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Aquatic Plant Control Research Program

Innovative Techniques for Improved Hydroacoustic Bottom Tracking in Dense Aquatic Vegetation

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Innovative Techniques for Improved Hydroacoustic Bottom Tracking in Dense Aquatic Vegetation

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Preface

The work reported herein was conducted jointly by the U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), and the U.S. Army Engineer District, New England (NAE). Funding for this work was provided by the Aquatic Plant Control Research Program (APCRP), Work Unit Number 33118, and the NAE. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the ERDC under the purview of the EL, Vicksburg, MS. Funding was provided under Department of the Army Appropriation 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology (CAPRT), Dr. John W. Barko, Director. Mr. Robert C. Gunkel, Jr., was Associate Director for the CAPRT. Program Monitor during this study was Mr. Timothy R. Toplisek, HQUSACE.

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This report was prepared by Mr. Bruce M. Sabol, Environmental Systems Branch (ESB), Ecosystem Evaluation and Engineering Division (EEED), EL, ERDC, and Mr. Stephen A. Johnston, NAE. Ms. Tere Demoss, ESB, provided assistance on statistical analysis.

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1 Introduction

The basis for acoustical bathymetric surveys is detecting and timing the echo from a short, vertically oriented pulse. The exact detection process may vary from system to system but is usually based on exceedence of some minimum threshold intensity and peak width. For bathymetric surveys of navigation channels, this approach usually works well. A typical navigation channel consists of open water above a distinct sediment interface, leading to no ambiguity in relating the time of the echoed pulse to the exact depth of the sediment interface. A decided exception to this occurs when the bottom is colonized with submersed aquatic vegetation. Under these conditions, the acoustical reflectivity of the gas-filled plant stems or blades generates an echo that arrives at the receiver before the true bottom echo. Depending on plant type, height, and density, these plant-generated returns may pass the test for the detected bottom and be declared as the bottom, underestimating the true depth. If undetected, this condition can lead to erroneous surveys of channel depth and overestimates of dredging quantities required to keep the channel at its authorized depth.

While this occurs in only a small percentage of the channels maintained by the U.S. Army Corps of Engineers, it is sufficiently common in certain regions to represent a major operational problem. A common "offending" plant species is *Zostera marina* (eelgrass), which occurs in cool, clear, shallow saltwater locations along much of the northeastern and Pacific coastline of the United States. Approximately 60 small boat harbors within the Corps' New England District have eelgrass established within the project bounds. Hydrographic surveying within these areas requires extra field work to properly identify the true bottom. Additional data processing and field checking are necessary to verify the existence of the eelgrass and to ascertain that the bottom has been successfully tracked. This simply causes extra work at locations which have a known history of eelgrass. The major concern occurs at locations where eelgrass presence is not suspected. Here, eelgrass presence may go undetected and can cause both an environmental problem and errors in estimated dredging quantities.

During the summer of 1998, a bathymetric condition survey in an eelgrass-infested channel (Wood Island Harbor) was conducted simultaneously using two very different hydroacoustic depth measurement systems. The first was an Odom EchoTrac 3200 MKII (Odom Hydrographic, Baton Rouge, LA) with a 200-kHz, 8-deg transducer, a widely used hydrographic system. The second system was the Submersed Aquatic Vegetation Early Warning System (SAVEWS), which uses the Biosonics DT4000 digital sounder (Biosonics Inc., Seattle, WA) with a

420-kHz, 6-deg transducer. SAVEWS (Sabol and Burczinski 1998) is specifically designed to detect submersed vegetation and measure canopy density and height. Analyses of the resulting data showed good agreement between depth estimates from the two systems in unvegetated areas but increasing disagreement as eelgrass density increased. This disagreement was thought to be the result of primarily the differing signal processing approaches used. A short exploratory study was conducted of alternative processing approaches using a sampling of the digital DT4000 data. Each of these aspects is discussed and evidence is presented that improved bottom tracking within vegetated areas can be achieved using existing sensor hardware with a modified signal processing approach.

Description of Systems

Odom echotrac

The *Odom* Echotrac model 3200 MKII sounder is the dedicated system on the Corps survey vessel used at Wood Island Harbor. A hull-mounted single-frequency (200-kHz) 8-deg transducer sends monotone pulses (pings) at 3 Hz (variable up to 20 Hz). The returned echo signal is digitized once it exceeds a user-set threshold. The digital stream is then corrected for geometric spread (time-varied gain) and processed by the digital signal processor (DSP). The DSP makes a bottom depth declaration based on the following steps.[1] The depth of maximum amplitude within the ping is determined. If this peak exceeds a specified width and its depth is within a specified limit from the previously declared depth, then it is output as the detected bottom depth. If either of these tests fail, a zero is output and subsequently removed in editing.

The output depth is the single digital output from the Odom system. These depth data and associated time stamp, along with the 1-Hz output from a horizontally colocated DGPS (Trimble 4000SSI, horizontal accuracy of ±1 ft) and tide measurements (radio transmitted every 0.1-ft change from a survey crew member at the tide gauge) are merged and stored on a PC using *Hypack* software (Coastal Oceanographic, Inc., Durham, CT).

SAVEWS

SAVEWS was temporarily mounted on the survey vessel. SAVEWS hardware consists of a commercially available digital echo sounder, a global positioning system (GPS), and a personal computer. The hydroacoustic component is a *Biosonics* DT4000 digital hydroacoustic sounder with a 420-kHz, 6-deg single-beam transducer that generates monotone pings at a user-set rate (typically 5 Hz) and duration (typically 0.1 ms). Return echoes are digitized at high frequency and dynamic range (22 bits) to generate a return envelope that is sampled at 41.67 kHz, corresponding to a depth increment of approximately 0.06 ft. Data are stored on the hard drive of a laptop PC that operates the system. Interspersed with the raw hydroacoustic returns are National Marine Electronics Association- (NMEA-) format position reports (latitude and longitude) recorded at

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[1] Personal Communication, 27 July 1999, Steve Asby, Odom Hydrographic.

0.5 Hz from a separate real-time differentially corrected GPS, using broadcasted corrections.

Following the survey, data are analyzed using a Corps-developed digital signal processing algorithm (Sabol and Burczinski 1998; Sabol, Melton, and Kasul 1998). The algorithm examines the signal to first detect and track the bottom. Next the spatial distribution of echo intensity above a specific threshold is examined immediately above the detected bottom for characteristics indicative of bottom-attached, submersed vegetation. Summary reports are output at the GPS data rate and include position, depth, plant coverage (percentage), and mean plant height within that localized area. Performance testing of the system in south Florida (Sabol et al. in preparation) has shown excellent bottom tracking performance under a wide range of seagrass densities, very good in situ plant height estimation, and reasonably good vegetation coverage estimation (relative to visual methods).

Accurate bottom tracking in areas of dense submersed vegetation can be problematic, particularly when bottom depth must be determined for each ping. While the bottom is typically the strongest reflector under normal conditions, seagrasses can be highly reflective over a broad range of sounder frequencies, depending on the species and density (Sabol, McCarthy, and Rocha 1997). Within-ping bottom detection is usually performed by identifying the depth corresponding with peak output voltage, leading edge threshold crossing, or some combination of features. These conditions may occur at the top of the vegetation canopy, instead of the actual bottom in densely vegetated areas. SAVEWS processing avoids this problem by examining the ensemble of pings between successive GPS reports. Within each ping, the depth corresponding to the sharpest rise in voltage squared (good bottom detector under unvegetated conditions) is determined and stored in a histogram data structure. When the next GPS report is encountered, the histogram is queried to determine the most commonly occurring depth (mode). This serves to eliminate bottom depth declarations corresponding to the tops of dense plant canopies. It is effective because it is highly unlikely that the "sharpest rise" depths would be identical for the irregular canopy surface within a localized area. It is very likely to occur for the smoother true bottom, which is occasionally "visible" to the sounder through the canopy.

Survey and Analyses

Site description

Wood Island Harbor is located at the south side of Saco Bay, Maine, between Hills Beach on the north and the village of Biddeford Pool on the south. The project was adopted in 1950, and it authorized a channel 122 m (400 ft) wide, 1,097 m (3,600 ft) long with a project depth of 2.4 m (8 ft). Improvement to the channel was authorized in 1992, consisting of a 1,280-m (4,200-ft) -long channel, 30.5 m (100 ft) wide, with an authorized depth of 3 m (10 ft). Typical tidal fluctuation is approximately 3 m (9.8 ft) from mean level low water. Eelgrass is well established within the channel and typically reaches peak densities between June and October.

Survey procedures and data processing

On the morning of August 7, 1998, SAVEWS was temporarily installed on the survey vessel and all horizontal offsets (distance fore/aft and distance off the center line of the vessel) relative to the Echotrac transducer and GPS antenna were measured. Six parallel survey lines, each approximately 671 m (2,200 ft) long, were run along the longitudinal axis of the channel and separated by approximately 8 m (25 ft). Tide elevation data were radio-transmitted to the survey boat at every 0.03 m (0.1 ft) change in depth. Both systems were operated simultaneously, generating six files each. After completing these transects, the survey vessel returned to the dock where a calibration plate suspended 2.9 m (9.5 ft) below the face of the SAVEWS transducer was used to compute local speed of sound for SAVEWS processing.

Time-based interpolation was performed on the raw Echotrac data to apply tidal corrections and horizontal position to each depth output. The resulting files consisted of a set of points, each with an associated location (state plane, Maine west), time, and depth (MLLW feet). Raw SAVEWS files were processed to intermediate files of position references depth (uncorrected for tides) and plant attributes. Time-based interpolation was likewise used to generate files consisting of a set of points, each with a horizontal position (state plane, Maine west), time, depth (MLLW feet), and plant density and height.

Because transducers were not collocated and because each system operated at a different data output rate (0.5-Hz SAVEWS, and 3.0-Hz Echotrac), there was not an exact one-to-one match of the points in each system's output files. Data were merged by pairing the closest SAVEWS point with each Echotrac point. Most merged points were within 3 m (10 ft) of each other and none were farther than 5.5 m (18 ft). The resulting data set contained over 8,000 paired data points.

Analyses and results

Site conditions based on SAVEWS results are illustrated in Figures 1 through 3. Unvegetated areas occurred in the northeast end of the channel, while the southwestern two-thirds was heavily vegetated with coverages up to 100 percent (Figure 1) and heights up to 3 ft (Figure 2). The shallowest portion occurred in the middle, while depths were greater at the northeast and southwest ends (Figure 3). No separate ground-truth measurements were made during this survey to assess accuracy of these estimates; however, extensive ground-truth analyses at other locations (Sabol et al. in preparation) hve shown that SAVEWS depth and vegetation estimates are very accurate under dense seagrass conditions.

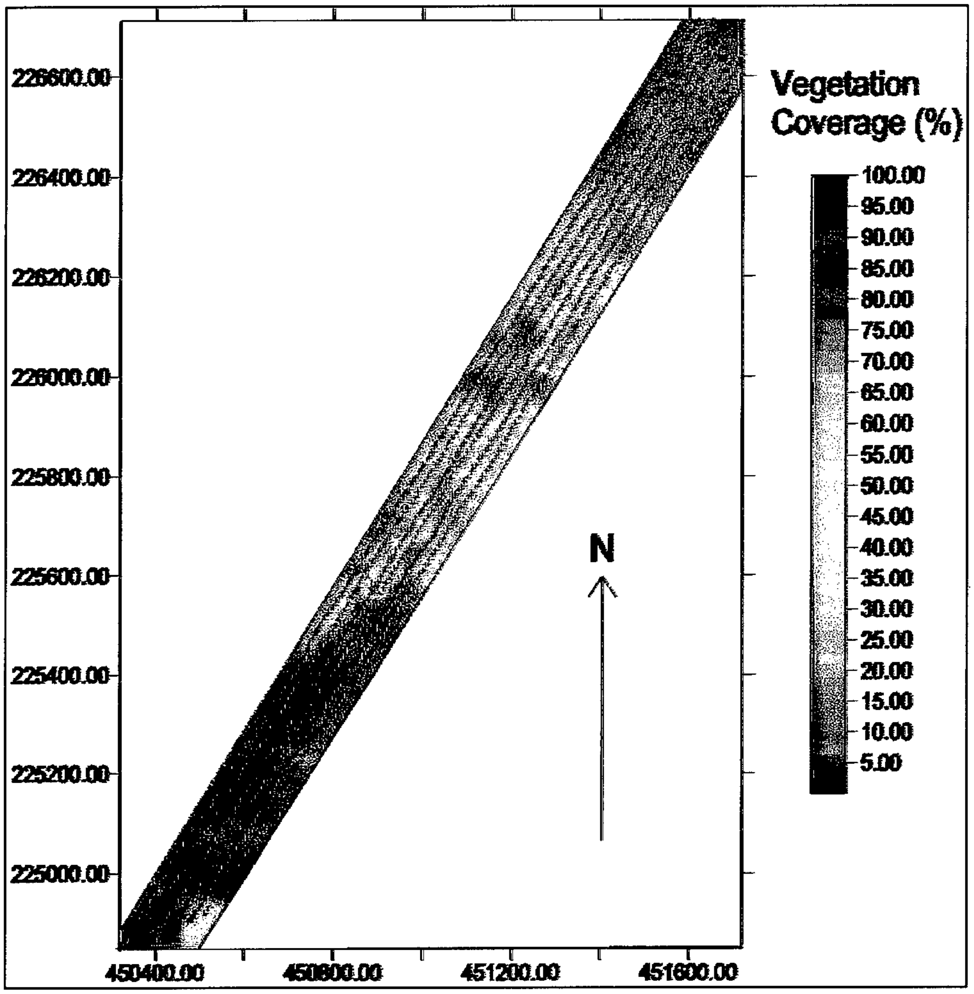


Figure 1. Vegetation coverage measured 7 August 1998; map generated using inverse distance weighted interpolation of SAVEWS coverage data. Coordinates in meters (feet) (Maine state plane, west); dots indicate output points

The paired depth estimates from the respective systems were differenced (SAVEWS depth minus Echotrac depth) to create a depth bias term, which is positive when the SAVEWS depth exceeds the Echotrac depth. Spatial distribution of these biases is illustrated in Figure 4. The vast majority of these biases show that SAVEWS depths exceed Echotrac depths. The depth bias map (Figure 4) closely mirrors the coverage (Figure 1) and plant height (Figure 2) maps. Mean depth biases and associated standard errors were computed by classes of plant coverage percent (0, >0 to 20, >20 to 40, >40 to 60, >60 to 80, >80 to <100, and 100) (Figure 5). Depth bias increases with vegetation coverage. For unvegetated areas, SAVEWS depths average about 51 mm (2 in.) more than Echotrac depths. The bias increases with vegetation coverage up to about 203 mm (8 in.) at 60-percent vegetation coverage. Even with the unvegetated depth bias removed (subtracting 51 mm (2 in.) from each coverage class), the bias is statistically significant ($\alpha<0.05$) for all vegetated classes, showing strong evidence of systematic depth underestimation for the Echotrac in vegetated areas.

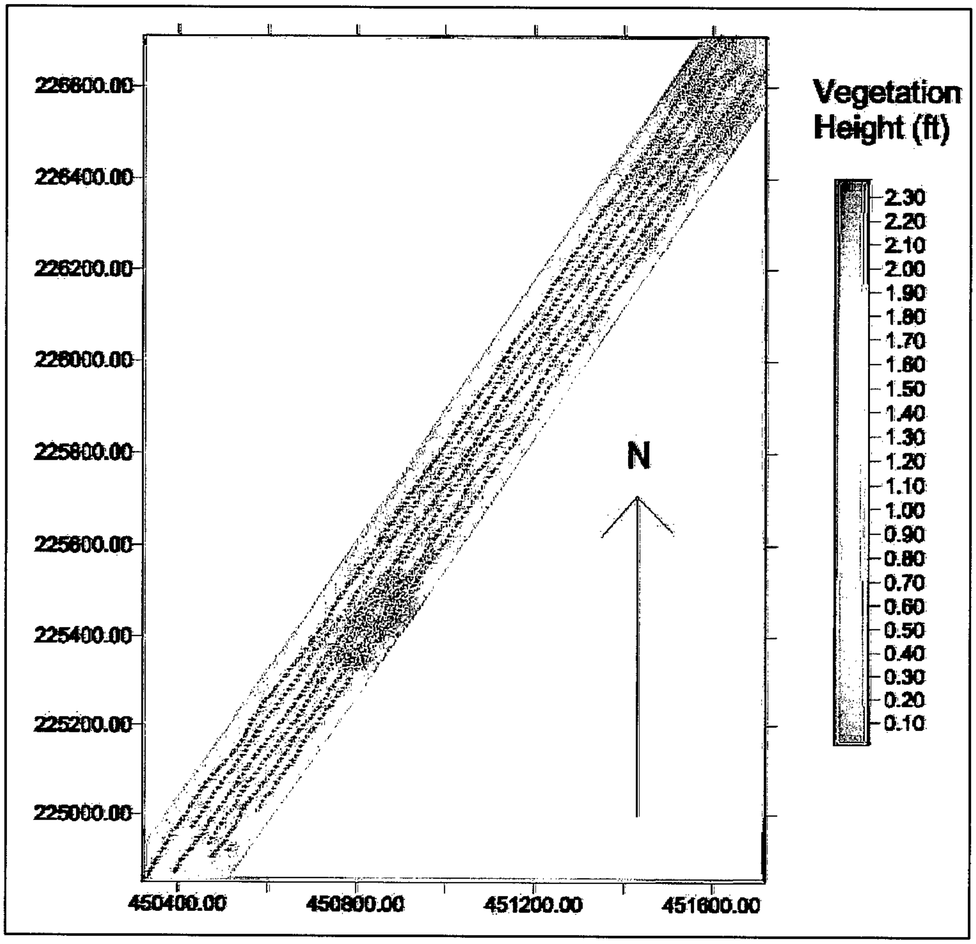


Figure 2. Mean vegetation height, measured 7 August 1998 with SAVEWS. Map generated using inverse distance weighted interpolation; coordinates in feet (Maine state plane, west), dots indicate location of output points. (To convert feet to meters, multiply by 0.3048.)

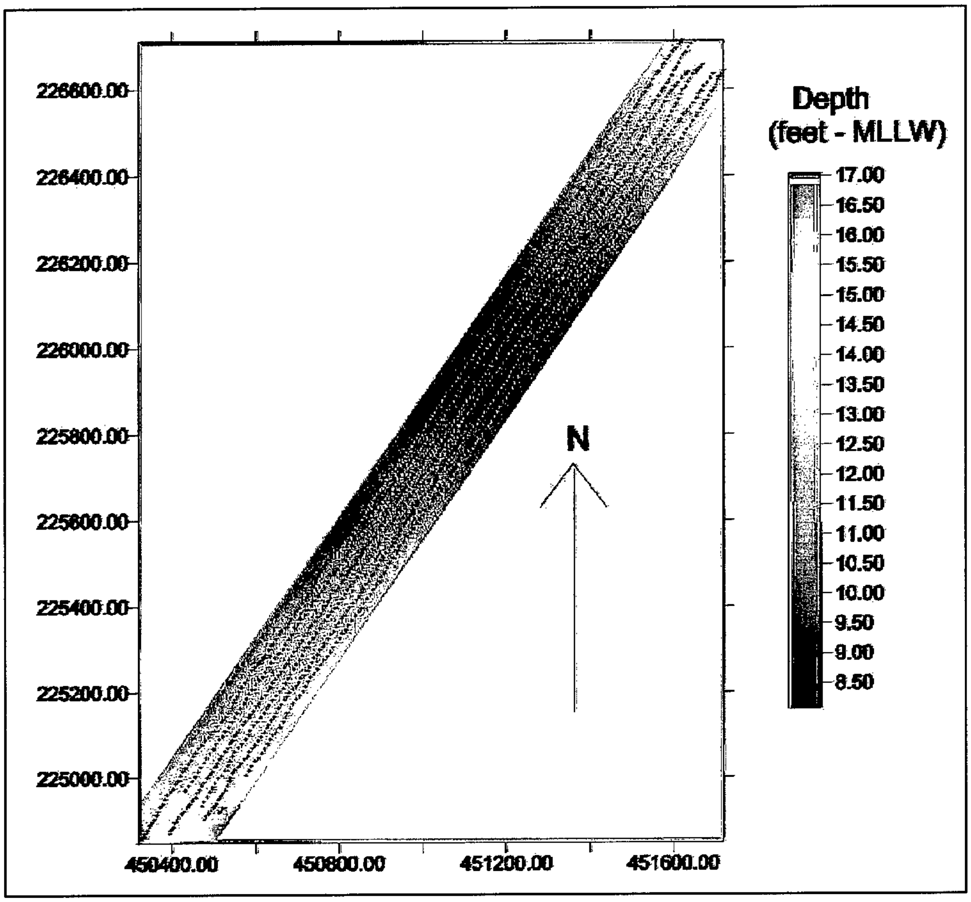


Figure 3. Depth measured 7 August 1998 with SAVEWS; map generated using inverse distance weighted interpolation. Coordinates in feet (Maine state plane, west); dots indicate locations of output points. (To convert feet to meters, multiply by 0.3048.)

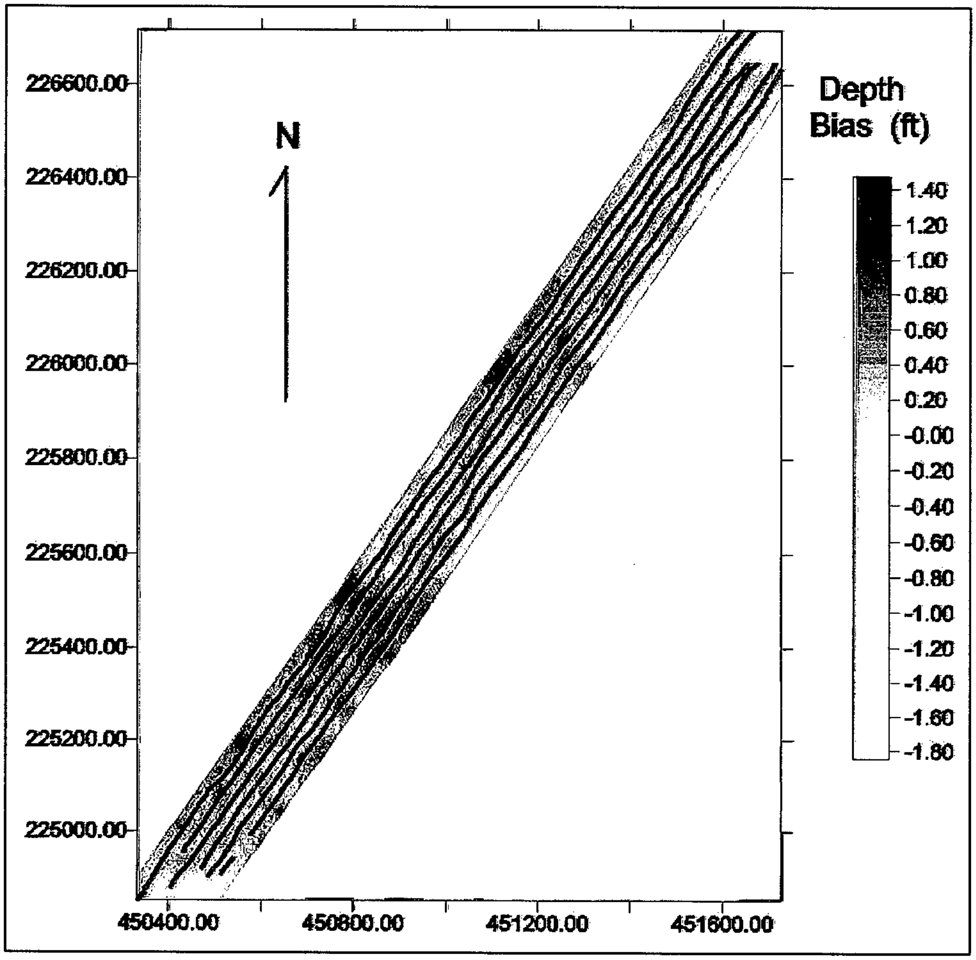


Figure 4. Depth bias (SAVEWS depth minus Echotrac depth); map generated using inverse distance weighted interpolation, coordinates in feet (Maine state plane, west). (To convert feet to meters, multiply by 0.3048)

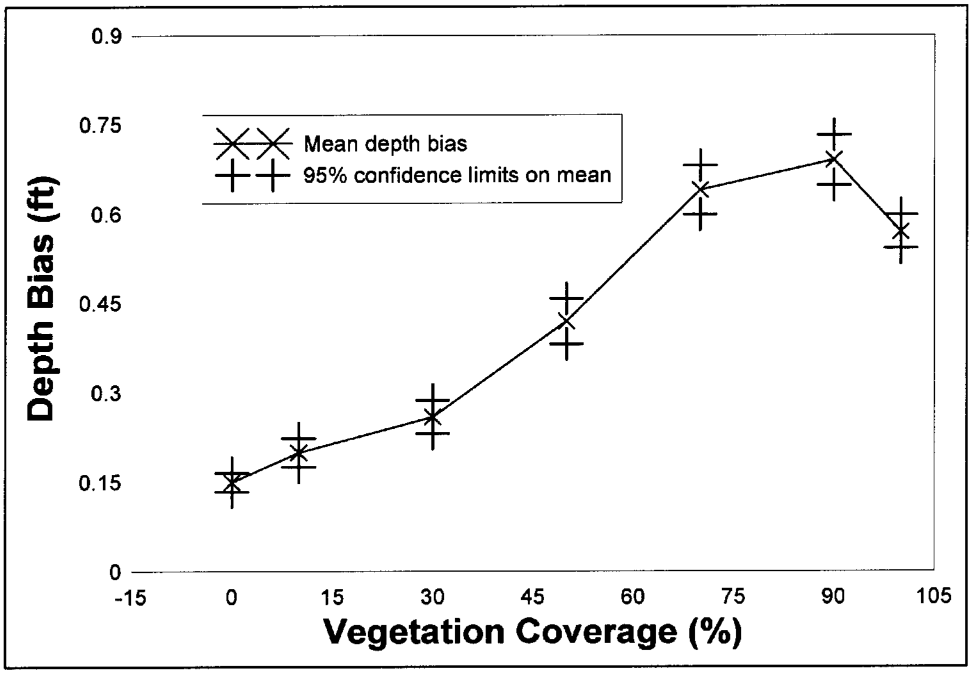
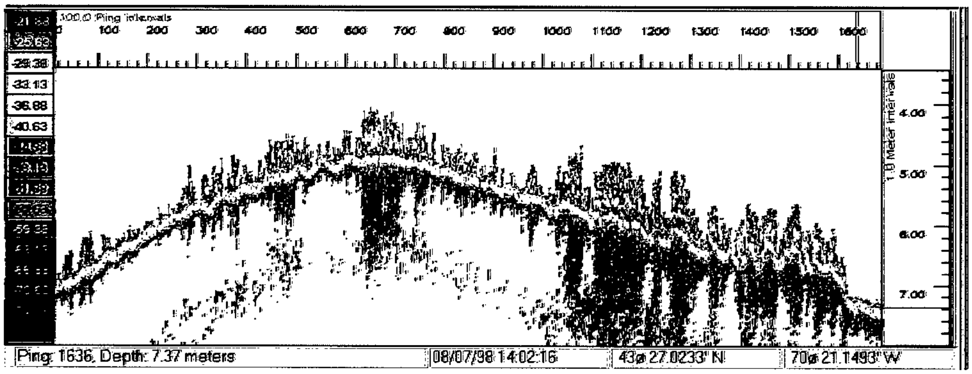


Figure 5. Mean depth bias by classes of vegetation coverage; bounded by 95-percent confidence interval of mean. (To convert feet to meters, multiply by 0.3048)

2 Exploring Alternative Processing Techniques

Approach

During early developmental work on SAVEWS (Sabol, Kasul, and Melton 1994), sensitivity to vegetation was observed to increased with acoustical frequency; therefore, echoes from the seagrass are expected to be stronger in the 420-kHz SAVEWS signal than the 200-kHz Echotrac signal. The fact that bottom detections from the Echotrac are frequently within the vegetation canopy suggests that the problem lies in the signal processing and not the signal itself. To investigate signal processing options, a single-survey transect, collected by SAVEWS, was selected for processing using different bottom tracking algorithms. A colorized echo intensity plot of this transect (Figure 6) shows typical bottom features in vegetated and unvegetated areas.



Ping: 1636, Depth: 7.37 meters | 08/07/98 14:02:16 | 43ø 27.0233' N | 70ø 21.1493' W

Figure 6. Colorized echo intensity (dB) plot of selected transect; depth (m) on vertical axis, ping number (distance along transect) on horizontal axis

The bottom typically generates the strongest echo returns and is characterized by a sharp rise in echo intensity and by very gradually changing depth from ping to ping. An unvegetated bottom (see the region around ping 210 in Figure 6) exhibits a strong return, with a signal "thickness" roughly corresponding to the pulse width (pulse duration times speed of sound in water). At the SAVEWS frequency (420 kHz), there is negligible penetration into the bottom (less than 0.3048 m (1 in.) in medium sand). Vegetation exhibits a continuous echo return immediately above the bottom, which is typically weaker than the bottom return but stronger than ambient water column "noise" (see the region around ping 1200 in Figure 6). Depth at the top of the vegetation canopy is much more variable from ping to ping than at the bottom, due to patchiness of vegetation and local variability in canopy height. A weak signal mirroring the vegetation appears "below" the bottom because of the reverberation (multiple scattering) of the signal within the vegetation. When vegetation or rough bottom conditions occur, the signal around the bottom appears to grow thicker, indicating a wider range of depths from which above-noise level returns are received.

Four different bottom tracking algorithms (Table 1) were run on the transect selected. These represent two levels of processing, each using two different features. In level 1, a single-depth output is generated for each ping, similar to the current Echotrac system. Feature A is intended to mimic the current DSP software in a simplistic manner. Depth is output at the peak in signal voltage without a peak width test or a depth gate test. This is intended to serve as a baseline for comparison with other techniques. Feature B represents the depth of the trailing edge of the bottom signal (-50 dB), corrected for pulse width. This is one of the basic bottom tracking signal features used in the SAVEWS processor. Both features and the plant height feature, discussed later, are illustrated in Figure 7. The assumption behind level 1 techniques is that accurate bottom tracking can be performed on a per-ping basis.

Table 1
Processing Approaches Examined

PROCESS LEVEL	FEATURE	DESCRIPTION (outputs consist of depth at which feature or criteria occur)	COMMENT
1 (per-ping depth output)	A	Peak voltage	Simplified version of Echotrac DSP
	B	Trailing edge of threshold (-50 dB) crossing minus pulse width	A signal feature used in SAVEWS
2 (postprocessing of per-ping output)	A	Postprocessing of 1A outputs to determine the most common depth (mode) within an 11-ping moving window	Processing step used in SAVEWS
	B	Postprocessing of 1B outputs to determine the most common depth (mode) within an 11-ping moving window	

In level 2, depth declarations are based on postprocessing of level 1 outputs. An 11-element moving window filter is passed through the level 1 output string. At each position of the window, the most commonly occurring value (mode) is deleted. This is similar to the SAVEWS bottom-tracking algorithm. Within a localized region (in this case, 11 pings or 1 sec on either side of the current location), the bottom depth would be expected to change very little, but plant height or other bottom irregularities would be more variable from ping to ping; thus, the true bottom should occur around the modal value. The two features of level 2 processing include using both level 1 features as input. Implementing level 2 techniques would include any necessary level 1 modifications plus development of a stand-alone postprocessing algorithm to manipulate the level 1 output data files. The assumptions behind level 2 techniques are that per-ping bottom tracking (level 1) will not work in densely vegetated areas and that multiple pings must be examined, although this additional processing can be done on per-ping depths output from level 1.

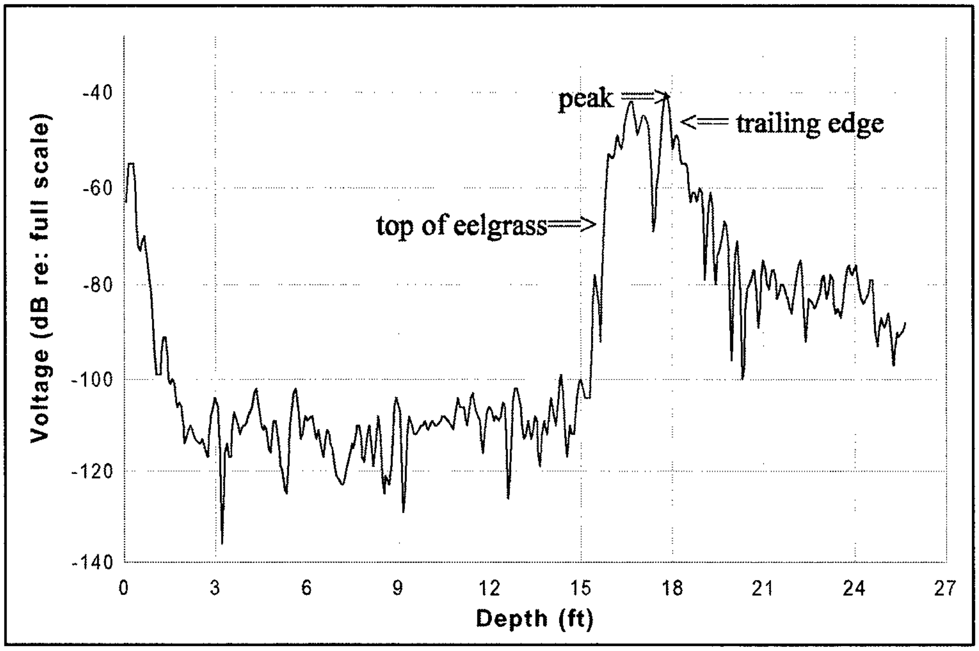


Figure 7. Echo intensity (dB) of a single ping (#1180) with processing features. (To convert feet to meters, multiply by 0.3048)

Results

Bottom tracking results are compared by level (Figures 8 and 9) and by feature (Figures 10 and 11). In each figure, the depth of the top of the vegetation is shown in green. This is based on the height above the detected bottom at which the noise threshold is first reached (feature used in SAVEWS for measuring vegetation height). When the green line converges with the other lines, vegetation is absent. The level 1 depths (Figure 8) show generally good agreement in areas of low eelgrass density. In areas of dense eelgrass, 1A depths frequently approach the vegetation canopy depth, becoming shallower than 1B depths. In most cases, the 1B depths track the apparent bottom in Figure 6. In a few instances in dense eelgrass (between 1,000 and 1,300 pings), the 1B depths exhibit spikes above the apparent bottom. The level 2 depths (Figure 9) show much closer agreement for all eelgrass densities. 2A and 2B depths were within 51 mm (2 in.) of each other over the entire line except for a single spike in 2A depth at around ping 680. The 11-ping moving mode filter produces a blocky (stepwise) output line. A moving window of fewer pings may result in a smoother line, although more spikes may be passed.

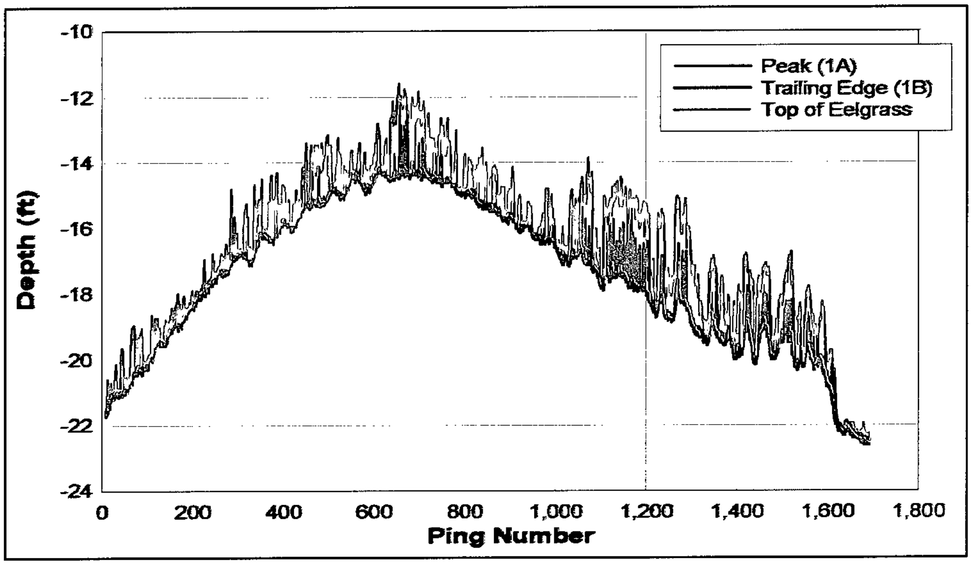


Figure 8. Comparison of level 1 depths and eelgrass height. (To convert feet to meters, multiply by 0.3048)

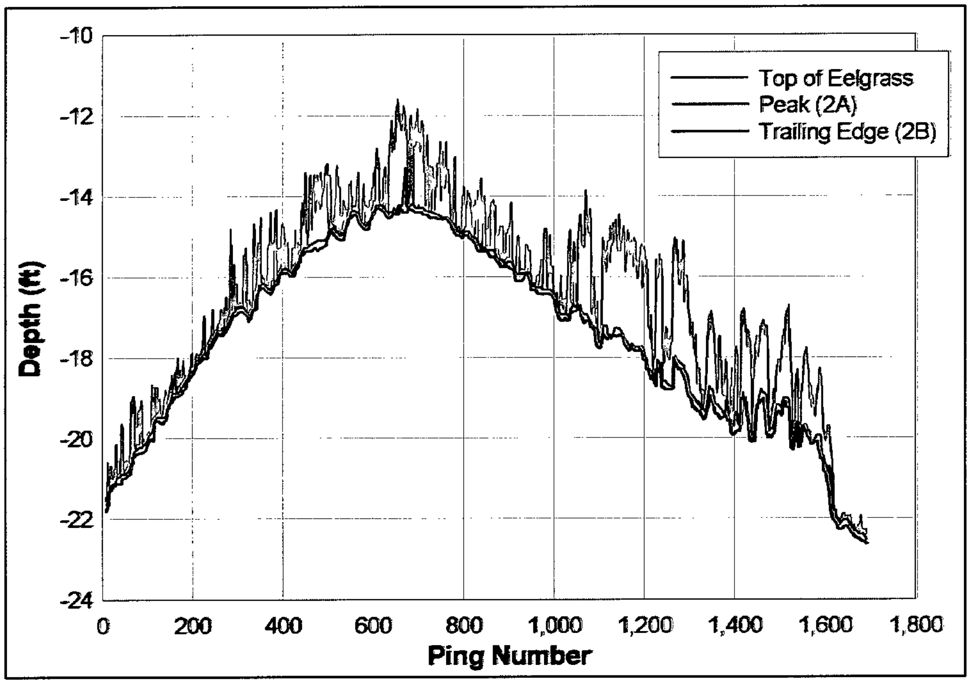


Figure 9. Comparison of level 2 depths and eelgrass height. (To convert feet to meters, multiply by 0.3048)

The direct effects of mode filtering on level 1 features are illustrated in Figures 10 and 11. Filtering the peak feature (1A, Figure 10) greatly reduces, but does not entirely eliminate, spiking. Filtering had a limited effect on the trailing edge feature (1B, Figure 11) which was able to track the apparent bottom most of the time without "spiking."

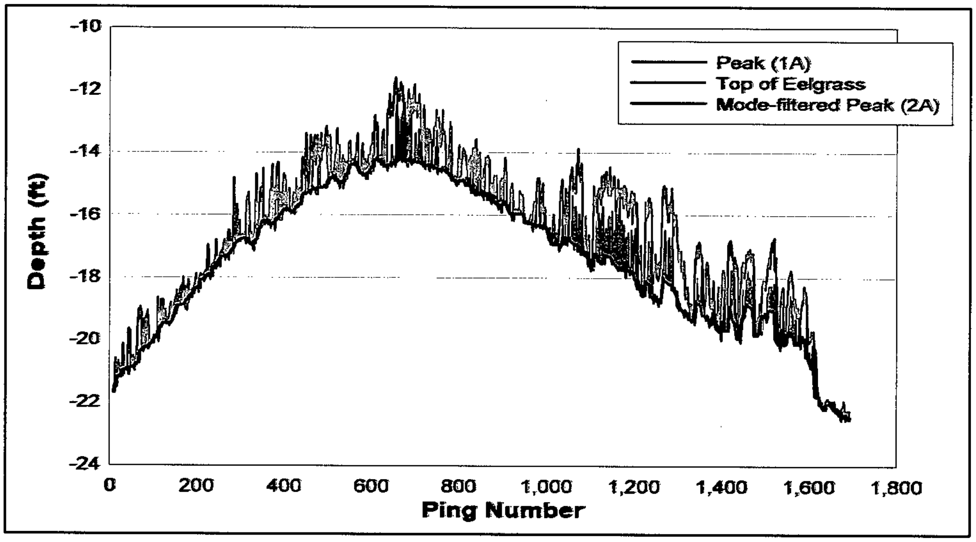


Figure 10. Effects of mode filtering on peak feature. (To convert feet to meters, multiply by 0.3048)

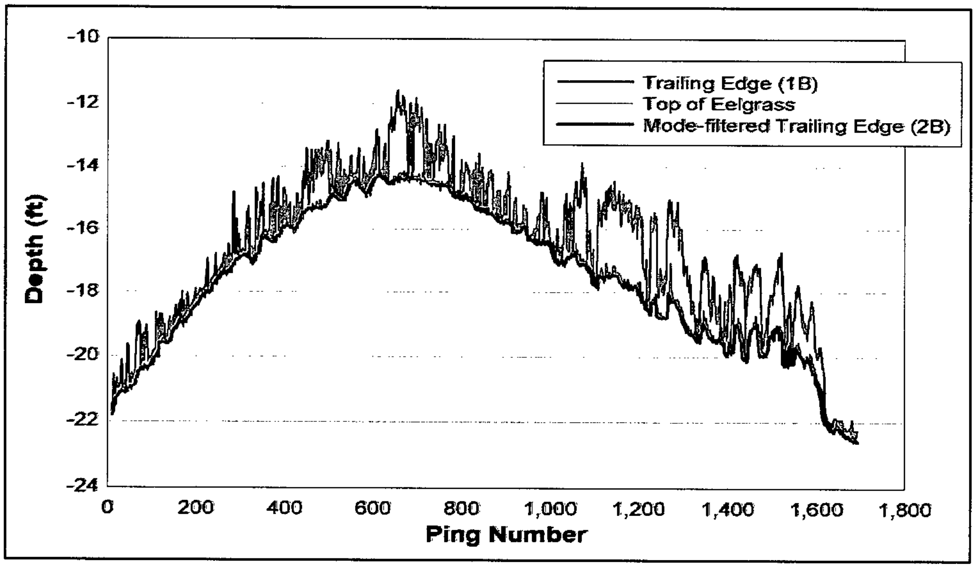


Figure 11. Effects of mode filtering on trailing edge feature. (To convert feet to meters, multiply by 0.3048)

3 Discussion

The tendency of a conventional bottom tracking DSP (single-ping peak picking) to underestimate true bottom depth in areas colonized with seagrass is observed empirically and confirmed in a comparison test of alternate processing approaches. The trailing edge feature (1B, Table 1) appears to be less affected by vegetation than the peak feature (1A) for bottom tracking performed on a per-ping basis. The apparent success of both features is improved by mode filtering; however, this needs some qualification. Mode filtering has the effect of throwing away outlying points, which may or may not be an appropriate thing to do. Under the right set of conditions (fast pinging rate, slow survey boat, and a bottom composed of fine sediments, which is unlikely to support a steep slope), the true bottom depth probably changes very little over a region of 10 to 20 pings, and mode filtering should work well to discard errant depth features attributable to the vegetation canopy. This may occur for many Corps channels but certainly not for all. Conditions may arise where an apparent outlier depth measurement is an object significant to navigation, such as a boulder or a wreck. In this case, it would be highly desirable to have a per-ping bottom tracker with enough "intelligence" to recognize such points.

This preliminary study demonstrates that bottom tracking in vegetated channels can be improved with minimal changes to the current processing approach and without the expense of new sensors. Further work is needed to investigate the performance of alternative processors under a wider range of conditions and to implement and test software under operational conditions.

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14. ABSTRACT

Detection of the true depth of the bottom beneath dense submersed aquatic vegetation is problematic using conventional hydroacoustic bottom tracking approaches. This may lead to underestimation of bottom depth, erroneous bathymetric maps, and overestimates of dredging quantities. A hydrographic data set was collected in Wood Island Harbor (a U.S. Army Corps of Engineers small boat harbor on the Maine coast, which contains heavy growth of Zostera marina (eelgrass)) to compare two single-beam transducer systems. One used conventional signal processing for bottom tracking, while the other employed an innovative alternative approach designed specifically for detecting submersed vegetation. Bottom tracking results between systems agreed well in unvegetated areas, but the conventional system increasingly underestimated bottom depth as vegetation density and height increased. This was attributed to failure to consider the high acoustical reflectivity of the vegetation canopy in digital signal processing. Alternative data processing approaches, using the captured raw digital signal, were evaluated to determine some easily implemented signal processing techniques to alleviate the problem. Several potentially feasible signal processing approaches, which could be used with existing hydrographic hardware, are identified and described.

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