth habits of the three dominant underwater plants of the Cockle Marsh region.



WIDGEON GRASS
RUPPIA MARINA



EEL GRASS
ZOSTERA MARINA



AGARDHIELLA SP.

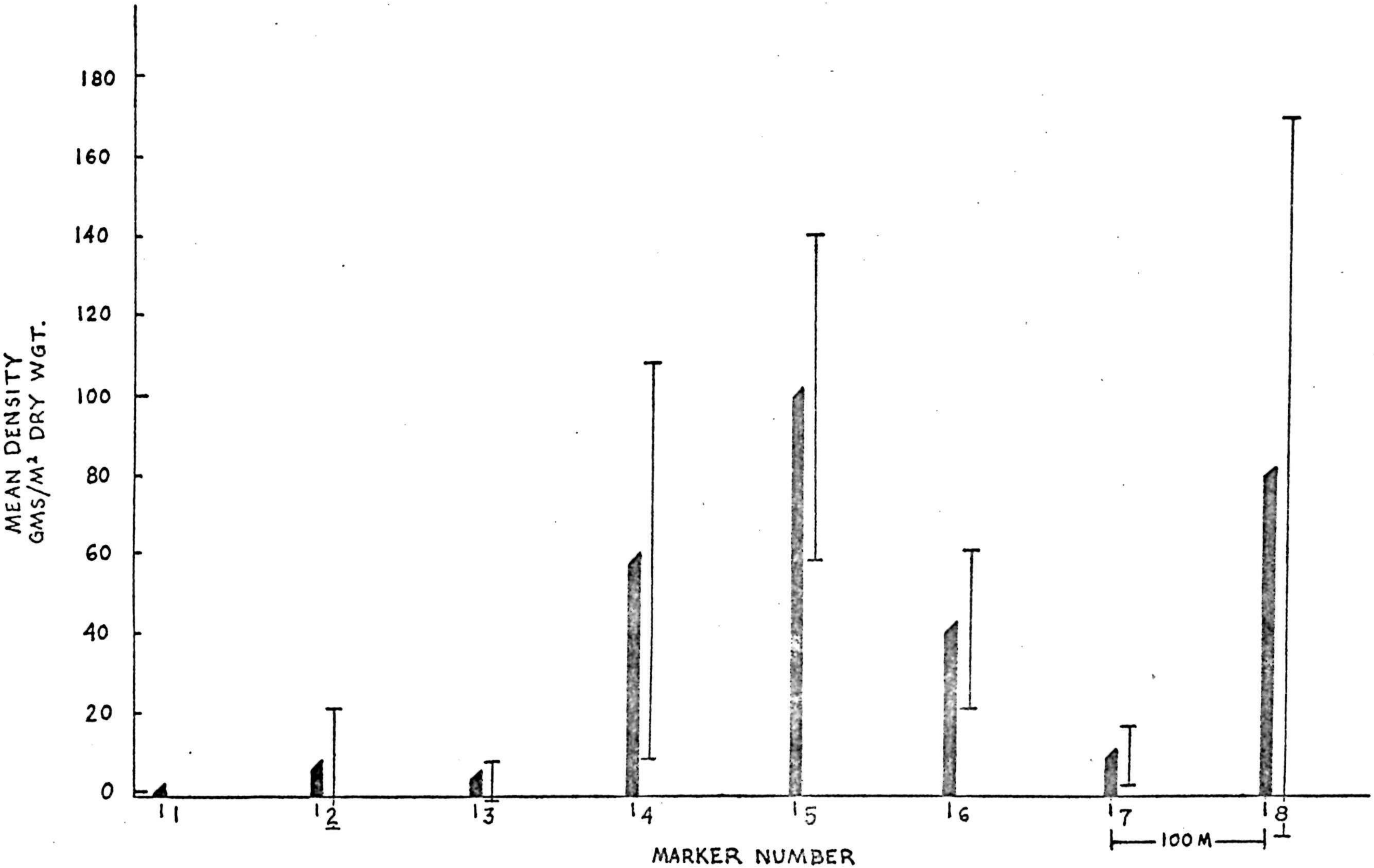
Table 1 presents the dry weights of vegetation from each site, the mean values for each, and standard deviations. Figure 6 shows the variation in mean density along the transect, the error bars representing one standard deviation. This conventional statistical analysis is included here because the sites were selected at random; each potential site on each 40 meter perpendicular had an equal probability of being selected. However, the mean density values and standard deviations are perhaps less important for our purposes then the identification and specific productivities of particular areas visible in aerial photographs. Table 2 lists parameters of several such areas including the healthy eel grass beds near Cockle Marsh, healthy Ruppia beds to the east along the transect, patchy peripheral areas, and grazed areas. More information of this type would enable researchers to estimate productivities of extensive regions using maps prepared from aerial photographs.

As discussed in the previous section, bottom samples were taken at each marker and were then evaluated by a relative, non-mechanical technique. The samples were put in jars and shaken to "homogenize" the mixture. That the mud content varied along the transect was obvious. The most "sandy" (almost pure sand) sample was given an arbitrary rating of 1, the most "muddy" (almost pure mud) a 5. Two individuals then independently assigned "bottom ratings" (BR) of mud, or organic, content to the remaining samples based on this arbitrary rating system.
Table 3 presents the results of this preliminary analysis. The significance of /BR - 3/ is derived from the discussion of mixed mud

Table 1. Dry weights of vegetation from each site and statistical analysis.

SITE NO.	$\rho\left(\frac{GMS}{MI}\right)$	$\bar{\rho}$	$\lvert\rho-\bar{\rho}\rvert^2$	STD. DEV. (σ)
1.19N	0	0.16	.026	0.4
1.13N	0		.026	
1.10N	.96		.640	
1.9N	0		.026	
1.7S	0		.026	
1.12S	0		.026	
2.18N	0	6.52	42.60	15.7
2.7N	0		42.60	
2.5N	0		42.60	
2.1S	0		42.60	
2.12S	.84		32.40	
2.14S	0		42.60	
2.15S	44.88		1475.00	
3.17N	1.52	3.04	2.32	3.9
3.10N	.92		4.51	
3.8N	9.72		44.80	
3.0	0		9.27	
4.12N	108.04	58.20	2499.0	49.3
4.7N	109.80		2670.0	
4.2S	72.68		211.0	
4.17S	0		3400.0	
4.20S	0		3400.0	
5.12N	72.16	99.65	753.0	41.7
5.11N	75.44		587.0	
5.3N	54.24		2070.0	
5.8S	131.32		1005.0	
5.16S	165.08		4290.0	
6.18N	5.64	41.20	1265.0	19.7
6.10N	56.32		229.0	
6.3S	63.76		510.0	
6.11S	55.08		193.0	
6.14S	33.44		60.4	
6.15S	32.40		77.7	
7.16N	1.88	8.08	38.6	7.6
7.13N	0		65.7	
7.6N	0		65.7	
7.2N	13.16		25.9	
7.10S	17.24		84.0	
7.6S	16.16		65.7	
8.17N	205.64	80.00	15,800.00	91.2
8.7N	0		6400.0	
8.5N	70.92		82.7	
8.1N	202.68		15,100.0	
8.14S	0		6400.0	
8.15S	0		6400.0	
3.12N	108.04	108.92	.64	.84
3.7N	109.80		.78	
3.2S	72.68	24.25	2350.0	34.2
3.17S	0		590.0	
3.20S	0		590.0	

Figure 6. Variation in mean density of dry weights along the transect.



MEAN DENSITY
GMS/M² DRY WGT.
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
100 M
MARKER NUMBER

Table 2. Parameters of several different underwater grassbed types encountered during the survey.

BED TYPE †	EXPECTED DENSITY RANGE (GMS/M² DRY WGT)	HEIGHT OF VEGETATION (IN.)
ZOSTERA GRAZED	0-10	0-3
ZOSTERA TALL, HEALTHY	70-130	8
ZOSTERA MEDIUM, HEALTHY	30-65	3-5
3/4 ZOSTERA-1/4 RUPPIA, TALL, HEALTHY	160-165	8
3/4 ZOSTERA-1/4 RUPPIA, MEDIUM, HEALTHY	40-60	3-5
1/2 ZOSTERA-1/2 RUPPIA, TALL, HEALTHY	100-110	8
RUPPIA TALL, HEALTHY	200-206	8-10

† ESTIMATES OF SPECIES COMPOSITION APPROXIMATE

Table 3. Average depth, vegetation density, bottom rating and deviation of bottom rating from the norm for each marker along the transect.

MARKER	AVG. DEPTH	$\bar{\rho}$ (GM/M^2)	$\overline{BR}$	$\lvert \overline{BR} - 3 \rvert$
1	1.25 M	.16	1	2
2	1.35	6.52	1	2
3	.85	3.04	4.5	1.5
4	.65	24.25$^+$	5	2
5	.70	99.65	4	1
6	1.25	41.20	2.5	.5
7	1.25	8.08	1	2
8	1.00	80.00	2	1

+ DENSITY OF SOUTHERN SITES AT MARKER NO. 4

and sand communities presented earlier. "3" is the median value on the arbitrary 1 - 5 scale, indicating a mud and sand mixture. Deviations from this value indicate a trend towards an all sand or all mud bottom type.

At this point it is necessary to explain the distinction made between the "north" and "south" sites of marker 4. As illustrated in Figure 7, productivity increases dramatically to the north along the perpendicular and falls off rapidly to zero to the south. As clearly illustrated in Figure 3, the southern segment of perpendicular no. 4 is behind Cockle Marsh Island while the northern half is not so protected. Because of this situation the southern bottom has a much higher mud content, probably due to marsh deposits. Swimming along the line in a southerly direction the transition from mud-sand to almost pure mud was apparent. The bottom sample from no. 4 was taken from a position south of the marker and thus should be associated not with the mean density of all the no. 4 sites but rather with those to the south of the marker. This was the only perpendicular where such a dramatic change in bottom type existed, hence the distinction between north and south here.

With this distinction having been made, the mean density for each marker was plotted against /BR - 3/, the deviation from a mixed bottom type. Deviations from the mixed bottom type, in either direction, seem to be correlated with decreased productivity. Those markers with mean densities of underwater vegetation less than the mean for all sites <u>all</u> deviated from rating 3 by 1.5 or more. Those with means greater than the average were all rated within 1 unit of the median, 3.

Figure 7. Productivity variation along the perpendicular at marker No. 4.

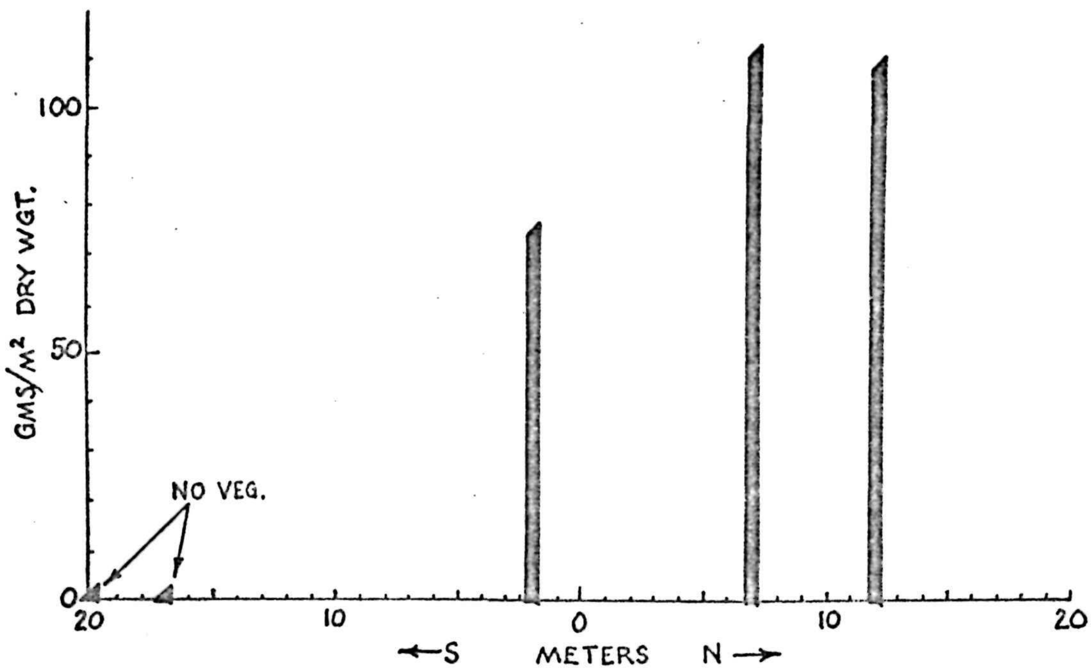
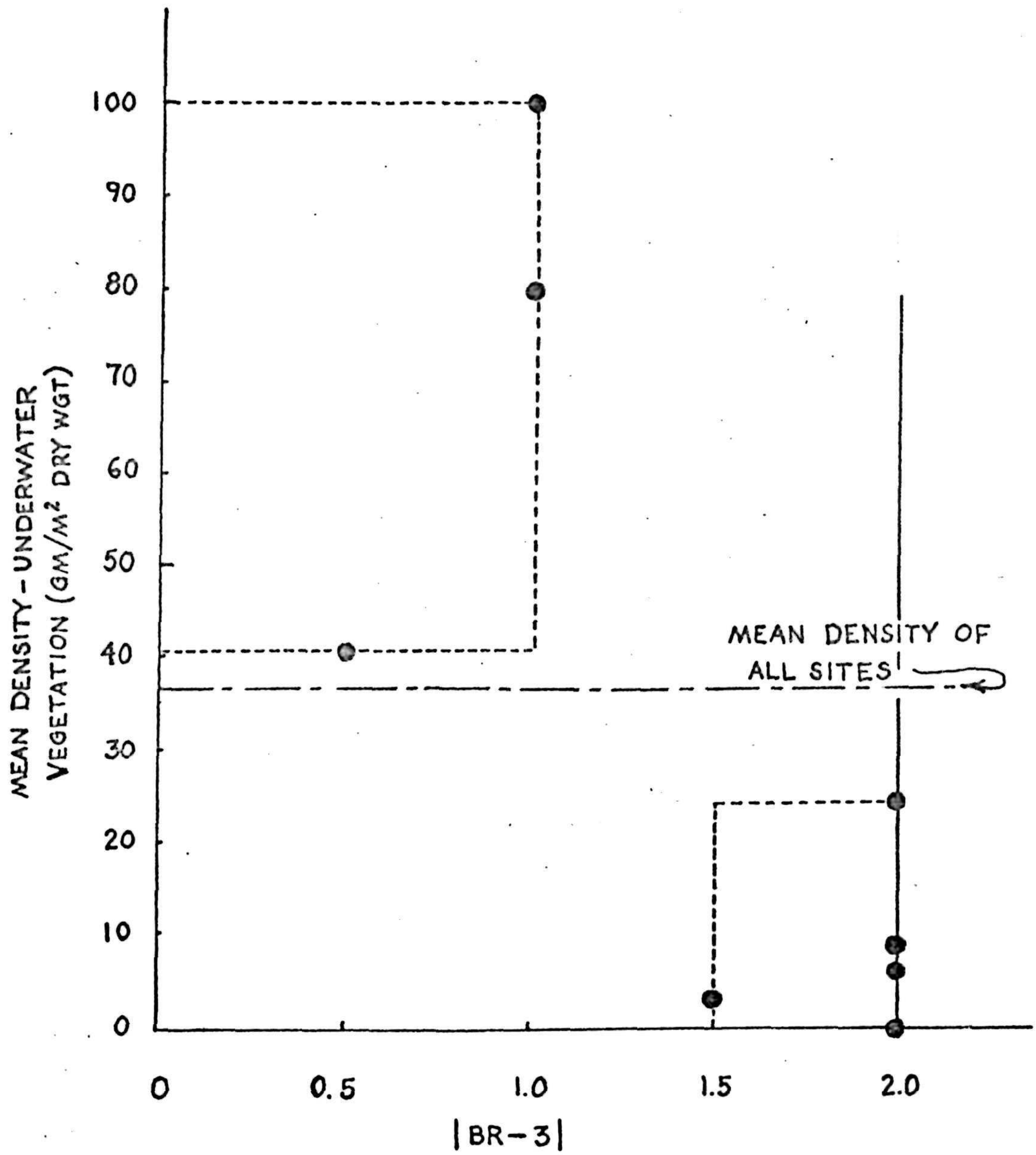

GMS/M² DRY WGT.
100
50
0
NO VEG.
20
10
0
10
20
←S
METERS
N →

Figure 8. Mean density of underwater vegetation plotted against bottom rating deviation from the norm of rating "3".


MEAN DENSITY - UNDERWATER VEGETATION (GM/M² DRY WGT)
100
90
80
70
60
50
40
30
20
10
0
MEAN DENSITY OF ALL SITES
0
0.5
1.0
1.5
2.0
|BR-3|

Proximity to the marsh island seems to have affected mud content as already discussed. Because estimates of depth can be made from aerial photographs it would be valuable to compile data on the effect of depth on mud content as well. With this in mind the bottom ratings were plotted against the depth at each marker during a spring high tide which covered Cockle Marsh Island (see Figure 9). Figure 10 shows an apparent decrease in mud content with depth. Physical analyses will be made of bottom sediments in future studies. More work along these lines could provide photo-interpretors with another valuable tool for use in interpreting estuarine conditions.

Photo-interpretation

Black and white low-altitude photographs of the Cockle Marsh survey region were available from 1958, 1963, 1967, and 1968. Maps were prepared by sketching an overlay on acetate film delineating marsh, underwater grassbeds, shallow (grey-white) areas, medium (grey) areas, and a peculiar dark area when present. This will be discussed further on. These maps were then transferred to paper by tracing on a light table. A series of high-altitude (60,000') color infrared transparencies from 1970 were also available. The large scale distributional features were clearly visible without magnification but grassbeds visible in the low-altitude shots were not. The IR transparency was then projected onto a screen. The result was a remarkably clear image with Cockle Marsh Island, its small interior pond, the underwater grassbeds, and the deep vs. shallow regions around the island clearly visible. Paper was taped

Figure 9. Looking south along Cockle Marsh Island at high tide.

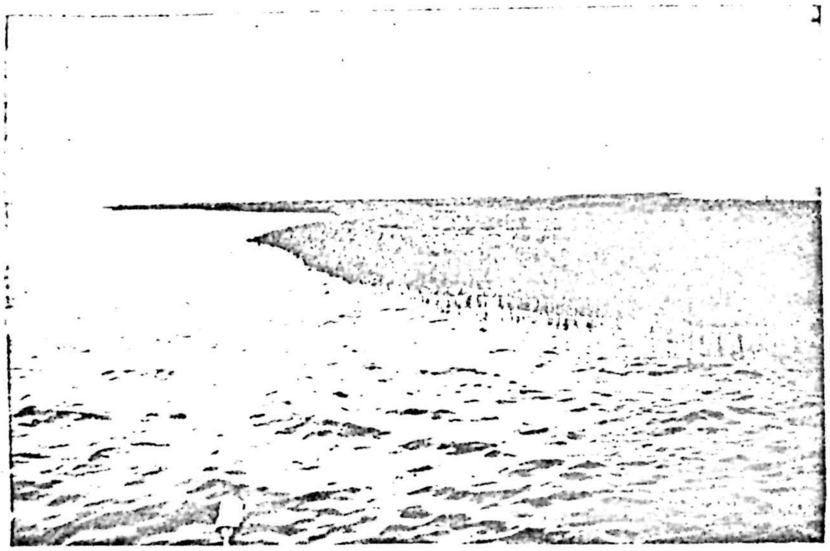
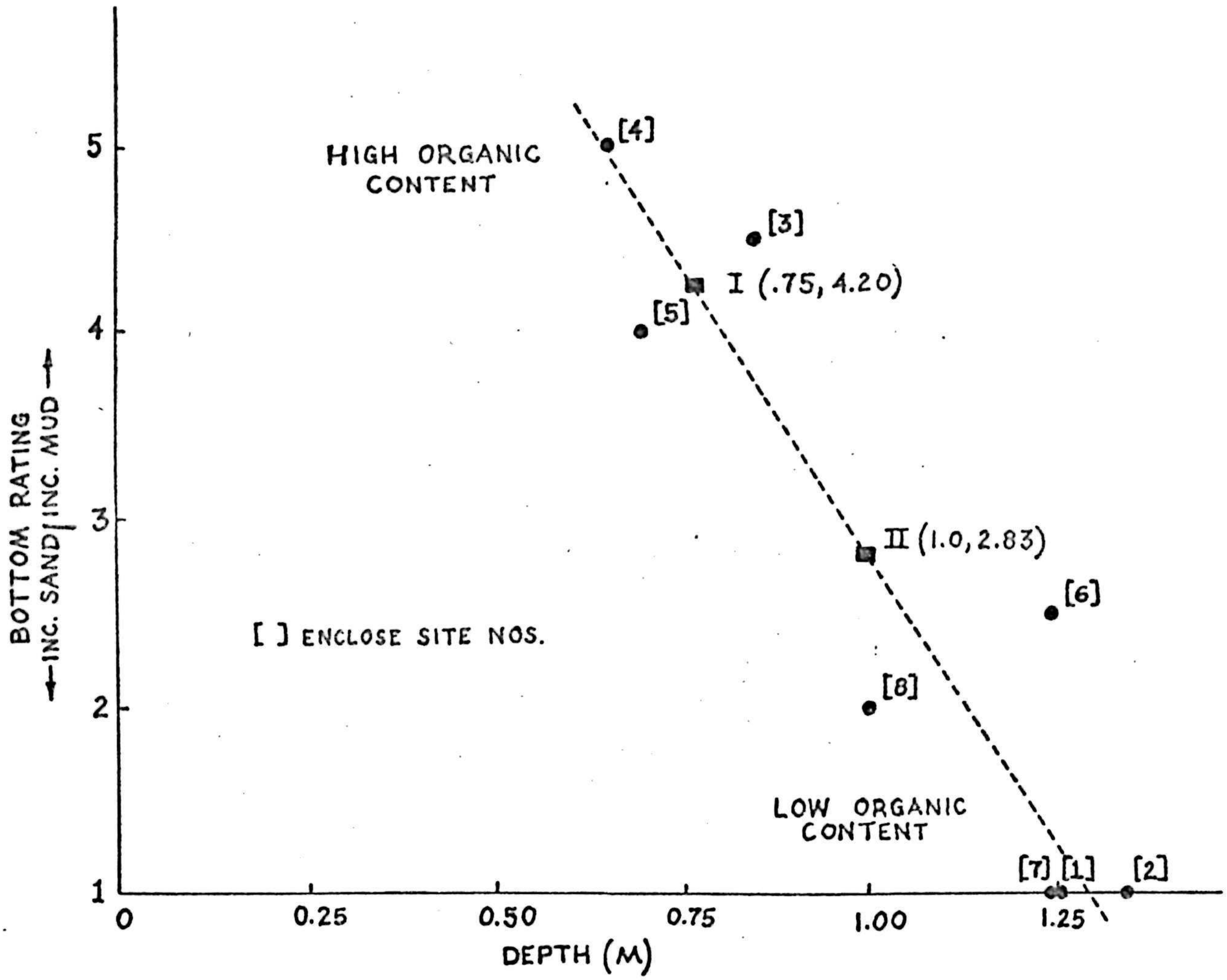


Figure 10. Bottom rating of mud content plotted against depth at the various markers.

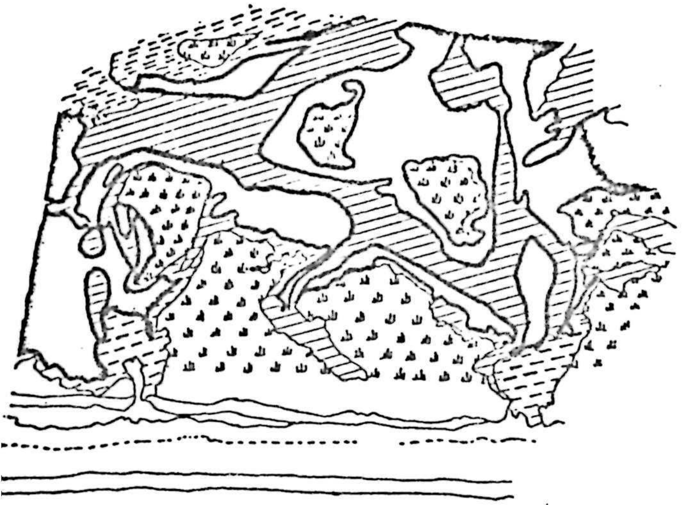


PTS. I AND II RESULTS OF BR = 8.32 − 5.50·(DEPTH), FOUND BY MINIMIZING Σd^2 FROM LINEAR FORM Y=AX+B to a wall, the image projected on it to a scale approximately equal to that of the low-altitude photographs, and the various features were mapped. (The interpretation of different colors and shades will be discussed in the last section). This map, along with the four from low-altitude photographs, is included in this report (Figures 11 - 15).

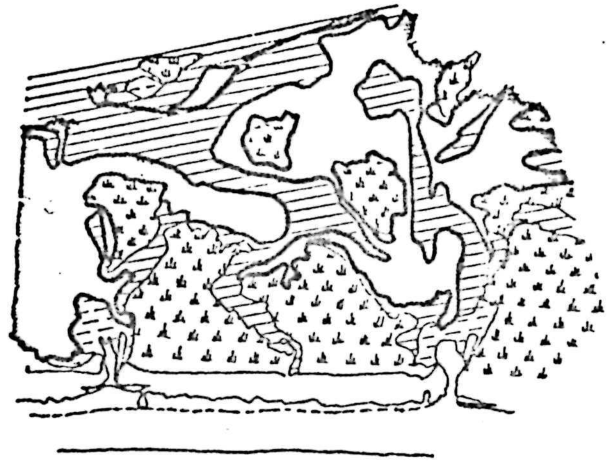
A line was drawn on copies of these maps to represent the transect surveyed. Following this line from the tip of Cockle Marsh towards Core Banks it was found to intersect five distinct regions: grassbeds, patchy grassbeds, no vegetation (light shade), and no vegetation (dark shade) before reaching the marsh lands behind Core Banks. The distributions along the lines were measured (one-dimensional) and plotted. Corrected to the same scale the results are shown in Figure 16. The agreement is remarkable, especially in the high-altitude case, illustrating the usefulness and potential of high-altitude photography.

Figures 11 - 16 illustrate an unusual sequence of events. In 1963 a dark cup-shaped area appears to the east of Cockle Marsh Island that was not present in 1958 photographs. It does not have the same tone or texture as the underwater grassbeds, nor do scattered, patchy areas appear anywhere on its periphery. In the 1967 photograph this area has clearly been colonized and the grass is continuous with a bed to the north which surrounds a nearby island. The shallow area south of Cockle Marsh, visible in the 1958 and 1963 photographs, has also

Figures 11-15. Underwater Vegetation Maps Prepared from Aerial Photographs

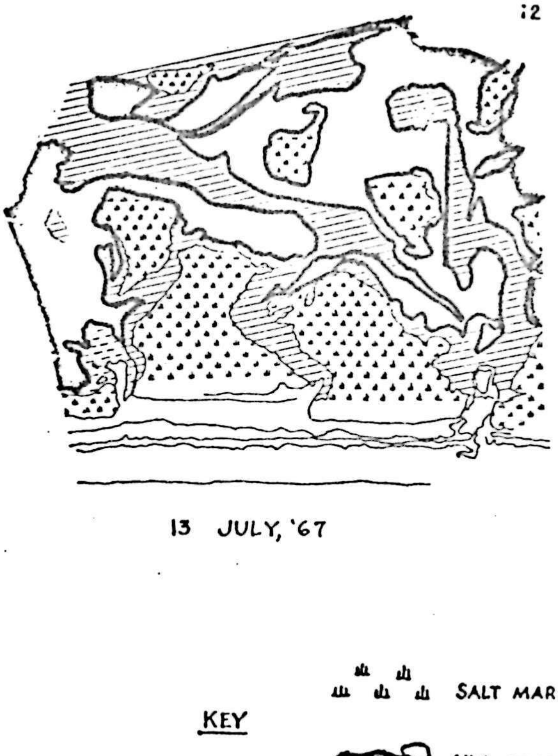


11 NOV., '58



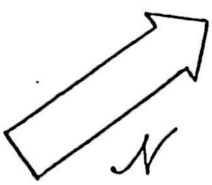
12 AUG., '63

14 OCT., '68



13 JULY, '67

15 SEPT., '70



KEY

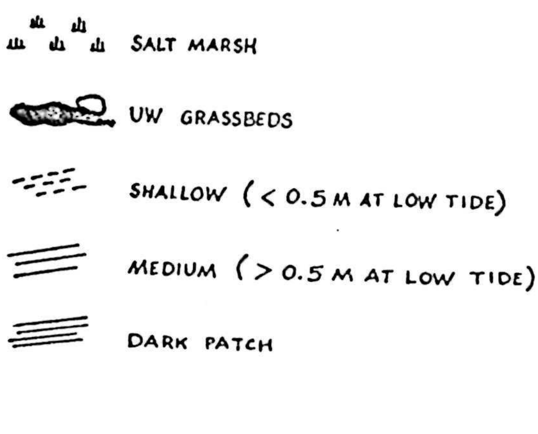
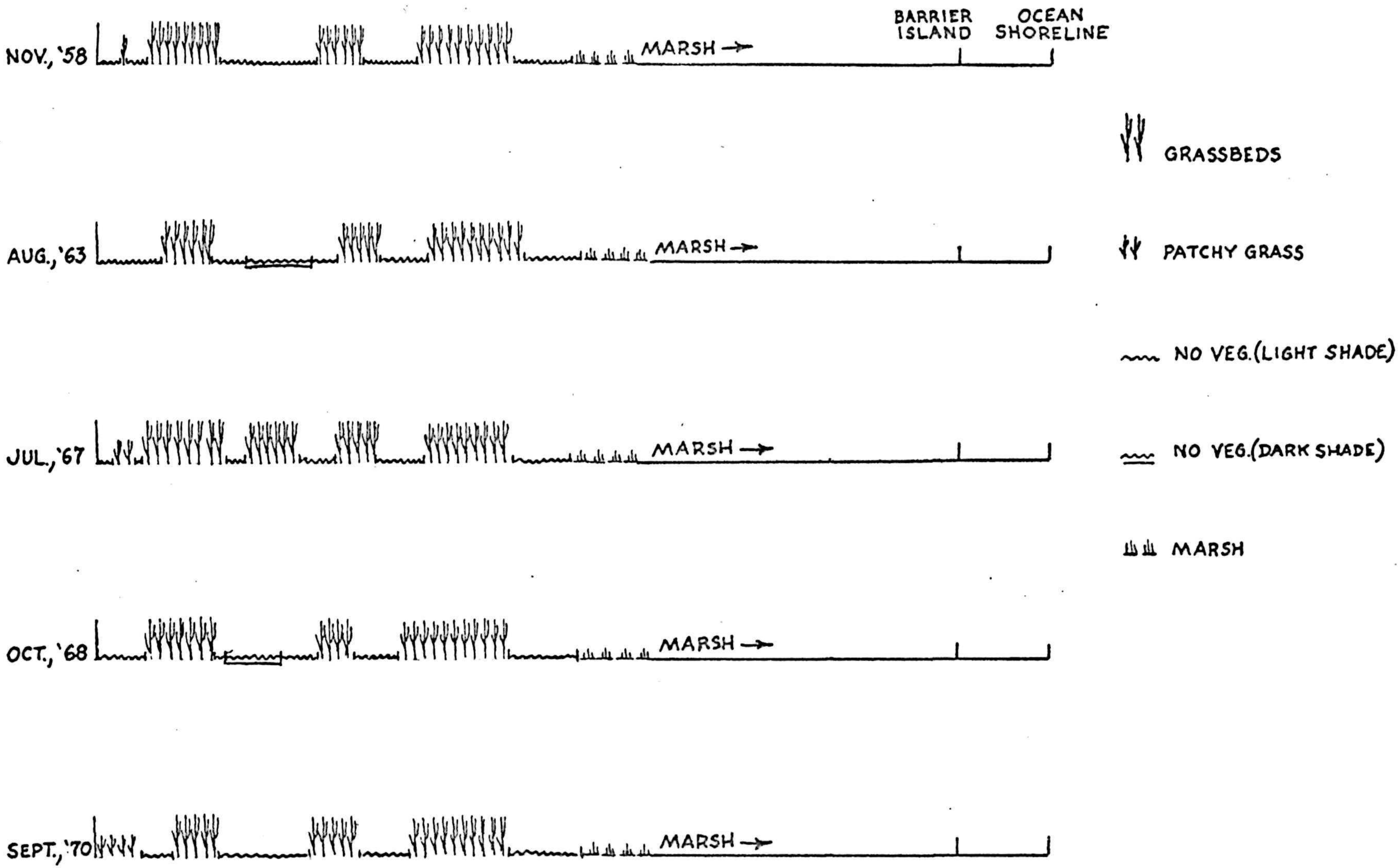


Figure 16. Distribution of vegetation and other features along the transect as determined from aerial photographs.

DISTRIBUTION OF UNDERWATER VEGETATION
ALONG TRANSECT AS DETERMINED
FROM AERIAL PHOTOS



been colonized. In 1968 the grass appears to have vanished from the "cup" and the beds appear to be shrinking or retreating from their boundaries of 1967. The cup has the same general appearance in the 1968 photograph as in the 1963 one. The area is not visible in the 1970 series, just as in 1958. The transect method of Figure 16 illustrates the same phenomenon.

To determine if any pattern could be established a standard area around Cockle Marsh Island was defined according to the procedure illustrated in Figure 17. A line was drawn perpendicular to the transect and just touching the western side of the island. A perpendicular to this line was then drawn so as to just touch the southern tip, this line being parallel to the transect. The distance between this second line and the transect is, of course, the length of Cockle Marsh (1_{cm}). With 2 1_{cm} as the side length and the right angle previously determined, a standard square area is defined, irregardless of scale differences. A planimeter was used to determine what per cent of the total area was covered by marsh and underwater grassbeds. The figures are listed in Table 4 and illustrated graphically in Figure 18.

The marsh appears to be receding as was expected due to the erosion observed on the western edge of Cockle Marsh. The grassbeds show no definite trend but a fluctuation that cannot presently be explained. The numbers available may indicate a cyclic pattern, but more information is needed to fill in the gaps. Not only is there no explanation for this type of phenomenon in the literature, but there is no indication that it has been observed before. As has been

Figure 17. Graphical procedure used to determine a "standard" area around Cockle Marsh Island.

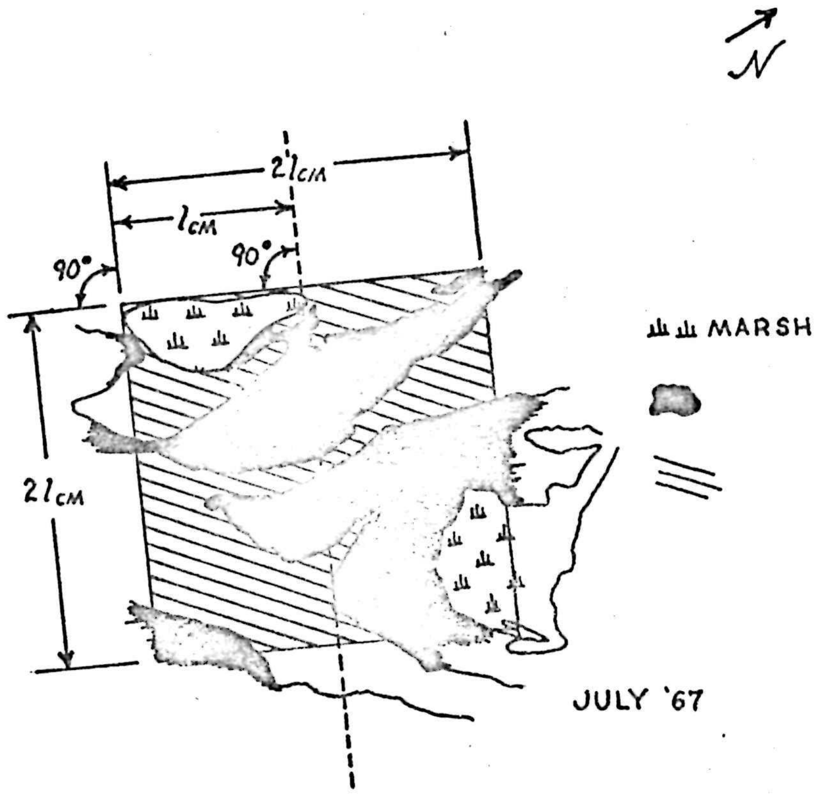
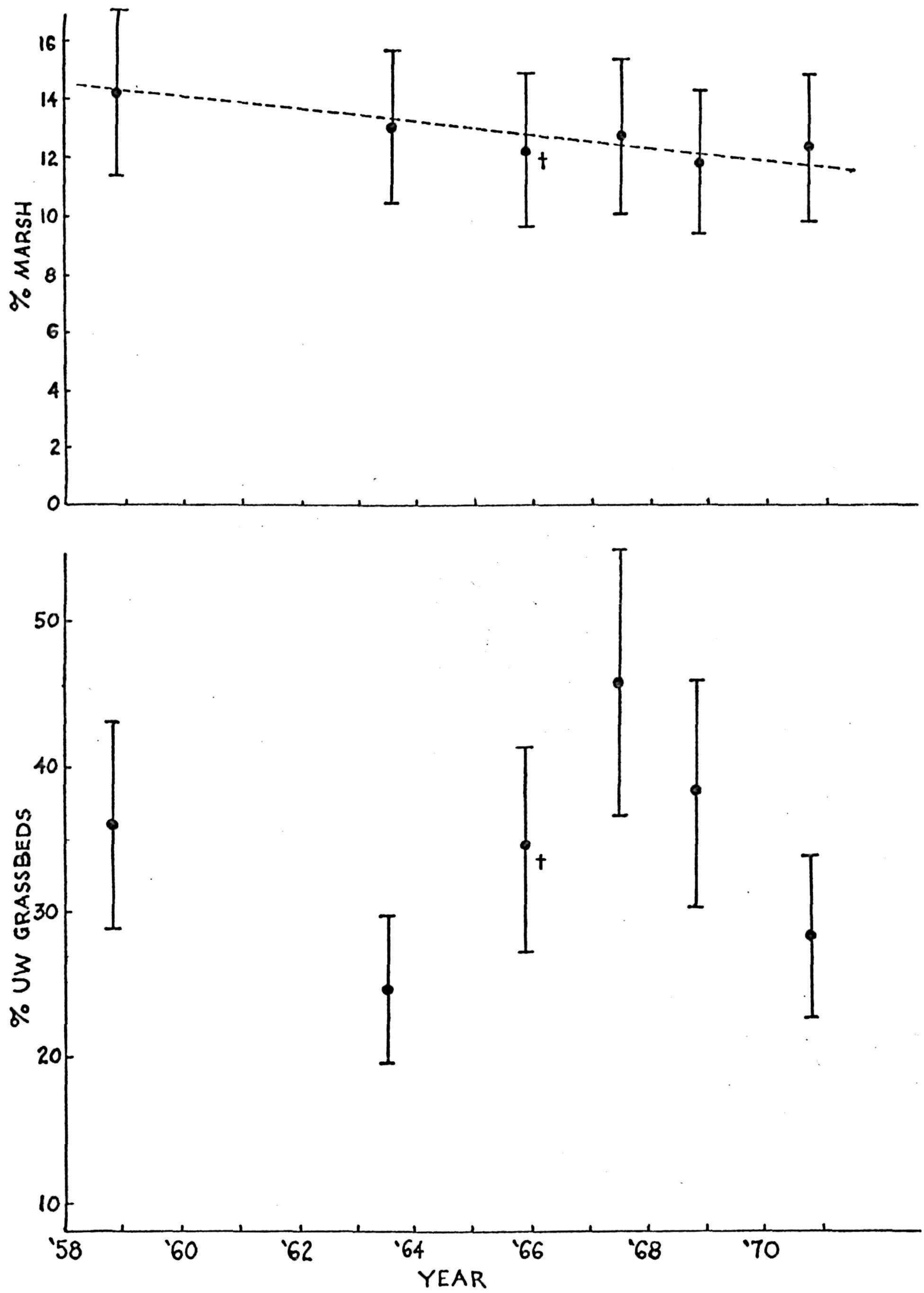

N
21cm
1cm
90°
90°
21cm
MARSH
JULY '67

Table 4. The percentages of the standard areas around Cockle Marsh occupied by marsh and underwater grassbeds. Also measured was the "dark patch" area east of the island when it appeared. (Measurements made using a polar planimeter.)

DATE	% MARSH	% UW GRASSBED	% PATCH
NOV., '58	14.1 ± 2.8	35.9 ± 7.2	—
AUG., '63	13.0 ± 2.6	24.7 ± 5.0	9.3 ± 1.9
JULY, '67	12.7 ± 2.6	45.7 ± 9.2	—
OCT., '68	11.8 ± 2.4	38.2 ± 7.7	6.0 ± 1.2
SEPT., '70	12.3 ± 2.5	28.2 ± 5.7	—

ESTIMATED ERRORS OF ± 5% IN PLANIMETER VALUES AND IN TRACING PROCESS RESULTS IN APPROX. ± 10% ERROR ASSOCIATED WITH EACH VALUE, THUS ESTABLISHING AN APPROX. POSSIBLE ERROR OF ± 20% IN THE RATIOS (% COVER VALUES).

Figure 18. Graphical presentation of the data in Table 4.


% MARSH
16
14
12
10
8
6
4
2
0
†
% UW GRASSBEDS
50
40
30
20
10
'58
'60
'62
'64
'66
'68
'70
YEAR

† SEE PAGE 58

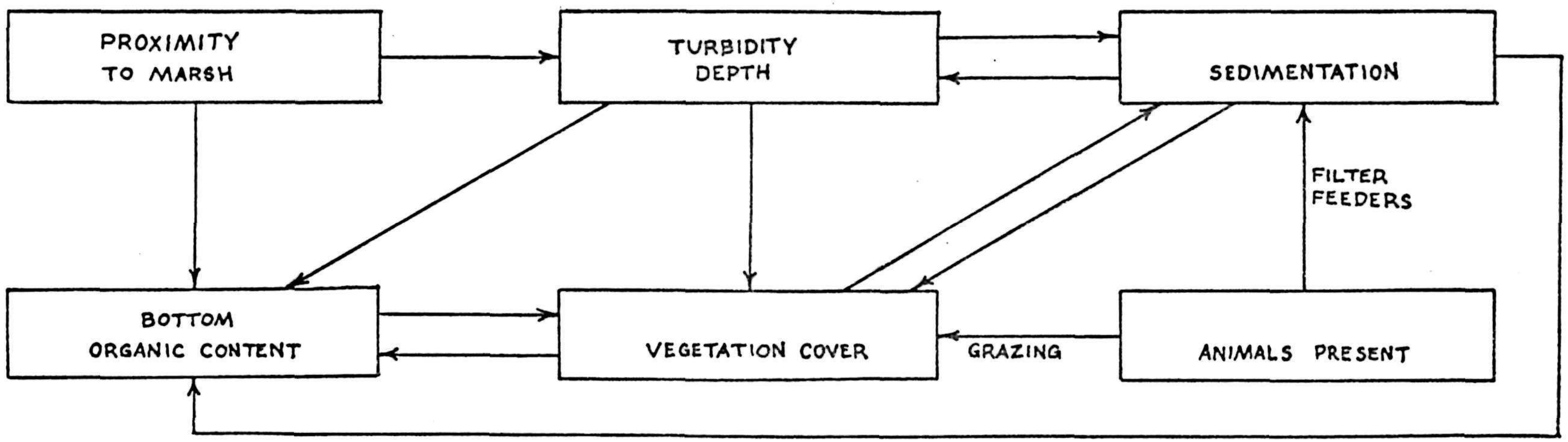
pointed out in this report, one advantage of aerial photography is the ability to detect anomalous features that would go unnoticed using more conventional techniques. This "grassbed anomaly" is one such feature.

I propose to investigate this phenomenon, using aerial photography as a research tool. It may be possible to develop a model of the system which accounts for several of the variables affecting vegetation cover. Figure 19 illustrates how such a model might be constructed. Gathering sufficient data to build a model would be a difficult and time consuming task with conventional methods, but aerial photography may greatly simplify matters. Some of the variables can be determined directly from the photographs; the rest, with new and improved techniques, might possibly be determined indirectly.

Value of Aerial Photo as Determined Directly from Program

The value of aerial photography has been established in the fields of agriculture, forestry, and geology. Coastal geologists have been using aerial photographs to monitor dynamic processes for years. The mapping of underwater as well as terrestrial features is another use that is nearing the "established value" category. Maps I have prepared and will prepare from aerial photographs in the near future clearly portray the barrier island communities, salt marshes, tidal creeks, channels, marsh islands and underwater grassbeds. The uses of such maps include park resource inventories, park management and ecological research.

Figure 19. Hypothetical model of interacting variables affecting underwater vegetation.


PROXIMITY TO MARSH
TURBIDITY DEPTH
SEDIMENTATION
FILTER FEEDERS
BOTTOM ORGANIC CONTENT
VEGETATION COVER
GRAZING
ANIMALS PRESENT

The accuracy and consistency of information determined from aerial photographs is demonstrated graphically in the photo-transect analysis of Figure 16 and in the maps of Figures 11 through 15. This work demonstrates not only the potential of low-altitude photography but high-altitude work as well. The map and transect from the 60,000 ft. transparency were excellent and compared favorably with those from the low-altitude prints. (For the relative scales and measurement abilities of high-and low-altitude photography see Appendix 2).

The value of aerial photography in monitoring changes in the distribution of underwater vegetation and ecological processes in general was demonstrated in the discussion of grassbed fluctuations and marsh recession presented earlier. Though working with a limited number of photographs, an ecological change that may have been heretofore unknown was detected. It is a safe assumption that this change would still be unknown were it not for aerial photography.

Conrad (1967) reports maximum depth for sighting bottom detail as about 30 meters for clear water, 3 - 5 meters for Atlantic coastal waters and about 1 meter or less for very turbid, dirty harbor water. Bottom detail can be seen in the estuary at high tide to depths of about 3 meters and dirty harbor water obscures most bottom detail in the vicinity of Morehead City, N.C. These findings tend to agree with those of Conrad, keeping in mind, however, that turbidity at low tide in the estuary can be extremely bad so the 3 meter figure will not apply.

High-Altitude and Satellite Photography

Recent tests (Vincent and Dolan) of measurements from high altitude photography at a scale of 120,000 with ground measurements indicated that all measurements were within 10 feet of each other (see Appendix 2). Accurate determinations of community outlines and linkages are possible under high magnification as discussed elsewhere in this report. Thus, analysis of benthic community distributions and relationships of features and processes is definitely possible, even at this scale. In fact, a preliminary survey of recently acquired infrared transparencies from 6000 feet indicates that, for underwater features at least, the high altitude photographs might prove superior overall. Bottom features can be measured and mapped with reasonable accuracy and the smaller scale, in Dolan's words, "reduce the significance of local variation and provides a better perspective on a regionwide basis." Work to date indicates that high altitude photography is an efficient method of monitoring large regional systems as well as more localized phenomena and will provide a large "data bank" for planning and management decisions.

The ultimate goal is to design instruments for use in an arbitrary vehicle, although most of the preliminary work has been performed from aircraft. Such aircraft tests, with care in data interpretation, are valid methods of evaluating orbital instrument performance, if atmospheric effects are understood (Conrad '67).

A long optical path through air has two primary effects 1) presence of high foreground brightness, and 2) loss of contrast and detail from atmospheric absorption and scattering, especially in the blue end of the spectrum. The first is due chiefly to Rayleigh scattering and is proportional to λ^{-4} (λ = wavelength) of the light traversing the air. This causes the bluish cast on the Gemini and Mercury photographs. The second is due to absorption, largely non-spectral, by the atmosphere and to particle scattering of the light reaching the objective lens from the target. Particle scattering is less dependent on λ than Rayleigh scattering but is still biased toward shorter λ's for clear air.

Most atmospheric optical effects take place in the lower atmosphere, consistent with the fact that most water, dust, CO_2, etc., are contained in the bottom few thousand feet of air. Above a certain altitude, therefore, the loss of contrast and detail due to atmospheric effects does not increase significantly with altitude.

Conrad and Short examined a Gemini photography to determine the value of coverage at this scale. The shot was enlarged onto black and white film. Major community boundaries could be seen, and "tonal and textural differences agreed, within scale limitations, with those observed on low-altitude coverage and in the field surveys."

It appears that considerable information about shallow water bottom features should be gained from spacecraft imagery. Large areas are covered in a short time and many large scale features can be detected that would be hard to detect in normal aerial photography. Many plant communities are visible in satellite photographs even though resolution is limited. Based on observations to date the identification of marine bottom communities does not depend as much on identification and resolution of discrete objects as it does on land, so over-water imagery may be of lower resolution and still be of comparable value.

Techniques and Methods

While this report has dealt exclusively with aerial photography, it should be kept in mind that many workers (e.g. Conrad and Short) suggest that aircraft and satellite cameras may be a needless luxury since instruments such as electro-optical multi-spectral imagers may satisfy most program requirements. Film cameras have superior resolution, but will this provide sufficient additional information to justify the added costs (e.g. film capsule recovery)? Electro-optical imagers also provide real-time data, which for many studies will be a necessity. Much work remains to be done in evaluating the relative merits of these various systems, but for the near future, photographic systems will continue to be the most popular remote sensing tool in biology. Other systems are generally too new to have produced a reliable body of literature; and photography is the best method available today for storing large amounts of data in a small space and for the simultaneous recording of many objects and phenomena.

Three film types, black and white, Ektachrome color, and Ektachrome Infrared Aero were evaluated. Infrared Aero has been used extensively in aerial survey work and has proved successful in many areas. The sensitivities of the three emulsion layer and the color balance of the dyes enhance and amplify color differences that, on conventional color photographs, may be overlooked. (For a discussion of how IR film works see Appendix 3). The red colors associated with healthy foliage are brighter and lighter in tone than the normally dark shades of green on conventional color film; and the fact that color differences are more readily spotted on the infrared film lends reliability to their interpretation.

Anderson (1970) reports that color IR film has the potential for giving much more information than standard color film in natural resource studies. His opinion is based on comparisons of simultaneous photographs of the estuarine region of Patuxent River, Maryland. He recommends the Wratten 15-G filter for general use and the 25-A for delineation of submerged aquatic plants.

Filtering qualities of water seem to render infrared photography of no more value than normal color or black and white for underwater studies. Underwater vegetation can be mapped with all three types of photographs. However, since infrared imagery is superior for terrestrial work, and since any aerial photography of the islands will include both land and water surfaces, it is recommended that infrared film be used in all future studies.

Photoenhancement techniques to quantitize photo-density distributions have not been used to date in this program. Research was done with an eye towards future use. Conrad (1967) reports that densitometry is the best method where instrumental examination is required. It can enhance or visually emphasize areas of a photograph which share a common characteristic (color, density).

Conrad (1968) reports on two processes of photoenhancement, Philco-Ford and Technical Operations. The Philco-Ford process is a "density-slicing" technique with the enhancement accomplished in steps. Technical Operations is a two-stage process. They first make isodensity traces and then scan them so regions of maximum density change are enhanced. The prints of density change are the most valuable. An isodensitrace is like a derivative of the image; the end product is a derivative of the isodensitrace or second derivative of the original image. Generally, the Technical Operations process is more effective at delineating bottom geology, Philco's in biological work.

Conrad and Short report that photo-enhancements from Philco-Ford and Technical Operations of 25,000 ft. photographs were remarkable matches of their maps prepared from photographs after extensive field work. It must be pointed out that an enhanced photograph does not "identify" anything, and it is too early to tell if unambiguous photo-interpretation keys can be developed. However, preliminary photoenhancement would probably lower field survey time even more than preliminary photographs alone. The photographs determine areas to be surveyed within certain limits; photoenhancement narrows those limits.

Conclusion

Before discussing some of the problems associated with remote sensing and making recommendations for the future, the state of the art is summarized in table form below. Listed are features that may be identified using aerial photography, as determined during the course of this investigation. Where the technique involved is not simple observation and is not discussed elsewhere in this report, a brief explanation of the method is given.

Geomorphic Features

Nearshore bar and troughs
Beach zones
Beach form
Dune areas
Marsh areas
Ponds
Sand and mud flats
Dune blowouts
Overwash fans
Relic beach ridges
Islands
Shoals
Channels

Hydrological Features

Water depth (density of photographic image, using photoenhancement)
Shoals, tidal flats, tidal inlets
Tidal range (tonal differences: exposed mudflats black, and light blue when under water, on IR Aero film)
Current patterns (silt distribution beyond river mouth, tidal currents show as meanders are traversed)
Channel locations and widths
Rip currents
Interior drainage on islands
Water mass boundaries (changes in light absorption, with apparent color shifts in blue green region)

Ecological Features

Underwater vegetation
Turbidity (quantitative turbidity levels matched to blue tones, point of maximum transmission shifts toward red as suspended matter is added)
Salinity (indicator plant species which require certain salinity ranges)
Temperature (thermal imagery, IR scanning)
Terrestrial vegetation (tonal differences among major species)
Nutrient pollution (indicator plant species such as photoplankton blooms)

It should be realized that there are problems and limitations inherent in the application of aerial photography to coastal research, its usefulness not withstanding. The reflectivity of water drops off markedly at the red and blue ends of the visible spectrum, so the detection of suspended material is most successful in the green and yellow regions. Little information is available in the near IR due to the high reflectivity of water in that part of the spectrum. IR is thus most useful for material in the top few mm such as algal plankton blooms, floating seaweeds, and waste materials. The optical properties of water are unaffected by temperature and salinity so direct information on these parameters cannot be obtained.

In almost all the literature, data are presented without reference to atmospheric and incident light conditions. Light intensity and spectral distribution in water vary considerably with sun angle and weather conditions, leading to inconsistencies between reports and between predicted and reported data (Conrad, 1967).

Photographic records are unavoidably influenced by variations in film emulsion and processing. In addition, the photo-interpreter may err, and radiometric measurements that form the basis of densitometry are good to only about 10%. Thus quantitative analysis based on photographs alone is somewhat risky.

In spite of the limitations it is reasonable to expect that usable data will be obtained from high-altitude and satellite photographs over shallow waters. More reference data is needed for ground truth to facilitate analysis of the photographs. Experimental work should be directed towards determining 1) the effect of altitude on visibility, resolution and contrast, 2) the effects of water depth and clarity on resolution, 3) the attenuation of contrast, and 4) the optimum filtering for ocean coverage.

Work by Philco-Ford shows an ability to enhance one particular material so it stands out from the aggregate when the materials have specific reflectivities. Laboratory and field tests on many samples are needed to determine whether a given material's reflectivity in each of the three color bands is unique.

The art of remote sensing is still in the formative stages, with the primary emphasis presently on evaluation of instruments and methods rather than on data accumulation. But the aerial photography branch of remote sensing has become established to the point where, with the essential conjunctive field work, a library of identified images can be assembled. A library would include information such as quantitative densitometry data correlated with various depths and vegetation types for given atmospheric conditions. All of this will require increased coordination between many teams composed of skilled, experienced investigators.

Appendix 1: Ecology of Estuaries.

As land masses are depressed the shores are submerged and the coastline migrates inward. When the land is uplifted shores emerge and the coastline moves seaward. Both processes may form estuaries, with some showing the effects of both. Local currents, wavea action, tides, stream deposition, glaciation and winds modify the original form of the shores.

Sea and land movements develop initial forms. Tectonic factors, glaciation and climatic forces result in the initial form. Patterns resulting from marine forces on initial forms are called sequential forms.

North Carolina rivers and streams are generally deprived of direct entrance to the sea by barrier beaches. The resulting coastal bodies of water, separated from the sea by these barrier beaches or by bars of marine origin are termed lagoons. Stream inflow and partial enclosure from the sea results in a salinity gradient within the lagoons.

After submergence, stream and sea processes of erosion, transport and deposition modify the topography of the immediate region and eventually the entire coast. Streams drop sediment upon meeting the encroached sea. Continued building by sedimentation results in broad, level silt deposits which become tidal flats. Currents and tides erode peninsulas, or headlands, depositing materials on the bottom of the estuary's seaward region. Deposits may develop as bars and spits in various positions relative to the mouth of the estuary. In time the estuary may fill with stream and tidal deposits. The rate and extent of sedimentation and filling are functions of original size, age, rate of upstream erosion, deposition by stream at mouths, tides, and longshore currents.

With light stream discharge and tidal currents coastal currents build depositional features like spits and baymouth bars across the estuarine mouth, restricting the entrance. In such a process, filling is apt to be accelerated. If the scouring action of streams and tidal currents is strong the deposition of entrance barriers is inhibited, fluvial sediments are carried further from the estuary, and the filling process is slowed.

A large volume of water (the difference in volume between high and low tide) flows in and out of the entrance in a short time. If stream discharge is great and the entrance narrow, a deep channel is cut. If the entrance is through easily eroded sediments, the depth is such as to be in equilibrium with the water volume moving through. Once equilibrium is established, there follows only a slight scouring or deposition. As filling of the estuary continues the entrance gets more shallow, gradually decreasing the volume of water passing through the tidal prism.

In a low coastal relief area, erosional effects of the sea are often buffered by inflowing streams. Sediment deposition exceeds removal by currents and barrier beaches and other features are formed i. e. spits.

Narrow-mouthed estuaries are characterized by decreased circulation, pronounced salinity gradients and more rapid development of sedimentation features such as spits and bars. Depth, breadth, and area are inherently unstable.

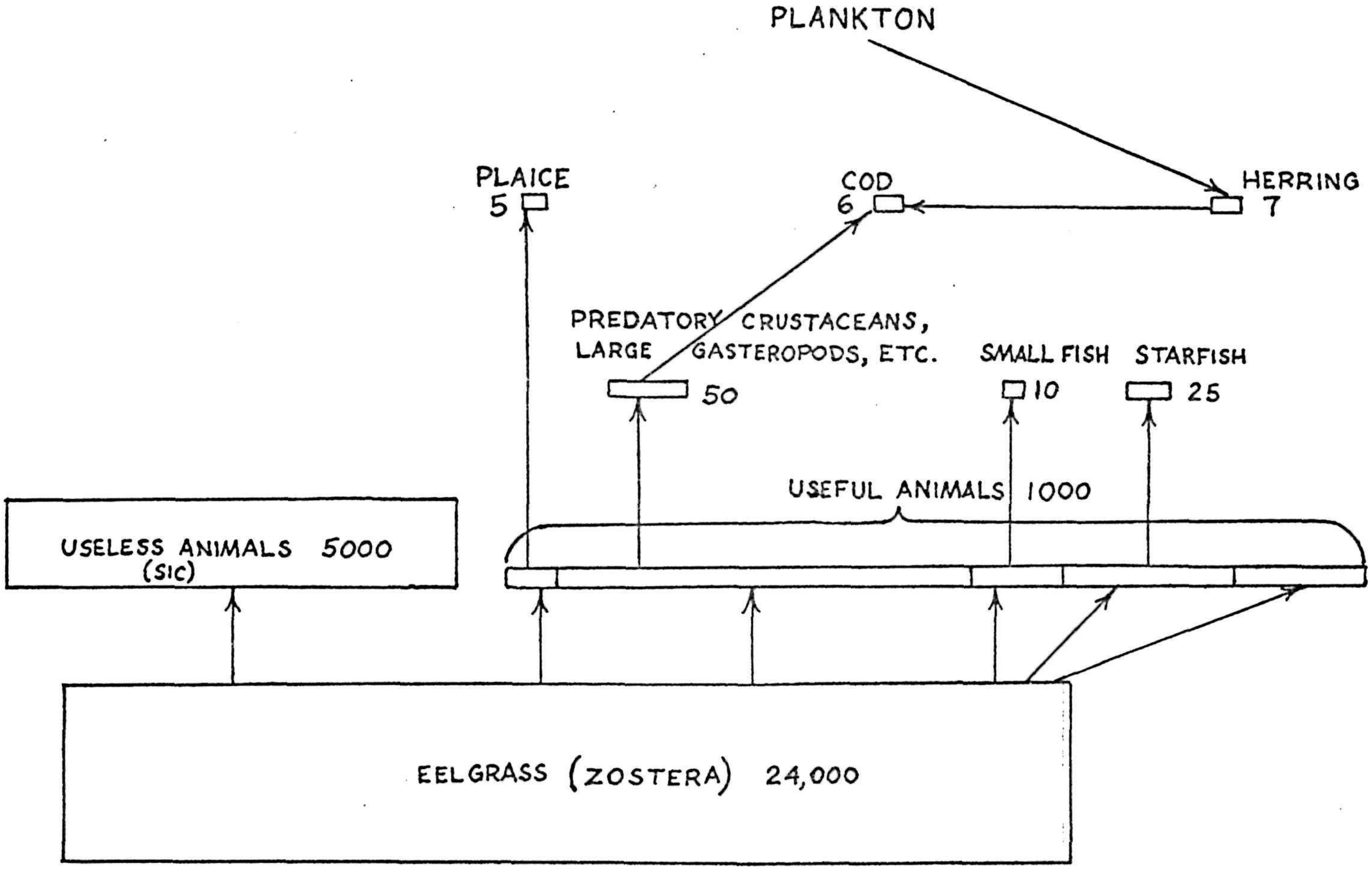
Shores are composed mainly of mixtures of silt, mud and sand in varying proportions and degree of compaction. Near the mouth, where the sea builds spits or other depositional features, the shores and substrate are conspicuously sandy. Inside the entrance the sand contains considerable quantities of mud. Zonation exists from sandy beaches on the seaward slope to mud flats or tidal marshes on the inner slope of bay mouth bars and spits. The coarse sediment of the mouth grades to finer materials in the head of the estuary, the sorting being associated with current action. The head region has reduced flow so fine muds are deposited. In the main channel and mouth coarser sediments make up the bottom.

The substrate influences the plant and animal inhabitants of the floor and shore. Pure mud or sand presents problems in maintaining living organisms. Mixtures of sand and mud seem to support richer faunas. The muds of the bottom hold more saline waters as the tides ebb, so bottom dwelling organisms that require higher salinities can exist farther into the estuary than ecologically similar forms in the fluctuating water above the bottom.

One of the most important benthic plants of estuarine regions is Zostera, or eelgrass. It is the most widely distributed marine angiosperm, occurring in coastal waters throughout the cooler regions of the northern hemisphere on sandy mud bottoms. In 1931-32 a great mortality due to infection was experienced over extensive areas. There has been a considerable return since 1940, especially important since many workers (Lotka, 1956) feel that the fundamental food of all marine forms in northern waters is "fine dust detritus" of the sea bottom, derived primarily from Zostera. Lotka discusses an investigation of the Kattegat, a shallow arm of the sea between Denmark and Sweden. The principal conclusions are illustrated in the diagram on the next page.

Tidal, or mud, flats commonly build up in estuarine basins. These depositional features, composed of loose, soft mud or mud and sand often develop and braid the original channel. Depending on the substrate and tidal action, vegetation may occupy the flats. Otherwise broad flat areas remain as barren features of the basin. Barring pollution, the tidal flats provide habitats for abundant fauna that feed on materials brought in by the tide or upon organic detritus of the substrate.

The above summary is taken largely from Odum, 1961.



FIGURES IN THOUSANDS OF TONS

Appendix 2: Measurement Abilities and Photographic Scale Comparisons (from Vincent and Dolan).

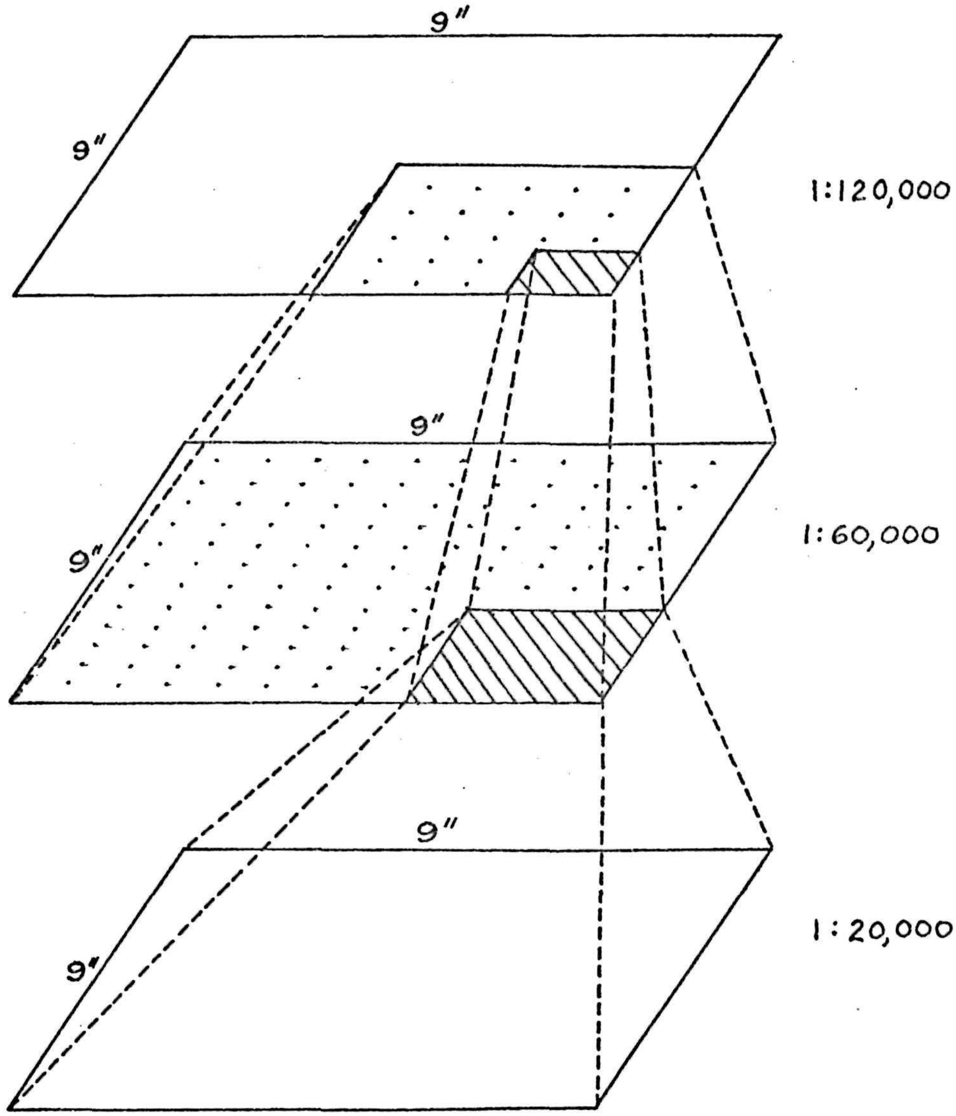
MEASUREMENT ABILITY

SCALE	MEAS. ABILITY
1:20,000 1" = 1/3 MILE	2' – 5'
1:60,000 1" = 1 MILE	5'
1:120,000 1" = 2 MILES	10'

MEASUREMENT SYSTEM APPLICATIONS

SYSTEM	MEASUREMENT RANGE	APPLICATIONS
SURVEY	1'	ENGINEERING STRUCTURES, GROUND TRUTH
LOW ALTITUDE PHOTOGRAPHY	2' – 5'	MEASUREMENT OF BEACH CHANGE, STORM DRAINAGE, CRITICAL REGIONS, SMALL AERIAL STUDIES
HIGH ALTITUDE PHOTOGRAPHY	5' – 10'	INTEGRATION OF REGIONAL RELATIONSHIPS, NON-CRITICAL MEASUREMENTS

PHOTOGRAPHIC SCALE COMPARISONS



Appendix 3: Brief Discussion of Ektochrome Infrared Aero Film (EKIR).

Important aspects of EKIR film performance are:

Healthy foliage generally appears bright red or magenta, with different species often showing different shades;

Unhealthy, dead or dying vegetation deviates from the red;

Image color formation is dependent on reflected energy of the green and red portions of the visible spectrum and of the near-infrared;

Plant leaves have a low level of visible reflectance and a high level of infrared reflectance;

IR reflectance is due to internal leaf structure;

Image formation is strictly photographic, film sensitivity being 500 - 900 mμ's.

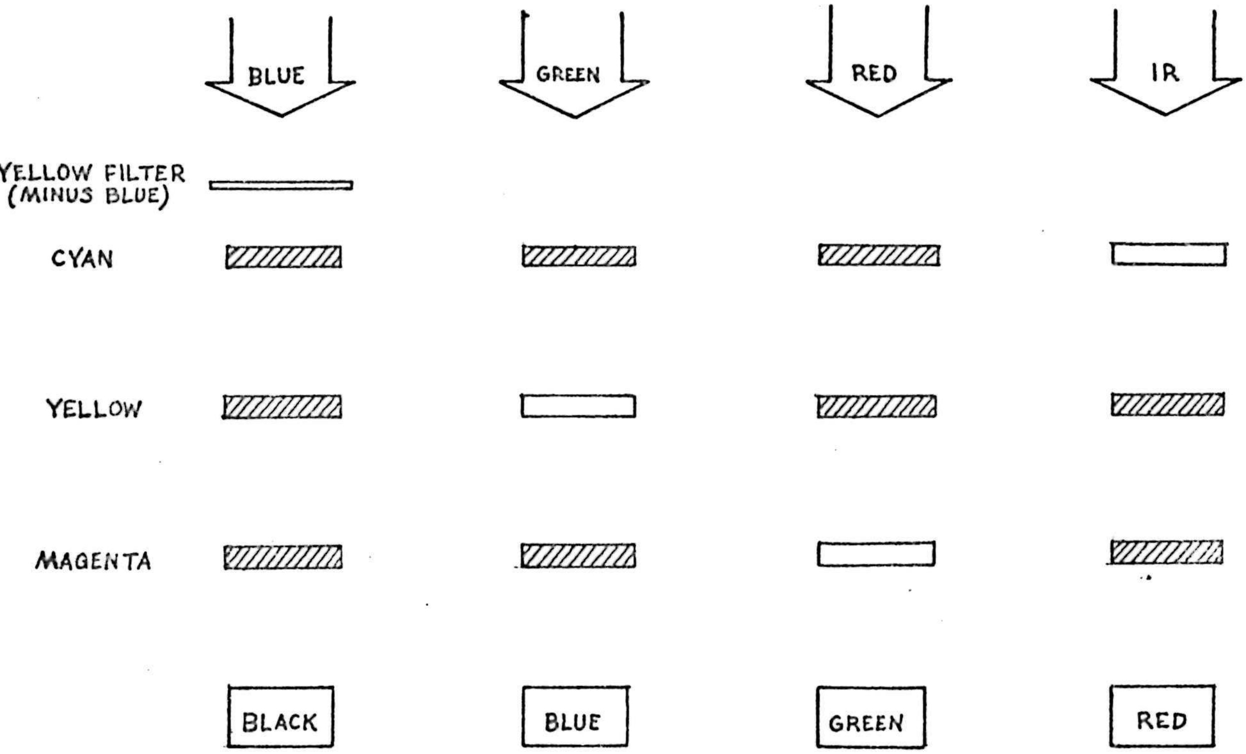
The three film emulsion layers are:

top - cyan forming, sensitive to near-infrared
middle - yellow forming, sensitive to green
bottom - magenta forming, sensitive to visible red

The dye does not form if the layer is exposed to radiation to which it is sensitive. All three layers are sensitive to visible radiation of wavelength less than 500 mμ, but this problem is eliminated with a yellow-filter. Blue reflecting objects do not sensitize any of the three layers, so all three dyes are formed (see diagram, next page). The subtractive effect of the dyes means that no light is transmitted, so the region turns out black.

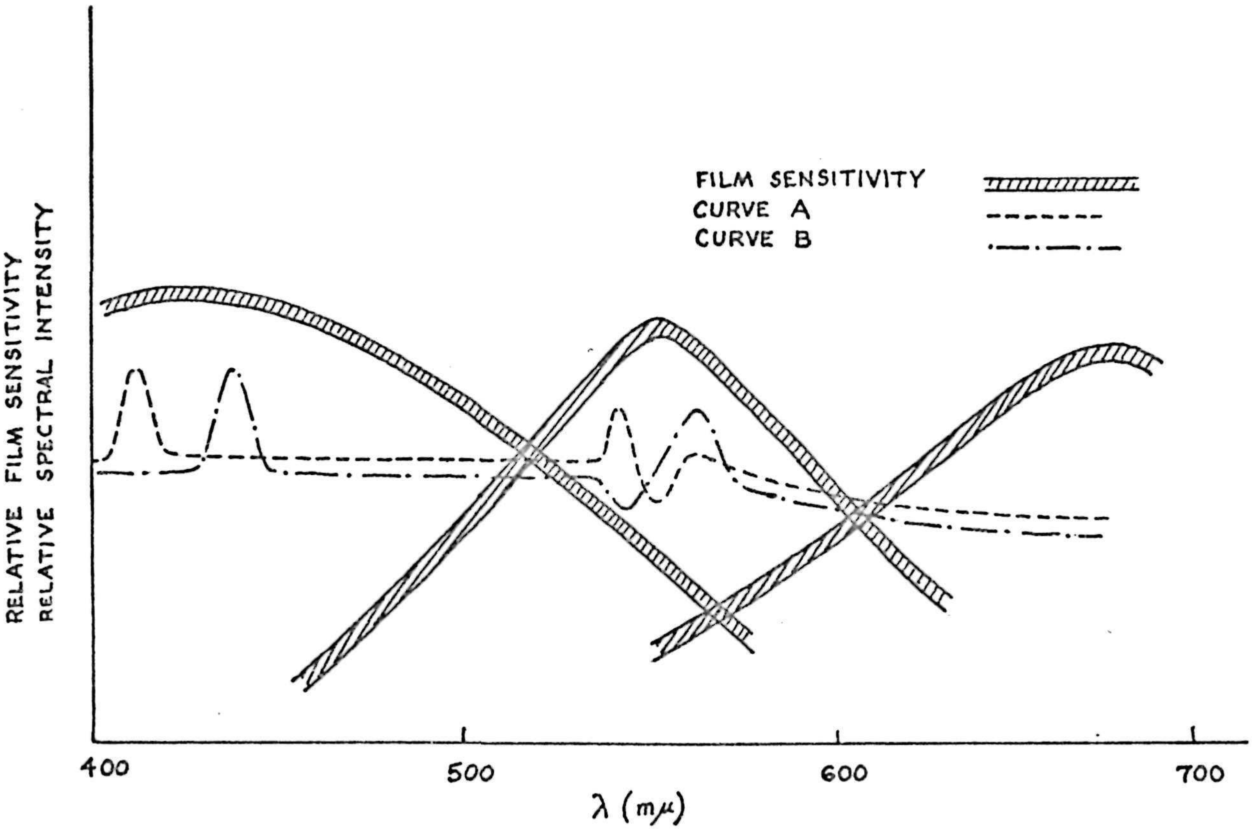
Infrared radiation exposes the cyan, leaving the yellow and magenta subtractive mixture and resulting in a red image when the final product is viewed by transmitted light (again see diagram).

The sensitivities of the emulsion layers and the color balance of the dyes enhance and amplify color differences that on conventional color photographs might be questionable or overlooked. The resulting red colors associated with plant foliage are brighter and lighter in tone than the normally dark shades of green on conventional color film. The tonal difference is more readily spotted on IR films, thus lending more reliability to their interpretation.


BLUE
GREEN
RED
IR
YELLOW FILTER
(MINUS BLUE)
CYAN
YELLOW
MAGENTA
BLACK
BLUE
GREEN
RED

Appendix 4: Color Resolution on Photographic Film.

One disadvantage of color film is that each of the three layers tends to integrate all incident energy to which it is sensitive. This means that small spectral differences, which may be apparent to the human eye, may not show up on the film. The figure illustrates hypothetical dissimilar spectral curves that cannot be resolved on conventional color film.



DISSIMILAR SPECTRAL CURVES, A AND B, THAT CANNOT BE RESOLVED ON CONVENTIONAL COLOR FILM

Addendum

As discussed on page 30 and illustrated in Figure 18 the underwater grassbeds appear to advance and retreat periodically in the vicinity of Cockle Marsh Island. It was stated that the data may indicate a cyclic pattern. After completion of this report another photograph of the region was located, this one dated October 27, 1965. A standard area was delineated according to the procedure described on page 30 and a planimeter was used to determine the portions of this area covered by salt marsh and underwater grassbeds. The results have been included in Figure 18. The per cent cover of grassbeds in the area lends support to the hypothesis of a periodic fluctuation.

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