TEMPORAL VARIATION IN DEPTH DISTRIBUTION OF COASTAL SUBMERGED VEGETATION:

Use of Dynamic Segmentation in Visualization of Transect-Surveyed Vegetation

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ABSTRACT

Annual/seasonal distribution of coastal submerged aquatic vegetation (SAV) along transects in Lake Pontchartrain, LA and Grand Bay National Estuarine Research Reserve, MS was visualized using dynamic segmentation. Vegetation survey data along the transects were stored as text files and then imported into ArcMap. SAV patches along the survey transects were added as linear feature events onto routes (transect lines). Water depth measurements, made at 3 meter intervals along each transect, for each year were interpolated into a grid surface and the water depth levels were reclassified into 0.3 m-depth intervals. SAV distribution along the line transects was overlaid on the grid surface. The temporal variation of SAV transect distribution was visualized and the vegetation patch patterns were related to the underwater sediment contours (or geomorphological structures) using semivariance analyses and fractal dimensions. Annual SAV abundance and distribution changes were primarily correlated by water clarity at large scales. At small sampling scales, the SAV patch pattern was related with sandbar structures.

1.0 INTRODUCTION

1.1 Importance of Temporal and Spatial Analyses in Coastal Vegetation Studies

Coastal Submerged Aquatic Vegetation (SAV) provides critical habitat for fish and wildlife and serves as an excellent water quality indicator (Dennison et al. 1993). Temporal changes in its distribution and abundance have been used to understand trends in aquatic environmental quality (Orth and Moore 1983). Areas that support estuarine SAV usually are impacted by greater anthropogenic influences and natural environmental fluctuations than marine seagrasses (Stevenson 1988). Long-term information on SAV dynamics in a specific landscape is needed to separate long-standing anthropogenic impacts from natural variation in the annual and seasonal patterns of SAV coverage (Lee Long and Thom 2001). Use of Geographic Information System (GIS) in coastal and estuarine studies has been increasing rapidly (Urbanski 1999, Thumerer et al. 2000, Lathrop et al. 2001, Higinbotham et al. 2004) as the importance of landscape level habitat assessments continues to grow.

As a part of long-term monitoring projects for coastal habitats in Louisiana and Mississippi, SAV has been surveyed annually and seasonally using fixed transects at permanent survey sites. At each survey site, SAV depth distribution has been documented along three to five transects that are perpendicular to the shoreline. Temporal and spatial dynamics in the patch size and patch distribution provide important information that is needed to understand SAV seasonal growth, inter- or intra-specific competition, and interdependency of landscape features with SAV patches.

1.2 Application of Dynamic Segmentation to Linear Features

Dynamic segmentation is a technique developed to present and analyze changes in attributes along linear features (Cadkin 2002a; ESRI 2004). The attributes that change along the linear feature are known as events in the technique, and the events are stored in a table. Each linear feature, or route, must have an associated measurement system (Cadkin 2002b). The routes and the events are linked by unique identifiers in their attribute tables.

The routes in the dynamic segmentation can be any linear objects including streets, streams, or pipelines (Cadkin 2002b). Dynamic segmentation also has been used in ecological studies including mining effects on streams (Johnson 2005), fish habitat inventory in streams (Byrne 1996), and modeling of predator and prey populations (Kliskey et al. 2000). The technique also can be applied to vegetation attributes surveyed using points along line transects or through continual observation along line transects.

1.3 Sampling Effects on Detection of Patterns

Research approaches with different spatial scales detect different levels of interaction between environmental factors (ecological process) and landscape patches such as vegetation distribution, areal coverage, biomass, and composition (Bian and Walsh 1993). Due to the difficulty and high costs to obtain detailed SAV measurements or sampling data, the conventional SAV distribution mappings, either field survey-based or through remotely sensed data, use relatively coarse sampling intervals (resolutions) for water depth classification, such as shallow, intermediate, and deep (0-1.0, 1.0-2.0, and 2.0-3.0 m, respectively). These coarse sampling techniques can only depict the SAV distribution patterns and the associated temporal dynamics that are governed by the ecological processes of larger scales.

While larger scale sampling (using coarse sampling intervals or low spatial resolutions) is sufficient to detect SAV depth limits and boundaries, finer sampling intervals should detect SAV patch patterns and patch dynamics influenced by sediment contours. Therefore, one of the most important tasks for landscape ecologists is to identify the proper sampling scales (spatial or temporal) for understanding particular phenomena or processes of interest.

Semivariance analysis is a frequently used multi-scale method in landscape ecology (Wu et al. 2000). Semivariance is the discrepancy in values measured at two points separated by space or time. When semivariance values are calculated for systematic incremental sample intervals and plotted against distance, then the semivariogram can be used to estimate the fractal dimension of a topographic profile or surface. The fractal dimensions are used to indicate the degrees of spatial dependence (autocorrelation) between two separate measures of a variable.

2.0 STUDY OBJECTIVES

The objective of our study was to visualize the temporal patch dynamics of SAV sampled along linear transects and to determine interdependency between the temporal/spatial SAV variations and fine landscape features. We hypothesized that: (1) there are SAV growing patterns that cannot be captured with coarse resolutions; (2) these patterns are partially associated with underwater profiles (sandbar patterns such as slope, aspect, and width); and (3) therefore, SAV patch dynamics are partially effected by these small-scale underwater structures. In order to achieve our study goal and to test hypotheses, we used dynamic segmentation to visualize the survey transects of SAV distribution; and we used semivariance and fractal analyses to identify the effective range of spatial scales within which variables of underwater surface profile and SAV patch distribution were spatially dependent.

3.0 STUDY AREAS

The Pontchartrain Basin, Louisiana and Grand Bay National Estuarine Research Reserve (GBNERR), Mississippi both include widespread shallow estuarine areas located at similar latitude (30°N) in northern Gulf of Mexico. Turbidities of GBNERR and Lake Pontchartrain are primarily influenced by wind-driven waves and seasonal storms. Therefore, SAV does not occur along shores subjected to high wave energy, which is driven by predominant winds in both study areas (Cho and Poirrier 2005; Cho and May 2006). *Ruppia maritima* is an important dominant SAV in both estuaries and adjacent marsh openings. The salinities at SAV beds in Grand Bay range 18-30 ppt, and the mean salinity of Lake Pontchartrain is 4 ppt with seasonal and annual variations. Other freshwater SAV species including *Vallisneria americana*, *Najas guadalupensis, Potamogeton pusillus, Myriophyllum spicatum* also occur in Lake Pontchartrain. In Grand Bay NERR, *Halodule wrightii* is an important seagrass species that occurs with *R. maritima*.

Lake Pontchartrain provides essential ecological/economic/cultural/recreational grounds for regional communities. Grand Bay NERR is one of the 27 reserves of the NERR System that provides essential wildlife habitat, and offers educational, research, and recreational opportunities for students, scientists, and the public (http://nerrs.noaa.gov/).

4.0 METHODS

4.1 Field Surveys

Lake Pontchartrain SAV has been surveyed annually with a line-intercept method since 1996. Each survey station (n = x) has its own survey marker where the GPS coordinates were recorded. A 50-m line was extended counterclockwise from each survey marker parallel to the natural shoreline. There were five transects established at random points (7, 14, 28, 32 and 49 m from the marker) along the 50-m-long designated shore, and they were extended into the lake, perpendicular to the shoreline. The length of a transect is the distance from the shoreline to the point of maximum depth of SAV occurrence (200 m or longer). Data on SAV species and its foliar coverage were collected by snorkeling along the transects; the start points and the end points of SAV patches that touched the transect lines were recorded. Water depth was measured at 3-m intervals along the transects.

Transect surveys were conducted at five sites in GBNERR during June/July and October of 2005 using a similar survey protocol. The coordinates at the survey sites were recorded using a GeoXT GPS (Trimble Navigation Ltd, Sunnyvale, CA) in June 2005. At Sites 1, 3, 4, and 5, three transects were extended from the shoreline using reel measuring tapes and metal posts. SAV depth distribution (the depths where SAV patches of each species are located), linear patch sizes (patch start and stop distances), density (bare, sparse, and dense) and species composition (*Ruppia maritima*, *Halodule wrightii*, mixed beds, or bare substrate) were recorded while snorkeling. At Site 2, one transect, instead of three, was used as a reference.

4.2 Data Integration

4.2.1 Visualization of SAV Depth Distribution

Survey stations were added as points on GIS base maps of Lake Pontchartrain and Grand Bay NERR. A text file was made containing the names of the stations and the latitude and longitude coordinates of survey markers in decimal degrees for each study area. In ArcMap, the transect lines were drawn as routes at the designated intervals (7, 14, 28, 32, and 49 m for Lake Pontchartrain and 0, 10, and 18 m for Grand Bay NERR) from the GPS points. Transect line features (routes) were converted to the x,y coordinate system in ArcInfo. These converted line features were added into the view as a route theme.

SAV data were stored in spread sheets and saved as text files (one file for each species and each year), then imported into ArcMap. Using dynamic segmentation, the line events (SAV patches) were added on routes (transect lines) as linear features.

Water depth measurements made along the survey transects for each year were interpolated into a grid surface and the water depth levels were reclassified into 0.3 m (one-foot) depth intervals. SAV distribution along the line transects was overlaid on the grid surface**.**

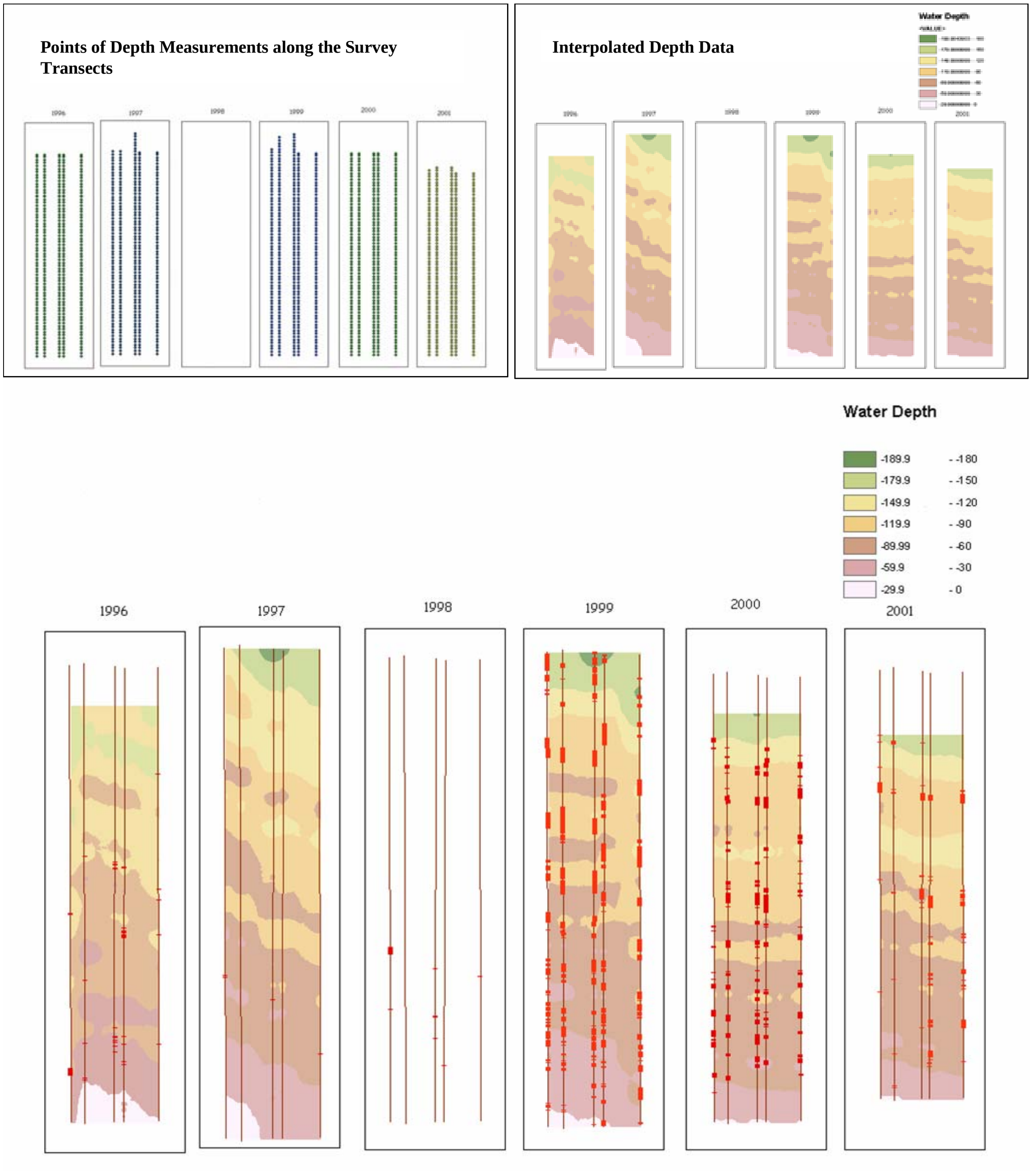
4.2.2 Sampling Scale Effects on Detection of Patterns

From the visualized SAV transect distributions, the survey site that showed the greatest temporal/spatial variations in SAV patch size and number was selected for this analysis. Water depth measured at 3 m intervals along the survey transects was plotted against distance from the shore at the sampling points to visualize the underwater depth profiles. Semivariance analyses were used to detect scale ranges of spatial dependencies of SAV foliar coverage and underwater geomorphological structures (slope, slope aspect and width of sandbars). Semivariance values were calculated for the systematic incremental sample intervals starting from 3 m and proceeding to 60 m at 3 m sampling increments. The values were calculated by averaging the sum of squared differences $1/(2N)\ \Sigma(Z_i - Z_{i+d})^2$, where N is the total data count, Z_i is either depth measurement or SAV coverage measurement at a distance from the shore, i is the starting point, and d is the sampling interval (Bian 1997). Semivariograms for SAV coverage and water depth were constructed by plotting the semivariance values at the sampling intervals (3, 6, 9,..., and 60 m). The break points on the semivariograms were examined visually. Fractal dimensions (D) were computed based on the semivariance values ($D = 2 - b/2$ for profiles, when b = slope of the regression of double logarithmic plot of semivariance values against sampling intervals) to estimate the degree of spatial dependencies between linear topographic profiles and SAV distribution (Xia and Clarke 1997). Correlation analyses were applied to SAV coverage, slope, aspect, and water depth at each sampling scale.

5.0 RESULTS AND DISCUSSION

5.1 Visualization of SAV Depth Distribution

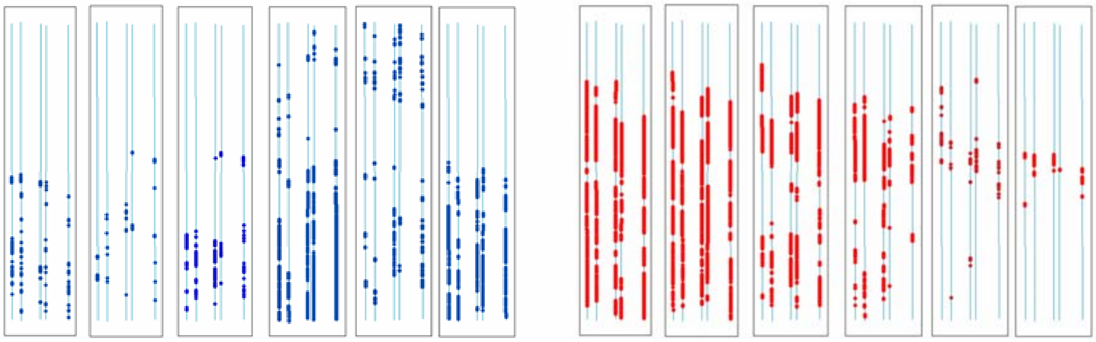
The SAV abundance, patch density, and species dominance changed significantly both annually (Figs. 1 and 2, L. Pontchartrain transects) and seasonally (Fig. 3, GBNERR transects). In Lake Pontchartrain, the maximum depth of SAV was limited to 1-m in turbid years (1997 and 1998) and increased to the 2-m contour in less turbid years (1999 and 2000). The relative abundance of *Ruppia* and *Halodule* changed between the seasonal surveys in GBNERR. SAV occurred more continuously along the transects in Grand Bay NERR whereas it appeared patchy and discontinuous in Lake Pontchartrain. If the SAV distributions were mapped using a coarse scale (i.e. 30 m resolution when using Landsat data), only the general boundaries of SAV growth could be delineated; the variation in patchiness within the SAV bed would not be captured. The extent of SAV depth boundary along the transects is determined mainly by mean water clarity and shoreface slope in both Lake Pontchartrain and Grand Bay NERR when there are no other prevailing limiting factors (Cho and Poirrier 2005; Cho and May 2006).



Points of Depth Measurements along the Survey Transects

Interpolated Depth Data

Figure 1. Changes in the SAV depth distribution along the survey transects at Fontainebleau State Park in Lake Pontchartrain (1996-2001). The unit for water depth is cm.



Annual Transect Distribution of *Ruppia maritima*

Annual Transect Distribution of *Vallisneria americana*

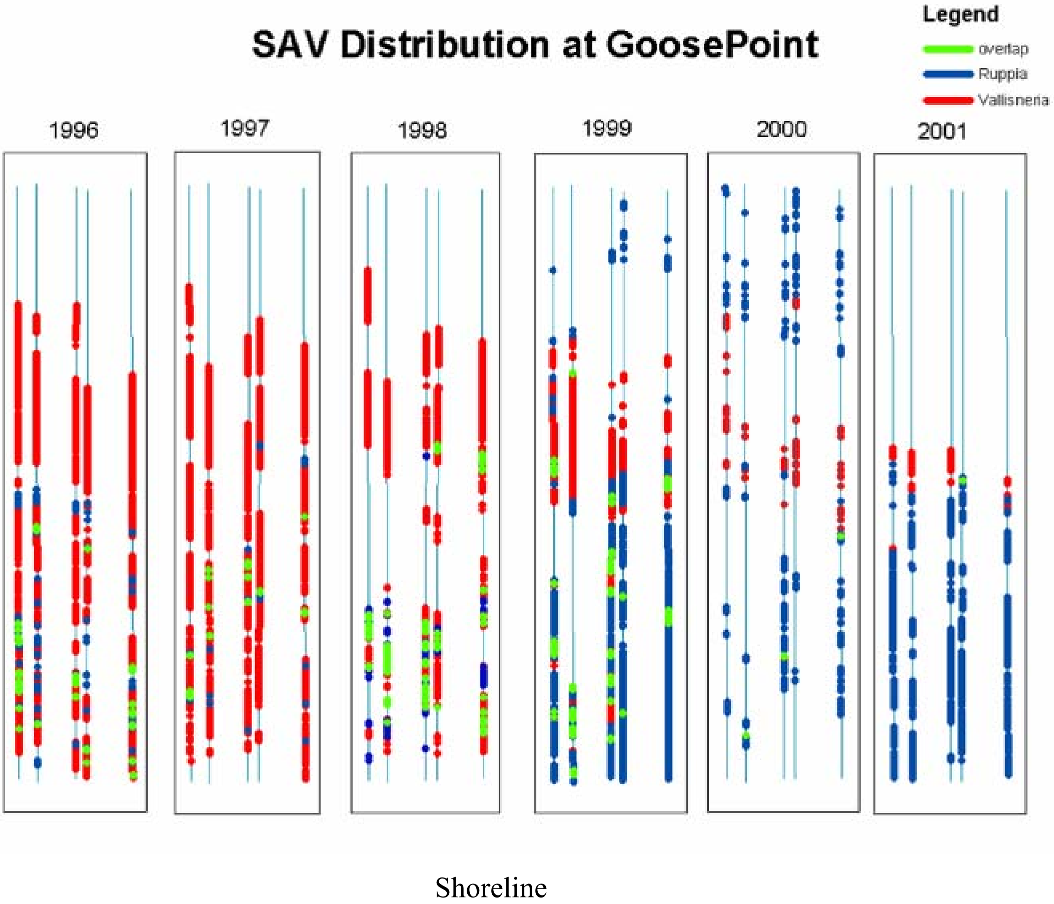


Figure 2. Changes in the SAV depth distribution and species abundance along the survey transects at Goose Point in Lake Pontchartrain (1996-2001).

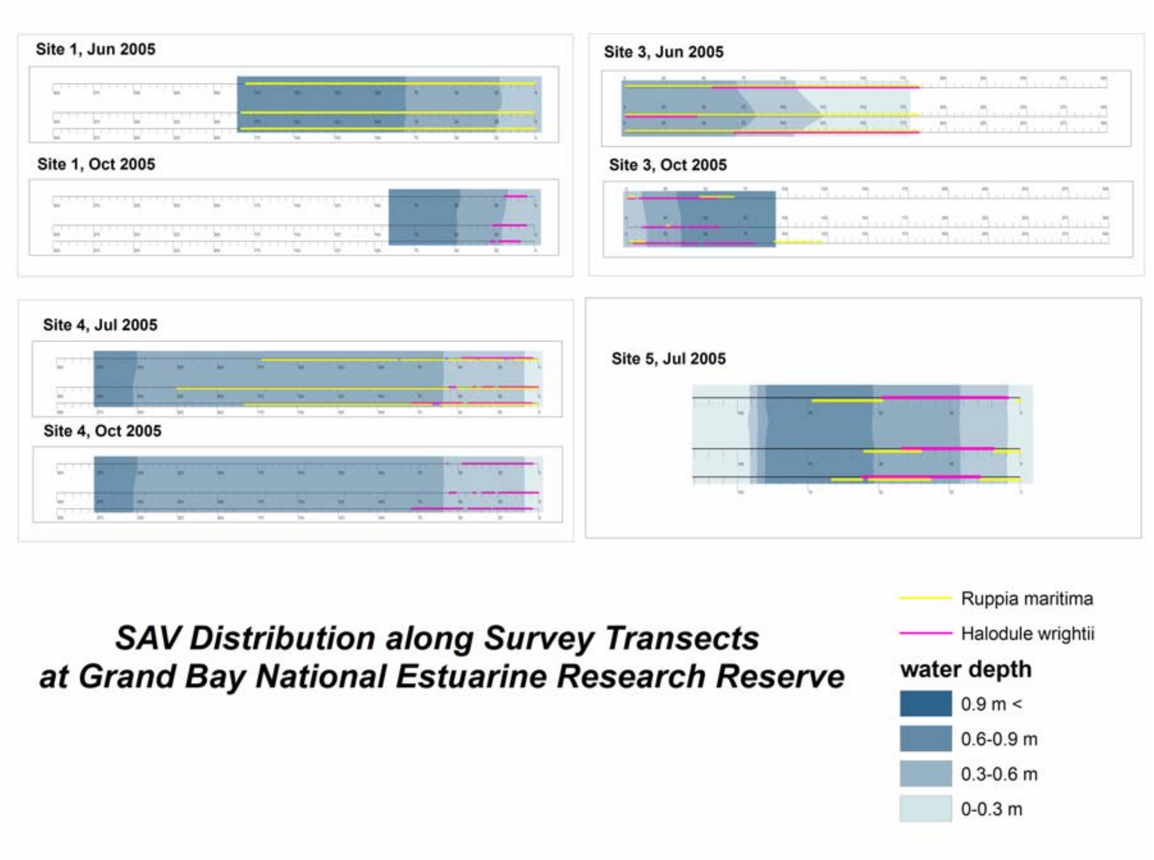


Figure 3. Changes in the SAV depth distribution and species abundance along the survey transects at study sites in Grand Bay National Estuarine Research Reserve (2005).

5.2 Scale Dependencies of SAV Patch Pattern and Underwater Profiles

The SAV abundance and depth data collected at a survey site in Lake Pontchartrain (Fontainebleau) were resampled at varying intervals. The resampled depth and SAV abundance values are plotted against distance from the shore in Fig. 4 and Fig 5. The number of peaks for both SAV abundance and depth profiles decreases as sampling interval increased. When the sampling interval was increased to 15 m or larger, the general SAV depth distribution trend (abundant in the intermediate depth and scarce in shallow and deep waters) and the general water depth trend (shallow, intermediate, and deep) were captured. However, the smaller sampling intervals (12 m or smaller) caught the SAV growth patterns (i.e., patchiness) and the sandbar structures that could not be detected with coarser sampling resolution.

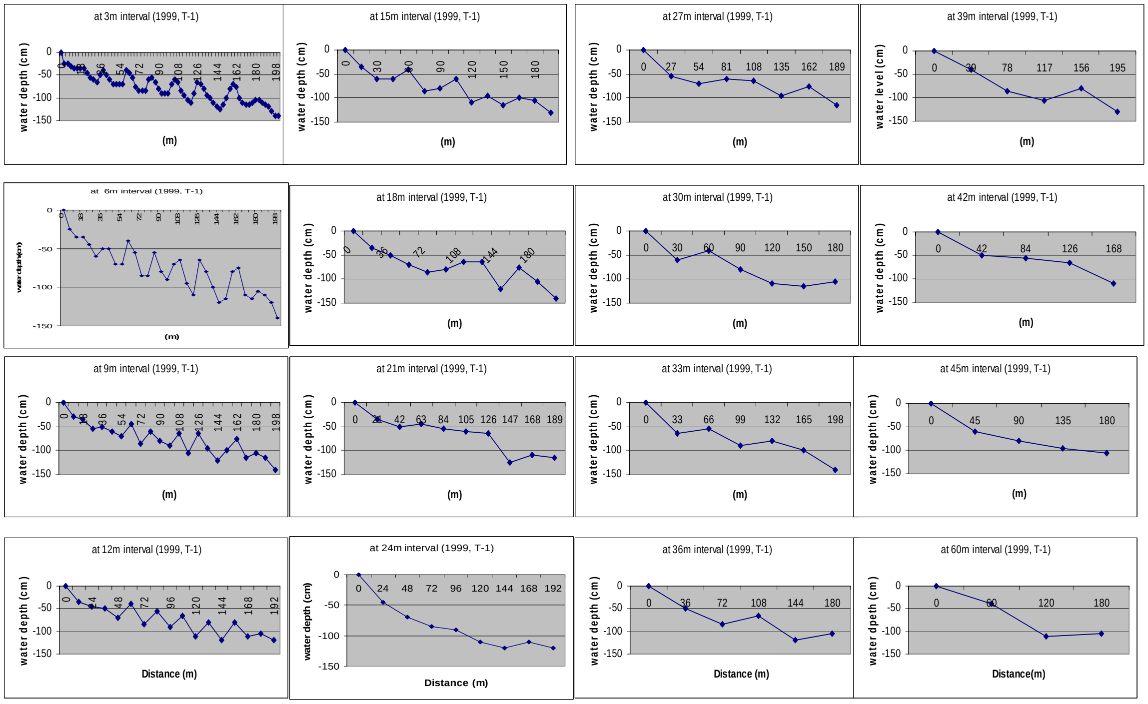


Figure 4. Water depth values taken along the survey transects resampled at varying intervals.

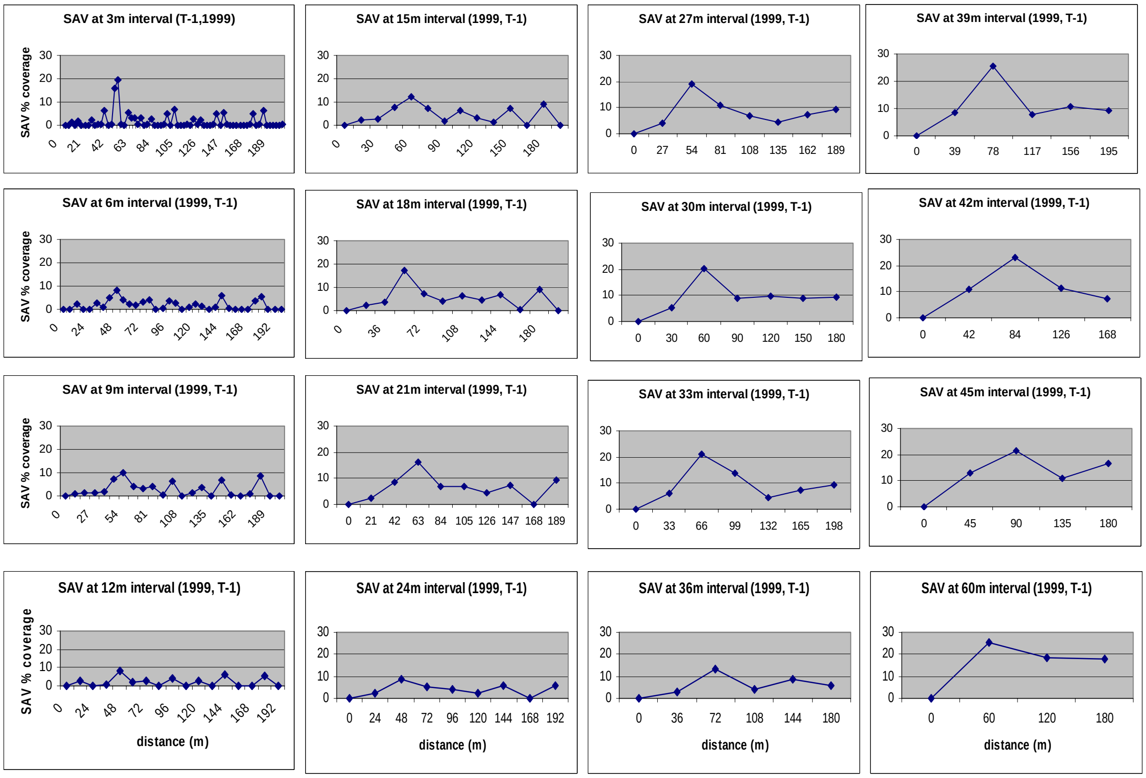


Figure 5. SAV coverage values resampled at varying sampling intervals.

Semivariograms were constructed to detect scale ranges of spatial dependencies of SAV coverage and underwater profile structures. The semivariogram for water depth showed the first break points at 24 m which indicates that the sandbars were more or less regularly arranged with a mean cycle of 24 m (Fig. 6). The breakpoints at 24 m for SAV semivariograms (Fig. 6) indicates that the SAV growth pattern is also influenced by the underwater sandbar structures. Therefore, the sampling intervals that were smaller than the average spacing of the sandbars (24 m) represented the effective range of spatial scales within which those variables were spatially dependent.

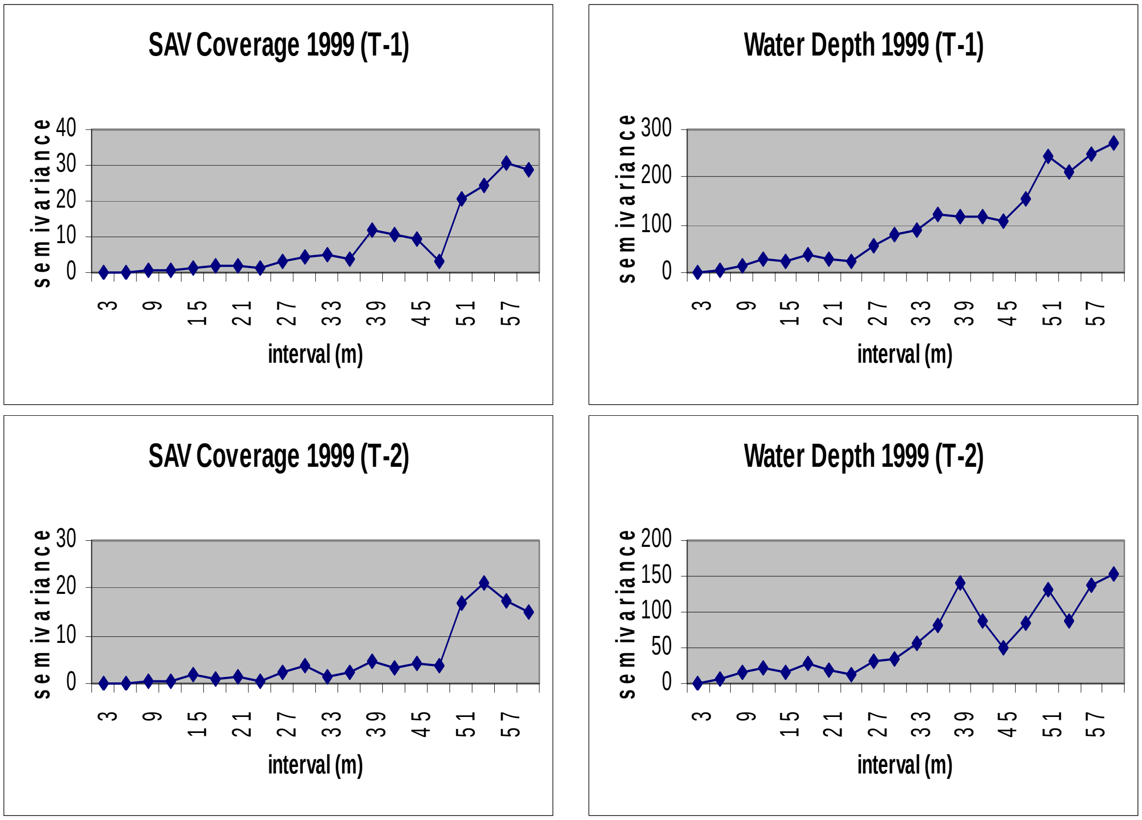


Figure 6. Semivariograms of SAV coverage and underwater profile structures for a survey site in Lake Pontchartrain, Louisiana (1999).

The fractal dimensions derived from the semivariance values for variables of SAV abundance, water depth, profile aspect, and profile slope are plotted against the sampling intervals in Fig. 7. At fine sampling intervals, dimension changes abruptly as the interval distance increases for all variables except aspect. Dimension for SAV distribution increases (complexity increases) and depth dimension decreases (complexity decreases) as interval distance is enlarged in fine resolution (3, 6, 9 m intervals). The dimension became more or less consistent after the 12 – 15 m interval. The underwater sandbar profiles and the SAV growing patterns were spatially dependent, but to different degrees depending upon the sampling intervals (sampling resolution). In fine scales (intervals of up to 12 m, or half of the average width of sandbars), SAV pattern is more strongly related to slope than water depth or aspect; at intermediated scales (15 – 42 m), slope, aspect and also water depth are the controlling factors of SAV patterns to similar degrees; at coarse scales (45 m or greater), water depth is more strongly related to SAV coverage.

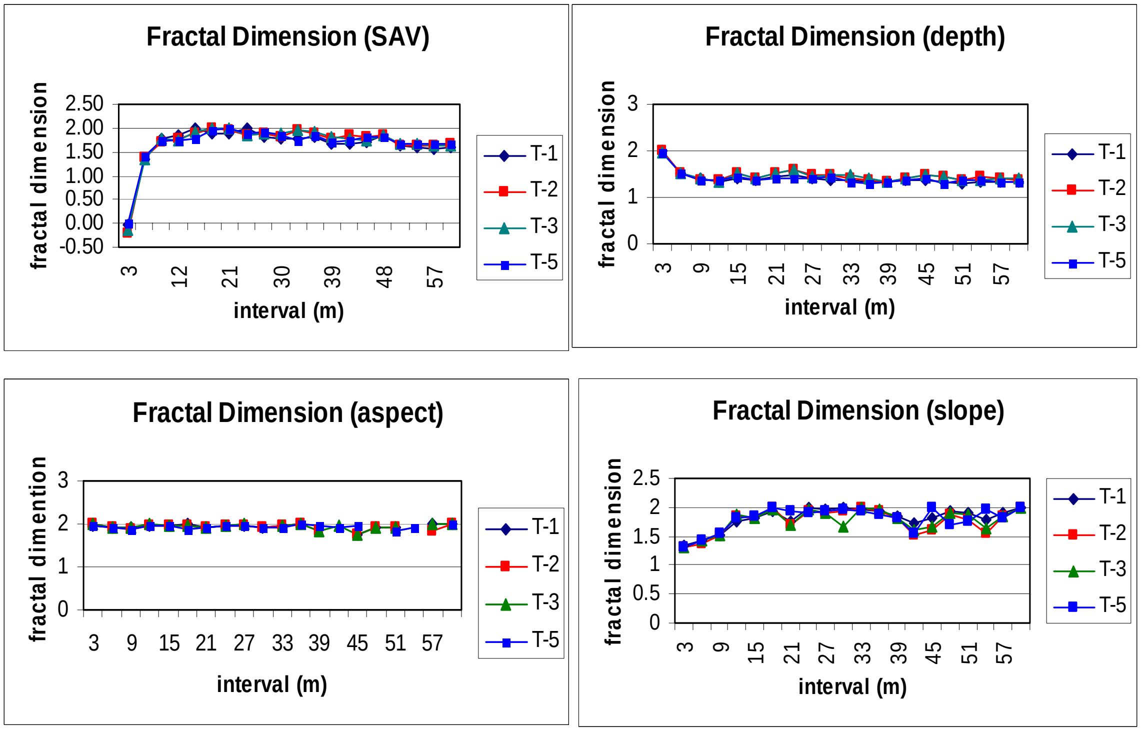


Figure 7. Scale-dependent changes in fractal dimensions for SAV patch size, water depth, underwater profile slope aspect, and profile slope.

Correlation coefficients among those four variables (SAV abundance, water depth, profile aspect, and profile slope) also indicated that there is a strong relationship between slope and SAV coverage at the finest sampling interval (3 m), and there is a high correlation between water depth and SAV coverage at both fine and coarse sampling intervals (3m through 12 m, and 27 m through 60 m) (Table 1). The negative correlation coefficients at fine sampling intervals between SAV and slope as well as between SAV and aspect indicated that SAV grows more abundantly on gentler slopes of sandbars that face the shoreline.

Table 1. Correlation coefficients between the SAV abundance and variables of water depth, underwater profile slope aspect, and profile slope at varying sampling scales (3-60 m intervals).

Sampling interval	Slope	Aspect	Depth
3	-0.192**	-0.158**	0.235**
6	-0.171	-0.162	0.265**
9	-0.004	-0.091	0.216*
12	0.203	-0.548**	0.338**
15	-0.052	-0.137	0.095
18	-0.073	-0.091	0.212
21	0.174	0.019	0.234
24	0.084	-0.290	0.328
27	-0.224	-0.010	0.441*
30	-0.355	0.234	0.469*
33	-0.457*	0.200	0.390*
36	-0.437	-0.509*	0.723**
45	-0.227	-0.187	0.717**
60	0.341	-0.246	0.719**

* : Correlation is significant at the 0.05 level (2-tailed).
**: Correlation is significant at the 0.01 level (2-tailed).

5.3 Visualization and Estimation of SAV Habitat Increase at a Coarse Resolution

As mentioned above, SAV depth boundaries are determined by water clarity (which controls light availability) as well as geomorphology (e.g. shoreface slope) of the habitat at the sampling scales commonly used in conventional SAV studies. Therefore, light attenuation as a function of K (vertical absorption coefficient) and depth can be used to infer SAV potential habitat that is controlled by the maximum depth boundary of SAV growth.

In Lake Pontchartrain, North shore SAV was continuous from Tangipahoa River to the west and Big Point to the east during the 2000 lake-wide surveys (Cho and Poirrier 2001). Under a scenario of clear lake water (K=1.2) in 2000 that permitted SAV colonization up to 2-m depth, total area of potential SAV beds was estimated. The base map of Lake Pontchartrain and bathymetric lines were downloaded from the U. S. Geological Survey web site (http://pubs.usgs.gov/openfile/of98-805/html/gismeta.htm). A polygon (that covers Tangipahoa River-Big Point-north shoreline-2m depth contour) was digitized in ArcMap. The digitized map was reprojected to the universal transverse Mercator (UTM) projection. The estimated potential SAV bed along the north shore (area of the digitized polygon) was approximately 29.6 km^2 (3,000 ha).

We conducted similar GIS modeling for Grand Bay NERR. Water depth data from NOAA's National Ocean Service were downloaded from the National Geophysical Data Center website (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html). These data were used in a kriging interpolation routine within the Spatial Analyst extension of ArcGIS 9.0 to obtain more complete coverage of the area of interest, Grand Bay NERR. The kriging routine produced a detailed raster surface which was reclassified to facilitate subsequent analyses. Assuming water clarity could be improved 20%, the maximum colonization depth for SAV would increase from 0.8 m to 1.1 m (Cho and May 2006). Based on GIS modeling, Cho and May (2006) estimated this water clarity improvement could increase potential SAV habitat at Grand Bay NERR by 35%, from approximately 1700 ha of potential habitat to about 2300 ha (Fig. 8 shows a representative survey site).

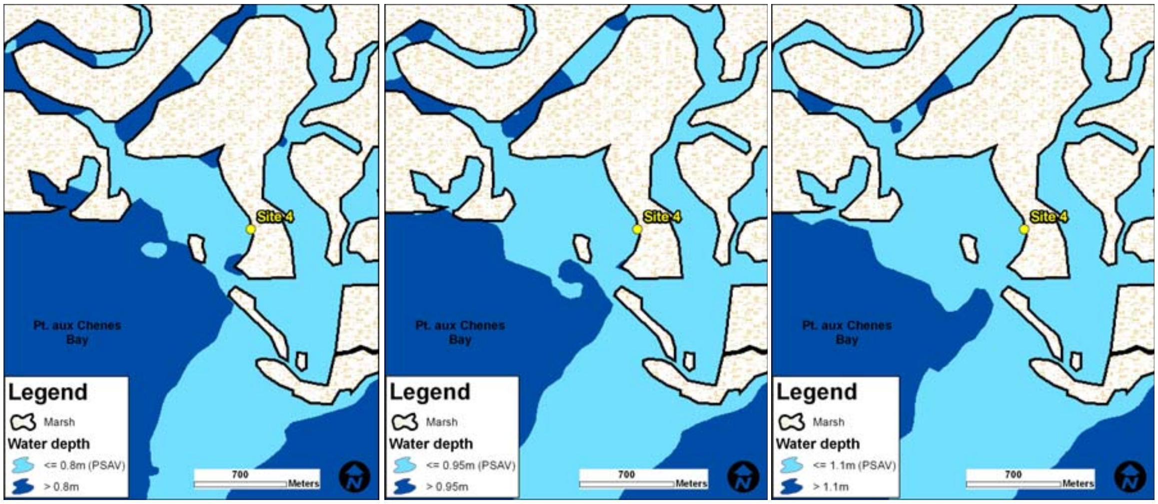


Figure 8. Visualization of Potential SAV habitat (PSAV) increase with water clarity improvement at Site 4 in Grand Bay NERR.

5.4 Implications

The effects of detailed underwater profiles on SAV patch patterns have not been appreciated due to the coarse resolution of depth measurements used in most SAV studies. The effect of underwater profile on SAV patch pattern appears to be associated with water levels in areas with shallow depth. During low water events, SAV growing on the crests of the sandbars is exposed to air. If the water level stays low for several days, the exposed SAV dies from the combined effects of desiccation and temperature (either high or low) stress (Cho 2003). Therefore, SAV loss occurs selectively on the crests. The results confirmed that there are SAV growth patterns that cannot be captured with the conventional coarse resolutions and these patterns were partially associated with underwater profiles.

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