



Demonstration of Commercial Off-the-Shelf (COTS) Acoustic Technologies for Manatee Detection

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INTRODUCTION: The Endangered Species Act (ESA) of 1973, which requires protection of threatened and endangered (T&E) species, has led the U.S. Fish and Wildlife Service (FWS) to closely examine U.S. Army Corps of Engineers (USACE) dredging and other activities in areas with known populations of aquatic T&E species. In particular, the FWS and the Florida Fish and Wildlife Conservation Commission (FWC) have expressed concern to the USACE Jacksonville District (SAJ) that clamshell bucket dredging operations at Port Canaveral, FL, might be harmful to the endangered Florida manatee (*Trichechus manatus latirostrus*, Figure 1), which inhabits that area. Manatee spotters, trained observers whose dedicated function is to look for manatees in the immediate vicinity, are routinely used on dredges operating at this site. However, visual spotting is more reliable during daylight hours, and is only effective when the animals are at or near the surface regardless of time of day. FWS and FWC maintain that night-time clamshell dredging poses an unacceptable risk to manatees and have proposed to limit dredging to daytime only, unless other detection methods become available. Through recent ESA-Section 7 coordination with FWS as well as coordination with FWC, SAJ has agreed to investigate technologies for enhanced and automated detection of manatees that would be effective under all operating conditions.

This agreement initially led to a brief study to examine the feasibility of night vision electro-optical equipment for night-time manatee spotting and detection (Sabol 2009). Thermal imagery was found to have some efficacy at detecting submersed, near-surface manatees under clear, calm weather conditions, but it did not appear to be sufficiently robust that it would be effective under all operating conditions. The technology focus was then placed on acoustics to detect manatees during clamshell dredging operations. This investigation is to be performed over a period of four years (2010-2013) with the results provided to the FWS and FWC for review and comment.

Acoustic detection systems are classified as either active or passive, and consist of various sensors and signal processing capabilities to detect, track, and potentially classify the underwater objects. Active systems transmit a measured pulse of acoustic energy, then monitor the time of arrival and amplitude of the echo return. From this, the range, bearing, and target strength of the reflecting object can be measured. Jaffe et al. (2007) showed that manatees exhibited substantial reflectivity to a 171-kHz acoustic source. Active systems are highly varied and consist of permutations of design parameters for frequency, pulse duration, rate, and power, beam angle, and number and configuration of detectors. Passive systems are listening devices intended to detect the active calls or sound generation of the intended target. They consist of microphone(s) and processing capability to identify and potentially estimate range of the intended target. Phillips et al. (2004)

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Figure 1. Florida manatee.

used systematically placed microphones to measure the rate and source level of West Indian manatee vocalizations, and to triangulate their positions. They measured the vocalization rate to be 1-2 calls per 5-minute interval and measured on-axis source level of vocalizations to be 112 dB (re: 1 μ Pa @ 1 m). They also noted significant directionality to the call. These rates and levels should be adequate for passive detection at ranges needed for this application. The configuration of a passive system would be based on design parameters such as number and location of microphones, microphone sensitivity, and microphone frequency responses.

To initiate the acoustic technology development task, SAJ hosted an Industry Day meeting in January 2010 to which dredging vendors and acoustic companies were invited. The need to protect manatees was described, as was a notional acoustic system that could be affixed to a dredge barge that would warn the dredge operator when a manatee was near dredging operations. A request for proposals was subsequently issued by SAJ to identify and contract with acoustic vendors who would test and demonstrate their commercial off-the-shelf (COTS) equipment for manatee detection under simulated operation conditions at Port Canaveral, FL. Contracts were let with five acoustic vendors, four active systems, and one passive system, with each conducting a 3-day test of their equipment. The demonstration was held during 12-28 July 2010 and in the vicinity of the Corps Port Canaveral Lock, Port Canaveral, Florida.

The purpose of this technical note is to document the testing described above. While this test focused on a district-specific issue, there is a broader problem with marine T&E species and Corps activities in general. It is quite likely that restrictions to Corps activities, including all types of

dredging and blasting, could be imposed because of the ESA and other legislation, such as the Marine Mammal Protection Act of 1972. Thus, the problem could become how to detect numerous species of aquatic animals, such as sea turtles and sturgeon, in addition to manatees. For this reason, this study was considered to be very significant to the Dredging Operations and Environmental Research (DOER) Program managed through the U.S. Army Engineer Research and Development Center (ERDC).

Under the small contracts let by SAJ, the vendors specifically require that proprietary information associated with their equipment not be made public. For this reason, specific contractors are not identified, and their equipment is described only in general terms. Certain identifying numbers and labels have been removed to preclude divulging of proprietary information. This action is not believed to significantly detract from the overall objective of evaluating the effectiveness of COTS acoustic equipment for close-range manatee detection. This report describes the systems tested and the experimental design, evaluates the performance of each system, and recommends functional performance requirements for the system that will be developed.

Methodology

Demonstration test plan and site. The five vendor demonstrations were held July 12-28, 2010 at Canaveral Harbor, Brevard County, Florida (Figure 2). Manatees at this location are typically present during spring, summer, and fall, and the Canaveral Lock and the harbor were considered ideal for the demonstrations. Each of the vendors demonstrated the capability of their system during daylight hours for three consecutive days. The first phase of each test occurred within the Canaveral Lock chamber (Figures 3 and 4) on a Corps pontoon boat. This 1- to 2-day phase was to allow vendors to set up and configure their equipment, and to demonstrate the ability to detect manatees when they are close and plentiful. After demonstrating success at detecting manatees within the lock chamber, the equipment was installed on a Corps work barge rigged with a crane and a 1.5-cy³ bucket (Figure 5). The barge was navigated to and moored in the West Turning Basin (Figure 6) where the 1- to 2-day second phase took place.

During the second phase, the bucket dredge simulated operations by performing controlled drops of the bucket, but not impacting or digging sediments below. Sediment handling would have required extensive permitting and potentially caused delay in the test, so disturbing sediments was avoided. This created a realistic bubble curtain without the increased suspended solids levels that would normally be associated with operational bucket dredging. This appears to be a minor departure from full realism, since bubbles are orders of magnitude more acoustically reflective than suspended solids. The overall objective of this phase was to demonstrate manatee detection under realistic operating conditions. Since the presence of actual manatees within the basin was not reliable, an appropriate submersed acoustic manatee surrogate was provided and used by each vendor. Also, in compliance with standard manatee protection measures, a dedicated professional observer¹ was present at all times in order to monitor manatee movements in the vicinity of Corps vessels and other moving equipment. The observer recorded the number and approximate location of manatees in order for Corps staff to compare visual observations with the number of manatee detections made by the various systems. There was no communication between the observer and the vendors. The following sequence of tests was conducted, as appropriate, for each vendor.

¹ Kevin Shelton and Jeff Glas, Ash Engineering, Inc.



Figure 2. Port Canaveral vicinity.



Figure 3. Port Canaveral Lock chamber.

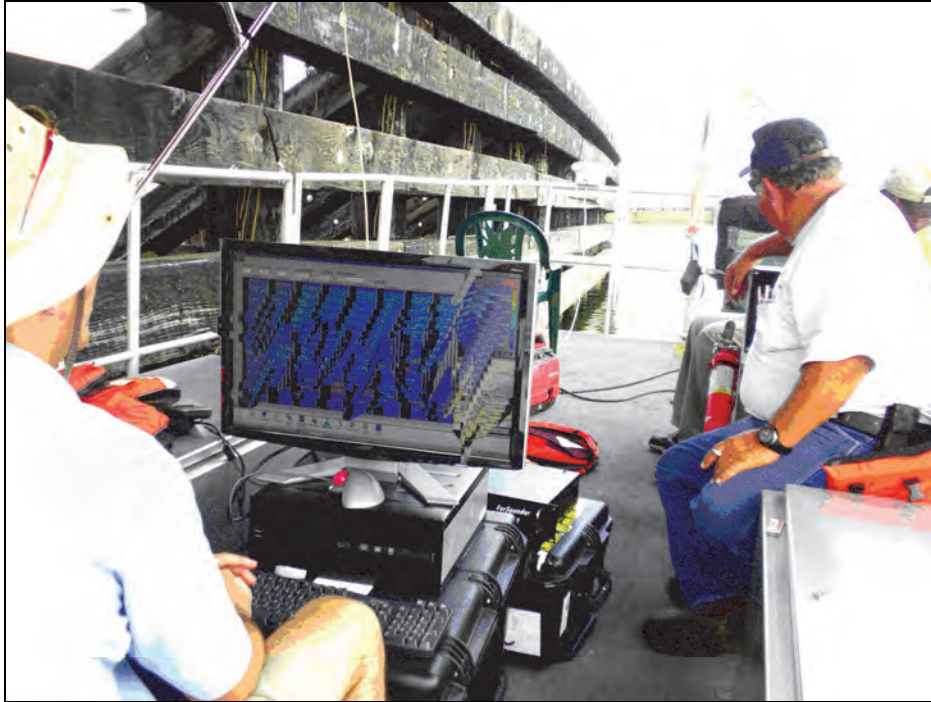


Figure 4. Acoustic equipment being tested on Corps pontoon boat in lock chamber.



Figure 5. Bucket dredge equipment used in simulated operation.



Figure 6. West Turning Basin showing barge mooring area.

1. Detection and other advanced functions (tracking and classification), if appropriate, were demonstrated without dredge operations.
2. Above functions were demonstrated with dredging operations.
3. Surrogate detection and tracking were demonstrated, at various ranges, without and with simultaneous bucket operations, including bucket operations between the sensor and the surrogate.

The demonstrations were monitored by SAJ (Paul Stodola), and visited by the USFWS, FWC, ERDC, and other SAJ staff. ERDC observed selected demonstrations, and provided review and comments on the scope of work for the demonstrations.

Equipment tested. Characteristics of equipment tested by the five vendors are summarized in Table 1. To avoid proprietary issues, the manufacturers are identified by letter. All are COTS instruments used for other applications and represent a fairly wide range of acoustic equipment types.

RESULTS: Results of each vendor test are described separately in the chronology of the testing. General statistics of each test are summarized in Table 2.

Vendor A's system was an active single-beam sonar system, intended primarily for commercial fishing. An enclosed submersible transducer housing with an electro-mechanical device rotates (up to 360°) and tilts the high-frequency (160-kHz) narrow-beam (6.5°) transducer as directed by the

Table 1. Characteristics of equipment tested.

Vendor ID	A	B	C	D	E
Sonar type	Active scanning single beam	Active forward looking array	Active broadband and split beam	Passive	Active split beam
Date tested	12-14 July	15-17 July	19-21 July	22-24 July	26-28 July
Frequency (kHz)	~160	~60	~165 (split beam)	Receiver frequency sensitivity not specified	~120
Beam shape	Conical 6.5 °	12° x 12° ^B	Conical 6 °		Conical 6 °
# transducers	single	96	Single	16-element linear array	Single
Pulse width, power	Both variable	? , 600 W _{rms}	Both variable	N/A	0.4 ms, 1000 W _{rms}
Scanning capability	360 ° electro-mechanical rotation plus tilt	None	Manually aimed	Omnidirectional reception of hydrophones, no scanning required	Electro-mechanically scanning, plus pan and tilt
Surrogate description	14" seawater-filled hollow steel sphere (TS=-20 dB)	Circular corner reflector (TS = -17dB)	Styrofoam molded to shape/size of manatee lungs	Speaker broadcasting recorded search call of calf seeking mother (savethemanatees.org/audio.htm)	12" metal radar corner reflector
Highest processing level claimed	Detection to 90 m, tracking ^A	Demonstrated system in data collection mode only	Detection, tracking, and classification	Call bearing and classification	Detection to 90 m, tracking, classification, and alerting
Current COTS application	Commercial fishing	Navigation and military	Fisheries	Research and military	Fisheries
Display/User interface	Revolving "weather radar" type display	Waterfall display (range by time [ping report], colorized by target strength)	Waterfall display (range by time [ping report], colorized by target strength)	Waterfall display of signal spectrum and bearing	Waterfall display (range by time [ping report], colorized by target strength)

Notes:

- A. Tracking generates a bearing and range time series.
- B. Effective angle based on software beam forming of 96-element array.

Table 2. Test results.

Vendor ID	A	B	C	D	E
Demonstrated range (m) for detection of manatee	83	73	>90	>366	120
Demonstrated range (m) for detection of surrogate	43	100	40	400	80
Subject to bubble blinding?	None observed	Blinding briefly occurred	Blinding briefly occurred	None observed ^C	Blinding briefly occurred
Time to scan 180° sector (min)	0.25 (step sector scan in 3.6° increments)	No scanning	No scanning	-0- (continuous omnidirectional reception)	3.0
Processing demonstrated	Detection ^D and tracking	Detection	Detection in both bands, classification in post processing	Detection and bearing estimation	Detection, tracking, clutter removal

Notes:

- A. Valid encounters are defined as occurrences of manatees within a vendor's claimed detection range at a time the equipment is operating in a search mode.
- B. In lock chamber.
- C. Surrogate test with dredging did not place dredge bucket in line between surrogate speaker and hydrophone.
- D. Most active systems were not configured for automated detection. Term is used here to indicate an obvious recognizable strong return from the location of the manatee or surrogate.

operator. The system demonstrated detection of manatees and surrogates up to 83 m. Object classification was not possible with this system. In addition, object detection was limited by the aqueous disturbances characteristic of dredging operations. The circular screen display is illustrated in Figure 7.

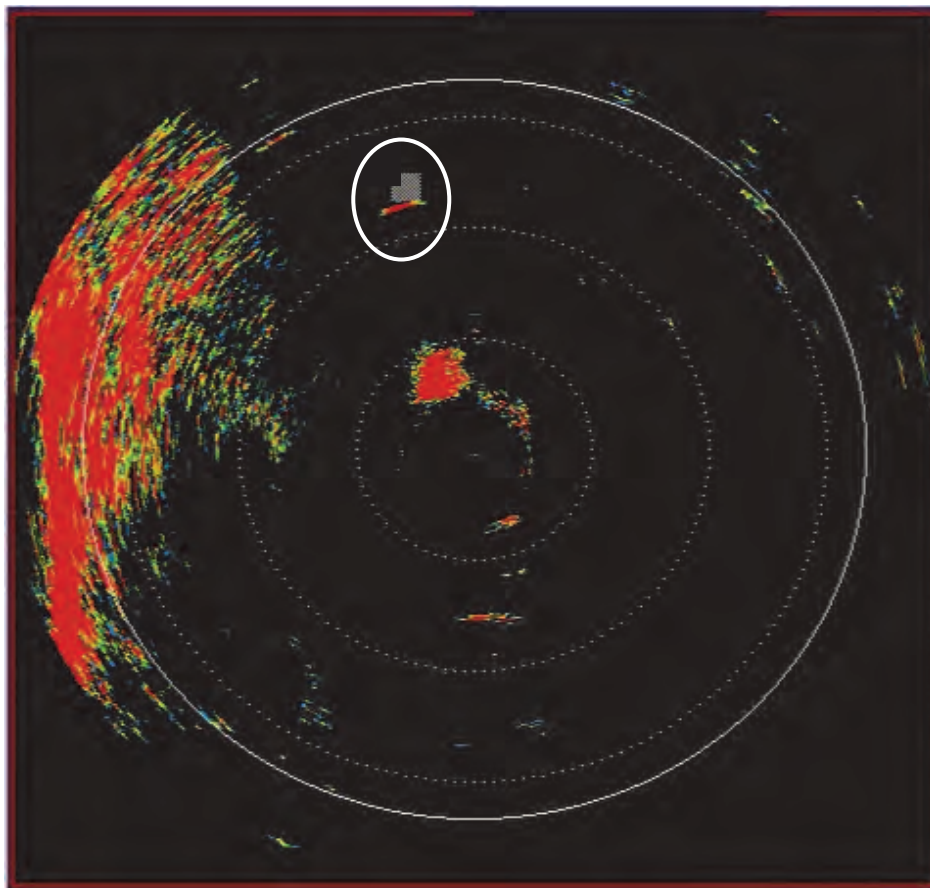


Figure 7. Vendor A's circular sonar plot showing manatee detection (circled) in the West Turning Basin. Besides visual confirmation when near surface, many underwater manatees were detected on the basis of movement of objects.

Vendor B's system was a multi-element active sonar array system, used for military and navigation purposes. Single source generates a narrowband frequency pulse of approximately 60 kHz. The receiver array consists of 96 elements oriented horizontally forward. When operated for its intended purpose, this system queries a 90° forward-looking sector for each pulse. In this test, the 96 elements were beam-formed by software to examine a single fixed-orientation (not moving or scanning) sector roughly 12° by 12°. This reduced capability configuration was used for signature collection purposes since the diver detection and classification software was not configured for manatees and could not be expected to function for manatees. The greatest range of a detected manatee was 73 m, while the surrogate was detected to 100 m. Significant obscuration, and potential false alarms, were caused by boat wakes. Classification of manatees and other objects was not demonstrated. In addition, object detection was disrupted by the bucket-induced bubble cloud. The horizontally scrolling waterfall display is illustrated in Figure 8.

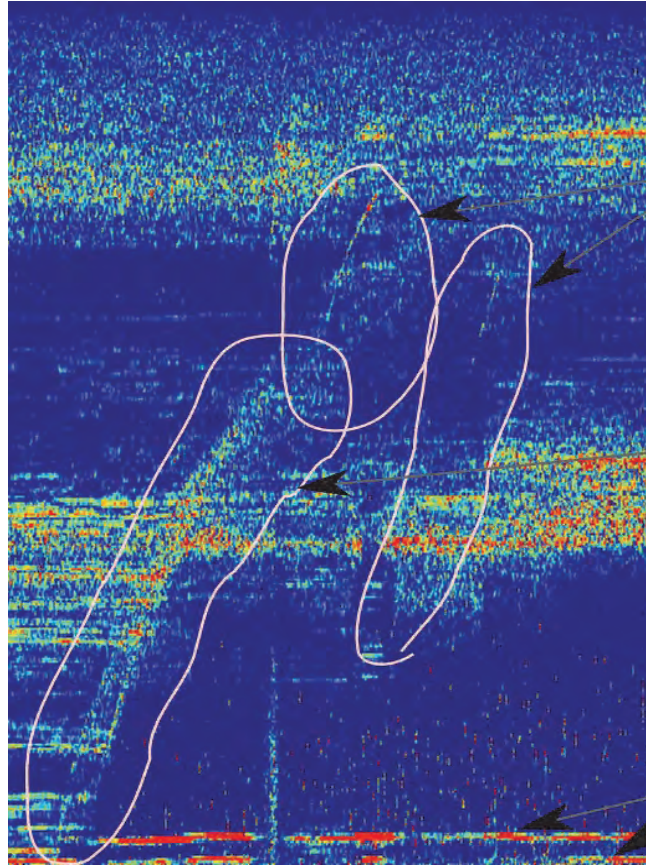


Figure 8. Vendor B horizontal scrolling (right to left) plot of range versus time with colorized echo intensity, showing movement of two manatees (upper enclosures), and a boat wake (lower enclosure). Immobile objects are represented by horizontal lines, such as the pilings toward the image bottom. Detection of manatees is enabled after the wake dissipates.

Manufacturer C's system was an active sonar system, COTS hybrid broadband/narrowband for research and other marine applications. The narrowband split beam was approximately 165 kHz. The broadband transducer extended ± 30 kHz around the split beam frequency. The beam width was 6° conical; it was not rotatable during demonstration. Manatee and surrogate detection were demonstrated in both bands at ranges exceeding 90 m. Because the transducers were not electro-mechanically steerable, tracking was not demonstrated. The acquired multiband data should permit classification of manatees and other objects. The feasibility of this was demonstrated in post processing. Both bands were temporarily "blinded" by the bucket-induced bubble cloud. Figure 9 is an example of the display.

Manufacturer D's system was the only passive sonar system demonstrated. An array of hydrophones was demonstrated to detect narrowband manatee vocalizations (real and surrogate recording) at underwater distances of greater than 1200 ft while also generating bearing estimates. However, only one relevant vocalization was detected during the demonstration. This observed low call rate might be attributable to manatee vocalization not oriented toward the

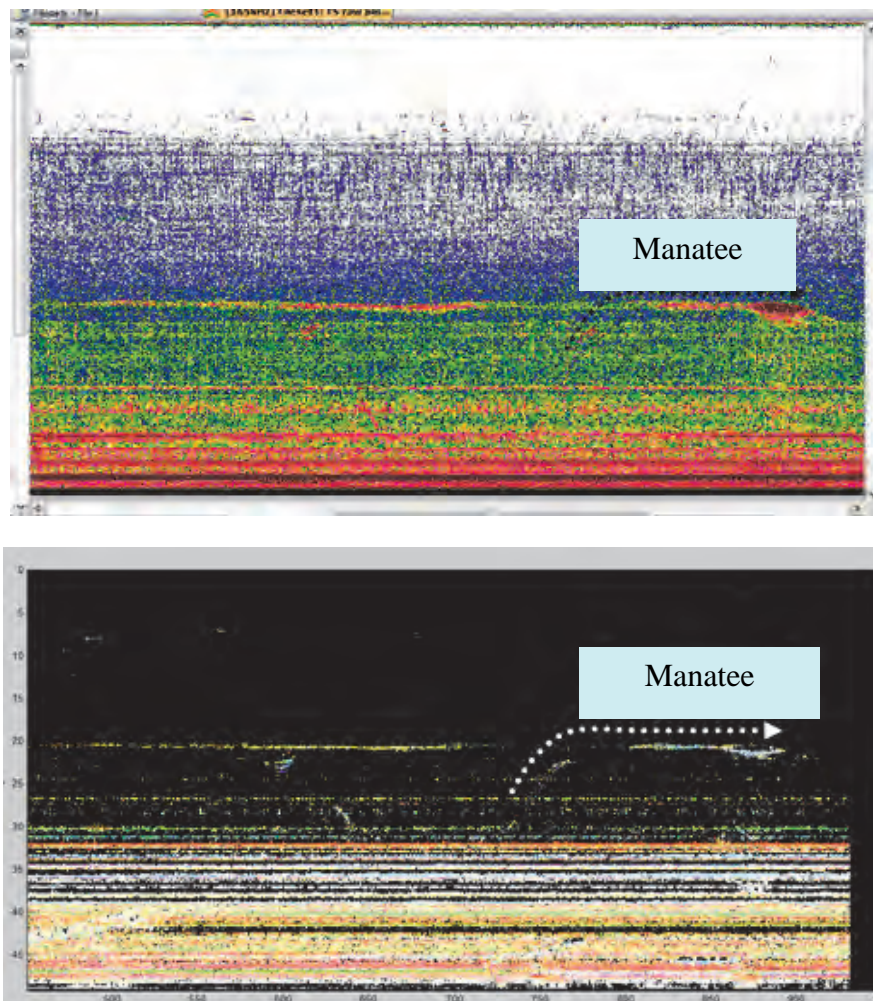


Figure 9. Vendor C horizontal scrolling display showing depth versus time with colorized echo intensity. Upper graphic is split beam, lower graphic is broadband, showing manatee detection in lock chamber.

passive sensor (call directionality noted by Phillips et al. (2004)), and not actually low call rate. The bucket-induced bubble cloud and added mechanical noise did not appear to blind the sensor because the signals are separable in frequency and bearing. Note, however, that the bucket was not in line between the surrogate and the hydrophone array (Figure 10).

Manufacturer E's system was an active sonar system, multipurpose COTS for fishing, navigation, and other marine applications. Its sonar pulses were at a narrowband frequency around 120 kHz. This split-beam system had a 6° conical beam and was electro-mechanically rotated in addition to having pan and tilt capability. The system demonstrated manatee detection to a range of 120 m. While more manatees were acoustically detected within the lock chamber than counted by the observer (surface sightings), no manatees were detected in the West Basin deployment in spite of several sightings. The split-beam capability allowed target strength (TS) measurements to be corrected to the acoustic axis, thus generating true TS values. Vendor technicians noted that manatee TS measurements were quite variable (± 15 dB), presumably due

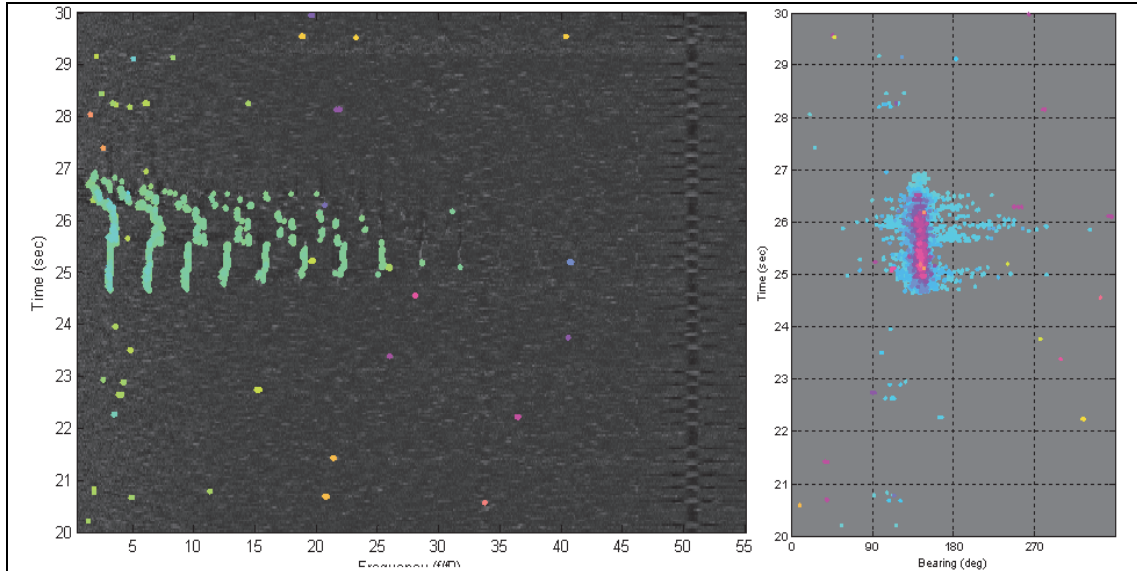


Figure 10. Vendor D vertical waterfall display plotting frequency (horizontal) versus time (vertical) on left graphic and bearing versus time on right graphic. Live manatee call illustrated.

to variable orientation of the manatee to the beam. Classification of manatees and other objects was not demonstrated. Other acoustic features found that could potentially be confused with manatees included boat wakes and schools of fish. In addition, object detection was limited by the aqueous disturbances characteristic of dredging operations. Figure 11 is an example data display with a manatee.

DISCUSSION: With the exception of surrogate use, this study was a field test and not a controlled experiment. Occurrences of manatees, particularly in the turning basin, were a random and relatively infrequent event. Thus, the percentage of detections for each respective system (compared to observer) is not a reliable metric of performance. The sample size was small and the slow searching systems were frequently looking elsewhere or performing some other task when a manatee did appear. For the most part, when vendor systems were actively looking for a manatee within their claimed detection range, they were successful. The one exception to this was the passive system (vendor D). Detected manatees vocalizations were much less frequent than the rate cited in the literature (Phillips et al. 2004); however, this might be attributable to call directionality, noted by Phillips. Calls not directed toward the sensor might not have been detected. In any case, it appears that passive detection would not be effective in this application, in spite of its long detection range for the detected call, ability to separate manatee calls from dredge noise, and simultaneous 360° continuous monitoring. All systems successfully detected manatees or their surrogates at or farther than their claimed detection range when not obscured by dredging-induced bubble clouds. When tracking is defined as generating a time series of detection positions, only active systems with electro-mechanically aiming were able to demonstrate tracking of manatees.

Most active systems suffered from some temporary loss of detection (“blinding”) when the bucket-induced bubble cloud was between the target and the transducer. The duration of “blinding” was typically short. However, two work-around solutions were offered:

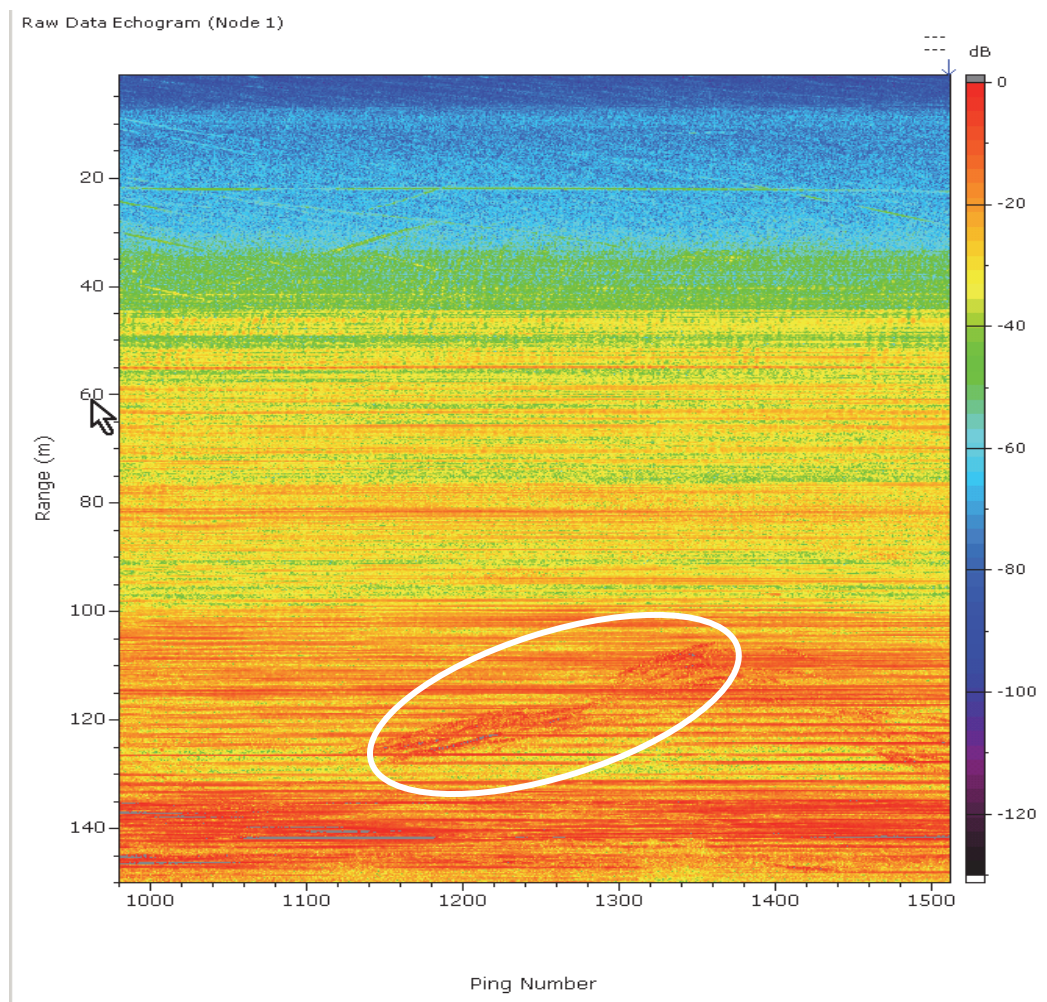


Figure 11. Vendor E echogram exhibiting a manatee detection (white ellipse) amongst the clutter of the lock chamber at a range of 120 m; display horizontally scrolls right to left.

1. Deploy the transducer at the deepest depth possible. The bubbles clear from the bottom up, so a deep deployment would be cleared before a shallow deployment, as was used in this study.
2. Deploy two or more transducers from different locations to provide overlapping fields of view of the search area. This way the entire search area can be seen, unobscured by bubbles, by at least one transducer at all times.

Two additional aspects of acoustic blinding need to be investigated relative to bucket dredging. The first is scale. A commercial-sized bucket is 20-40 yd³, as opposed to the 1.5-yd³ bucket used in this study. How will this order of magnitude increase affect the loss of detection? Secondly, the incremental effect of sediments disturbed during the dredging operation needs to be examined. The initial assessment was that sediment would be a minor effect relative to bubbles, but this needs to be confirmed.

Observing the various systems in operation pointed out the importance of processing capabilities and user interface design. Several systems used some degree of advanced processing to achieve clutter reduction (eliminating the confusing background signal that may obscure detection) and target classification. Systems that repeatedly scan a stationary background (generated by measurements from a stationary platform) can use change detection techniques, such as frame differencing, to remove the background part of the signal, leaving only the part of the signal that has changed from the previous scan, i.e. moving objects. Once an initial detection was made, several systems were able to characterize the signature sufficiently to determine whether or not the detection was most likely a manatee, although none of the systems implemented this function to operate automatically. Candidate features that may be applicable here include: target strength (dB), target depth (in range), target width (angular width times range), and target speed (derived scan-to-scan differencing of target position). This suggests that classification is well within the realm of feasibility. Lastly, user interface is extremely important. The user interface and display of most systems were not optimized for this application and it was difficult for the observing non-experts to interpret. Extensive thought will need to go into designing an effective display for any operational system to be used by non-experts.

The main shortfall of the active systems tested was their inability to rapidly search the area of interest. Determining the specific requirements for an effective manatee warning system requires examining critical distances and time lines associated with this application. Factors influencing these distances and time lines include:

1. Manatee swimming speed. Manatee swimming speeds have been cited at up to 5 mph (www.savethemanatee.org/manfacts.htm) under normal conditions, and as much as 20 mph for short bursts when a manatee is startled.
2. Time required to halt dredging operations. How many seconds in advance must the dredge operator be alerted before the operation ceases?
3. Update rate. What time interval is required to completely search the radius of search?
4. Tracking and classification scans. How many times (scans) must a target be viewed to reliably track and classify it?

As an example, assume it takes 15 sec for the dredge operator to secure dredging operations. In that time a manatee could travel 33.5 m (5 mph x 0.447 mps/mps x 15 sec); so a warning radius of 35 m is established. Next assume it takes at least five acoustic measurements (scans) of a manatee for the classifier to reliably determine that the target is a manatee and not something else such as a school of fish or a porpoise. This must be combined with the update rate to determine the alerting range. The achievable update rate is a function of the state of technology and expense of the equipment. A fast update rate (say 2 Hz for a 360° search) could make for a reliable system but it might exclude some system types and drive cost up; therefore, a rate of 0.2 Hz (one 360° scan every 5 sec) is more achievable. Five scans would take 25 seconds, during which time the manatee could travel 55.9 m (round up to 60 m). So a 100-m search radius would provide sufficient time to detect, classify, and warn the dredge operator of a manatee swimming at 5 mph directly at the bucket location. This hypothetical example illustrates the trade-off analyses necessary in specifying the system functional requirements.

CONCLUSIONS AND RECOMMENDATIONS: While none of the five systems demonstrated appeared to currently be suitable to serve as an operational manatee warning system for bucket dredging operations, various functions performed by several of these systems did demonstrate effectiveness. All five systems demonstrated detection within their claimed detection range. The passive system does not appear feasible for this application because the rate of detected vocalization is less frequent than expected, although the detection range is very large by comparison to the active systems. Several demonstrated classification and tracking. All active systems tested demonstrated either slow scanning or no scanning capability.

Resolving the manatee issue with bucket dredging is certainly critical, particularly for SAJ and other districts where manatees occur. The manatee/bucket dredging issue, however, represents a special case of a broader problem with T&E species and marine mammals, and Corps activities. An automated alerting system that could be configured to detect, track, and classify any number of species of interest (for example: sturgeon, sea turtles, and porpoises) would be of widespread interest for the Corps, and potentially other agencies and organizations. Requirements for a single-species system might be developed using the same type of process described in the “Discussion” section: however, there would be great benefit to a single system that could be configured to detect different species in different scenarios. The attributes listed below recommended generic capabilities for such a system:

1. Configurable scanning rate with a maximum rate of 0.5 Hz (one complete 360° scan every 2 sec) to detect potential targets entering search radius.
2. Configurable search radius of up to 100 m.
3. Capability to classify and track potential targets detected within the search radius.
4. Configurable classification of different target animals designated by the operator (ex: manatees, sturgeon, sea turtles, etc.).
5. Automated archival recording of all detected targets.
6. Automated alerting of equipment operator when targets classified as an organism of interest enter, or are projected to enter, a critical distance (specific distance set by operator) of a designated point of operation (bucket drop, blast location, etc).
7. Advanced user interface to allow easy interpretation of results by a single minimally trained technician.

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