Great Lakes Fish and Wildlife Restoration Act
Final Report

Project Title: Identifying Potential Lake Trout Spawning Habitat in Lake Erie

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Study Objectives

Lake trout (*Salvelinus namaycush*) are a species native to Lake Erie but were extirpated early in the 20th century due to a variety of factors including overfishing, lamprey predation, and pollution. Efforts to restore a viable population include increasingly intensive stocking efforts over the past 40 years (Markham et al. 2008). Despite these efforts, little to no natural reproduction is occurring. According to Markham et al. (2008), the lack of knowledge of known lake trout spawning areas has been identified as a major impediment to restoration efforts in Lake Erie and a critical need for the future.

In 2005, the Lake Erie Committee of the Great lakes Fish Commission called for a collaborative effort of the Coldwater Task Group (CWTG) and Habitat Task Group (HTG) to assess the quality, quantity and location of potential lake trout spawning habitat in Lake Erie. This would not only allow us to understand if habitat is limiting lake trout production but could also direct stocking efforts over prime habitat, because these fish are believed to undergo natal homing. Based on existing literature from other lakes (Edsall et al. 1992; Edsall and Kennedy 1995; Fitzsimons 1995; Gunn 1995; Marsden et al. 1995) and from Lake Erie (Fitzsimons and Williston 2000), areas most suitable for lake trout spawning consist of: steep slopes (>8%), surfaces with deep interstices (~30 cm), coarse, loose substrates (e.g., boulders cobble), and moderate wave activity or bottom currents that remove fine sediments. Using this information, the HTG/CWTG developed a GIS model to locate potential habitat and created a list of priority sites at which to test the predictive model by collecting fine-scale habitat information.

To address these research needs, we used the following approach:

1. Collect field data from historical and potential lake trout spawning areas in Lake Erie using sidescan sonar, RoxAnn™ seabed classification system, underwater video, and sediment sampling to validate and update the HTG's GIS model and confirm environmental characteristics of historical and potential lake trout spawning areas. Review of habitat characteristics at historical spawning sites from the literature. Apply the HTG GIS model to the eastern and central Basins of Lake Erie to confirm suitability of reported historical spawning sites and to identify potential new spawning habitat sites.

2. Identify areas of potential spawning habitat based on the presence or absence of environmental characteristics similar to those associated with historical lake trout spawning sites in Lake Erie (or from other lakes) using our acquired side-scan sonar, RoxAnn™, underwater video, and lakebed substrate sample data. Use these data to identify and prioritize potential high-quality lake trout stocking sites in Lake Erie.

3. Develop preliminary linkages and connections between potential lake trout spawning and nursery habitats by analyzing seasonal nearshore and open-lake water circulation patterns. Following identification of high-priority potential lake trout spawning sites, we wanted to utilize existing data and expertise to evaluate current flow and circulation patterns that link potential spawning sites to nursery habitats. More extensive analyses and modeling work, while ultimately necessary for assessing connectivity of spawning and rearing habitat, is beyond the scope of the proposed project.

Description of Tasks

Task 1 Conduct Substrate surveys using Sidescan sonar, RoxAnn™ and underwater video.

We used several different types of tools to assess potential lake trout spawning habitat across multiple spatial scales (Figure 1). Information collected at the lowest resolution covers the greatest extent. High resolution data collection provides more detailed information but covers a smaller extent due to increases in collection and processing time. We selected the study sites using a predictive GIS model at the broadest scale. At a more detailed level, we employed RoxAnn™, which is an acoustic seabed classification system that uses information from attributes of the first and second return echoes of a single beam sonar pulse. This backscatter information provided indications of substrate roughness and hardness. Sidescan sonar provided images of acoustic reflectivity created by backscatter from surficial features and objects at the sediment-water interface. Reflected acoustic energy (backscatter) is received and processed by the tool in order to provide a continuous acoustic image or "map" of the bottom. The most detailed information was collected using drop cameras and/or video cameras. These cameras were used to validate substrate composition and structure. Lakebed areas with a specific backscatter response and/or substrate contacts can be readily examined by digitally recording underwater video data along drift transects. Environmental characteristics such as grain size (boulder, cobble, gravel, and bedrock), interstitial spaces, presence or absence of fine-grained sediments (sand, silt, and clay), sedimentary structures indicative of flow conditions; and encrustation by invasive species were evaluated using underwater video data at some locations. Bottom samples were also taken to verify texture and composition and to confirm materials observed in the underwater video.

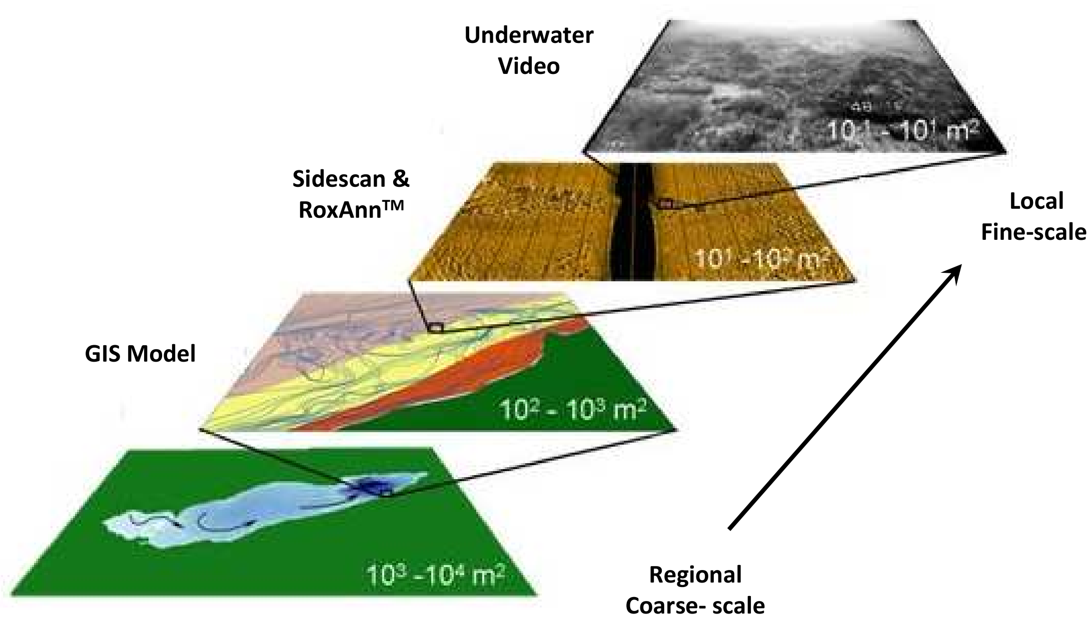

Figure 1. Multiscalar habitat assessment of lake trout spawning habitats in Lake Erie.

The extent of the Sidescan and RoxAnn™ surveys and corresponding underwater video conducted in the East Basin of Lake Erie are summarized in Tables 1 and 2, respectively. Between 2007 and 2009, we collected almost 630 line km (340 line nm) of sidescan data, which covered over 75 km^2 of potential habitat. RoxAnn™ surveys totaled almost 79 km^2 or 500 line km (270 line nm). Figure 2 depicts all sites sampled including those on the North Shore that were funded in a concurrent project using Canada-Ontario Agreement (COA) monies.

Table 1. Sidescan sonar surveys conducted over potential lake trout spawning habitat in the eastern basin of Lake Erie.

Site	Year	Line km (nm)	Area (km^2)	Range (m)	UW Video
Brocton Shoal	2007	43.6 (23.8)	Recon	200	Yes
Brocton Shoal	2007	21.5 (11.6)	2.47	75	Yes
Brocton Shoal	2009	71.5 (38.6)	10.37	100	Yes
Brocton Shoal	2009	56.7 (30.6)	2.17	50	Yes
Long Point Ridge	2009	261.2 (141.0)	31.88	100	No
Clear Creek Ridge	2009	136.8 (73.9)	23.67	100	No
Presque Isle East	2009	37.8 (20.4)	4.53	75	No

Table 2. RoxAnn™ surveys conducted over potential lake trout spawning habitat in the eastern basin of Lake Erie.

Site	Year	Line km (nm)	Area (km^2)	Line Spacing (m)	UW Video
Brocton	2008	128.0 (69.1)	12.6	200	Yes
Long Point & Clear Creek Ridges	2009	307.0 (165.8)	60.0	200	Yes
Presque Isle Knob	2009	63.4 (34.3)	6.1	200	Yes

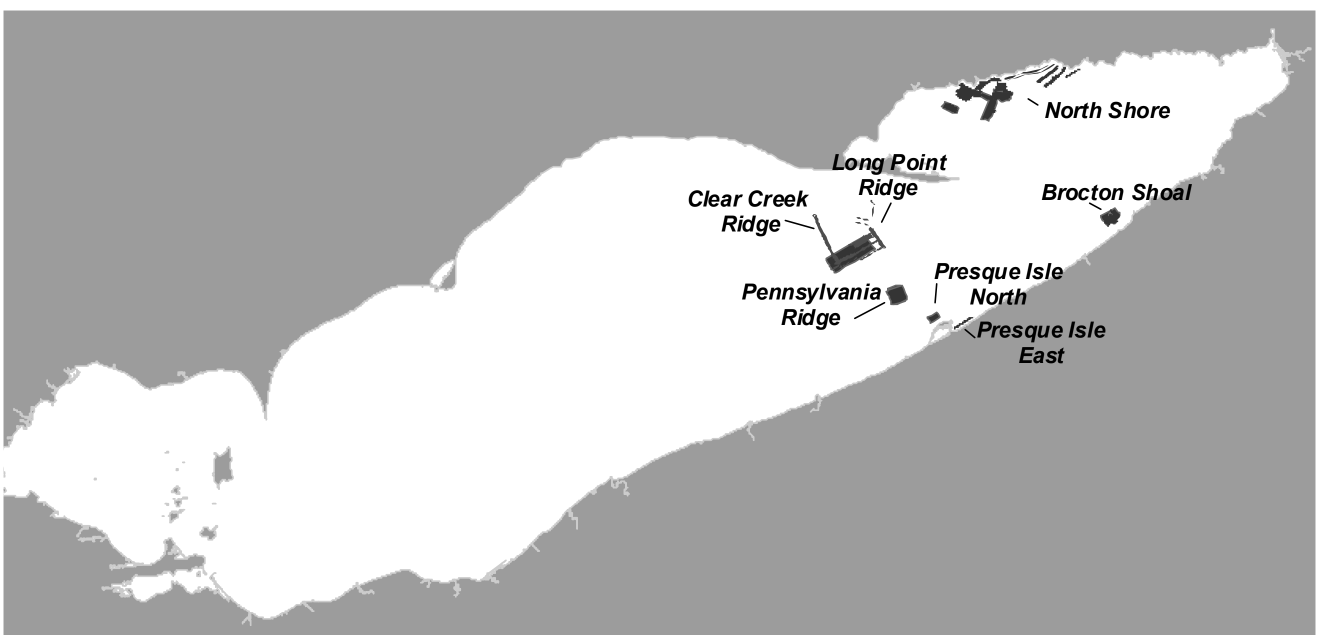

Figure 2. RoxAnn™, sidescan sonar, and underwater video surveys of potential lake trout spawning habitat were conducted in the East Basin of Lake Erie.

Task 2 Develop habitat classification schemes

The information that can be derived using each of the three survey techniques differs. RoxAnn™ results in values that can be used to determine substrate hardness and roughness. Principal components analysis, or other clustering techniques, can be used to separate these values into different classes. These classes are then assigned a substrate category based on information from underwater videos and Ponar samples. The resulting data from sidescan sonar are geo-referenced images that can be mosaicked and immediately brought into a GIS. Habitat areas are delineated based on visual interpretation of the imagery. Underwater video can then be used to inform the other two techniques. In addition, the video is useful for detecting other environmental factors that cannot be detected by the RoxAnn™ or sidescan. At these sites, this includes macrophytes and invasive dreissenids.

In December 2009, we formulated a habitat classification scheme for the underwater video. Habitat was classified according to the following:

- Percent bottom composition of fines (silt or clay), sand, cobble, boulder, bedrock, dreissenid shells, floc, and gravel
- Presence of material that gives an indication of the energy flow in the area (i.e. physical descriptions of sand waves, druse balls)
- Presence of substances that could affect fish distribution (i.e. continuous gas stream, non-continuous gas stream from soft substrate)
- Presence of invasives (i.e. attached and unattached filamentous algae, dreissenids, round gobies)

An undergraduate student from Oberlin College (OH), Joshua Morse, assisted in the development of this methodology and applied it to portions of the North shore video during a one-month Winter Term Project in January 2010. He also gave an oral presentation about this work at the 2010 IAGLR meeting. Morse has completed sections on the North shore and will continue with the Presque Isle and Brocton sites in January 2011. Upon completion, this database will be used as a GIS overlay to validate the categorization of the roughness-hardness coefficients of the RoxAnn™ dataset.

Task 3 Summarize the habitat assessments

Brocton Shoal Complex (Figure 3): This site was selected because it is one of three historic spawning locations for lake trout in the U.S. waters of Lake Erie (Goodyear et al. 1982). Brocton Shoal is one of the prime reference sites and has been the focus of extensive lake trout stocking and continued monitoring efforts by the NYSDEC for many years. In the late 1980's, Edsall et al. (1992) used sidescan sonar to map the distribution of substrates and described abundant clean, cobble substrate with deep interstitial spaces on based on underwater video data from Brocton Shoal. The area surveyed by Edsall et al. (1992) was located over the largest and most significant bathymetric high at Brocton Shoal. In preparation for the GLFWRA study, additional sidescan sonar and underwater video data were

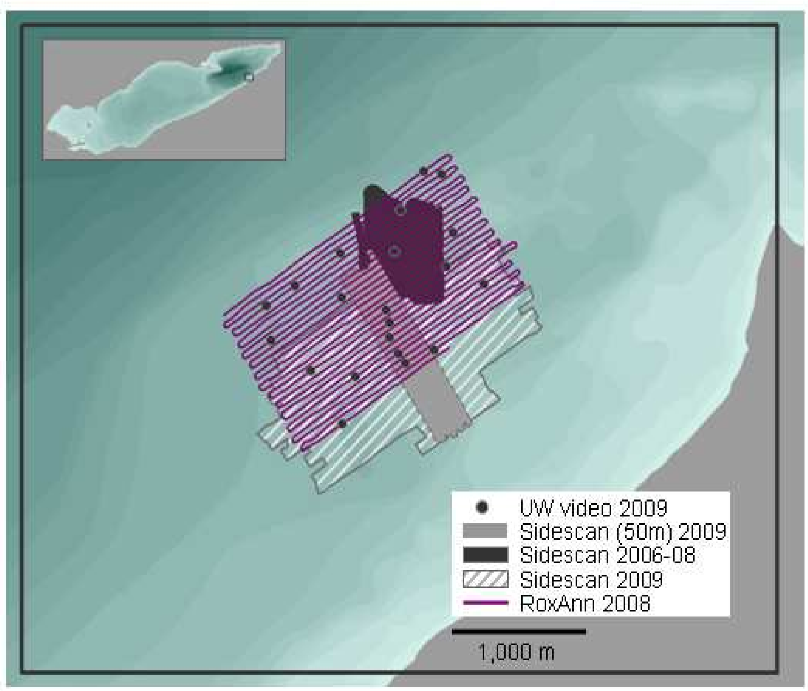

Figure 3. Habitat assessments at historic lake trout spawning grounds in Brocton Shoal, NY.

collected in 2007 over the Edsall study site to evaluate the use of newer sidescan sonar technologies for habitat mapping. In 2008, Environment Canada acquired RoxAnn™ and underwater video data (as in-kind match) to compare the RoxAnn™ data with earlier sidescan sonar data. Initial interpretation of the sidescan sonar surveys showed sparsely distributed areas of suitably-sized cobble-boulder substrate distributed either in relatively small rock piles (10 m^2 - 5000 m^2) or long sinuous narrow cobble-boulder ridges. There were, however, indications of potentially suitable habitat at the edge of the southwestern portion of the shoal (outside the historic study area).

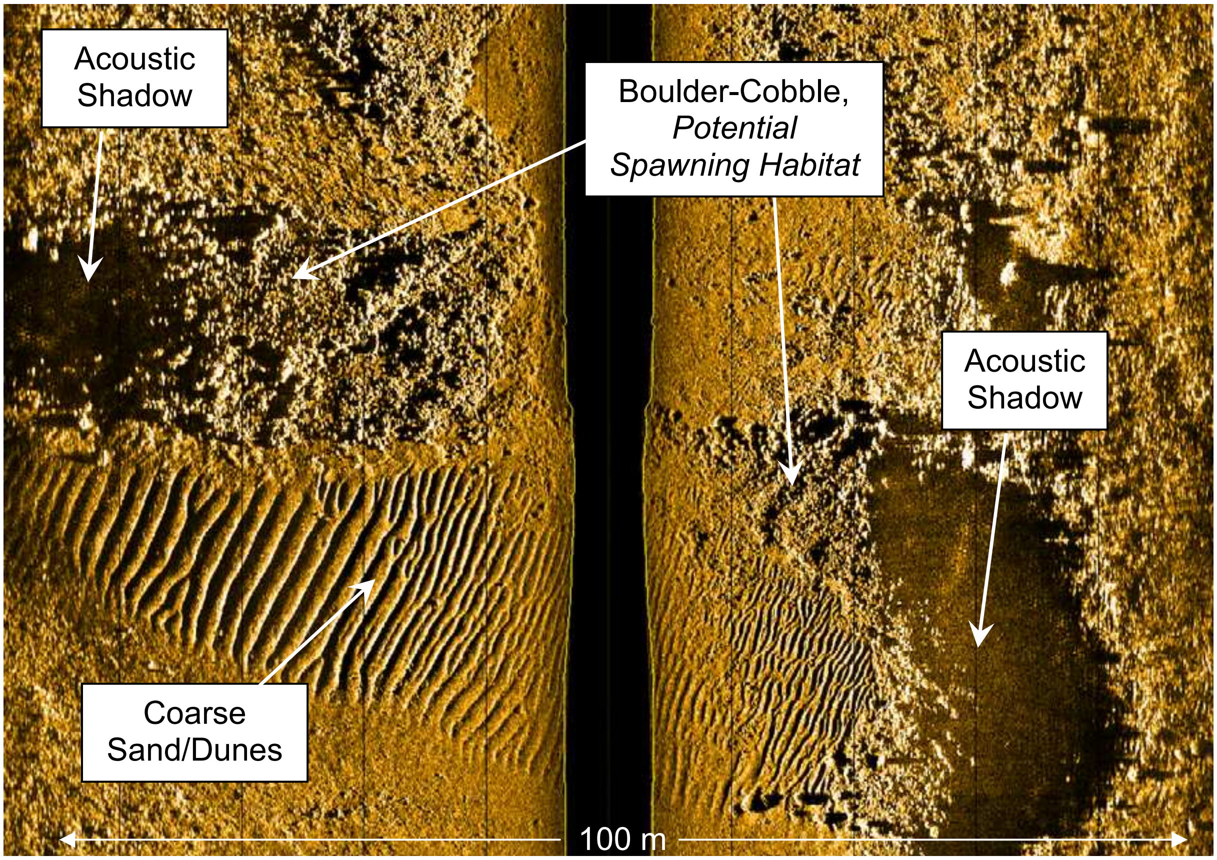

Figure 4. Brocton Shoal sidescan sonar image. Lakebed consists of multiple long sinuous boulder-cobble ridges (upper left and center), bedrock scarps with associated boulder-cobble debris (center right), boulder-cobble rock piles, and sand deposits with large-scale dune forms (left center). Distance between reference lines is 10m. Image width is 100m.

In the spring of 2009, a more detailed sidescan sonar survey was completed over Brocton Shoal, including the area south and west of the Edsall study site. Within this survey area, an extensive complex of sinuous cobble-boulder ridges and rock piles was discovered across the bathymetric saddle south of the main Brocton Shoal high (Figure 4). This area contains a complex pattern of long sinuous cobble-boulder ridges, bedrock scarps and scarp debris, and boulder-cobble rock piles. Many of these ridges exhibit physical characteristics suitable for lake trout spawning habitat. Of the entire area surveyed with sidescan across years at Brocton (12.2 km^2), the majority of the substrate was coarse sand-cobble (68%) and bedrock (23%; Table 3 and Figure 5). Although the classification is conducted somewhat differently for the RoxAnn™ data, the result is similar such that the dominant substrate type consists of a sand-cobble mix, followed by bedrock (Table 4).

Table 3. Results of habitat and substrate assessments using sidescan sonar at Brocton Shoal.

Substrate	Overlying Habitat	Area (m^2)	% Area
Fine-Medium Sand & Boulder Cobble Debris	Boulder Cobble Pile	6	<0.01
Bedrock Blocks and Fractured Bedrock & Boulder Cobble Debris		8	<0.01
Coarse Sand-Cobble & Boulder Cobble Debris	Boulder Cobble Pile	49	<0.01
Fine-Medium Sand & Coarse Sand-Cobble		13189	0.11
Bedrock Blocks and Fractured Bedrock & Boulder Cobble Debris		33211	0.27
Coarse Sand-Cobble & Boulder Cobble Debris		51641	0.42
Coarse Sand-Cobble	Boulder Cobble Pile	146928	1.20
Fine-Medium Sand		887590	7.26
Bedrock Blocks and Fractured Bedrock		2831219	23.15
Coarse Sand-Cobble		8265412	67.59

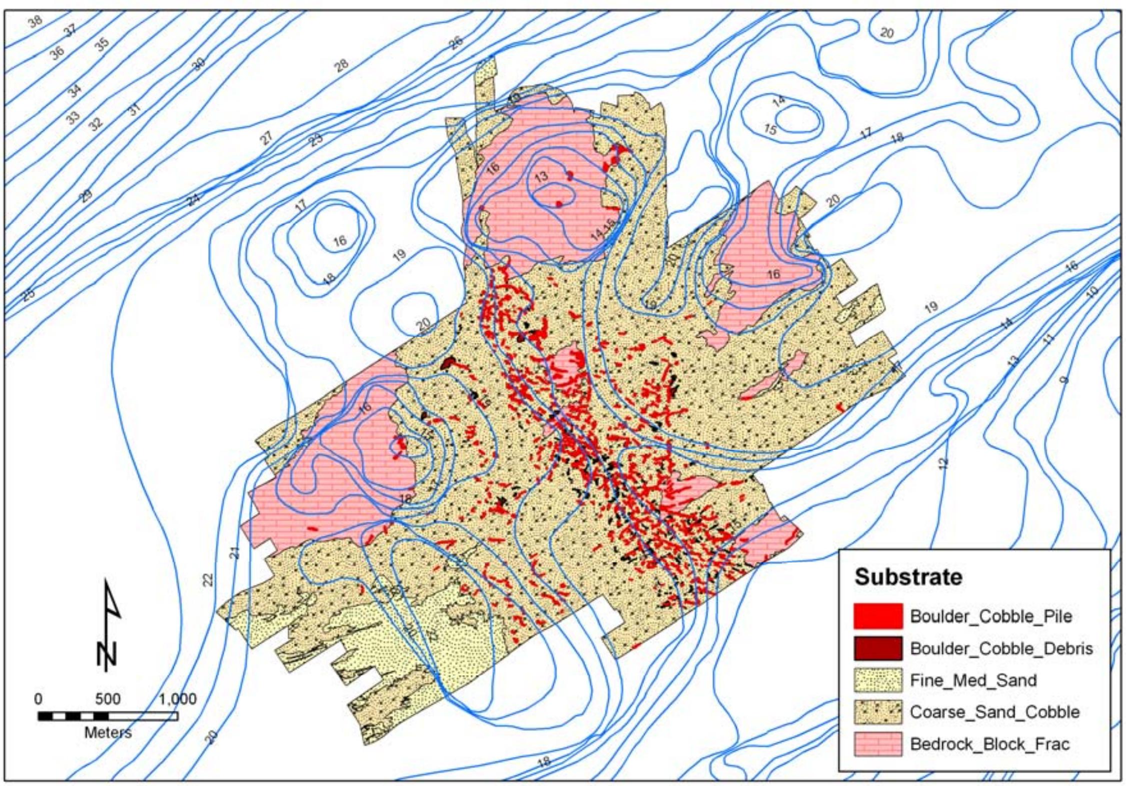

Figure 5. Substrate and habitat interpretations from sidescan sonar surveys at Brocton Shoal, NY.

Table 4. Results of substrate assessments using RoxAnn™ at Brocton Shoal.

Substrate	Area (m^2)	% Area
Silty-sand to Sand	430950	3.6
Unknown	2243600	18.5
Bedrock	3085250	25.5
Cobble sand-silt mix	6362475	52.5

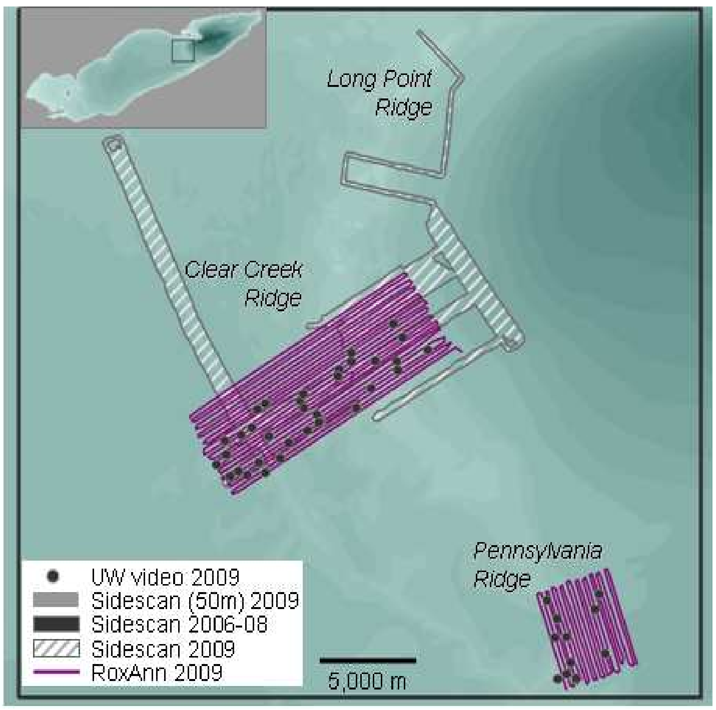

Figure 6. Habitat assessments of the Long Point, Clear Creek, and Pennsylvania Ridge Complex.

Long Point, Clear Creek, and Pennsylvania Ridge Complex (Figure 6): Sidescan sonar and additional RoxAnn™ data were acquired from the Long Point, Clear Creek, and Pennsylvania Ridges in 2009. These sites were selected because they represent a major north-south trending bathymetric feature that separates the central and eastern basins of Lake Erie and may be underlain by bedrock and/or glacial deposits, which may serve as potential spawning substrate. Analysis of the 1-m NOAA bathymetry indicated several areas with suitably steep (>5%) slopes and similar bathymetric heterogeneity analogous to the Brocton Shoal reference site. Moreover, exposure to high-energy storm events and strong currents may increase the potential for coarse-grained substrates that may be suitable as potential spawning habitat. The Ridge is also located in close proximity to potential deepwater lake trout nursery habitat in the eastern basin of Lake Erie.

In 2009, RoxAnn™ and underwater video surveys were conducted on all three Ridges and Presque Isle Knob (Figures 6 and 9). The Pennsylvania Ridge and the Presque Isle Knob sites were predominantly covered in sand. Due to the lack of suitable habitat found in the RoxAnn™ survey, a decision was made not to collect sidescan sonar data from the Pennsylvania Ridge and the Presque Isle Knob sites.

In 2009, sidescan sonar surveys were completed over the Clear Creek and Long Point Ridges. The sidescan sonar data confirmed what the RoxAnn™ data showed - most of the Clear Creek and Long Point Ridges are also composed of highly mobile sand and fine gravel substrates (Figure 7). At Long Point Ridge (Table 5), there are cohesive materials and coarse gravel and cobble lag deposits as well. Coarse sand sheets with dune forms and/or megaripples were also detected. Those deposits are somewhat limited in areal extent. Within the northeast portion of the area surveyed, there are elongate ridges of highly reflective material which were initially thought to be ridges of coarse sand. However, after closer examination, many of these features appear to have smooth surfaces (no dune forms or megaripples) and do not have the characteristic edges typically associated with migrating sand waves. These areas may be cohesive material (possibly clay till) exposed between extensive deposits of coarse sand and gravel, but further examination of underwater video is necessary. There are many (several hundred) of these elongate features exposed on the east flank of the Ridge. The distribution of these features varies, but in general the numbers increase as you descend the east flank of the Ridge. The coarse nature of cobble lag deposits to the southeast is one of the reasons why we decided to acquire additional data to east of our initial survey location (i.e. the north-south oriented lines) when we were in the field. Unfortunately, further examination did not reveal any characteristics suitable as potential lake trout spawning habitat. Clear Creek Ridge had similar substrate composition to Long Point Ridge (Table 6 and Figure 8). There were, however, limited areas of boulder-cobble substrates on the southern portion of Clear Creek Ridge, which may be suitable for spawning lake trout.

RoxAnn^{TM} surveys showed that most areas of Clear Creek and Long Point Ridges were comprised of highly mobile sand and fine gravel substrates (Table 7). Well-defined sand-ridges (~ 20 cm high) at depths of 17-20 m and the absence of dreissenids on the scattered gravel deposits indicate that the western and central portions of the ridge complex are high energy areas. The sidescan and RoxAnn results differed somewhat at these Ridges. The sidescan detected some of the gravel, clay and boulder substrates that RoxAnn^{TM} did not.

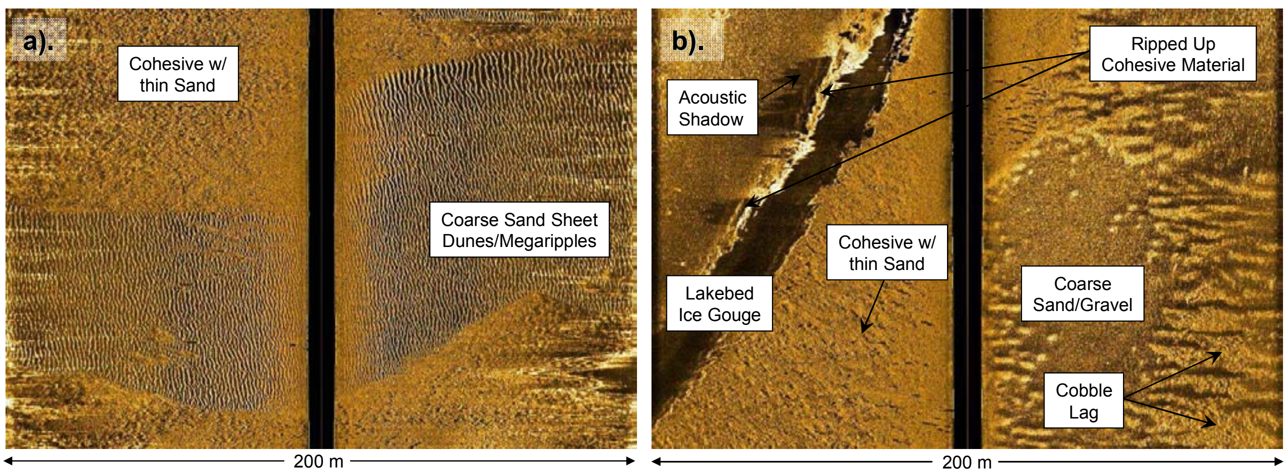

Figure 7. Sidescan sonar images demonstrating: the predominant sand substrate and sand veneer overlaying cohesive material at Clear Creek Ridge (a) and the cohesive bedsurface being exposed at the edges of an ice gouge at Long Point Ridge (b).

Table 5. Results of habitat and substrate assessments using sidescan sonar at Long Point Ridge.

Substrate	Area (m^2)	% Area
Cohesive clay	310490	1.1
Coarse sand sheet dunes	512332	1.8
Sand, cohesive clay, cobble lag	2826545	10.2
Coarse sand-gravel, cohesive ridges	3179385	11.5
Coarse sand-gravel, patchy cohesive	5229681	18.9
Medium coarse sand-gravel	15677546	56.5

Table 6. Results of habitat and substrate assessments using sidescan sonar at Clear Creek Ridge.

Substrate	Area (m^2)	% Area
Boulder, cobble	8335	0.07
Fine to medium sand	505021	4.04
Cohesive clay, cobble lag	985571	7.89
Coarse sand sheet dunes	1018179	8.15
Cohesive clay, coarse sand	2402916	19.23
Coarse sand, gravel, cobble	7572606	60.60

Table 7. Results of substrate assessments using RoxAnn™ across Long Point and Clear Creek ridges.

Substrate	Area (m^2)	% Area
Well-defined dunes -coarse mix	7226725	13
Coarse non-consolidated sand	7715150	13
Gravel, sand, shell mix – shallow	15633750	27
Shallow variegated sand waves	26665075	47

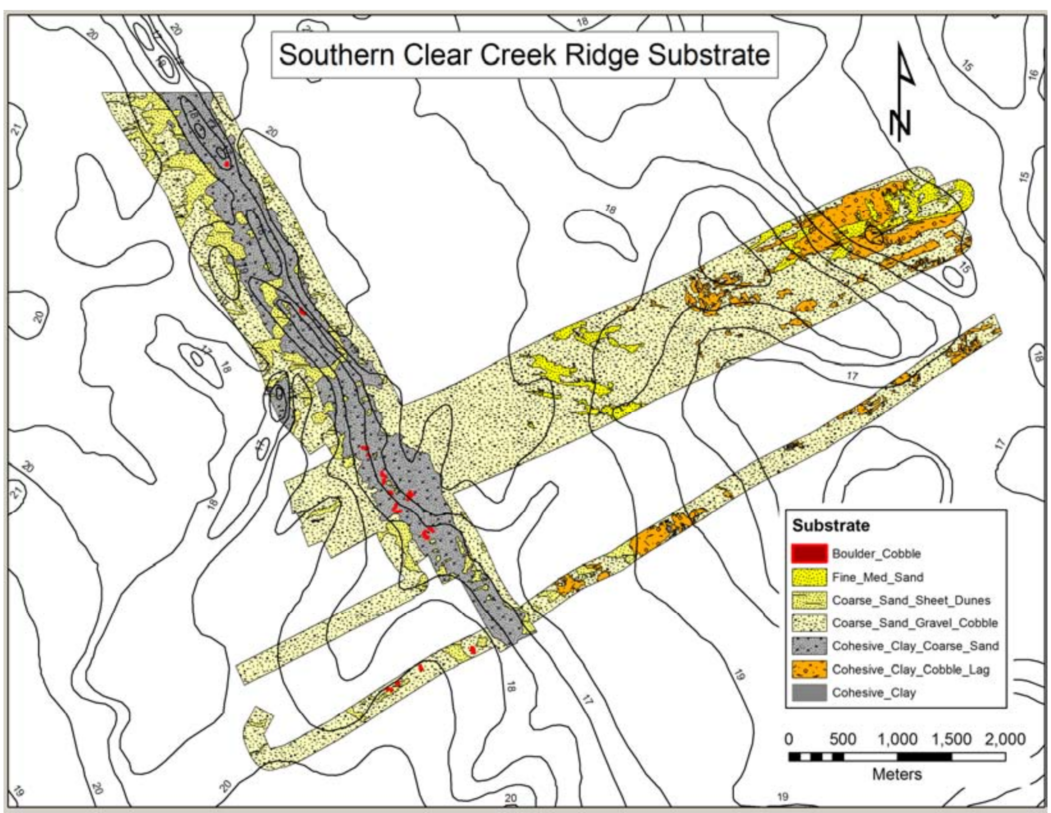

Figure 8. Substrate and habitat interpretations from sidescan sonar surveys at Clear Creek Ridge.

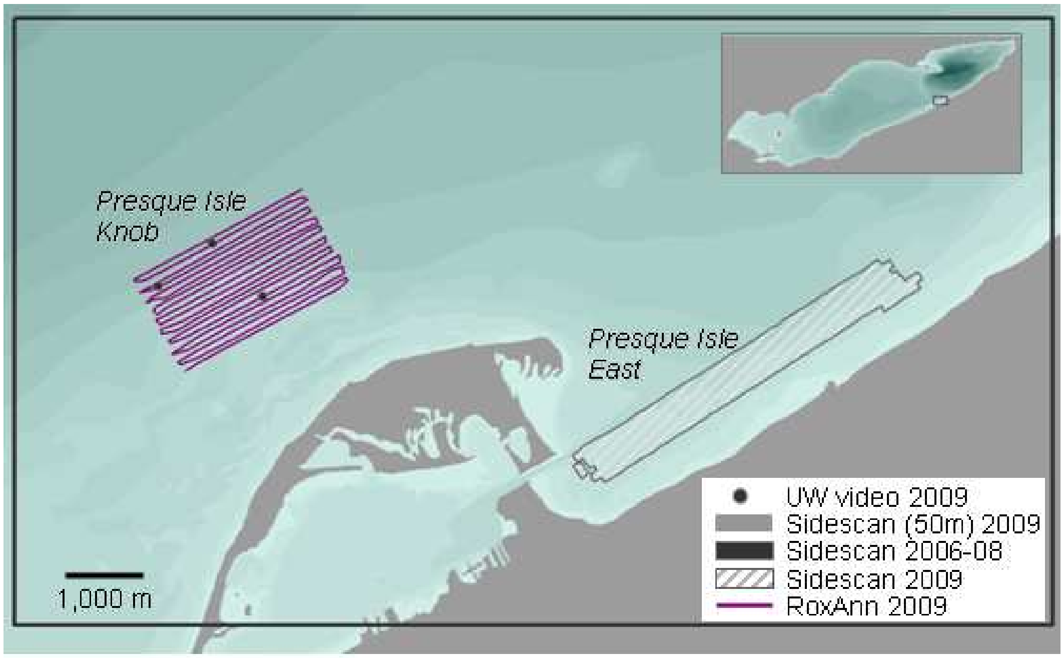

Figure 9. Habitat assessments at Presque Isle, PA.

Presque Isle East (Figure 9): During the 2009 field season, we became aware of a survey by the PA Department of Environmental Protection (PA DEP) that was conducted annually in the fall to collect lake trout for contaminant analysis. After several discussions with PA DEP biologist Jim Grazio, we surveyed the south end of the Presque Isle channel entrance in late November 2009 using sidescan sonar. We included locations where large numbers of spawning condition lake trout were observed (and collected) by PA DEP. From the sidescan survey, the predominant substrate classes at this site were sand (52%), stepped bedrock (39%), and to a lesser degree, fractured bedrock (8%, Figure 10 and Table 8).

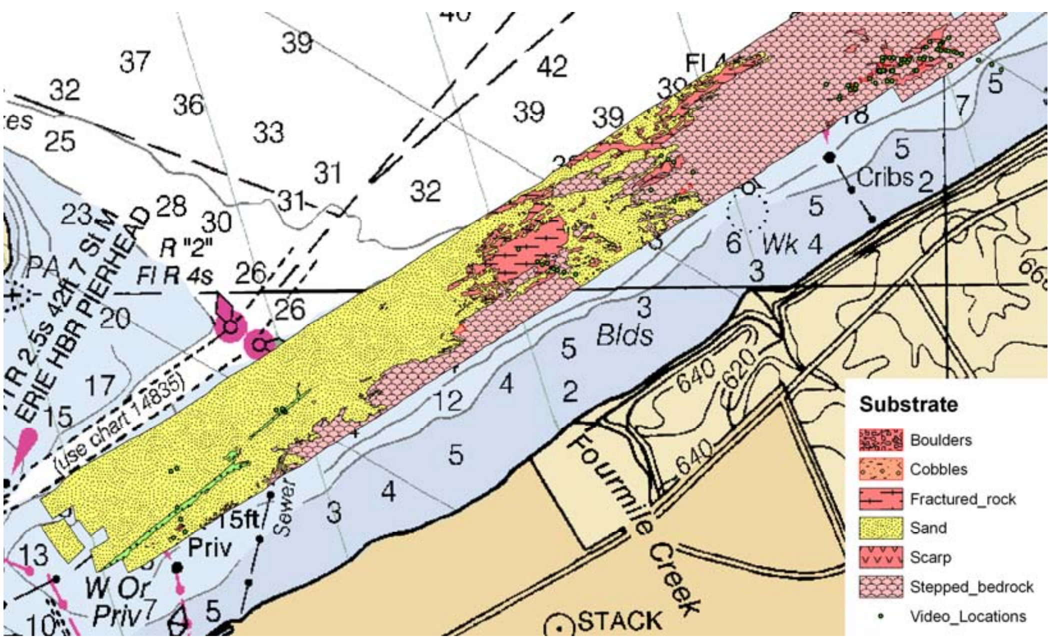

Figure 10. Substrate and habitat interpretations from sidescan sonar surveys at the Presque Isle East survey site.

Table 8. Results of habitat and substrate assessments using sidescan sonar at Presque Isle East.

Substrate	Overlying Habitat	Area (m^2)	% Area
Sand	Cobble	219	<0.01
Stepped bedrock	Cobble	2883	0.06
Boulders		8009	0.17
Stepped bedrock	Scarp	14172	0.31
Rock armoring stone cover		44877	0.98
Fractured rock		365824	7.99
Stepped bedrock		1779380	38.85
Sand		2364422	51.63

Task 4 Identifying potential lake trout spawning habitat

Brocton Shoal (Figure 11) : As previously mentioned, our first attempt at surveying lake trout spawning habitat in 2007 with sidescan sonar at Brocton Shoal resulted in a mere 0.94% of the total area covered in boulder-cobble piles (1 structure for every 21,800 m^2). The highest density of these piles was at the southern portion of this survey. In 2009, we extended the survey to include these southerly areas and found that 1.64% of the new survey was covered with boulder-cobble piles (1 structure for every 5,000 m^2). We found that 73% of these (N=406) were located on the main ridge running through the study area.

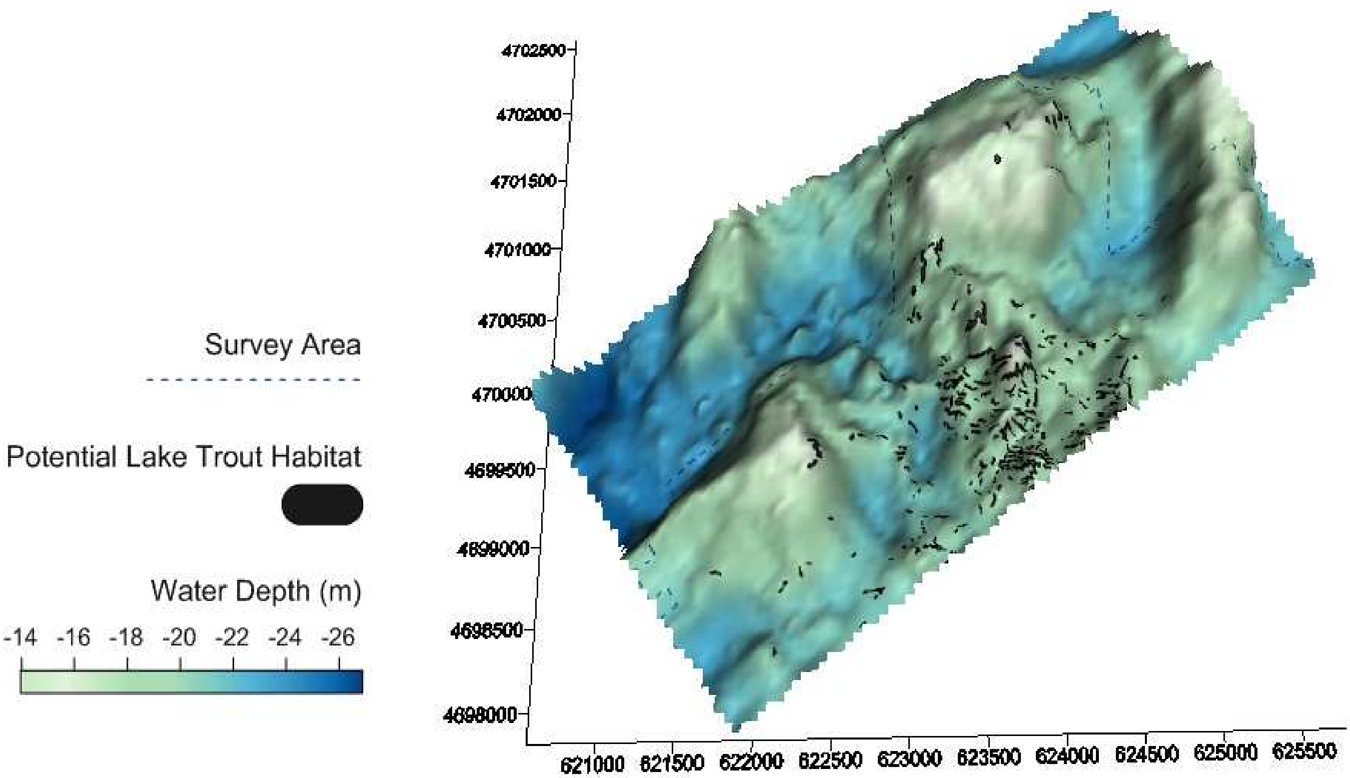

Figure 11. Distribution of potential lake trout spawning substrate at Brocton Shoal, NY. Coordinates are in UTM Zone 17N NAD83.

On average, these boulder-cobble structures were 325 m^2 (Figure 12). Based on minimum bounding regions (MBR; Frye 2008), piles averaged 44 m in length and 14 m in width (Figure 13). When we compare the depths at which boulder-cobble piles were present, we found that the area of boulder-cobble piles located at depths of 16-17 meters was greater than the proportion of area available in the survey area (Figure 14). Using the 'Calculate Distance Band from Neighbor Counts' function in ArcToolbox (ESRI 1999-2008), we calculated the distance between centroids of these boulder-cobble features and found the average distance between features was 74 m (range 10-919 m). In the densest area, the average distance between features was 57 m.

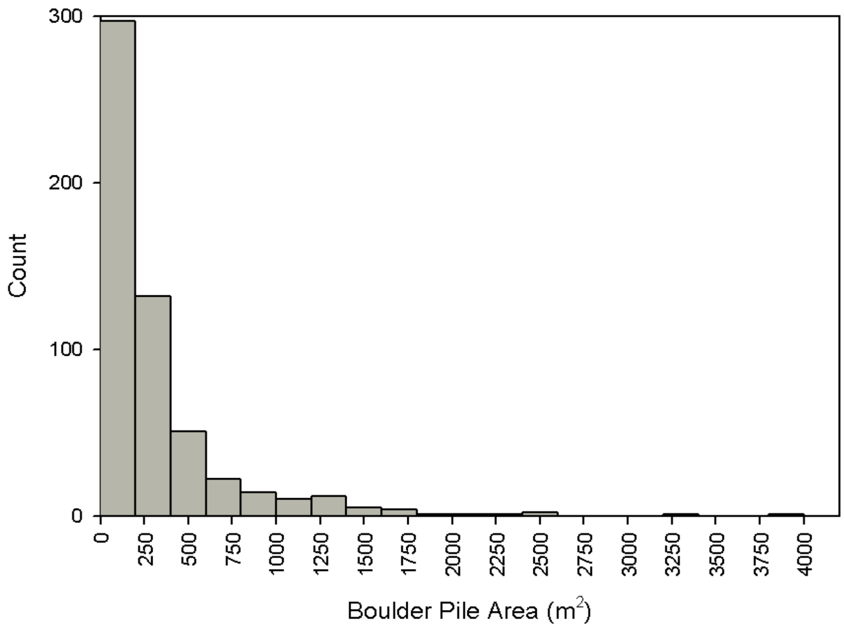

Figure 12. Frequency distribution of potential lake trout habitat by feature size (i.e. area expressed in m^2) at Brocton Shoal, NY.

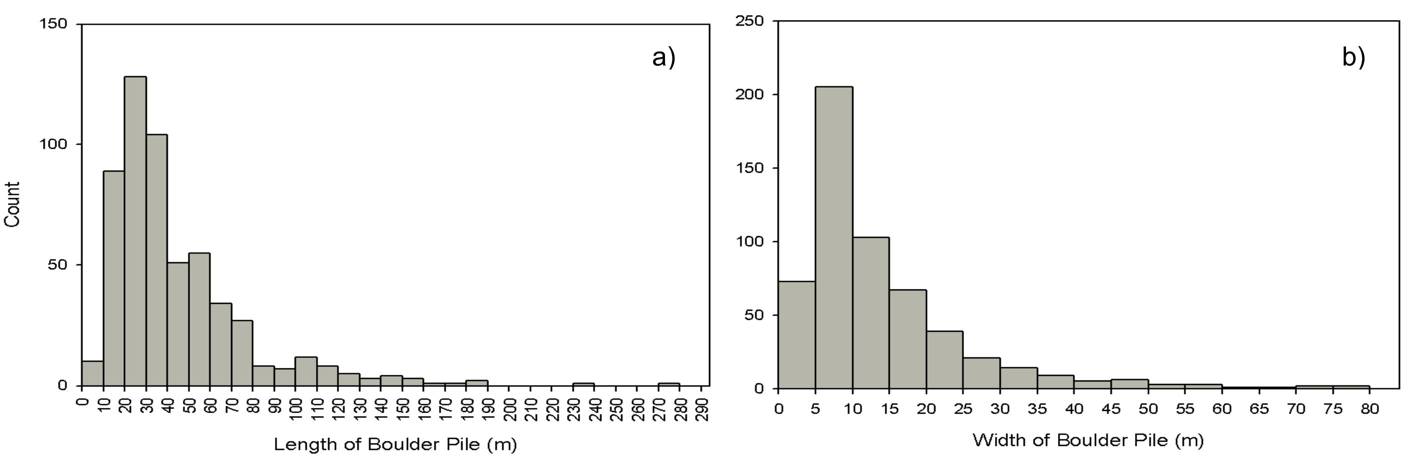

Figure 13. Frequency distribution of potential lake trout habitat by feature a). length and b). width derived from minimum bounding regions at Brocton Shoal, NY.

We also found that these boulder-cobble features are four times more likely to be found over coarse sand-cobble substrates than over bedrock substrates at Brocton Shoal according to the sidescan classification. When overlaid with the RoxAnn™ substrate classes, over 98% of boulder-cobble features are found over the cobble sand-silt mix classification (Figure 15).

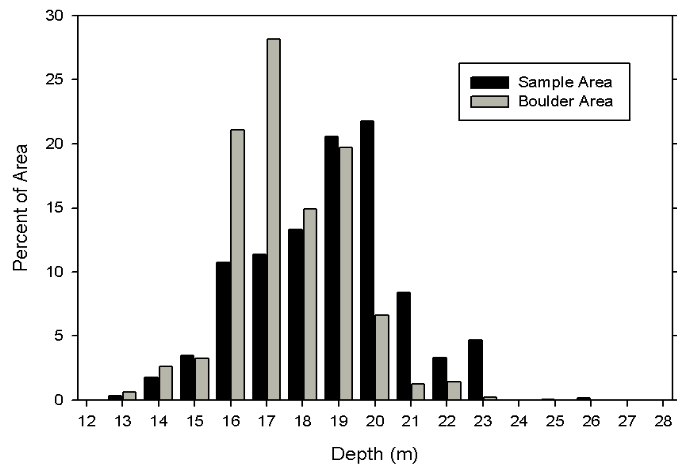

Figure 14. Percent areal coverage of the sample area (black) and potential lake trout habitat (grey) by one meter water depth intervals at Brocton Shoal, NY.

Presque Isle (Figure 16): Presque Isle was assessed because of the presence of lake trout in spawning condition in PADEP fall gill net surveys. In the area where lake trout are reliably captured in that survey, the density of boulder habitats was 1:22,530, covering about 5% of the area. However, when the entire survey area was quantified, only 0.17% was covered in boulder habitat (1:654,250). There was no boulder habitat located at the Presque Isle survey site outside of the gill net sample site. Of these 7 boulder aggregations, features were approximately 1,144 m^2 on average (range: 297-3,384 m^2). Based on minimum bounding regions, average length was 65 m and width was 31 m. All boulder features at Presque Isle were found in 8 m of water, although depths from 3-13 m were sampled (Figure 17). The average distance between bedrock feature centroids was 177 m. Unlike at Brocton Shoal where boulders were associated with sand substrate, the boulder habitat at Presque Isle appears mostly to be associated with fractured bedrock.

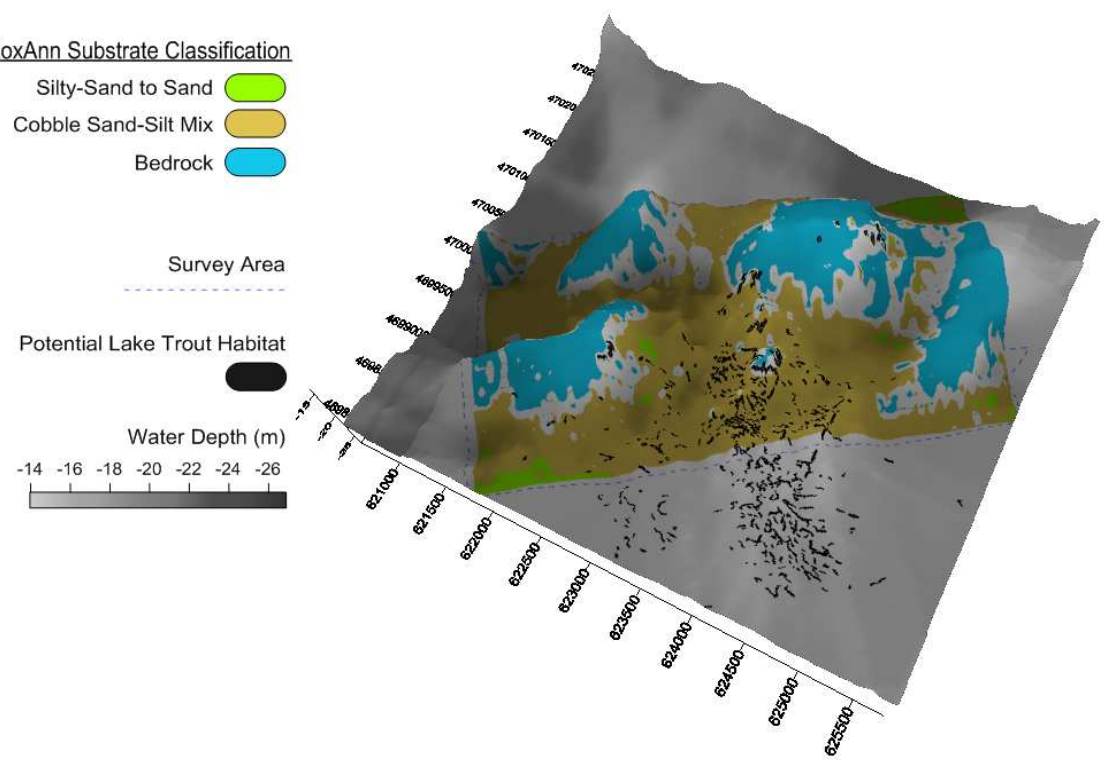

Figure 15. A 3-dimensional depiction of RoxAnn substrate classification overlaid with potential lake trout features at the Long Point-Clear Creek Ridge complex.

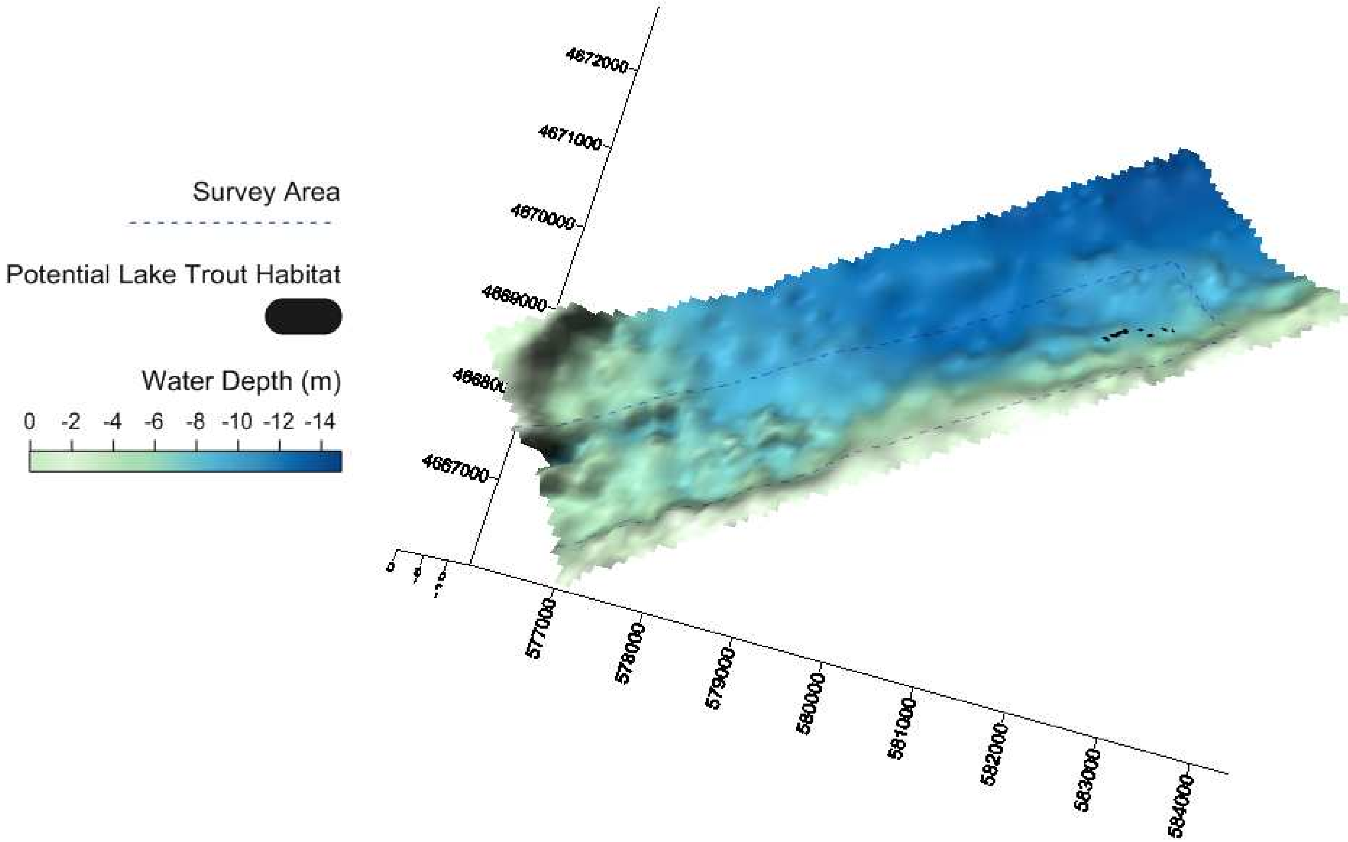

Figure 16. Distribution of potential lake trout spawning substrate at Presque Isle East, PA. All boulder features were located in the southeastern portion of the sample area. Coordinates are in UTM Zone 17N NAD83.

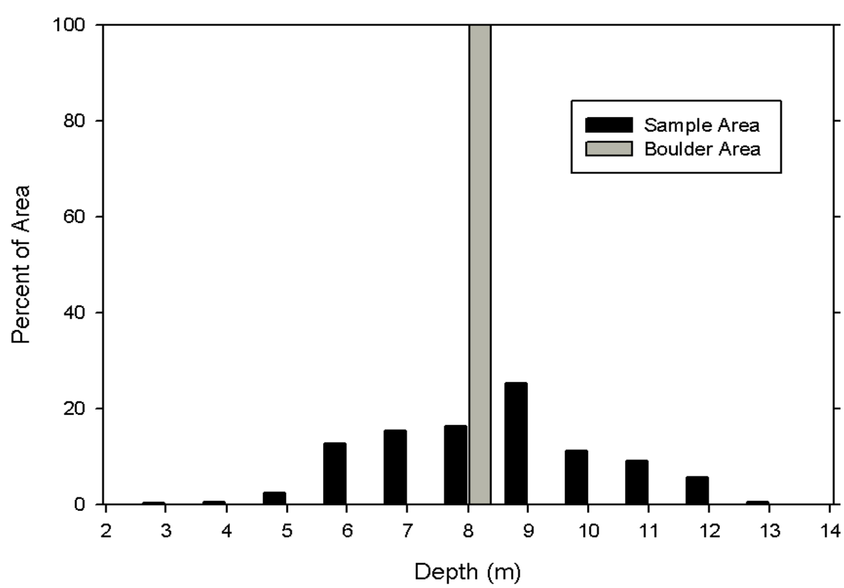

Figure 17. Percent areal coverage of the sample area (black) and potential lake trout habitat (grey) by one meter water depth intervals at Presque Isle East, PA.

The highly fractured bedrock and associated rock debris (Figure 18), which are relatively abundant at Presque Isle, could also serve as potential lake trout spawning habitat. These areas will need to be further assessed to determine the availability of interstitial spaces.

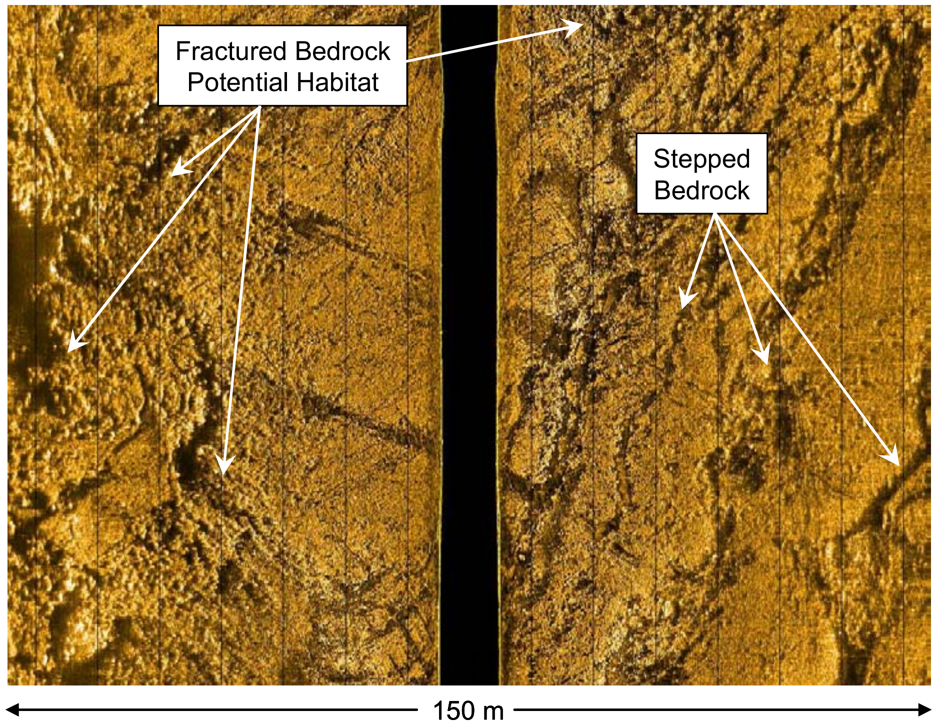

Figure 18. Presque Isle East sidescan sonar image. Lakebed consists of exposed fractured bedrock overlain by thin coarse sand deposits, cobble-boulder rock piles (center right). Distance between reference lines is 10 m. Image width is 150 m.

Long Point and Clear Creek Ridge (Figure 19): Although no suitable spawning habitat was detected at Long Point Ridge, a limited amount of potential spawning substrate was detected with sidescan at Clear Creek Ridge. The total area surveyed with sidescan at Clear Creek only produced 16 distinct features that may be suitable habitat. In the southern portion of the ridge, where boulder-cobble features are at their densest, there was 1 feature for every 482 m^2. The average area, MBR length and width were 521m^2, 53 m, and 20 m, respectively. In this area, the average distance between features was 514 m. The average water depth of all boulder-cobble features was similar to at Brocton Shoal (18 m). Almost all potential habitat was found on substrate classified as a gravel, sand, shell mix by RoxAnn (Figure 20).

A summary of how the primary substrates and characteristics of potential lake trout spawning habitat at the survey sites can be found in Table 9. According to the sidescan surveys, all sites were predominantly comprised of sand substrates. At Brocton and Presque Isle East, the secondary substrate was bedrock and there was more spawning substrate than at the Ridge locations. According to the RoxAnn^{TM} surveys, spawning substrate was most atop a sand-silt cobble mix at Brocton and over a sand, gravel, and shell mix on the Ridge. Although structures were largest in size at Presque Isle (average = 1144 m^2), Brocton had considerably more spawning structures (577 compared to 7 structures at Presque Isle East and 16 structures at the Ridge). Overall, the Ridge locations had the least amount of spawning substrate, but in the portion of this site where potential habitat was present, these structures were denser per unit area than at the other sites. Depths of suitable substrate were comparable amongst sites except for Presque Isle East, which was shallower than the others (8 m compared to 18 m).

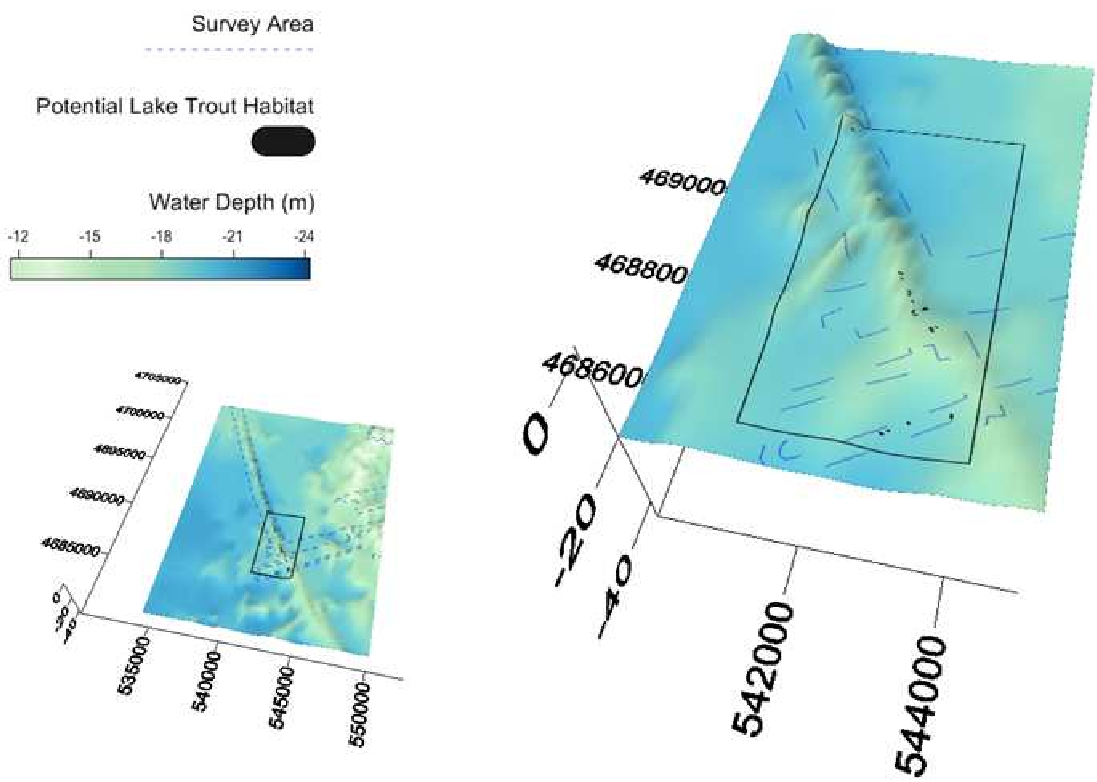

Figure 19. Distribution of potential lake trout spawning substrate at Clear Creek Ridge.

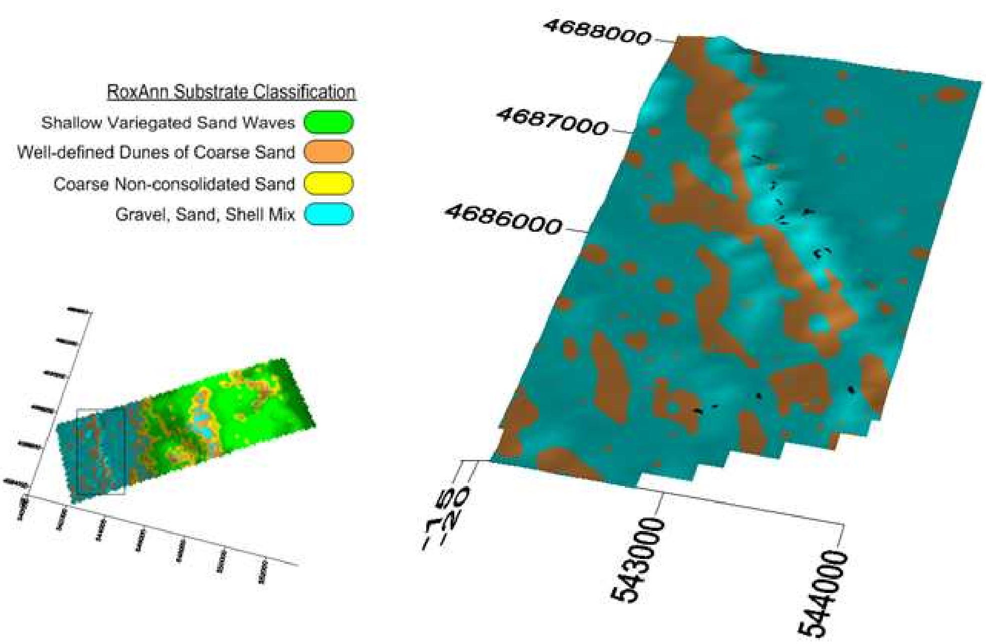

Figure 20. A 3-dimensional depiction of RoxAnn substrate classification overlaid with potential lake trout features at the Clear Creek-Long Point Ridge site.

Table 9. Summary of substrate types and lake trout habitat characteristics at survey sites. RoxAnn surveys at Long Point Ridge include portions of the Clear Creek Ridge.

General Survey	Brocton Shoal	Presque Isle East	Long Point Ridge	Clear Creek Ridge
Sidescan				
Primary substrate (%)	Coarse sand-cobble (68)	Sand (52)	Medium coarse-sand gravel (57)	Cohesive clay, coarse sand (61)
Secondary substrate (%)	Bedrock (23)	Stepped Bedrock (39)	Coarse sand-gravel, patchy cohesive (34)	Coarse sand, gravel, patchy cohesive (19)
RoxAnn				
Primary substrate (%)	Sand-silt cobble mix (53)	-	Shallow variegated sand waves (47)	
Secondary substrate (%)	Bedrock (26)	-	Gravel, sand, shell mix - shallow (27)	
Lake trout spawning habitat				
Entire Survey				
N of features in survey area	554	7	16	
Lake trout habitat, areal coverage (%)	1.47	0.17	0.07	
Average area per feature (m^2)	325	1,144	521	
Average MBR length (m)	44	65	53	
Average MBR width (m)	14	31	20	
Average water depth of features (m)	18	8	18	
Average distance to nearest neighbor at densest (m)	57	177	514	
Predominant underlying substrate, Sidescan	Coarse sand-cobble	Fractured Bedrock		
Predominant underlying substrate, RoxAnn	Sand-silt cobble mix		Gravel, Sand, Shell Mix	
Region with densest coverage				
Total Area (m^2)	2,067,420	157,645	251,595	
Lake trout habitat, areal coverage (%)	1.64	5.00	1.9	
Density (features:m^2)	1:5,000	1:22,530	1:482	

Overlaying sediment and invasives: Although the greatest areal coverage of cobble-boulder substrate was found at the southern portion of the Brocton Shoal site, examination of underwater video data shows that many areas thought to be historic spawning sites are affected by increased rates of sedimentation (Figure 21). Interstitial spaces, which are essential for lake trout eggs to develop successfully, are clogged with fine silt and pseudofeces from dreissenids. Therefore, we may have been able to identify cobble-boulder substrates with the RoxAnn™ and sidescan, but we now need to determine the extent to which these substrates may be compromised by sedimentation and invasives.

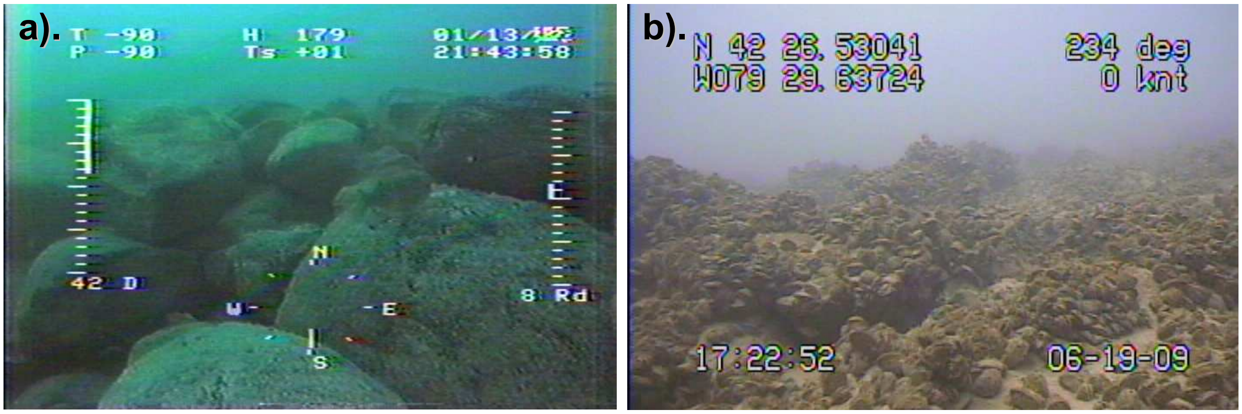

Figure 21. Increased siltation and the presence of invasives have altered lake trout spawning habitat. This is a comparison of images from Brocton Shoal in the late 1980’s ((a), Edsall et al. 1992) to our surveys in 2009 (b).

Task 5 Modification of the GIS Model

The original GIS model developed by the HTG in 2006 predicted potential lake trout spawning habitat locations based on a combination of steep slopes (>5%) and hard substrate (bedrock and/or glacial till) using existing bathymetric (NOAA) and substrate data layers (Haltuch 2000). Subsequent analyses of the Brocton Shoal data have shown that bathymetric heterogeneity may also be indicative of potential spawning substrates. Bathymetric heterogeneity was incorporated into the GIS model, and we used these factors to identify and prioritize subsequent eastern basin survey sites for this project.

Interpretive work from sidescan sonar and RoxAnn^{TM} surveys in the eastern basin of Lake Erie clearly demonstrates the inadequacy of current substrate maps and bathymetric data. The substrate map generated from sidescan sonar data at a North shore site clearly shows large areas of exposed bedrock in an area that was originally mapped as glacial till (grey area on map; Figure 22). Also present are complex habitat structures including bedrock scarps with steeply sloping coarse-grained scarp debris, the rock piles and linear boulder-cobble ridges that rest on the bedrock platform, or fractured bedrock which may serve as potential lake trout spawning habitat. Many of these habitat features are relatively small-scale and not detected by more traditional substrate mapping and/or bathymetric surveys. Less than 1% of the lakebed has been mapped at a resolution suitable to identify, characterize, and map potential fish habitat in Lake Erie.

As we mentioned previously, historic spawning substrates may now be compromised by increased sedimentation and dreissenid coverage. As lake trout may avoid areas with higher sedimentation rates, modifications may be necessary to the existing GIS model. Additional work is needed to determine the sources and relative contribution of tributary loadings and/or resuspended fine sediments to sediment loads over potential spawning habitats. The effects of seasonal changes in lake circulation patterns, frequency of wind and storm events, seasonal tributary loadings may be incorporated into the GIS model as well. By incorporating these factors into the model, locations with high sedimentation rates could be eliminated, even though the underlying substrate would otherwise be considered to be potential lake trout spawning substrate.

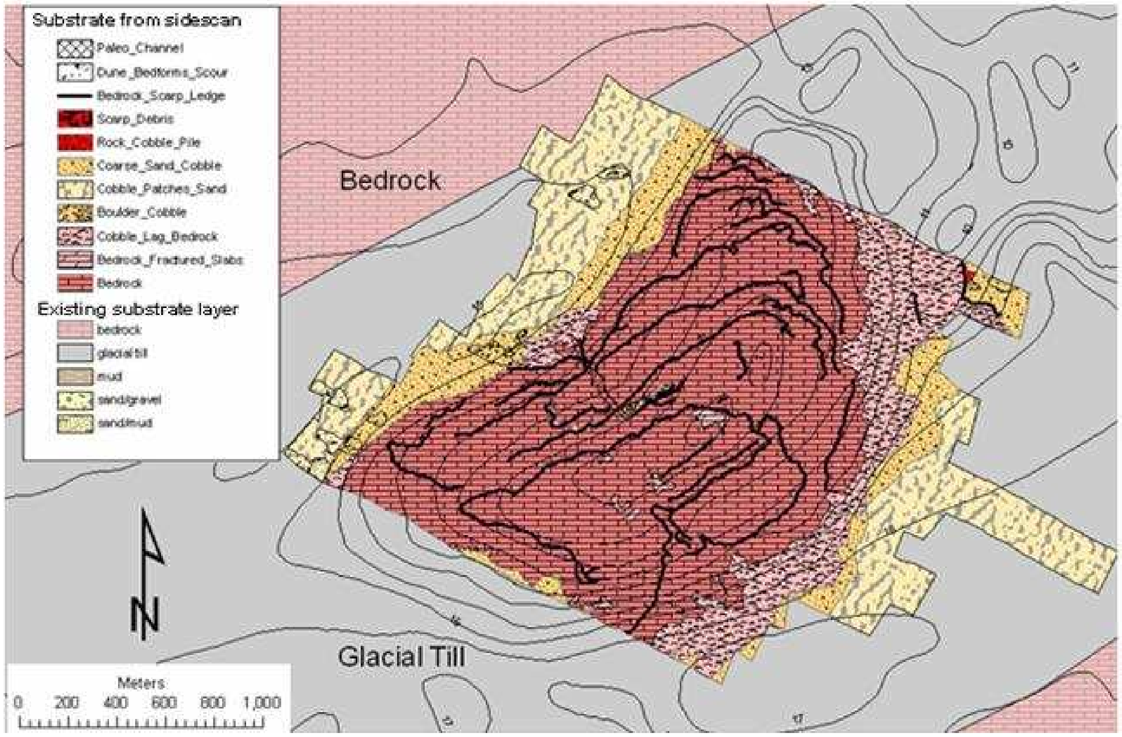

Figure 22. Existing substrate map (grey baselayer) overlaid with habitat interpretations from sidescan sonar data. Habitat maps from the new sidescan imagery capture structure at a more biologically-relevant scale than previous bathymetric and substrate maps.

Task 6 Develop preliminary linkages and connections between potential lake trout spawning and nursery habitats

Several studies have found that by early May, young-of-the-year fish rapidly move from spawning beds to deeper water nursery areas (Royce 1951, Martin 1957, DeRoche 1969, Jude et al. 1981). Other studies have found that young-of-the-year individuals stay near spawning grounds throughout much of the summer (Eschmeyer 1956, Stauffer 1981, Wagner 1981). Peck (1982) notes that young-of-the-year fish move from spawning grounds onto sandy substrates. Changes in water depth, temperature, and/or potential harsh environmental conditions in shallow water areas may trigger this offshore movement.

The timing of this offshore movement may be significant due to seasonal changes in the direction and magnitude of currents at different locations within the Lake. For instance, mean winter circulation along the southern Lake Erie shoreline is considered to be easterly, yet changes to westerly in the summer (Beletsky et al. 1999). This would result in two very different advection processes for young-of-the-year lake trout. It is likely that young lake trout would be susceptible to changes in seasonal timing and circulation patterns during the year. León et al. (2005) documented changes in circulation patterns between early and late summer over the Long Point and Clear Creek ridges. Moreover, surface and subsurface currents can flow in opposite directions over the ridge (Bolsenga and Herdendorf 1993). The project team continues to review the literature and is collaborating with other investigators (modelers) to better understand the importance of changing circulation patterns and connectivity between potential spawning and nursery habitats in Lake Erie.

Major findings and accomplishments

The focus of this work was to address whether the location and characteristics of potential lake trout spawning habitat can be identified using newly developed GIS tools and field equipment and used to verify habitat suitability and structure based on comparisons with environmental characteristics from historic lake trout spawning sites. Based on the sidescan sonar and RoxAnn™ surveys, multiple sites exhibit physical habitat characteristics deemed suitable for potential use by lake trout as spawning substrate. These areas include sites within the Brocton Shoal complex near Dunkirk, New York, a shallow-water nearshore site east of Presque Isle, Pennsylvania, and multiple sites within the Nanticoke Shoal, Peacock Point, Hoover Point South, and Hoover Point East survey areas along the north shore of Canada. All of these sites are located adjacent to deeper water areas that are assumed to serve as potential nursery habitat for lake trout in the eastern basin of Lake Erie. Little suitable substrate was found at Long Point Ridge, Pennsylvania Ridge, Presque Isle Knob, and Clear Creek Ridge.

Although, suitable *substrate* was found with sidescan at portions of the study sites, more detailed inspection with underwater cameras indicate that some of these areas do not have suitable spawning *habitat*. That is, some of the preferred cobble substrates are covered in dreissenid sp. and Cladophora sp. This includes the historic, reference site Brocton Shoal. The physical structure of these organisms can clog interstitial spaces necessary for egg protection and reduce energy associated with waves and currents over coarse substrates causing an increase in siltation, especially in interstitial spaces. Siltation may be augmented by dreissenid pseudofeces. Siltation reduces the volume of interstitial space available and may smother/suffocate eggs that are deposited in the interstitial spaces.

This significant alteration of habitat by invasives may explain low catches of lake trout in recent spawning surveys at historic and anecdotal spawning sites, which tended to be in deeper waters. For lake trout, nearshore areas that historically may not have been prime spawning locations may now be the best sites remaining that have the substrate and interstitial space characteristics necessary for these fish to spawn and reproduce successfully. Our work suggests that the higher energy environments in nearshore areas may 1) reduce the density of lithophyllic species, and 2) minimize siltation within interstitial spaces. Recent work east of Presque Isle, Pennsylvania, indicates that lake trout may be using shallow water nearshore areas (~5 to 10 m water depths) as spawning habitat. This is corroborated by a NYSDEC survey, which found spawning condition fish at depths less than 2m. Potential reproductive success in these nearshore habitats still needs to be assessed. It is possible that the high energy associated with these areas may be detrimental to egg development and larval success, but further work is necessary.

Overall we did not feel that the GIS model performed well even though there was some spawning substrate at most sites. The primary reason for this is likely the coarse resolution at which the input layers were collected. Data collected for this study (and additional data collected as part of a similar study funded by the Canada Ontario Agreement) clearly demonstrate that existing substrate coverages are inaccurate. Portions of existing regional substrate maps may not be reliable and we caution that any interpretations or policies developed based on those maps be applied and used with caution due to inaccuracies in the underlying datasets. In addition to substrate maps, existing bathymetric datasets do not have the fine-scale resolution necessary to identify potential habitats. The best regional bathymetric dataset available is the 1-m NOAA bathymetry. Many of the potential habitat areas observed using sidescan sonar (that exhibit significant relief) can not be resolved using existing bathymetric maps, including the 1-m NOAA bathymetry. Our work clearly demonstrates the need for more detailed high-resolution bathymetry in the Great Lakes. The issues with the baselayers may be part of the reason that the GIS model did not detect the Presque Isle East spawning site. The bathymetric patterns at this site were not similar to those at the Brocton reference location. We are presently attempting to modify the model to detect such areas, considering the issues with the existing base layers.

Management implications

Although final substrate and habitat classification maps were not completed yet, preliminary data from sidescan, RoxAnn™ and underwater video were used to identify locations of highly suitable lake trout spawning habitat. These locations were provided to NYSDEC and OMNR for consideration as potential stocking locations for yearling lake trout. The OMNR used this detailed information to select stocking locations on Nanticoke Shoal. Due to various constraints from transporting and survival issues, lake trout were not stocked directly over any potential spawning habitat in NY. However, Brocton Shoal is located within a few miles of the stocking site. In 2009, OMNR stocked 50,000 lake trout on Nanticoke Shoal and NYSDEC stocked 173,342 lake trout near Brocton Shoal. This combined effort was the second highest annual stocking effort on Lake Erie since coordinated lake trout restoration efforts began in 1982.

NYSDEC also used the high-resolution substrate data to select areas for placement of egg trap lines, which are used to determine if lake trout were spawning over these areas (Figure 23). Two egg trap lines were deployed on raised rock ridges (i.e. suspected spawning areas) on Brocton Shoal from November 5-24, 2008, and three egg trap lines were set from November 10 through December 2, 2009. No lake trout eggs were collected in either year. However, the invasive bloody red shrimp *Hemimysis* were collected in both years.

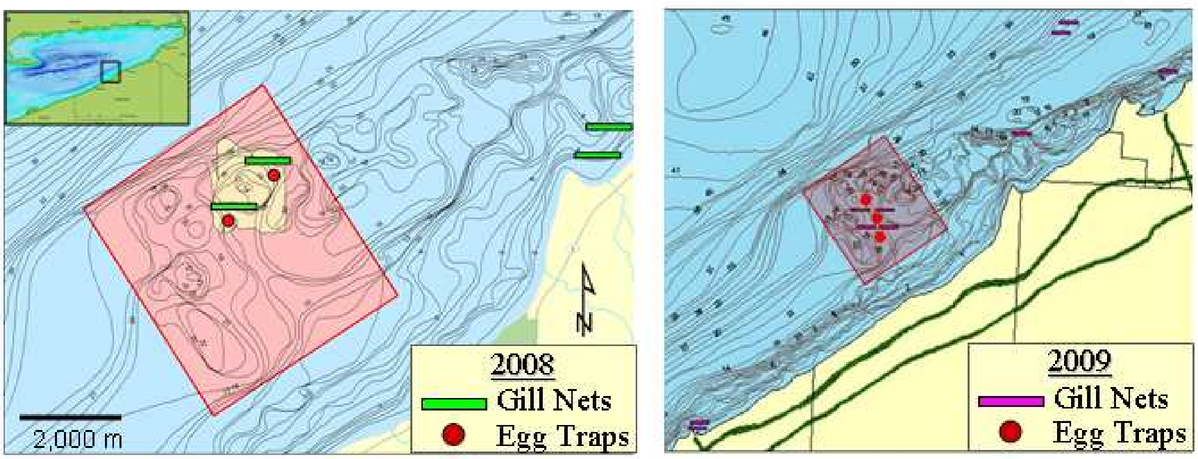

Figure 23. Placement of egg traps and gill nets at Brocton Shoal was selected based on sidescan sonar data in 2008 and 2009.

Lastly, there is considerable interested being expressed by developers of offshore wind farms, especially along the Ridge Complex, for high resolution substrate datasets. There was some discussion that this area may be suitable, because it is offshore yet relatively shallow. Based on our assessment, most of the substrate is sand and cohesive material, which may not be desirable for turbine installation. Because lake trout stocks are in the re-building phase, it is also a good time to promote habitat enhancement at turbine bases. If turbines are installed, it would be beneficial to add cobble structure to the base thereby providing additional habitat that may be suitable for the spawning of a variety of species.

Future research

The work that we have conducted has provided insight on the quality and quantity of potential spawning substrates. Because we found significant habitat alteration by invasive species at some historic spawning grounds, it is now imperative to better understand how the fish may be responding to this change. For example, we mentioned that we have collected more spawning condition fish at nearshore areas in recent surveys. We need to determine if this is related to the strains that have been stocked recently or if this is how the fish are adapting to habitat alterations in offshore spawning areas or if they are merely staging in these areas. Corresponding habitat and bathymetric mapping at the highest resolution possible would also be important. Potential reproductive success in these nearshore habitats still needs to be assessed. It is possible that the higher energy of these areas may be detrimental to egg development, but further work is necessary. Although gill netting is the method we commonly use to asses lake trout, an on-site video monitoring program or acoustic tagging study would provide much more detailed information about localized habitat usage. This would include both potential habitat sites in shallow nearshore and deepwater areas. The monitoring work should include simultaneous acquisition of water current, temperature, turbidity, and other water quality parameters of interest.

It is obvious that dreissenids and Cladophora are clogging interstitial spaces. However, it is also essential to understand the source of the increased sedimentation in these areas. It may be from pseudofeces or decreased water flow from the structure of the invasives, but there may be larger scale forces acting upon these areas that we may be able to incorporate into the GIS model. At Presque Isle North, for example, dreissenid coverage is intermittent and it would benefit this research greatly if we knew why certain areas were void of dreissenids while neighboring areas are infested.

One potential future project that has emerged is a habitat improvement project for Brocton Shoal. Underwater camera photos taken in both 1987 and 2009 revealed the severe degradation of the cobble rock piles that has occurred due to dreissenid mussel invasion and subsequent sedimentation. The state of the current substrate is degraded to the point where interstitial spaces that are needed for successful lake trout reproduction are no longer available, rendering this once prime habitat virtually useless. In order to make this habitat once again viable, sedimentation and mussels would need to be cleaned off the rocks so spaces were once again available. Although only practical on a small-scale, this may be able to be accomplished with the use of a water jet system. If small areas of prime spawning habitat could be cleaned, underwater cameras and sampling during spawning could be used to monitor the sites and determine if lake trout are utilizing the areas once again. Long term monitoring would also be useful to determine the rate of dreissenid invasion and re-sedimentation.

Lastly, virtually no work has been done on lake trout nursery habitat in Lake Erie. The lack of data severely limits our ability to assess the importance of connectivity to spawning habitat. A suite of studies to identify and evaluate lake trout nursery habitat and connectivity to spawning habitat would be the next step towards understanding the reproductive success of lake trout in Lake Erie, once the behavior of spawning adults is better understood. A current assessment of juvenile behavior is also necessary in light of our findings of habitat alteration.

Presentations and outreach activities

Mackey, S.D., T.M. MacDougall, J.L. Markham, H. Biberhofer, A. Gorman, and P. Kocovsky. Effects of Lithophyllic Species on Potential Lake Trout Spawning Substrates in the Eastern Basin of Lake Erie. 2010. International Association of Great Lakes Research, Toronto, ON, CA (poster presentation)

Morse, J., H. Biberhofer, A.M. Gorman, P. M. Kocovsky, T. MacDougall, S. D. Mackey, and J. Markham. 2010. Creating a Database of Lake Trout (Salvelinus namaycush) Spawning Habitat in the Eastern Basin of Lake Erie. International Association of Great Lakes Research, Toronto, ON, CA (oral presentation)

Mackey, S., H. Biberhofer, A.M. Gorman, P. M. Kocovsky, T. MacDougall and J. Markham. 2008. Preliminary Assessment of Lake Trout Spawning Habitat in the Eastern Basin of Lake Erie. International Association of Great Lakes Research, Trent University, Peterborough, ON, CA (oral presentation)

Kocovsky, P., H. Biberhofer, A.M. Gorman, T. MacDougall, S. D. Mackey, and J. Markham. Assessing Potential Spawning Habitat to Assist Lake Trout Restoration in Lake Erie. Presented to the Lake Erie Committee of the Great Lakes Fishery Commission. March 2009, Windsor, ON (oral presentation)

All geospatial datasets are also being sent to the Lake Erie GIS:
http://ifrgis.snre.umich.edu/projects/GLGIS/support_docs/html/lake_GISs/LEGIS_index.htm

Relevant images: Electronic versions of all imagery and photographs will be included with the hard copy of the report.

Geographic region

Coordinates are in UTM Zone 17N NAD83. See GIS files, including Survey_sites.shp for bounding areas. These will be included with the hard copy of the report.

Location	Survey	Hectares	X-centroid	Y-centroid
Brocton Shoal	RoxAnn	1257	623158.46	4700186.715
Brocton Shoal	Sidescan	217	623741.2878	4699505.85
Brocton Shoal	Sidescan	1037	623611.3148	4699169.279
Clear Creek Ridge	Sidescan	2367	539811.7567	4692322.123
Clear Creek, Long Point Ridge	RoxAnn	5977	546771.506	4688873.748
Long Point Ridge	Sidescan	3189	552784.921	4696402.669
Pennsylvania Ridge	RoxAnn	1869	560388.09	4677093.174
Presque Isle East	Sidescan	454	578520.0342	4668033.332
Presque Isle North	RoxAnn	615	571171.7966	4670467.585

Reports

Morse, J., H. Biberhofer, A.M. Gorman, P. M. Kocovsky, T. MacDougall, S. D. Mackey, and J. Markham. 2010. Creating a Database of Lake Trout (*Salvelinus namaycush*) Spawning Habitat in the Eastern Basin of Lake Erie. Oberlin College. Undergraduate Research Report, 13 p.

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