Evaluating the Use of Aerial Imagery to Measure Shoreline Features in Michigan Lakes

by

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Abstract

Aerial and satellite imagery is being investigated in the state of Michigan as a possible supplement in the measurement of lakeshore development features such as house density, dock density, and armored shoreline percent, which are shown to have negative impacts on lake ecosystems. I evaluated the feasibility of using aerial imagery to measure armored shoreline percent by comparing imagery derived estimates of armored shoreline percent with field sampled values from a set of lakes in Michigan and determined that the measurements were comparable. I then performed statistical analyses on a sample of 210 Michigan lakes stratified by three regions to determine relationships between armored shoreline percent, house density, dock density, lake area, and region. Results of the analyses showed that both armored shoreline percent and dock density increased with house density. Region was found to affect dock density. Armored shoreline percent increased with lake area only for lakes larger than 2 km^2, with no relationship in smaller lakes. I then evaluated the usage of aerial images in counting shoreline features using a subset of 50 lakes and the same stratification. Counts for the three features were made using computer software, and statistical analysis was performed between the image estimates and field counts. Region was found to affect the house density image estimates. A majority of the image estimates for house density and armored shoreline percent had accuracies above 90% (considering field values as correct), while estimates for dock density had significantly lower accuracies. There was a 95% probability that an image estimate for house density was within 3.46 units/km of the value obtained from a field sample, an image estimate for dock density was within 10.08 units/km of the value obtained from a field sample, and an image estimate for armored shoreline percent was within 0.33 units of the value obtained from a field sample. Total time spent on the image estimates was 37.50 hours for one person, compared with 98.76 hours for the field samples, which required a crew of two people. These results show that the image estimation method can be successfully used by agencies to reduce the time needed for reliable measurements.

Introduction

Real estate development along the shorelines of North American lakes is rapidly increasing, especially in the Great Lakes region. The primary forms of development are houses and seasonal cabins, which are increasing in number each year. Docks and armored shoreline are typically installed along with the houses and cabins. As a result, the water quality, habitats, and biology of these lakes have been greatly affected (Radomski and Goeman 2001). House development impacts water quality through the placement of impervious surfaces and the replacement of natural vegetation for lawns, leading to higher runoff volume with less natural infiltration and greater nutrient discharge. Runoff includes nutrients such as phosphorus, which are responsible for increased algal growth (Hunt et al. 2006). Coarse woody debris is also reduced, decreasing habitat and cover for fish and macroinvertebrates (Jennings et al. 2001, Christensen et al. 1996). Docks alter or remove submerged vegetation, which serves as fish spawning areas, and contribute to the reduction of floating and emergent vegetation (Radomski et al. 2010). Armored shoreline destroys shoreline vegetation which provides animal habitat, shore protection from waves, and filtration of soil and dissolved nutrients moving into the lake (Engel and Pederson 1998). Increases in all of these features occur at the individual property level but has a cumulative impact on lake habitat (Jennings et al. 1999). Because of this, determining the number of shoreline features along lakeshores is important in evaluating current ecological conditions and planning future management actions.

The State of Michigan Department of Natural Resources has developed the Lakes Status and Trends Program to monitor and assess the impacts of human activities on inland lakes. This program requires field sampling of lakes for the counts of shoreline and habitat features. The traditional method of sampling a lake in Michigan to obtain counts of shoreline features requires travel to the lake and the use of a boat. Two or three people gather data onboard the boat as it travels parallel to the shore at a distance of 30-60 m. Data is recorded in 305 m intervals (transects) which are measured by GPS. For each transect, counts are made of houses, docks, armored shoreline percent, and submerged trees. An index of vegetation cover is also assigned. Houses are counted if they have obvious lake frontage with a contiguous lawn between the dwelling and the lake. Docks are counted only if they are in use (e.g. in the water), with the size and the number of hoists/mooring positions not being evaluated. Armored shoreline percent is a visual estimate of the amount of armoring per transect. Armoring includes wood or steel sheet pilings, cement walls, gabions in a vertical or sloping position, and loosely placed cobble that is more than decorative (Michigan DNR 2004).

Though reliable, field sampling of lakes for counts of shoreline features has several major drawbacks. First, there is a large time requirement consisting of travel time to and from each lake, boat and equipment setup, and the sampling itself. There is also the monetary cost of travel, equipment, supplies, and labor. Field sampling is weather dependent, as strong storms can prevent safe boat operation. Sufficient visibility is required in order to see the shoreline features being counted, which also limits sampling to daylight hours. Because of these constraints, only a limited number of lakes can be sampled in a year while there are thousands of lakes in the state. In order to increase the number of lakes sampled per year and to minimize costs, the Institute for Fisheries Research (a joint unit of the Michigan DNR and the University of Michigan) is investigating the use of aerial photographs and satellite imagery for estimates of house density, dock density, and armored shoreline percent per lake as they can potentially eliminate or reduce the need for field surveys and the cost and time associated with performing them. Free, high resolution aerial images are available through websites like Google Maps (http://maps.google.com) and Bing (http://www.bing.com/maps), which are capable of showing distinct, individual units of shoreline features. The objective of this study was to determine if measurements of shoreline features obtained by using aerial images are comparable to measurements from field samples with a significant reduction in sampling time.

Methods

Approach.—There were several components to this study. First, it was important to evaluate the feasibility of using aerial imagery to measure armored shoreline percent, since this feature is not as readily identifiable as houses or docks. Using a set of test lakes where armored shoreline percent was measured multiple times, I initially compared my measurements of armored shoreline percent from aerial imagery to the field samples to see if comparable results could be obtained. Next, because there is correlation between the different shoreline features and because some features may not be visible in all images, I then conducted a series of statistical analyses to test the hypothesis that armored shoreline percent increases with house density, and the hypothesis that dock density increases with house density along a lakeshore. These hypotheses were tested using a larger set of field sampled lakes from Michigan. Finally, I used aerial imagery to calculate house density, dock density, and armored shoreline percent for a sample of lakes that have field sampled data, and evaluated the accuracy between the results of the two methods.

Preliminary feasibility assessment.—In order to test the feasibility of using aerial imagery to identify and measure armored shoreline, three testing lakes were selected from a list of Michigan lakes in which armored shoreline was measured multiple times. The lakes tested were Crooked Lake and Halfmoon Lake in Washtenaw County, and Wamplers Lake in Jackson County. Crooked Lake and Halfmoon Lake were field sampled three times, while Wamplers Lake was field sampled twice. The Google Earth software (Google 2013) and the “bird’s eye” angled views from the Bing Maps website (Microsoft 2013) were the primary sources of aerial imagery for this study. Google Earth was used to mark and measure armored shoreline segments directly on the image, while the “bird’s eye” views from Bing assisted in armored shoreline identification by showing the vertical contact between the water and land. I produced estimates of armored shoreline percent before looking at the field sampled counts to avoid measurement bias. Using images from both sources, shoreline segments were identified as armored if the appearance was unnatural (such as piles of rocks, concrete, constructed walls, or wooden barriers). After identification, armored shoreline was marked and measured by using the line and measurement tools in Google Earth. The individual line segment measurements (in meters) were added together to produce a total armored shoreline length measurement for each lake. Total armored shoreline percent was obtained by dividing the total length of image estimated armored shoreline by the total perimeter of the lake, which was obtained from Kevin Wehrly (Institute for Fisheries Research, personal communication). The mean armored shoreline percent along with standard deviation was then calculated from the field sampled data for each lake. The difference between the image estimate and the field sampled mean was calculated and divided by the standard deviation of the field sampled mean as a means of comparing the closeness of the measurements. A maximum distance of 2 standard deviations was used as a guideline to consider the two values equal.

Correlation of shoreline feature relationships.—Data were obtained from the Institute for Fisheries Research in a spreadsheet consisting of 332 lakes across Michigan. Data included field measurements for the number of houses and docks, armored shoreline percent, and the perimeter and area for each lake. The number of houses and docks were each divided by the lake's perimeter to calculate house density and dock density respectively, which allowed for density comparisons across lakes of different sizes. For this study, a stratified random sample of 210 lakes was used. Stratification was based on the three major regions in Michigan (Upper Peninsula, northern Lower Peninsula, and southern Lower Peninsula) to account for the large difference in the number of lakes sampled between these regions in the dataset. To randomly select the sample lakes from the dataset, lakes were sorted by region and numbered sequentially from 1 within each region. A random integer generator from random.org was used to select 70 lakes from each of the three regions.

The computer software "R" (R Institue for Statistical Computing 2012) was used to conduct the following statistical analyses. Before recording results, each analysis was first tested for equal variance and normality using NPP and Residual plots and by using the Shapiro-Wilk test for normality. Transformation was needed on all variables because the Shapiro test showed that these variables were not normally distributed ($P < 0.05$). An ANCOVA was used to test if region affected the relationship between house density and armored shoreline percent. From this relationship, the prediction confidence band between house density and armored shoreline percent was calculated in order to evaluate future samples or estimates of armored shoreline percent. Because the number of docks is highly correlated with the number of houses, a separate ANCOVA was used to test if region affected the relationship between house density and dock density. A Tukey HSD test was performed if region was found to have a significant effect on the dependent variable. Finally, a simple linear regression was used to test if lake area had an effect on armored shoreline percent. For all tests, $\alpha = 0.05$.

Evaluation of the use of aerial imagery to count shoreline features.**—**For the study, 50 lakes were selected from the spreadsheet using the same three-region stratification. Lakes were selected to be as evenly geographically distributed as possible under the criteria of sufficient image resolution and feature visibility, in order to eliminate errors based on discrepancy in image quality between different counties. Aerial imagery was obtained from Google Earth, Bing Maps, and the Michigan Department of Natural Resources. Multiple image sources were used to account for differences among them in feature visibility and presence, such as resolution, leaf cover, or season. These differences can cause some features to be visible on one image while causing other features to be visible on another. For all features, a unit was counted if it appeared in at least one image, but not counted if it is clearly not present in the most recent image. Google Earth was the program used to mark and measure these shoreline features. In Google Earth, each lake was represented by a separate folder under the "Places" sidebar, with a single placemark type used for all houses and a second single placemark type used for all docks. Individual units were labeled numerically and sequentially along the lake perimeter, and were saved in the folder of the respective lake. Armored shoreline line segments were unlabeled and also saved in the folder of the respective lake. The computer software "R" was used for all statistical calculations and graphing. Shoreline features were first counted as individual units (single houses and docks, armored shoreline segments). A building on an image was counted as a house unless it was clearly identifiable as another structure based on surrounding features. Houses were counted if they were within 100 m of the lakeshore. An apartment building was counted as one structure and structures clearly associated with a house (such as garages, sheds, barns) were excluded. Docks were counted using summer images if possible, as they are not as prevalent in other seasons. Both parallel and perpendicular docks were counted, while docks attached to other docks were excluded. Shoreline was counted as armored using criteria set in the preliminary feasibility assessment. All feature counts were converted to density by dividing them by the lake perimeter.

Density measures for all three shoreline features per lake were recorded in a spreadsheet where additional values were calculated. Important values calculated for each lake were the percent difference and density difference between the field sampled and image estimated density counts based on the field sample count, and the accuracy of the image estimate indicating how close it is to the field sampled count in terms of percent. Notes were made to explain the abnormally low counts for some of the lakes. Statistical tests were used to determine if additional factors influenced the image estimates. A chi-square test was conducted to determine if the change direction (positive or negative) of the percent/density difference for each feature was dependent on region, and an independent *t*-test was used to determine if the Bing Maps “birds eye” view affected the absolute difference for armored shoreline percent. For the *t*-test, all armored shoreline percent values were transformed using arcsine square root, and all lakes with a field sampled armored shoreline percent of zero along with lakes without an image estimate were excluded. For all tests, $\alpha = 0.05$.

Data distribution of the difference and accuracy values for all three shoreline features was the key measure of how close the image estimates were to the field sampled counts. The maximum, minimum, mean, and median were calculated for the percent difference, density difference, and accuracy of house density, dock density, and armored shoreline percent (excluding density difference for armored shoreline percent). The number of image estimates falling within specified accuracy ranges for each shoreline feature was recorded, along with the percentage of the total number of lakes within those ranges. Accuracy ranges were 90-100%, 80-90%, 70-80%, 60-70%, 50-60%, and < 50% for all features. The 95% range of values for each feature was calculated for both percent difference and density difference using the top 95% of lakes based on the difference value used, to establish the expected maximum deviation for any image estimate for each feature.

Range evaluation.—The image estimates for armored shoreline percent were compared with the field sampled house density counts for each lake using the prediction band for the armored shoreline percent/house density correlation to test if the image estimates fell within expected values with 95% certainty. Transformations of arcsine square root for armored shoreline percent and square root for house density were used as needed. The number of image estimates within the predictive band for the feature was recorded as a percent.

Time calculation for field counts.—The amount of time spent obtaining counts of shoreline features in the field was represented by the equation $y = 0.0384x^{3.7023}$, where *y* was the time spent (in hours) and *x* was the common logarithm of lake area in acres (K. Wehrly, personal communication). This equation was used for each lake in the sample to generate the time spent per lake, and the times for each lake were summed to generate the time spent for the entire sample of lakes.

Time estimation for image estimates.—After all image estimates were made, the amount of time spent obtaining these estimates was calculated based on the average time needed to count individual units for each shoreline feature. Feature units were used instead of lake size because whole sections of the lake could be viewed simultaneously on an image while non-developed sections of the lake could be skipped. Time estimates were made after all image estimates were completed to account for the increase in user sampling speed due to experience. Three lakes were sampled from the dataset for each shoreline feature. House density was estimated for Clifford Lake in Montcalm County, Ford Lake in Washtenaw County, and Long Lake in Cheboygan County; dock density was estimated for Clifford Lake in Montcalm County, Duck Lake in Grand Traverse County, and North Manistique Lake in Luce County; and armored shoreline percent was estimated for Clifford Lake in Montcalm County, Coldwater Lake in Isabella County, and Pratt Lake in Gladwin County. The time estimate per individual feature unit was made by dividing the total feature count by total time (in decimal minutes) taken per lake. The average time per feature unit was obtained by averaging the results from the three lakes sampled. To calculate the total time spent to obtain all image estimates per feature in the sample, the sum of the estimates for a feature was divided by the average time per feature unit and converted to hours. The sums for each feature were then added together to produce the total time spent for all features in the sample. Average time spent per lake was calculated by dividing the total time spent by the number of lakes in the sample. Times were compared between the field sampled total and the image estimated total to evaluate the effectiveness of images in reducing sampling time.

Results

Preliminary Feasibility Assessment for Image Based Assessment of Armored Shoreline

Mean field sampled armored shoreline percents for Crooked, Halfmoon, and Wamplers lakes were 21, 15, and 60 percent respectively, and image estimated armored shoreline percents were 37.4, 24, and 58.2 percent respectively (Table 1). For all three lakes, the difference between the image estimate and the average field count of armored shoreline percent was less than 2 SD: 0.89, 1.11, and 1.27 SDs, respectively. For this reason, the image estimates were considered to be equivalent measurements to the field sampled counts.

Table 1: Armored shoreline percent ($AS_{\%}$) values for three Michigan lakes showing measurements obtained from on-the-lake boat surveys (field sampled) and measurements derived from aerial imagery along with the absolute difference in means of the two sampling methods for each lake, measured in standard deviations.

Sample	**Lake**	**Field-Sampled $AS_{\%}$**	**Aerial Imagery-Derived $AS_{\%}$**	**Absolute Difference in Means (in SDs)**
1	Crooked	9		
2	Crooked	11		
3	Crooked	42		
	Mean	**21.0**	**37.4**	**0.89**
	SD	**18.5**		
1	Halfmoon	11		
2	Halfmoon	9		
3	Halfmoon	24		
	Mean	**15.0**	**24.0**	**1.11**
	SD	**8.1**		
1	Wamplers	59		
2	Wamplers	61		
	Mean	**60.0**	**58.2**	**1.27**
	SD	**1.4**		

Relationships between Armored Shoreline and House Density, Dock Density, and Lake Area

The ANCOVA of house density and armored shoreline percent showed that the interaction between region and house density was not significant ($F_{2,\,204} = 2.722$, $P = 0.0681$) (Table 2). As such, the relationship was simplified to a univariate linear regression, which showed a significant relationship between house density and armored shoreline percent ($F_{1,\,208} = 147.7$, $P < 2*10^{-16}$, $R^2 = 0.41$) (Table 3). The slope (b = 0.12) indicated an increase in armored shoreline percent with an increase in house density per lake (Figure 1).

Table 2: ANCOVA table for the relationship between house density in conjunction with location and armored shoreline percent. Bold values indicate significant relationships.

	Df	**SS**	**MS**	**F value**	**P value**
sqrt_houses	1	9.275	9.275	**151.516**	**$<2*10^{-16}$**
Region	2	0.240	0.120	1.958	0.1438
Interaction	2	0.333	0.167	2.722	0.0681
Residuals	204	12.488	0.061		

Table 3: ANOVA table for the linear regression between house density and armored shoreline percent. Bold values indicate significant relationships.

	Df	**SS**	**MS**	**F value**	**P value**
Houses	1	9.275	9.275	**147.7**	**$<2*10^{-16}$**
Residuals	208	13.061	0.063		

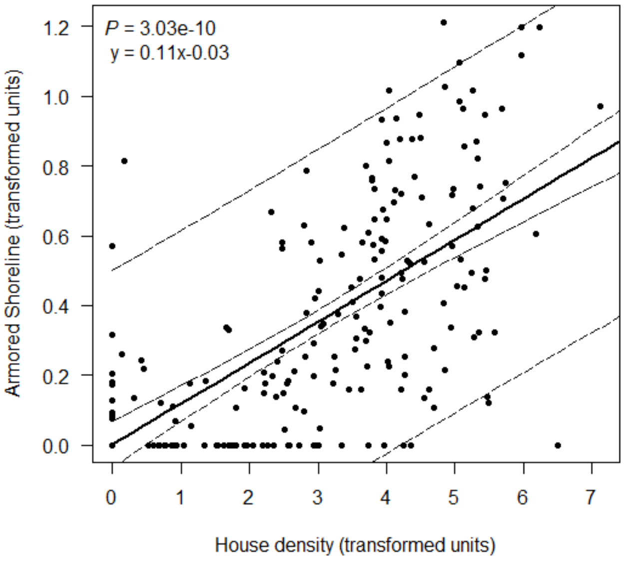

Figure 1: The relationship between armored shoreline percent and house density for a stratified random sample of 210 Michigan lakes. The solid black regression line confirms that arcsine square root transformed armored shoreline percent increased with the square root transformed house density. Dashed lines close to the regression line represent the 95% confidence interval and the second set of dotted lines represents the 95% prediction interval. The prediction interval was calculated to be ± 1.00 transformed armored shoreline units.

The ANCOVA of house density and dock density had a non-significant interaction between house density and region ($F_{2, 204} = 2.22$, $P = 0.111$) (Table 4), but there was a significant relationship between dock density and region. As such, only the interaction was removed from the ANCOVA model. The simplified model showed that there was a significant relationship between region and dock density ($F_{2, 206} = 13.03$, $P = 4.7*10^{-6}$) and a significant relationship between house density and dock density ($F_{2, 204} = 3726.71$, $P < 2*10^{-16}$, $R^2 = 0.95$) (Table 5). The common slope for all locations (b = 0.89) indicated an increase in dock density with an increase in house density per lake that was close to a 1:1 ratio (Figure 2). The Tukey HSD test showed that the difference in dock density between the southern Lower Peninsula and northern Lower Peninsula was not significant ($P = 0.1309$), but the difference was significant between the Upper Peninsula and northern Lower Peninsula ($P = 9*10^{-7}$) and between the Upper Peninsula and southern Lower Peninsula ($P < 10^{-8}$).

Table 4: ANCOVA table for the relationship between house density in conjunction with region and dock density. Bold values indicate significant relationships.

	Df	**SS**	**MS**	**F value**	**P value**
Houses	1	565.6	565.6	**3726.71**	**$<2*10^{-16}$**
Region	2	4.0	2.0	**13.18**	**$4.13*10^{-6}$**
Interaction	2	0.7	0.3	2.22	0.111
Residuals	204	31.0	0.2		

Table 5: Simplified ANCOVA table for the relationship between house density and dock density with the interaction between house density and location being non-significant. Bold values indicate significant relationships.

	Df	**SS**	**MS**	**F value**	**P value**
Houses	1	565.6	565.6	**3683.09**	**$<2*10^{-16}$**
Region	2	4.0	4.0	**13.03**	**$4.7*10^{-6}$**
Residuals	206	31.6	31.6		R^2=0.9474

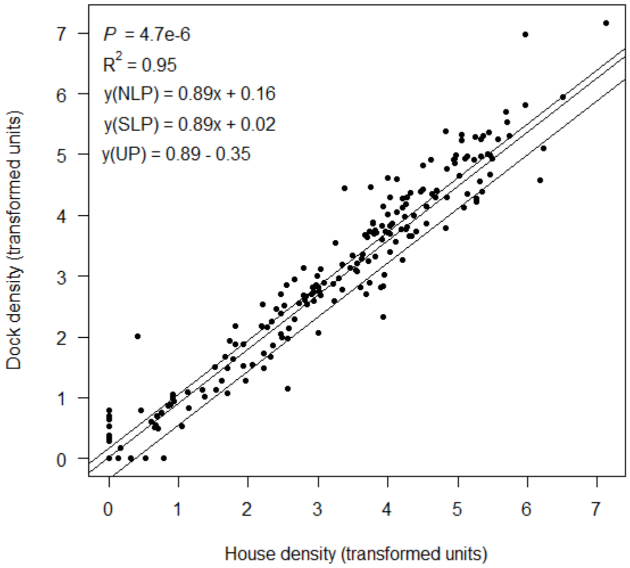

Figure 2: An ANCOVA was performed on a stratified random sample of 210 Michigan lakes with the relationship between square root transformed dock density and region being significant. *P*-value for this relationship is shown. The transformed dock density was shown to increase with the square root transformed house density. Equations are shown for three regions: northern Lower Peninsula (NLP, top line), southern Lower Peninsula (SLP, middle line), and Upper Peninsula (UP, bottom line) of Michigan. Slopes for all three locations were the same, with a Tukey HSD test showing a significant difference in dock density between the UP and NLP ($P = 9*10^{-7}$) and between the UP and SLP ($P < 10^{-8}$).

The linear regression between lake area and armored shoreline percent could not be normalized with variable transformation for the entire range of area values. However, an initial scatter plot of the two untransformed variables showed that there was an abrupt switch in the relationship at a lake area of 2 km^2 (Figure 3). Shapiro test results showed that there was non-normality for lakes under 2 km^2 in area ($P = 1.8*10^{-4}$), and normality for lakes greater than 2 km^2 in area ($P = 0.2601$). A simple linear regression was performed on the subset of lakes with areas greater than 2 km^2. This regression showed that there was a significant relationship between area and armored shoreline percent for this subset ($F_{1, 52} = 9.721$, $P = 0.00297$, $R^2 = 0.15$) (Table 6). The slope (b = 0.11) indicated a slight increase in armored shoreline percent with increasing lake area (Figure 4).

Table 6: ANOVA table for the linear regression between natural log transformed lake area and arcsine square root transformed armored shoreline percent for the subset of sampled of Michigan lakes greater than 2 km^2 in area . Bold values indicate significant relationships.

	Df	SS	MS	F value	P value
Area	1	0.780	0.7798	**9.721**	**0.00297**
Residuals	52	4.171	0.0802		R^2=0.1575

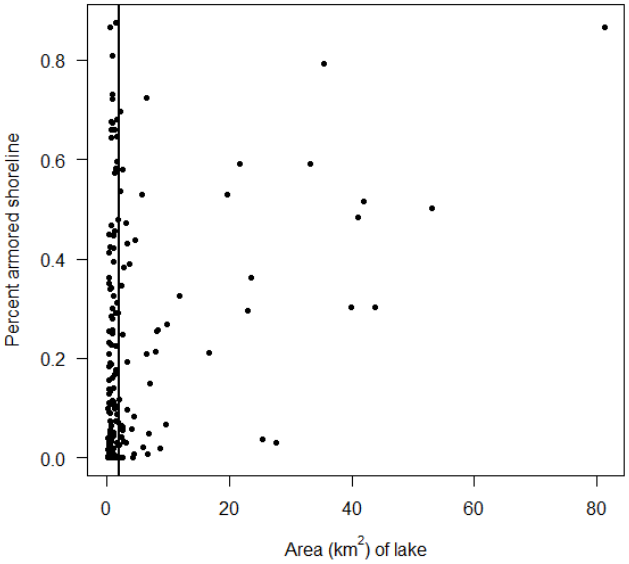

Figure 3: Scatterplot showing the distribution of armored shoreline percent and lake area for a stratified random sample of 210 Michigan lakes. Vertical line indicates the 2 km^2 division between normally distributed larger lakes (*P* = 0.2601, *N* = 54) and non-normally distributed smaller lakes (*P* = 1.8*10^{-4}, *N* = 156).

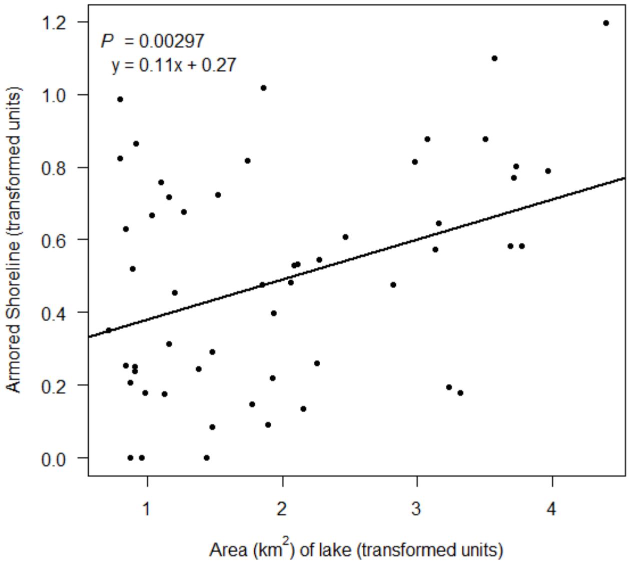

Figure 4: A simple linear regression on a stratified random sample of 54 Michigan lakes with lake area > 2 km^2 was performed on with *P*-value shown. The arcsine square root transformed armored shoreline percent was shown to increase with the natural log transformed area based on the equation shown.

Preliminary Statistical Tests of Other Variables

The chi-square test of change direction and region for house density showed a significant relationship between change direction and region ($X^2 = 8.198$, $P = 0.0165$) (Table 7). Based on the table, the house density image estimates for lakes in the northern Lower Peninsula tend to be larger than the field counts, while those in the Upper Peninsula tend to be smaller than the field counts. Location did not appear to affect change direction in house density among lakes in the southern Lower Peninsula. The chi-square tests of change direction and region for dock density and armored shoreline percent showed no significant relationship between change direction and region ($X^2 = 4.561$, $P = 0.1022$ dock density; $X^2 = 1.851$, $P = 0.3963$ armored shoreline percent) (Table 2, Table 3). Region did not appear to affect change direction for these features.

Table 7: Chi-square table testing if region affected the change direction of the difference between image estimates and field counts of house density in a subset of Michigan lakes. Bold values indicate significant relationships.

Region	**Obs (-)**	**Obs (+)**	**Obs (Tot)**	**Exp (-)**	**Exp (+)**	**Exp (Tot)**	**X^2**	**Df**	**P value**
NLP	2	8	10	5.23	4.77	10	**8.198**	2	**0.0165**
SLP	13	10	23	12.02	10.98	23			
UP	9	2	11	5.75	5.25	11			
Total	23	21	44	23	21	44			

Table 8: Chi-square table testing if region affected the change direction of the difference between image estimates and field counts of dock density in a subset of Michigan lakes. Bold values indicate significant relationships.

Region	**Obs (-)**	**Obs (+)**	**Obs (Tot)**	**Exp (-)**	**Exp (+)**	**Exp (Tot)**	**X^2**	**Df**	**P value**
NLP	4	6	10	6.52	3.48	10	4.561	2	0.1022
SLP	16	8	24	15.65	8.35	24			
UP	10	2	12	7.83	4.18	12			
Total	30	16	46	30	16	46			

Table 9: Chi-square table testing if region affected the change direction of the difference between image estimates field counts of armored shoreline percent in a subset of Michigan lakes. Bold values indicate significant relationships.

Region	**Obs (-)**	**Obs (+)**	**Obs (Tot)**	**Exp (-)**	**Exp (+)**	**Exp (Tot)**	**X^2**	**Df**	**P value**
NLP	6	2	8	4.8	3.2	8	1.851	2	0.3963
SLP	15	9	24	14.4	9.6	24			
UP	6	7	13	7.8	5.2	13			
Total	27	18	45	27	18	45			

The independent *t*-test for differences in armored shoreline percent based on image source indicated that the image source had no effect on the absolute difference ($t = 1.7812$, df = 43, $P = 0.0819$). The “birds eye” Bing imagery did not appear to either improve or detract from the armored shoreline percent image estimates.

Differences between Image Estimates and Field Counts

In both percent difference and absolute difference, the maximum and minimum values for house density and armored shoreline percent were significantly closer to zero than those of dock density, which indicated a smaller range of difference values (Table 10). Mean and median difference values for house density and armored shoreline percent were close to zero, which indicated a balance of positive and negative values. In assessing accuracy of the image-derived values, it was assumed that field values were correct. Mean and median accuracy values for house density and armored shoreline percent were above 90% with a minimum value of around 50%, which indicated a large distribution of high accuracy values. These values were lower for dock density, which indicated a more dispersed distribution.

Table 10: Chart of the maximum, minimum, mean, and median values for the percent difference (top), density difference (middle), and accuracy (bottom) of the three measured shoreline feature units. Differences equaled the field count minus the image estimate for each feature per lake in a subset of Michigan lakes. Accuracy equaled the inverse of the absolute value for percent difference. There were no density difference values for armored shoreline because percent difference equals density difference (armored length/shoreline length). Outliers were excluded from this chart.

Unit	**Maximum % difference**	**Minimum % difference**	**Mean % difference**	**Median % difference**
House	39%	-36%	-2%	-1%
Dock	67%	-77%	-12%	-7%
Armor	31%	-52%	-3%	-1%

Unit	**Maximum density difference (units/km)**	**Minimum density difference (units/km)**	**Mean density difference (units/km)**	**Median density difference (units/km)**
House	4.09	-4.72	-0.20	0
Dock	6.02	-10.40	-2.02	-0.48

Unit	**Maximum accuracy**	**Minimum accuracy**	**Mean accuracy**	**Median accuracy**
House	100%	61%	92%	96%
Dock	100%	23%	76%	81%
Armor	100%	49%	90%	94%

The specific distribution of the accuracy values for house density, dock density, and armored shoreline percent indicated that a sizeable majority of image estimates for house density and armored shoreline percent had an accuracy level of 90% and above (70% and 68% respectively), with significantly lower proportions in the lower accuracy levels. However, there were significantly fewer image estimates for dock density having an accuracy level of 90% and above (39%), with higher proportions in the lower accuracy levels (Table 11). Based on these distributions, image estimates of house density and armored shoreline percent were more accurate than image estimates of dock density.

Table 11: Number of lakes having an image estimated accuracy within specified accuracy ranges for the three measured shoreline variables, and the percentage of the total number of lakes within those ranges. Outliers were excluded from this table.

	House		**Dock**		**Armor**	
Accuracy Level	**#**	**% of total**	**#**	**% of total**	**#**	**% of total**
90-100%	32	70%	19	39%	32	68%
80-90%	7	15%	6	12%	9	19%
70-60%	4	9%	8	16%	2	4%
60-70%	2	4%	7	14%	3	6%
50-60%	0	0%	3	6%	1	2%
<50%	1	2%	6	12%	0	0%

Range Testing

Using the prediction range from the house density/armored shoreline percent correlation, 43 out of 47 total armored shoreline percent image estimates fell within the 95% prediction interval, yielding an accuracy of 91.5%. This accuracy indicated that the image estimates were within the expected range and that there were no major systemic errors from the image estimation method.

Range calculations for house density, dock density, and armored shoreline percent based on the accuracies for the image estimates were as follows (Table 12). The use of both percent and density range values depending on the size of the image count did detract significantly from the 95% range for the individual calculations. The dock density 95% ranges were greater than two times the house density 95% ranges. Based on these ranges, there was a 95% probability that an image estimate for house density was within 3.46 units/km of the value obtained from a field sample, an image estimate for dock density was within 10.08 units/km of the value obtained from a field sample, and an image estimate for armored shoreline percent was within 0.33 units of the value obtained from a field sample.

Table 12: Range calculation table for house density, dock density, and armored shoreline percent, based on the highest 95% of accuracy values for each feature. "x" represents the image estimated count for that feature, and "z" represents the image estimated count which produced equal percent and density ranges. The percent range was used for values less than z, and the density range was used for values greater than z to preserve balance. There were no density difference values for armored shoreline because percent difference equals density difference (armored length/shoreline length)

Feature	Percent range	Density range	Percent=Density	Estimates in range
House density	x ± 0.27x	x ± 3.46 h/km	z = 12.81 h/km	93%
Dock density	x ± 0.67x	x ± 10.08 d/km	z = 15.04 d/km	92%
Percent armor	x ± 0.33	N/A	N/A	95%

Time Estimates

The amount of time spent obtaining counts of shoreline features in the field for all lakes in the sample was calculated to be 98.8 hours, while the amount of time obtaining image estimates for all lakes in the sample was calculated to be 37.5 hours. Average time spent per lake for field counts was 1.98 hours, while the average time spent per lake for image estimates was 0.75 hours. The amount of time saved by the image estimates was estimated to be 38% of the field count time.

Discussion

Correlation of Shoreline Feature Relationships

Armored shoreline on lakeshores is strongly associated with the presence of houses, as homeowners install armoring to protect their properties from soil erosion and wave action (Engel and Pederson 1998). The significant relationship between armored shoreline percent and house density per lake allows for a rough estimate of the armored shoreline percent given a specific house density. This estimate is facilitated by the prediction interval, which can be useful in determining a reasonable range of values for armored shoreline percent on a lake. However, there was considerable scatter around the regression line which does not make prediction from the regression equation a suitable alternative for actual measurements, specifically at higher house densities. This relationship does assist with imagery measurements, as the range of armored shoreline percent can be used to check if a given measurement is acceptable or not. This can help determine if additional resources are needed beforehand to increase efficiency. Specifically, if a measurement of armored shoreline percent from aerial imagery falls outside of the predicted range, it is likely that an error was made in the measurement and the armored shoreline percent should be resampled. Another possibility is that for repeated measurements outside the range, the imagery used does not accurately portray armored shoreline. In this case either additional imagery or field measurements are needed for that particular lake.

The relationship between house density and armored shoreline did not depend on which of the three major regions in Michigan the lake was in. However, dock density appeared to be higher in the Upper Peninsula for any given house density. Lakes in the Upper Peninsula tend to be larger than those in the Lower Peninsula based on the dataset, and they might be able to support a higher density of boat activity. Thus, in order to estimate dock density from the house density of a lake, a separate equation is needed for lakes in the Upper Peninsula than what is used for lakes in the Lower Peninsula. The relationship between lake area and the amount of armored shoreline was also statistically significant, but only for lakes above 2 km^2 in area. This is likely due to wave action increasing with lake area, with 2 km^2 possibly representing a point where wave forces begin to cause levels of erosion sufficient enough to prompt homeowners to install armored shoreline (Wehrly et al. 2012). This relationship did not explain much of the variation in the regression line ($R^2 = 0.15$) and so may not be as useful as other factors in estimating armored shoreline percent. A possible future study could involve the analysis of wave forces as a function of lake area, and the resulting influence on armored shoreline percent.

Accuracy Assessment of Image Estimated Shoreline Feature Counts

The accuracies of the image estimated house densities, dock densities, and armored shoreline percent followed a similar pattern: large number of lakes with accuracies above 90%, with lower numbers in successive 10% ranges. The majority of image estimates for house densities and armored shoreline percent were above 90%, indicating that aerial imagery derived measurements are just as reliable as field sampled measurements for the majority of samples. For dock density, however, the majority of accuracies were below 90% with a range that extended well below the accuracy values of house density and armored shoreline percent. There are several reasons for this discrepancy. First, docks are more often in use during the warmer months of the year and are not visible during the colder months. Because not all lakes have summer images available, there can be errors in the number of docks recorded in some lakes. Even by using the summer images, docks can be obscured by shoreline vegetation prevalent during that period. Finally, many docks are non-permanent structures and can be added or removed from the property, changing the dock count depending on the image date.

The most useful measure of the relative accuracy of image estimated density compared to field sampled density is the range calculation, as it gives a single index of how close an image estimate is to a corresponding field count with 95% certainty. It shows a result similar to the analysis of accuracies, as the range of maximum dock density differences was three times higher than that of house density. The range calculations are reliable estimates as to what range of values the actual density count can be, based on the image estimate.

The image estimation method cut sampling time by 38% based on the field sampling time alone. Although this does not take into consideration the travel and set-up time that was eliminated by using this method, it is still a significant amount of savings. As this image estimation method is new, the time estimates are only approximations and can change with the sampling experience of the user and the refinement of sampling procedures. Even so, the image estimation method has shown tremendous potential in sampling time reduction and should be refined further.

Limitations and Recommendations for Future Study

Correlation of shoreline feature relationships.—Although this study showed a strong correlation between armored shoreline percent and house density, other variables that could influence how much armoring a lakeshore has should be included to improve the strength of the relationship. Other possible factors include the surrounding land use type, amount of lakeshore erosion, amount of shoreline vegetation, and the distance of houses from a lakeshore. These unknowns mean that sampling, (field or imagery) is still required to obtain reliable measurements of armored shoreline percent. Another limitation in the study design is that there were twice as many lakes sampled in the southern Lower Peninsula than for each of the other two regions in the dataset, which was why equal numbers of lakes were subsampled from each region. Also, the specific location of houses and armored shoreline along the lakeshore were not taken into account, so it is not conclusive that armored shoreline increases in the proximity of houses. Future studies should use spatial analysis techniques to evaluate the spatial concordance between these two and additional variables.

Accuracy assessment of image estimated shoreline feature counts.—Although the image estimation method appears to be satisfactory in producing accurate house density counts, there were certain errors which prevented this method from achieving greater accuracy. First, non-house structures could have been counted in the image estimates due to difficulties in identifying the types of structures from an aerial view. Guidelines for determining which structures count as houses in an image should be developed to aid in this process. Tree cover can also obscure structures in an aerial image, but this can be mitigated somewhat by using images from the winter months. The year the image was taken is also significant since structures may have been built or demolished between the date of the image and that of the field sample. Finally, although it is known that increases in the counts of any of the three shoreline features has a measurable impact on lake habitat, a specific relationship between size of feature count and size of specific lake impact is not clear. This means that it is difficult to fully evaluate the image estimation method apart from considering its utility and relative performance in lake impact assessment. I recommend initially using the image estimation method in conjunction with field sampling, to determine if the levels of accuracy seen in this study are sufficient for the needs of the impact assessment.

In conclusion, this study has shown that image estimation of shoreline features is comparable to field sampled measurements with a significant reduction in sampling time, which will allow agencies to spend less money, time, and resources on obtaining counts of house density, dock density, and armored shoreline percent along lakeshores. Even though estimates of dock density are not as accurate as estimates of the other features, the strong relationship between this feature and house density allows for potential extrapolation of dock density from house density. As the quantitative relationship between the size of the shoreline feature count and specific habitat effects is more fully known, image estimation will become a powerful tool in lakeshore management.

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