Feasibility of Using Satellite Imagery to Remotely Identify Lake Trout Spawning Sites

Research Final Report
to the Great Lakes Fishery Trust

Grant 2012.1234

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PROJECT ABSTRACT

Grant #: 2012.1234

Title: Feasibility of Using Satellite Imagery to Remotely Identify Lake Trout Spawning Sites

Abstract body:

Purpose:

The availability and quality of spawning habitat may limit lake trout recovery in the Great Lakes, but little is known about the location and characteristics of current spawning habitats. Recent methods used to identify lake trout spawning locations include egg surveys and fry traps, which are time- and labor-intensive and spatially limited. Due to the observation that lake trout spawning sites are relatively clean of overlaying algae compared to areas not used for spawning, we hypothesized that spawning sites could be identified using satellite imagery. We assessed the feasibility of using high-resolution satellite imagery to assess whether known spawning and non-spawning sites could be accurately differentiated from the patterns of change in spectral characteristics between pre-spawning and post-spawning images.

Objectives:

A. Determine whether commercial, high-resolution satellite imagery can be used to distinguish among different densities of algae on substrate within a known lake trout spawning area

B. Evaluate the degree to which such imagery can be used to detect changes in algae density over time at a fine spatial scale

C. Assess whether known spawning and non-spawning sites with similar bathymetry and substrate characteristics can be accurately differentiated by comparing the spectral characteristics of pre- and post-spawning satellite images

Methods:

A. To determine whether commercial, high-resolution satellite imagery can be used to distinguish among different densities of algae on substrate within a known lake trout spawning area, we used a pre-spawning satellite image collected with the Pléiades 1A satellite on 27 September 2013. The image was pre-processed using established atmospheric correction protocols, whereby image pixel values were converted to top of atmosphere (TOA) radiance. Initial analysis revealed salt and pepper noise in the TOA radiance values, which was due at least in part to reflection off the water surface. To suppress the noise, a Guassian smoothing filter was applied to each spectral band in the image; the central pixel was assigned a weight of 0.25, the four nearest neighbors weights of 0.125, and the four diagonal neighbors weights of 0.0625. Lastly, we corrected for the effect of variation in water column depth on bottom reflectance by generating a depth-invariant (DI) index of bottom type for each pixel in the image using the following equation (Brooks et al. 2014):

$$\textit{depth-invariant index}_{ij} = \ln (L_i - L_{si}) - [(K_i / K_j) * \ln (L_j - L_{sj})]$$

where ln $(L_i - L_{si})$ is the natural log of the pixel value for band i minus the mean deep water value for band i and K_i / K_j is the water attenuation coefficient ratio between bands i and j, where $K_i / K_j = a + (a^2 + 1)^{1/2}$, $a = (\sigma_{ii} - \sigma_{jj}) / 2\sigma_{ij}$, σ_{ii} = variance of X_i, σ_{jj} = variance of X_j, and σ_{ij} = covariance of X_i and X_j.

To assess whether high-resolution satellite images can successfully identify spatial variation in algae coverage on known lake trout spawning reefs, the DI index values were compared against estimates of algae cover determined from underwater photographs of substrates at 180 sites on two reefs. Five photographs, each covering an area of approximately 1 m^2, were taken at each site. Percent algae cover in each photograph was determined in Adobe Photoshop by using the 'magic wand' selection tool to highlight all pixels containing algae and expressing that value as a percentage of the total number of pixels in the image. This value was averaged across the five photographs at each location to produce a single estimate of algae cover for each site.

B. To evaluate the degree to which satellite imagery can be used to detect changes in algae density over time, a second Pléiades 1A satellite image was collected during the post-spawning period (25 November 2013), and its spectral properties were compared against the pre-spawning image (27 September 2013). The post-spawning satellite image was pre-processed as in A (above), but to make comparisons between the two images, it was necessary to also normalize the November image to the September image. Normalization was done using relative radiometric normalization (Schott et al. 1988), which is a line conversion procedure that assumes a linear relationship between individual image bands across time for pseudo-invariant features that are spatially well-defined and spectrally stable (e.g., areas of deep water, and bright, shallow areas with no vegetation). The normalization expression was as follows:

$$DN'_{2i} = \frac{\sigma_{1i}}{\sigma_{2i}} DN_{2i} + \overline{DN_{1\iota}} - \frac{\sigma_{1i}}{\sigma_{2i}} \overline{DN_{2\iota}}\,,$$

where DN_1 is the reference (September) image, DN_2 is the image to be normalized (November), DN'_{2i} is the normalized November image, $\overline{DN_{1\iota}}$ and $\overline{DN_{2\iota}}$ are the means of the pseudo-invariant pixels for the two images, and σ_{1i} and σ_{2i} are their respective standard deviations.

To assess how well changes in the spectral properties of the pre- and post-spawning images reflected changes in algae density on the reefs, we calculated change in bottom radiance for both the green and blue bands of the image. Because relative changes were focused at specific sites, correction for depth was not necessary (because no appreciable change in water depth occurred during the spawning period), so there was no need to calculate DI index values for the two dates.

As in A above, spectral changes were compared against ground truth data collected by underwater video. Unfortunately, the combination of an uncharacteristically late start to the lake trout spawning season (3 weeks late) and poor weather conditions in fall 2013 limited our ability to collect post-spawning underwater substrate images. In the end, our analysis was limited to 11 sites for which we had both pre- and post-spawning substrate images.

C. To assess whether known spawning and non-spawning sites with similar bathymetry and substrate characteristics can be accurately differentiated by comparing the spectral characteristics of pre- and post-spawning satellite images, we parameterized a binary regression model describing the probability of observing egg deposition as a function of the spectral properties of the normalized pre- and post-spawning satellite images on a single reef (Horseshoe Reef, where 19 sites were used to parameterize the model). We then applied the binomial model across the geographic range (at depths of 12 m or less) of the two satellite images (Figure 4) and tested it against 30 sites surveyed for egg deposition on a second reef (Binder Reef) to assess the model's predictive power.

Results:

A. Using a depth-invariant (DI) radiance index, spatial variation in algae cover was quantified within a single satellite image up to approximately 70% cover. Areas with greater than 70% cover were not distinguishable from one another based on the spectral properties of the image.

B. Results indicated that changes in the radiance of the blue spectral band performed best at predicting areas that had been cleaned of algae. Using this technique, areas where algae cover decreased were distinguishable from areas where algae cover remained stable or increased. Larger changes in algae cover were easier to distinguish than smaller changes in algae cover.

C. The best binomial model for predicting egg deposition based on changes in the spectral properties of pre- and post-spawning satellite images included both initial bottom radiance and change in bottom radiance (i.e. eggs were most likely to be deposited in substrates that were clean at the beginning of the spawning season or were cleaned during the spawning season). Overall, the model, which was parameterized at Horseshoe Reef, correctly predicted egg deposition at 87% of surveyed sites on Binder Reef. However, the model was more accurate at predicting sites without eggs (95%) than with eggs (70%).

Conclusions:

Our results supported the likelihood that high-resolution multispectral satellite imagery can be used to distinguish among algae densities and detect changes in algae density over time (Objectives A & B). The regression model developed from the satellite data performed fairly well at discriminating between sites on a reef where lake trout eggs were present vs. absent (Objective C), but it more accurately predicted sites where eggs were absent than where they were present, overpredicting the latter category. This was likely because these shallow water areas can be cleaned by processes unrelated to spawning activity (e.g., algae sloughing caused by wave action and strong surface currents) and not all cleaned areas have suitable substrate for egg incubation.

At the refuge scale, areas predicted to be spawning habitat based on changes in the spectral properties of pre- and post-spawning satellite images correspond with the locations of shallow submerged glacial features that are likely to contain patches of cobble substrate that is suitable for successful lake trout spawning. Some of the glacial features in our study area did not have areas of cleaned substrate, suggesting that at broad scale, satellite sensing techniques can be used to differentiate submerged features that are likely to support lake trout spawning activity from those that are not.

Combined, these results suggest that the greatest value of satellite imaging techniques to identification of lake trout spawning habitat may be the ability to exclude certain habitats as being likely lake trout spawning habitats, thus, greatly reducing the amount of field surveying that would be required to assess spawning activity in the area. These methods, however, are limited by clarity of the water in the mapped area. In northern Lake Huron, which has relatively clear water, the lake bottom could be classified to a maximum depth of approximately 12 m in the satellite image that were acquired. Because of this bottom detection depth limit, our methods would not be appropriate for mapping spawning habitat in areas with significantly lower water clarity than northern Lake Huron.

Given the cloudiness of the Great Lakes region in the fall when lake trout spawn, the greatest challenge to successful application of satellite imagery methods is the ability to acquire two cloud-free images of suitable satellite geometry within two different, fairly narrow temporal windows. If the findings of this study were developed into an operational product, it would likely be more feasible to collect aerial imagery, which can be shot from optimal angles to reduce artifacts like surface glint, and would not be reliant on clear skies. In the course of the study, we performed preliminary tests of a method for acquiring nearshore imagery using a small unmanned aerial vehicle (UAV) with a nadir camera. Results indicated that image quality was potentially sufficient to replace satellite images in our analyses for areas that could be covered with UAV flights.

FINAL NARATIVE REPORT

Grant: 2012.1234

Project Title: Feasibility of Using Satellite Imaging to Remotely Identify Lake Trout Spawning Sites

Grantee Organization: Great Lakes Fishery Commission

Project Team: Thomas R. Binder, Amanda G. Grimm, Colin N. Brooks, Stephen C. Riley, and Charles C. Krueger.

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Key Search Words: lake trout, spawning, habitat, remote sensing

Background/Overview

1. **Briefly summarize the project description as outlined in the original proposal.**

   Lake trout supported a valuable commercial fishery in the Great Lakes until the 1940s, when overfishing and predation by sea lamprey caused the extirpation of most populations (Hansen 1999; Krueger and Ebener 2004, Muir et el. 2012). Despite more than 40 years of stocking, however, self-sustaining populations have only recovered in Lake Superior and in Parry Sound, Lake Huron (Reid et al. 2001). Recent catches of wild lake trout fry and adults in assessment surveys in Lake Huron (Riley et al. 2007; He et al. 2012), however, suggest that widespread natural reproduction and recruitment is occurring there.

   Understanding mechanisms that limit recruitment of lake trout is critical to their successful rehabilitation. Potential contributing factors that have been proposed include excessive fishing and sea lamprey predation, egg and fry predation, thiamine deficiency complex, and inappropriate spawning behavior by hatchery raised trout (Krueger et al. 1995, Jones et al. 1995, Bronte et al. 2003, Riley et al. 2011). Many of these proposed mechanisms center on reproductive failure and lack of recruitment of early life stages into the population, so a more complete understanding of lake trout reproduction in the Great Lakes is essential to understand impediments to recovery.

   Much of what is known about lake trout reproduction has been inferred from observations by commercial fishermen or from studies on small inland lakes (Gunn 1995). One challenge of studying reproductive behavior over such large spatial scales is the difficulty in identifying individual spawning sites. To date, lake trout spawning sites have been identified through surveys with divers, egg and fry traps, remotely operated vehicles (ROVs), and acoustic telemetry (Marsden et al. 1995).

These techniques are time and labor intensive, and are limited in both scale and resolution.

Remote sensing via satellite has the capability to provide high-resolution (~ 2 m^2), low-cost mapping of Great Lakes nearshore regions, which could be used to identify lake trout spawning sites. Lake trout often spawn on nearshore reefs in discrete areas, and spawning sites may be identified as areas where algae have been cleaned from substrate. Based on methods developed at the Michigan Tech Research Institute (MTRI) for mapping *Cladophora* blooms in Lake Michigan (Shuchman et al. 2013, Brooks et al. 2014), we hypothesized that these areas should be identifiable from high-resolution satellite imagery. As there have been relatively few applications of remote sensing to map fish habitats (Herold et al. 2007; Mellin et al. 2009), this is an innovative application of this technology.

We tested the feasibility of applying satellite remote sensing methods to identify lake trout spawning sites in a 12-km^2 region of the Drummond Island Refuge, Lake Huron (Figure 1), where potential spawning sites are typically covered by attached algae that is removed prior to or during spawning (T. Binder, personal observation). This site provided a unique opportunity to conduct this feasibility study because successful reproduction of lake trout is occurring there and because we have collected high-resolution bathymetry, substrate, and fish behavior data at this site during an on-going large-scale acoustic telemetry study of lake trout spawning behavior. Nonetheless, the technique used here could be adopted to identify potential nearshore lake trout spawning sites across most of the Great Lakes basin, especially in Lake Michigan and Lake Ontario.

The potential for use of remote satellite imaging methods to identify nearshore lake trout spawning sites was assessed using a three-staged (objectives) approach:

D. Determine whether commercial, high-resolution satellite imagery can be used to distinguish among different densities of algae on substrate within a known lake trout spawning area

E. Evaluate the degree to which such imagery can be used to detect changes in algae density over time at a fine spatial scale

F. Assess whether known spawning and non-spawning sites with similar bathymetry and substrate characteristics can be accurately differentiated by comparing the spectral characteristics of pre- and post-spawning satellite images

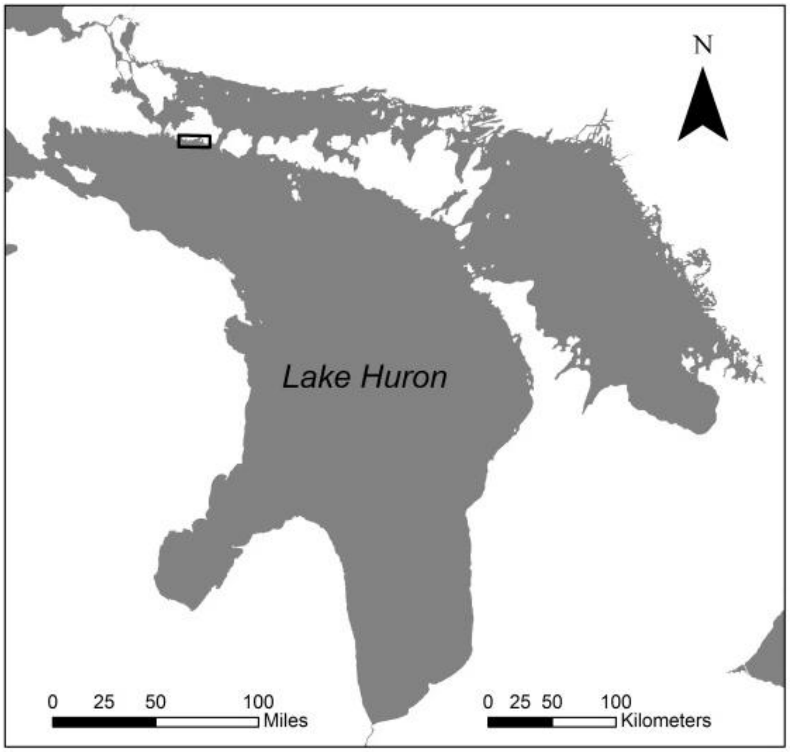


Figure 1. Location of field study site (outlined in black) on south side of Drummond Island, in northern Lake Huron.

2. **Briefly summarize any significant changes to the work performed in comparison to the plan of work originally proposed and funded. If changes were made, describe how they affected your ability to achieve the intended outcomes for the work.**

   No significant changes were made to the project.

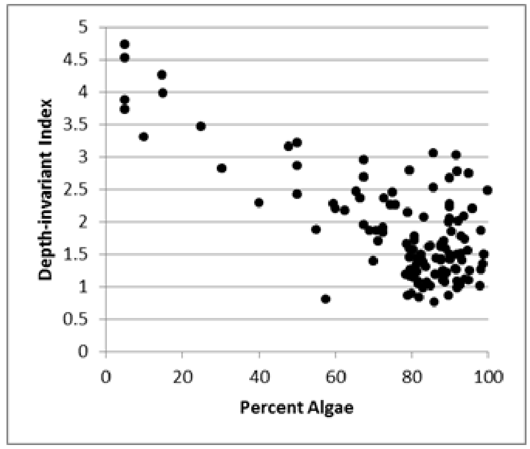
Outcomes

3. **To what extent and how (if at all) did this research project advance scientific knowledge of the issue?**

   This project has developed a tool to help researchers identify potential lake trout spawning sites in nearshore areas of the Great Lakes. In this novel application of remote sensing, our work has verified that satellite images can be used to quantify spatial and temporal variation in algae cover on substrate, and thus identify areas of cleaned substrate that might serve as suitable lake trout spawning habitat.

   Using a depth-invariant (DI) radiance index, an index of bottom brightness that compensates for the light-absorptive properties of water, we were able to quantify spatial variation in algae cover within a single satellite image up to approximately 70% cover. Areas with greater than 70% cover were not distinguishable from one another based on spectral properties (Figure 2).

Figure 2. Relationship between depth-invariant (DI) index and percent algae coverage in the pre-spawning satellite image taken in September 2013. Percent algae coverage was determined from underwater video and still photography.



The greater challenge was comparing algae coverage between the two images. Our initial work with the DI index revealed that error introduced by DI index calculation and the differences between the two images in the attenuation ratio between the green and blue bands introduced noise in the change analysis, so we chose instead to compare normalized blue and green bands separately, which eliminated the need to correct for depth (because we were comparing the same sites) and produced far better results. In the end, the blue band gave the best results, probably because blue light penetrates deeper into water. Using this technique, we were able to successfully distinguish substrates that had been cleaned of algae from substrates that had not been cleaned of algae. An uncharacteristically late spawning season and poor weather conditions in late fall of 2013 precluded us from collecting post-spawning underwater images for many of the sites we assessed for bottom brightness in the pre-spawning image. Nonetheless, based on the 11 sites for which we did collect both pre- and post-spawning underwater photographs for ground truthing, there was a strong correlation between change in bottom radiance in the blue band of the two satellite images and change in percent algae cover (Figure 3).

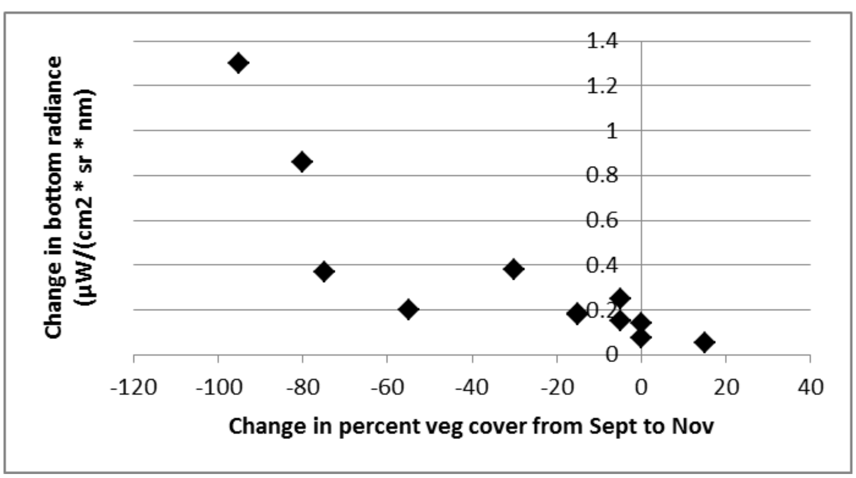


Figure 3. Change in bottom radiance (blue band) versus change in percent algae cover between September and November, 2013. Percent algae cover was determined from underwater video.

In the final stage of our assessment of the use of remote satellite sensing methods to identify potential lake trout spawning sites, we used 19 sites surveyed for egg deposition on Horseshoe Reef to parameterize a binomial regression describing the probability of observing egg deposition as a function of the spectral properties of the pre- and post-spawning satellite images. We then applied the binomial model across the geographic range (at depths of 15 m or less) of the two satellite images (Figure 4) and tested it against 30 sites surveyed for egg deposition on Binder Reef to assess the model's predictive power. The best model for predicting egg deposition on Horseshoe Reef included initial bottom radiance in the pre-spawning satellite image and change in bottom radiance in the blue band between the pre- and post-spawning satellite images (i.e. eggs were most likely to be found in areas that were bright in the pre-spawning satellite image, or got significantly brighter between the pre- and post-spawning images). The selected model was:

$$probability_i = \frac{1}{1 + exp(-(-142.157 + 14.472C + 146.440I))}$$

where *C* is the change in the blue spectral band at a given site *i* between the September and November images and *I* is the September depth-invariant index value at that site, indicating pre-spawning substrate brightness.

Overall accuracy of the binomial model at predicting spawning at sites on Binder Reef was 87%. However, accuracy was better for sites predicted not to be used for spawning (correct prediction at 19 of 20 sites; 95%) than for sites predicted to be used for spawning (correct prediction at 7 of 10 sites; 70%). Two of the three sites that were incorrectly predicted as being spawning sites had high initial brightness, and the third displayed a large increase in brightness between the pre- and post-spawning images. Overprediction of sites used for spawning is likely due to other processes at play, unrelated to lake trout spawning (i.e., sloughing of benthic algae caused by ice scour and strong waves and currents), that clean the substrate in the nearshore zone. Moreover, not all clean substrate will be suitable habitat for over-winter egg incubation.

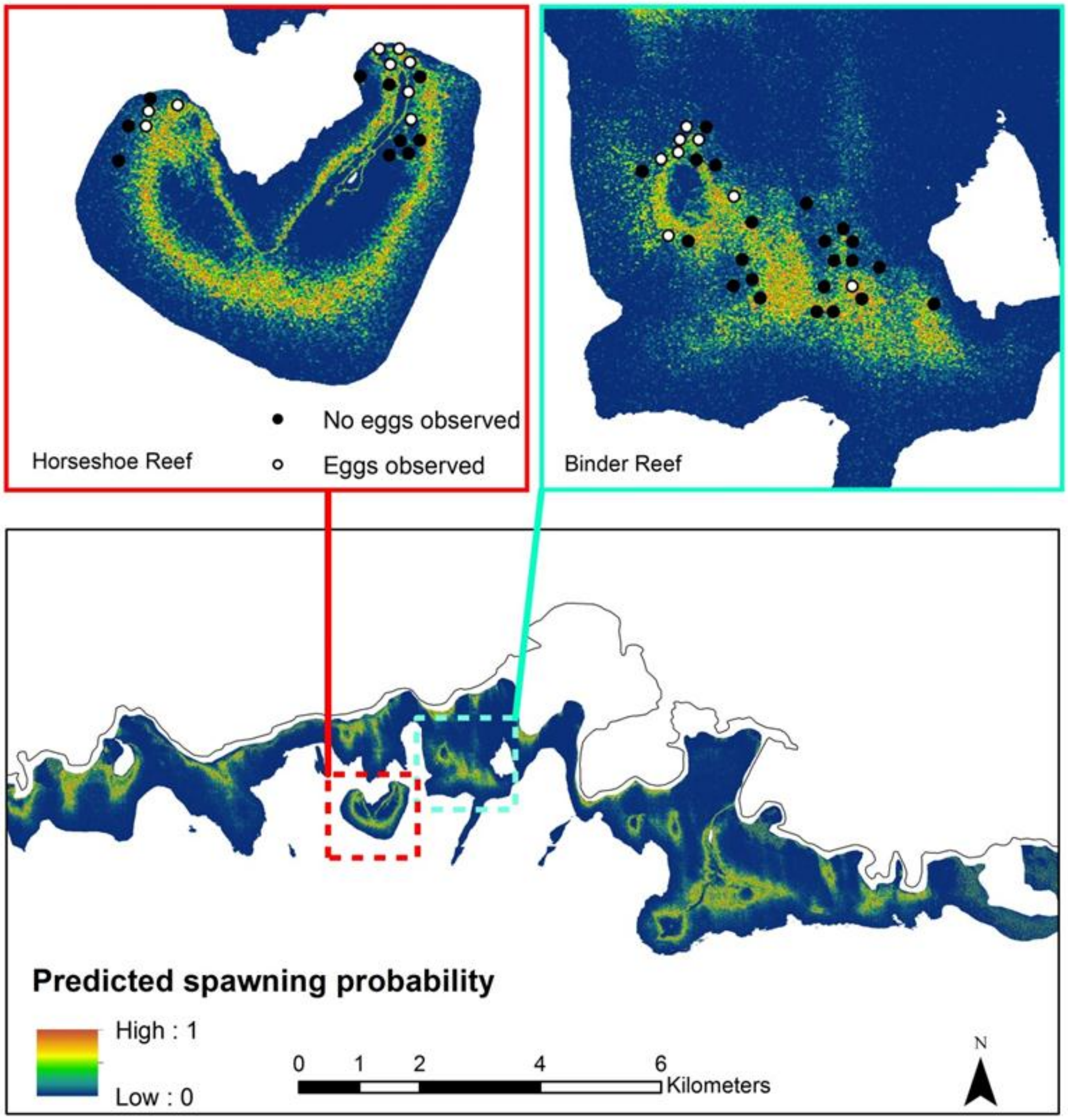


Figure 4. Map of potential lake trout spawning habitats on the south shore of Drummond Island as determined by the spectral properties of pre- and post-spawning satellite images. Warmer colors on the map indicate areas with higher likelihood of spawning activity. Insets show Horseshoe Reef and Binder Reef with sites surveyed for eggs overlaid. Black dots represent surveyed sites with eggs absent and white dots represent surveyed sites with eggs present.

4. **To what extent and how (if at all) did this project contribute to the education and advancement of graduate or undergraduate students focused on Great Lakes fishery issues?**

This project contributed to the advancement of Steven Farha, a Masters-level graduate student at Michigan State University, who was involved in data collection. This project will complement his thesis research, which is focused on assessing lake trout spawning habitat selection within the Drummond Island Refuge.

5. **To what extent and how (if at all) did this work help you or others on your team build new relationships with others in the research or management communities?**

   As a result of this project, new relationships were built between researchers from the Great Lakes Fishery Commission (GLFC), Michigan State University, and U.S. Geological Survey (Great Lakes Science Center) and researchers from Michigan Tech Research Institute (a research center of Michigan Technological University located in Ann Arbor, MI).

6. **To what extent and how (if at all) do the findings have action implications for fishery managers?**

   The primary product of this project is a tool that can help Great Lakes fishery managers identify potential lake trout spawning habitat at large scales and at relatively little cost, which will assist in lake trout restoration. The results of this project are too recent to have been applied in management.

7. **Considering the above or other factors not listed, what do you consider to be the most important benefits or outcomes of the project?**

   The most important benefit of this project is the potential to identify and study the characteristics of lake trout spawning habitat in the Great Lakes. Very little is known about these habitats due to the difficulties associated with fieldwork in these large systems. This study evaluated a potentially powerful tool for helping to identifying lake trout spawning habitat at large scales and at relatively low cost, which will advance the ability of researchers to study mechanisms limiting recruitment of Great Lakes lake trout. With further refining, this tool should be useful for helping to identify shallow-water spawning habitats at locations like Boulder Reef, Richard's Reef, and Gull Island Shoal in Lake Michigan, and elsewhere in lakes Huron, Superior, and Ontario.

Related Efforts

8. **Was this project a standalone effort, or was there a broader effort beyond the part funded by the GLFT? Have other funders been involved, either during the time of your GLFT grant or subsequently?**

   This project was associated with and took advantage of products from a larger effort funded by the Great Lakes Restoration Initiative (GLRI) through a project awarded to the GLFC and administered by the USEPA.

9. **Has there been any spin-off work or follow-up work related to this project? Did this work inspire subsequent, related research involving you or others?**

   Follow-up work related to this project is anticipated but has not yet been conducted. In particular, we would like to further refine our technique and apply it to identify previously unknown lake trout spawning sites in the Great Lakes. We have also investigated the feasibility of replacing satellite images with aerial photographs collected with an unmanned aerial vehicle (UAV), which would eliminate many of the challenges associated with procuring high-quality cloud-free satellite images during the right pre- and post-spawning times.

Communication/Publication of Findings

10. **List publications, presentations, websites, and other forms of formal dissemination of the project deliverables, tools, or results, including those that are *planned* or *in process*.**

    A publication based on this research is in preparation for submission to the *Journal of Great Lakes Research* (submission expected in December 2014). A presentation from this research will be given at the IAGLR annual meeting in 2015.

11. **Please characterize your efforts to share the findings of this research with state, federal, Tribal, and interjurisdictional (e.g., Great Lakes Fishery Commission) agencies charged with management responsibilities for the Great Lakes fishery.**

    Results from this research will be shared with state, federal, tribal, and interjurisdictional agencies through the Lake Huron Technical Committee, the Lake Huron Committee, and other Lake Committees at GLFC-sponsored meetings and at a presentation that will be given at the IAGLR annual meeting in 2015.

12. **Please identify technical reports and materials attached to this report by name and indicate for each whether you are requesting that GLFT restrict access to the materials while you seek publication.**

    There are no technical reports or other materials for which we request restricted access.

13. **Manuscripts. Grantees submitting one or more publications or pending publications in lieu of a standalone technical report must submit a cover memo that confirms that all aspects of the funded research are incorporated in the published work, and in cases of multiple publications, identifies or crosswalks the grant-funded objectives to the published article containing results.**

    All aspects of this research will be incorporated into the publication that is in preparation.

Discussion

This study is the first to apply satellite remote sensing to map fish habitat in a Great Lake. The results supported the likelihood that high-resolution multispectral satellite imagery can distinguish among algae densities and detect changes in density over time (Stages A & B), though this should be confirmed with a more robust in situ dataset. The regression model developed from the satellite data performed fairly well at discriminating between sites where lake trout eggs were present vs. absent (Stage C), but the model more accurately predicted sites where eggs were absent than where they were present. The large area predicted to be spawning habitat at the refuge scale suggests that either more field data are needed to tune the model or the spectral parameters included as predictors capture only some of the characteristics of sites used for spawning.

Sites where eggs were deposited tended to be brighter than non-spawning sites in the September satellite image, and the change in brightness between the two dates tended to be more positive for spawning sites. This corresponds with the pre-existing beliefs based on fish observations that lake trout select clean areas of cobble for spawning and that these areas are kept clean during the spawning season. There was a fair amount of overlap in both initial brightness and change in brightness between the two groups, so the inclusion of both in the regression model was necessary for reasonable predictive accuracy. However, the fact that the model was less accurate at predicting sites with egg deposition than sites without egg deposition points to the fact that shallow, nearshore substrates can be cleaned by processes unrelated to lake trout spawning and that not all cleaned substrate will be suitable for over-winter egg incubation.

The results of this method are limited by the clarity of the water in the mapped area. Because northern Lake Huron is fairly clear, the lake bottom could be classified to a maximum depth of approximately 12 m in the obtained images, but the field data indicate that some spawning areas were present in deeper water beyond the satellite bottom detection depth limit. Because of this, this method would not be appropriate for mapping likely spawning habitat at deep-water sites or in areas with significantly lower water clarity than northern Lake Huron.

The pattern of predicted spawning habitat largely corresponds with the locations of shallow submerged glacial features within the study area (Figure 4), which Riley et al. (2014) recently reported are associated with lake trout spawning site selection. However, identification of these bedforms as likely habitat was patchy, and large areas of cobble on these features that became darker and thus likely more heavily vegetated during the spawning season were assigned low probabilities of egg presence. This, combined with the predictive performance of the model, suggests that satellite imagery may be useful for distinguishing submerged features that are likely to support lake trout spawning activity from those that are not, thus, reducing the amount of field surveying required to assess spawning activity in the area.

A major challenge of the study was the need to acquire two cloud-free images of suitable satellite geometry within two different, fairly narrow temporal windows. Especially given the cloudiness of the Great Lakes region in the fall, if the findings of this study were developed into an operational product, it would likely be more feasible to collect aerial imagery. In the course of this study, we performed preliminary tests of a method for acquiring nearshore imagery using a small unmanned aerial vehicle (UAV) with a nadir camera and results indicated that the

UAV images are of sufficient quality to replace satellite images in our analyses. The benefits of using aerial photographs over satellite images are: 1) collection of imagery can be timed more precisely and reliably, as cloud cover will not be an issue, 2) the angle of the photograph is easier to control to optimize optics and reduce issues like sun glint, and 3) the spatial resolution of aerial photographs will be finer than that of satellite photographs. However, surveying an area with a UAV is more labor intensive than with a satellite, and the total area that can be covered with a UAV will be smaller than can be covered by satellite imaging.

In many nearshore areas of the Great Lakes, submerged aquatic vegetation (SAV) cover is increasing due to changes in phosphorus availability and water clarity driven by invasive mussels (Brooks et al. 2014). Given the association of spawning sites with bare cobble, this increase in SAV growth may lessen the availability of suitable spawning sites for lake trout, though this has not been well studied. This project provided an evaluation of the ability to identify lake trout spawning habitats in nearshore areas of the Great Lakes using satellite imagery. Our results suggest that this technique is feasible for the identification of areas used by spawning for lake trout near Drummond Island, and we expect that the technique could be widely applied throughout the Great Lakes.

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