Report on the Use of Side Scan Sonar to Locate Variable Milfoil in Pawtuckaway Lake

Introduction

The report details a study in the use of side scan sonar to locate variable milfoil in Pawtuckaway Lake along with the conclusions from that study.

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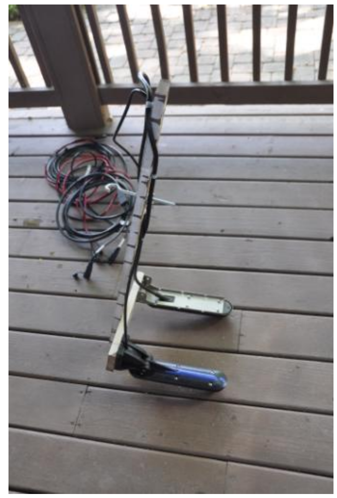
Background

Variable milfoil was first discovered in Pawtuckaway Lake in 2014. An active search and removal process was commenced that year and has continued to the present time. Weed Watchers are used to do surface searches and a team of volunteer snorkelers and divers perform underwater searches regularly throughout the summer. After being located and marked, volunteer certified Weed Control Divers extract the milfoil by hand pulling and then collecting it in mesh bags. While milfoil has been kept under relative control with only scattered plants in the infected areas, new areas of infestation were found in 2019 and 2020. These areas were far removed from the known infected areas leading to concerns about the possibility of undiscovered areas of infestation. Since it is not feasible to do underwater searches throughout the lake areas that could support the growth of milfoil, other methods for doing efficient and effective searches of those areas were researched. They included the use of underwater cameras, drones, autonomous submersibles, and sonar. After studying the feasibility of each of these approaches, it was felt that a side scan sonar might have the best balance of efficiency, effectiveness, and cost. A grant from the Lamprey River Advisory Committee was applied for and approved. The equipment was purchased in May 2020 and used throughout the summer. The use, methodology, and findings are presented in this report.

EQUIPMENT

The equipment used was a Lowrance HDS Live 16 sonar, a Lowrance 3D Structure Scan module, and two transducers. One transducer was capable of down scan, 2D scan, and side scan. The other transducer was capable of 2D, side scan, and 3D.

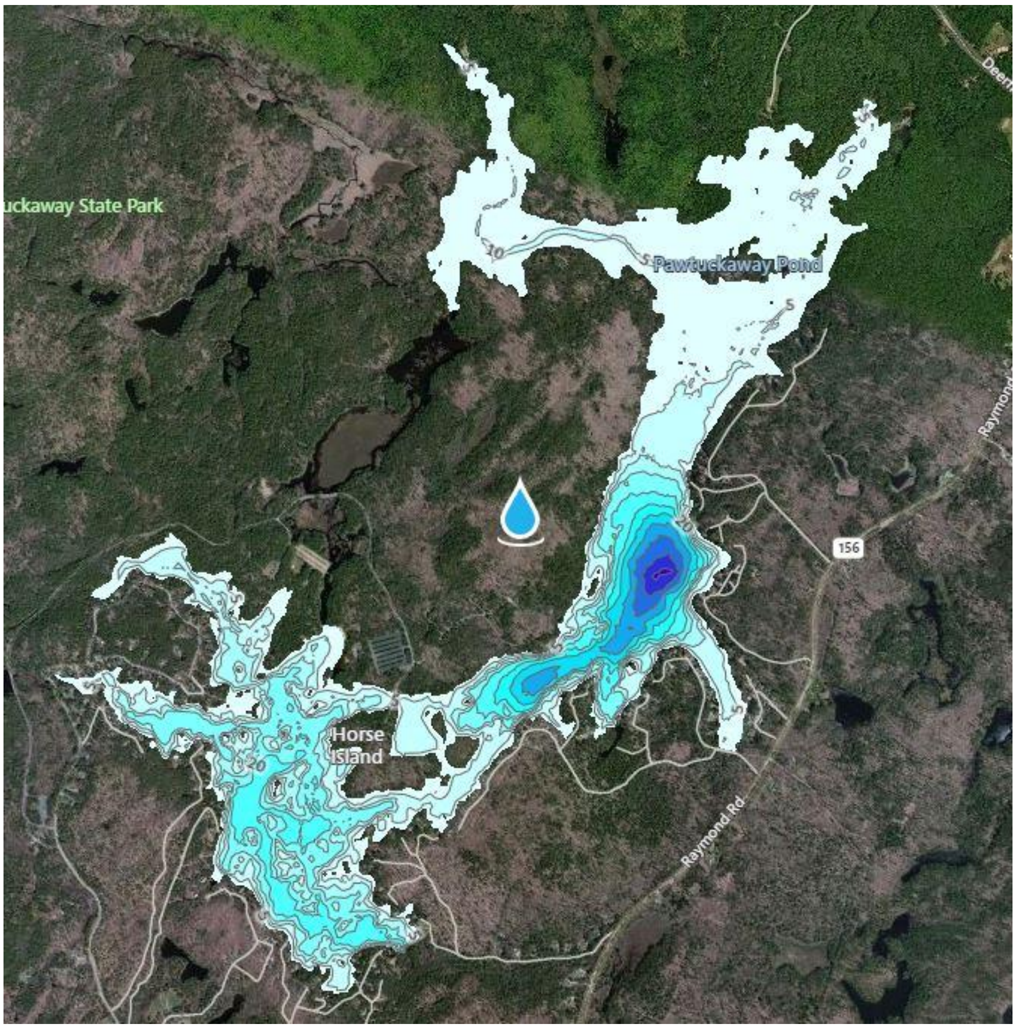
Display Unit with 3D module



Transducers

Lake Topology

Pawtuckaway Lake is a relatively shallow 784-acre (3.17 km^2) lake in Southeastern New Hampshire. Over the past 7 years we have determined that, given the water clarity and sunlight penetration in the lake, milfoil can grow in depths down to about 12 feet. Unfortunately, approximately 50 percent of the lake is within that depth.



Pawtuckaway Lake Bathymetric Map

All White and Lightest Blue Areas are shallow enough for variable milfoil growth

Milfoil Areas 2020

PRIOR RESEARCH

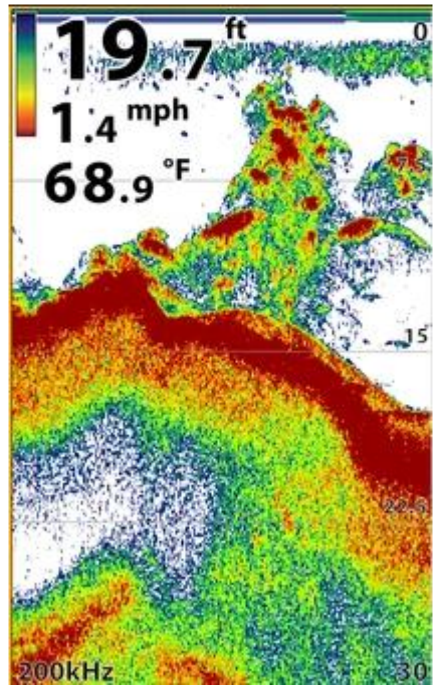
Most of the available literature on the use of side scan sonar for underwater vegetation surveys comes in two distinct forms: one, its use by fishermen to find suitable terrain for locating fish, and two, large scale surveys of water bodies to do general biomass studies. The former only note the distinction between various species of underwater vegetation as an incidental comment and the latter tend to be interested in large areas and concentrations of aquatic vegetation. Neither of these sources provided much definitive information as to the feasibility of what we were trying to achieve in Pawtuckaway Lake. Our interest was in using sonar to find single milfoil plants or small clumps of milfoil which stood above the surrounding weed bed.

Sonar Basics

This section is somewhat technical and can be skipped if the reader is only interested in the methodology of use and results of the study.

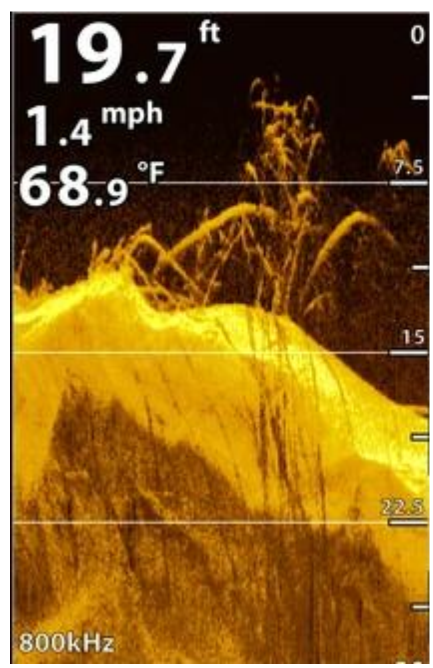
In this section I will be referring to sonar only in the context of its underwater use.

Sonar uses high frequency sound waves propagated through the water and reflected off underwater objects to develop a picture of the underwater environment. Generally speaking there are four types of sonar/sonar displays available for consumer use. They are 2-D, down imaging, side scan, and 3D sonar.



DOWN IMAGING is the oldest form of sonar and has been in use for fish finding for decades, albeit with continually improvements in the technology. Down imaging sends a circular cone of sound down into the water and produces a display like this.

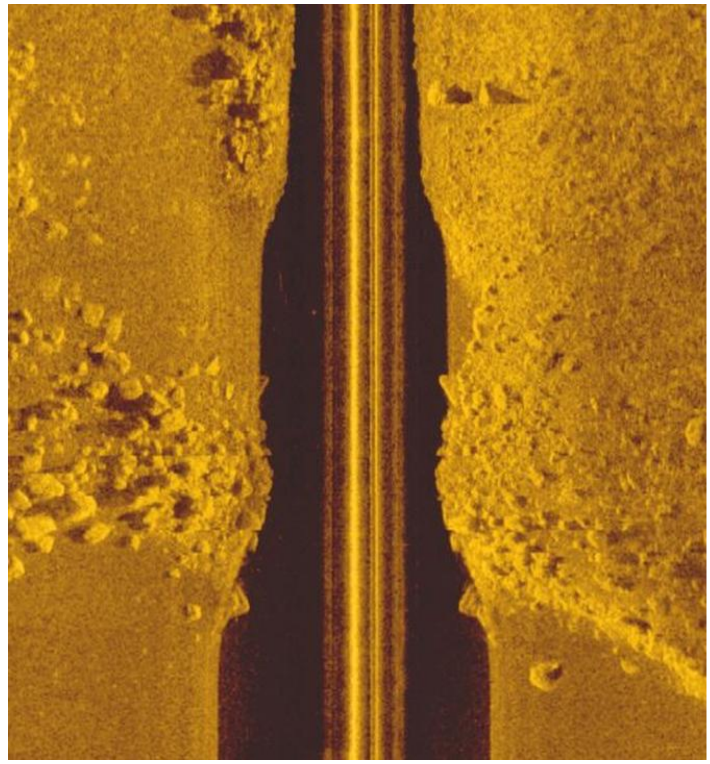
This shows a cross section of the water within the cone under the boat. The surface is at the top of the picture and the floor of the waterbody at the bottom. It shows the objects in the water column in that cone, with object density represented by various colors. It is important to note that it does not show where the objects are within that cone. They could be directly under the boat or off to the front, back, or sides.



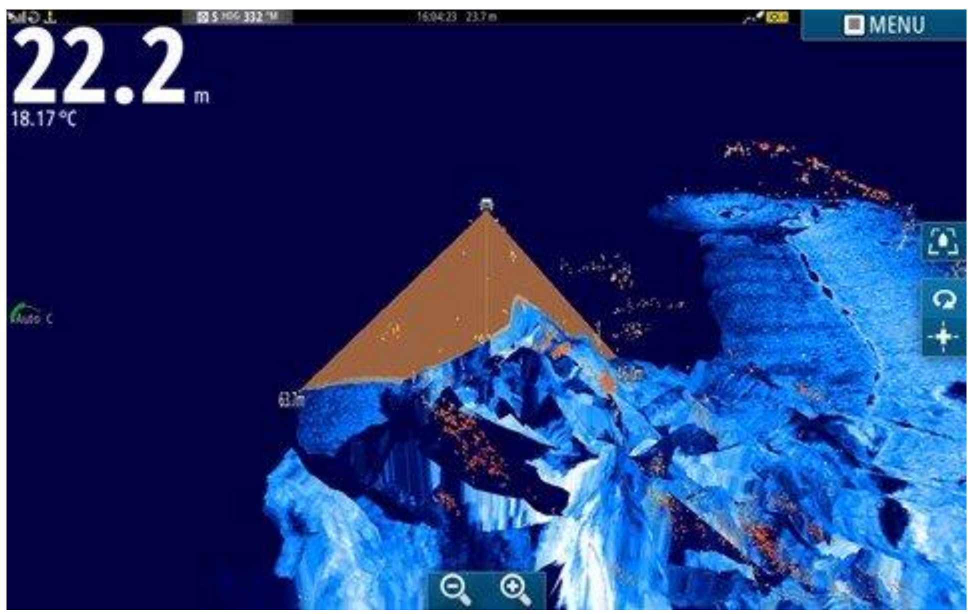
2D sonar is similar but the sonar signal is a narrow oval with the major axis perpendicular to the boat's directlon. It therefore can show a more precise image of the structure under the boat, but it still cannot show whether the object is directly under the boat or off to the sides. This is the same area as the previous display but using 2D sonar.

The objects rising off the bottom in both pictures are sunken trees. Note how they show up more clearly in the 2D display.

SIDE SCAN sonar projects a beam from side to side like 2D, but the display shows the resulting returns as it would be viewed from overhead rather than as a cross section. In the display to the right, the path of the boat is the central line, the water column is the symmetric area to the left and right of the boat path and the areas beyond that are the sonar reflections. With side scan sonar the objects and their distance from the boat can be seen and measured.



3D Sonar displays a 3 dimensional picture of the volume under the boat's path. The image can be panned and rotated in three dimensions so any object can be viewed from any direction.



The sonar equipment purchased through this grant enables all of the above modes of operation. We will elaborate further on the uses of each mode in the methodology section.

METHODOLOGY

STARTUP/LEARNING

After installation of the sonar, the first task was learning how to operate the equipment and explore its various modes and options. This process took a couple of weeks, using the unit on a variety of sonar runs throughout the lake. The intent at this point was not to find milfoil but simply to understand the sonar unit functions and learn to interpret what we were seeing on the sonar display. Learning to interpret sonar results is akin to learning to read an X-ray. After a little training it is easy to spot abnormalities in an X-ray but learning how to differentiate between the many possible reasons for the abnormalities takes a lot more time.

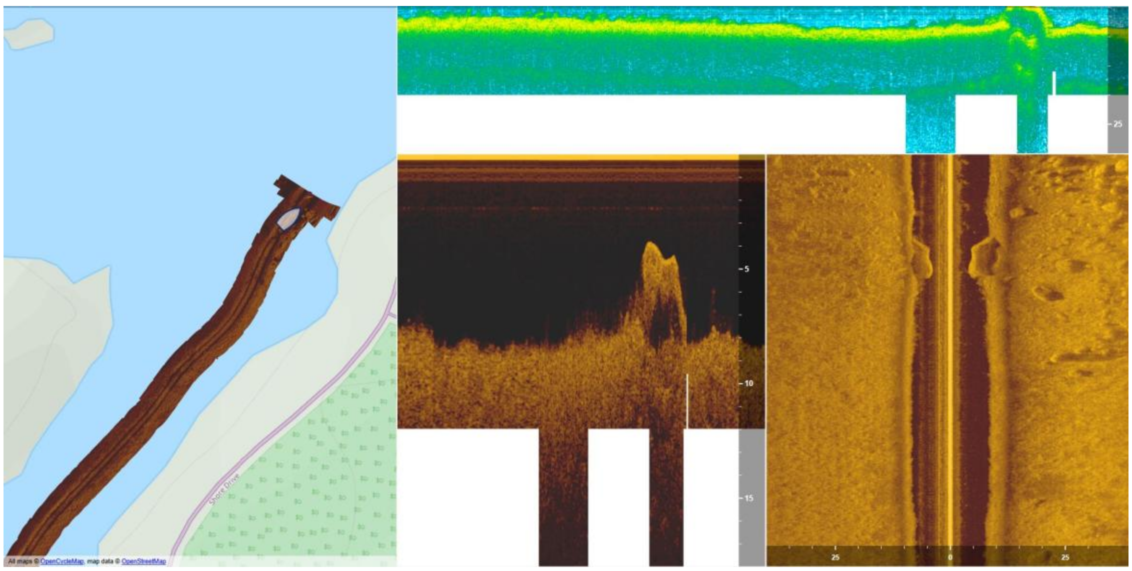
After this initial phase the next step was to start learning what milfoil looks like on the sonar and how it might appear different from other types of vegetation. In Pawtuckaway Lake we have managed to control the milfoil in known areas such that they are still scattered plants which we find and remove before they spread into beds or become very large. This is good news for the lake but presents a problem when looking for "test material" to ascertain what the sonar signature of milfoil looks like. The biggest opportunity to find large milfoil, therefore, is in the early summer when milfoil has had a late fall and early spring to grow undetected. As a result most of our learning about how to detect milfoil with sonar occurred relatively early in the summer.

DETECTION AND ANALYSIS

Since it was necessary to learn what milfoil looks like with the sonar, we made many sonar runs in the areas where we had found milfoil in prior years. It was our original intent to use the sonar in real time to locate suspicious areas that would be subject to further underwater investigation to confirm or rule out the presence of milfoil. We quickly deemed this idea as not the most effective. One of the reasons was that it would have required the presence of two people in the boat, one to operate the boat and another to observe the sonar display. The second reason was that it is difficult to do a careful analysis of what is being observed while the boat is moving and sonar images are scrolling across the screen. As we get better in interpreting the sonar results this may become more feasible but, for now, it is not the most effective way to observe sonar readings. Instead we relied primarily on the recording capability of the sonar unit to save all of the sonar data on microSD chips for later analysis. We removed the chips from the sonar and uploaded the data to a PC where we analyzed the information using Reefmaster software. This allowed us to take as much time as necessary to scroll through the data, changing color palettes and other settings, enlarging various areas, and correlating different views of the data as necessary to determine areas of interest. We then marked those areas with GPS waypoints and took that data back on the lake to drop markers in those areas for further investigation. This is the methodology we have used since early in our work.

PC SOFTWARE

As noted earlier, we did most of the analysis using Reefmaster PC software by uploading the MicroSD sonar logs to a PC. As shown in the image below the Reefmaster software allows the synchronized display of all available views of the sonar data. It can show the boat path relative to a map, down scan, 2D, and side scan information or any combination of those. Each view can be independently enlarged and the brightness and contrast altered to improve the data analysis. Different color palettes can also be used to emphasis different aspects of the sonar data. Also, after noticing an area of interest, waypoints can be marked directly on the display in any view. These waypoints can be saved on the MicroSD card for use in finding that spot with the sonar or uploaded to a handheld GPS for the same purpose. As mentioned earlier, this is the primary way that we used to locate suspicious areas of interest. While this post analysis takes some time, it does speed up the acquisition of the sonar data since only one person is needed to operate the boat while making sonar runs and very little time is spent observing the display at the same time.



Screenshot of Reefmaster Sonar Viewer on a PC showing different views of the same location

Left window is sonar track of boat showing the current boat location, top right window is down scan sonar, middle window is the 2D sonar view, and the lower right window is the side scan view. Note how the rock in the upper part of the side scan display shows in the different views

Search Methodology

We have found that the best technique for searching any given area is to traverse the perimeter of the area in question and then make multiple overlapping parallel passes through the area. The passes should be as long as possible, i.e. along the longest dimension of the area in question. The side scan unit we are using can scan a path approximately 4x the water depth on either side of the boat. So, in our lake, where the areas to be searched are typically 14 feet deep or less, each pass can cover 80-100 feet of width. However, it is important to make overlapping passes, both to get multiple views of every spot in the search area as well as to insure the optimal “shadowing” of any tall vegetation. This will be covered more fully in the Analysis Detail section.

According to Lowrance, side scan sonar is most effective at boat speeds of between 6 and 10 knots. Most of our sonar searches were performed along shorelines where many rocks are present and no-wake speed rules apply. As a consequence, most sonar runs were limited to a speed of 4-6 knots.

Learning Techniques for Analysis

In order to learn how to recognize milfoil with the sonar, we used two different techniques which we have termed pre-search analysis and post-search analysis. In the pre-search analysis case, we reviewed the sonar logs on the PC, noting suspicious areas. Using the GPS data from that analysis, we dropped markers in those locations. Our resident divers then went to those areas to observe what was near the marker. In the post-search analysis case, we made sonar runs in an area before an underwater search. We then took GPS readings where divers found milfoil and compared those locations with a review of the sonar logs to see what the sonar showed in those locations.

Results

Pre-Search Analysis Tests

With the relative paucity of large milfoil plants in the lake, our sample size is limited and became even more limited as the season progressed since we had already removed the milfoil from known infested areas. The truest test of sonar's ability to locate milfoil is the pre-search analysis case since it was done "blind" as opposed to the post-search analysis. We were able to perform a pre-search analysis in three separate areas of the lake where milfoil had been found in previous years. The table below contains the results.

Pre-Search Analysis Results

Area	Number of Suspicious Areas Marked	Number of Areas Containing Milfoil	Number of Areas Containing Other Tall Vegetation	Nothing Found
North End of South Channel	6	4	2	0
South End of South Channel	4	2	1	1
Gove's Cove	4	2	1(floating buoy)	1
Totals	14	8	4	2

In 85% of the cases above there was some tall vegetation found near the spots that were marked. The non-milfoil cases were primarily tall native weeds, mostly large leaf pond weed. With only two cases of "Nothing Found", there is not enough data to explain what the sonar image displayed except that it might have been some nearby object too far away from the marker to be clearly associated with it. That will be covered in more detail in the limitations section. This analysis tells us what we can see but doesn't answer the question about what is there that sonar can't locate.

Post-Search Analysis Tests

The post-search analysis case can give us an indication of what is there that we can't observe in the sonar data or that appears different from what we were expecting. For this analysis, a sonar run was made in the area of each dive a few days before the dive. After the dive, having marked all the milfoil that was found, GPS readings were taken of each marked location. The GPS coordinates were then overlaid on the sonar logs on the PC and the logs were compared with the actual milfoil findings. Out of approximately 75 milfoil plants/clusters that were found during our weekly summer underwater searches, only 3 could be definitely identified on the sonar logs. While this sounds like a poor result, it should be noted that very few large milfoil plants were found after the pre-search analysis tests and associated removal activities. The three plants that were apparent in the sonar logs were large and rose several feet above the surrounding vegetation. The rest of the plants were smaller, sometimes rising above the surrounding weed bed, but were generally very thin or rose only a foot or so higher than their surroundings. With such limited data, we have not been able to reach any conclusions as to why some larger plants were not detected.

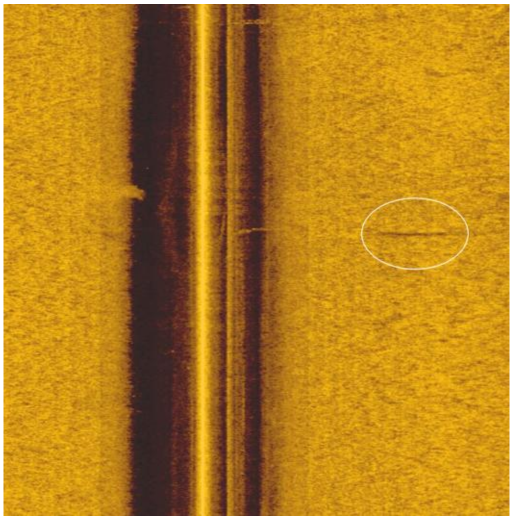
Analysis Detail

As mentioned earlier, sonar runs were made at speeds of 4-6 knots. If we assume an average water depth of 8 feet, the side scan sonar would cover a swath of 64 feet, 32 feet on each side of the boat. It was very beneficial to do overlapping passes to try to pass over the milfoil with 2D or get a stronger sonar "shadow" by having the milfoil well off to the side of the boat's path. As a result, we tried to make passes in the search zone about 32 feet apart. Running the boat at an average of 5 knots meant that we could scan about 15-20 acres per hour depending on the topology of the area and the number of obstructions. Little attempt was made to analyze the sonar data in real-time. The PC analysis time varied widely but generally took about 33-50% of the time needed to make the sonar runs, or about 30-40 acres analyzed per hour. Additional time was also required to load GPS waypoints onto a handheld GPS or back onto the sonar unit.

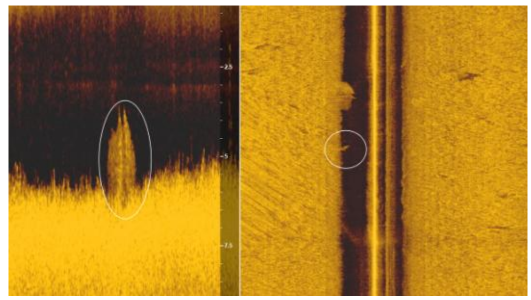
It was our expectation that side scan sonar would be able to detect plants that rise up above the general weed bed and that we could analyze large areas effectively and efficiently. While I believe our results bear out that general conclusion, it has not worked out quite as we had expected.

In the search areas i.e. those less than 14 feet deep and most usually 10 feet or less, the lake bottom is generally covered with an average of 12-18 inches of native vegetation. This is primarily tape grass and bladderwort with some areas of coontail. This meant that the sonar returns showed a great deal of vegetation "clutter" which made looking for milfoil more challenging.

Side scan sonar is like viewing an open forest from a drone late in the afternoon on a sunny day. When viewing trees that are off to the side of the drone, they cast a sun shadow. The further to the side, the longer the shadow. Similarly with side scan, anything rising up from the bottom of a water body to the side of the boat path will cast a sonar shadow. The taller the object and the further off the boat path, the longer the shadow. The darkness of the shadow will also depend on the reflectivity of the object. Rocks are certainly more definitive than vegetation, for example. However, something directly under the boat path or near the path will cast little to no shadow. For that reason it is important to search the area in question with overlapping passes so that everything can be viewed at an angle. Also, any large vegetation cluster passing under or nearly under the boat will display in a 2D view as an abrupt rise in the water "depth". This has also pointed up the utility of being able to see different views of the same area. That means not only more than one side scan view of the same area, but also a 2D view. Being able to visualize the same area with different views simultaneously on the PC has been a very effective technique.



Milfoil Shadow in Side Scan View



Milfoil under Boat
No side scan shadow but abrupt rise in vegetation

While it was our intention to use the 3D capability as a valuable adjunct to 2D and side scan, we have not been able to employ it so far. The early use of this capability was unsatisfactory and we worked with the manufacturer on many occasions to resolve our problems with little success. Finally, the manufacturer agreed that something was wrong with the 3D module and it was shipped back to the factory for analysis. We finally received a working 3D module and transducer in early October, so our investigation in the use of 3D will have to wait until next year.

In addition, the 3D capability is only available in real time. There is currently no software available to view 3D data on the PC. Therefore it will require two operators on the boat, one to navigate and one to look at the sonar display while analyzing the 3D views.

Operational Use of Sonar

The intent of the sonar was to be able to scan large areas of the lake where milfoil could grow but where it is not known to currently exist. After performing the test runs mentioned earlier, many of those areas of the lake were searched with sonar. Suspect locations were identified and searched. We were pleased that no such suspect areas contained milfoil.

Limitations

As mentioned earlier, making long parallel passes is the most effective. One of the reasons for this is sonar “smearing”. This happens when making a turn. The sonar readings on the outside of the turn are normal but, on the inside of the turn, the sonar actually backtracks over the same area creating a fuzzy, almost wavy, image. It effectively obscures the image so no analysis can be done. As a consequence, the search pattern needs to be able to cover every part of the area while steering the boat in a straight line as much as possible.

We also feel that having the sonar on as stable a platform as possible increases the quality of the sonar readings. We do not, however, have any experimental data to verify this. What we are searching for are fine details in sonar shadows and differentiating plant growth from other underwater structures such as rocks and trees. Any rocking of the platform makes the sonar detail less crisp and the readings less definitive. In our work, we used a pontoon boat exclusively. We think that a stable platform may be especially necessary when using 3D although, as previously mentioned, we have not yet had an opportunity to experiment with that capability.

We also have come to understand the accuracy limitations of sonar and GPS. The sonar unit has an internal GPS which it correlates with the sonar log. The reported GPS accuracy from the Lowrance display is usually in the 25-30' range. Additionally, a variable amount of potential error is introduced when marking a waypoint on the sonar log on the PC. Finally, when dropping a marker in a suspicious area using the same coordinates on a handheld GPS, there is also a GPS reported position accuracy of around 15'. If all these errors add rather than cancelling, our marking may be off by 50' or more. While that is certainly sufficient to use when investigating potential milfoil in a new area, it is not accurate enough to replace methodical searching of a known milfoil area to locate plants.

While about 50% of Pawtuckaway Lake is within the 12 foot depth where we believe that milfoil can grow, about 40% of that, or roughly 20% of the lake is too shallow and/or rocky to permit safe use of boats to perform sonar scans. Even if those areas could be safely navigated, the weed bed there is generally quite dense. The shallowness would also mean that the height difference between the general native weed population and any milfoil would be too slight to be able to discriminate between native weeds and the presence of milfoil.

We have also found that familiarity with the general underwater characteristics of the lake is a significant help in interpreting the sonar data. Knowing the general expectations of bottom composition, native weedbed, underwater obstructions, non-vegetative structures such as fallen trees, etc., help to understand what "normal" sonar readings will look like and assist in spotting "abnormal" vegetation.

Finally, a temporary limitation has been the inability of study the use of 3D sonar. The 3D Structurescan module was apparently defective and, despite many calls to Lowrance Customer Support, no on-site resolution was found. Consequently, the unit was shipped back to the factory and a new unit was not received until early October. We hope to investigate the use of 3D in the 2021 summer season.

Conclusions

While we are still learning how to read the sonar data, our abilities keep improving and our results indicate that large milfoil plants that rise two feet or more above the surrounding vegetation can be detected through side scan and 2D sonar techniques. Also, plants that are larger in diameter, as well as relatively taller, have a more distinct signature as would be expected. In known areas of milfoil, sonar will not be the primary method of locating milfoil plants since we would expect a variety of plant sizes and not all would be detected with sonar. That situation will still require direct viewing by divers.

Despite those limitations, our intention in using sonar is to find milfoil in previously unsuspected areas where single plants or small clusters have grown to a significant size. This has been what we have experienced in every case where milfoil has been discovered in new areas. We have not yet learned how to discriminate between such milfoil plants and other tall vegetation; in fact it may never be possible. In our experience, however, there are not so many “false positives” that it would be unreasonable to investigate every anomalous area indicated on the sonar especially early in the summer when most native vegetation is still small. Late in the summer, other vegetation, such as pond weed and bladderwort can have a significant presence in the water column and will increase the number of false positives. While other vegetation, such as tape grass, can also grow tall, their relative mass and density does not seem to present an analysis issue. While it is a subjective measure, we believe that sonar can determine a high percentage of large milfoil plants that stand well above the surrounding vegetation, probably around 80%. Our false negative rate, i.e. plants ostensibly large enough to be detected by the sonar but not apparent in the sonar logs is harder to quantify since there is a lot of subjectivity involved in making that calculation but, in our limited experience, it probably runs around 10%.

We have also found that, as expected, sonar is far more efficient in terms of resources than underwater searches. Over the past five years we have learned that underwater searches take about one person hour per acre while the search and analysis time for sonar is about 10 acres per person hour. This order of magnitude increase in productivity makes it feasible to satisfy our original goal of searching a high percentage of potential areas of infestation on a regular basis with reasonable amounts of time and effort.

In conclusion we are encouraged by our early results in detecting milfoil with sonar and expect our success rate will grow with experience We are also hoping that the 3D capability will prove to be a valuable addition to our ability to locate milfoil.

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