MTR 986

(appendix A, see MTR 987)

SYNTHESIZING SEAGRASS MODELS: APPLICATION TO ECOLOGICAL FORECASTS

FINAL REPORT
NOAA Award No. NA17OP2667
TIME PERIOD: 09/01/02 – 09/30/04

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Project Summary:

The major goal of this project was to synthesize available information on the dynamics of seagrass landscapes in response to anthropogenic stressors and natural variability by reviewing models representing various aspects of seagrass ecosystems and to develop a comparative analysis of their required input data, their spatial and temporal scales of application, the metrics of their input and output, the utility of the data (e.g., potential audience and types of management issues).

Objectives:

I. Synthesize available information on seagrass models for use as forecasting or predictive tools through a comparative analysis and the production of two directed critiques,
   a. A Mangers Synthesis & Critique, and
   b. A Landscape Ecologist's Synthesis &Critique.

II. Employ the National Centers for Coastal Ocean Science (NCCOS) Hydrogeographic Model as a forecasting tool to quantitatively forecast:
   a. the response of a seagrass landscape to extreme wind events, anthropogenic stressors and natural variability in three geographic

locations: Tampa Bay (Florida), Southern Pamlico Sound (North Carolina), and Chesapeake Bay (Maryland and Virginia),

b. where exposure to hydrodynamic processes, when added to water quality data, creates improved measures of (exclusion) zones where seagrass cannot exist, and
c. the potential for restoration of seagrass habitats within the aforementioned three geographic locations.

Product 1: Synthesis Documents

After an initial meeting held on December 12, 2002 at NOAA's Beaufort Lab in North Carolina a comprehensive literature review was conducted using two electronic library search engines: BIOSIS (BioAgIndex) and Cambridge Scientific Abstracts (Ecology Abstracts & Biological Sciences and Living Resources). Search words used were seagrass, model(s), forecast, and prediction. More than 3200 citations were collected and examined from Biological Sciences and Living Resources, 1500 from Ecology Abstracts, and 165 citations from BioAgIndex.

A parallel "literature" search was also conducted on the World Wide Web using the Google™ search engine with the same search words listed above. Less conventional, the procedure employed was to open each identified web page (> 9000 web pages were found using the term **seagrass model** as the search parameter) and attempt to locate a published description of the model. Only one unpublished model (Short's Great Bay Estuarine Model) was included in synthesis document.

Dr. Robbins requested permission to combine the two synthesis documents into one and was granted permission by Ms. Elizabeth Turner on Nov. 3, 2004. The synthesis document entitled **Modeling Seagrasses: A Synthesis of Available Models**, can be found attached as Appendix A.

Product 2: Graphical User Interface (GUI) Model

The NCCOS Hydrogeographic model is a spatially explicit model of wind generated wave exposure. The model calculates a relative exposure index (REI) based on a summation of the product of wind speed (**V** – top five percent of hourly wind observations (ms^{-1})), wind duration (**P** – percent frequency of winds occurring from each respective direction), and water depth (**idwF** – an inversed distance weighted effective fetch measure). Effective fetch in each of the eight compass headings (**i** = 1 to 8) is determined by measuring fetch along four lines radiating out from either side of the **i**th compass heading at 11.25° increments, including the **i**th heading (n = 9). Effective fetch is then calculated by summing the product of the fetch x cosine of the angle of departure from the **i**th heading over each of the nine lines and dividing by the sum of the cosine of all the angles. This weighting of multiple fetch measures for each compass heading helps account for irregularities in shoreline geometry that could misrepresent the potential of wind wave development from a given compass heading (Shore Protection Manual 1977). Effective fetch is further weighted by analyzing the influence of water depth along each fetch ray (Robbins et al. 2002).

Bathymetric data for Tampa Bay were acquired from the FWRI in an ArcInfo GRID format and in ASCII format for Chesapeake Bay and Core Sound from the National Geophysical Data Center (NGDC). The ASCII text files contain geographic location and depth for each of sounding with a depth resolution of 0.10 m. ASCII files were converted to an ArcInfo GRID format by first converting the text files into an ArcInfo TIN format. For all three sites, grid resolution was set constant at 100 meters.

Shoreline coverages are also necessary to run the hydrogeographic model. The shoreline is used to calculate the actual fetch for a location by clipping the rays generated in each compass direction from that location with the shoreline. The clipped rays give the actual fetch for that particular direction. These rays are later combined with depth to get effective fetch. An ArcInfo shoreline coverage for Tampa Bay was provided by the Florida Marine Research Institute. NOS shoreline coverages were used for other two sites. All the coverages and grids are converted in standard UTM projections to maintain consistency.

After refining the REI algorithm the team recognized the need to provide a user friendly, stand alone tool to managers, which led to the creation of a graphical user interface (GUI) application dubbed the Wave Exposure Model (WEMo). WEMo allows a researcher to develop a project that includes the dynamics of seagrass areal extent or the potential to restore seagrass to specific sites. The model requires the user to input four variables, a bathymetric grid (ARC-based), a shoreline (shapefile), wind data (duration and speed from the 8 major compass headings) and a file that defines georeferenced points or sites of interest (Figure 7). Model output includes a table that lists the REI value for each point, a shapefile of the points, and a contour plot of interpolated REI values. Currently the contour plot has to be generated outside of WEMo using ARC or other GIS software.

Product 3: WEMo Applied

One of our initial goals for this product was to quantifiably forecast the response of seagrass to extreme events. As part of this effort, we acquired all available wind, seagrass and water quality data for each our target estuaries (description of the data can be found in Appendix B).

A preliminary model run was conducted to determine the optimal spatial scale at which to re-sample seagrass aerial photographs. These results are reported in Appendix C.

Historical aerial photographs of each estuary were analyzed for seagrass coverage (see Appendix D for methodology). Sites were chosen within each estuary based on previous studies by each PI. A summary of site number, interpretation years and grid cell size is illustrated in Table 1.

Table 1: Summary of analysis by estuary.

	Chesapeake Bay	**Core Sound**	**Tampa Bay**
Number of Sites	31	29	27
Interpretation Years	1995, 1996, 1997	1995	1950, 1999, 2002
Grid size (m)	50 x 50	50 x 50	10 x 10, 25 x 25, 50 x 50

Using WEMo, we ran the model for all sites within each estuary producing a table with REI values for each site (Appendix E). Using these values we calculated the relationship between REI and seagrass percent cover (interpreted using 50m x 50m grid cells) and found the relationships were very weak (Figures 1 – 3). We also found the relationship was not consistent among estuaries with Chesapeake Bay and Tampa Bay having positive relationships while Core Sound has a negative relationship. Based on these results we were unable to either forecast the response of seagrass to extreme events or assess the potential for restoration of seagrass habitats in each chosen estuary as we had hoped. However, this set back was based on the scale at which we chose to interpret seagrass from our historical photographs and does not negatively reflect on the usability of the REI model. Based on our previous studies (e.g. Fonseca et al. 2002), when seagrass cover is interpreted as vector data (e.g. polygons are drawn around areas with seagrass) the use of WEMo as a tool for predicting seagrass cover is recommended with the appropriate caveats.

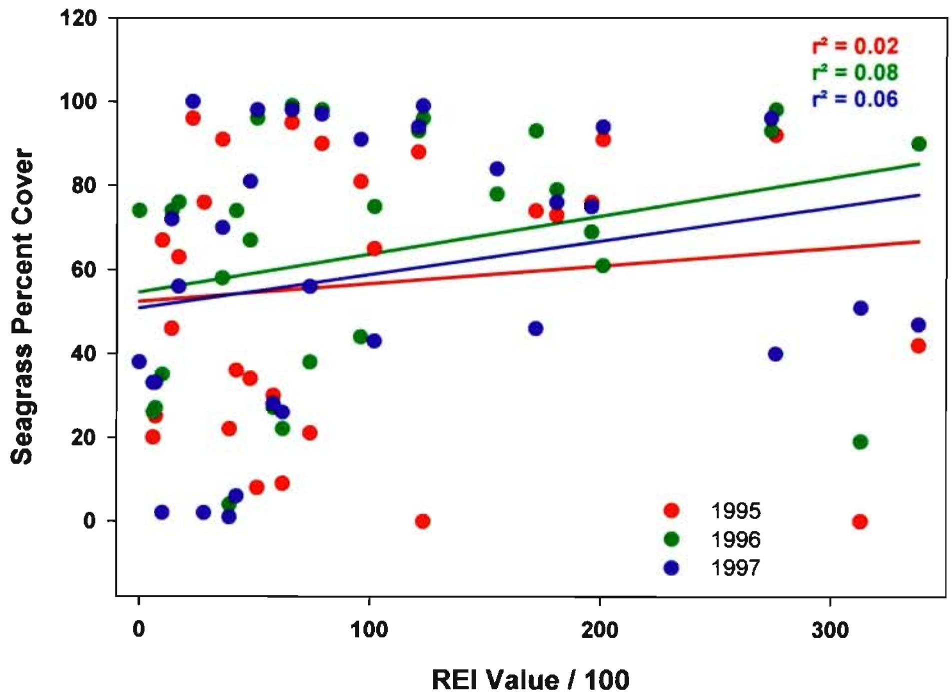


Figure 1: Relationship between seagrass percent cover and REI values for Chesapeake Bay for 1995, 1996, and 1997. Percent cover was calculated using 50m x 50m grid cells.

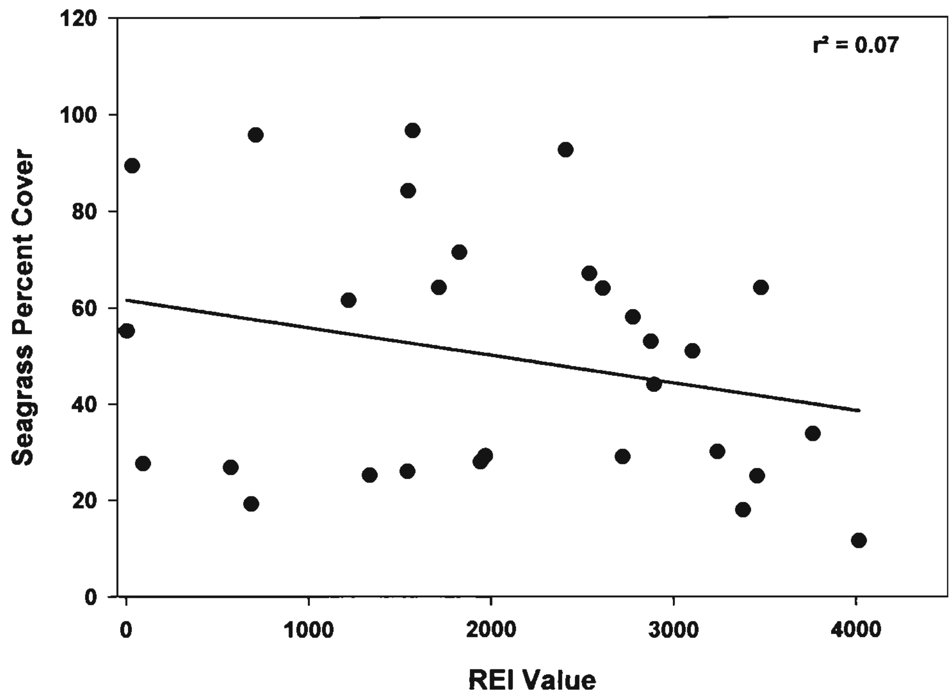


Figure 2: Relationship between seagrass percent cover and REI values for Core Sound for 1995. Percent cover was calculated using 50m x 50m grid cells.

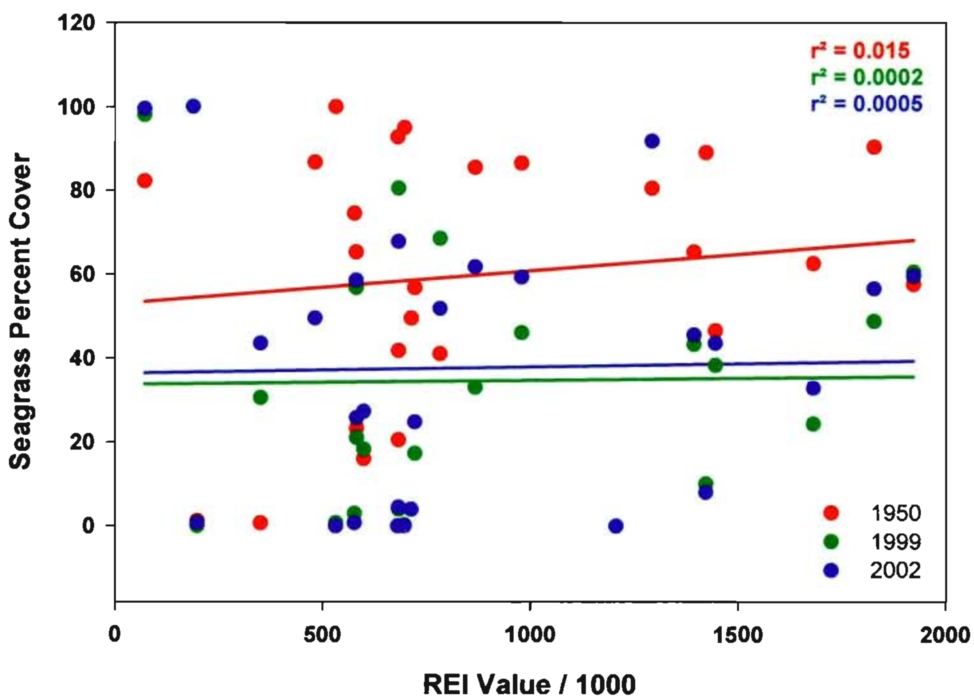


Figure 3: Relationship between seagrass percent cover and REI values for Tampa Bay for 1950, 1999, and 2002. Percent cover was calculated using 50m x 50m grid cells.

Product 4: Webpage

The project's website is being hosted by Mote Marine Laboratory and is located at

http://www.mote.org/~robbins/Synthesis/

The website contains information that can also be found in Product 1 and illustrates WEMo. Also found on the site are downloadable copies of Product 1 (in pdf format), WEMo's user manual (in pdf format) and a functional copy of WEMo.

Fonseca, MS, Whitfield, PE, Kelly, NM and Bell, SS (2002) Modeling seagrass landscape pattern and associated ecological attributes. Ecological Applications 12:218-237

APPENDIX B

Wind Data

The sources for wind data for all three sites were the National Data Buoy Center (NDBC) and the Physical Oceanographic Real-Time System (PORTS).

Tampa Bay: Wind data from four stations (Port Manatee, Old Port Tampa, St. Petersburg and McKay Bay) were acquired from the PORTS database; no NDBC data were available for Tampa Bay. These data cover an 8-year period (1995 – 2002). However, with the exception of the St. Petersburg station, the data contain a 2-year gap (1997 & 1998). Wind data were combined across years within each station and exceedance wind speeds and duration by direction were extracted from plots of normal distribution curves. An illustration of exceedance values can be seen in Figure 1. Visual analysis of the data suggests that are no differences between three of the stations while the fourth, Old Tampa Bay was different (Figure 2). Based on this assessment the hydrogeographic model was run the St. Petersburg wind data and excluding Old Tampa Bay from the analysis.

Chesapeake Bay: Wind data from seven stations (Bay Bridge Tunnel, Kiptopeke Beach, Lewisetta, Money Point, Sewells Point, Solomon Islands, and Tolchester) across the Bay covering an 8-year period (1995 – 2002) were acquired from PORTS and wind data from two stations (Thomas Point and Bay Bridge Tunnel) covering a 5-year period (1997 – 2001) were acquired from NDBC. A similar exercise for determining exceedance wind speed and duration values as described for Tampa Bay was undertaken with these data. We found that Chesapeake Bay could be split geographically with north Chesapeake Bay being represented by the Thomas Point wind station (Figure 3) and south Chesapeake Bay being represented by the Sewell Point wind station (Figure 4).

Core Sound: Wind data from a single NDBC site within North Carolina were acquired for use in the hydrogeographic model. This data set covered a 7-year period (1995 – 2001); no PORTS data were available. Again, determination of exceedance wind values (Figure 5) were completed following the procedure described above.

Seagrass and Water Quality Data

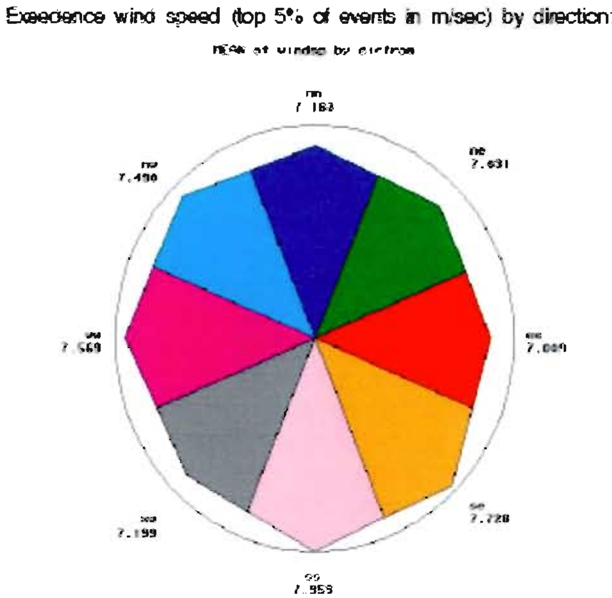
Tampa Bay: Seagrass maps (ArcInfo coverages) covering an 18-year period were acquired from the Florida's Fish & Wildlife Research Institute (FWRI). Additionally, nine sets of aerial photographs covering the 18-year period were acquired from the Southwest Florida Water Management District. Water quality data including measures of nitrogen, salinity, phytoplankton concentrations, suspended particulates, and oxygen concentrations covering a 25-year period are available internally from Mote Marine Laboratory.

Chesapeake Bay: Twenty-three seagrass coverages covering a 30-year period were acquired from the Virginia Institute of Marine Science. Water quality data (from 1940s to present) were acquired from several agencies: EPA Chesapeake Bay Program, Maryland Department of Natural Resources, Alliance for the Chesapeake Bay, US Geological

Survey, and US Department of Agriculture. Nine parameters were common to these data sets: nutrients, light, total suspended solids, salinity, temperature, dissolved oxygen, chlorophyll, river discharge, and aerial cover of submersed aquatic vegetation (SAV).

Core Sound: As with the wind data, seagrass data for Core Sound is also more limited than either Tampa Bay or Chesapeake Bay. Specifically, only a single, seagrass coverage based on 1998 natural color aerial photographs is available for Core Sound from NOAA. A smaller suite of infrared aerial photographs flown during 2002, are also available from NOAA. No source of water quality data was available for Core Sound.

Figure 1: Example of exceedance wind speed values and frequencies for three wind stations in Tampa Bay. These data are from the St. Petersburg PORTS wind station. Note that while the exceedance wind values are similar across all compass headings, the greatest frequency of wind occurred from the northwest.



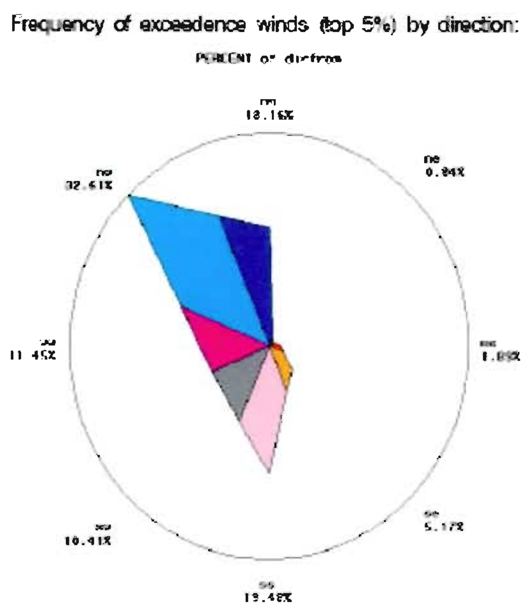
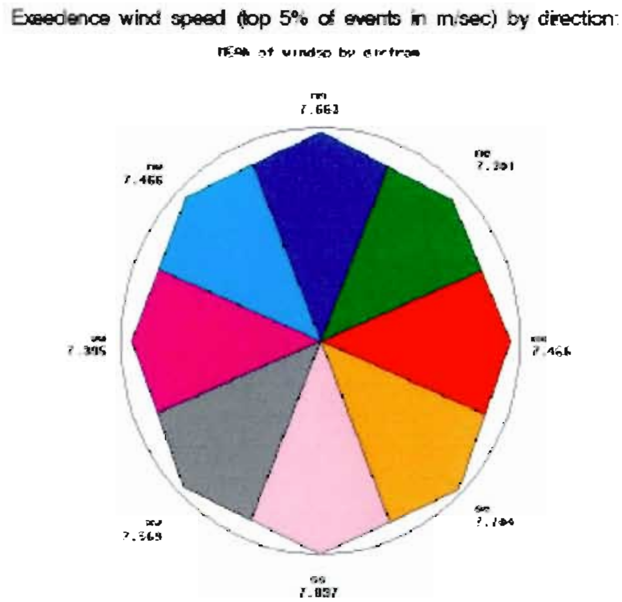


Figure 2: Exceedance wind speed values and frequencies for the Old Tampa Bay wind station. Note the obvious difference in wind speed and frequency direction in these plots as compared to Figure 1.



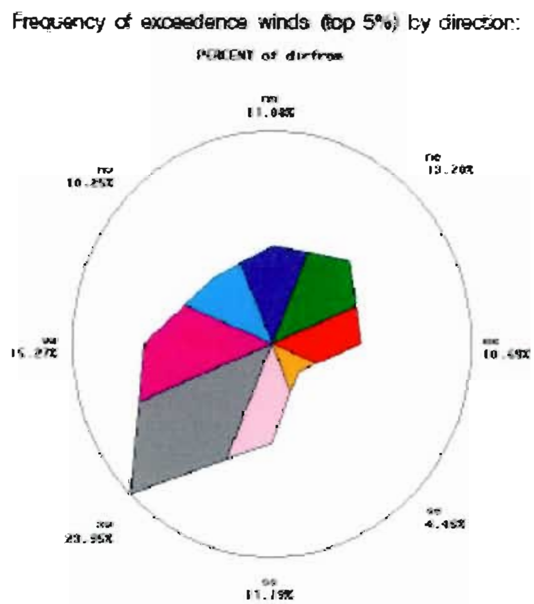
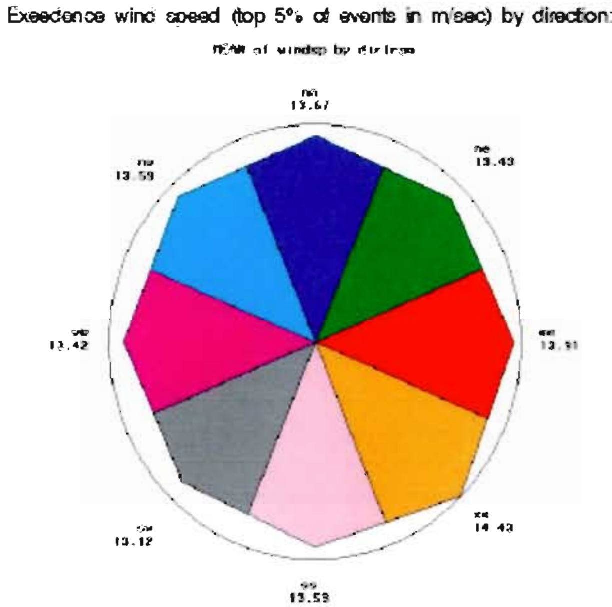


Figure 3: Exceedance wind speed values and frequencies for the Thomas Point wind station in Chesapeake Bay. Note the bilateral distribution of wind frequency with winds from both the northwest and south.



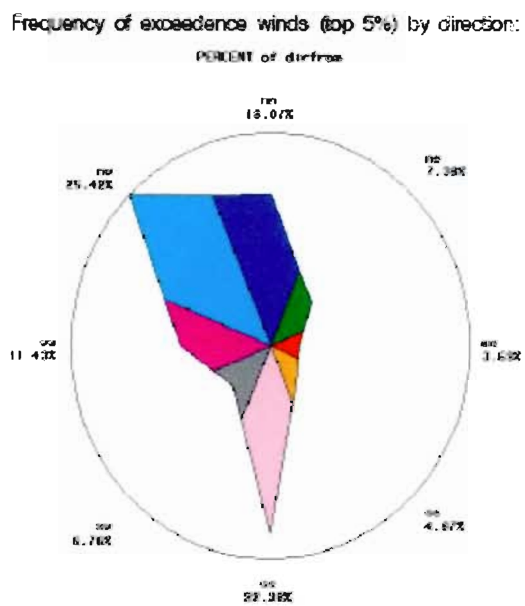
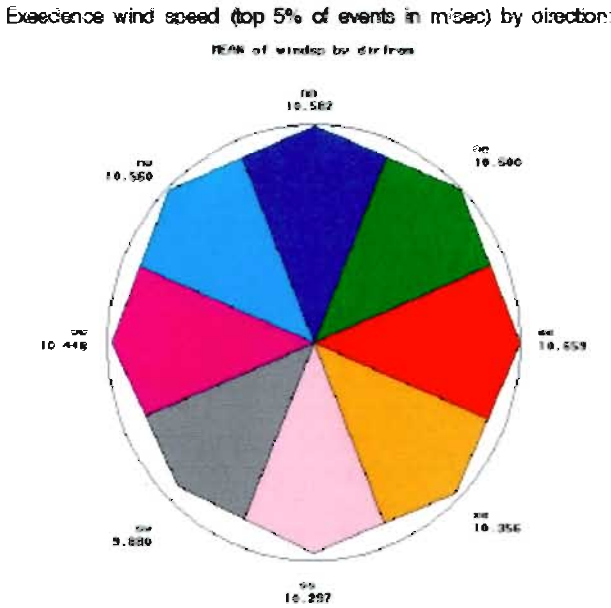


Figure 4: Exceedance wind speed values and frequencies for the Sewell Point wind station in Chesapeake Bay. Exceedance wind values are not only smaller than those at Thomas Point, but the direction from which exceedance winds occur most often is from the north rather than from the northwest or south.



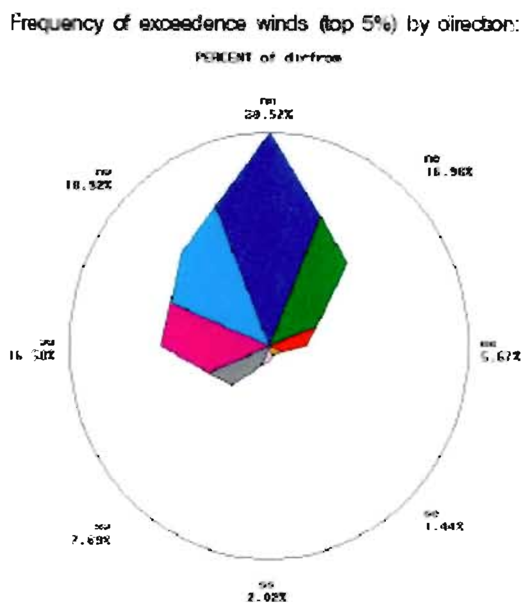
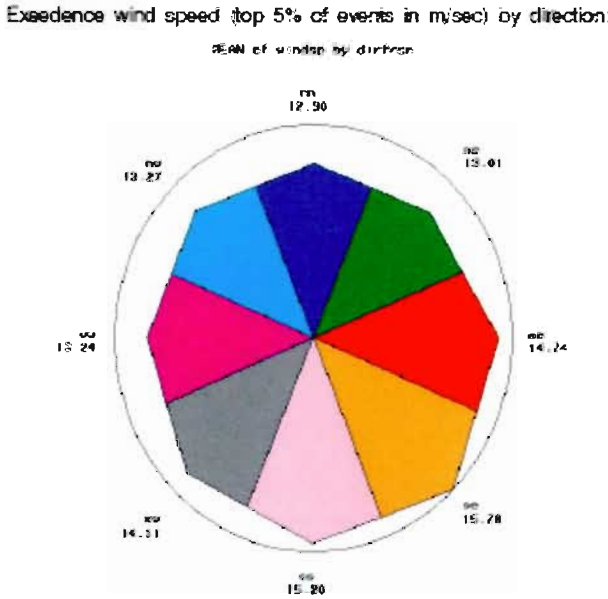
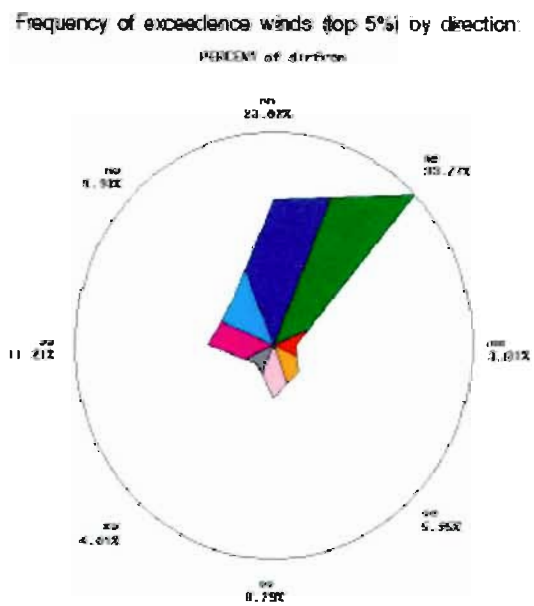


Figure 5: Exceedance wind speed values and frequencies for Core Sound, North Carolina.





APPENDIX C

Calibration of Sampling Resolutions for Detecting Spatial Patterns of Submerged Aquatic Vegetation.

Geospatial Data

Imagery: Digital aerial photographs were interpreted to extract geospatial data for use in a geostatistical analysis. The aerial photography was acquired under optimal environmental conditions considering the phonologic stage of SAV species, tidal height, atmospheric conditions, sun angle, water clarity, and wind speed to capture the SAV signatures (Orth et al, 2003, Dobson et al, 1995). Virginia Institute Marine Science's (VIMS) Chesapeake Bay Submerged Aquatic Vegetation Program provided 1:24,000 scale rectified digital black and white aerial photography acquired in 2002 for the Chesapeake Bay sites. Horizontal ground control points for the VIMS scanned aerial photography were extracted from USGS digital orthophoto quarter quads (DOQQ) and the vertical control points were from USGS digital elevation models. ERDAS Orthobase ™ image processing software was used to orthorectify the scanned images (Orth et al, 2003). Total root mean square (RMS) errors for the VMS flightlines used in the analysis ranged from 0.3 – 0.4m (personal communication with David Wilcox). Southwest Florida Water Management District provided 1:24,000 scale rectified digital natural color photography acquired in 2002 for the Tampa Bay sites. Pixel resolution was one meter for Tampa Bay and Chesapeake Bay images. The North Carolina 1:20,000 scale natural color aerial photography was acquired on October 16, 1995. North Carolina aerial photography was scanned at 600 dpi (.85m x .85m), rectified with ground control points located with Trimble PRO XL DGPS receiver (submeter accuracy), and resampled to 1.5m pixel resolution. A color mosaic of southern Core Sound was created using a piecewise polynomial rectification with a total RMS error of 1.90 using ERDAS ™ software. All rectified images were georeferenced to Universal Transverse Mercator (UTM) projection and NAD83 datum. Digital aerial photography for the three geographic regions served as visual backdrops for choosing sites in patchy submerged aquatic vegetation.

Sites: Submerged aquatic vegetation is depicted on digital aerial photography by spatial patterns of dark (SAV) and light (bottom) tones characterizing patterns of SAV and bare habitat. Three sites located in patchy SAV were selected in Chesapeake Bay (Figures 1a – c), Core Sound, North Carolina (Figures 2a – c), and Tampa Bay, Florida (Figures 3a – c). The 500m x 500m spatial extent of each site was centered on site coordinates extracted from the rectified digital aerial photography (Table 1).

Creating Points for three sampling resolutions: Three sampling resolutions of 10m, 25m, and 50m were chosen to determine the appropriate spatial pattern of patchy seagrass habitat from aerial photographs at this level of resolution. For the North Carolina sites, 10m, 25m, and 50m cell fishnet coverages were generated parallel to the shore in ESRI ArcInfo GIS software. The fishnet command generated $10m^2$, $25m^2$, and $50m^2$ cells stretching over Core Sound simulating grids with equivalent cell sizes. The 10m, 25m, and 50m cell fishnet shapefiles for Tampa Bay and Chesapeake Bay sites were created in

ESRI ArcGIS ArcView 8 (see Appendix D for the steps to create the fishnets at three resolutions using ESRI ArcGIS software).

Visual Photo-interpretation of points: Centroids were evaluated for the presence/absence of seagrass from on-screen images of each aerial photograph.

Elements of interpretation –
1. Influence of Film Type; scale
2. Choice of visual photo-interpretative scale (1:3000 scale allowed the 500m x 500m study areas and overall pattern of seagrass and bare substrate to be seen within each image; 1:500 scale used for each 50m x 50m cell)

Recommnendations –
1. Knowledge of local SAV species and phenology.
2. Knowledge of how different species and varying densities may be expressed differently.
3. 1:500 scale seems to be the best for determining presence or absence of seagrass.

Geostatistical Analysis

Input Data: Photo-interpreted observations of submerged aquatic vegetation (SAV) (presence or absence at 10m, 25m, and 50m sampling resolutions) from three geographic regions (n=9) were analyzed for spatial dependency using a semivariance analysis. A geostatistical analysis program, $GS^{+\,TM}$ software (Robertson 2000) was employed to measure and model the spatial relationships at each sampling resolution. Active lag distance was set at 700m and lag class distance intervals were 10m, 25m, and 50m. Input data sets of 10m, 25m, and 50m sampling resolutions consisted of 2500, 400, and 100 points, respectively. Best-fit models were calculated for both isotropic and anisotropic semivariograms for each of the three sampling resolutions (n=27).

Semi-variance Analysis Results: Table 2 lists the geographic region, number of site, three sampling resolutions per site, nugget variance (C_0), range (A_0), regression coefficient (r^2), and residual sum of squares (RSS), spatial pattern dependency, and best-fit model selected by the $GS^{+\,TM}$ software. The software selected the linear model for all sampling resolutions for North Carolina site 1, the 50m sampling resolution for North Carolina site 3, and the 50m for Tampa Bay site 2. An arbitrary range within the spatial extent was assigned by the software to be the distance interval for the last lag class of the linear models since there is no sill. Therefore, all linear models were considered spatially dependent across the range sampled (Robertson 2000). Spatial pattern dependency is indicated in table 2 as D = dependency or I = independent (uncorrelated beyond the range). Figures 6-8 show the 27 best-fit isotropic variogram models by sampling resolution.

Discussion: Initially we used the highest regression coefficient (r^2) as the statistic for choosing the appropriate sampling resolution for a site and thus, we assumed the sampling resolution selected most often would provide the best overall sampling resolution for all estuaries. However, further consideration of how our choice of sampling resolution would affect our final product, we decided that RSS was selected as a more robust parameter for choosing the best sampling resolution. This can be justified when one considers that the lowest RSS value provides information about the effect of outlier points plus it examines the pattern in the spatial information of the array that the regression coefficient does not provide. We also believe that the RSS value was more appropriate as a statistic because we were not simply looking for the semi-variance to be explained by the separation distance of paired points but instead sought spatial information explaining the random processes relating similarity among paired points to an array of distances between the paired points within an extent. The lowest RSS values for Florida sites indicated 25m as the appropriate sampling resolution. The lowest RSS values for Chesapeake Bay sites and North Carolina sites indicated 50m as the best sampling resolution to capture the spatial pattern of submerged aquatic vegetation.

Table 1. UTM Coordinates of Sites / Acquisition Date of Aerial Photography

Region	Site	X Coordinate	Y Coordinate	Image Date
Chesapeake Bay	10	412385.18	4139525.04	06/14/02
	48a	388737.60	4273058.05	09/05/02
	60	409679.49	4375153.50	11/14/02
Core Sound, NC	1	360886.85	3837445.12	10/16/95
	2	359581.85	3836805.22	10/16/95
	3	363103.27	3840846.75	10/16/95
Tampa Bay, Fla	1	343890.00	3079500.00	07/27/02
	2	348836.00	3084488.85	09/23/02
	3	336833.09	3046737.92	06/11/02

Table 2. Semi-variance Analysis of three sites from three geographic regions (n=9) at three sampling resolutions (n=27). Bold type numbers are highest regression coefficient (r^2) and lowest residual sum of squares (RSS). Spatial pattern indicated as D = spatially dependent or I = independent (uncorrelated beyond the range).

Region	Site	Sampling Resolution	Nugget C_0	Range A_0	r^2	RSS	Spatial Pattern	Model
Chesapeake Bay	10	10	0.094	144	0.80	0.0238	I	exponential
		25	0.117	494	**0.90**	6.859E-03	I	spherical
		50	0.099	130	0.65	**5.149E-03**	I	exponential
	48a	10	0.110	2110	**0.84**	0.0549	D	spherical
		25	0.126	2110	0.80	9.490E-03	D	spherical
		50	0.138	1222	0.72	**5.068E-03**	D	spherical
	60	10	0.052	119	0.07	0.341	I	spherical
		25	0.076	147	0.12	0.0813	I	spherical
		50	0.171	991	**0.21**	**0.0147**	D	exponential
Core Sound, NC	1	10	0.218	686	**0.45**	0.0199	D	linear
		25	0.243	637	0.18	0.0222	D	linear
		50	0.2042	568	0.10	**3.829E-03**	D	linear
	2	10	0.066	59	0.03	0.248	I	spherical
		25	0.066	162	**0.26**	0.0834	I	spherical
		50	0.0664	91	0.04	**0.0198**	I	spherical
	3	10	0.103	2110	0.42	0.0991	D	spherical
		25	0.140	2110	**0.51**	0.0353	D	spherical
		50	0.1424	568	0.01	**6.063E-03**	D	linear
Tampa Bay, FLA	1	10	0.103	2110	0.93	0.0200	D	spherical
		25	0.096	1831	**0.97**	**3.755E-03**	D	spherical
		50	0.106	2110	0.84	0.0103	D	spherical
	2	10	0.180	2110	0.57	0.0757	D	spherical
		25	0.214	2104	**0.59**	**4.287E-03**	D	exponential
		50	0.231	568	0.02	7.149E-03	D	linear
	3	10	0.187	2110	**0.83**	0.0328	D	spherical
		25	0.204	1678	0.82	**5.732E-04**	D	spherical
		50	0.1971	2110	0.70	5.678E-03	D	spherical

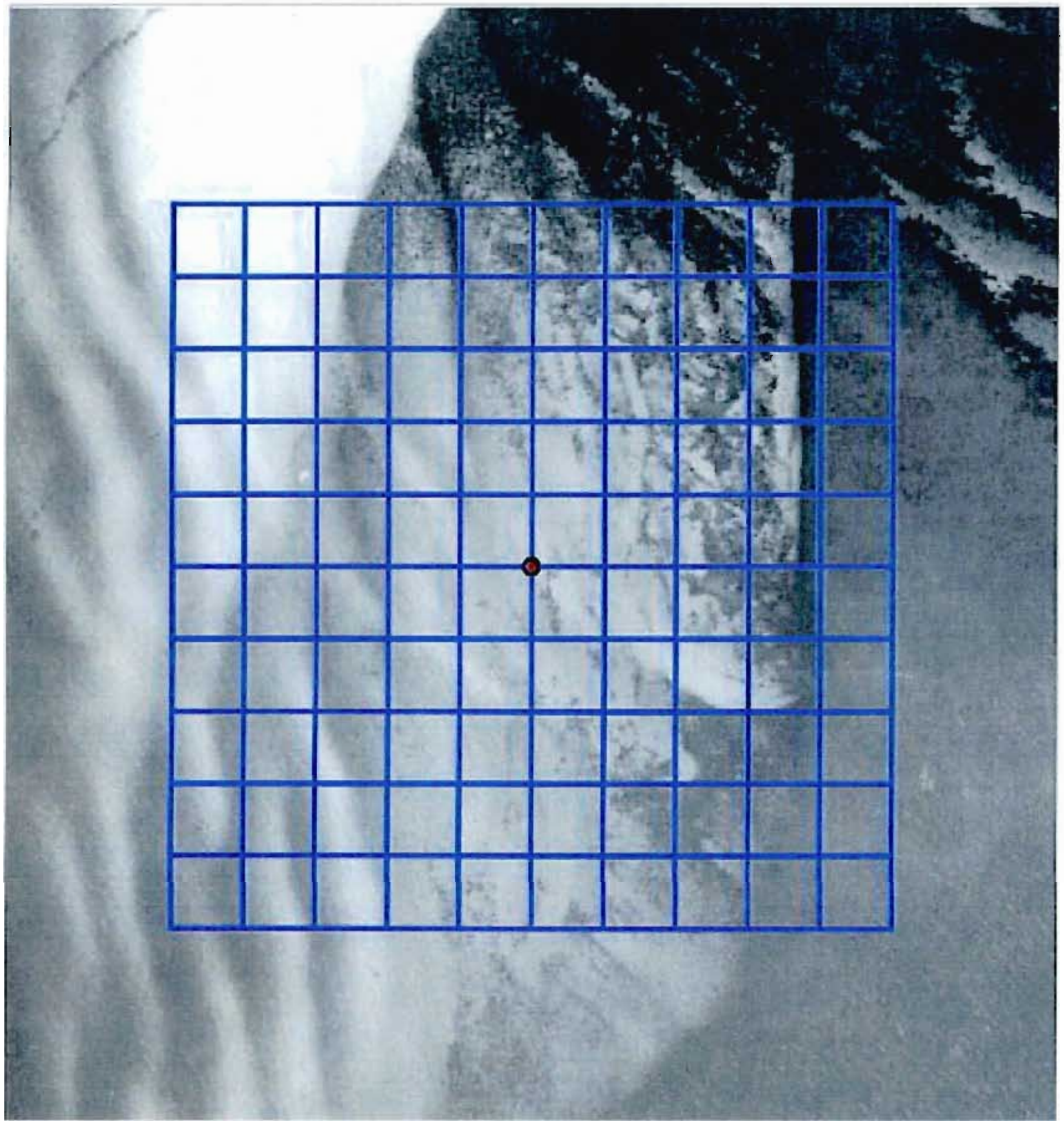


Figure 1a. Chesapeake Bay sites 10 centered in 50m x 50m fishnet superimposed on black and white digital aerial photography at 1:5000 scale. Spatial arrangement of dark tones and color depicting patchy submerged aquatic vegetation.

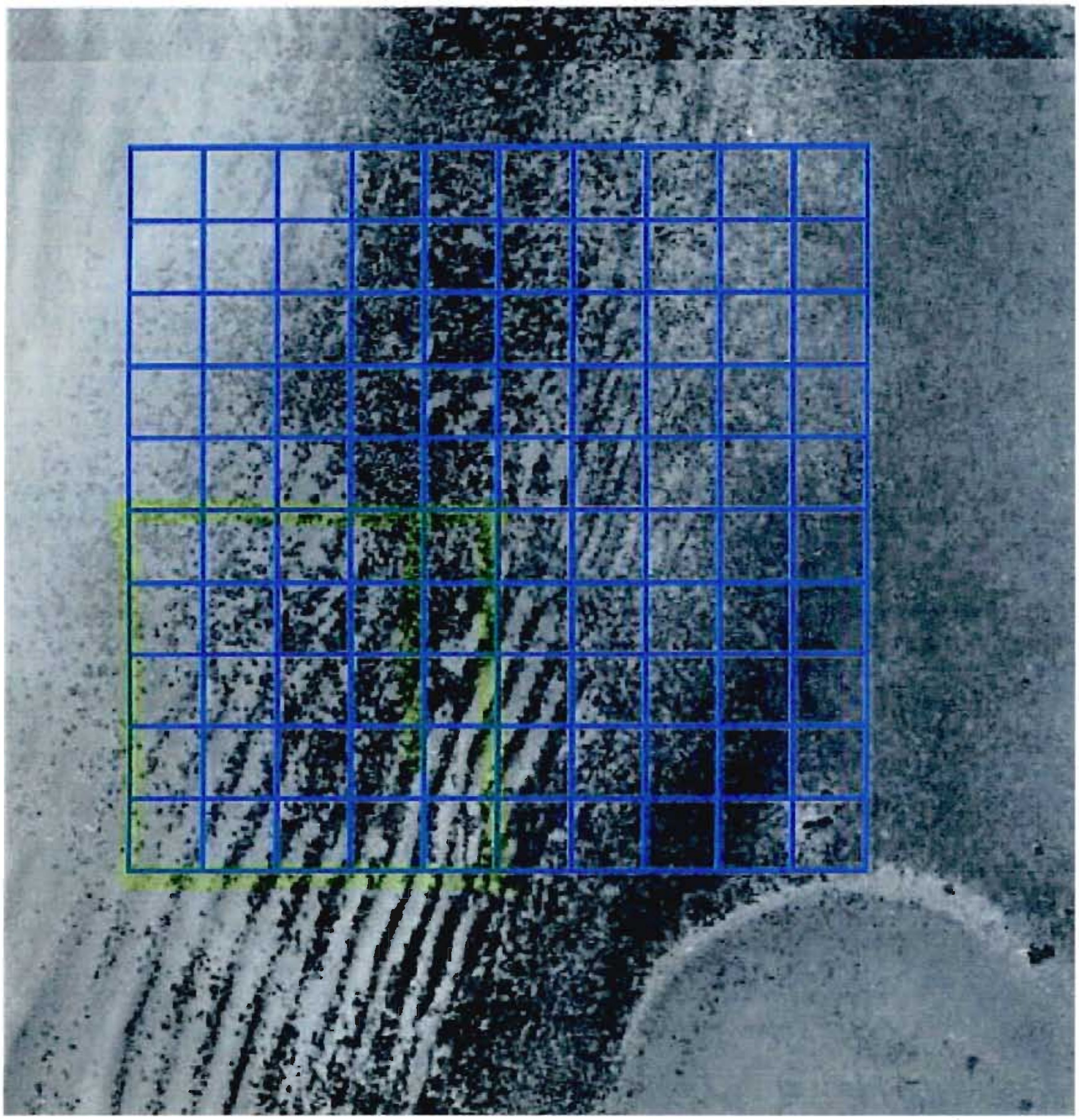


Figure 1b. Chesapeake Bay Site 48a centered in 50m x 50m fishnet superimposed on black and white digital aerial photography at 1:5000 scale. Dark tones are characteristic of spatial patterns of submerged aquatic vegetation.

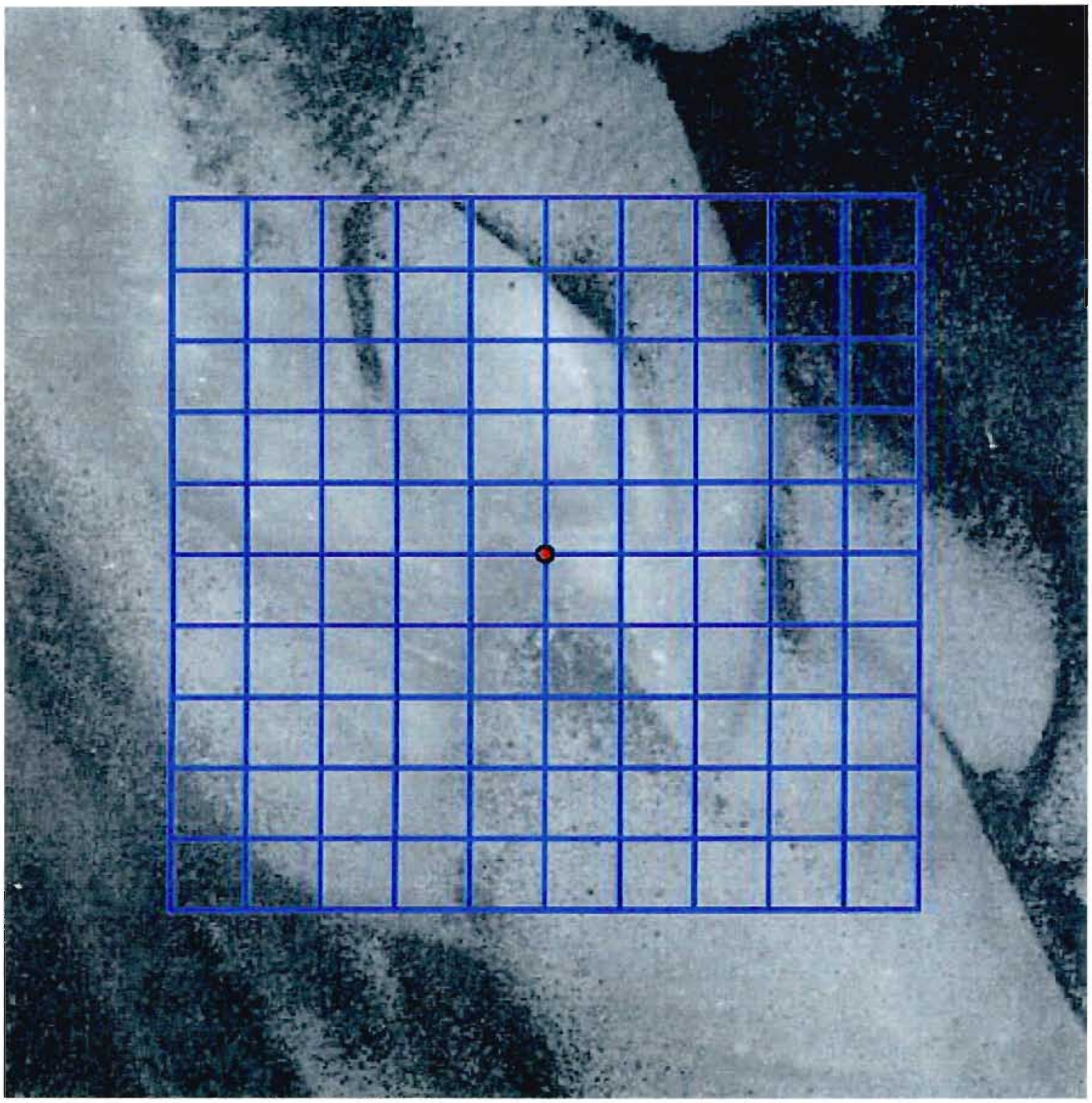


Figure 1c. Chesapeake Bay Site 60 centered in 50m x 50m fishnet superimposed on black and white digital aerial photography at 1:5000 scale. Dark tones are characteristic of spatial patterns of submerged aquatic vegetation.

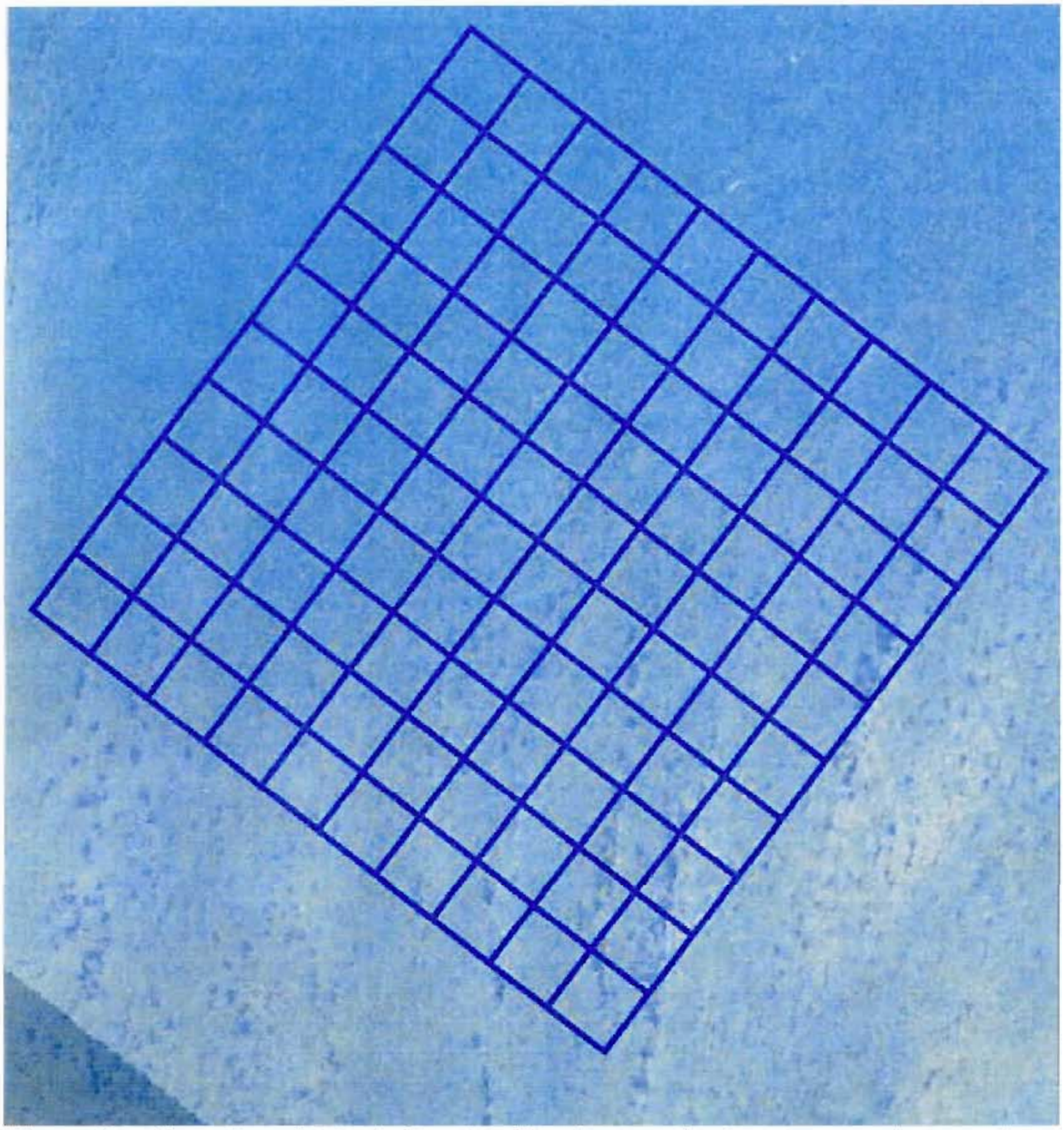


Figure 2a. Core Sound, North Carolina Site 1: natural color photography superimposed with 50m x 50m fishnet and exported at 1:5000 scale. Dark tones and texture are patchy seagrass surrounded by light tones of sandy bottom.

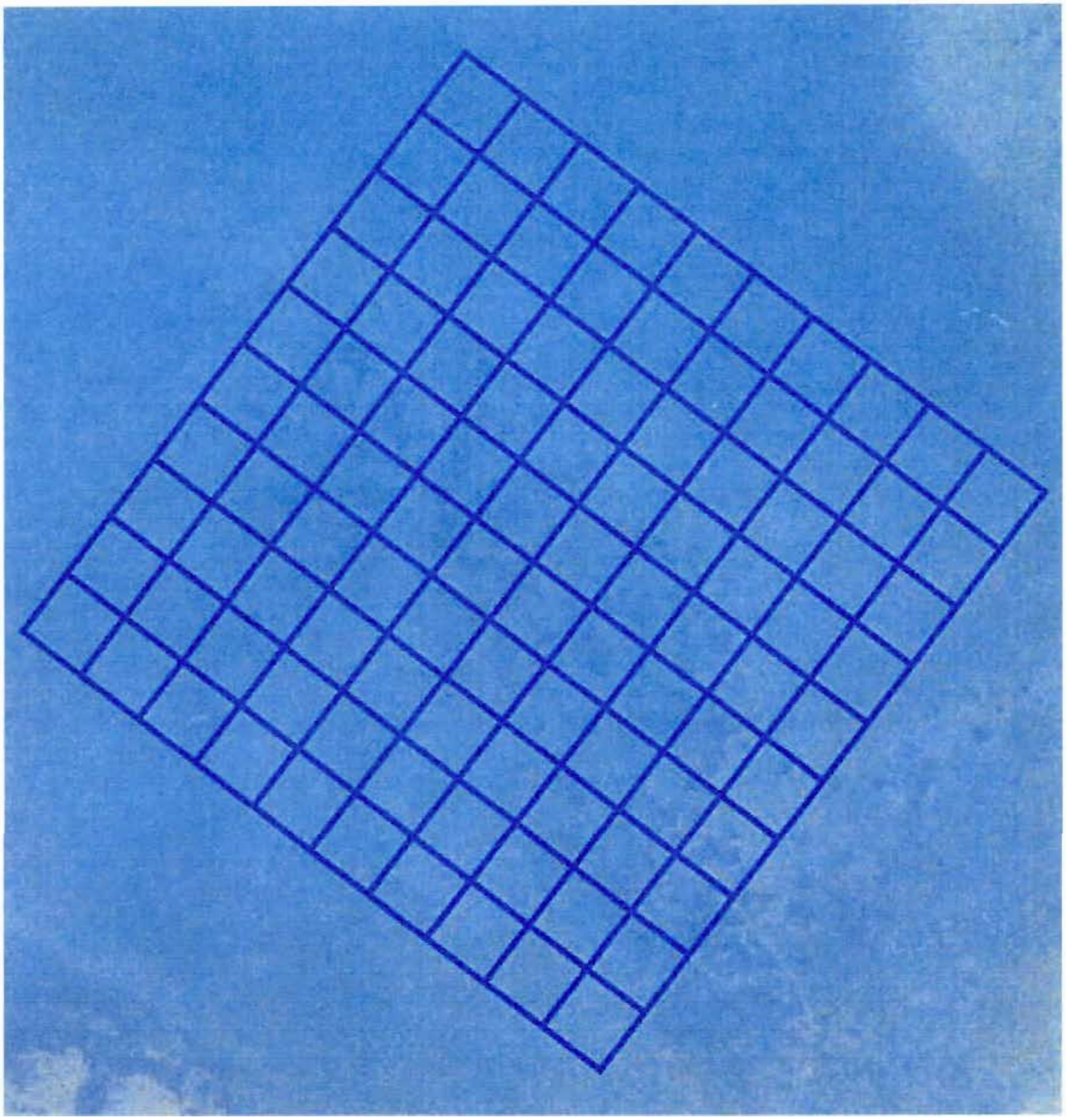


Figure 2b. Core Sound, North Carolina Site 2: digital natural color aerial photography superimposed with 50m x 50m fishnet and exported at 1:5000 scale. Dark tones and texture indicate patchy seagrass surrounded with deeper water than the seagrass patches in Figure 3a.

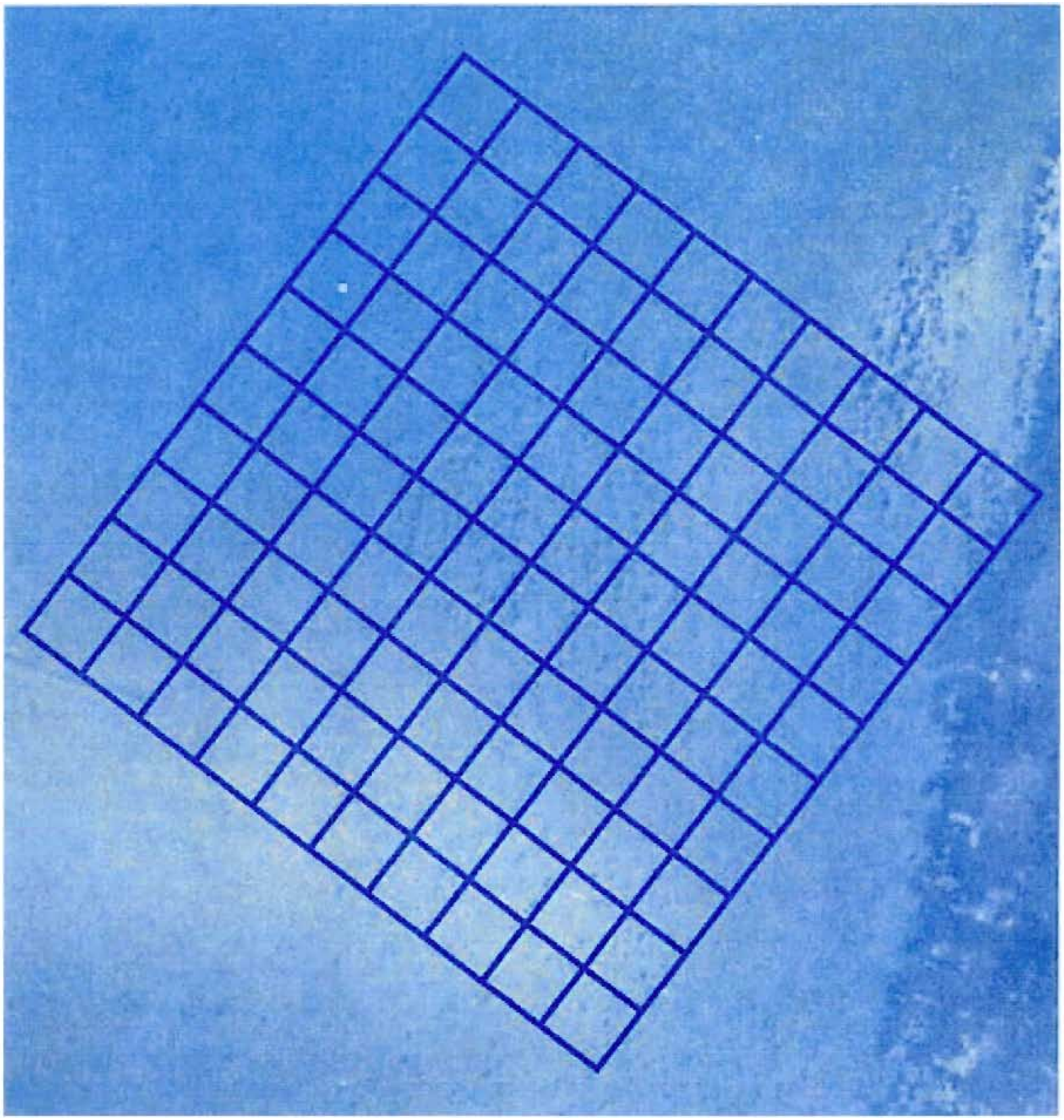


Figure 2c. Core Sound, North Carolina Site 3: digital natural color aerial photography superimposed with 50m x 50m fishnet and exported at 1:5000 scale. Darker tones and texture characterize patchy seagrass surrounded by lighter tones of sandy bottom. Far right corner of image shows dense seagrass habitat.

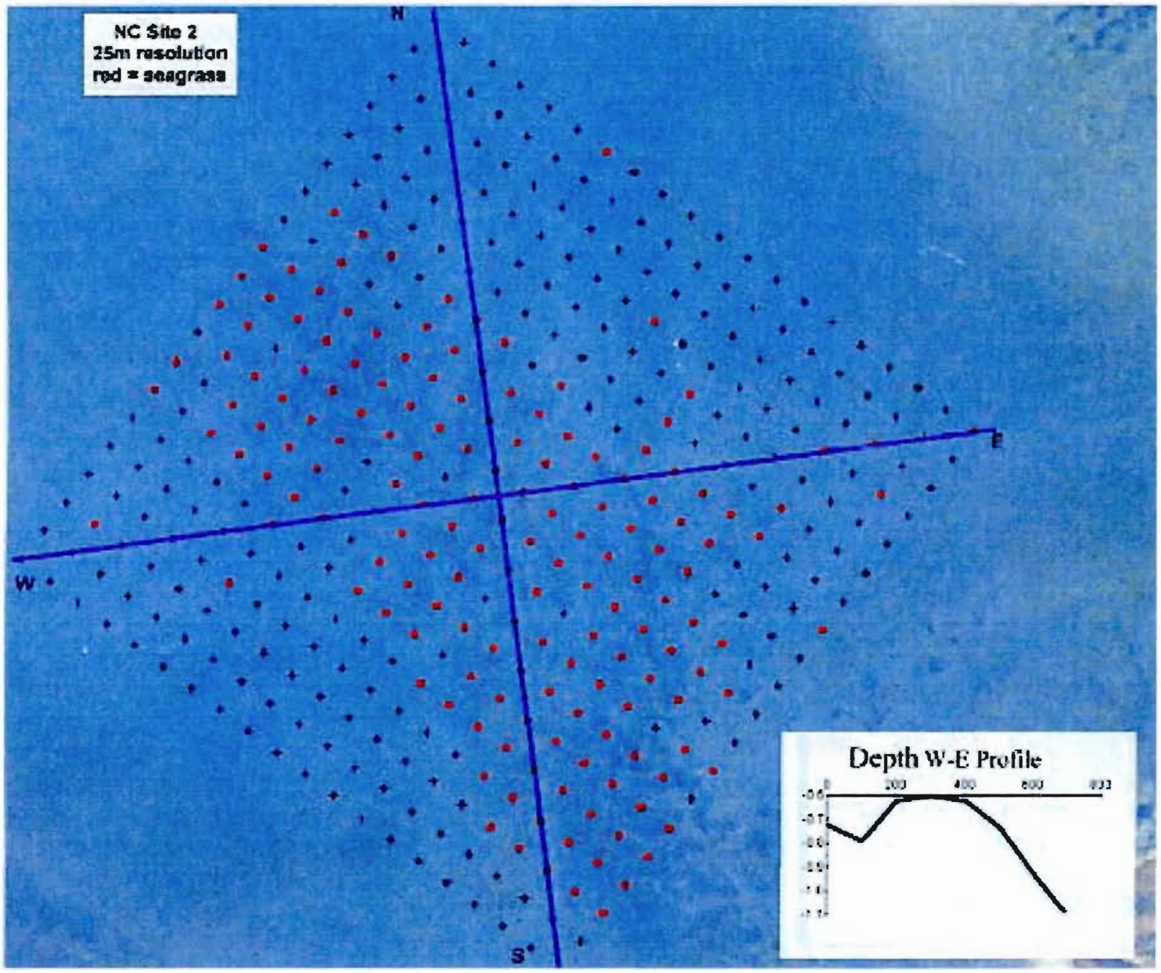


Figure 3a. Tampa Bay Site 2 centered in 50m x 50m fishnet superimposed on digital natural color aerial photography at 1:5000 scale. Spatial patterns of dark tones and color indicating patchy seagrass.

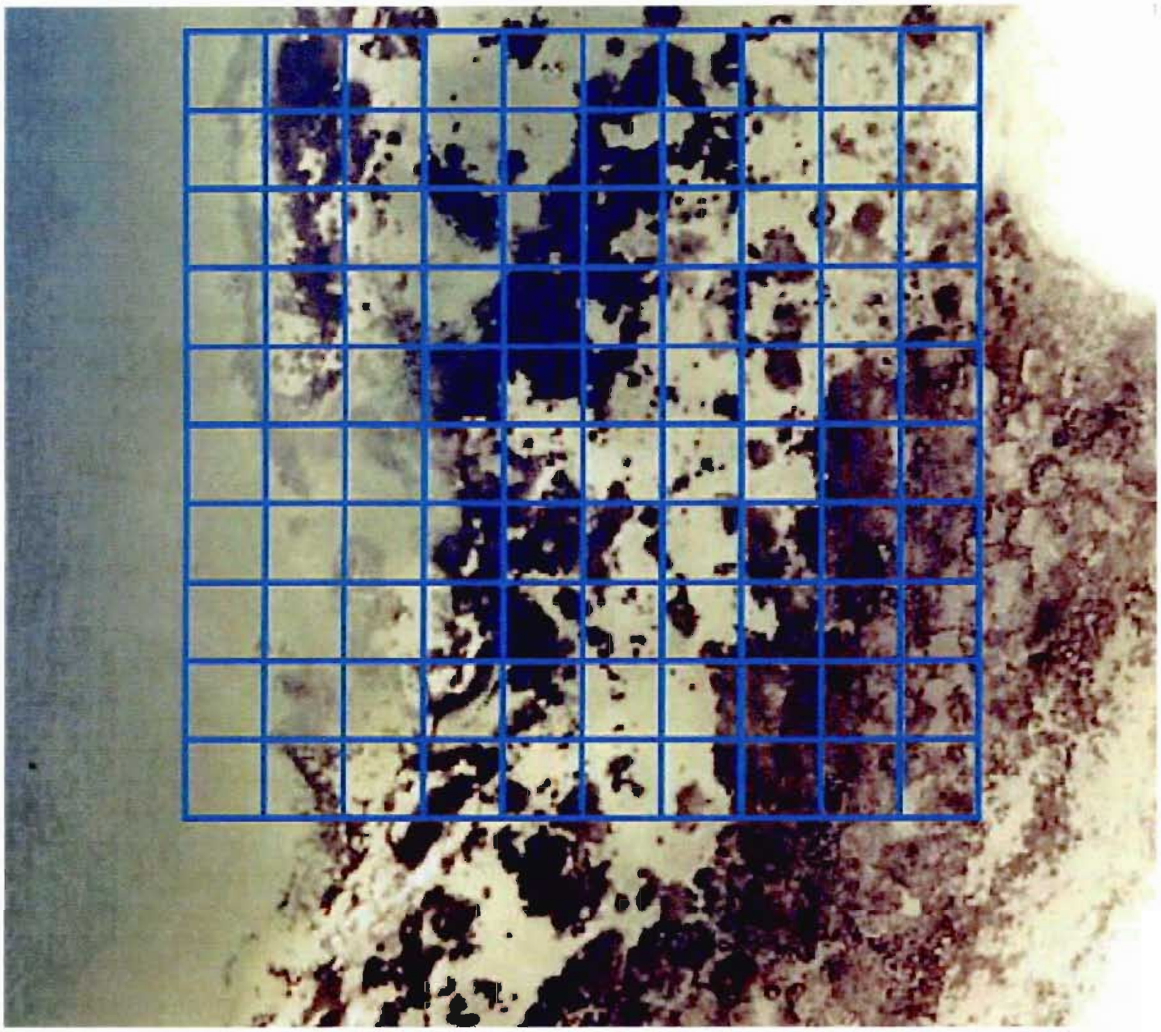


Figure 3b. Tampa Bay Site 2 centered in 50m x 50m fishnet superimposed on digital natural color aerial photography at 1:5000 scale. Spatial patterns of dark tones and color indicating patchy seagrass.

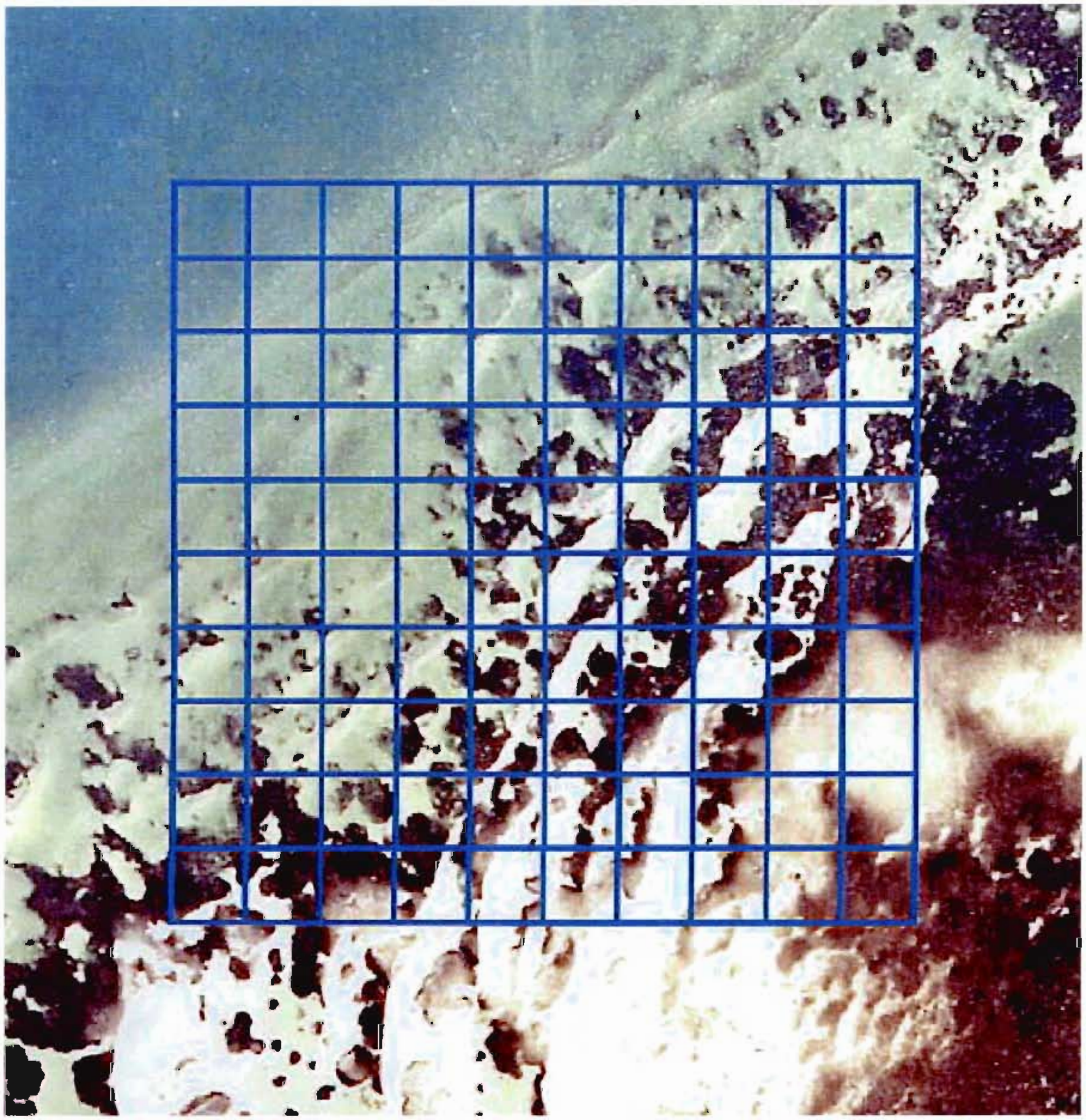


Figure 3c. Tampa Bay Site 3 centered in 50m x 50m fishnet superimposed on natural color digital aerial photography at 1:5000 scale. Spatial patterns of dark tones and color indicating patchy seagrass.

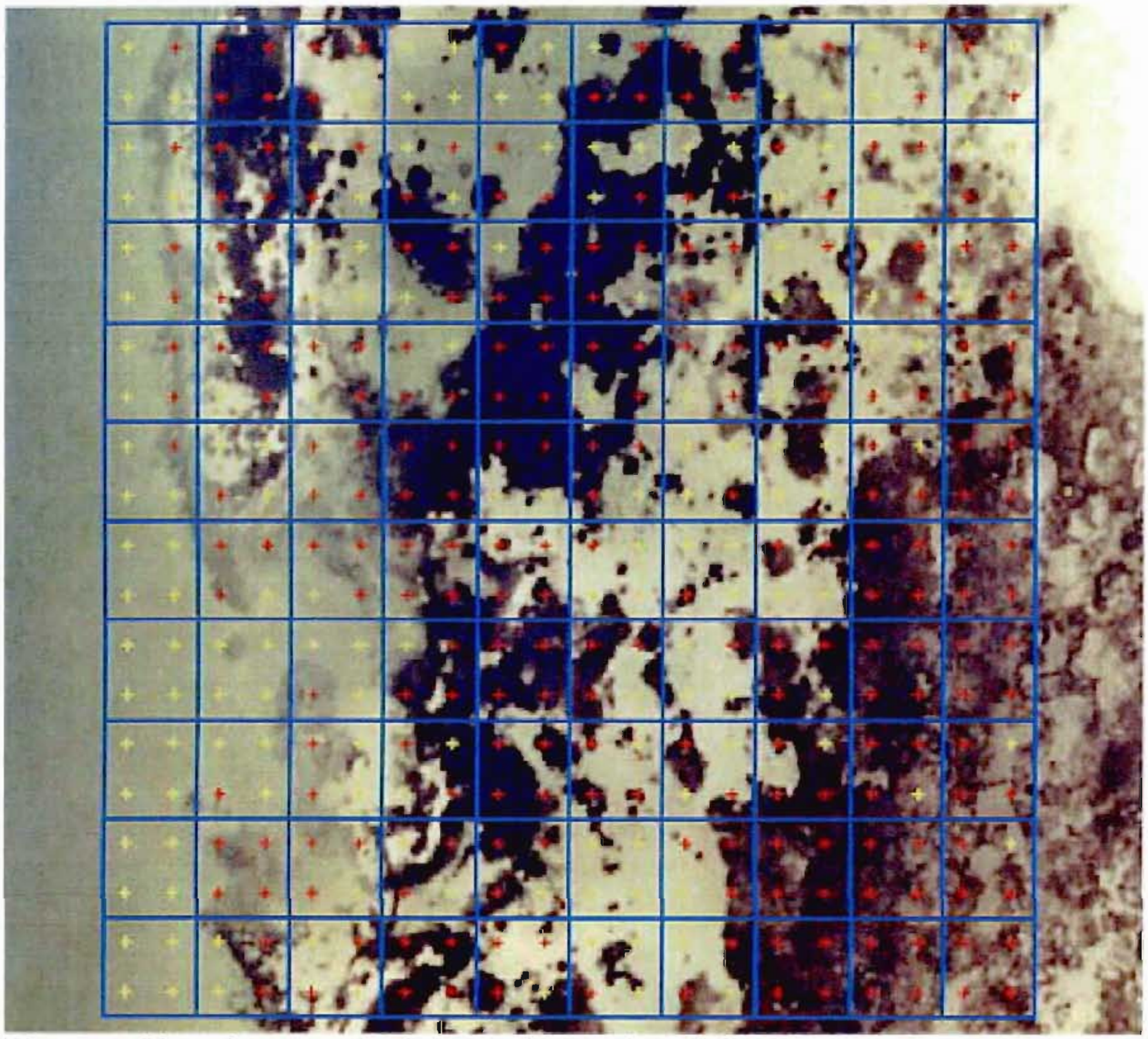


Figure 4. Photo-interpreted points superimposed on digital aerial photography at Site 2 in Tampa Bay. Blue outline is 50m fishnet cell covering 50mm x 500m extent; red and yellow crosses represent seagrass and "no seagrass" at 25m sampling resolution; image scale is 1:3000.

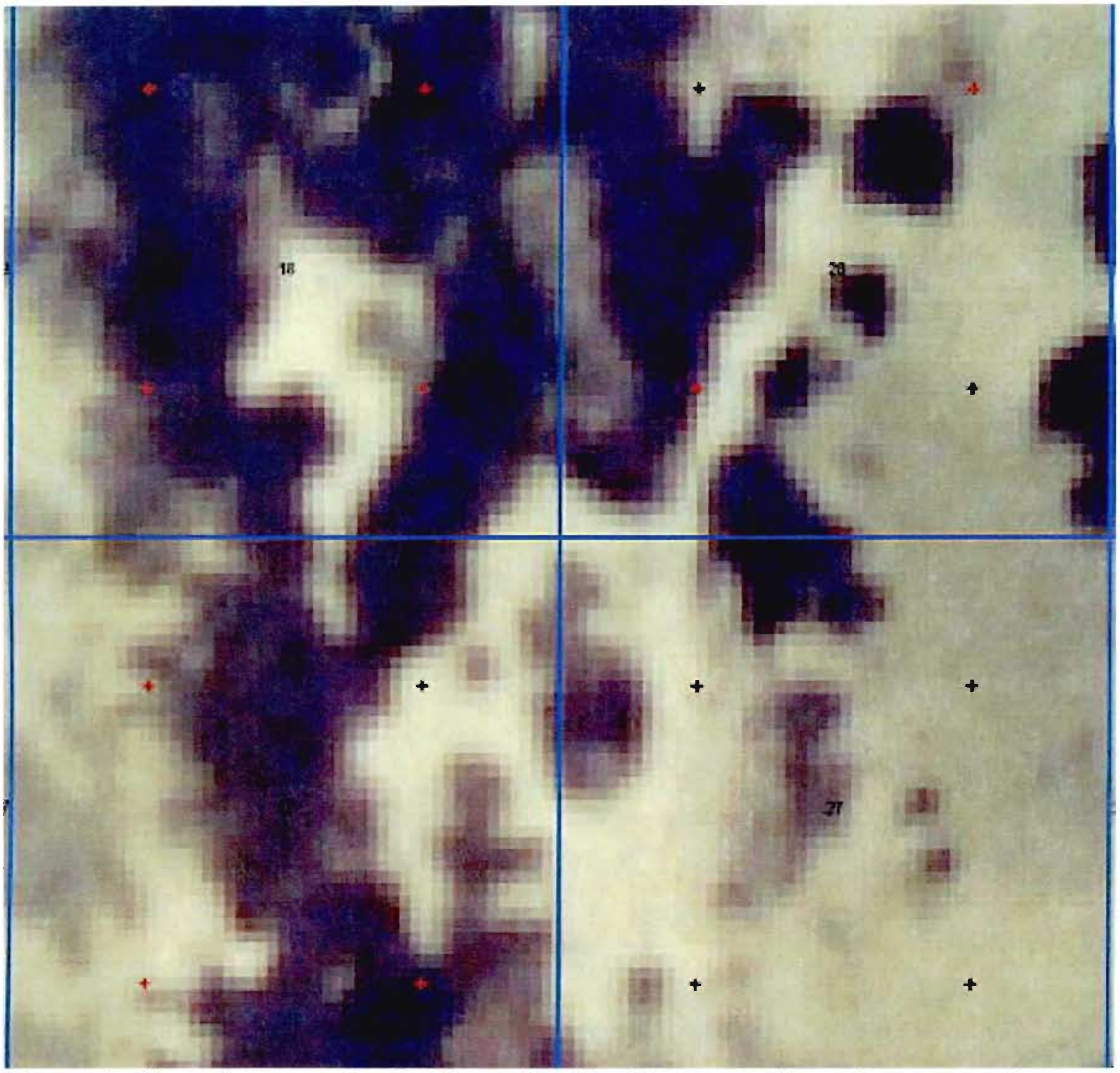
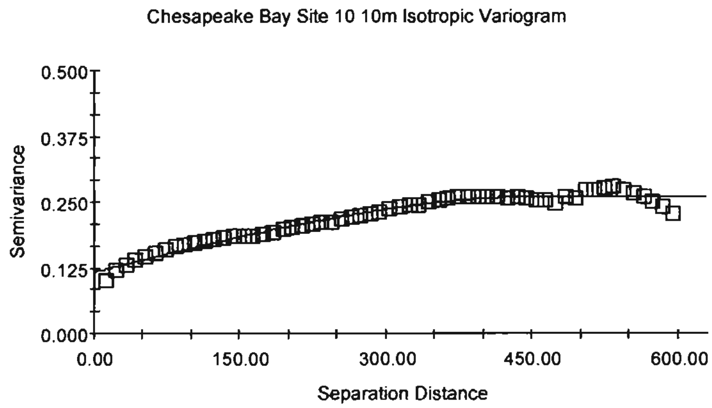
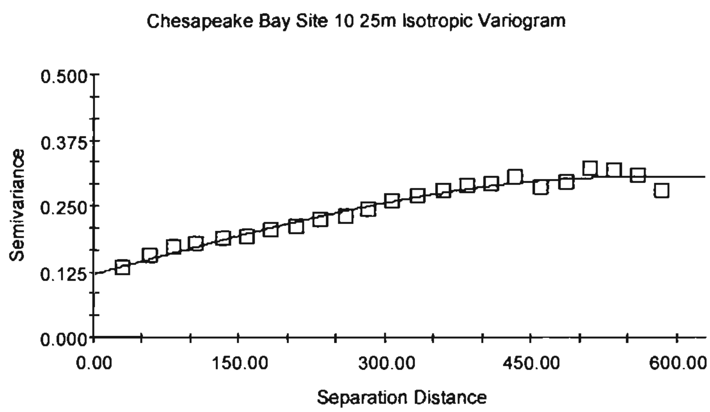


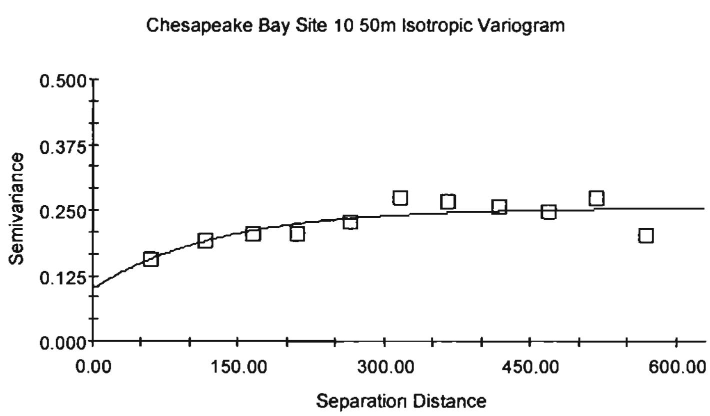
Figure 5. Photo-interpreted points located at Site 2 in Tampa Bay. Zooming to the 1:500 scale is often necessary to finalize interpretations. Red crosses are seagrass and black crosses are absence of seagrass.



Spherical model (Co = 0.1164; Co + C = 0.2608; Ao = 469.00; r2 = 0.960; RSS = 4.613E-03)

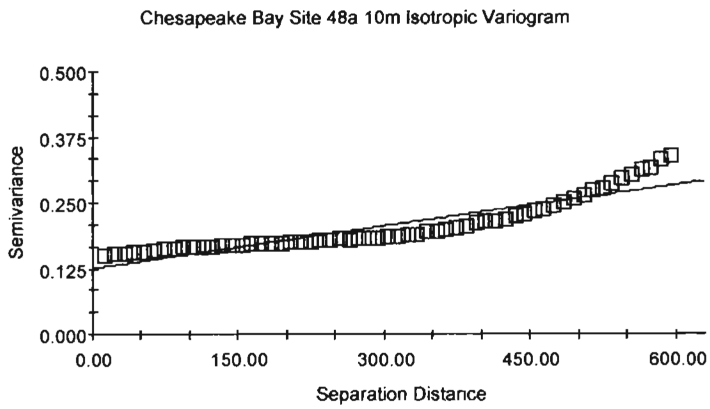


Spherical model (Co = 0.1196; Co + C = 0.3052; Ao = 555.00; r2 = 0.971; RSS = 2.031E-03)

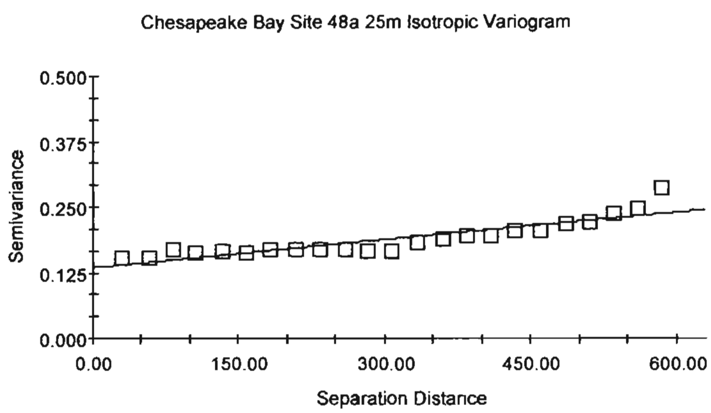


Exponential model (Co = 0.0993; Co + C = 0.2546; Ao = 130.00; r2 = 0.653; RSS = 5.149E-03)

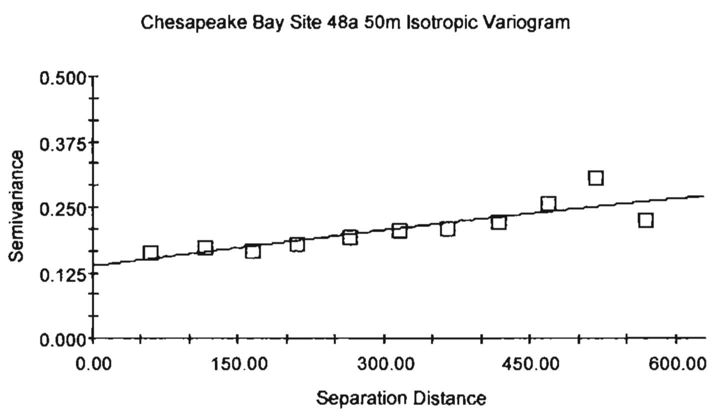
Figure 6a: Isotropic variograms for each sampling resolution for Chesapeake Bay site 10.



Spherical model (Co = 0.1250; Co + C = 0.5060; Ao = 2110.00; r2 = 0.837; RSS = 0.0238)

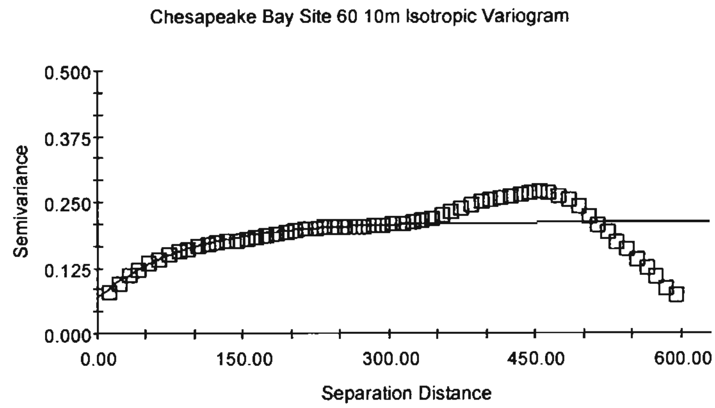


Spherical model (Co = 0.1343; Co + C = 0.3876; Ao = 2110.00; r2 = 0.793; RSS = 5.261E-03)

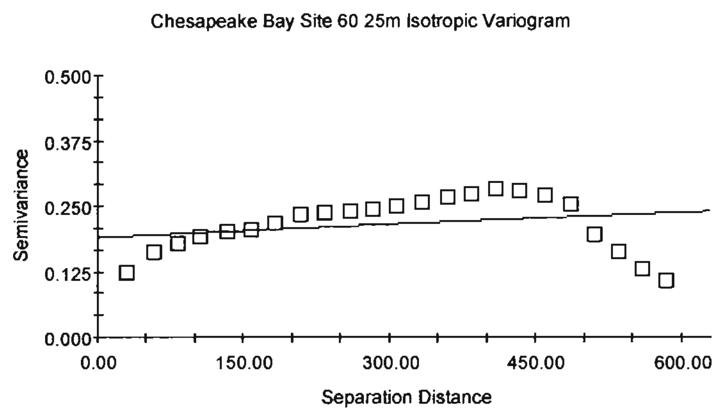


Spherical model (Co = 0.1376; Co + C = 0.3272; Ao = 1222.00; r2 = 0.720; RSS = 5.068E-03)

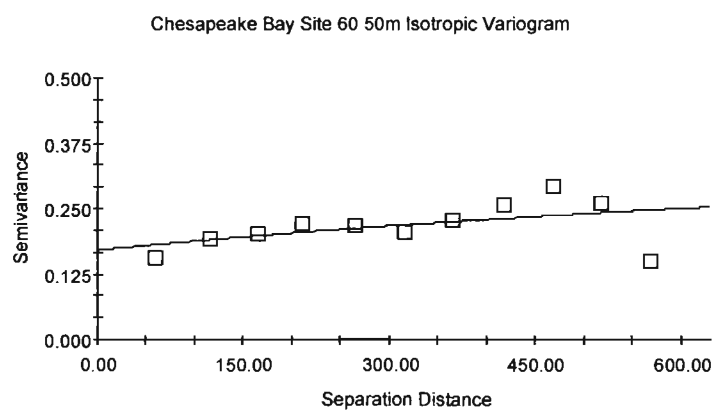
Figure 6b: Isotropic variograms for each sampling resolution for Chesapeake Bay site 48a.



Exponential model (Co = 0.0666; Co + C = 0.2102; Ao = 87.00; r2 = 0.379; RSS = 0.0927)



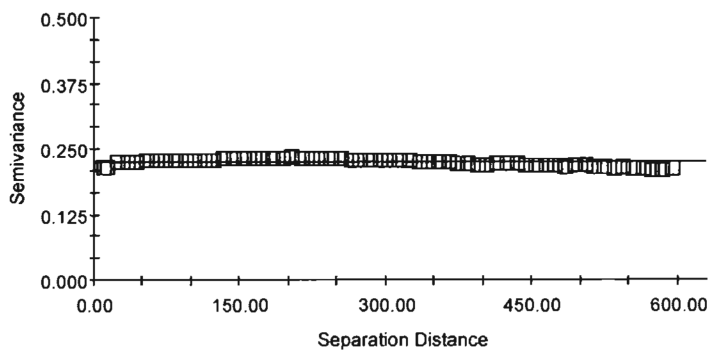
Exponential model (Co = 0.1899; Co + C = 0.3808; Ao = 2110.00; r2 = 0.019; RSS = 0.0595)



Exponential model (Co = 0.1707; Co + C = 0.3424; Ao = 969.00; r2 = 0.211; RSS = 0.0147)

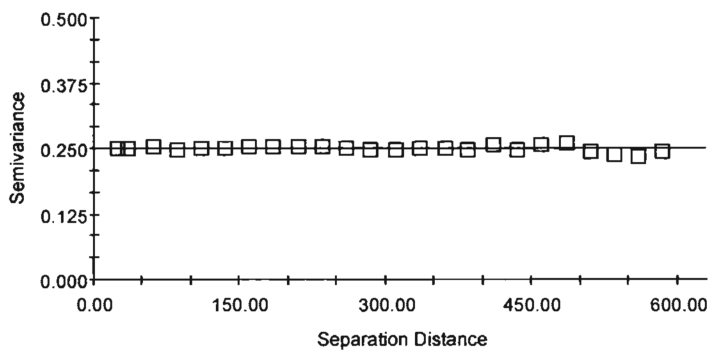
Figure 6c: Isotropic variograms for each sampling resolution for Chesapeake Bay site 60.

NC Site 1 10m Isotropic Variogram



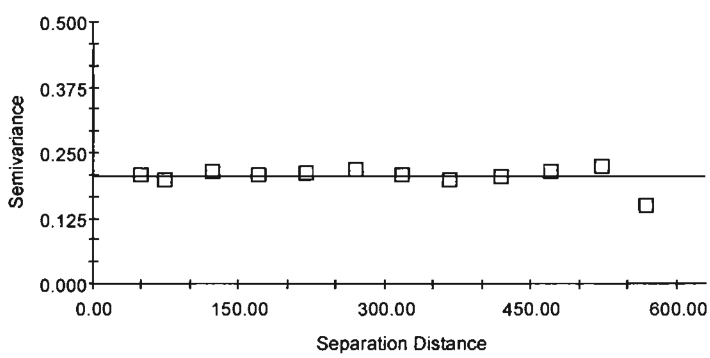
Linear model (Co = 0.22; Co + C = 0.22; Ao = 594.52; r2 = 0.500; RSS = 2.843E-03)

NC Site 1 25m Isotropic Variogram



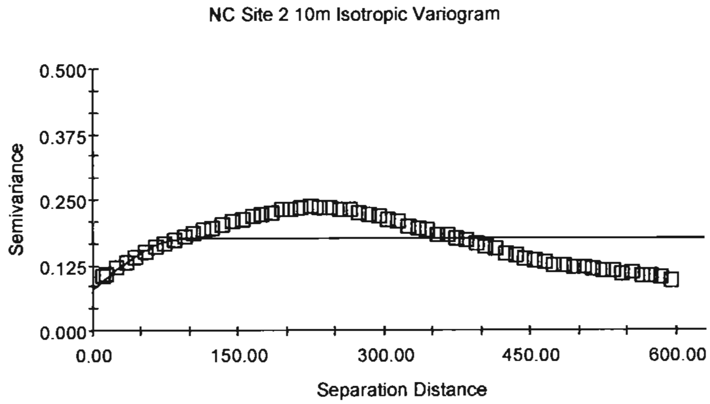
Linear model (Co = 0.2492; Co + C = 0.2492; Ao = 583.72; r2 = 0.132; RSS = 7.444E-04)

NC Site 1 50m Isotropic Variogram

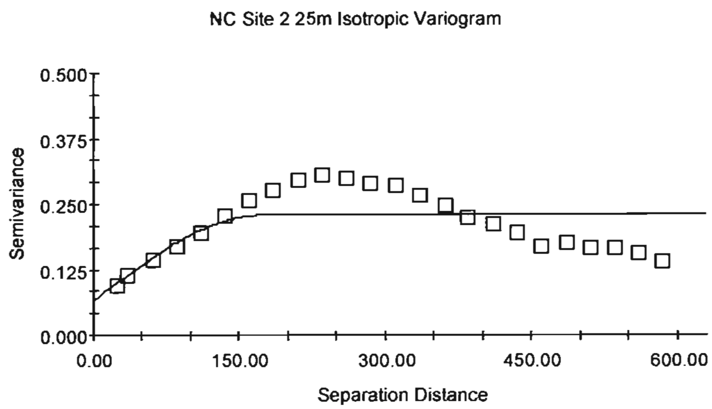


Linear model (Co = 0.2042; Co + C = 0.2042; Ao = 568.33; r2 = 0.104; RSS = 3.829E-03)

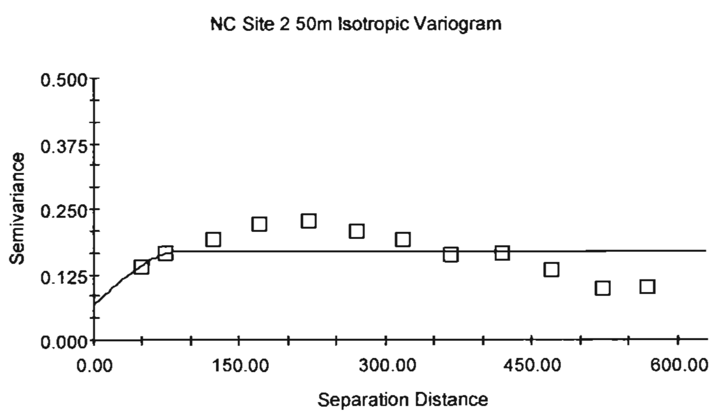
Figure 7a: Isotropic variograms for each sampling resolution for Core Sound site 1.



Spherical model (Co = 0.0770; Co + C = 0.1740; Ao = 92.00; r2 = 0.120;
RSS = 0.108)

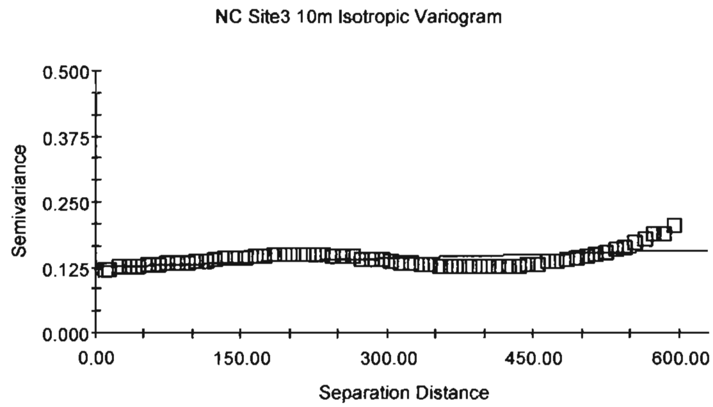


Spherical model (Co = 0.0656; Co + C = 0.2292; Ao = 174.00; r2 = 0.381;
RSS = 0.0574)

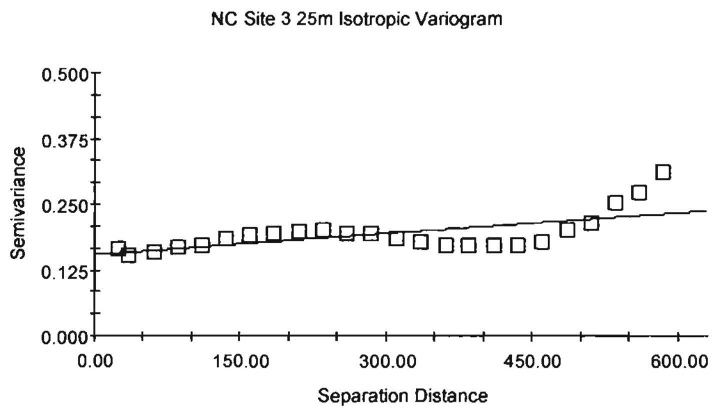


Spherical model (Co = 0.0664; Co + C = 0.1698; Ao = 91.00; r2 = 0.037;
RSS = 0.0198)

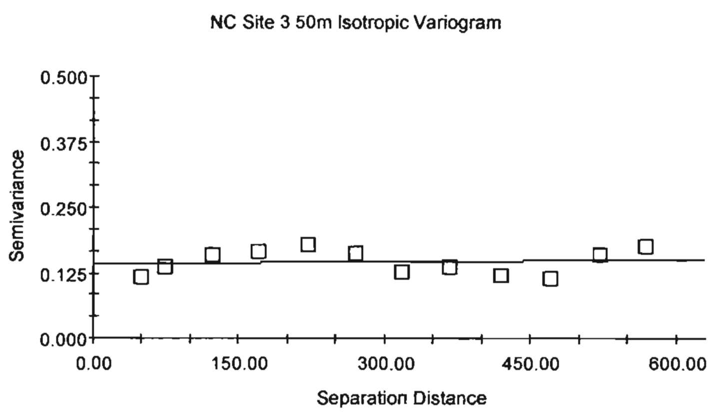
Figure 7b: Isotropic variograms for each sampling resolution for Core Sound site 2.



Exponential model (Co = 0.1250; Co + C = 0.2510; Ao = 2110.00; r2 = 0.236; RSS = 0.0128)

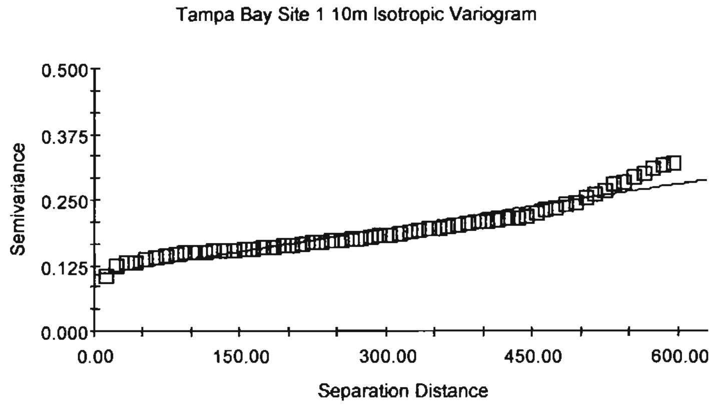


Spherical model (Co = 0.1539; Co + C = 0.3468; Ao = 2110.00; r2 = 0.424; RSS = 0.0179)

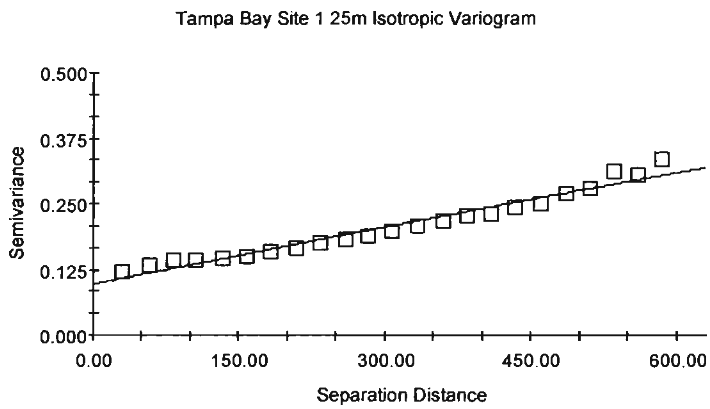


Linear model (Co = 0.1424; Co + C = 0.1492; Ao = 568.33; r2 = 0.008; RSS = 6.063E-03)

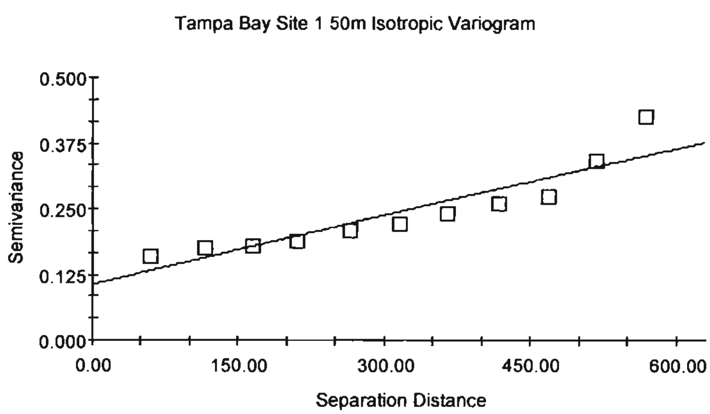
Figure 7c: Isotropic variograms for each sampling resolution for Core Sound site 3.



Spherical model (Co = 0.1070; Co + C = 0.5220; Ao = 2110.00; r2 = 0.914; RSS = 0.0134)

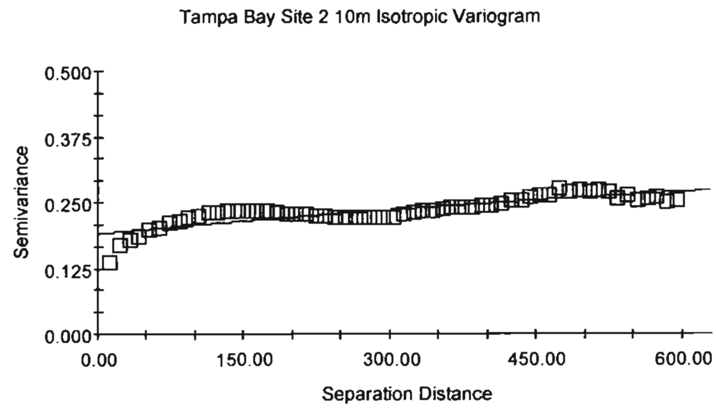


Spherical model (Co = 0.0970; Co + C = 0.5600; Ao = 1899.00; r2 = 0.959; RSS = 3.534E-03)

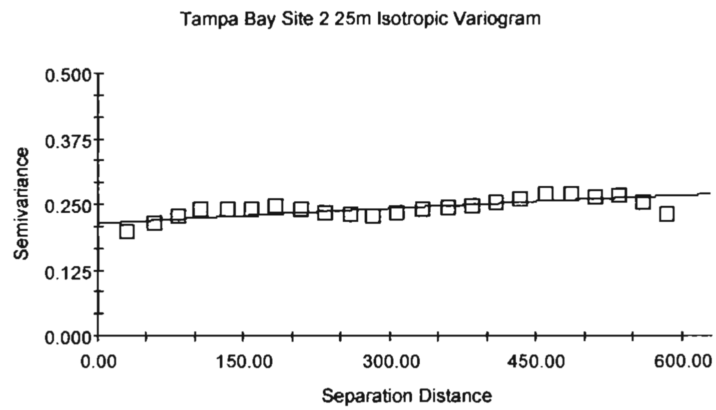


Spherical model (Co = 0.1060; Co + C = 0.7280; Ao = 2110.00; r2 = 0.840; RSS = 0.0103)

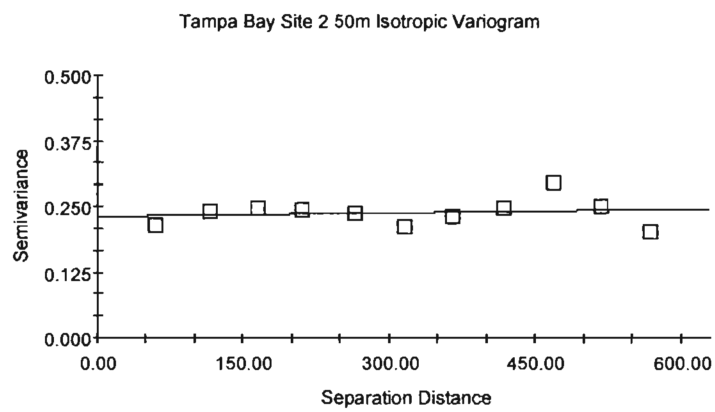
Figure 8a: Isotropic variograms for each sampling resolution for Tampa Bay site 1.



Exponential model (Co = 0.1905; Co + C = 0.3820; Ao = 1125.00; r2 = 0.717; RSS = 0.0114)



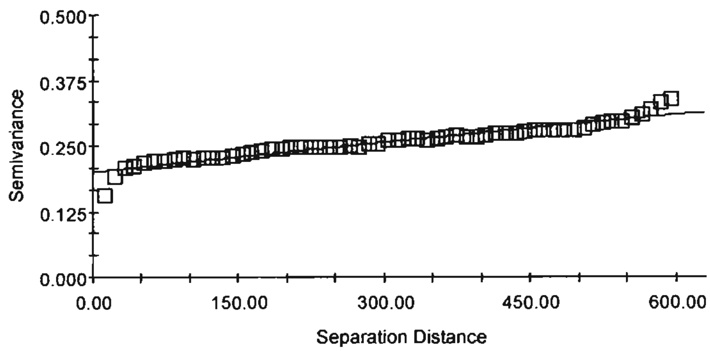
Exponential model (Co = 0.2136; Co + C = 0.4282; Ao = 2110.00; r2 = 0.528; RSS = 3.371E-03)



Linear model (Co = 0.2310; Co + C = 0.2435; Ao = 568.33; r2 = 0.021; RSS = 7.149E-03)

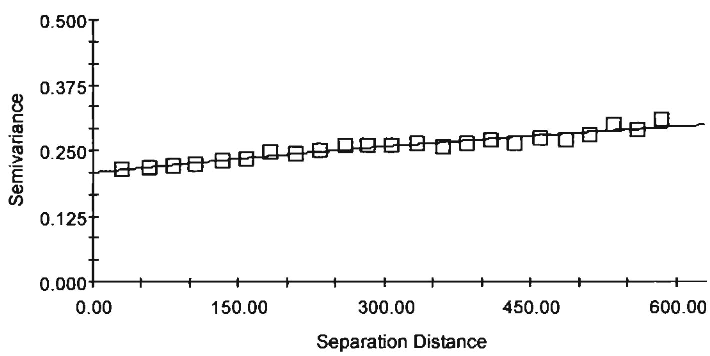
Figure 8b: Isotropic variograms for each sampling resolution for Tampa Bay site 2.

Tampa Bay Site 3 10m Isotropic Variogram



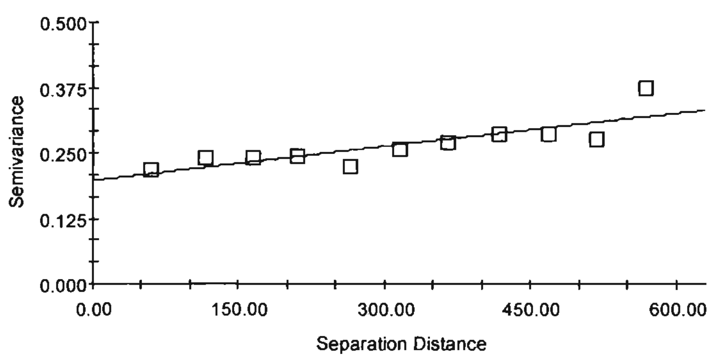
Spherical model (Co = 0.2002; Co + C = 0.4014; Ao = 1591.00; r2 = 0.909; RSS = 5.661E-03)

Tampa Bay Site 3 25m Isotropic Variogram



Exponential model (Co = 0.2081; Co + C = 0.4312; Ao = 1220.00; r2 = 0.931; RSS = 9.637E-04)

Tampa Bay Site 3 50m Isotropic Variogram



Spherical model (Co = 0.1971; Co + C = 0.5062; Ao = 2110.00; r2 = 0.699; RSS = 5.678E-03)

Figure 8c: Isotropic variograms for each sampling resolution for Tampa Bay site 3.

APPENDIX D

Steps used to create photointerpretation points using ESRI ArcGIS software.

1. Add image that encompasses a site to ArcMap.
2. Using the Fishnet (Nicholas 2003) extension available from ESRI, create a fishnet at the appropriate scale.
    a) Enter UTM XY coordinates (lower left corner of fishnet).
    b) Subtract 250m from the X and Y coordinates to center fishnet on site
    c) Create 10m x 10m fishnet: Rows = 50; Columns = 50; Cell size: Width = 10; Height = 10.
    d) Create 25m x 25m fishnet: Rows = 20; Columns = 20; Cell size: Width = 25; Height = 25.
    e) Create 50m x 50m fishnet: Rows = 10; Columns = 10; Cell size: Width = 50; Height = 50.
    f) Name output shapefile
    g) Define coordinate system by image's coordinate system.
3. Use the XTools (DataEast 2002) extension available from ESRI, to create points (centroids) at the center of each fishnet cell and add XY coordinates.
    a) Select "Shapes to Centroid" tool.
    b) Select output shapefile.
    c) Add XY coordinates.

Steps used to interpret aerial photographs using ESRI ArcGis software.

1. Overlay centroid shapefile to be interpreted on image with site of interest.
2. Open centroid shapefile attribute table.
    a) Add a numeric field named "class" to define centroid attributes
3. Edit shapefile.
    a) Select individual centroids that are judged to be seagrass at a large view (e.g. 1:3000)
    b) Change view (1:2000) and select additional centroids or deselect those erroneously selected.
    c) Continue at greater scales up to but not exceeding 1:500
4. In the attribute table right click the class field and then choose "calculate values".
5. Change values to Class = 1.

DataEast (2002) XTools Pro for ArcGIS Desktop. Version 1.1.0, Build 30
http://www.xtoolpro.com

Nicholoas, R (2003) Create a grid polygon shapefile.
http://arcscripts.esri.com/details.asp?dbid=12807

APPENDIX E

Table 1: Chesapeake Bay seagrass percent cover based on historical aerial photointerpretations (50m x 50m grid cells). Also reported are Site IDs, XY coordinates, and REI values for each site.

Site	1995	1996	1997	Index
1	46	74	72	1407
4	8	96	98	5093
5	76	2	2	2756
6	34	67	81	4773
7	67	35	2	972
8	91	58	70	3553
9	63	76	56	1698
10	93	93	96	27378
11	0	19	51	31266
13	92	98	40	27561
15	73	79	76	18087
16	42	90	47	33839
18	88	93	94	12092
20	65	75	43	10172
21	91	61	94	20131
23	74	93	46	17246
24	76	69	75	19566
25	84	78	84	15502
28	0	96	99	12320
31	74	74	38	0
36	25	27	33	710
38	30	27	28	5772
40	22	4	1	3855
41	36	74	6	4163
42	20	26	33	599
48	90	98	97	7864
50	95	99	98	6622
53	9	22	26	6196
56	21	38	56	7429
58	81	44	91	9629
60	96	100	100	2306

Table 2: Core Sound seagrass percent cover based on historical aerial photointerpretations (50m x 50m grid cells). Also reported are Site IDs, XY coordinates, and REI values for each site.

Site	1995	Index
897	84	1545
931	96	709
830	55	3
831	71	1827
763	97	1569
727	67	2536
2001	58	2773
464	34	3764
422	12	4013
2002	64	3475
542	18	3380
617	25	3456
582	53	2875
5422	51	3101
622	93	2405
657	89	32
1120	19	685
1096	28	91
1045	26	1543
1080	25	1334
991	64	2608
992	28	1942
925	29	2719
862	44	2891
17	64	1712
21	29	1967
23	61	1218
24	27	573
28	30	3239
897	84	1545
931	96	709

Table 3: Tampa Bay seagrass percent cover based on historical aerial photointerpretations (50m x 50m grid cells). Also reported are REI values for each site.

Site	1950	1999	2002	Index
3	0	0	0	1206633
4	65	43	46	1393966
5	63	24	33	1682369
6	23	21	26	581677
7	65	57	59	580440
8	21	4	5	682803
9	42	81	68	682803
10	41	69	52	782923
15	95	0	0	696962
16	93	0	0	680983
17	75	3	1	576415
18	100	1	0	531546
21	90	49	57	1827847
23	89	10	8	1422769
24	1	31	44	350019
25	57	17	25	722225
26	16	18	27	599167
27	87		50	481351
28	1	0	1	197683
32	86	33	62	867575
33	87	46	59	979192
34	47	38	44	1445227
39	50	4	4	713834
43	58	61	60	1922614
44	81	92	92	1292596
47	100	100	100	188137
58	82	98	100	71343