Distribution and seasonal biomass of drift macroalgae in the Indian River Lagoon (Florida, USA) estimated with acoustic seafloor classification (QTCView, Echoplus)

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Abstract

Three areas of the Indian River Lagoon, Florida (USA) were surveyed to show seasonal changes in the distribution and biomass of macroalgae and seagrass. Acoustic seafloor discrimination based on first and second echo returns of a 50 kHz and 200 kHz signal, and two different survey systems (QTCView and Echoplus) were used. System verification in both the field and a controlled environment showed it was possible to distinguish acoustically between seagrass, sparse algae, and dense algae. Accuracy of distinction of three classes (algae, seagrass, bare substratum) was around 60%. Maps were produced by regridding the survey area to a regular grid and using a nearest-neighbor interpolation to provide filled polygons. Biomass was calculated by counting pixels assigned to substratum classes with known wet-weight biomass values (sparse algae 250 g m\(^{-2}\), dense algae 2000 g m\(^{-2}\), seagrass 100 g m\(^{-2}\)) that were measured in the field. In three study areas (Melbourne, Sebastian Inlet, and Cocoa Beach), a dependence of algal biomass on depth and season was observed. Seagrass most frequently occurred in water less than 1 m deep, and in November, seagrass beds tended to be covered by dense algae that also extended up- and downstream of shoals in the Lagoon. In March, the pattern was similar, with the exception that some areas of previously dense algae had started thinning into sparse algae. Macrophyte biomass was lowest in May in the Melbourne and Cocoa Beach study areas, with the opposite situation in the Sebastian Inlet study area. In May, seagrass areas were largely devoid of dense algae and most algae accumulations were sparse. In August, dense algae covered large areas of the deep Lagoon floor while shoals were largely free of algae or had only sparse cover. We suggest this summer pattern to reflect moribund algae being washed from the shallows to deeper channels and from there being removed from the lagoonal ecosystem either through tidal passages into the open ocean or by degradation and breakdown in situ. The differences
1. Introduction

Seagrass and macroalgae beds are key ecosystems in the Indian River Lagoon (Florida, USA), which is a shallow, largely enclosed, coastal waterbody separated from the Atlantic Ocean by a series of barrier islands (Fig. 1). The Lagoon’s salinity is variable with tidal movements, but generally lower than normal marine (35 ppt) and water is typically turbid. There are seven species of seagrass present. The three most abundant, canopy forming species are *Halodule wrightii*, *Syringodium filiforme*, and *Thalassia testudinum* (Morris et al., 2000). These species of seagrass often occur in dense beds together with or adjacent to drift macroalgae where biomass has been estimated at 3 times, in extreme cases 100 times, that of seagrass (Morris and Hall, 2001). Due to their great abundance, drift macroalgae are considered to have a habitat value comparable to that of seagrass and since the densities of animals on the two vegetation-types are similar and they share about 75% of the same species (Virnstein and Howard, 1987), the drift macroalgae are generally considered an extension of the seagrass habitat. The estimation of drift algae biomass is important for the determination of overall nutrient release and/or uptake in the Indian River Lagoon system (Virnstein and Carbonara, 1985). Hence, maps of seasonal distribution are needed.

An easy and accurate way of mapping shallow benthic habitats is by passive optical remote-sensing using airphotos or satellite imagery (multi- or hyperspectral, Green et al., 2000; Dierssen et al., 2003;...
Zimmermann, 2003). However, the typically turbid conditions in the Indian River Lagoon, largely driven by nutrient input and sediment re-suspension, usually render optical methods inappropriate. Acoustic sea-floor discrimination provides an alternative that is not dependent on water clarity. The method is well established (Chivers et al., 1990; Preston et al., 2000; Lawrence and Bates, 2001; Ellingsen et al., 2002; Riegl and Purkis, 2005) and several commercially available systems exist (among others RoxAnn, Biosonics, Echoplus, QTCView; for reviews see Hamilton et al., 1999; Lawrence and Bates, 2001; Bates and Whitehead, 2001; Sabol et al., 2002; Kenny et al., 2003) that are capable of detecting differences in sediment types (Hamilton et al., 1999; Preston et al., 2000; Freitas et al., 2003a,b) and can differentiate artifacts from sediments (Lawrence and Bates, 2001). It has also been used to detect biotopes by jointly using biological and acoustic sampling (Freitas et al., 2003a,b). In this present study we examined the suitability of the QTCView Series V (Quester Tangent Co., Sidney, B.C.) and Echoplus (SEA Ltd, Bath, UK) systems to detect boundaries of areas covered by different densities of seagrass and drift algae in shallow waters of mostly less than 2 m depth. It was our goal to estimate seasonal biomass and map distribution in three test areas of the Indian River Lagoon (Melbourne, Sebastian Inlet, Cocoa Beach).

2. Materials and methods

Three areas within the Indian River Lagoon, Florida, USA (Fig. 1) were surveyed in November 2002, March 2003, May 2003 and September 2003. The winter (November 2002) and summer (May 2002) surveys covered the biggest area in order to account for maximum seasonal variability in seagrass and algal standing stock.

The Melbourne survey area was situated immediately to the south of the US 192 causeway (Fig. 1) and was characterized by a navigation channel (4 m) in the middle, shallowing to depths of less than 1 m on the Lagoon’s sides. Also, two headlands existed on the eastern shoreline, from which shoals extended towards the Lagoon’s center. The Sebastian Inlet survey area (Fig. 1) was situated immediately to the south of Sebastian Inlet. Maximum depth in the area was 3.6 m while the shallowest areas were at 0.9 m. No deep navigation channel was found within the Sebastian Inlet study area. The Cocoa Beach survey area was situated between the Port Canaveral and Cocoa Beach causeways and was characterized by shallow sides and a deeper navigation channel in the middle, where water depths reached over 5 m. It had the deepest and widest central trough of all three study areas. Also, two headlands existed on the eastern shoreline, from which shoals extended towards the Lagoon’s center. Of these, the northern shoal was bigger. Both shoals were, at least over the survey period, permanent features.

The surveys were conducted from a 7-m survey vessel equipped with a Trimble Ag132 global positioning system (dGPS) that used coast-guard beacon differential corrections to obtain real-time horizontal positioning accuracies of mostly less than 1.2 m horizontal dilution of precision. Data were logged as NMEA-GGA string, which encodes the horizontal accuracy of each position, to allow quality control of positioning during data processing. Geo-rectified aerial photographs of the survey areas were loaded into the softwares Fugawi and Hypack, that were interfaced with the dGPS unit to allow real-time monitoring of vessel position with respect to the imagery and planned survey lines. Sonar signals were obtained using a 50 kHz signal from a Suzuki TGN60-50H-12L transducer and a 200 kHz signal from a Suzuki TGW50-200-10L omnidirectional transducer, both with 0.4-ms pulse width and a 5-Hz sampling frequency with a beam angle of 42° (50 kHz) and 12° (200 kHz), respectively, provided by a Suzuki 5200/6dB depth sounder. Signal saturation was avoided by an autogain control feature in both survey systems. Depth was determined by using the QTCView bottom picking algorithm, which was accurate to at least 10 cm (tested with bar checks; Brinker and Minnick, 1994) and by direct cross-checks of displayed bathymetry and measured depth with a weighted line at several sites. Survey lines were spaced variably, but mostly not more than 100 m apart.

The principles of acoustic ground-discrimination based on single-beam echosounders employed by the systems are well-reviewed elsewhere (Chivers et al., 1990; Hamilton et al., 1999; Preston et al., 2000; Lawrence and Bates, 2001; Bates and Whitehead, 2001; Freitas et al., 2003a,b; Riegl and Purkis,
strong indication of best split level

Score decreases to an inflection point which is
dian approach (Quester Tangent Corporation, 2002). The
two systems are based on similar assumptions and record
the characteristics of reflected waveforms to
generate habitat classifications based on the acoustic
diversity of collected echoes which encode scattering
and penetration properties of different types of sea-
floor (Chivers et al., 1990; Preston et al., 1999; Hamilton et al., 1999). The typical process involves
a hydrographic survey during which acoustic data are collected. In QTCView, these are recorded as time-stamped, dGPS-geolocated digitized envelopes of the first echo. Data are then processed in the software QTC Impact and checked by the operator for correct time-stamps, correct depths, and correct signal-strengths. All signals that do not pass an appropriate level of quality control are discarded and not used for further processing. Data are also displayed on a bathymetry plot, where recorded depths are checked against the blanking (minimum recordable) and maximum depths set for the survey and any faulty depth picks are removed manually before further processing. In QTC Impact software, the echoes are digitized, subjected to a variety of analyses (cumulative amplitudes and ratios of cumulative amplitudes, amplitude quantiles, amplitude histograms, power spectra, wavelet packet transforms) by the acquisition software (Preston et al., 2001, 2004). After being normalized to a range between 0 and unity, they are subjected to Principal Components Analysis (PCA) for data reduction. The first three principle components of each echo are retained (called Q values), according to the assumption that these explain the majority of variability in the data set (Quester Tangent Corporation, 2002). Datapoints are then projected into pseudo-three-dimensional space along these three components, and subjected to cluster analysis using a Bayesian approach (Quester Tangent Corporation, 2002). The user decides on the number of desirable clusters and also chooses which cluster is split how often. Clustering decisions are guided by three statistics that are offered by the program called “CPI” (Cluster Performance Index), “Chi²” and “Total Score”. Total Score decreases to an inflection point which is ‘a strong indication of best split level’ (Quester Tangent Corporation, 2002). CPI increases with more cluster splitting (Kirlin and Dizaji, 2000; Freitas et al., 2003b), while Chi² decreases with more cluster splitting, reaching maximum/minimum values at optimal split level (Quester Tangent Corporation, 2002). In our case, the number of desired clusters was easily identified, since we knew from the surveys which seafloor classes were encountered. These were always 4 or fewer classes (dense algae, sparse algae, seagrass, and bare seafloor that was not further differentiated).

Reviews of the functioning of the QTC system and critiques can be found in Hamilton et al. (1999), Hamilton (2001), Legendre et al. (2002), Preston and Kirlin (2002), von Szalay and McConnaughey (2002), Ellingsen et al. (2002), Freitas et al. (2003a,b), Riegl and Purkis (2005), Moyer et al. (in press). The QTC dataset was reduced to a three-column matrix consisting of a single x,y geo-referenced class category z that was obtained from the cluster analysis.

Echoplus uses first and second echo. It timegates the first echo signal to ignore the first strong peak(s) and processes only the latter part plus the entire second echo. The Echoplus is similar to RoxAnn (Hamilton, 2001), which was extensively tested by Hamilton et al. (1999). Echoplus is entirely self-contained and internally compensates for frequency, depth, power level and pulse length. Pulse amplitude and length are measured on every transmission, the outputs scaled accordingly, and absorption corrections factored in. The first echo is digitized and time-gated in a way that only its tail (backscatter component) is used for analysis along with the entire second echo. The measurements from first and second echo are collapsed into two indices, E1 and E2, for the first and second echo respectively. The user has no influence on the formation of these indices and collects a geo-referenced string of variables (latitude, longitude, E1, E2). All data above the 95th and below the 5th percentile were rejected as outliers and all data were normalized to the 95th percentile, resulting in a range between 0 and unity. First return (E1) was plotted against second return (E2) data in a scatterplot, which showed whether data clustered or not. In order to produce spatially continuous habitat maps and “fill in the blanks” between survey lines, we resampled the irregular survey data (grid exclusively along the survey tracks) to a regular grid of 10-
m pixel size. Interpolation used a nearest-neighbor algorithm for categorical data, i.e. the classes produced by QTC cluster analyses (Davis, 2002; Riegl and Purkis, 2005) or geostatistics, in this case ordinary point kriging, based on the spatial autocorrelation inherent in landscape patterns, for the continuous variable output of the Echoplus (Matheron, 1971; Greenstreet et al., 1997; Middleton, 2000; Hamilton, 2001; Papritz and Stein, 2002; Walter et al., 2002). On categorical data, kriging is not the method of choice, since fractional classes, such as will be produced by kriging, appear non-sensical. To evaluate the accuracy of the acoustic ground discrimination, groundtruthing transects consisting of geo-referenced images obtained by video camera drops were collected. The habitat types observed in the videos were then compared to the extrapolated maps. Accuracy of these maps was then assessed using a confusion matrix approach (Ma and Redmond, 1995), which assesses how often classes are confused (i.e. mapped as something that groundtruthing proves them not to be). An Atlantis AUW-5600 color underwater camera was used to capture video images along groundtruthing survey lines. The video signal was time stamped and merged with positioning information. Incoming video with GPS and time-stamp information was recorded in Digital Hi-8 format using a Video Walkman. Total linear distances of 1.4 km and 5.5 km were surveyed in the Sebastian Inlet and Melbourne areas, respectively. In Cocoa Beach, groundtruthing was performed by a stratified-random arrangement of video-camera drops. Data were more equally spaced over the survey area, rather than along lines, such as in the other two study areas. Groundtruthing statistics were only calculated for the Melbourne and Sebastian River survey areas.

2.1. Verification

In order to verify that the classes obtained by QTCView and Echoplus really reflected seagrass, sparse algae, dense algae and bare seafloor, two approaches were taken: (1) for verification in the study area where the survey vessel was positioned over a discrete habitat patch, the habitat was verified by means of video drop-camera or spot-dive, and then a small dataset, containing between 1000 and 1500 echo traces, was obtained over dense algae (approximately 2000 g wet weight m\(^{-2}\), which is equivalent to approximately 230 g dry weight, was spread in the transducer footprint to cover the entire insonified seafloor), sparse algae (approximately 250 g wet weight m\(^{-2}\) were concentrated as a single clump in the center of the transducer footprint), seagrass, and bare seafloor. (2) verification in the Nova SE University marina (comparable salinity and temperature to the field trial area), where collected drift algae were placed in various densities underneath a suspended transducer. Data files of 1500 echo traces were obtained with an empty basket large enough to encompass the entire area of the footprint. Then, 250 g of algae were added into the basket (“sparse algae”) and another file of 1500 echo traces was obtained, then, an additional 1750 g algae (“dense algae”) were added and another file of about 1500 traces was obtained. This procedure was repeated in 1.8 m and 1.3 m depth. Additionally, separate files with different settings of blanking depth and signal length were obtained to evaluate whether these factors had any influence. Since the transducer was in a stable position and not moving, signal stacking performed by QTC View did not affect footprint size, which could easily be determined by trigonometry. Data were then subjected to cluster analysis in order to evaluate whether discrimination was obtained. Because seagrass and drift algae differed between the study areas in species composition, length, density, and other factors important for echo formation, and also differences in composition of sediment (category “bare sediment”) between the study areas was unknown, we considered it unwise to use the verification files as calibration files, but rather as a reasonable approximation of expected conditions. If during the verification trials all seagrass, algae and sediment categories that could be encountered in the field had been tested and true calibration datasets produced, evaluation of survey data could have proceeded using discriminant functions (Davis, 2002) rather than cluster analysis.

2.2. Estimation of macroalgal biomass

Biomass was estimated by counting the color-coded pixels assigned to each substratum class in the extrapolated maps for each survey area. Values were calculated as total biomass in kg per sample.
area. Uncleaned wet weight (including animals, water, dirt) biomass was calculated as number of 1 m² pixels times 2 kg for dense algae, 0.25 kg for sparse algae. These values were the same as those used for the acoustic verification described above. When adequately cleaned and remeasured, the biomass of the clumps used for verification was compatible to that occurring naturally (Morris et al., 2000). Seagrass biomass was considered to be on average 0.1 kg per m² (range between 0.4 and 0.04 kg m⁻² wet weight, with more sparse than dense seagrass occurring in the study area. We therefore biased data towards a lower value). The sizes of the survey areas were calculated from the total number of pixels in the extrapolated maps times pixel-size. Biomass was only calculated for the November 2002 and May 2003 surveys since the total surveyed areas were comparable. March and August 2003 encompassed smaller areas.

All data evaluation in this paper was done with code written in Matlab 6.1.

3. Results

3.1. Verification of QTCView’s ability to detect algae

In the Sebastian Inlet survey area, algae were successively added into the transducer’s footprint at depths of 1.2 and 1.5 m (Fig. 2). Data split into three classes and a new unique class only appeared when algae were added over the sand. This class represented the acoustic signal of the algae (Fig. 3). When seagrass was introduced under the transducer, a clear 4-

Fig. 2. Illustration of the density of algae referred to in the text. (A) sparse algae (~250 g m⁻² uncleaned wet weight) (B) dense algae (~2000 g m⁻² uncleaned wet weight). Both within a footprint of 57 cm radius (outlined by a rope), as would be realistic with the 50 kHz transducer (42° opening angle) at 1.5 m depth.

Fig. 3. Differentiation of algae from seagrass from bare substratum using QTCView. Left figure shows PCA and class assignment by cluster analysis. Right figure shows depth and sequence of signals. Algae and substratum signals occur together when algae are put under the transducer. Trials with pure bare substratum provided a clear and unique acoustic signature.
class split was achieved, which again corresponded to the a priori known number of seafloor classes. Fig. 3 also shows that not all signals were uniform when algae were introduced under the transducer. After cluster-splitting, a relatively high percentage was grouped with the category bare substratum. The physical reasons for this phenomenon remain unclear.

In the verification experiments at the university marina (Fig. 4), data from trials at 1.8-m depth allowed a three-class split, where at least one class could be assigned to dense algae, while results were not clear for the sparse algae. Clear separation between data taken with dense algae, sparse algae and empty basket were found. A distinct class (black in Fig. 5) represented dense algae, and another class (grey in Fig. 5) represented the sparser algae and a third class (white in Fig. 5), which was closer to the sparse algae class than the dense algae class, represented the absence of algae. The depth-plot of Trial 1 in Fig. 5 clearly shows that dense and sparse algae created a signal by reflecting the acoustic pulse at the depth of the basket (0.7 m). When removed, the acoustic pulse was reflected at the depth of the substratum (1.6 m) and not at that of the now empty basket indicating that indeed the algae, and not the basket, were responsible for the scatter. Also, the depth plot of Trial 2 (Fig. 5) showed that dense algae scattered the acoustic signal at their surface, which was about 5cm above the substratum. Sparse algae formed clumps resulting in a different depth-reading than the bare substratum.

3.2. Echoplus results

A plot of first against second echoes from the August 2003 survey in the Sebastian Inlet survey area (Fig. 6A) collected by the Echoplus, showed three distinct clusters: one group of low E1 and E2 values, one group of high E2 but low E1 values, and one group of low E2 and high E1 values (Fig. 6). Since E1 largely encodes surface roughness and E2 surface hardness, low values in both were believed to correspond to flat and soft, muddy substratum (i.e., the category bare substratum), low E1 (roughness) and high E2 (hardness) indicated a stronger substratum than algae signal and thus was believed to encode shelly, hard sand. High roughness (E1) and low hardness (E2) indicated a stronger surface scatter component and thus was believed to encode dense algae. Sparse algae formed a cloud of data in between the dense algae and hard substratum clusters. These assumptions were verified with groundtruthing video camera drops.

The “digital numbers” (numeric codes for E1 and E2) were also plotted in sequence (Fig. 6B), allowing for further groundtruthing of the assumption that E1 encoded the density of algae. Since the time sequence of the digital numbers corresponded to their geographical position, it was possible to groundtruth the information contained in the signals with camera drops. High E1 values (between 0.75 and 1) corresponded to dense algae, medium E1 values (0.6 to 0.75) corresponded to sparse algae, and low E1 values (0.55–0.6) corresponded to bare substratum.
A similar relationship was found for E2 values. High E2 values (0.8 to 1) were found associated with bare, shelly substratum and sparse algae, medium E2 values (0.5–0.7) corresponded to dense algae, and low E2 values (0.3–0.5) corresponded to bare substratum (Fig. 6C).

3.3. Distribution of algal biomass in Melbourne survey area

The QTCView survey in November 2002 (50 kHz) discriminated clearly all four classes of substratum, with “sparse algae” covering less area than “dense algae” and having a far lower cumulative biomass in the survey area (Table 3). Algae were concentrated along the lateral shoals of the study area, the biggest patches occurring on the northeastern and northwestern shoals (Fig. 7A). Much of the entire eastern fringe was covered by dense algae. Where seagrass was found, it was usually associated with algae. Dense algae were also found covering large patches of the central survey area (Fig. 7A). The QTCView survey in March 2003 (not illustrated in Fig. 7) encompassed the two northern shoals that had shown the densest coverage. The dense algae had remained but decreased in areal coverage on both shoals, and the western shoal showed some seagrass signal but remained algae-dominated. Previously, in November, the dense algae cover in the seagrass had drowned most seagrass signals. Also on the eastern shoal, the overall amount of dense algae appeared to have decreased in March, replaced by sparse algae.

In May 2003, using a 200 kHz signal and QTCView, four substratum classes were observed (Fig. 7B) which coincided with classes observed in November. Dense algae covered more area than sparse
algae and seagrass and had a higher biomass than both other categories together (Table 3). The northern shoals were covered by dense algae and seagrass occupied similar areas as in November. The northwestern shoal showed some mixture of seagrass and sparse algae, but algae still dominated. The northwestern shoal had less algae. Only few areas of dense algae cover remained on both the northern and southern sides of the shoal and in the deep channel. Also the southeastern shoal showed seagrass cover with a fringe of sparse algae and patches of dense algae on the upstream and downstream sides (Fig. 7 B).

In the August 2003 QTCView and Echoplus surveys, only three classes were found in sufficient density to be mapped, the class “sparse algae” was rare. Several areas of dense algae were found in the lee of the shoals and in the deep channel. The northwestern shoal now showed more seagrass than algae. Dense algae clumps appeared moribund, being flaccid with little pigmentation. We assume that they had previously lived in and around the seagrass and on the shoals.

Total biomass of macrophytes decreased by over 50% between autumn 2002 and spring 2003 in the Melbourne study area (Table 3).
3.4. Distribution of algal biomass in Sebastian inlet survey area

The November 2002 (Fig. 7C) 50-kHz survey discriminated four classes of substratum. Seagrass occurred on the northern and southern shoals, and was surrounded by sparse algae forming a dense apron. Almost a quarter of the survey area was covered by sparse algae (Table 3), with smaller patches of dense algae concentrated near the southern shoal.

In March 2003, two surveys (50 and 200 kHz) found more dense algae on the northern shoal than in November. Dense algae covered most of the seagrass and sparse algae surrounded these areas, which only showed in the 50 kHz survey. Most of the deeper survey area was bare substratum. The 50 kHz survey found a contiguous area of dense algae towards the southern shoal, while the 200 kHz survey suggested several patches of sparse algae in roughly the same area.

In May 2003 (Fig. 7D), a 200-kHz survey discriminated the same four classes. Unlike in the Melbourne study area, overall macrophyte cover had not decreased and dense algae covered as much area as sparse algae and seagrass (Table 3). The northern shoals, near Sebastian Inlet, were characterized by seagrass signals with only small areas showing dense algae cover with surrounding sparse algae (Fig. 7D).
Another large seagrass area was on the southernmost shoal. Most dense algae were concentrated in the southern and western sections and surrounded by sparse algae. Seagrass and dense algae also existed in the deep and sheltered northeastern part of the basin, adjacent to mangroves. Most deeper area were bare.

Between November 2002 and May 2003, the overall biomass of macrophytes had remained almost unchanged (Table 3).

The August 2003 Echoplus surveys were conducted on 200 kHz, discriminating bare substratum, sparse algae, and dense algae. No seagrass areas were surveyed. Different to Melbourne, algal cover in the Sebastian Inlet survey area increased in August. Most of the deeper basin was covered by dense algae or sparse algae (Fig. 7 D). Large clumps of algae were found along the waterline. The least algal cover was found in the western and southern sections.

3.5. Distribution of algal biomass in Cocoa beach survey area

The November 2002, QTCView survey discriminated four classes of substratum (Fig. 7E). Algae...
formed an almost continuous fringe along the lateral shoals, but were also found in the deeper central part of the study area. Seagrass was almost always neighbored by accumulations of algae and concentrated on the northwestern shallow fringe of the study area, the northeastern shoal, and the southern central shoal. Dense algae covered more area than sparse algae and seagrass (Table 3).

In May 2003 (Fig. 7F), the area covered by the survey was smaller than that of the November survey (Table 3, Fig. 7F). Seagrass was found on the southern central shoal and along the eastern and western shoals, while algae cover in the shallows had decreased. Cover of sparse algae in the deeper parts of the study area had increased, however. Sparse algae covered far more area than seagrass or dense algae (Table 3). Between November 2002 and May 2003, macrophyte cover had increased due to sparse algae in the deep Lagoon, but biomass had dropped dramatically (Table 3).

In August 2003, Echoplus and QTCView surveys were conducted in the northern part of the survey area following the same survey lines (Fig. 8). In this relatively deep area, only algae and bare substratum occurred. Both surveys differentiated algae from bare substratum, and identified an area of dense algae in the northernmost part of the area. For map extrapolation of the Echoplus survey, digital E1 numbers were binned into algae- and non-algae classes according to Fig. 6B. The two systems differed in detection of algae in the southern, sparser, part. The Echoplus showed few algae signals in this area, while the QTCView showed a significant number of well-spaced algae signals.

3.6. Groundtruthing and accuracy assessment

Video surveys confirmed the presence of the four bottom types observed by the acoustic surveys. In the Melbourne 50 kHz survey area, all four seafloor classes were also seen in the groundtruthing data. For this reason, dense and sparse algae were considered separate classes for accuracy assessment. Overall, accuracy was only 36% (Table 1A) and high confusion was evident among all classes, with highest confusion between dense and sparse algae. The confusion matrix was then recalculated with dense and sparse algae classes pooled (Table 1B) resulting in a three-class accuracy of 59%. The Sebastian Inlet groundtruthing did not encounter dense algae, resulting in only one ‘algae’ class (Table 2).

Two confusion matrices were produced which compared the extrapolated maps derived from the acoustic surveys. Overall, accuracy was about 60% (Table 2). The surveys and resulting extrapolated maps were very good at predicting areas of algae

<table>
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<tr>
<th>Table 1</th>
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<td>(A) Error matrix (Ma and Redmond, 1995) for Melbourne study area with dense and sparse algae as separate classes; (B) with dense and sparse algae pooled as a single class</td>
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<th>Dense algae</th>
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Columns are classified categories on the maps, rows are accuracy assessment data obtained from video surveys. Bold number in italics is the total accuracy.
However, some confusion did exist between areas of sand and seagrass.

### 4. Discussion

The study shows that two different acoustic ground discrimination systems, QTCView and EchoPlus, were capable, within limits, not only of differentiating sediment types, which is well published (Hamilton et al., 1999; Morrison et al., 2001; Freitas et al., 2003a,b) but were also able to detect algae and seagrass. A three-class confusion matrix based on QTCView surveys, suggested a total accuracy of nearly 60% for seagrass-algae-bare substratum. The two algae classes (sparse versus dense) showed high confusion, and clearly more work is needed to improve discrimination, either through improved signal processing or data analysis at the post-processing stage. But since ground-truthing information was collected after surveys for logistical reasons and drift algae are mobile, it is possible that the observed high confusion values are partly a sampling artifact caused by the algae having moved (aggregated, dispersed, etc.) in the time between the surveys and the groundtruthing. From both verification experiments and field survey data, it was apparent that seagrass and drift algae indeed produced unique echo classes.

Under controlled conditions as well as in the field, it was difficult to obtain files containing only echoes that could be clearly ascribed to either algae or seagrass with the QTCView instrument. Usually all files containing echoes from algae or seagrass also included a large proportion of echoes (up to half) from bare substratum. This high intermixed proportion of bottom signals was more pronounced with the algae than with the seagrass, but occurred with both vegetation types. This suggests that the bottom signal occurred as frequently as the vegetation signals themselves, even when the area under the transducer appeared to be entirely covered by vegetation. We cannot provide a satisfactory explanation why this is so, and several possibilities exist. The easiest is to assume that unattached drift algae rolled in and out of the transducer’s footprint, as was indeed sometimes observed. However, even when the algae were anchored, and when the attached seagrass was used as a target, a proportion of signals still had the acoustic qualities of signals derived from bare substratum (Figs. 3 and 5). The EchoPlus appeared to give a somewhat clearer distinction (Figs. 6 and 8), which could, however, largely be due to the way classes were assigned as binned intervals of the digital number provided by the EchoPlus, while in the QTCView system classes are assigned based on the position of signals in pseudo-3-dimensional space after PCA. Depending on the width of the chosen bins, accuracy of discrimination could be influenced. The QTCView system uses at that last step at least three variables (the first three principal components characterizing each echo) for the binning into groups, in contrast, we used only the single digital number (E1) of EchoPlus for obtaining Fig. 8.

Reasons for confusion of algae and bare substratum echoes may either be a relatively weak scattering ability of the algae and/or the different signal properties and/or the processing steps. QTCView uses the entire signal envelope of the first echo (it ignores all multipath echoes, Collins and Lacroix, 1997) which Preston et al. (2000) and Freitas et al. (2003a,b) showed to provide good discrimination ability of sediment geotechnical variables. However, Chivers et al. (1990) reports that the first peak(s) of the echo is strongly influenced by subsurface reverberation, while the echo’s tail primarily encodes scatter, which is the reasoning followed in signal processing of the
Echoplus. It is possible that much acoustic energy passes through the vegetation layer to primarily interact with the substratum and many signals may be more strongly influenced by the underlying substratum than the overlying vegetation. Thus, at least in theory, some benefit could be seen in emphasizing the trailing edge and the multipath echo when discrimination of macrophytes or other purely surficial structures is desired, since this should minimize the subsurface reverberation component. Sabol and Johnston (2001) and Sabol et al. (2002) used higher frequency echosounders and different signal processing in their acoustic evaluations of submerged aquatic vegetation.

Interpretation of the seafloor classification is aided by regridding the surveys and “enhancing” them through extrapolation and spatial statistical methods (Guan et al., 1999; Middleton, 2000; Davis, 2002; Walter et al., 2002; Papritz and Stein, 2002), which allows the production of maps with closed surfaces. While some artifacts may be introduced, it is difficult to evaluate the validity and meaning of either the QTCView or the Echoplus acoustic ground discrimination by evaluating the survey lines only. An alternative would be to cover the entire seafloor with acoustic signals, but this is not practical since the shallow water depths result in a small footprint even of swath systems, like side-scanning or multibeam sonars.

Bathymetry influenced the distribution of drift algae in all three study areas. The pattern was clearer in Melbourne and Cocoa Beach than in Sebastian Inlet. In Cocoa Beach and Melbourne, the areas of densest algae accumulation were always towards the Lagoon’s edges where the shallow areas (<1.5 m deep) showed, depending on season, a continuous fringe of either dense or sparse algae. This situation was also observed by other surveys in the same area (Nielsen et al., 2000). In the Sebastian Inlet area, dense algae were found as well on the shoals as in the deeper areas. Seagrass was restricted to the shallowest areas (<1 m depth) and algae had a clear tendency to accumulate around and within these seagrass meadows. This made the unequivocal acoustic discrimination of seagrass difficult.

Drift algae were encountered in the deeper parts of the Lagoon and also accumulated around and within seagrass areas, particularly in winter. In the Melbourne and Cocoa Beach survey areas, macrophyte biomass was low in spring, while in the Sebastian Inlet area it was high (Table 3). Algae density, in particular of freely drifting algae in the deeper parts of the Lagoon, in the Melbourne and Cocoa Beach areas increased again towards autumn, in August. It is assumed that the higher values in algal biomass in the Sebastian Inlet study area, which is situated near a major inlet with a very active hydrodynamic regime, could have been due to local, current-driven, accumulation of algae. We assume that the observed absence of a uniform seasonal pattern in biomass and distribution of algae and seagrass among the study areas is an expression of a generally high spatial and temporal variability of macrophyte, in particular algae, dynamics in the Indian River Lagoon.

5. Conclusion

- Acoustic ground discrimination using QTCView and Echoplus proved useful tools not only to map the distribution of seagrass and drift macroalgae in the Indian River Lagoon.

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Seagrass</th>
<th>Dense algae</th>
<th>Sparse algae</th>
<th>Total macrophyte cover/biomass</th>
<th>Bare substratum</th>
<th>Size of survey</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% area (tons)</td>
<td>% area (tons)</td>
<td>% area (tons)</td>
<td>% area (tons)</td>
<td>% area</td>
<td>in km²</td>
</tr>
<tr>
<td>Melbourne Nov. 02</td>
<td>7 (60.04)</td>
<td>26 (4704.2)</td>
<td>3 (71.7)</td>
<td>36 (4835.9)</td>
<td>64</td>
<td>8.9</td>
</tr>
<tr>
<td>Melbourne May 03</td>
<td>5 (41.91)</td>
<td>10 (1795)</td>
<td>4 (78.9)</td>
<td>19 (1915.8)</td>
<td>81</td>
<td>8.5</td>
</tr>
<tr>
<td>Sebastian Nov.02</td>
<td>6 (54.69)</td>
<td>8 (1623.8)</td>
<td>22 (533.6)</td>
<td>36 (2212.1)</td>
<td>64</td>
<td>9.6</td>
</tr>
<tr>
<td>Sebastian May 03</td>
<td>12 (102.5)</td>
<td>12 (2140.6)</td>
<td>12 (267.6)</td>
<td>36 (2510.7)</td>
<td>64</td>
<td>8.6</td>
</tr>
<tr>
<td>Cocoa Nov. 02</td>
<td>4 (52.14)</td>
<td>19 (5296)</td>
<td>2 (86.6)</td>
<td>25 (5434.7)</td>
<td>75</td>
<td>13.9</td>
</tr>
<tr>
<td>Cocoa May 03</td>
<td>4 (39.56)</td>
<td>2 (343.2)</td>
<td>30 (736.4)</td>
<td>36 (1119.2)</td>
<td>64</td>
<td>9.8</td>
</tr>
</tbody>
</table>
• The maps of macrophyte distribution extrapolated from the acoustic surveys also allowed a coarse estimation of biomass.
• Macrophyte (algae and seagrass) biomass varied with the seasons but the pattern was not uniform among study areas.
• More work is necessary to increase the accuracy of acoustic surveys.

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