Final Report:

Mapping the Distribution and Abundance of Macroalgae in the Indian River Lagoon

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Bernhard Riegl, PhD
J. Greg Foster, PhD
Nova Southeastern University
Oceanographic Center,
Dania Beach, FL

For the

St. Johns River Water Management District

EXECUTIVE SUMMARY

This report presents the results of a large-scale acoustic survey conducted in Apr-May 2008. The objective was to quantify the abundance and distribution of seasonal drift macroalgae in the Indian River Lagoon. Indian River was surveyed from the Sebastian Inlet to its northernmost extent in the Titusville area. Banana River was surveyed from its convergence with the Indian River northward to the Federal Manatee Zone near Cape Canaveral. The survey vessel was navigated along pre-planned lines running east-west and spaced 200 m apart. The river edges were surveyed to a minimum depth of approximately 1.3 m. Hydroacoustic data were collected with a BioSonics DT-X echosounder and two multi-plexed digital transducers operating at 38 and 418 kHz. The previous lagoon-wide survey (Contract SI 44112) utilized a QTC View echosounder and a single 200 kHz transducer. The switch to a BioSonics system was recommended in the 2005 final report and motivated by the greater temporal consistency afforded by the digital transducers. The 38 and 418 kHz hydroacoustic data were processed with BioSonics Visual Bottom Typer (VBT) seabed classification software to obtain values of E1’ (time integral of the squared amplitude of the 1st part of the 1st echo waveform), E1 (2nd part of 1st echo), E2 (complete 2nd echo), and FD (fractal dimension characterizing the shape of the 1st echo). A novel approach to supervised classification was developed for acoustic discrimination between three major seabed classes; bare substrate, drift macroalgae, and short SAV (~10cm<). A training catalog was compiled from 131 sonar+video samples collected across the extent of the study area. The 38 & 418 kHz E1’, E1, E2, and FD datasets were merged and submitted to a series of three linear discriminant analyses to isolate and extract pure end-member records, e.g. contiguous drift macroalgae, from hydroacoustic samples that were oftentimes heterogeneous, e.g. sparse drift macroalgae. The Fisher’s linear discriminant functions from the third and final discriminant analysis were used to classify each of the 500,000+ hydroacoustic survey records as either bare, drift macroalgae, or short SAV. The classified survey records were then used to calculate the biomass of drift macroalgae as the product of average percent cover times wet weight. The drift macroalgae biomass was found to be 69,859 metric tons (wet weight) within the 293.1 km^2 study area. The biomass per unit area (238.3 kg per km^2) was roughly 34% less than reported for the 2005 survey, in general agreement with field observations. The mean percent cover of drift macroalgae was (i) significantly greater within the navigation channels (18.3%) than outside (12.2%), and (ii) significantly greater in the Indian River (12.9%) than in the Banana River (9.3%). The overall predictive accuracy of total SAV was 78.9% (n=246) at three levels of cover (0-33, 33-66, and 66-100%). The Tau coefficient, a measure of the improvement of the classification scheme over random assignment, was 0.683 ± 0.076 (95% CI), i.e. the rate of misclassifications was 68.3% less than would be expected from random assignment of hydroacoustic records to total SAV cover. In conclusion, the conversion from a single analog transducer to two digital transducers in conjunction with new post-processing techniques has realized the original goal of establishing an accurate, efficient, and temporally consistent method for acoustically mapping drift macroalgae biomass.

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Team:

Principal Investigator: Bernhard Riegl, PhD
Associate Professor, Nova Southeastern University
Oceanographic Center
8000 N. Ocean Drive, Dania FL 33004
954-262 3671

Principal Surveyor: Greg Foster, PhD Candidate
Research Scientist, Nova Southeastern University
Oceanographic Center
8000 N. Ocean Drive, Dania FL 33004
954-262 3630

Surveyor: Kristi Foster, PhD Candidate
Research Scientist, Nova Southeastern University
Oceanographic Center
8000 N. Ocean Drive, Dania FL 33004
954-262 3630

METHODS AND MATERIALS

Survey Area

The acoustic survey was completed between the dates of April 1 - May 21, 2008, during the historic peak of drift macroalgae biomass. Indian River was surveyed from its origin in the Titusville area (28.7664^{o}) southward to Wabasso, just below the Sebastian Inlet (27.8743^{o}) (Appendix A1). Banana River was surveyed from the Federal Manatee Zone near Cape Canaveral (28.4329^{o}) southward to its convergence with Indian River in the Melbourne area (28.1571^{o}). The survey vessel was navigated along pre-planned lines, running east-west and spaced 200 m apart. The depth of water column surveyed ranged from 1.3 to 4.5 m and averaged 2.2 m.

Sonar Equipment

The survey was conducted from a 7.5 m v-hull boat with a 0.5 m draft. Hydroacoustic data was acquired with a BioSonics DT-X echosounder and two multiplexed, single-beam digital transducers with full beam widths of 10^{o} (38 kHz) and 6.4^{o} (418 kHz), operated at 5-Hz sampling frequency and 0.4 ms pulse duration. The Transmit Power Reduction (-9.1 db) option within the BioSonics Visual Acquisition (VisAcq) software was used to reduce the onset of reverberation at the shallowest depths. The remaining VisAcq settings are displayed in Figure 1. The two transducers were located on a swing-arm mounted to the gunwale. The GPS antenna was mounted directly above for optimal integration of acoustical and positional data strings. Global positioning data were collected with a Trimble Ag132 dGPS, differentially corrected against the WAAS signal to achieve positioning accuracies less than 0.9 m horizontal dilution of precision. The dGPS signal was interfaced with HypackMax© to provide real-time monitoring of vessel position with respect to the aerial images and pre-planned survey lines. To avoid turbulence-induced signal contamination, evident as a rolling oscillation on the real-time VisAcq display, vessel speed was adjusted to maintain a net speed (vessel+drift) of approximately 4.5 knots.

Transducer Assignment	
Channel 1	418 kHz
Channel 2	38 kHz
Hardware Parameters	
Operating Mode	SingleBeam
Transmit Power Reduction (db)	-9.1
Pulse Duration (µs)	400
Pulse Rate (Hz)	5
Pulse Type	Active
Environment Parameters	
Beginning Range (m)	0.05
Ending Range (m)	25
Ambient Water Temp (^{o}C)	25
Water Salinity (ppt)	30
Depth for Sound Velocity (m)	2.2
ph for Absorption Calculations	8.4
Collection Threshold (db)	-130

Figure 1. The critical settings used for the BioSonics DT-X echosounder (Table). Swing-arm in traveling position with 420 kHz (top) and 38 kHz (bottom) transducers and Trimble antenna (Upper Image). Inside V-Berth of survey vessel with (left-to-right) BioSonics DT-X echosounder, Trimble receiver, and acquisition PC (Lower Image).

Data Processing

The 38 and 418 kHz hydroacoustic data were processed with BioSonics Visual Bottom Typer (VBT) seabed classification software (v1.10.6.3) to obtain values of E1’ (time integral of the squared amplitude of the 1st part of the 1st echo waveform), E1 (2nd part of 1st echo), E2 (complete 2nd echo), and FD (fractal dimension characterizing the shape of the 1st echo). VBT allows the user to define the width of each Bottom Sampling Window in units of “samples”, i.e. the 41,667 Hz clock-speed of the DT-X internal processor. This critical setting is better understood by converting to units of meters via the speed of sound in water (Figure 2). The split between E1’ and E1 was set such that E1 would capture the trailing edge of the first echo. This emphasized sensitivity to the presence of SAV, as scattering from the vegetative canopy increases the proportion of signal returning to the transducer in the trailing edge of the first echo. Other values of VBT user-defined settings are displayed in Figure 2, alongside representative waveforms acquired over bare substrate and over drift macroalgae.

Sampling Window Settings	
E1' (samples)	20
E1 (samples)	40
E2 (samples)	90
Bottom Pick Settings	
Peak Threshold (db)	-43
Peak Width (samples)	5
Btm Detection Threshold (db)	-70
Above Btm Blanking (samples)	1
Tracking Window (samples)	66
Transducer Settings	
Speed of Sound (m/s)	1531.1
Time Varied Gain	20logR
Processing Threshold (db)	-80
Report Settings	
Pings per Report	5
Energy Filter (%)	50

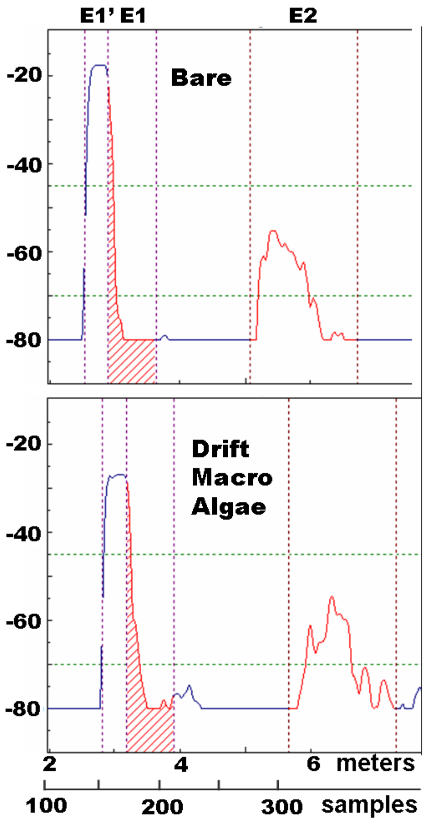


Figure 2. The critical settings of Visual Bottom Typer software used to process 38 and 418 kHz hydroacoustic data (Table). Representative waveforms acquired over bare substrate (top) and drift macroalgae (bottom). The settings for the width of the Bottom Sampling Windows, critical to the quantification of E1', E1, and E2, are shown in units of as samples (bottom scale) and in units of meters (top scale), the latter based on the speed of sound in water and the 41,667 Hz sampling rate of the DT-X echosounder.

Quality Assurance

Log-transformed values of E1', E1, E2 and un-transformed values of FD were passed through a series of filters to identify and remove "irregular" hydroacoustic returns. The first filter checked the differential depth between successive pings against a specified maximum value. This filter removed waveforms that contacted the seabed at angles exceeding normal-incidence, typically caused by excessive vessel roll. The next filter removed records with depth-picks less than 1.3 m, at which point near-field noise begins to contaminate the signal. The next filter removed records with depth-picks exceeding the 99.5 percentile recorded within a particular survey tile, usually the result of grossly misshapen waveforms. The remaining two filters protected against potentially excessive outliers by removing records for which any of the eight acoustic parameters fell beyond the 1 and 99 percentiles. Only those records for which all eight acoustic parameters passed all filters were passed onto the next stage of processing. Of the 600,000+ pings recorded during the survey, approximately 20% were removed by the series of filters and the subsequent compilation process.

Normalizing to Reference Depth

Because the current version of VBT does not normalize echo length to a reference depth, the log-transformed and filtered values of E1’, E1, and E2 were empirically normalized to median survey depth to produce depth-invariant values of acoustic energy. Depth-normalization models were constructed using the “BARE” sub-set of the supervised catalog, for which it could be assumed that depth (via geometric spreading) was the primary factor affecting the shape of echo returns (and not varying abundance of SAV). Third-order polynomials were fit to plots of log(E) versus depth for each of the six acoustic energy parameters (Figure 3). Correction factors were applied to each hydroacoustic record, calculated as the ratio of model-predicted acoustic energy at actual depth divided by the model-predicted acoustic energy at the median depth.

Catalog Collection and Processing

A total of 195 catalog samples were collected within the study area, spanning the spectrum of vegetative cover (this number was reduced to 166 after quality assurance and 131 after class assignment). Each catalog sample consisted of a 30-90 second sonar file and a geo-referenced video file, acquired as the vessel drifted in idle. 109 catalog samples were collected during the 2007 BioSonics trial and the remaining 86 were collected during the 2008 lagoon-wide survey. The catalog data was subjected to the same VBT post-processing, depth-normalization, and quality assurance as described previously for the survey data. 166 of the 195 catalog samples passed quality assurance, totaling 9,672 records. Most of the catalog samples that did not pass quality assurance were collected from depths of 1.0-1.3 m and were thus rejected by the minimum depth filter.

Each video was reviewed post-survey and assigned a percent coverage of (1) bare substrate, (2) short SAV (~10cm<), and (3) drift macroalgae and tall SAV. Short SAV was typically *Caluerpa prolifera* but also included *Halophila spp*. and miscellaneous taxa of macroalgae generally less than 10 cm tall. Tall SAV was predominantly *Syringodium filiforme* and occasionally *Thalassia testudinium*. In nearly every sample where tall SAV was observed, drift macroalgae was either interspersed between or overlying the tall SAV. Because of this, and the relatively low frequency of tall SAV compared to drift macroalgae, it was not attempted to acoustically distinguish tall SAV from drift macroalgae.

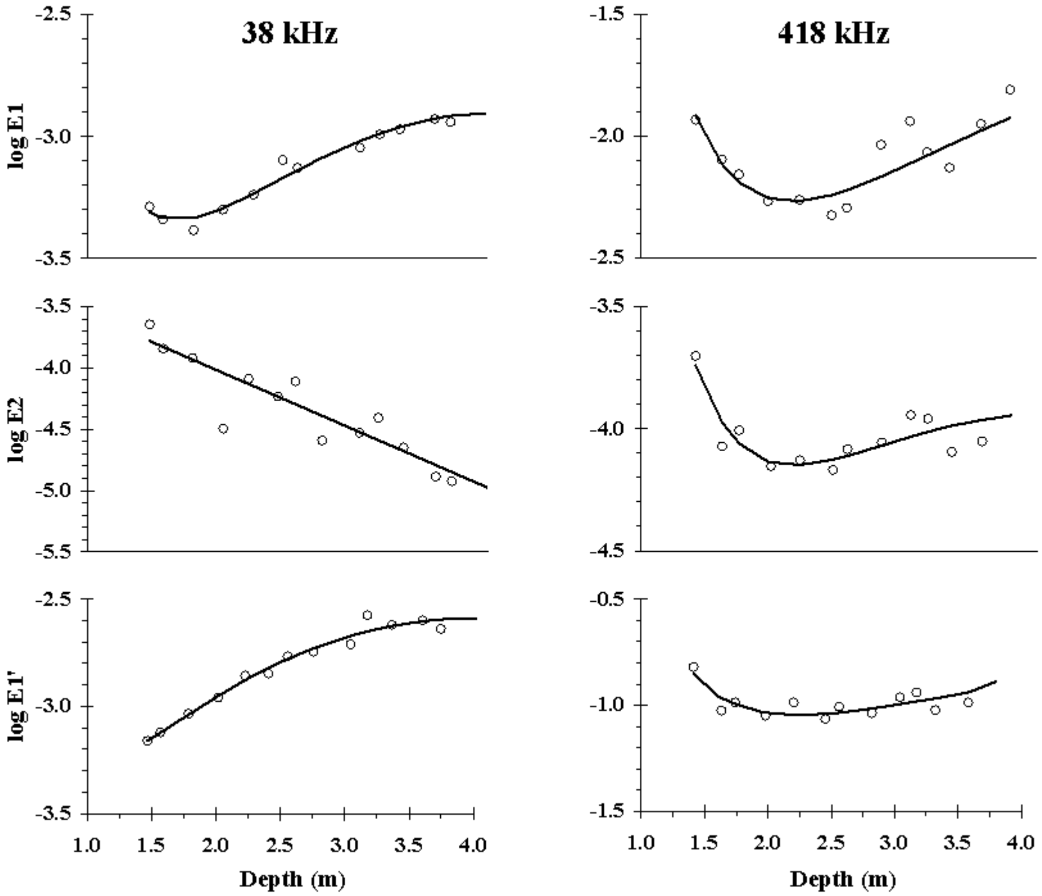


Figure 3. Depth trends of log-transformed echo returns (open circles) and fitted curves (solid lines) used for empirical depth-normalization of acoustic energy parameters. Data was limited to the "bare" sub-set of the supervised catalog, for which it could be assumed that depth, via geometric spreading, was the only factor affecting the echo return.

Selecting a Classification Scheme

Two factors dominated the selection of an appropriate classification scheme. First, the large number of acoustic survey records (500,000+) dictated a supervised classification scheme, i.e. the batch-wise classification of survey records using functions derived from a much smaller training dataset. Second, the need to distinguish between short SAV and drift macroalgae dictated a categorical classification scheme. Linear discriminant analysis was identified as the simplest and most established method meeting both criteria, particularly since it is designed to maximize between-group differences.

Creating the Classification Scheme

Ideally, the hydroacoustic records submitted to a linear discriminant analysis (LDA) classification scheme should be pure end-member classes, i.e. completely bare or contiguous SAV of a particular class. The catalog should also include as many locations as possible so that all ranges of depth and sediment class are adequately represented. Otherwise, extraneous geophysical factors could falsely inform the classification process. Because of the logistical difficulties of acquiring end-member sonar samples, e.g. finding and double-anchoring over a small patch of contiguous SAV, a novel method was developed for extracting pure end-member records from samples acquired over heterogeneous benthos.

First, the 166 catalog samples passing quality assurance were categorized based on the type and amount of SAV cover apparent in the accompanying videos. Samples with less than 10% total SAV cover were designated as BARE. Samples with greater than 33% cover of drift macroalgae and tall SAV were designated as DMA. Samples with greater than 50% cover of short SAV were designated as SHORT. 131 of the 166 catalog samples fell into one of these three categories, totally 7,523 records.

Next, the 7,523 hydroacoustic records were passed through a series of three discriminant analyses, using the 38&418 kHz E1', E1, E2, and FD as predictor variables. Only those records that (1) correctly classed by the discriminant analysis and (2) exceeded a minimum probability of group membership were passed onto the next LDA (Figure 4). This had the effect of retaining only those records that belonged to the desired end-member class. For example, hydroacoustic records acquired over SAV would be removed from a catalog sample categorized as BARE but containing a small amount of SAV. Conversely, hydroacoustic records acquired over bare sediment would be removed from a catalog sample classified as DMA.

Classifying Hydroacoustic Records

Linear discriminant analysis generates a set of Fisher's linear discriminant functions, which are based on the linear combinations of predictor variables (38 and 418 kHz E1', E1, E2, FD) that provide the best discrimination between the groups represented in the catalog, i.e. bare, short SAV, and drift macroalgae. The Fisher's linear discriminant functions from the third-pass LDA were used to classify hydroacoustic records, based on the values of the eight acoustic parameters (Figure 5). This was done by multiplying each Fisher's coefficient by the value of the corresponding variable, summing the products, and adding the constant to get a score for each of the three categories (BARE, DMA, and SHORT). Each of the 500,000+ records was classified as the category with the largest score. The final layer of classification was to compute the proportion of BARE, DMA, and SHORT assignments for a group of ten sequential records, yielding a total of 49,592 geo-located records.

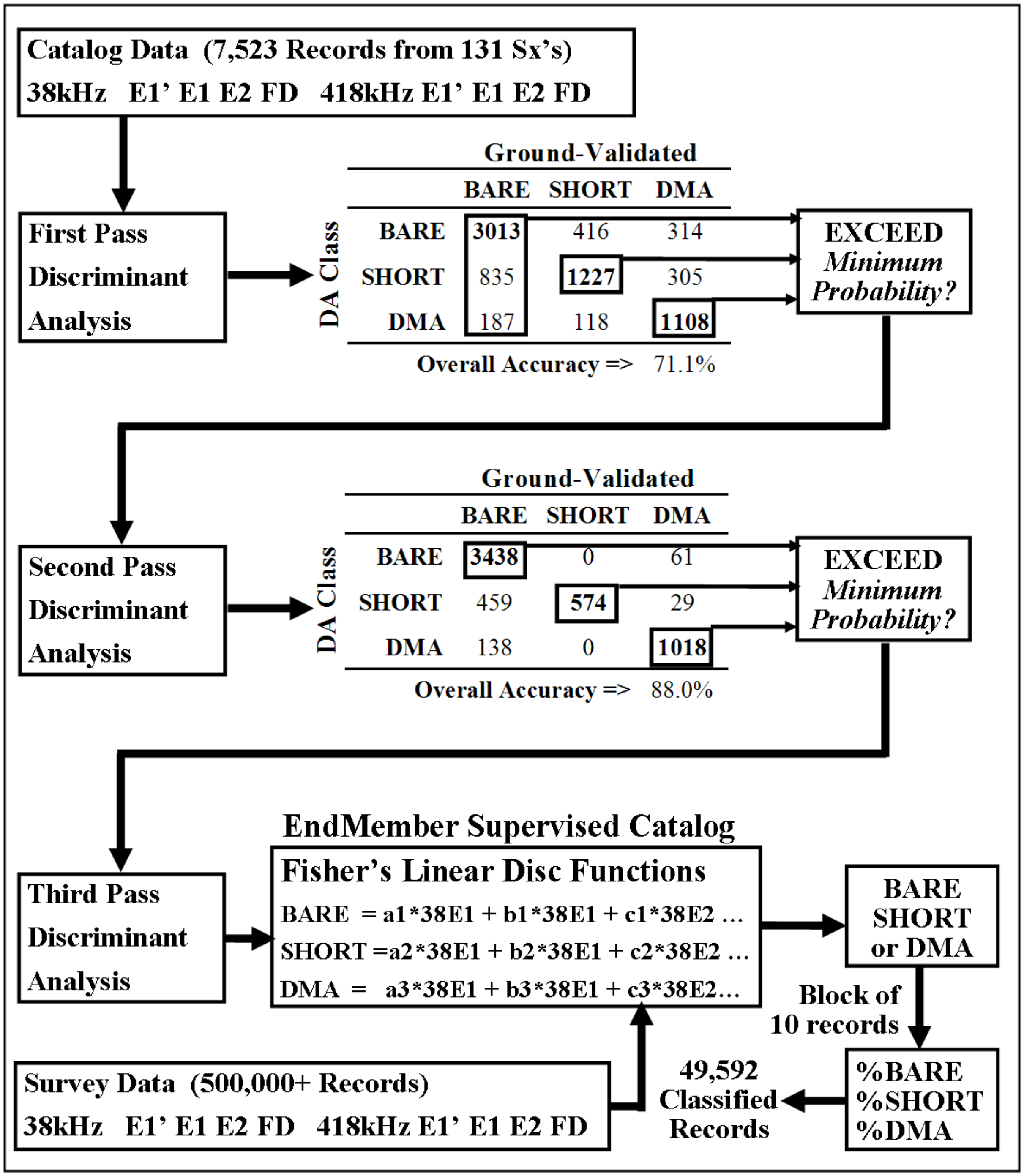


Figure 4. Multiple Linear Discriminant Analysis scheme for extracting pure end-member acoustic records from a catalog of 30-90 second hydroacoustic samples acquired over heterogeneous benthos. Only those catalog records (1) classifying correctly and (2) exceeding a minimum probability for group membership pass onto the next Discriminant Analysis. The Fisher's Linear Discriminant Functions obtained from the 3rd Pass Discriminant Analysis were used to classify survey data into one of three end-member classes (bare, drift macroalgae, or short SAV).

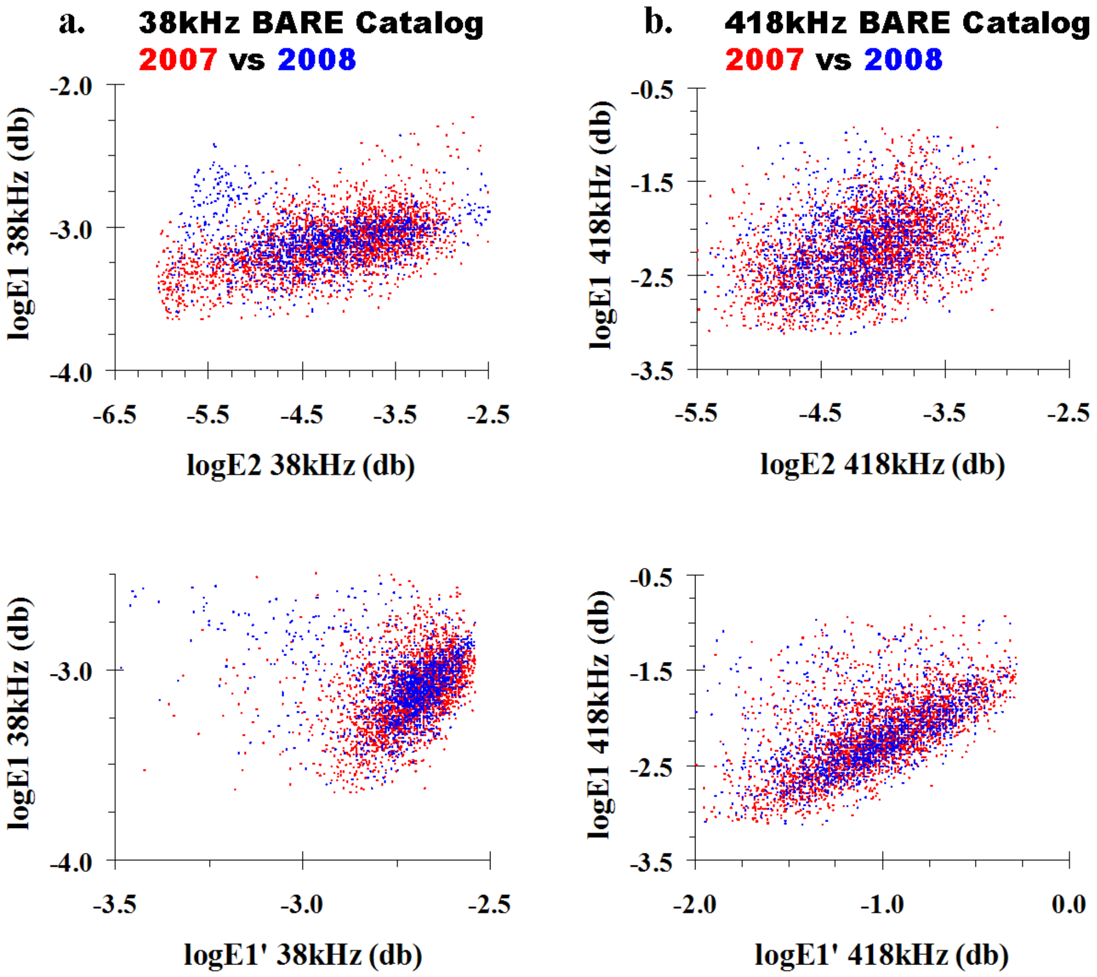


Figure 5. Scatterplots of E1 vs E2 and E1 vs E1' at (a) 38 kHz frequency and (b) 418 frequency for BARE catalog samples collected from 41 sites during the 2007 pilot survey (red) and 27 sites during the 2008 lagoon-wide survey (red).

Partitioning by SJRWMD Segments and Proximity to Navigation Channel

The 49,592 geo-located acoustic muck records were joined with a SJRWMD shapefile of Indian River Lagoon segments (IRL_Segments.shp) in ArcMap v 9.0. These records were further sub-divided by clipping to a SJRWMD shapefile of navigation channels (ICW.shp). The segment-average percent cover of SHORT and DMA were calculated as the simple average of records falling within a particular segment, either within or outside of navigation channels. The area surveyed within each segment was obtained by clipping the segment shapefile to the actual survey extent.

Metadata

Using the methods described above, the 500,000+ pairs of 38 & 420 kHz pings were post-processed into 49,592 geo-located records. A brief explanation of each field follows:

418_ZCORR: The bottom-depth obtained from the 418 kHz output of Visual Bottom Typer, corrected for the depth of the transducer below the waterline.

DA_HC: The habitat class assignment obtained from the third-pass Fisher's linear discriminant functions; 1=BARE, 2=SHORT SAV (~10cm<), 3=DMA (drift macroalgae).

BARE: The proportion of ten records classified as BARE.

SHORT: The proportion of ten records classified as SHORT.

DMA: The proportion of ten records classified as DMA.

SAV Coverage Maps

Ordinary point kriging, a geostatistical method based on the spatial autocorrelation inherent in landscape patterns, was used to produce spatially continuous maps of SHORT and DMA percent cover. Each kriged contour feature was subsequently clipped to the perimeter of the area traversed within each survey tile, i.e. the boundaries of the contour maps do not extend beyond the area of acoustic sampling.

Verifying Temporal and Spatial Consistency

A supervised classification scheme requires temporal and spatial consistency of predictor variables over the entire course of data acquisition. Classification accuracy would diminish if the baseline values of the acoustic energy parameters shifted, due either to instrument drift or the intrusion of extraneous geophysical factors. The qualities of spatial and temporal consistency are clearly evident in the E1vsE2 and E1vsE1' scatterplots of BARE catalog data (Figure 5). The 68 BARE catalog samples were collected across the extent of the study area, i.e. spatially consistent. 41 of the samples were collected in Apr-May 2007 and 27 of the samples were collected in Apr-May 2008, i.e. temporally consistent.

Ground Validation Sampling

A total of 265 ground-validation samples were collected in-line with the survey by intermittently slowing to idle speed, deploying a weighted video camera overboard, and simultaneously recording sonar and video for a period of 30-60 seconds. The Trimble dGPS latitude and longitude and UTC time were burned onto the recorded video for post-survey synchronization with hydroacoustic data. The ground-validation video samples were reviewed post-survey and assigned a visually-estimated percent coverage of (1) bare substrate, (2) short SAV, and (3) drift macroalgae and tall SAV. The ground-validation data was subjected to the same VBT post-processing, depth-normalization, and quality assurance as described previously for the survey data. Of the 265 samples collected, 246 remained for ground-validation analysis, totaling 8,285 hydroacoustic records. Each of the 8,285 records was classified as either BARE, SHORT, or DMA using the same Fisher's linear discriminant functions used to classify the survey data. The acoustically-predicted cover of SHORT and DMA was then calculated for each of the 246 ground-validation samples, as the simple average of the 30-60 classified records per sample.

Accuracy Assessment

The accuracy assessment was performed directly on the hydroacoustic records, not on the kriged contour plots of percent cover, because (i) biomass was calculated directly from individual hydroacoustic records, and (ii) the heterogeneous nature of the benthos would introduce uncertainty if the area sampled was not within the acoustic footprint. A confusion matrix was constructed as a square array of numbers arranged in rows (linear discriminant analysis classification) and columns (ground-truthed classification). An accuracy assessment could not be conducted on the individual percent cover of drift macroalgae and short SAV, since many ground-truthing samples were a mixture of both. Instead, the accuracy assessment was based on total SAV (short SAV plus drift macroalgae) grouped into three abundance categories; 0-33, 33-66, and 66-100% cover. The overall accuracy (Po) was calculated as the sum of the major diagonal, i.e. correct classifications, divided by the total number of ground-validation samples. Each diagonal element was divided by the column total to yield a producer's accuracy and by the row total to yield a user's accuracy. The producer's and user's accuracies provide different perspectives on classification accuracy. The producer's accuracy (omission/exclusion error) indicates how well the mapper classified a particular category, i.e. the percentage of times that substrate known to be sparsely covered was correctly interpreted sparse cover. The user's accuracy (commission/inclusion error) indicates how often map categories were classified correctly, i.e. the percentage of times that a sample classified as sparse cover was actually sparse and not abundant or contiguous.

The Tau coefficient is a measure of the improvement of classification accuracy over a random assignment of map units to map categories. The form of Tau based on equal *a priori* probability of group membership (T_e) was used for this study. In this case, the probability of random agreement simplifies to the reciprocal of the number of categories ($1/r$), and T_e is simply an adjustment of P_o by the number of map categories. As the number of categories increases, the probability of random agreement diminishes, and T_e approaches P_o. Values of T_e were calculated as follows:

Tau coefficient for equal probability of group membership = $T_e = (P_o - 1/r) / (1 - 1/r)$

RESULTS

Assessing the Supervised Catalog

The effect of successive linear discriminant analyses (LDA) can be seen as an increasing separation of data clouds in the scatterplots of canonical variable scores (Figure 6a), the result of retaining only end-member records. The greater discriminatory power of an LDA utilizing eight acoustic parameters is made clear by comparing the LDA scatterplots to the individual 38 and 418 kHz E1vsE2 scatterplots, populated by the same LDA datasets (Figure 6a vs Figures 6b-c). The E1vsE2 bottom ratio method is commonly employed for seabed classification, but as expected the reduced information resulting from using just two predictor variables at a single frequency provides less discriminatory power than using eight variables at two frequencies (Figure 6a). Moreover, LDA is an eigenvector-based technique designed to maximize the separation of *a priori* groups, compared to the relatively simplistic Cartesian-based E1vsE2 bottom ratio method.

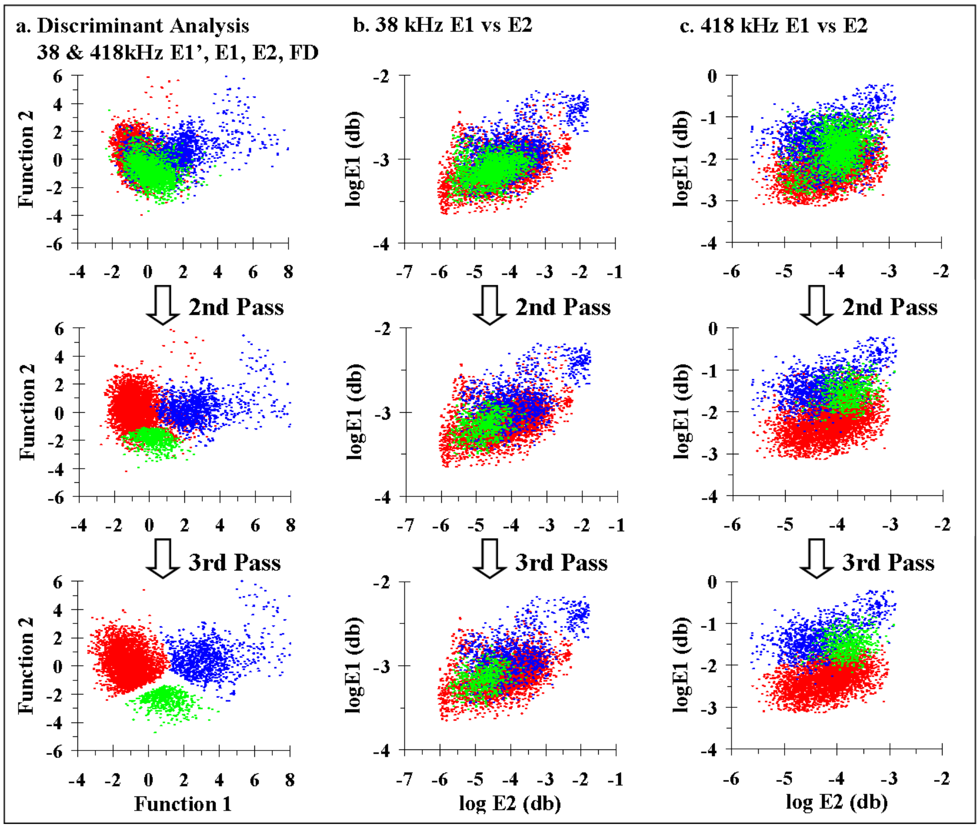


Figure 6. Discrimination of Bare (red), Drift MA (blue), and Short SAV (green) catalog records after multiple passes through (a) Linear Discriminant Analyses using 38 and 418 kHz E1', E1, E2, and FD as predictor variables. The advantage of utilizing eight acoustic variables is evident when the same data is presented as (b) the 38 kHz E1 vs E2 Bottom Ratio or (c) the 418 kHz E1 vs E2 Bottom Ratio.

The LDA catalog was checked for internal consistency by classifying the 166 catalog samples that passed quality assurance with the Fisher's linear discriminant functions from the third-pass discriminant analysis (Table 1). The acoustically-predicted cover of DMA and SHORT was calculated for each of the 166 catalog samples, as the simple average of the 30-90 classified hydroacoustic records belonging to each sample. Figure 7 displays the acoustically-predicted percent DMA and SHORT cover versus the visually-estimated cover of the 166 catalog samples. To better illustrate the overall trends, the average predicted values were also calculated for ground-truthed values in the range of 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, and 80-100% cover.

DMA Catalog: The DMA model generally performed well across the full range of coverage, as seen in both the scatterplot of predicted versus ground-truthed cover and in the model residuals (predicted minus ground-truthed percent cover). The DMA model only slightly under-predicted cover, by 10-20%, as ground-truthed cover exceeded 50%.

Short SAV Catalog: The under-prediction of the SHORT model was more pronounced, averaging approximately 35% as ground-validated cover exceeded 50%. This resulted from the way in which the multi-pass LDA scheme discriminated between the overlapping SHORT and BARE data clouds. Moving down the column of Figure 6a, after the 1st Pass Discriminant Analysis the SHORT and BARE categories can be seen to overlap. After the 3rd Pass Discriminant Analysis the previous region of overlap was assigned to the BARE category, and hence the under-estimation of short SAV at the upper range of coverage. But this underestimation is not critical to the final outcome, because (1) the primary objective was to quantify the biomass of drift macroalgae, and (2) based on ground-truthing samples, roughly two-thirds of the short SAV biomass came from areas of less than 50% cover.

Classifying Survey Data

The Fisher's linear discriminant functions (Table 1) resulting from the third-pass LDA were used to classify each of the 500,000+ survey records as either BARE, DMA, or SHORT. This was done by multiplying each coefficient by the value of the corresponding acoustic parameter, summing the products, and adding the constant to get a score for each of the three categories. Survey records were assigned to the category with the largest discriminant function score. The final layer of classification was created by tallying the assignments for a range of ten consecutive records and computing the proportion of BARE, DMA, and SHORT assignments for each group of ten records.

Table 1. Values of Fisher's Linear Discriminant Functions used to classify hydroacoustic records.

Variable	BARE	SHORT	DMA
E1 38kHz	-58.7	-60.9	-57.8
E2 38kHz	29.5	25.8	29.6
E1' 38kHz	-131.6	-129.3	-128.6
FD 38kHz	46314.8	46294.8	46362.3
E1 418kHz	-75.5	-64.1	-60.8
E2 418kHz	-44.0	-40.6	-47.3
E1' 418kHz	29.5	26.2	20.9
FD 418kHz	1397.7	1365.9	1418.5
Constant	-24595.2	-24529.6	-24651.5

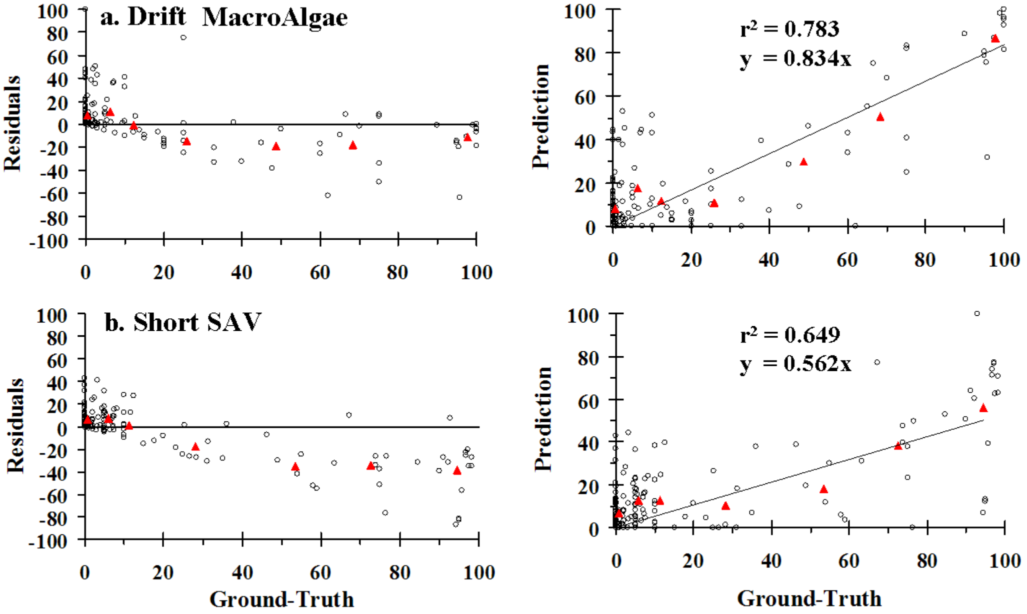


Figure 7. The internal consistency of the LDA catalog was evaluated by comparing acoustically-predicted values (right) and model residuals (left) of (a) drift macroalgae and (b) short SAV for the 166 catalog samples. Displayed as individual catalog samples (open circle) and as the average of catalog samples falling within bins of ground-truthed cover (solid triangle). Linear regression was performed on individual samples.

SAV Coverage Maps

Ordinary point kriging, a geostatistical method based on the spatial autocorrelation inherent in landscape patterns, was used to produce spatially continuous maps of SHORT and DMA percent cover. Each kriged contour feature was subsequently clipped to the perimeter of the area traversed within each survey tile, i.e. the boundaries of the contour maps do not extend beyond the area of acoustic sampling (Appendix A2-A9).

Accuracy Assessment

A confusion matrix could not be produced for the individual categories of drift macroalgae and short SAV, since many ground-truthing samples were a mixture of both. Instead, the percent cover of drift macroalgae and short SAV were summed and grouped into three abundance categories; 0-33, 33-66, and 66-100% cover. The important distinction is that the confusion matrix was based on the classified hydroacoustic records, not on the kriged contour plots of percent cover. Performing accuracy assessment directly on the classified hydroacoustic records was deemed most appropriate, since biomass was calculated directly from individual hydroacoustic records. The overall predictive accuracy for the 246 ground-truthing samples was 78.9% for the three coverage categories of total SAV cover. The Tau coefficient for equal probability of group membership (T_e) was 0.683 ± 0.076 (α=0.05), i.e. the rate of misclassifications was 68.3% less than would be expected from random assignment of hydroacoustic records to SAV cover. (Table 2).

Table 2. Confusion matrix of 246 ground-validation samples comparing acoustically-predicted versus visually-estimated for three abundance ranges of Total SAV (short SAV plus drift macroalgae).

		Ground-Truthed				
	Total SAV	**0 to 33**	**33 to 66**	**66 to 100**	**i+**	**Users**
Predicted	**0 to 33**	**157**	9	3	169	92.9%
	33 to 66	27	**19**	10	56	33.9%
	66 to 100	3	0	**18**	21	85.7%
	+i	187	28	31	194	**<= Diag**
	Producers	84.0%	67.9%	58.1%	**n =>**	246

Overall Accuracy (P_o) 78.9%

Tau (T_e) = 0.683 ± 0.076

To assess the accuracy of the individual predictions of drift macroalgae and short SAV, the relationship between acoustically-predicted percent cover and the visually-estimated percent cover was examined by simple linear regression. Figure 8 displays the acoustically-predicted percent cover drift macroalgae and short SAV versus the visually-estimated cover for each of the 246 ground-validation samples. To better illustrate the overall trends, the average predicted values were also calculated for ground-validated values in the range of 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, and 80-100% cover.

DMA: As seen previously with the catalog data, DMA classification performed well across the full range of coverage as judged by both the scatterplot of predicted versus ground-truthed cover and the model residuals (predicted minus ground-truthed percent cover). DMA cover was slightly under-predicted as ground-validated cover increased beyond 20%, evidenced by the residuals plot and the value of the regression coefficient (b = 0.784). Overall, the residuals averaged only 0.25%, indicating a slight over-prediction at lower levels of DMA cover. DMA classification generally performed well across the full range of full range of cover, evidenced by the high coefficient of determination (r^2 = 0.65).

Short SAV: As seen in the catalog data, SHORT cover was under-predicted at the upper ranges. This underestimation was not critical to the final outcome, because (1) the primary objective was to quantify the biomass of drift macroalgae, and (2) based on ground-truthing samples, roughly two-thirds of the short SAV biomass came from areas of less than 50% cover.

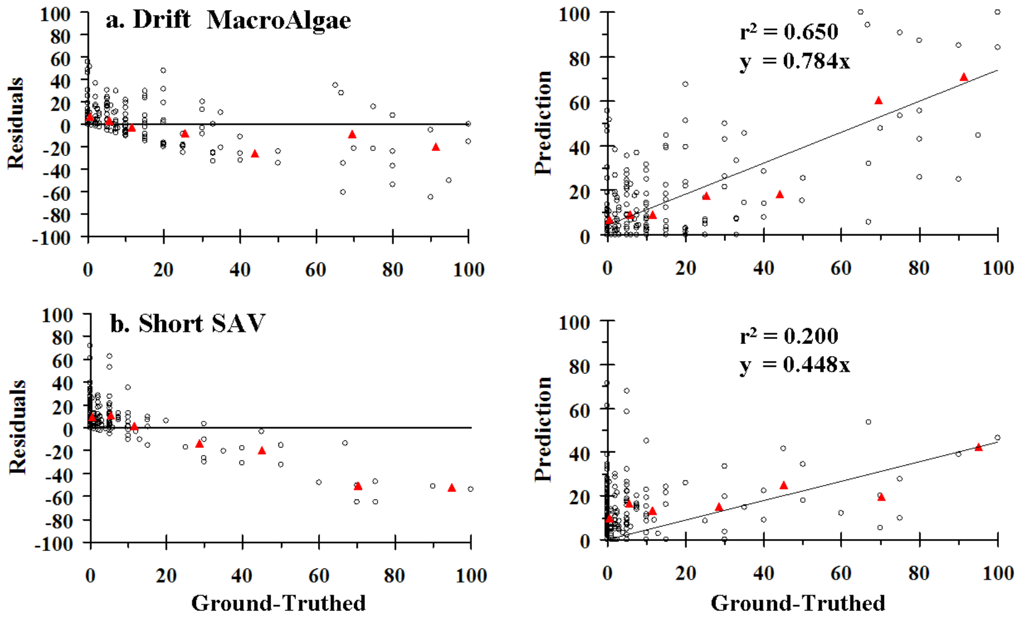


Figure 8. Acoustically-predicted values (right) and model residuals (left) of (a) drift macroalgae and (b) short SAV for the 246 ground-validation samples. Displayed as individual ground-validation samples (open circle) and as the average of samples falling within bins of ground-truthed cover (solid triangle). Linear regression was performed on individual samples.

Drift Macroalgae Biomass

The average percent cover of short SAV and drift macroalgae was calculated individually for the SJRWMD segments shown in Appendix A1, using the ten-record averages of classified hydroacoustic records (Table 3). The lagoon-wide percent cover of DMA and SHORT was found to be 11.2 and 24.1% respectively, compared to 18.5 and 24.6% from the 2005 survey.

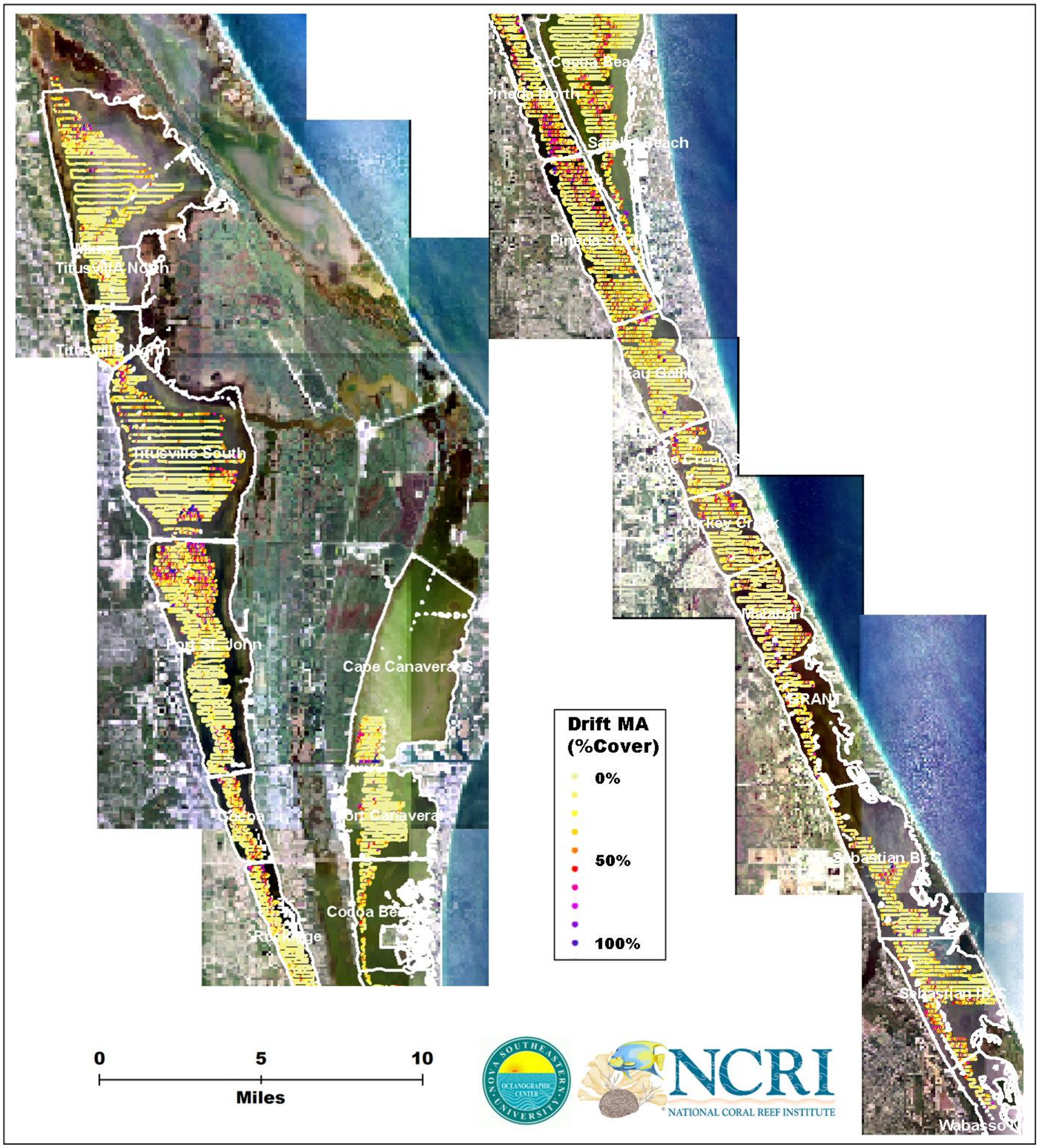
The biomass of drift macroalgae within each SJRWMD segment was calculated as the product of the average percent cover of drift macroalgae, segment area, and the wet weight of drift macroalgae (2000 metric tons per km^2) measured in the 2004 pilot study. At the time of the survey (April 1 - May 21, 2008) the drift macroalgae biomass was found to be 69,859 metric tons w.w. within the 293.1 km^2 study area. The biomass per unit area (238.3 kg per km^2) was roughly 34% less than reported for the 2005 survey, in general agreement with field observations.

An independent samples t test was performed to assess whether a difference in mean drift macroalgae cover existed between (1) records from within the navigation channels versus outside of navigation channels, or (2) records from the Indian River versus the Banana River (excluding navigation channels). The Levene test showed a significant difference between the variances of both comparisons, so the unequal variances version of the t test was used. The mean percentage of drift macroalgae was greater within the navigation channels (M=18.3%, n=1477) than outside (M=12.2%, n=48139), and the difference was found to be statistically significant ($p<0.001$, two-tailed). The 95% CI around the difference between these sample means ranged from 4.92 to 7.21%. The mean percentage of drift macroalgae was slightly greater in the Indian River (M=12.9%, n=39374) than in the Banana River (M=9.3%, n=8765), and the difference was found to be statistically significant ($p<0.001$, two-tailed). The 95% CI around the difference between these sample means ranged from 3.25 to 3.98%.

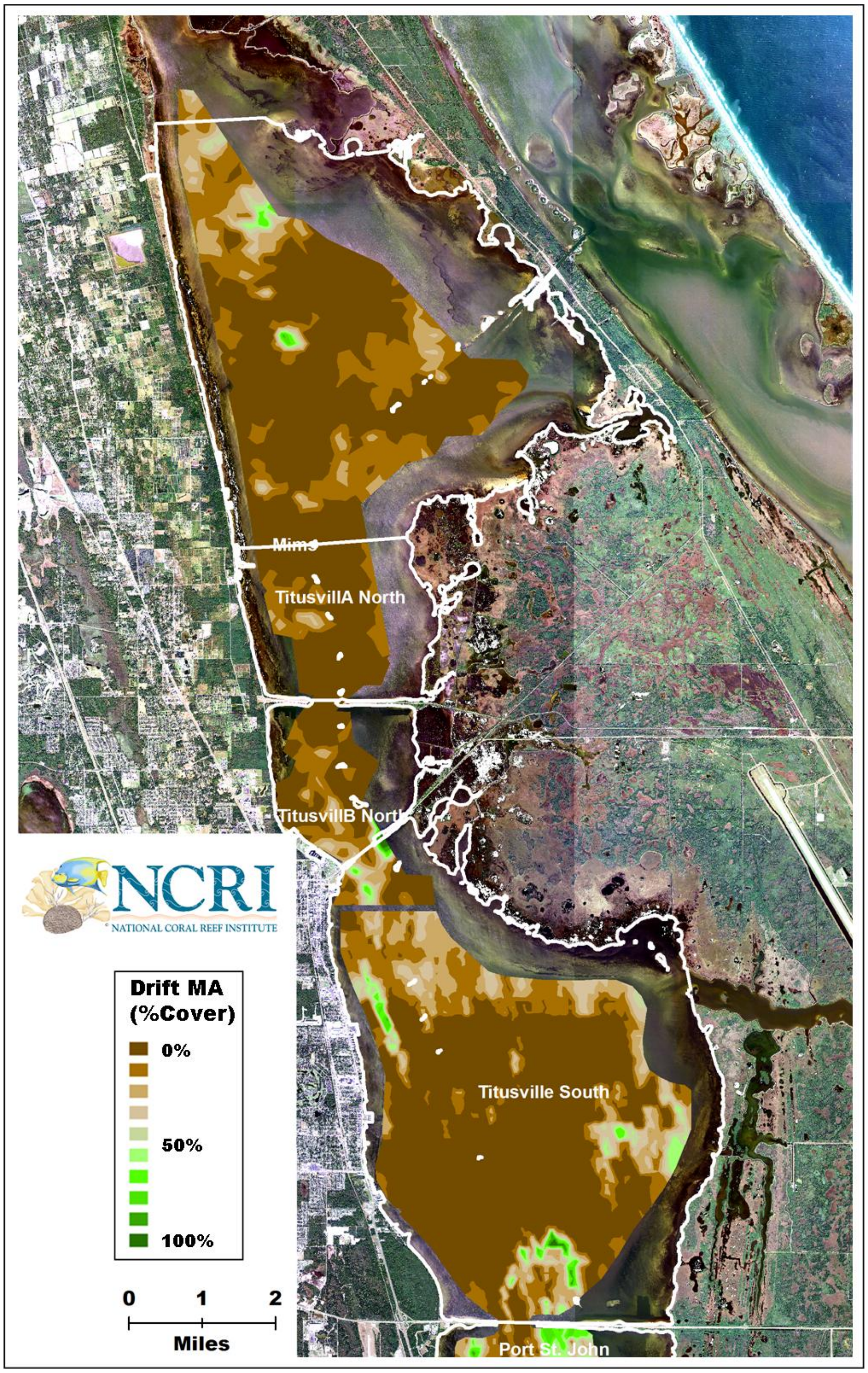
Table 3. Drift macroalgae biomass and proportions (0-1) of short SAV (~10cm<) and drift macroalgae cover, partitioned by SJRWMD segments and by proximity to navigation channels.

		Inside Navigation Channel						Outside Navigation Channel						DMA wet wt metric tons
				Acoustic Cover						Acoustic Cover				
IRL Segment	Loc	n	Mean Depth (m)	Short SAV	Drift MA	Total	Survey Area (km^2)	n	Mean Depth (m)	Short SAV	Drift MA	Total	Survey Area (km^2)	
Mims	IR	16	2.82	0.33	0.53	0.85	0.36	4254	1.78	0.31	0.09	0.40	33.60	6208
TitusvillA North	IR	25	3.30	0.26	0.29	0.56	0.28	1155	1.81	0.33	0.05	0.37	7.31	736
TitusvillB North	IR	66	3.72	0.08	0.21	0.29	0.36	859	2.10	0.17	0.10	0.27	5.12	1049
Titusville South	IR	86	3.07	0.18	0.16	0.34	0.98	5542	2.25	0.25	0.10	0.35	46.33	9152
Port St. John	IR	229	2.95	0.14	0.24	0.38	1.40	6177	2.14	0.19	0.13	0.32	31.97	8643
Cocoa	IR	104	3.61	0.05	0.17	0.22	0.37	1591	2.61	0.18	0.16	0.34	5.85	1960
Rocklege	IR	123	3.21	0.12	0.13	0.26	0.80	1988	2.82	0.18	0.10	0.28	10.03	2267
Pineda North	IR	126	3.91	0.01	0.18	0.18	0.76	1968	2.99	0.14	0.19	0.33	9.56	4000
Pineda South	IR	123	3.82	0.01	0.25	0.26	0.69	3482	3.12	0.12	0.19	0.31	16.98	6749
Eau Gallie	IR	76	3.83	0.01	0.16	0.16	0.31	2466	2.79	0.14	0.13	0.27	11.80	3143
Crane Creek Seg	IR	48	3.47	0.04	0.10	0.14	0.30	1216	2.54	0.16	0.15	0.31	6.55	2082
Turkey Creek	IR	48	3.24	0.06	0.09	0.15	0.38	1717	2.59	0.13	0.15	0.27	8.90	2739
Malabar	IR	55	3.03	0.07	0.09	0.15	0.40	2401	2.34	0.16	0.12	0.27	11.76	2812
Grant	IR	85	2.84	0.20	0.16	0.36	0.57	723	2.05	0.24	0.15	0.39	4.91	1601
Sebastian Br C	IR	87	2.63	0.13	0.12	0.25	0.65	1596	1.83	0.15	0.13	0.28	9.51	2663
Sebastian IR C	IR	70	2.46	0.31	0.07	0.38	0.55	1982	1.86	0.24	0.16	0.40	11.68	3933
Wabasso North	IR	46	3.25	0.13	0.10	0.23	0.23	220	1.90	0.28	0.13	0.42	1.47	459
Cape Canaveral S	BR	67	2.93	0.09	0.46	0.54	0.43	993	2.22	0.14	0.11	0.25	4.25	1067
Port Canaveral	BR	18	3.25	0.04	0.17	0.21	0.12	2216	2.15	0.19	0.03	0.22	11.90	743
Cocoa Beach	BR							481	2.01	0.35	0.14	0.50	3.68	1052
S. Cocoa Beach	BR							4678	2.31	0.39	0.10	0.50	26.54	5556
Satellite Beach	BR							389	2.11	0.24	0.18	0.43	3.38	1242
Total =>							10.0						283.1	69859
Weighted Lagoon Average =>			3.19	0.12	0.19	0.32			2.28	0.23	0.12	0.35		

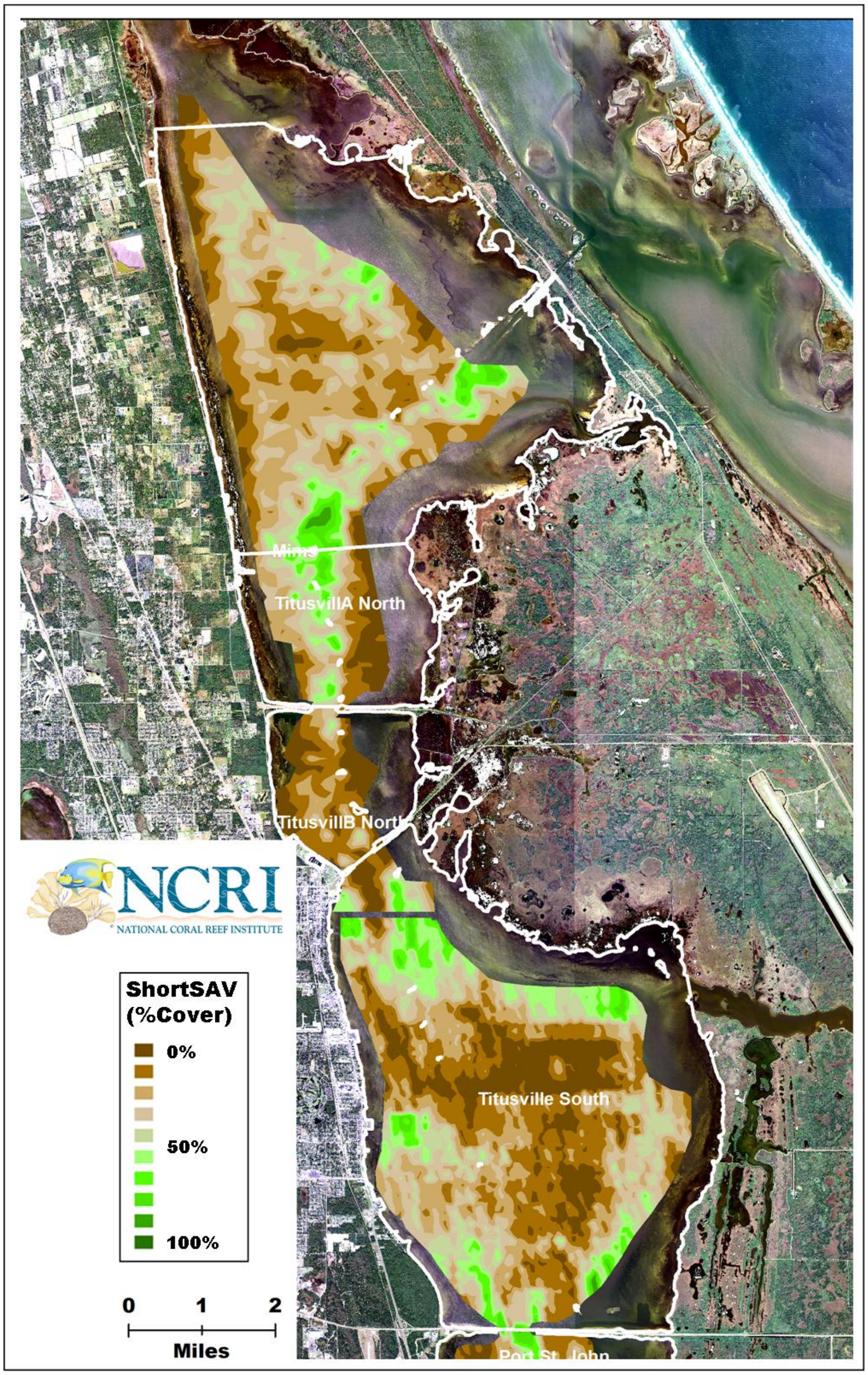
APPENDIX



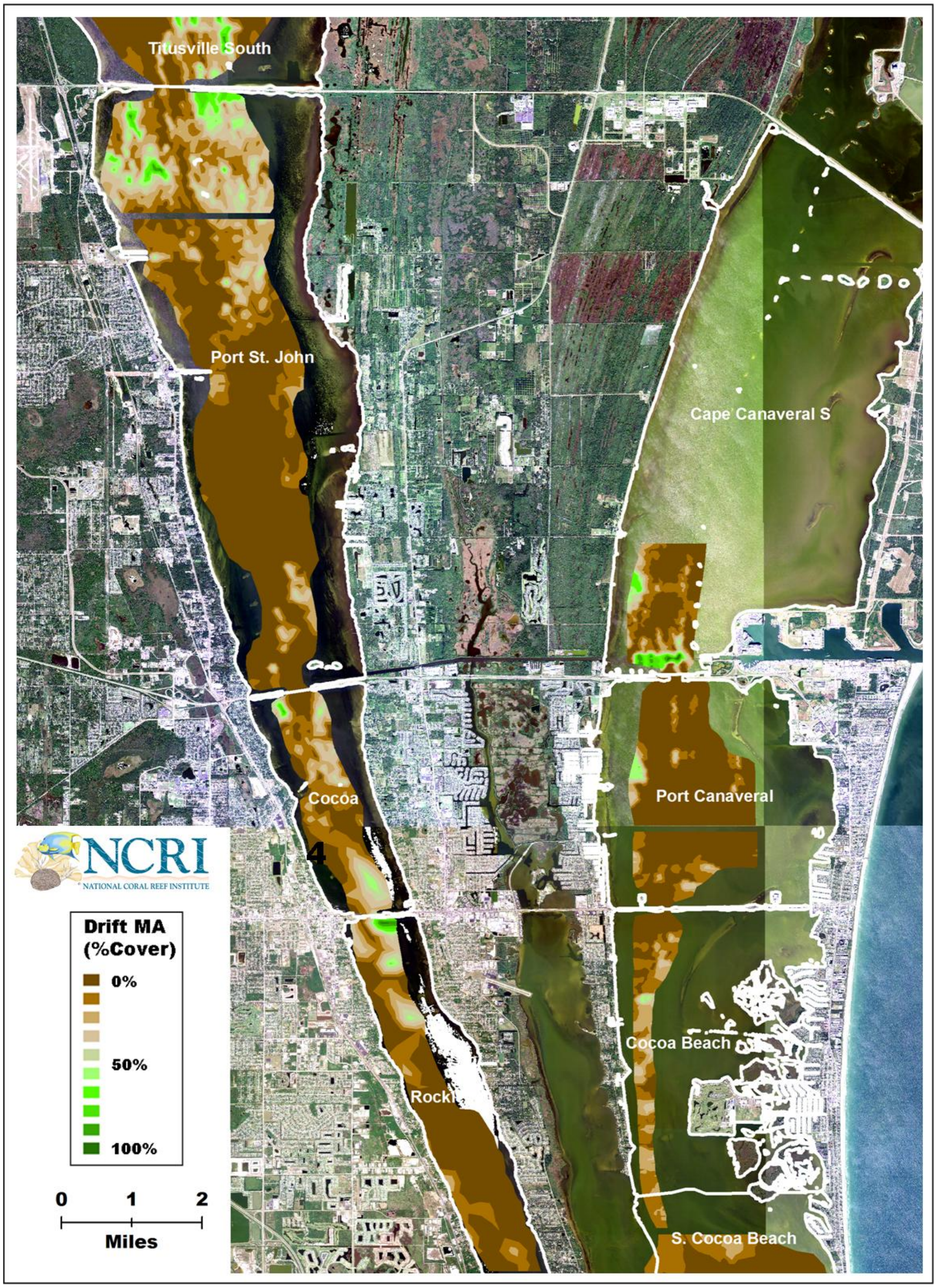
Appendix A1. Extent of the 2008 acoustic survey, displaying the trackplot of the acoustically-derived percent cover of drift macroalgae. The boundaries of SJRWMD segments are displayed for reference.



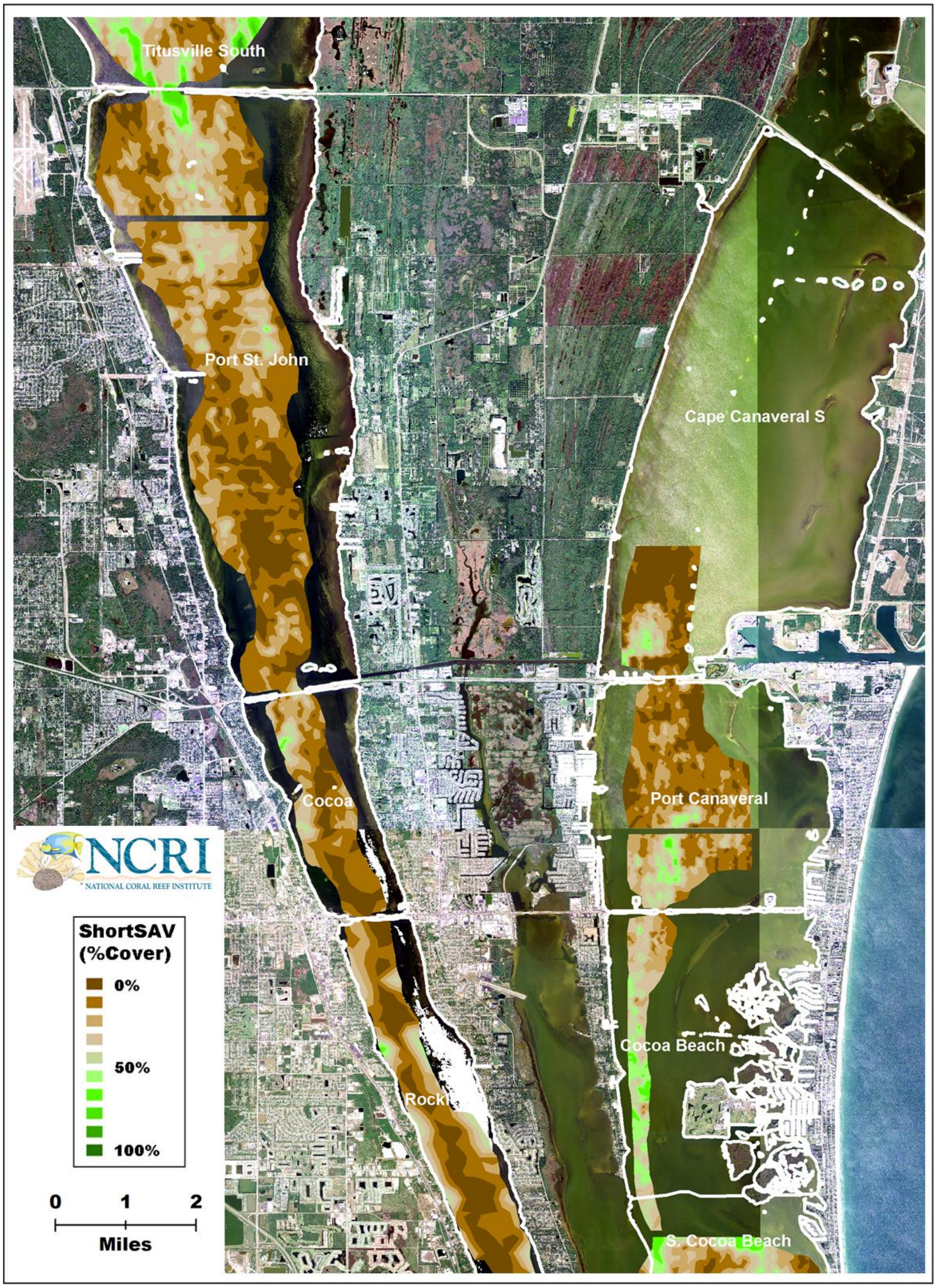
Appendix A2. Kriged contour plot of acoustically-predicted percent cover of drift macroalgae. The boundaries of SJRWMD segments are displayed for reference.



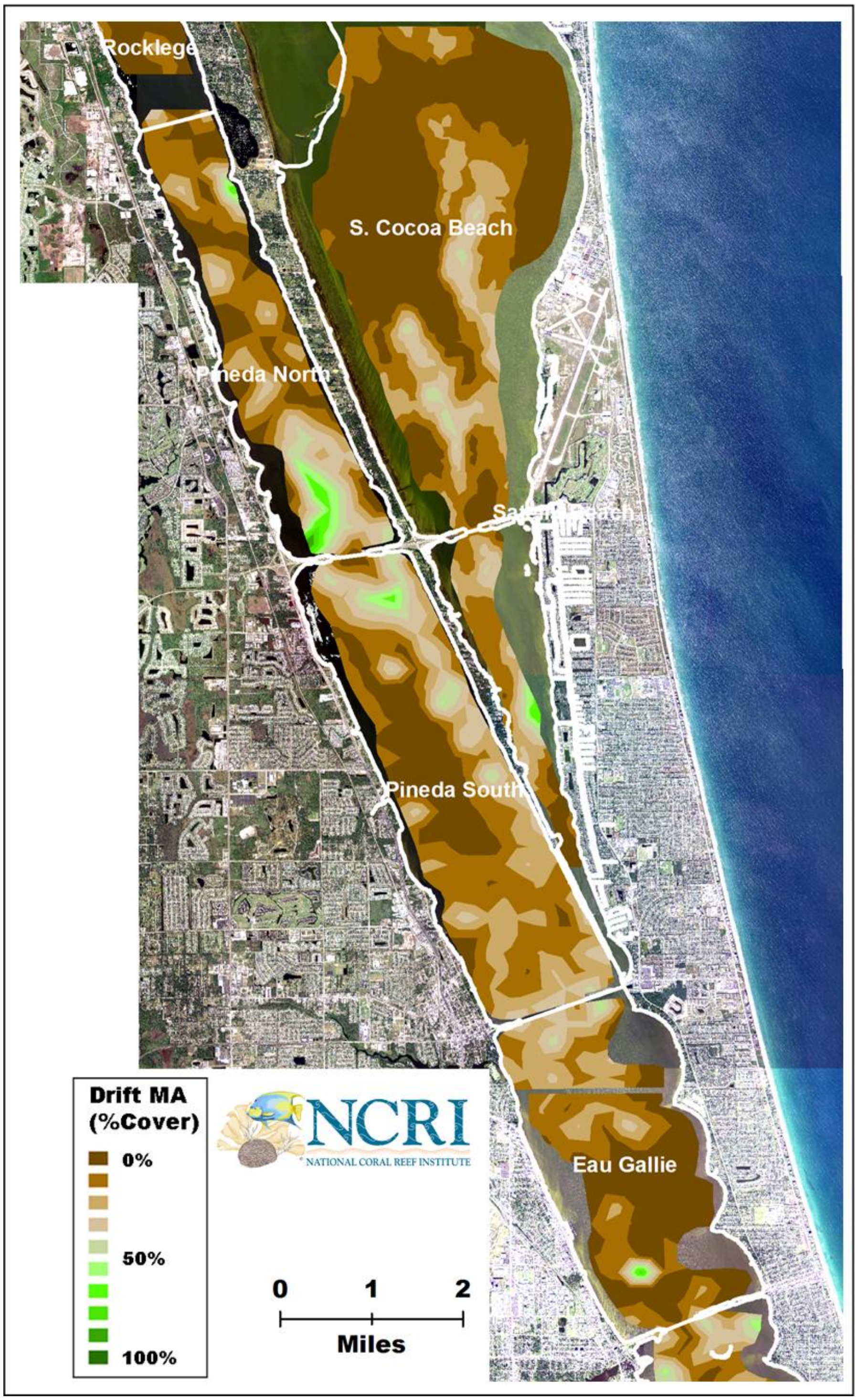
Appendix A3. Kriged contour plot of acoustically-predicted percent cover of short submerged aquatic vegetation (canopy height ~10cm<). The boundaries of SJRWMD segments are displayed for reference.



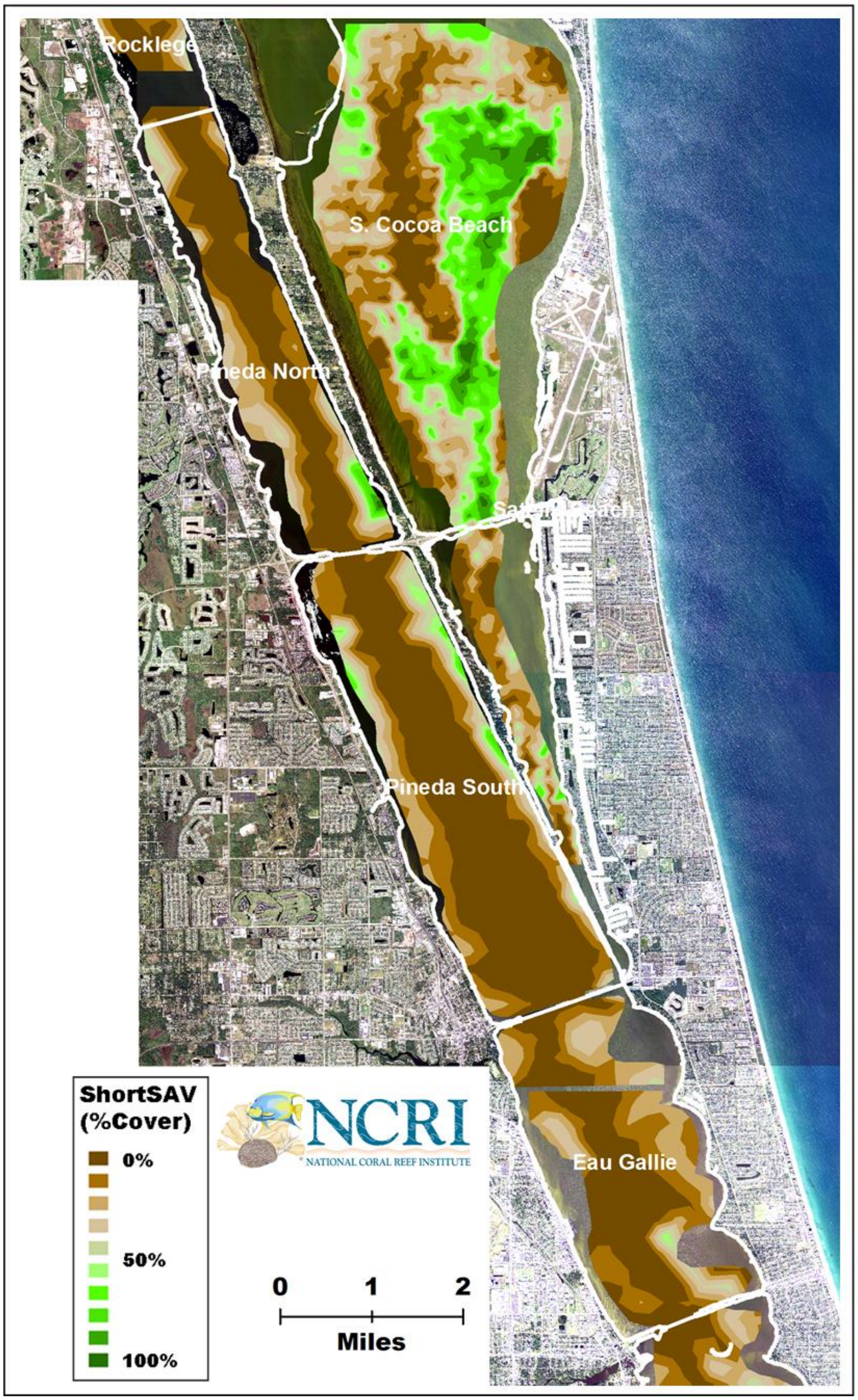
Appendix A4. Kriged contour plot of acoustically-predicted percent cover of drift macroalgae. The boundaries of SJRWMD segments are displayed for reference.



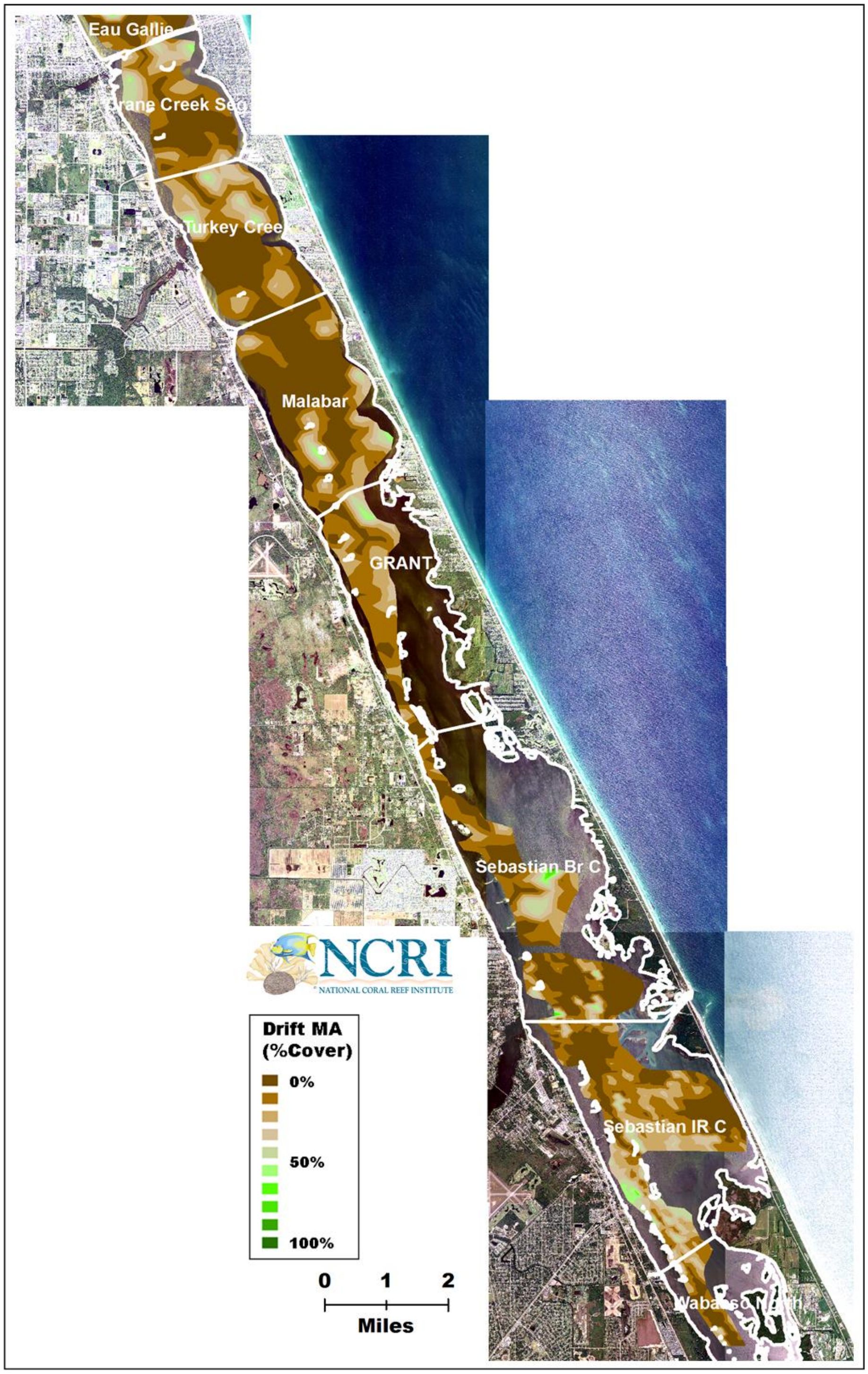
Appendix A5. Kriged contour plot of acoustically-predicted percent cover of short submerged aquatic vegetation (canopy height ~10cm<). The boundaries of SJRWMD segments are displayed for reference.



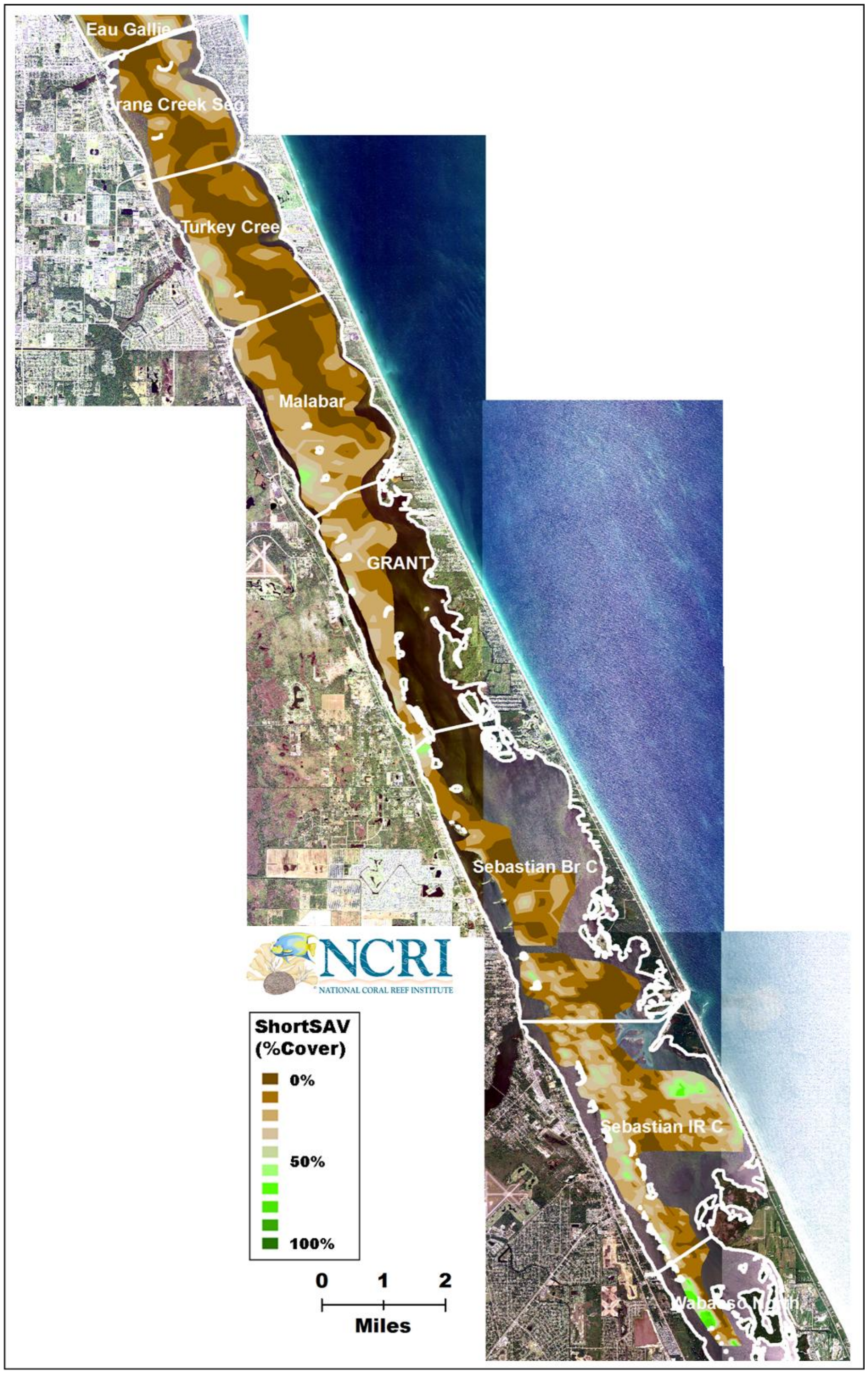
Appendix A6. Kriged contour plot of acoustically-predicted percent cover of drift macroalgae. The boundaries of SJRWMD segments are displayed for reference.



A7. Kriged contour plot of acoustically-predicted percent cover of short submerged aquatic vegetation (canopy height ~10cm<). The boundaries of SJRWMD segments are displayed for reference.



Appendix A8. Kriged contour plot of acoustically-predicted percent cover of drift macroalgae. The boundaries of SJRWMD segments are displayed for reference.



A9. Kriged contour plot of acoustically-predicted percent cover of short submerged aquatic vegetation (canopy height ~10cm<). The boundaries of SJRWMD segments are displayed for reference.