

FINAL REPORT: EVALUATION OF LAKE TROUT SPAWNING HABITAT AT LAKE MICHIGAN'S MID-LAKE REEF COMPLEX.

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This Final Report includes a Brief Report and an Extended Report. The latter is updated information from previous Progress Reports. The Brief Report summarizes the major findings pertinent to the major project objectives, along with emerging issues. From here we will progress to a report to the Great Lakes Fishery Commission (a brief presentation was delivered to the Lake Michigan Technical Committee on 29 Jan. 2013). Concurrently we will be writing manuscripts for publication.

Brief Report

The major objective of this three-year project was to generate likely “best” areas for possible initiation of time-series sampling for lake trout egg deposition and fry production for the Mid-Lake Reef Complex (MLRC), the suite of reefs that separate Lake Michigan’s southern and northern basins. These reefs were identified as a major and perhaps most important spawning area by commercial fishers interviewed by Coberly and Horrall (1980), a report that changed emphasis on stocking to the MLRC rather than coastal reefs. In effect this has been a six-year project because this report combines elements of Projects (2004–2006) and (2008–2010 plus 2012). Parts have been reported by Janssen et al. (2006), Janssen et al. (2007), and Warner et al (2009). Also the trajectory of the project has interacted with management policy as well as agency sampling. The context of this work has been recently changed due to strong evidence of natural reproduction (Hansen et al. in press). However, their work is not evidence of strong natural reproduction and the natural reproduction is not necessarily due to spawning at the MLRC. However, our demonstration, reported herein, of numerous areas of egg deposition and fry production generates a very explicit and testable hypothesis that lake trout spawning at the MLRC is responsible, at least in part for the documented natural reproduction.

While not explicit in our proposal objectives, we also generate a more general model of physical factors conducive to lake trout spawning. Previous work had focused on shallow reef and beach spawning lake trout in which the ventilating current is due to wave surge. These reefs are characterized by cobble with a steep slope. For the MLRC the spawning is dispersed among probably numerous sub-reefs, some of which have a cobble talus slope, but some of which are atop level bedrock adjacent to a dropoff. In the latter situation deep currents of Lake Michigan produce a ventilating flow. Important is a hydrodynamic “edge effect” in which ventilating flows are accelerated close to the dropoff edge. With the rugosity of the cobble the flow becomes turbulent and able to penetrate the interstitial spaces where eggs incubate. Hence, in the more general model it is a turbulent flow, from waves where shallow and edges where deep, and cobble that are

requirements for spawning. We hope to collaborate with experts in hydrodynamics to generate a quantitative model for lake trout spawning habitat.

Highlights

We have strong evidence that ROV based egg suction sampling correlates well with counts of eggs in egg traps. Based on ten pairs of sites for which we have both egg trap and ROV suction sampling data, there is a strong correlation (Fig. 13; $r^2 = 0.784$ ($P < 0.001$, also $r^2 = 0.759$, $P < 0.001$ for log-normalized data)) between the two sampling techniques. The egg trap and ROV data are independent estimators of relative egg abundance for two reasons, first because they are very different methods and, second, because they were taken 1-2 years apart.

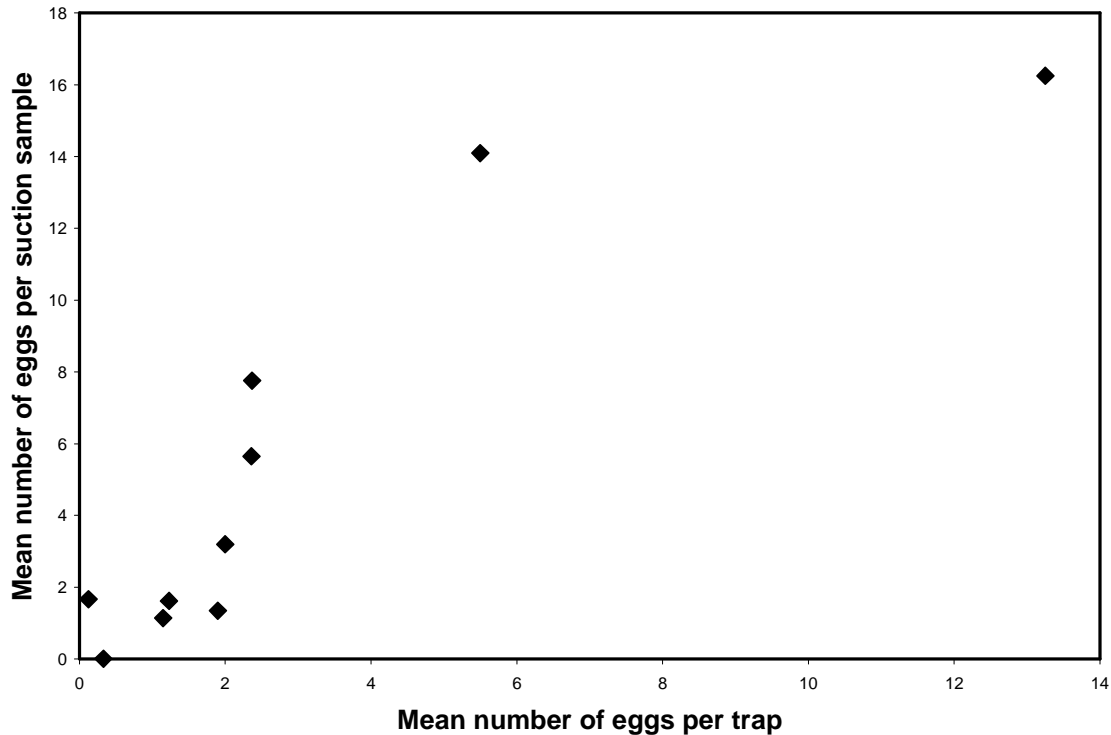
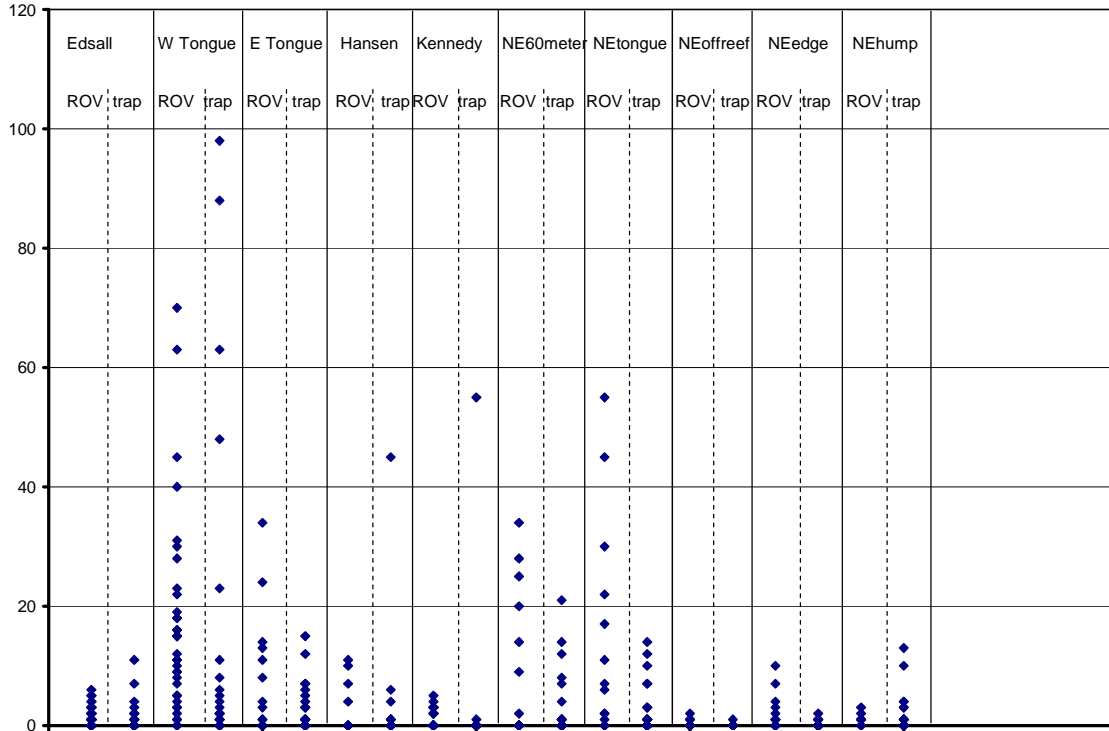


Fig. 13. Correlation between ROV-based suction sampling for lake trout eggs and deepwater egg trap catch. The Coefficient of Determination $r^2 = 0.784$ ($P < 0.001$) ($r^2 = 0.759$, $P < 0.001$ for log-normalized data) Current evidence indicates that the egg trap counts are quantitative, so the strong correlation indicates that ROV suction sampling success is a useful indicator of relative egg deposition.

Because we have two independent estimates of relative egg density we can analyze these data as a two-factor Analysis of Variance (ANOVA) with collection technique (confounded with year) as one factor and site as the second factor (the of interest) and log (number of eggs) as the dependent variable. There was a highly significant site effect ($F_{9,506} = 39.02$, $P < 0.001$). While ANOVA's are generally robust to deviations to normality, we consider this analysis as very preliminary. We are investigating strong

evidence of hyperdispersion of counts, i.e. data are not log-normal distributed and what this likely means biologically. For example, hyperdispersion is likely due to clustering of eggs from individual spawning ejections.



(Fig. 12 in the expanded report). Egg counts per ROV 2-minute suction sample and per egg trap for 10 sites. Edsall Ridge and Kennedy (Hump) are at Sheboygan Reef, East Reef sites are W. Tongue, E Tongue and Hansen (Point), and Northeast Reef sites are NE 60 meter, NE tongue, NE off reef, NE edge, and NE hump.

We saw and collected lake trout sac-fry on all of the sites at which we found eggs. The video has been pre-reviewed by the technician and Janssen will confirm sightings from the condensed video. The most significant result was the collection of a sac-fry near the north end of the mapped area at a depth of 63 meters, a new depth record. The approximate location is the northmost arrow in Fig. 2 in the main body of this report.

The most troubling finding was seeing and collecting the first round gobies, a total of five, at the Mid-Lake Reef Complex. Two were collected and were large enough to be mature. We presume these migrated from the western coast of Lake Michigan. It is unlikely that round gobies will reproduce because the summer temperature is about 5° C and round gobies apparently spawn during spring warm-up when the temperature reaches about 10° C. None-the-less, we do find round goby nests along the west coast at low temperatures due to persistent upwelling events. Summer coastal temperatures are commonly as cold as 6 - 8° C at nest depth.

We also have been refining our primary objective, which is to provide recommended sub-reef sites and sampling strategies for efficient monitoring of lake trout spawning at the Mid-Lake Reef Complex. Using a combination of egg density, sac-fry sightings and collections, and logistical ease for deploying egg traps, the western sector of the South Tongue of East Reef is the most favored site within the sampled MLRC for efficient monitoring. This site not only has the highest egg densities, but it appears to be spatially the most extensive, so is a large target for deployment of egg traps. We think that it also has the highest sac-fry densities, but this may not be demonstrated clearly statistically. For Sheboygan Reef we would recommend Edsall Ridge over Kennedy Hump primarily because Edsall Ridge is extensive, hence a large target for egg trap deployment. For Northeast Reef we propose the south end of the long dropoff, but the sub-reefs at Northeast Reef are a difficult target.

Despite our conclusion that the South Tongue of East Reef is the best sub-reef, we think that it is very likely that the edge of Northeast Reef's long dropoff, including its southern end, may be the most productive area because of its vast area.

Presentations

November 28-29, 2012. **Fish & habitat: offshore deep reefs.** Offshore Wind Energy – Understanding Impacts on Great Lakes Fishery and other Aquatic Resources Great Lakes Environmental Research Laboratory, Ann Arbor, MI

December 12, 2012. **Deepwater lake trout spawning habitat.** “Reintroduction of Native Fishes” Workshop. Great Lakes Fishery Commission, Ann Arbor, MI

January 29, 2013. **Mid-Lake Reef lake trout spawning update.** Lake Michigan Technical Committee, DesPlaines, IL

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Hanson, S. D., M. E. Holey, T. J. Treska, C. R. Bronte, and T. Eggebraaten. In press. Evidence of wild juvenile lake trout recruitment in western Lake Michigan. *N. Am. J. Fish. Management*

Janssen, J., D. J. Jude, T. A. Edsall, R. W. Paddock, N. Watrus, M. Toneys, and P. McKee. 2006. Evidence of lake trout reproduction at Lake Michigan's mid-lake reef complex. *J. Great Lakes Res.* 32:749-763.

Janssen, J, J. E. Marsden, C. R. Bronte, D. J. Jude, S. P. Sitar, F. W. Goetz. 2007. Challenges to Deep-water Reproduction by Lake Trout: Pertinence to Restoration in Lake Michigan. *J. Great Lakes Res.* 33 (Suppl. 1): 59-74.

Warner, D. M., R. M. Claramunt, J. Janssen, and D. Jude. 2009. Abundance and distribution of spawning lake trout on Sheboygan Reef in Lake Michigan. *Journal of Great Lakes Research.* 35: 147-153.

EXTENDED REPORT

OBJECTIVE 1. BATHYMETRY MAPPING OF NORTHEAST REEF AND THE NORTH FLANK OF SHEBOYGAN REEF

Northeast Reef

In 2009 we modified our strategy for Northeast Reef bathymetry mapping slightly based on a preliminary map of Northeast Reef constructed mainly using NOAA data with some additional conventional single beam (fish finder) sonar. Dr. Wattrus estimated the time needed for multibeam mapping and it appeared that we might not have enough time to complete mapping. A few weeks before the multibeam mapping we constructed a more detailed preliminary map using the Furuno sonar in combination with a real time mapping program (written in 'R') that allowed us to adjust the cruise track as we were mapping. Operationally this meant that when we could track the dropoff areas by zig-zagging over the dropoff. This strategy revealed a long dropoff area toward the north (Figure 1, arrow A) and two "points" with steep dropoffs toward the south (Figure 1, arrows B and C). Between these areas the dropoff was too gentle to be of interest. We then focused the multibeam survey on sites A, B, and C and completed the mapping data collection in about 24 hours, about half the time estimated by Wattrus based on the NOAA data.

Sites B and C are similar in bathymetry to sites at East Reef where we have found lake trout egg deposition and sac-fry production. However, C, the southern site is covered by a veneer of sand and we saw no bioacoustic evidence of spawner lake trout in late October. Site B has smooth contours along its southern face and that is a sand veneer. Site B's northern face is much more irregular and we confirmed that it is rocky and that eggs are deposited there (See Objective 3).

Site A is the most interesting of all of the sites thus far mapped at the Mid-Lake Reef Complex. Its slope appears to be about 20° – 30°, over 5 km long, and it includes rocky talus slopes. One unexpected finding is that there is cobble consistently atop the reef plateau, but set back from the dropoff by a distance of 10-20 meters. Where we sampled these via ROV we found lake trout eggs. Based on egg and sac-fry sampling in 2009-2010 we think that Site A may dwarf all other Mid-Lake Reef sites for potential lake trout spawning habitat. The largest previous site (East Reef south tongue, western side) that we found is on a scale of about 100 m long extending from about 50 – 60 m deep.

43d1'14.676"N 87d54'15.408"W depth 8.5 m

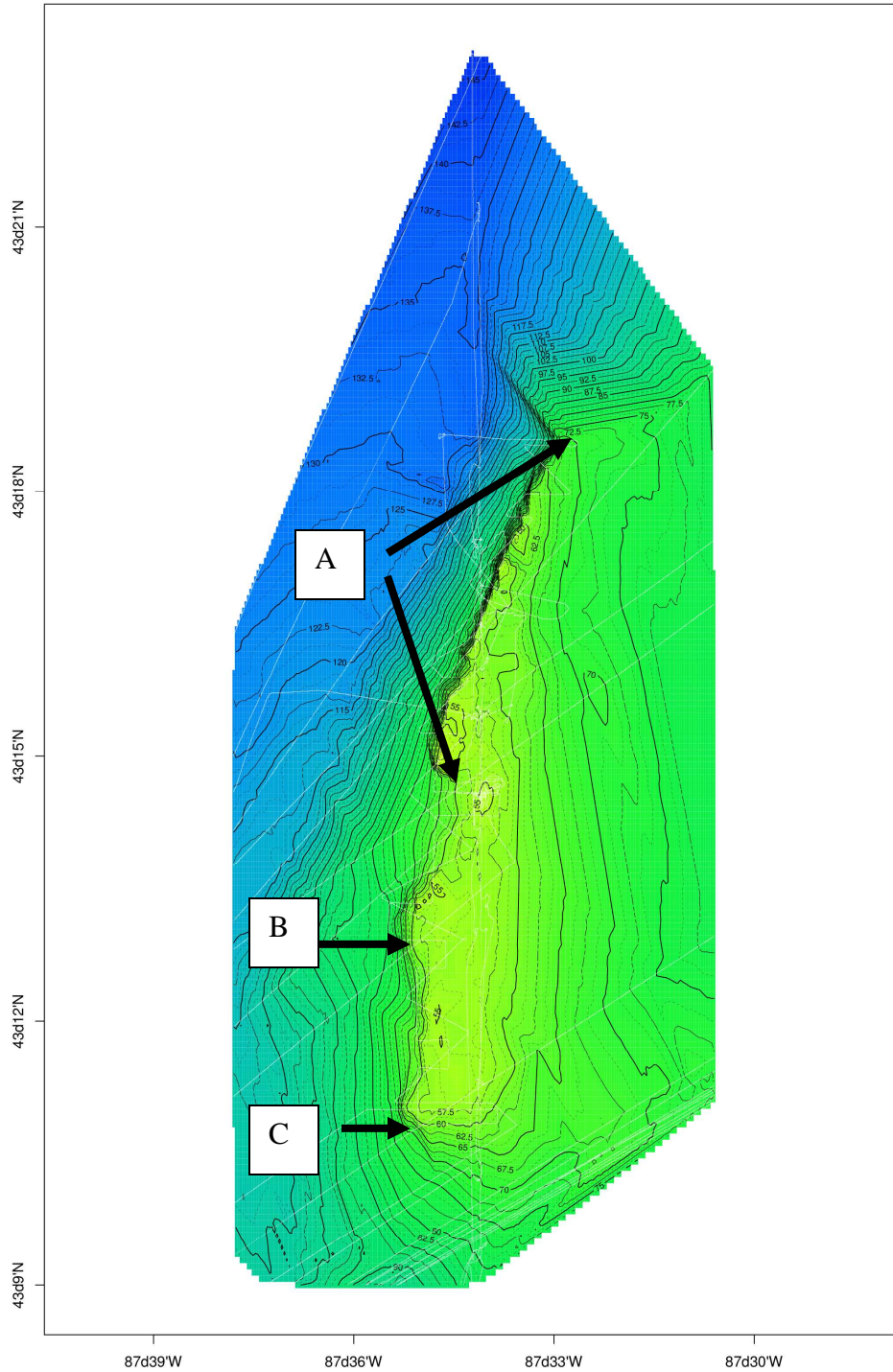


Figure 1. Preliminary Northeast Reef Map based on single beam sonar and Tom Hansen's mapping software. Depth contours are shown and depth is also color coded. This map was used to identify areas for detailed multibeam mapping. The preliminary multibeam maps for areas A, B, and C are shown in Figures 2, 3, and 4 respectively.

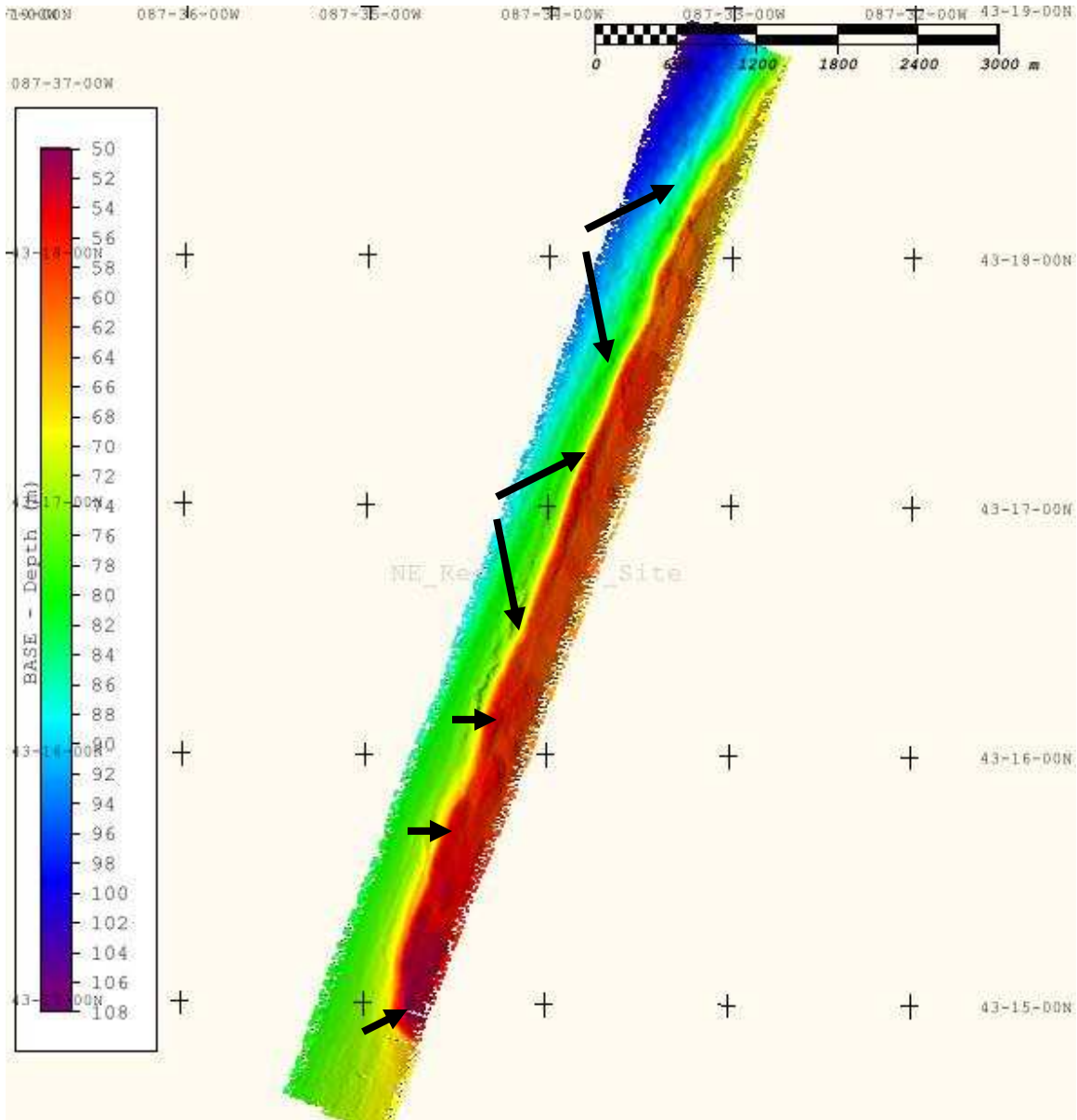


Figure 2. Northeast Reef, Section A. Depths are color-coded. This is an extensive dropoff area with the dropoff having a slope of about $20^{\circ} - 30^{\circ}$. If this section is cobble and boulder it may be the most extensive lake trout spawning habitat mapped thus far. Arrows point to areas of cobble piled atop the reef. Where we have sampled these via ROV we have found lake trout eggs and sac-fry have been either seen or collected at most of these sites, including the northmost arrow. A version of this map showing labeled contour lines is given in Figure

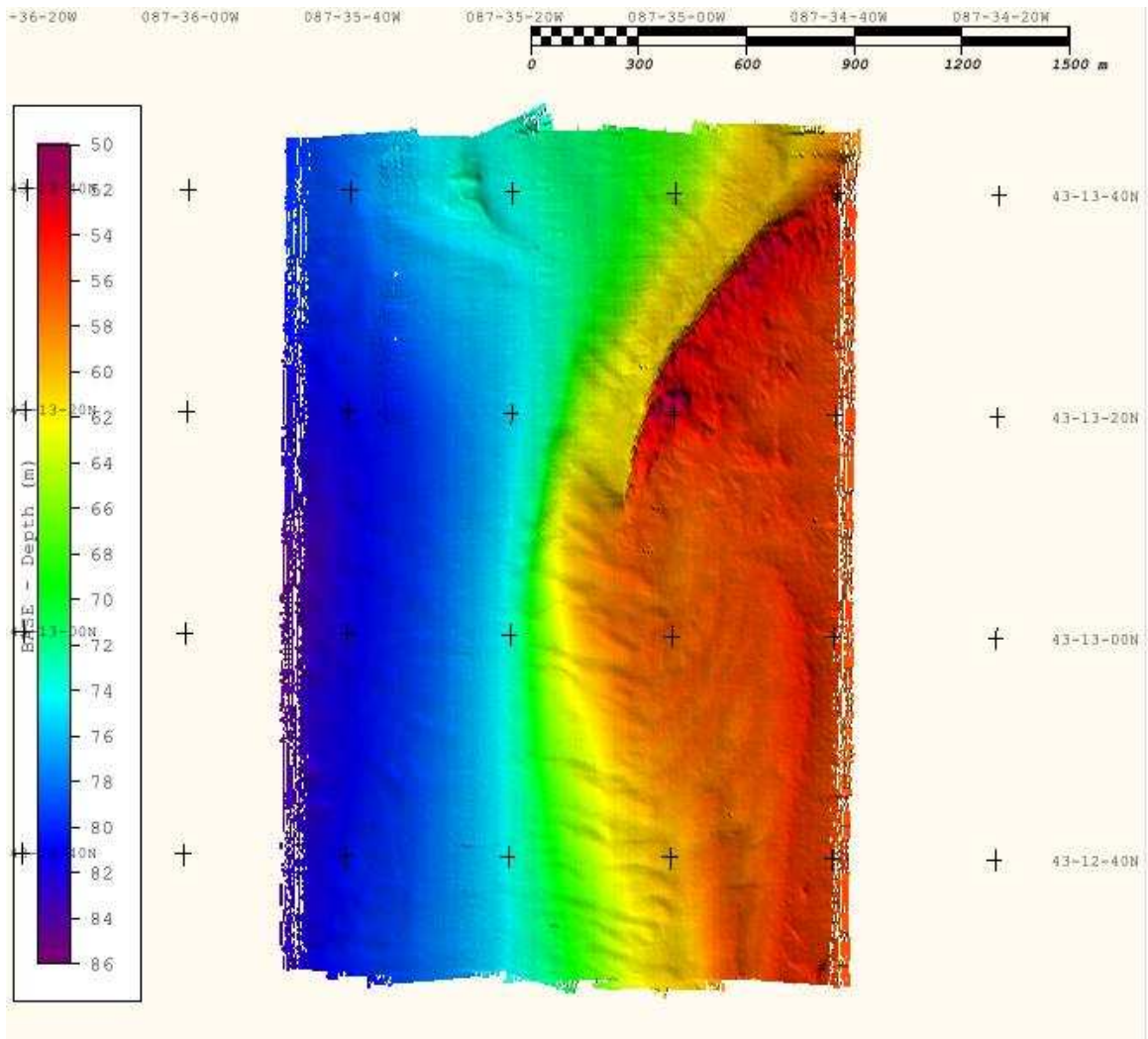


Figure 3. Northeast Reef, Section B. Depths are color-coded. The south part of this submerged point is smooth and covered by sand so is unlikely to be viable lake trout spawning habitat. The north part has an irregular sharp dropoff and is rocky with cobble atop the reef that contained lake trout eggs. .

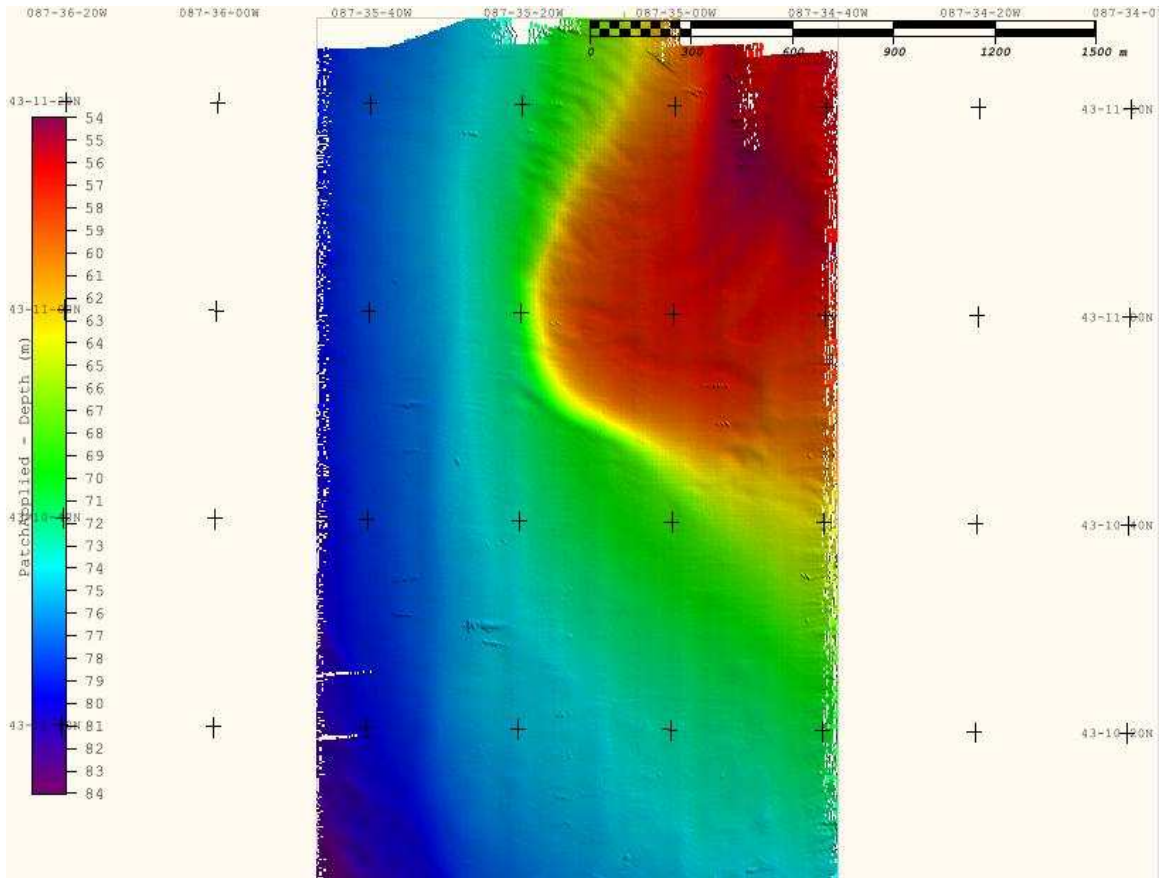


Figure 4. Northeast Reef, Section C. Depths are color-coded. The entire point is very smooth and sand covered, hence is unlikely to be viable lake trout spawning habitat

Sheboygan Reef.

In 2009 we mapped the north flank (usually upcurrent flank) of Sheboygan Reef (Figure 5) to a depth of about 60 meters, the maximum depth at which we had found lake trout eggs at East Reef (previous work). This sector is immediately north of the part of Sheboygan Reef mapped in 2003. Eventually we will combine the two maps.

The known lake trout spawning sites (viable eggs and sac-fry collected) for Sheboygan Reef are (1) a ridge, about 1.5 km long, 30 m wide, and 2-3 m high composed of cobble and (2) a hump. Several similar sites are visible on the map, including a cluster of narrow ridges, about 1/3 to 1 km long are toward the northeast (A). One of these extends down a slope that faces the prevailing current direction. Broader humps and ridges (B) lie towards the west. We will look at these bathymetry data in greater detail. These sites were targets for bioacoustic sampling.

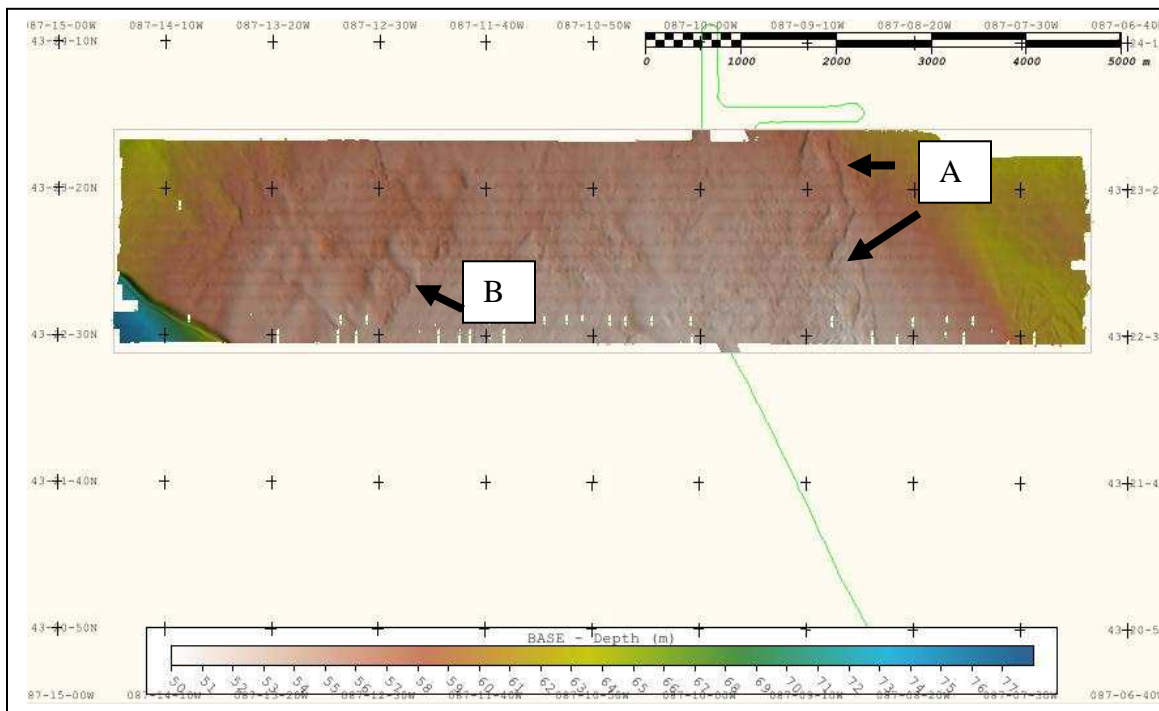


Figure 5. North flank of Sheboygan Reef. This sector is just north of the area mapped in 2003. Two areas of ridges (A and B) are indicated and these are candidates for lake trout spawning. The ridges along the eastern dropoff may receive strong currents from the northeast, the prevailing current direction.

OBJECTIVE 2: BIOACOUSTIC SAMPLING (OBJECTIVE 5, GILL NETTING, IS COMPLEMENTARY AND INCLUDED HERE).

Bioacoustic sampling targeting lake trout of reproductive size was done on 20 and 28 October (Northeast Reef) and 22 October (Sheboygan Reef). The 20 October bioacoustic sampling was complemented by Wisconsin DNR gill net sampling for adult lake trout. The gill net set was nearby and approximately parallel to the bioacoustic track for that day. This allowed for ground-truthing of fish sizes.

The results for Northeast Reef were extremely promising (Fig. 6). For Section A there were large echos, presumably lake trout, all along the long dropoff. The gill net (1600 feet) was set toward the southern end of the acoustic transect and captured 167 lake trout and 2 burbot. The catch per effort exceeded that for East Reef, their previous best site. These data, combined with promising ROV-based egg collecting, may indicate that Section A is about 6 km of continuous or nearly continuous viable lake trout spawning habitat. If so, this dwarfs all previous Mid-Lake Reef sites. Examination of the Northeast Reef Section A's bathymetry suggests that the viable habitat extends some distance north, as yet unmapped.

At Northeast Reef Section B we also found dense presumptive lake trout echos (Fig. 7) with more than 400 targets estimated to be larger than 450 mm. We found little evidence of lake trout aggregations at the north flank of Sheboygan Reef. (Fig. 8); only 16 targets estimated to be larger than 450 mm were recorded. All of these were associated with a low ridge (about 1 m relief relative to the surrounding terrain) adjacent to a slight dropoff at the northeast sector of the map. This may suggest that there is a more significant feature just north of the mapped area.

The bioacoustic results for Northeast Reef present a challenge, but a good one with respect to lake trout spawning. The challenge is that there is much more potential good habitat than we anticipated.

A potentially useful way to deal with this is to correlate lake trout individual location with its underlying substrate. On ROV dives we generally see lake trout only over areas of cobble where we also collect eggs. Lake trout are usually not seen at adjacent areas of bedrock. We are currently attempting to correlate individual lake trout echos with an acoustic estimate of the seabed type (seabed classification). Watrus has obtained new software for multibeam seabed classification and will begin analysis soon. If that processing is not successful we will use the acoustic data from the bioacoustic assessment instead, but it will give less spatial coverage. If there is good correlation between lake trout echos and seabed type then we may be able to predict lake trout spawning sites from seabed classification maps.

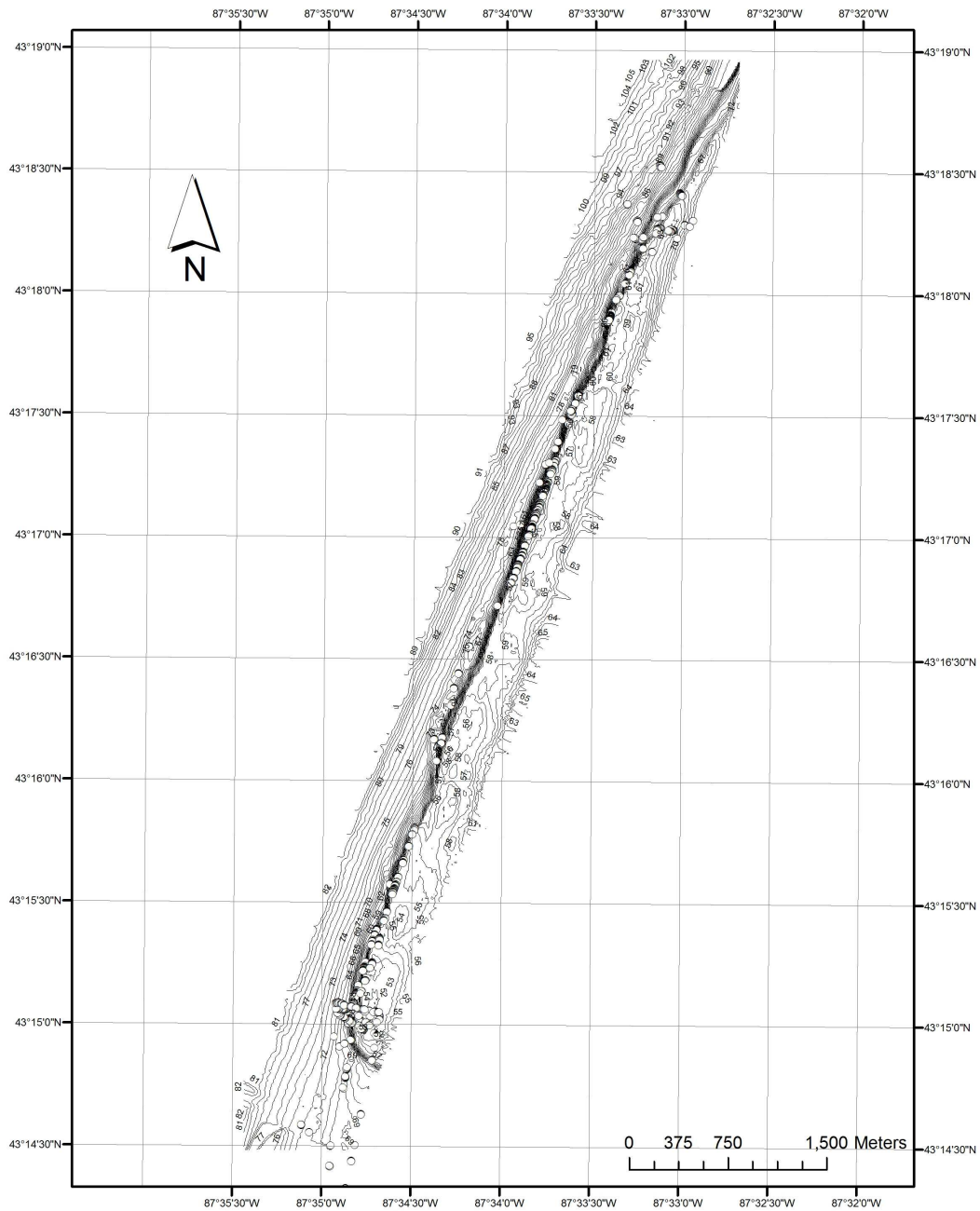


Figure 6. Bathymetry of Section A. of Northeast Reef. Circles indicate probable adult lake trout echos from bioacoustics. We are attempting to generate a seabed classification map to determine whether individual echos correlate with bottom substrate type. This would facilitate locating new spawning sites.

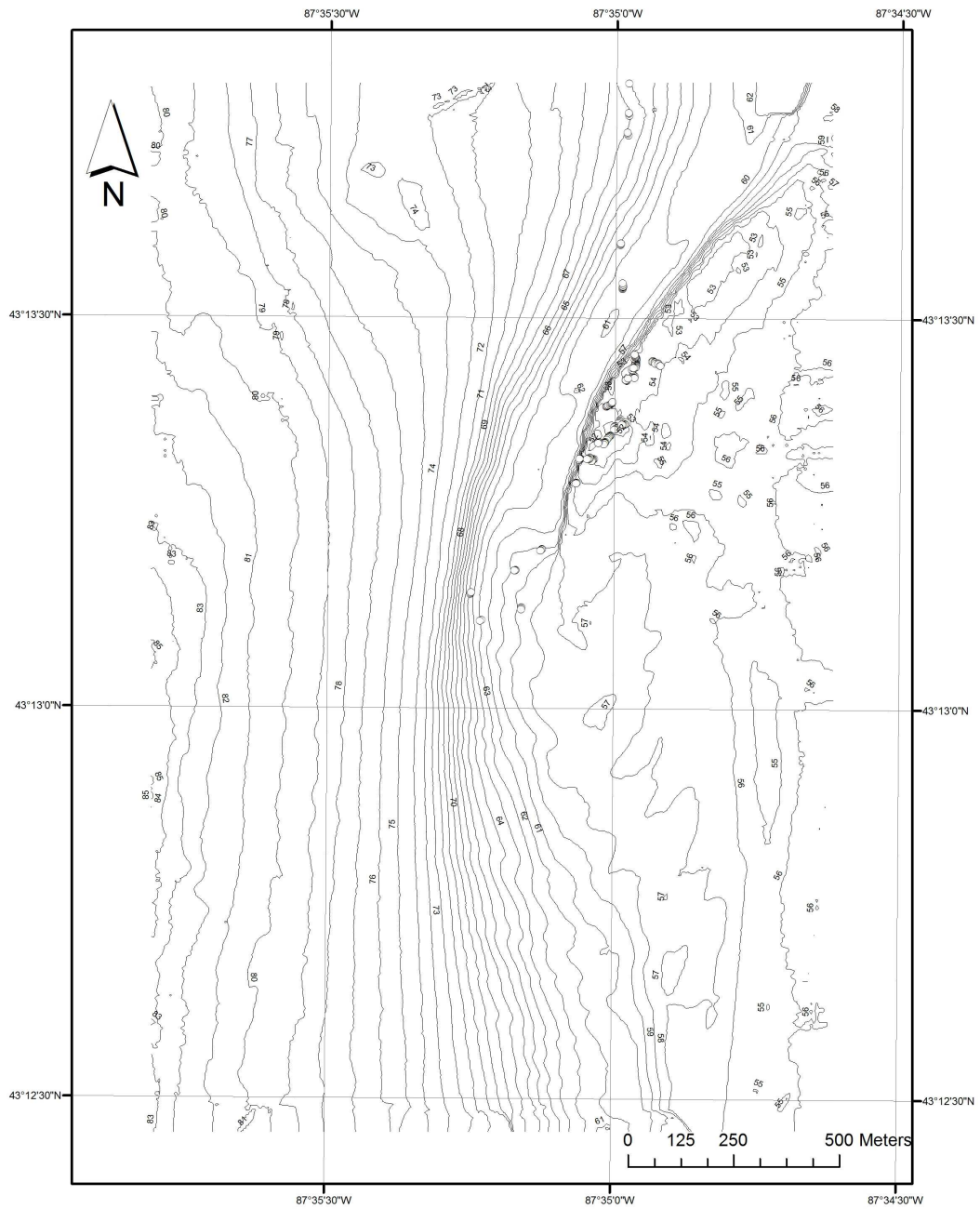


Figure 7. Bathymetry of Section B. of Northeast Reef. Open circles indicate probable adult lake trout echos from bioacoustics.

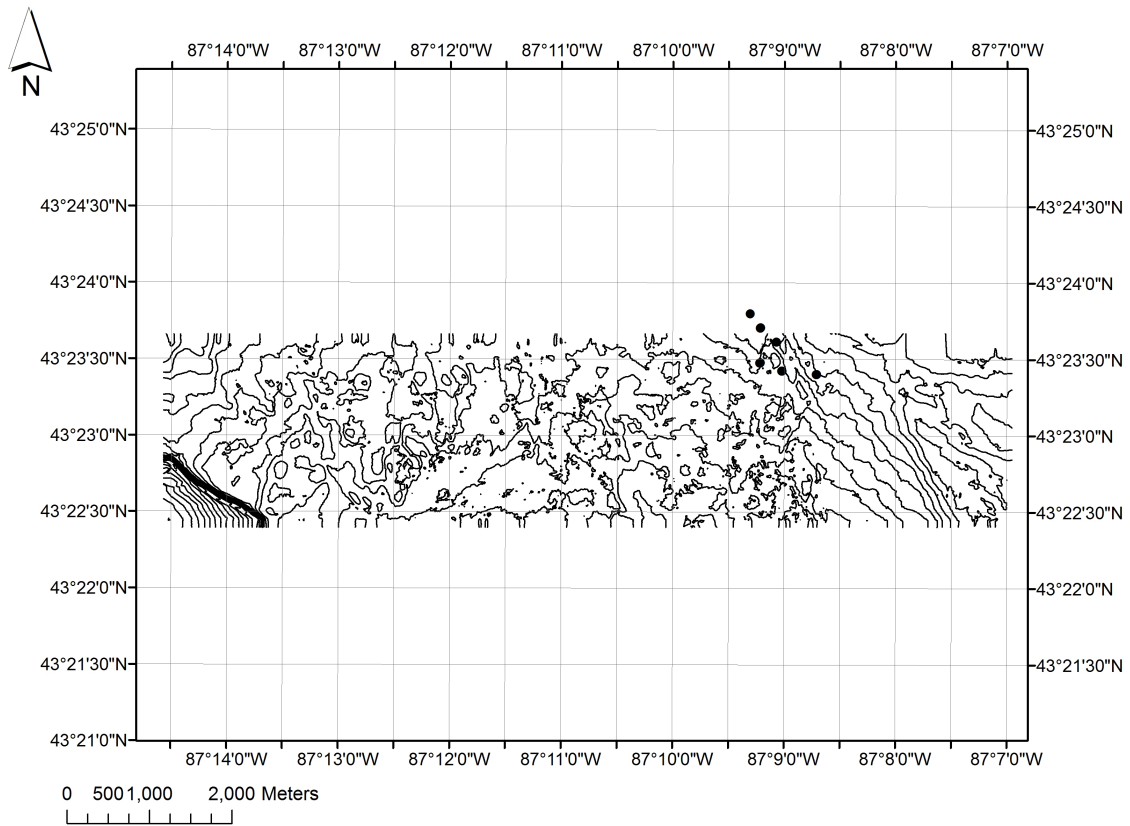


Fig. 8. Bathymetry of the north flank of Sheboygan Reef. Closed circles indicate probable adult lake trout echos from bioacoustics. The circles overlap, a total of 16 probable adult lake trout were recorded, far fewer than at Northeast Reef or for a previous study south of this newly mapped area. These are associated with a low ridge adjacent to a slight dropoff.

OBJECTIVE 3: ROV-BASED SUCTION SAMPLING FOR EGGS

Fall 2010 sampling: The Fall sampling included ROV-based egg sampling combined with deployment and recovery of egg traps (Objective 6). We had some minor issues with the research vessel's rudder which limited operations to very calm days. But we had excellent success collecting eggs at sites. After further evaluation some of these sites will be targeted for egg trap deployment for fall, 2011.

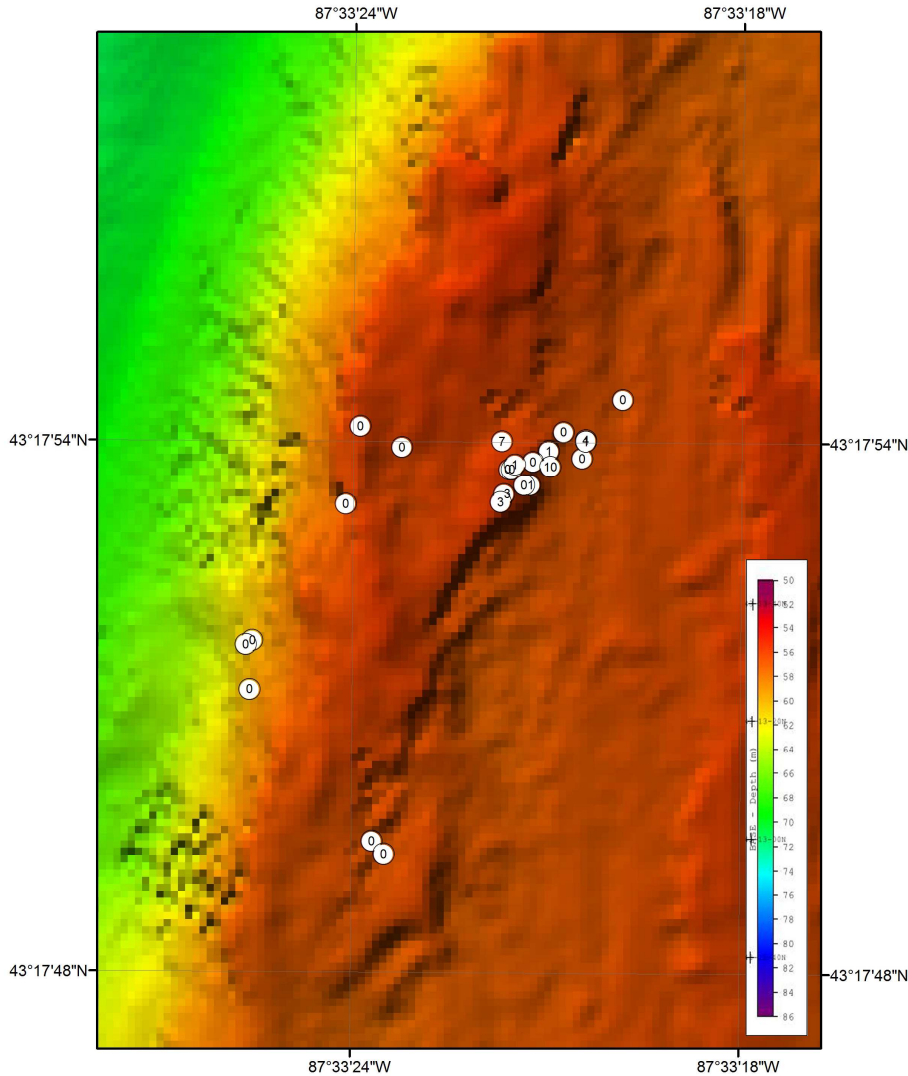


Figure 8. Bathymetry at the north end of Section A of Northeast Reef with results from ROV-based egg suction sampling in 2010. Circles indicate location of suction sampling events and numbers within the circles indicate the estimate of number of eggs collected. Lake trout sac fry were not seen via ROV at this site in spring, 2010. Further egg sampling was done in November 2010 but we have not yet plotted those data.

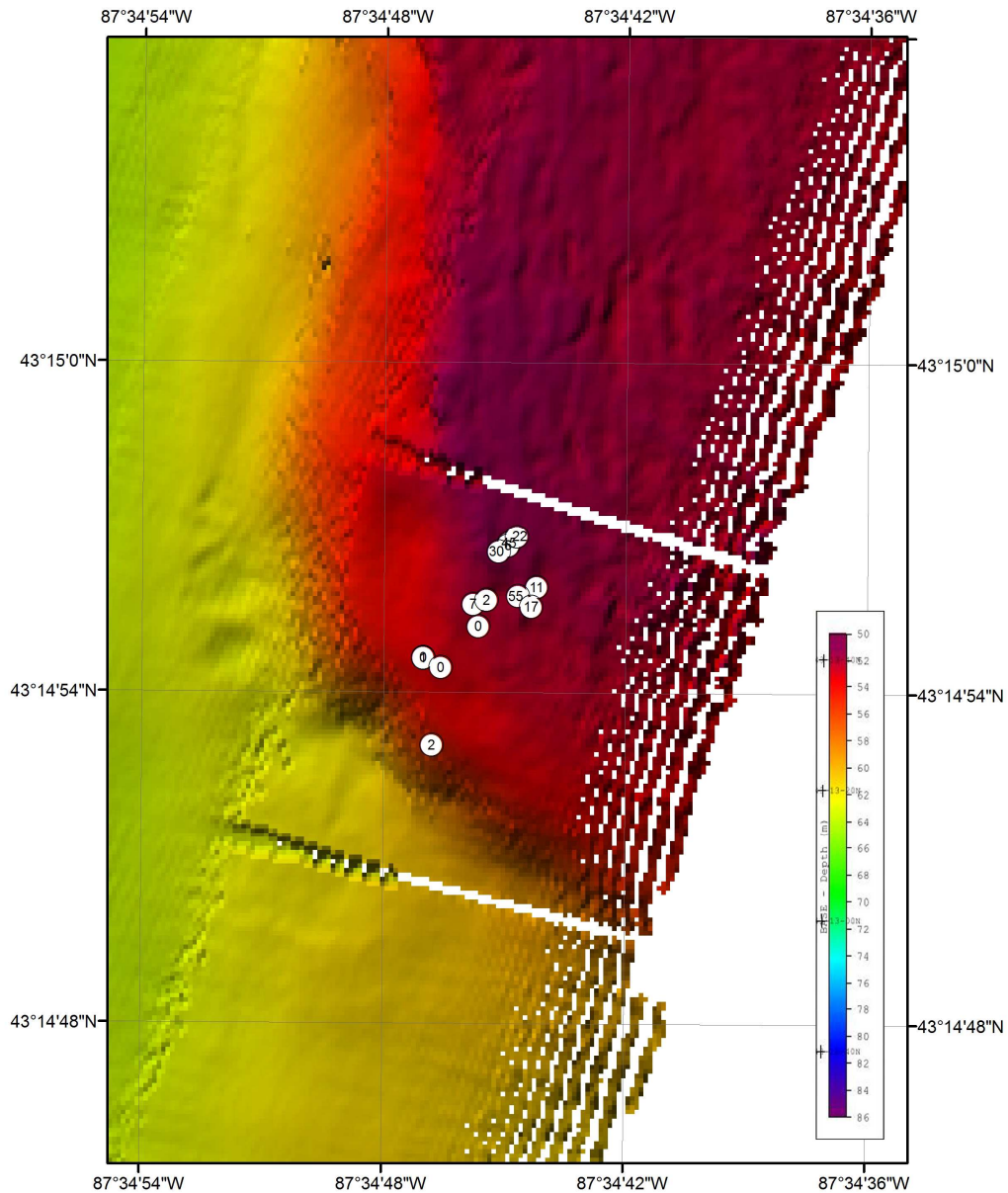


Figure 9. Bathymetry at the south end of Section A of Northeast Reef with results from ROV-based egg suction sampling. Circles indicate location of suction sampling events and numbers within the circles indicate the estimate of number of eggs collected. Video recordings are being reviewed to refine estimates. Lake trout sac fry were seen and captured via ROV at this site in spring, 2010. Further ROV-based egg sampling was done in November 2010 but we have not yet plotted those data. This is one of the sites sampled via deepwater egg traps in fall 2010.

OBJECTIVE 4. ROV BASED ELECTROSHOCKING FOR LAKE TROUT SAC FRY.

We sampled for lake trout sac fry via ROV-based electroshocking on five dates in 2010, and four dates in 2012. The video record for 2010 has been completely reviewed and that for 2012 has undergone a preliminary review.

Date	Approximate Latitude/Longitude	Visuals	Captures
28 April 2010	43 14.9 87 34.74	6	1
03 May 2010	43 13.3 87 35.00	2	1
05 May 2010	43 17.9 87 33.4	3	0
17 May 2010	43 14.9 87 34.8	8	4
24 May 2010	43 15.6 87 34.6	2	1
25 April 2012	43 15.1 87 34.7	5	1
3 May 2012	43 14.9 87 34.8	5	1
10 May 2012	43 16.9 87 34.3	8	2
15 May 2012	43 18.3 87 33.1	1	1

Our experience is that, during review of the video record, additional lake trout sac-fry are seen. We are encouraged that all of the sites where we found lake trout eggs deposited in fall, 2009 are producing sac-fry.

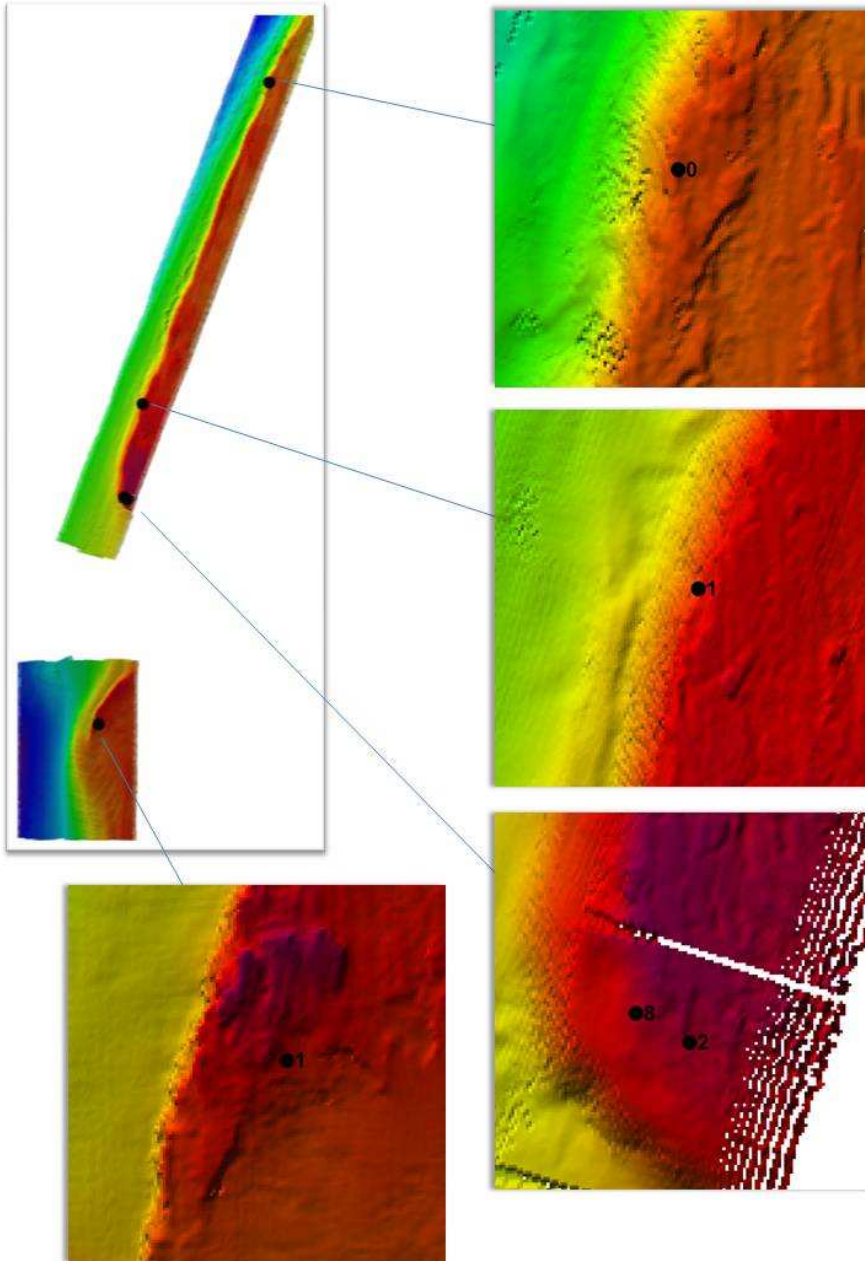


Fig. 11. Locations of lake trout sac-fry seen during ROV-based electroshocking

OBJECTIVE 5: BEAM TRAWLING FOR LAKE TROUT FRY

We beam trawled for post sac fry on two dates in 2010: June 21 and July 1. A total of 3 lake trout fry were captured with the latitude range being from 43 15.02 87 34.722 to 43 17.2 87 33.8. In 2012 we sampled on June 11 and 13 and collected only one fry. We sampled slightly earlier because temperature records indicated that Lake Michigan had an unusually warm winter.

0.001, also $r^2 = 0.759$, $P < 0.001$ for log-normalized data)) between the two sampling techniques. By the end of the project we will have several additional data points and will complete this assessment.

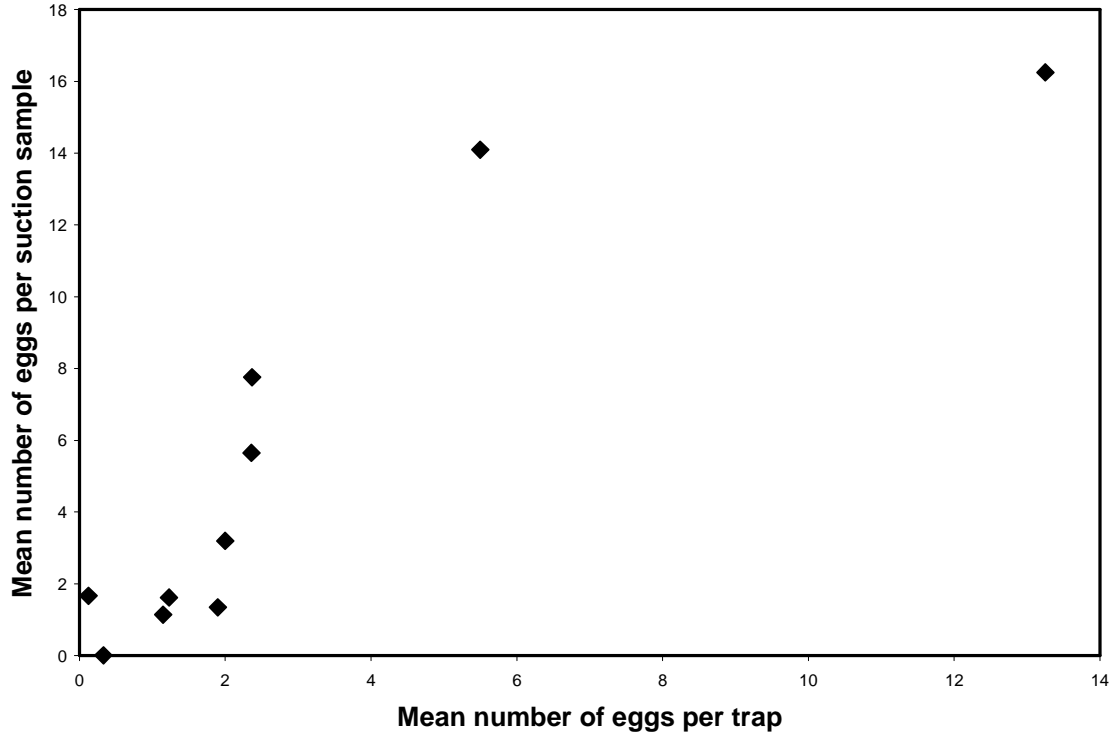
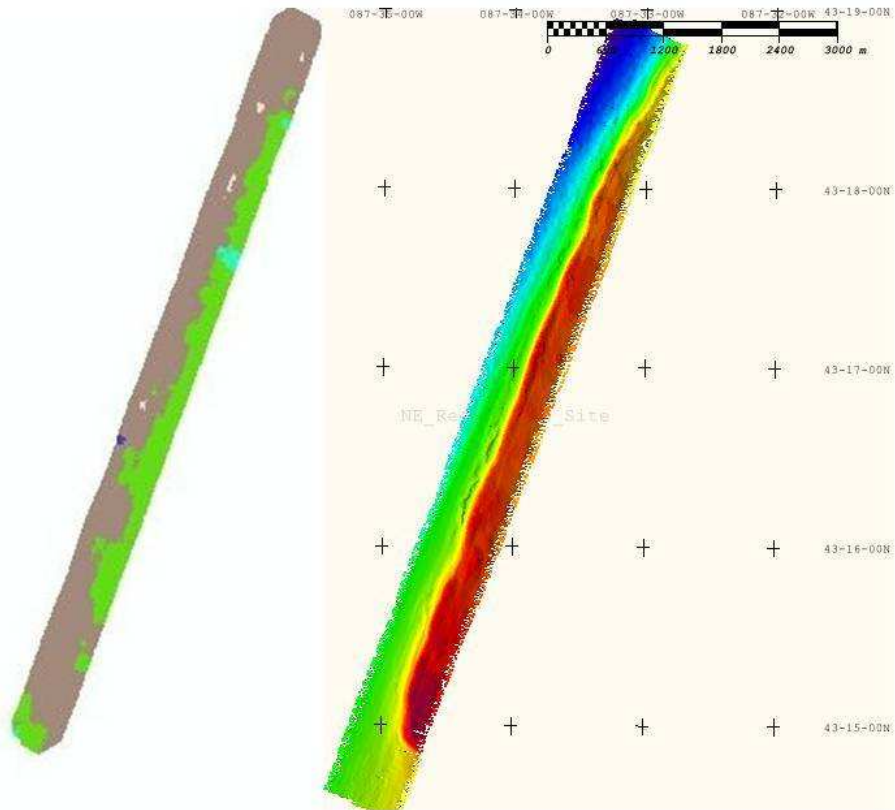


Fig. 13. Correlation between ROV-based suction sampling for lake trout eggs and deepwater egg trap catch. The Coefficient of Determination $r^2 = 0.784$ ($P < 0.001$) ($r^2 = 0.759$, $P < 0.001$ for log-normalized data) Current evidence indicates that the egg trap counts are quantitative, so the strong correlation indicates that ROV suction sampling success is a useful indicator of relative egg deposition.

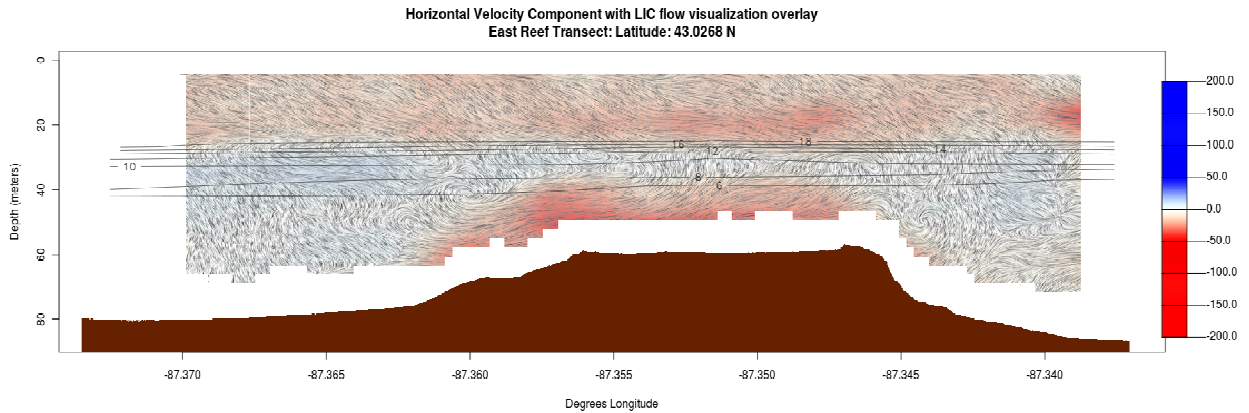
We find this result very useful for future research on deepwater reefs. While ROV-based sampling is much more equipment intensive, it does provide more rapid results and it is a more efficient means for searching for new spawning sites. In particular, for Lake Michigan there has been some discussion about stocking at deep water sites near Fox Island. We would recommend ROV-based preliminary location and assessment of spawning sites with subsequent ROV-based sampling when the lake trout are old enough to spawn.

ANCILLARY WORK

Nigel Wattrus, who produced the multibeam bathymetry maps, has been working on using that data for “seabed analysis,” which estimates substrate type. The images below combine the bathymetry (left side) and seabed analyses. The green is evidently sand/sand over rock and the tannish is more bare rock. The reader must excuse me it this makes little sense because I’m red-green color blind, but this modifies other aspects of my color vision. Wattrus and we will be fine tuning this based on ground-truthing, so this is very preliminary.



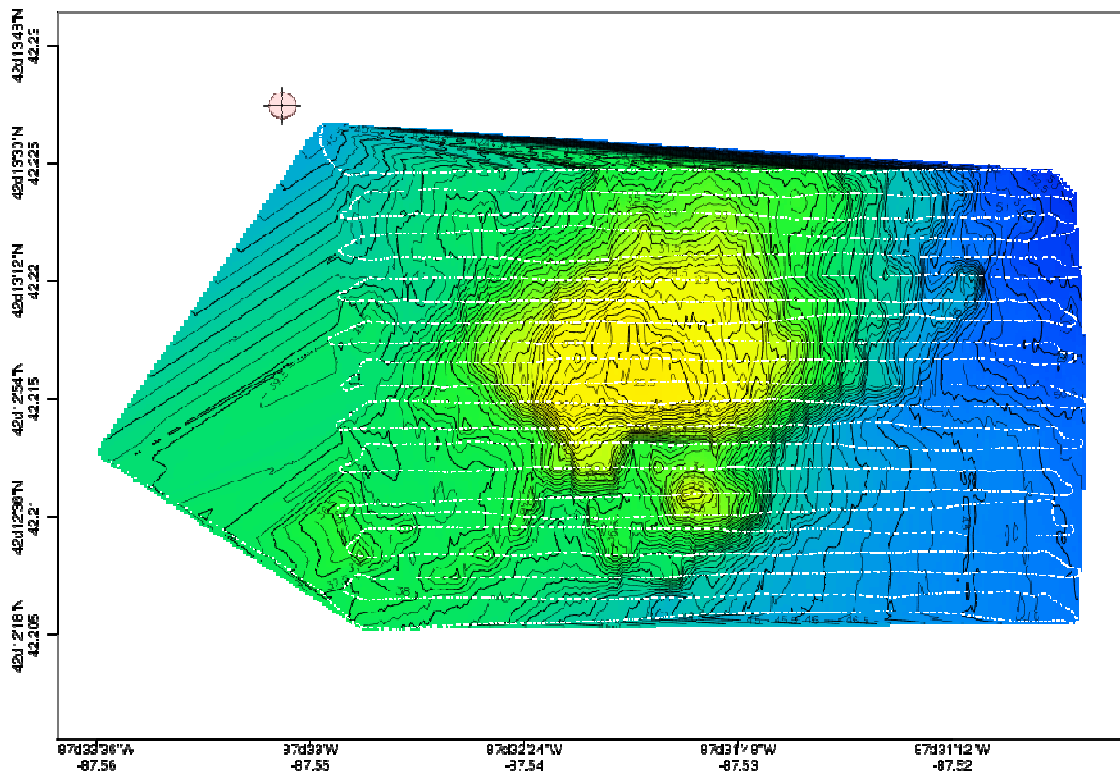
We have also been experimenting with an Acoustic Doppler Current Profiler (ADCP) to look at currents at the Mid-Lake Reefs. An example is shown below, but an animation is even better at showing the currents (<http://waterbase.uwm.edu/adp/>). For incubating lake trout eggs ventilation is essential for delivering oxygen and removing carbon dioxide and metabolic wastes. Once we have established “priority” spawning sites it would enhance our understanding of deepwater spawning sites to have measurements of currents. The example below shows that we are now capable of doing that.



ADCP measurements of currents at our likely best lake trout spawning site at East Reef, the southwestern most of the Mid-Lake Reefs. These are summer currents so this figure mainly illustrates our capability. But, it also shows that currents accelerate at the reef summit, a condition that will enhance ventilation of incubating lake trout eggs. For an animation please see: <http://waterbase.uwm.edu/adp/>

We modified the Illinois Natural History Survey’s bathymetry sonar system so that it can produce bathymetry maps. Below a map of Julian’s Reef, a site at which we first found deepwater lake trout eggs via ROV in 1995. We hope to re-visit the site in the future and expect to assist INHS adopt our deepwater technologies to better assess lake trout reproduction at Julian’s reef and at least one other small deepwater reef off of Illinois.

Bathymetry w. Heesky tracks



Bathymetry map of Julian's Reef, historically an important lake trout spawning reef in Illinois and currently a priority area for restoration of lake trout natural reproduction. Bathymetry data was collected using a conventional depthfinder sonar; mapping was done in real time. Courtesy of INHS.