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DISTRIBUTION AND POPULATION DYNAMICS OF BEECH
SCALE (*CRYPTOCOCUS FAGISUGA*) IN MICHIGAN

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Daniel Wieferich

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M.S. degree in Fisheries and Wildlife

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DISTRIBUTION AND POPULATION DYNAMICS OF BEECH SCALE (*CRYPTOCOCUS FAGISUGA*) IN MICHIGAN

By

Daniel Wieferich

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

DISTRIBUTION AND POPULATION DYNAMICS OF BEECH SCALE (*CRYPTOCOCUS FAGISUGA*) IN MICHIGAN

By

Daniel Wieferich

Beech scale is a newly invading insect pest in Michigan, and consequently little is know about their distribution and population dynamics. Beech scale densities were estimated using qualitative visual assessments and a new quantitative method of digital photography. Samples from 803 sites, from 2005-2009, across Michigan show that beech scale has infested most of the distribution of beech in the Upper Peninsula, and the north and western ranges of beech in the Lower Peninsula. In addition, beech scale was found on several islands. Beech scale is distributed in 12 satellite populations, which differed in density and spread rates. Also, some satellite populations are on islands further from the mainland than wind dispersal is thought to carry scales. Four of five satellites tracked from 2007-2008 showed increases in density whereas one satellite declined. Within-year scale densities follow beech scale biology, showing slight decreases in summer months when adults die, increases in fall when the new generation of beech scale become visible, and slight decreases or no change in winter months when scales are dormant.

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This research would not have been possible without the generous financial support by the United States Forest Service PTIPS Program, thank you.

I would also like to recognize a few of the people who assisted with my research. My advisors Daniel Hayes and Deborah McCullough, and my committee member Gary Roloff have helped me immensely throughout my graduate program. In addition, my numerous field/lab assistants have been crucial in collecting and analyzing my data. These assistants included Jon Wagner, Christy Thomas, Shayna Hart, Justin Miller, Justin Hodgins, Nicholas Wieferich and James Wieferich.

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Introduction

Beech scale *(Cryptococcus fagisuga Lind.)*(Hemiptera; Coccidae) is a sap-feeding insect native to western Asia and southeastern Europe (Gwiazdowski et al. 2006) that is invasive throughout North America. In North America, beech scales are host specific, feeding only on American beech (*Fagus grandifolia*) (Ehrlich 1934). Although beech scales reproduce annually, each parthenogenic adult can lay up to an estimated 50 eggs (Wainhouse and Gate 1988), making populations capable of rapid expansion. Beech scales are only mobile as 1^{st} instars, the stage also known as crawlers (Ehrlich 1934). During this stage, crawlers move to a suitable location on their current tree or disperse to another host tree. Wind is thought to be the main vector of dispersal (Felt 1933; Wainhouse 1980), although migratory birds, wildlife and human movement of infested logs may also play a role in dispersal (Ehrlich 1934; Houston 1994; Morin et al. 2007). After dispersing to a suitable location, scales insert their stylets into the bark and begin to feed on the sieve cells in the secondary phloem of the tree (Telewski 2009). Scales secrete white waxy wool over themselves as they feed. At this stage scales molt and become immobile for the remainder of their lives.

When beech scales pierce the bark of beech trees they allow entry of two native fungi, *Neonectria faginata* Castleburry et al. and *Neonectria ditissima* (Tul.& C.Tul.) Samuels and Rossman, into the trees (Elrich 1934; Castlebury et al. 2006). Once established on a tree, *Neonectria* will progress through and kill the living tissues of bark, cortex, phloem, cambium, and sapwood (Ehrlich 1934). As lesions coalesce, the tree looses capabilities to transport and store nutrients, which kills or reduces the health of the tree (Ehrlich 1934).

Three phases of BBD have been defined (Shigo 1972; Houston and O'Brien 1983; Houston 1994). The "advancing front", refers to an area newly infested with beech scale and without *Neonectria* infestation (Houston and O'Brien 1983). The second phase is known as the "killing front", which represents areas occupied by large populations of beech scale and abundant *Neonectria* infection, causing beech mortality. As the killing front of beech bark disease passes through a landscape, an estimated 50 % of beech trees over 25 centimeters in diameter are expected to die (Houston 1994). The third and final phase of BBD is the "aftermath forest", referring to areas where the disease is well established and continually affects current and regenerating beech trees. In aftermath forests, beech scale populations decline because most surviving beech trees are reduced in health from the *Neonectria* invasions (Shigo 1972; Houston 1994).

Beech scale, *Neonectria faginata* and *Neonectria ditissima* were documented in Michigan for the first time in 2000 (O'Brien et al. 2001; Castlebury et al. 2006), placing the state's beech resource at risk from beech bark disease. Michigan has approximately 15 million beech trees over 22 centimeters in diameter at breast height (DBH) (Heyd 2005). These trees provide food and habitat for many species of wildlife such as black bear, white tailed deer, and ruffed grouse (Burns and Honkala 1990). American beech trees are also valued economically for use in pulpwood production, flooring, furniture, veneer, plywood, charcoal, baskets and other woodenware (Burns and Honkala 1990). In addition, beech trees are valued aesthetically, both in natural settings and as ornamental trees.

A critical step in the management of an invasive species such as beech scale is to determine the distribution of the invader and its hosts. Morin et al. (2005) mapped the approximate beech distribution by interpolating the U.S. Forest Service forest inventory analysis (FIA) (Hansen et al. 1993) basal area data for the northeastern United States, including Michigan. Although this dataset shows beech distribution in Michigan, it was at a coarse 1 km resolution (Morin et al. 2005). In addition, FIA plots are only located in forested areas, which would not detect beech trees in other land types such as urban and agricultural areas.

The distribution of beech scale has not been fully documented for Michigan. From 2001 to 2003, Petrillo et al. (2005) monitored beech scale in Michigan to evaluate impacts of beech bark disease. This study, however, focused on selected areas of the state, and did not develop a complete state-wide map of the distribution of beech scale. Similarly, from 2002 to 2003, Kearney et al. (2005) evaluated the impact of beech bark disease on wildlife resources, in a subset of established plots by Petrillo et al. (2005). Morin et al. (2007) described the broad-scale distribution and predicted spread of beech scale across the eastern United States, including Michigan. Their study, however, their study provided only a coarse level of resolution at a county level. In this study, we implemented an intensive survey to document the statewide distribution of beech scale and beech trees spanning most of Michigan. Beech scale distribution was documented for a five year timeframe, enabling us to assess the progression of the advancing front over time. We mapped the annual distribution of beech scale in Michigan from 2005-2009 and determined the annual change in beech scale distribution (area) for the sampled years.

Methods

From May to August of 2005, we established 418 sites in 73 of Michigan's 83 counties (Figure 1.1). Sites were primarily on forested lands, but beech trees in agricultural and urban landscapes were also sampled. The beech basal area map produced by Morin et al. (2005) and a spatial land use layer provided by the Michigan DNR (MDNR) assisted us in locating areas potentially containing beech trees. As discussed the Morin et al. (2005) map used FIA data to estimate beech basal area at a 1km resolution. The MDNR spatial layer (30 m resolution), known as Integrated Forest Monitoring Assessment and Prescription (IFMAP) (MDNR 2003), allowed us to identify areas designated as northern hardwood cover type, which often includes beech (MDNR 2003) (Figure 1.2). Although these sources helped to initially guide sampling, additional areas were also explored to determine whether beech trees and beech scale were present. This ensured that a high proportion of the beech resource was included in the study. In addition, this allowed us to evaluate the usefulness of the IFMAP layer for locating beech trees. All of our sites containing beech trees were overlaid on the IFMAP layer to determine the proportion of sites that corresponded with northern hardwoods using ESRI® ArcMap.

Stands were initially examined for beech tree presence from the roadside. If the habitat appeared suitable, but no beech was seen from the road, we walked through the stand. Two types of sites were established, depending on accessibility of land. The first type of site was located on public land or on private land where we had permission to access the property. In these sites three variable-radius plots were established using a Panama 10 basal area factor (BAF) angle gauge (prism). Handheld GPS units (Garmin

Etrex), supporting 30 m accuracy, were used to collect coordinates of plot centers. A center plot was identified as the first area encountered with at least three large beech trees. Then two additional plots, one established 100 m to the north or south of the center plot, and the second 100 m to the east or west. The directions for the second and third plots were randomly selected, unless property lines limited their directionality, in which case we re-randomized and selected from assessable directions. At each site, the basal area of the stand was recorded using the 10 BAF prism and each beech tree in the three plots was evaluated for beech scale presence by visually examining the most visible portion of the tree (below 4 meters). If the upper portions of the trunk or branches were visibly infested, we recorded it.

The second type of site was established in areas with limited or minimal access (e.g., private property) and in non-forested areas (e.g., roadside parks, campgrounds, landscape trees). In areas with limited access, we sampled the first ten beech trees encountered along the road to assess presence of beech scale. Similarly in non-forested areas, we sampled the first ten beech trees encountered. On some occasions, less than ten beech trees were available, in which case we sampled all available beech trees. Similar to variable radius plots, beech scale infestation was determined by visually examining each tree.

From May to August in 2006 to 2009, we continued to sample the areas across Lower and Upper Michigan (Figures 1.4 – 1.7). When beech scale was detected, additional sites were established in concentric circles approximately 1 km apart to accurately delineate the advancing front every summer. Also, sites where beech scale was absent in the previous year, but located in close proximity (< 5 km) to the advancing front were revisited to assess the advancement of beech scale over time. In situations where beech scale was present at revisited sites, the next closest, previously uninfested site was revisited. This process continued until a buffer of uninfested sites was established. If few sites with beech trees existed along the advancing front, an adaptive sampling technique was used to fill gaps in the sampling distribution. This technique involved establishing new site locations within 10 km of sites known to be infested and in between the advancing front and the closest uninfested sites. The availability of these sites was limited by beech presence and land accessibility. Once beech scale infestation was observed, a site was assumed to have beech scale through the remainder of the study and therefore was not resampled.

In 2006, 48 sites that were uninfested in 2005 were revisited and 231 new sites were established. In 2007, 43 sites that were uninfested in 2006 were revisited and 52 new sites were established. In 2008, 60 sites that were uninfested in 2007 were revisited and 21 sites were created. In 2009, 103 sites that were uninfested in 2008 were revisited and 81 sites were created. Over the study as a whole, 803 sites were established and 254 revisits were performed (Figure 1.7). The sites were distributed across 11 of 15 counties in the Upper Peninsula and 62 of 68 counties in the Lower Peninsula.

Beech trees on six of the state's larger islands were examined, including Beaver, Bois Blanc, Drummond, Mackinac, North Manitou and South Manitou Islands. These islands differed substantially in size (roughly 14.5 to 645 km^2) and location (< 2 to 24 km from mainland) (Table 1.1). Similar techniques were used to sample islands as on the mainland. Due to time and money constraints, islands were not sampled every year (Table 1.1).

After sampling was completed, results were imported into ESRI® ArcGIS 9.2. We defined satellite populations, which represented beech scale infestations separated geographically from one another by at least 20 km of uninfested stands with some beech component. Using the Hawth's Analysis Tools extention in ArcMAP (Beyer 2004), the total infested area of each satellite population was calculated for each year using the minimum convex polygon (MCP) method. Mohr (1947) defines a MCP as the complete enclosure of all data points by connecting the outer locations in such a way as to create a convex polygon. Areas of minimum convex polygons for consecutive years were compared to evaluate annual change in beech scale distribution.

Results

Distribution of Beech Trees and Evaluation of Beech Tree Spatial Data Layers

Beech trees were located in 696 sites in 57 of the 73 sampled counties in Michigan (Figure 1.7). Beech occurred across the majority of the Lower Peninsula, including 49 of the 62 sampled counties (Figure 1.7). Although beech was widely distributed, our data showed that most beech was concentrated in the north and western parts of the Lower Peninsula. On the other hand, in the Upper Peninsula, our sampling located beech trees across the eastern eight counties. In addition, beech trees were present on all six of the islands we sampled.

The documentation of beech distribution allowed us to make comparisons with other spatial data sets that can be used to predict the occurrence of beech. The northern hardwoods layer of IFMAP was a poor indicator of beech presence. Of our 696 sites with beech, only 140 sites overlapped with land classified as northern hardwoods. The remaining 556 sites did not overlay areas classified as the northern hardwood type. These results show that overall, the distribution of northern hardwood cover type underestimates the range of beech trees in Michigan. In some cases, such as the western portion of the Upper Peninsula, extensive areas classified as northern hardwoods in IFMAP had no beech (Figure 1.2). Morin et al. (2005) mapped beech basal area using FIA data, which we qualitatively compared to our observed occurrence of beech. The datasets showed generally good correspondence between beech tree presence and absence across the state, except in regions dominated by agricultural and urban environments (e.g. southeastern Michigan).

Distribution of Beech Scale in the Lower Peninsula

In 2005, beech scale was distributed across substantial areas in the north and western portion of Michigan's Lower Peninsula (Figure 1.1, Figure 1.8 and Table 1.2). Three distinct satellite populations of beech scale were identified in the Lower Peninsula near Cadillac, Ludington and in Emmet counties (Figure 1.8), covering approximately 2,667 km^2 (Table 1.2).

From 2005 to 2009, beech scale distribution across the Lower Peninsula substantially increased. Area infested increased every year (Table 1.2), but expanded especially from 2006 to 2007, where it increased by 35%. Overall, the beech scale distribution expanded by 146 %. A new satellite population was detected in Charlevoix in 2006, where one isolated group of beech trees was infested. Two additional satellite populations were discovered in 2009, one in Crawford county and one in Cheboygan county (Figure 1.8). Also, the Cadillac and Ludington populations coalesced in 2009.

Even with the spread over the last five years, much of the forested area containing beech in the eastern part of the Lower Peninsula remains uninfested.

There were large differences in overall expansion of beech scale distribution between the different satellite populations in the Lower Peninsula from 2005 to 2009 (Table 1.7). The Ludington population spread slowly, only expanding by 40% before coalescing with the Cadillac population. The Cadillac satellite expanded more rapidly, increasing in area by 290% from 2005-2008. The Emmet population expanded most rapidly with an initial area of 77 km^2 in 2005 increasing to 841 km^2 in 2008 and 1155 km^2 in 2009, a change of 992 % and 1400 % respectively. The new satellite population in Charlevoix found in 2006, did not appear to spread throughout the remainder of the study.

Distribution of Beech Scale in the Upper Peninsula

In 2005, a majority of the Upper Peninsula's stands of beech dominated forest were infested by beech scale (Figure 1.1), with an infested area encompassing approximately 6,214 km^2. Unlike the Lower Peninsula, there was only one contiguous beech scale population in the Upper Peninsula until 2009, when beech scale was found southwest of the main population in Menominee county (Figure 1.8). From 2006-2009, beech scale distribution expanded east and west (Figure 1.8). The infested area encompassed 8,203 km^2 and 9,187 km^2 in 2006 and 2007, respectively (Table 1.1). The infested area then expanded to 10,373 km^2 in 2008. By 2009, beech scale extended throughout nearly all of the beech dominated forests in the Upper Peninsula, with exception of the most western extent, expanding in area to 11,373 km^2 (including the Menominee satellite) (Table 1.1).

Distribution of Beech Scale on Islands

In 2005, beech scale was present in three of the 12 sites that were sampled across Beaver Island. A total of 16 km^2 was infested in 2005. Beaver Island was resampled in 2006 using sixteen sites; five sites were infested with beech scale, seven sites contained beech trees with no scale detected, and three sites contained no beech trees. The total known infested area increased 125 percent from 2005 to 2006, when 36 km^2 was infested.

Eight sites with beech trees were established on Drummond Island in 2006, but no beech scale was detected. In 2008, these eight sites were revisited and one other site was established. Beech scale was present in two of the nine sites, both located in the south-central portion of the island. A sample of only two infested sites was inadequate for an estimate of infested area using the minimum convex polygon method. In 2009, the remaining seven sites were revisited. Beech scale was present at two more sites, with a total infested area of 12 km^2.

Beech scale was present in 2006 on both Bois Blanc and Mackinac Islands. Of the nine sites on Bois Blanc Island, the four western sites had beech scale present in an area covering approximately 4 km^2. Seven of the 13 sites on Mackinac Island contained beech scale. Unlike the other islands, Mackinac Island had infested sites scattered throughout the island, with a total of 3 km^2 infested.

In 2005, both the North and South Manitou Islands were sampled, but there was no evidence of beech scale on either island. A total of 15 sites were established across North Manitou Island, while time restraints limited sampling on South Manitou Island to three sites. To be more thorough, we established six additional sites on South Manitou Island in 2006, but did not detect beech scale.

Discussion

Our data allowed us to evaluate the effectiveness of the northern hardwoods layer of IFMAP and the beech basal area map by Morin et al. (2005) for predicting beech distribution in Michigan. We do not recommend using the northern hardwoods layer in IFMAP to estimate beech distribution. Beech presence was over-estimated in some regions and underestimated in other regions. The overestimation of beech likely occurred in areas where northern hardwoods were present, yet without the beech component. The underestimation of beech trees likely occurred because beech can be found in more vegetation types than just northern hardwoods. On the other hand, beech basal area mapped using FIA data (Morin et al. 2005) did provide useful predictions of beech distribution in forested areas. We suggest users should be conscious of the coarse resolution of FIA data, and that the data used to create the map only included samples from forested areas. These two characteristics reduce accuracy in regions of the state dominated by non-forested land types.

Our study expanded on previous efforts to describe the distribution of beech scale. Morin et al. (2007) compiled beech scale presence in 2003 across the eastern United States, including Michigan, at a county level resolution, which missed detailed scale distribution. At the time of their study, Morin et al. (2007) showed beech scale occured primarily in the eastern Upper Peninsula and northwestern Lower Peninsula. This study also modeled beech scale spread, predicting scale infestations in seven year increments using 2003 as the initial year. Our 2009 data is similar to the model predictions for 2010, but delineates the advancing front more clearly on an annual basis. In addition, our results suggest the Morin et al. (2007) model over-predicted spread in areas with limited distribution of beech (e.g. western Upper Peninsula and southern Lower Peninsula). Using data from 2005 to 2007, Schwalm (2009) estimated beech scale to spread 4 km/year and 1.5 km/year in the Upper and Lower Peninsulas of Michigan, respectively. Our data suggest beech scale may be spreading more rapidly in both peninsulas than Schwalm (2009) predicted. Similar to results noted by Schwalm (2009), satellites spread more quickly in the Upper Peninsula than the Lower Peninsula.

Like many other states, studies of BBD in Michigan have largely focused on the impacts of beech bark disease rather than the distribution of beech scale, i.e. the advancing front (Kearny et al. 2005; Petrillo et al. 2005). Petrillo et al. (2005) provided the most complete record of beech scale distribution, surveying 284 sites in 30 counties and five islands from 2001-2003. Our five year study expanded on these projects with 803 total sites and 254 revisits across 73 counties and 6 islands, allowing us to define a finer scale and more complete distribution of beech scale. Our distribution results detected nine satellite populations not documented by Petrillo et al. (2005), including Charlevoix, Cheboygan, Crawford, Emmet, Menominee, Beaver Island, Mackinac Island, Bois Blanc Island and Drummond Island. In addition, our data showed satellite populations, defined in previous studies, to be much larger in area. The differences observed in beech scale populations from previous studies are largely due to their continued spread since these studies, although our intense sampling helped identify several new satellite populations. In addition, our data allowed us to estimate the area of infestations, enabling us to monitor spread of beech scale over time.

Our data suggests that beech basal area may be one factor affecting initial beech scale infestations. In 2005, most of the infested area in the Upper Peninsula had a relatively high beech basal area, according to the beech basal area map created by Morin et al. (2005) (0.2 – 7 m^2/ha; 0.87 – 30.5 ft^2/acre). By 2009, beech scale had spread to most of the remaining forests where beech basal area was > 0.2 m^2/ha. Much of the remaining beech areas had a low beech basal area (< 0.2 m^2/ha), with exception of a small area isolated southwest of the infestation (i.e. southern Menominee County). Similarly, the satellites in the Lower Peninsula all started in areas with beech basal areas > 0.2 m^2/ha. Unlike the Upper Peninsula, there are still uninfested locations with relatively high beech basal areas, although most of the uninfested regions are dominated by agricultural and urban developments (MDNR 2003). These results suggest that beech scale initially established in areas with relatively high beech basal area, spreading to surrounding areas, including those of lower beech basal areas. We suggest that managers consider beech basal area when studying and modeling spread of beech scale.

In addition to documenting the statewide distribution of beech scale, we calculated minimum convex polygons (MCP) to infer spread rates of beech scale over time. We used the MCP method because it is capable of using presence data to estimate distribution. Several other techniques using presence and absence data were also explored such as inverse distance weighting and kriging, but our sampling distribution varied annually, making annual comparisons of these estimations inappropriate. One disadvantage of the MCP technique is overestimation of distribution, especially in cases where irregular shaped ranges are present (Burgman and Fox 2002). This was observed in some satellite populations, where absence data was within the MCP estimation of beech scale presence. We believe the MCP provided reasonable estimations of relative annual range expansion of beech scale in our project.

Overall, satellite populations seemed to differ in spread rates. The Ludington satellite population spread the slowest, which may be due to a more fragmented population of beech in surrounding locations, because of areas with no beech and higher densities of urban and agricultural lands. In contrast, the Cadillac and Emmet populations increased rapidly. Unlike the Ludington satellite population, these populations were in close proximity to a more continuous distribution of beech. In addition to spatial differences in spread rates, beech scale has not spread evenly year to year. This suggests that external factors such as weather may affect the spread of beech scale.

The numerous satellite populations also allow us to infer mechanisms of dispersal. Previous studies suggest that beech scale's primary mode of natural dispersal is wind (Felt 1933; Wainhouse 1980). Wainhouse (1980) showed that wind speeds of less than two meters per second cause a mean dispersal of crawlers 10 m, limited by the initial height of the insect and wind speed. Wainhouse and Gate (1980) also suggest that scale crawlers above the canopy combined with high wind speeds may be responsible for long-range dispersal of 6-18 kilometers per year occurring in North America. Other forms of dispersal (e.g. migratory birds, wildlife and human movement of infested logs) may also play a role in spreading beech scale, but no concrete evidence has been published (Ehrlich 1934; Houston 1994; Morin et al. 2007). Of these modes of dispersal, the most probable mode of long-range transport is movement of infested logs by humans and the spread of scale via migratory birds. We detected the formation of several satellite populations of beech scale that were > 20 km apart, suggesting that wind dispersal was not responsible. Other modes of dispersal such as those discussed above are likely playing large roles in the dispersal of beech scale in Michigan.

The unique opportunity to sample beech scale on six of Michigan's islands also provided insights into mechanisms of spread, especially anthropogenic actions. Although all islands differed in size and location, the only islands without beech scale were the Manitou Islands, which were unique because they have no permanent residents (Table 1.1). In addition, Beaver Island is located farther from the mainland (24 km) than any other island, making it unlikely that wind dispersal deposited scales on trees on the island, yet it was infested. This again suggests that humans may have played a role in spreading beech scale to Beaver Island too. Also, Beaver Island is located in flyways of several migratory bird species, so migratory birds may have transported beech scale to the island (Lincoln 1939).

Knowing Michigan's distribution of beech scale over time can be a valuable tool for natural resource managers, allowing beech bark disease to be incorporated in management plans. Current information about beech scale distribution can be used to help reduce the spread and impacts of beech scale and BBD by reducing overstory beech density and overmature beech in areas adjacent to infestations that are dominated by beech trees (Mielke et al. 1987). In addition, the distribution of beech scale can help managers determine when impacts of BBD are likely to occur. Distribution data can be incorporated into a guidance plan for beech management and future timber sale activity For example the restriction of timber and firewood harvest during the crawler stage could likely minimize anthropogenic transportation of actively dispersing scales.

The fast paced spread of beech scale in Michigan, due to the combination of local and long distance dispersal is similar to previous observations in the northeastern United States. In the northeastern states beech scale was often first documented in isolated satellites, where it then expanded locally. For example, satellite populations of beech scale were discovered in Massachusetts, Maine, New Hampshire, New York and New Jersey in 1935, in West Virginia in 1990, in North Carolina and Tennessee in 1999, and in Ohio and Michigan in 2001. All of these satellite populations meet our definition of being separated geographically from the established scale populations by at least 20 km of uninfested stands with some beech component. Our data confirms that long distance dispersal is occurring throughout Michigan too, shown by the development of several distinct satellite populations. With the ability of beech scale to spread at variable rates, the remaining states with uninfested beech trees should be monitored and preparations should be made for beech scale infestations in the near future.

Table 1.1: Michigan islands sampled as part of our study. The years each island was sampled follows the island name, showing the total number of plots and number of plots infested in the given year. Residents indicates whether permanent residents live on the island. Distance represents shortest straight line distance to Michigan's mainland (measured in ArcGIS 9.2). Area (km^2) refers to island size.

Island	# Plots	# Plots with beech scale	Lake	Residents	Distance (km)	Area (km^2)
Beaver			Michigan	Yes	24	144.5
2005	12	3				
2006	15	5				
Bois Blanc			Huron	Yes	6	127
2006	9	4				
Drummond			Huron	Yes	< 2	645
2006	10	0				
2008	9	2				
2009	8	3				
Mackinac			Huron	Yes	4	14.5
2006	13	7				
N. Manitou			Michigan	No	11	22
2005	14	0				
S. Manitou			Michigan	No	11	21
2005	3	0				
2006	6	0				

Table 1.2: Area (km^2) infested by beech scale in each year of sampling, as determined by the minimum convex polygon method. Dashes (--) represent timeframe without sampling. NA* = Not enough points to create minimum convex polygon. The same value was assigned to Cadillac and Ludington in 2009 because the two populations coalesced.

	Year				
Satellite	2005	2006	2007	2008	2009
Cadillac	51	136	144	199	5,200
Ludington	2,539	2,813	3,287	3,560	
Charlevoix	0	NA*	NA*	NA*	NA*
Cheboygan	0	--	--	--	NA*
Crawford	0	--	--	--	196
Emmet	77	149	739	841	1,155
Total Lower Peninsula	2,667	3,098	4,170	4,600	6,551
Menominee	0	--	--	--	255
Upper Peninsula	6,214	8,203	9,187	10,373	11,547
Total Upper Peninsula	6,214	8,203	9,187	10,373	11,802
Beaver Island	16	36	--	--	--
Bois Blanc Island	--	4	--	--	--
Drummond Island	--	--	--	NA*	12
Mackinac Island	--	3	--	--	--
North Manitou Island	0	--	--	--	--
South Manitou Island	0	0	--	--	--
Overall Total	8,897	11,344	13,357	14,973	18,365

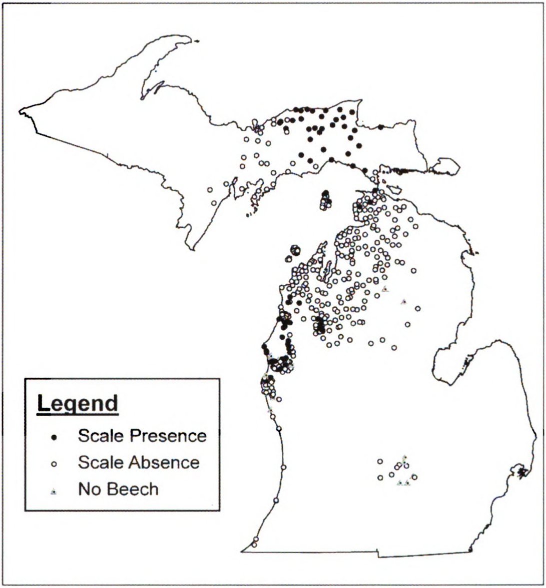

Figure 1.1: Sampling plot locations and results from 2005. Dark circles indicate sites that were infested with beech scale. Open circles specify sites uninfested and triangles indicate sites that were visited but had no beech trees.

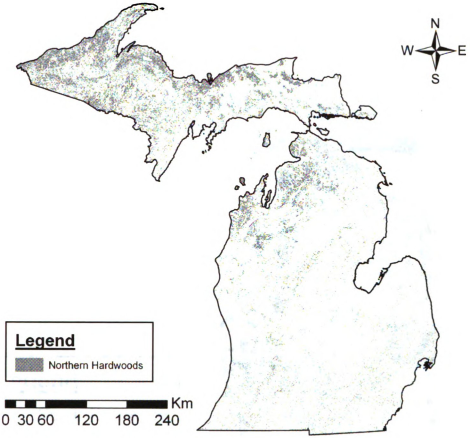

Figure 1.2: The northern hardwoods layer of Michigan, derived from the IFMAP dataset.

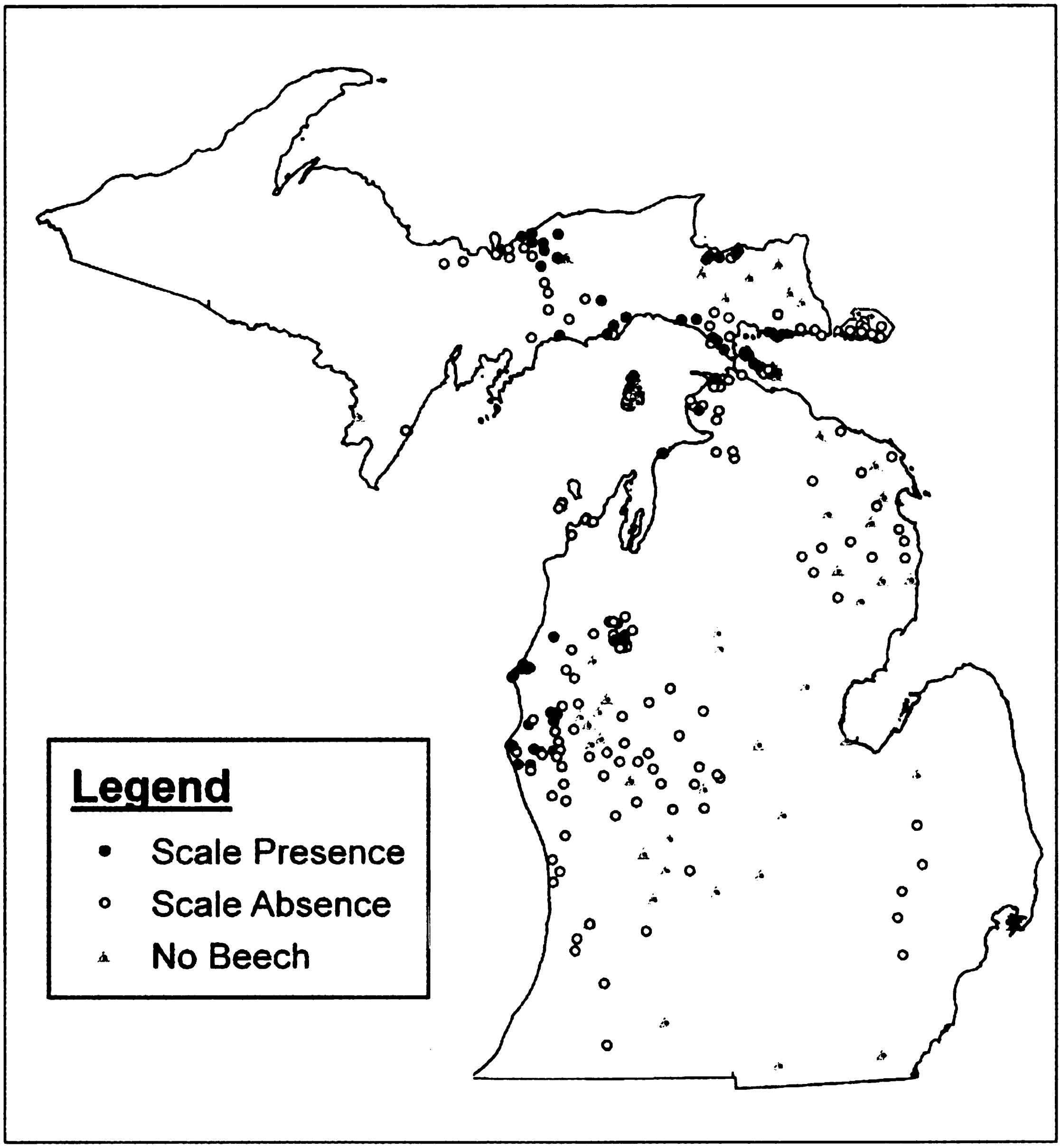

Figure 1.3: Sampling plot locations and results from 2006. Dark circles indicate sites that were infested with beech scale. Open circles specify sites uninfested and triangles indicate sites that were visited but had no beech trees.

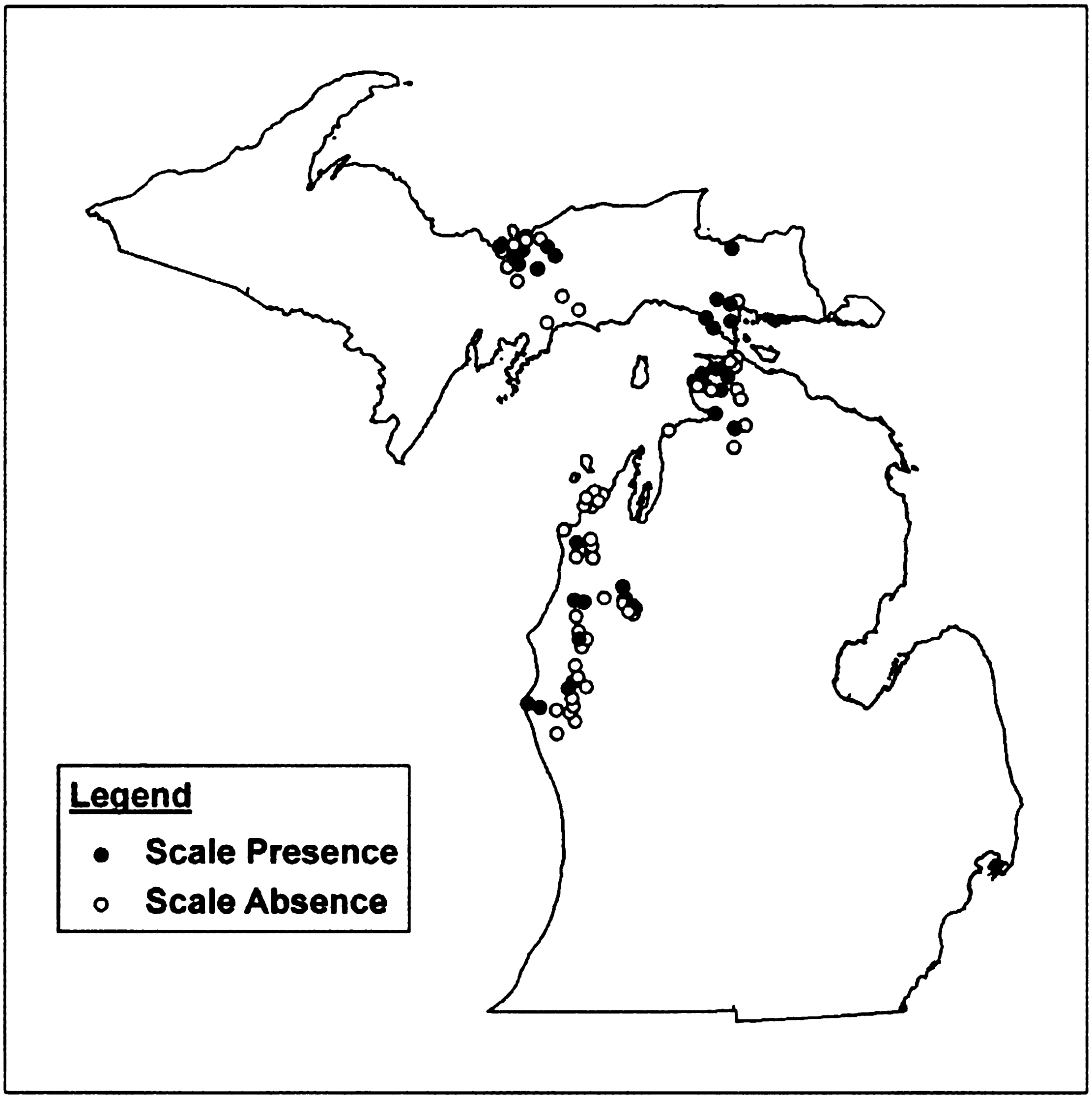

Figure 1.4: Sampling plot locations and results from 2007. Dark circles indicate sites that were infested with beech scale. Open circles specify sites uninfested.

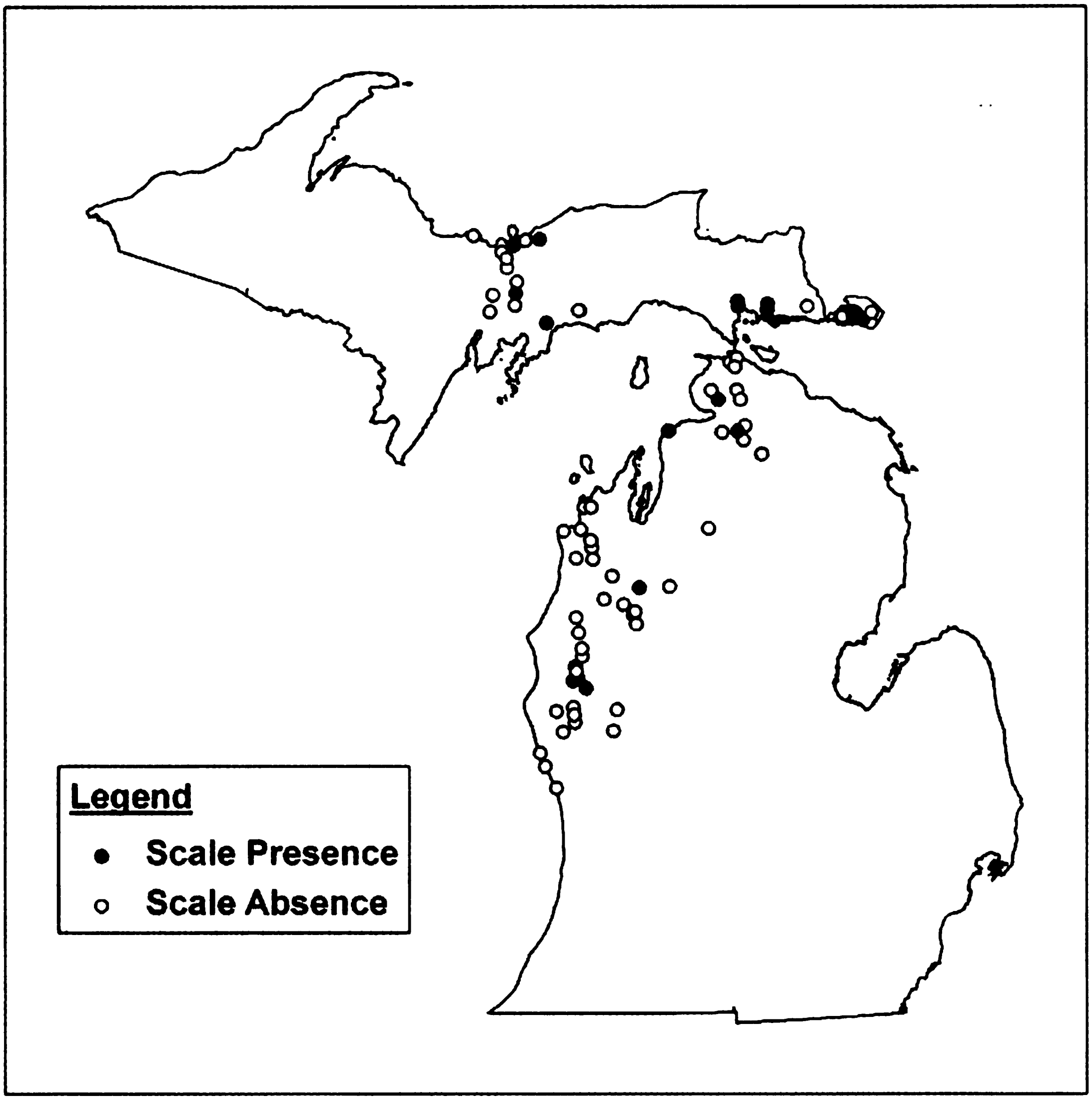

Figure 1.5: Sampling plot locations and results from 2008. Dark circles indicate sites that were infested with beech scale. Open circles specify sites uninfested.

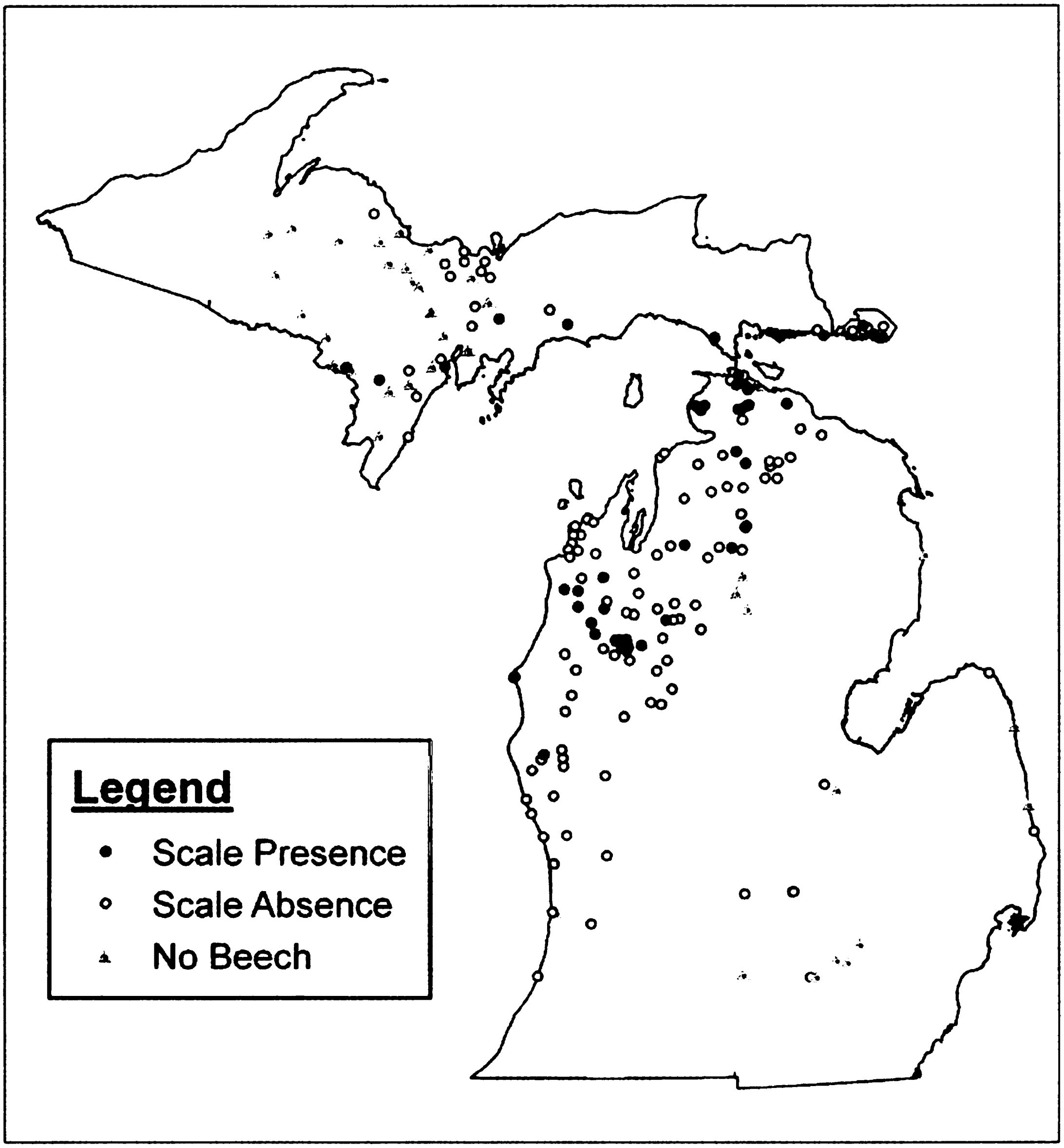

Figure 1.6: Sampling plot locations and results from 2009. Dark circles indicate sites that were infested with beech scale. Open circles specify sites uninfested and triangles indicate sites that were visited but had no beech trees.

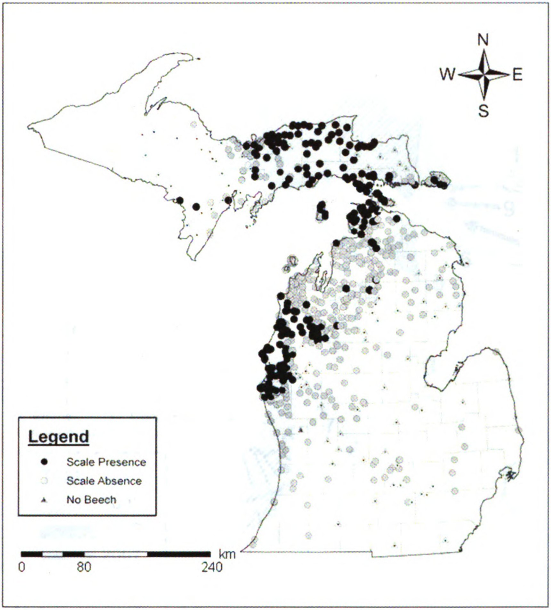

Figure 1.7: Sampling plot locations and results from 2005-2009. Dark circles indicate sites that were infested with beech scale. Shaded circles specify sites uninfested and triangles indicate sites that were visited but had no beech trees.

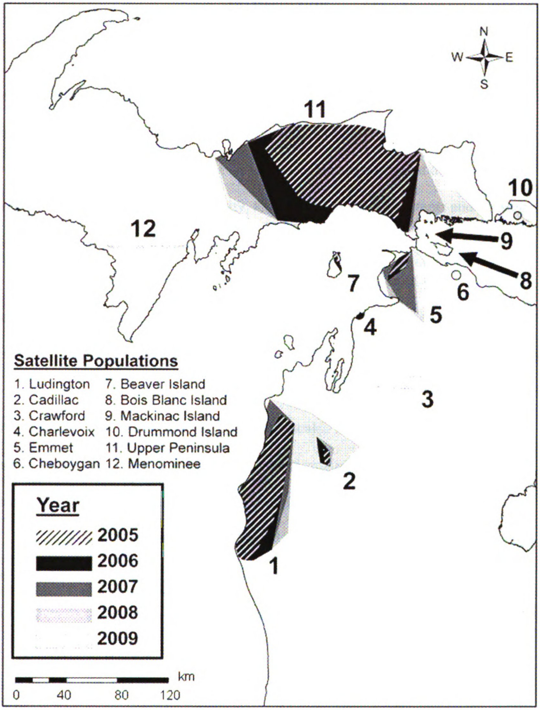

Figure 1.8: Beech scale satellite populations defined in Michigan by sampling year. Minimum convex polygons were used to identify boundaries of infestation.

Introduction

Invasive forest insects cause substantial economic and ecological damage across the world (Sakai et. al 2001; NRC 2002). Recent costs of invasive forest insects in the United States were estimated to be approximately $4 billion per year (USDA Forest Service 2007). These insects also cause irreplaceable alteration and destruction to forest systems by depleting biodiversity, altering unique forest systems and causing species endangerment and extinction (Wilcove et al. 1998).

When studying invasive forest insects, scales (Hemiptera: Coccidae) are of special concern. Scales are generally sap feeders and several species reproduce parthenogenically (Miller and Kostarab 1979). Miller et al. (2005) found that roughly 25 % of scale insects in the United States are non-native, a high percentage compared to other insect groups. Many of these non-native scales are major pests of crops, plants or trees in the United States, causing economic and ecological damages (Miller and Kosztarab 1979; Miller et al. 2005; Kondo et al. 2008).

Beech scale (*Cryptococcus fagisuga Lind.*) is one of the many invasive scales in the United States. Originally from western Asia and southeastern Europe (Gwiazdowski et al. 2006), beech scale was unintentionally transported to Nova Scotia on imported nursery stock in 1890, where it spread to the United States sometime thereafter (Ehrlich 1932). Beech scale is host-specific to American beech (*Fagus grandifolia*) (Ehrlich 1934), and has spread through most beech dominated forests of the United States (Morin et al. 2007).

Despite the widespread distribution and long-term presence of beech scale in the United States (Morin et al. 2007), few quantitative descriptions of its population dynamics are available (Houston et. al 1979). Like most scale insects, beech scales reproduce by parthenogenesis, allowing populations to build exponentially even from a single individual (Ehrlich 1934). During mid-summer, each adult lays approximately 50 eggs before dying (Wainhouse and Gate 1988). Eggs hatch into first instars, also known as crawlers or nymphs, in late summer. Crawlers are equipped with legs and antennae allowing for mobility (Ehrlich 1932). They may move to a suitable location on their current tree or are carried by wind or wildlife, to nearby host trees (Ehrlich 1932; Felt 1933; Wainhouse 1980; Houston 1994; Morin et al. 2007). After moving to a suitable location, crawlers pierce the outer bark with their stylets to feed on the phloem of the tree. Crawlers molt into second instars, shedding their legs and becoming immobile. As they feed, the scales secrete a white waxy coating over their bodies, allowing for protection from weather and predators. The second instars overwinter and molt into an adult stage the following spring (Ehrlich 1932).

Despite the univoltine life cycle and immobility of beech scale that make the study of its population dynamics in a natural setting more feasible than that of most invasive insects, little is known about beech scale population dynamics. Most previous studies on beech scale population dynamics used a qualitative ranking system to estimate scale density. Several authors, including Houston et al. (2005) and Kearny et al. (2005), have visually ranked beech scale density. This is a quick and simple way of assessing beech scale populations but is subjective and gives coarse results. In other studies, individual scales on trees were counted (Wainhouse1980; Gardner 2005), but the time required makes it difficult to implement this approach for multiple trees and sites. Further, while counting individual scales gives a true census within the sample area, the sample area usually represents a small fraction of the total scale population. For example, Wainhouse (1980) used four 1 cm^2 samples to represent beech density on an entire tree.

Digital photography can be a useful way to study beech scale because a high contrast typically exists between the grey bark of beech trees and the white waxy substance secreted over the immobile scales. We devised and evaluated a method of quantifying beech scale density using digital photography. In addition, we compared accuracy and efficiency of four techniques of assessing beech scale density on digital photographs. Our goal was to determine if digital photography could provide quantifiable results that were more time and cost efficient than previous methods such as individual scale counts. We also wanted to determine if this method would also allow for reproducible results of beech scale density estimates. This could enable scientists to monitor effects of weather or other factors affecting scale dynamics over time.

Methods

Relationship between scale abundance and area of wax

We created an index to test the accuracy of using the percentage of bark area covered by beech scales' waxy coating to quantify the number of scales. From May to October 2008, samples of infested beech tree bark were collected using a bark punch and were brought back to the lab for processing. A total of 105 samples, each 2.14 cm in diameter, were collected from five distinct beech scale populations throughout Michigan; 22 samples were collected from 2 sites in Ludington's scale populations in May, 21 samples from 2 sites in Cadillac in May, 23 samples from 2 sites in Emmet in

June, 12 samples from 1 different site in Emmet scale populations in October, and 27 from 3 sites in the Upper Peninsula in July. No more than four samples were collected from one tree and samples were from all aspects and heights less than 2.5 m of the tree. Approximately one third of the samples had only a sparse amount of beech scale wax, one third of the samples had an intermediate amount and one third appeared to be heavily infested, with high amounts of scale wax. To collect each sample, the punch was first used to delineate the sample area on the tree. After sample areas were delineated, they were photographed and then removed from the tree with the bark punch (see *Photograph collection below*).

Photographs were analyzed using image analysis software called ImageJ (available at http://rsb.info.nih.gov/ij; developed by Wayne Rasband, National Institutes of Health, Bethesda, MD.), which allowed us to manually apply a binary threshold to each photograph (Appendix B). Based on the brightness associated with each pixel, the threshold was adjusted to select pixels that contained the white wax from beech scale. Thresholds were different for each photograph, depending on photo quality, brightness and contrast. The selected pixels were then used to calculate the percentage of pixels covered with scale wax. After each photo was analyzed, the number of beech scales on the sample of bark was counted using a microscope.

A linear regression was used to represent the relationship between the area covered by wax and the number of insects in the sample. We used the equation $y = a + bx$, where y represents the number of insects, x is the area of wax coverage, b is the slope and a is the y-intercept.

Photograph and qualitative data collection

We established 26 eight meter fixed-radius plots from July to August 2007. In each plot, all beech trees over 6 cm in diameter at breast height (DBH) were tagged to ensure unique identification in subsequent visits. Individual plots contained two to 22 beech trees, with a mean number of 10 ± 1 beech trees per plot. When less than eight beech trees were present in one plot, beech trees closest to the plot were tagged until at least 8 trees were included. There were two exceptions, where only five and seven beech trees were tagged, due to low beech basal area.

A qualitative ranking of beech scale abundance was recorded for each tree to allow for visual estimation methods used in previous studies to be compared to the digital photography method. We used a four point qualitative ranking system using reference cards (Figure 2.1), which help produce consistent rankings. Qualitative ranks were 0 = no beech scale, 1 = trace populations, 2 = patchy populations and 3= heavy populations. Qualitative ranking was performed by walking around the tree searching for signs of beech scale (i.e. white wax) on the readily visible portion of the tree, < 4 m above ground. If the upper portions of the tree were also visibly infested, this was incorporated into the ranking.

After all beech trees in a plot were tagged and measured, three unique photographs were taken of each tree. A stratified random sampling technique was used to determine photo heights and aspects. One photo was taken at 0.9, 1.2 and 1.5 m heights. Each photo height was assigned a random aspect before arriving at the site. Photos were taken using a tripod with a built-in stabilizer to ensure the camera was the same distance from the tree (30 cm) for each photograph. To reduce potential problems, a duplicate photo was taken at each setting. If shadows were present within the photo area, sunlight was blocked using a clipboard to reduce contrast within the photo.

To study annual change in beech scale populations, all sites were revisited 365 days (± 30 days) after establishment. In addition, a subset of 14 plots was revisited more frequently to detect within-year changes of beech scale populations (Figure 2.2). The 14 plots were revisited in October and December 2007, and January, March, May, June, July and October 2008, and March and June of 2009. Due to a snowstorm, only half of the plots were accessible in December 2007, but remaining sites were revisited in early January 2008. During each revisit, qualitative and quantitative measures of beech scale were again recorded. All photos were retaken on the same trees and at the same heights and aspects of original visits to assess changes in beech scale density.

Photograph evaluation

Two general approaches were developed and tested to determine an efficient method of quantifying beech scale density through digital photograph analysis. The first approach used image processing software to calculate beech scale density on each photo. In the second approach, we compared three sub-sampling techniques to estimate scale density on each photograph. Thirty photographs that represented unique trees, representing various sizes of beech trees and beech scale densities, were selected to test both techniques. An equal number of photographs were selected from the following classifications: large diameter beech trees (> 18 cm DBH) with heavy, moderate, and low visual estimates of scale infestations and small diameter trees (< 18 cm DBH) with heavy, moderate, and low infestations. Scale density, time required for analysis, and problems encountered were recorded for each technique. Each technique was practiced on ten different photos before the trial was conducted. This allowed the user to become familiar with the protocol, making the time of analysis representative of the method in routine practice.

The first approach used ImageJ software as described in *Relationship between scale abundance and area of wax*. This program allowed us to adjust a binary threshold to select pixels with wax. Selected pixels were used to calculate density of infestation within each photograph.

The second approach used Adobe Photoshop Elements ® software, which allowed a system of random grids to be constructed and overlaid on each photo. Three techniques were tested using the grids to sub-sample the images under different constraints. For all three sub-sampling techniques, photographs were overlaid with an 8x8 grid (64 cells total).

In the first sub-sampling technique, the 64 cells were used to randomly predetermine eight grids, each containing eight transparent cells for photo evaluation (Figure 2.3). Transparent grid cells were non-overlapping between grids (Figure 2.3). One grid was randomly assigned for each photo, allowing us to visually estimate scale coverage within the eight transparent grid cells. A qualitative rank of scale density was assigned to each transparent grid cell. Zero represented no scale, one represented 1-25% of the grid cell being infested, two represented 26-50%, three represented 51-75% and four represented 76-100%. When the tree occupied less than half of a grid cell, the cell was assigned a "no value" ranking, meaning it was not used in the analysis. This was common in photos of trees with small diameters because smaller trees did not span the entire photo. This occurrence reduced the number of cells evaluated in such cases. After each grid cell was assigned a scale density, the eight cells were averaged to represent beech scale density of the entire photograph.

The second technique used the same predetermined grid cells and evaluation techniques as the first technique. Unlike the previous technique, two predetermined grids were overlaid on each photo, allowing for 16 grid cells to be evaluated. Techniques 1 and 2 were expected to have low processing times for each photograph because they used random subsamples.

The third technique used a single grid approach (64 total cells). A total of 15 randomly selected grid cells were used to subsample the photo. Unlike techniques 1 and 2, this technique required each sampled cell to overlay the tree within the photograph ensuring the total sample included 15 grid cells. In cases where a grid cell did not overlay the photograph, it was discarded and another cell was randomly selected. The 15 grid cells were ranked qualitatively, similar to the first two techniques and values were averaged for the photograph. This technique was expected to allow for a randomization of sampling for each photo and a more consistent sample size than methods 1 and 2, but require more time than the first two methods because grids new grids were created for each photo.

Some common rules were established with the three subsampling techniques using Adobe Photoshop to maintain consistency throughout the analysis.

- Grid cells were only used if more than half of the cell overlaid the tree;
- Scale infestation on the grid line was not counted;

- If less than 4 grid cells overlaid the tree, then a new grid was randomly selected.

Results

Relationship between wax and scale abundance

A positive linear relationship existed between percentage of the photographed area covered by the white wax and the true number of beech scales (Figure 2.4). The number of beech scales counted on each sample ranged from 0 to 1,768. The equation, $y = 869.02x + 45.798$, yielded an adjusted r^2 value of 0.796 ($p < 0.0001$), indicating that one cm^2 of white wax in the photo represented approximately 869 beech scales. As expected an intercept close to zero was observed (Figure 2.4).

Digital photography

Digital photography produced more precise and less subjective results than qualitative analysis, but required more time. This method took one hour to analyze all 30 photos, taking approximately two minutes per photo, or six minutes per tree. In addition, 2.3 to 3.5 minutes per photo were required to process photos in the lab (Table 2.1). In contrast, the qualitative estimate of scale density only took two minutes per tree and required no further processing. Overall, a tree sampled with digital photography took greater than six times as long as a qualitative assessment of the same tree.

The binary threshold method was the most time consuming technique (Table 2.1). This approach, however, had the lowest coefficient of variation, indicating it was more precise than other techniques. This technique resulted in a mean area of 0.13 cm^2 of white wax per photo. The sub-sample 1 technique was least time consuming; sub-sample 2 and 3 methods took approximately 1.5 times as long. The three sub-sampling techniques had similar coefficients of variation and mean values of white wax per photo, indicating similar accuracy and precision. Sub-sample 1 included an average sample size of 5.7 cells, while sub-sample 2 and sub-sample 3 had average samples sizes of 11.1 and 14.9 cells, respectively.

Qualitative results

The mean proportion of a tree that was infested, as measured by digital photographs, varied strongly across categories assigned by visual assessment (Figure 2.5). In general, the central 50 % of digital measures for each category did not overlap with adjacent categories (Figure 2.5). In addition, the qualitative method allowed for complete assessment of each tree. This method, however, gave less precise data than digital photographs and no form of visual documentation for later reference.

Discussion

Although we found no evidence that digital photos were used previously to evaluate population dynamics of beech scale, similar techniques have been used for applications such as quantifying percentage forest canopy cover, calibration of pesticide spray from airplanes, and land-use classification (Englund et al. 2000; Holownicki et. al 2002; Bruzzone and Fernandez Prieto 2000). Foresters often use hemispherical canopy-photographs to quantify canopy cover and understory light availability (Englund et al. 2000; Nobis and Hunziker 2004). The photos in these studies are often processed in a similar manner as the binary threshold method and are thought to provide advantages such as versatility and lasting records (Englund et al. 2000).

Our results demonstrate digital photography is a useful technique for capturing beech scale density. Unlike most insects that are capable of moving throughout their entire life, the immobility of beech scale makes it easier to study over time. In addition, the white wax secreted by beech scale provides contrast from the bark of host trees, allowing for identification in photos, even when implementing a threshold technique. These traits also allowed an index of abundance to be created using digital photography. Unlike visual assessments, digital photography provides a lasting record of beech scale abundance at a given time, allowing for more precise comparisons of density over time. In addition, digital photography provides concrete and reproducible results, unlike the subjective results of visual assessments.

Although our photographic technique was effective, there are cases where the use of simple qualitative assessments of beech scale may be useful. Qualitative ranking systems using reference photos gave comparable beech scale rankings as the binary threshold technique, yet reduced time expenditures greatly. Also, several qualitative assessments were accomplished in minutes in the field, while photo analysis required more time for field collection plus hours of processing in the lab. With this in mind, qualitative assessments may be more suitable for situations that do not require quantitative data or when rapid assessment is desirable. Also, qualitative methods may be more useful than photos when sampling is conducted in areas that contain a trace of beech scale. Qualitative assessment of the entire visible portion of the tree increases the likelihood of detecting small amounts of beech scale, while sub-sampling with digital photography may fail to capture traces of scale by chance alone. In such situations, a double-sampling approach using both qualitative and quantitative ranking may be superior.

The binary threshold method was the most precise of the four techniques for quantifying beech scale density from digital photography. The threshold data is most precise because it directly measures scale density on the complete photograph while the other methods only sub-sample the photo. Although the binary threshold method was most precise, it was also the most time consuming of tested methods. We feel, however, that the marginal cost in processing time is worth the additional precision if studying population dynamics. Also, if a sub-sampling approach of photos is desired, we recommend the sub-sampling 1 technique because it requires the least processing time and produces similar results as other sub-sampling techniques.

Although data processing using binary threshold measurements had its advantages, minor problems arose in this application. One of the largest challenges involves the lack of consistency in contrast within and between photos. The most frequent contrast problem within a single photo was shadows covering portions of the photo. This made automated detection of beech scale difficult. We minimized this problem in the field by shading the entire photo frame with a clipboard. The most common contrast issue among photos included differences in bark roughness, overall photo brightness or bark coloration which made it unfeasible to use a set threshold for all photographs. We had to set individual thresholds to best represent beech scale on each photo, which required additional processing time. Another limitation of using binary threshold measurements to assess scale density was misclassification of other white coloration on the bark. Examples of misclassifications included snow, spider eggs, and other light-colored insects. Compared to beech scale, however, the surface areas of these misidentified objects were minute. In addition, ImageJ encountered some problems identifying beech scale when trees were covered with light colored moss and lichens. Most of these problems were dealt with by manipulating images using paint options in ImageJ to increase contrast of the wax and bark by changing color of infested pixels, improving threshold sensitivity. Although paint options allowed us to cope with problems, these issues still made the analysis more time consuming.

We recommend that new advances in digital photo analysis be explored in future applications for assessing beech scale density and dynamics. Nobis and Hunziker (2004) suggest automatic threshold algorithms may be less time consuming and more objective, comprehensible and reproducible. Other image processing software exists and could also be explored, to determine if they provide greater processing capabilities and reduced processing time.

Given our success of quantifying beech scale density we feel this method could be expanded to broader use. In particular, other insects with characteristics similar to beech scale could be efficiently monitored using digital photography. Insects that are mostly immobile during their life cycle and have high contrast with their host plant would be most suitable. Some of these insects may include hemlock woolly adelgid *(Adelges tsugae;* Annand*)*, balsam woolly adelgid (*Adelges piceae*; Ratzeburg), and other scale species.

Table 2.1: Comparison of the four digital photography analysis techniques are summarized below. Time refers to the average time to analyze a single photograph, mean scale and coefficient of variation refer to the beech scale rating for each method. The binary threshold method gives an area measure (cm^2), while sub-sample methods give qualitative ratings. Average sample size for sub-sampling techniques refers to number of cells used in sub-sampling, where "no value" cells are not included.

Technique	Time (min/photo)	Mean Scale	Coefficient of Variation	Average Sample Size
Binary Threshold	4.0	0.13	0.40	Entire Photo
Sub-sample 1	2.3	0.92	0.60	5.7 grid cells
Sub-sample 2	3.5	0.96	0.54	11.1 grid cells
Sub-sample 3	3.1	0.94	0.75	14.9 grid cells

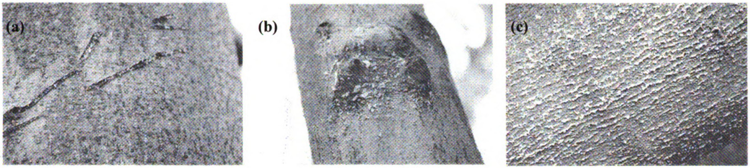

Figure 2.1: Reference photos for the four point qualitative ranking system. A zero was given to trees with no beech scale. **(a)** One was assigned to trees with a trace of beech scale. **(b)** Two was assigned to trees with patches of beech scale. **(c)** Three was assigned to trees with heavy infestations of beech scale.

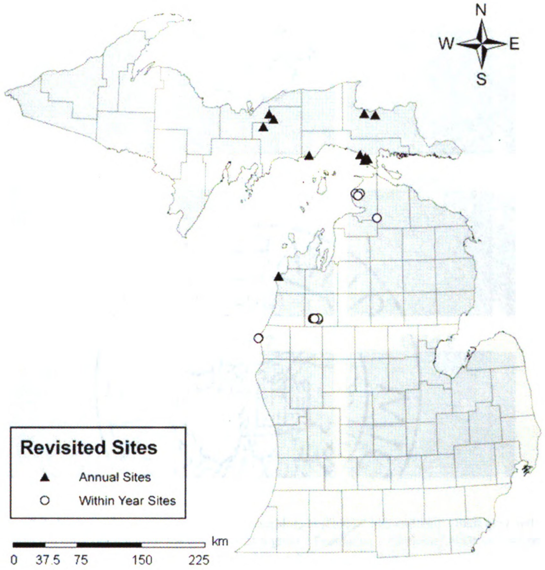

Figure 2.2: A total of 26 sites were established and revisited after one year (Annual Sites). A subset of 14 sites was also revisited multiple times within a year (Within Year Sites).

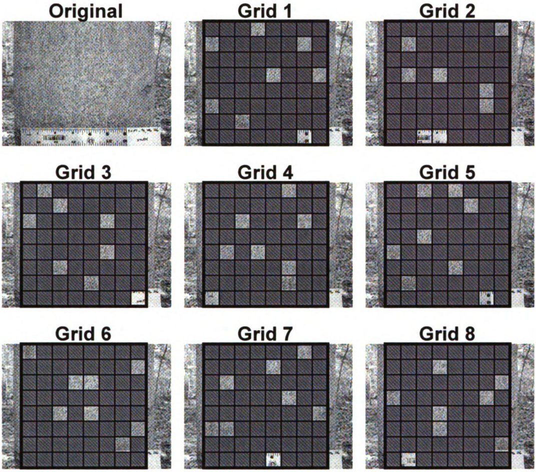

Figure 2.3: Eight grids were created for sub-sampling technique one and two. Each grid cell was selected only once within the entire set of 8 grids. Technique 1 randomly selected one grid to sub-sample a photo (total of 8 grid cells) while technique two used two grids (total of 16 unique grid cells).

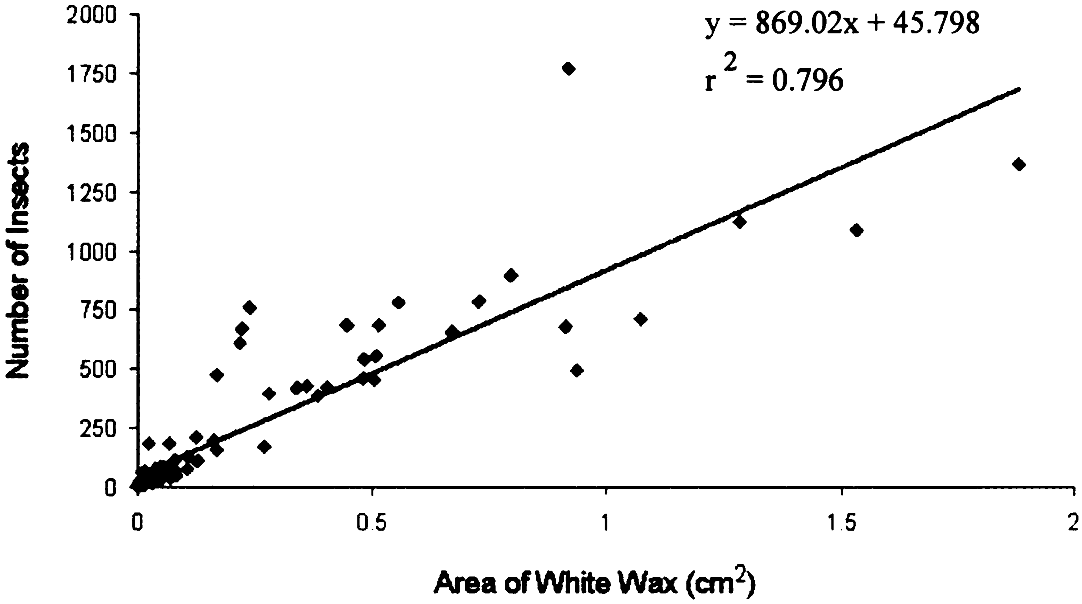

Figure 2.4: Index of abundance relating number of beech scales to area (cm^2) of white waxy substance secreted by the insects. Data were collected between May and October.

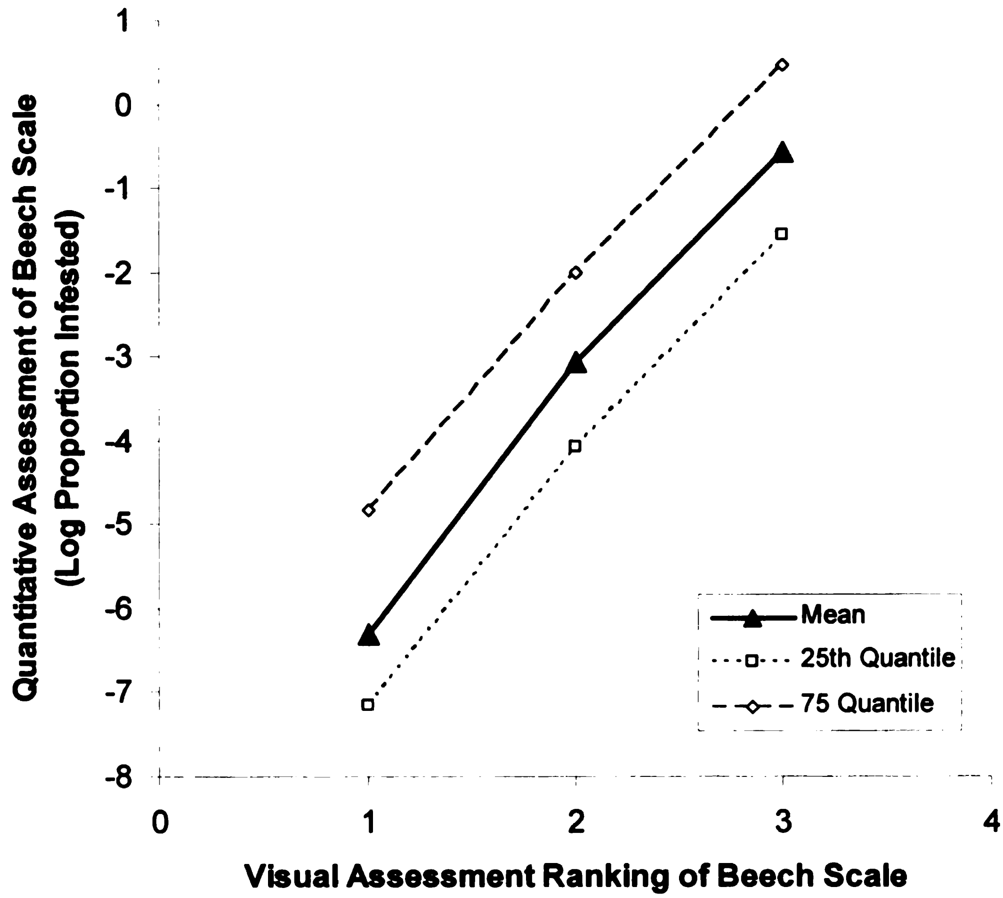

Figure 2.5: Relationship between qualitative estimates of beech scale infestation based on visual analysis and log quantitative measures as determined from binary threshold methods.

Introduction

Beech scale *(Cryptococcus fagisuga Lind.)*(Hemiptera: Coccidae), an invasive forest insect native to western Asia and southeastern Europe (Gwiazdowski et al. 2006), has been invading North American beech forests since its introduction in 1890 (Ehrlich 1934). Beech scale in North America is host specific to American beech trees (*Fagus grandifolia*). Beech scale adults are univoltine and each individual can lay approximately 50 eggs (Wainhouse and Gate 1988). Populations are capable of a rapid increase because all individuals are females and they reproduce parthenogenically (Ehrlich 1934). Beech scales are mobile only as 1^{st} instars, referred to as crawlers. Crawlers are active from late summer to early fall, and must find a suitable location on the bole or large branches of a beech tree where they can insert their stylets and feed on the sieve cells of the secondary phloem (Ehrlich 1934; Telewski 2009). During dispersal, crawlers sustain a high mortality estimated at 86% (Wainhouse and Gate 1988). Once feeding begins beech scale molt to the second instar and are immobile for the remainder of their lives (Ehrlich 1934). Scales secrete a waxy substance over themselves as they feed for protection from weather and predators (Ehrlich 1934). Even with the wax, scales are subject to mortality when air temperatures drop below -37° C (-35° F) and they are not protected by snow (Houston and O'Brien 1983). Several native predators such as the twice-stabbed ladybird beetle (*Chilocorus stigma* Say), cecidomyid flies (*Lestidiplosis* sp.) and gall gnats (Diptera: Cecidomyidae, *Lestodiplosis* spp.) feed on beech scale (Wainhouse and Gate 1988; Houston 1994).

Beech scale establishment represents the first stage of beech bark disease (BBD), referred to as the advancing front. The second phase involves the infection of trees by *Neonectria spp.* fungi (Ehrlich 1934; Houston 1994; Castlebury et al. 2006). The minute wounds created when beech scales insert their stylets permit entry of the fungi (Ehrlich 1934). The fungus invades and kills living tissues of the bark, cortex, phloem, cambium, and sapwood (Ehrlich 1934). As lesions coalesce the tree looses abilities to transport and store nutrients, which kills or reduces the health of the tree (Ehrlich 1934). More than 50% mortality of trees over 25 cm in diameter may occur (Houston 1994), altering forest composition and causing economic loss (Houston 1994).

Although beech scale was first described in Europe in the 1840s (Ehrlich 1934), little is known about change in beech scale populations over time, especially on American beech trees. This is surprising given the fundamental importance of understanding the population dynamics of invasive species. The few studies that have addressed beech scale dynamics relied on visual qualitative assessments of local beech density on individual trees (Houston et al. 1979; Wainhouse and Gate 1988; Gora et al. 1994; Houston 1994). Although this method is a quick and simple way of assessing scale density, it is also subjective and yields coarse results. Also, all but one of these studies were conducted in European beech stands, where beech scale are suspected to interact with hosts differently than in American beech stands (Houston 1994). In addition, studies by Gora et al. (1994) and Wainhouse and Gate (1988) assessed scale density at five year intervals but did not monitor within year and annual population changes. Houston et al. (1979) assessed annual change in beech scale densities for three years, but only in a plantation of European beech trees. Houston (1994) compared annual change of beech scale density on American beech trees in two different stages of BBD. Houston (1994) found the stands newly infested with beech scale to generally increase in scale density annually, while the long-infested stands sustained more constant, lower beech scale densities.

We analyzed changes in beech scale densities on American beech trees in Michigan using both qualitative and quantitative methods. We observed within-year changes in scale density to understand the rate at which scale populations increase on individual trees and whether detectable scale mortality occurs. Effects of tree and plot characteristics on annual changes in populations of beech scale were evaluated at the tree and plot levels.

Methods

Site Establishment and Sampling Techniques

We established a fixed-radius plot, eight meters in diameter, in 26 locations during July and August of 2007 (Figure 3.1). Plots were widely dispersed across the distribution of beech scale at that time (Chapter 1). Plots were selected within each of five satellite populations documented by Schwalm (2009), but the Upper Peninsula (U.P.) was split into two regions due to the large size of this satellite population. Six plots were located in the eastern U.P. (E.U.P.), four in the central U.P. (C.U.P.), four in the Emmet satellite, three in the Ludington satellite, two in the Benzie satellite and seven in the Cadillac satellite (Figure 3.1). Most plots were established in infested areas, but two plots were uninfested, being 200 m from the nearest infested tree at the time of establishment to observe spread from nearby populations.

All beech trees over 6 cm in diameter at breast height (DBH) were tagged to ensure unique identification in subsequent visits. Species and DBH were recorded for all trees within the plot to allow for calculations of basal area. Individual plots contained 2 to 22 beech trees, with a mean number of 9.92 (± 0.78) beech trees per plot. When less then eight beech trees were present in a plot, the beech trees closest to the plot were tagged until at least eight trees were included. There were two plots with low beech density, where only five and seven beech trees were tagged.

Qualitative visual estimates and digital photography methods (Chapter 2) were both used to assess beech scale density. Qualitative estimates were used to document beech scale on entire trees. As described in Chapter 2, we used a four point qualitative ranking system using reference cards, which helped produce consistent rankings. Qualitative ranks were performed by walking around the tree searching for signs of beech scale (i.e. white wax). Scale density was ranked as 0 = no beech scale, 1 = trace populations, 2 = patchy populations and 3= heavy populations. The method focused on the readily visible portion of the tree trunk, < 4 m aboveground. If only upper portions of the trunk or branches were visibly infested, density was recorded in a similar manner. The digital photography method was used to quantitatively monitor changes of beech scale density within designated areas on each tree. Three unique photographs were taken of each tree, using a stratified random sampling design to assign photo aspects at selected heights. One photo was taken at each 0.9, 1.2 and 1.5 m above ground and each of the three photos was assigned a random aspect before arriving at the site. Photos were taken using a tripod with a built-in stabilizer to ensure the camera was the same distance from the tree (30 cm) for each photograph. To reduce potential problems, a duplicate photo was taken at each setting. If shadows were present within the photo area, sunlight was blocked using a clipboard to reduce contrast within the photo.

Site Revisits

After all plots were established, sites were revisited to assess change in beech scale densities. During each revisit, qualitative and quantitative measures of beech scale were recorded. All photos were retaken on the same trees and at the same heights and aspects of original visits, allowing direct comparison of changes in beech scale density at various levels (i.e. individual photo, tree, and plot). Annual change in scale density involved a revisit after one year (± 30 days) and was observed at three sample time frames including July 2007- 2008, October 2007-2008, and March 2008-2009 (Table 3.1). In addition to annual revisits, a subset of 14 plots was revisited ten times to document within-year changes in beech scale density from July 2007 to June 2009 (Table 3.1). Due to a snow storm, only half of the plots were accessible in December 2007, but the remaining plots were revisited in early January 2008 (Table 3.1).

Population Density Over Time

As described in Chapter 2, we created an index of scale abundance that showed a linear relationship between the number of beech scales and the percentage of bark covered with wax. This allowed us to quantify scale density using photographs of beech scale wax. We used the binary threshold technique described in Chapter 2 to analyze photos. ImageJ was used to apply a binary threshold, which identified pixels with beech scale wax based on pixel brightness. The software was also used to calculate the percentage of photographed bark that was infested. Thresholds were manually set for each photograph, depending on photo quality, photo brightness and photo contrast.

SAS 9.1 ® was used to analyze within-year and annual changes of scale densities using both photo data and qualitative data. One tree from the Emmet satellite was removed from the dataset because it had beech scale densities approximately 36 standard deviations above the mean. In addition, data from Cadillac in December 2007 and from Emmet in October 2007 and March 2009 were removed because less than 75 % of trees were sampled due to undesirable weather, and disproportional sampling of uninfested and infested trees. Analyses of scale density at the tree level were conducted by averaging the scale density of all photos from the same tree and with the qualitative assessments. Fisher's Exact test was used to determine if the proportions of trees with increasing, decreasing and constant densities of beech scale differed among regions. A general linear model was used to determine the relationship between tree DBH, initial scale abundance and region with annual change of beech scale density on individual trees. Annual change in beech scale density was calculated based on a tree's average scale density from the annual revisit (Year 2) minus the tree's mean scale density from the initial visit (Year 1). Similarly, a general linear model was used to determine the significance of sight variables including beech tree basal area, other tree basal area, average beech tree DBH, average initial scale abundance and region for explaining the annual change of beech scale density averaged for each plot.

The rate of change in population density was represented by dividing Year 1 population densities by Year 2 population densities. This ratio allowed us to minimize the number of zero values in our dataset by assigning a 1 (no change) to trees with no scale in Year 1 and Year 2. More specifically, there were only two trees where Year 2 was a zero and could not be included in the ratio.

Results

Seasonal Cycle of Beech Scale Density on Individual Trees

Beech scale density fluctuated between July 2007 and June 2009. Overall mean beech scale density decreased from 0.282% of bark infested in July 2007 to 0.129% in June 2009. Between July and October of both years, the mean infested area increased (Figure 3.2). Area infested decreased from October 2007 to March 2008, remained relatively stable from March 2008 to June 2008, this showed a slight decrease from June 2008 to July 2008. Population density remained stable from October 2008 to June 2009 (Figure 3.2).

Patterns of within year change in beech scale populations depended on region and time (year and month) of sampling ($p < 0.001$) (Figure 3.2). The Cadillac and Ludington regions had similar initial beech scale density, with 0.323% and 0.545 % of bark infested, respectively. These sites also had similar trends in scale density throughout the study (Figure 3.2). Scale density in both regions was constant between July and October 2007 then decreased from October 2007 to March 2008. Both populations remained constant until July 2008, where a slight decrease occurred (Figure 3.2). In October 2008, both populations showed slight increases. In March 2009, the Ludington population decreased slightly while Cadillac remained constant. Densities at both sites remained constant from March to June 2009.

The Emmet region started with a much lower mean scale density than Ludington and Cadillac, with an average of 0.003% of sampled bark infested. The within year trend of beech scale density also differed from the other regions (Figure 3.2). From July 2007 to January 2008, the density increased, and decreased in density between January and March 2008. The density then remained constant until it slightly decreased in July 2008. The population increased substantially (four fold increase) from July to October 2008. The population increased again from December 2008 to June 2009, where a mean of 0.033% bark was infested, which was about 11-fold higher than at the beginning of the study.

Annual Beech Scale Dynamics

Photo Analysis of Scale Density on Individual Trees

When digital photos were used to analyze scale densities on individual trees, trends in beech scale density over time differed significantly by region and sample period (July 2007-2008, October 2007-2008, and March 2008-2009) ($p < 0.001$) (Table 3.2). Scale density increased across years in the Cadillac region during March and July sample periods, but density decreased from October 2007 to 2008. During the March sampling period, scale density increased on 44 % of trees, while density on 36 % of trees decreased. In contrast, scale density on a majority of trees decreased during July and October sample periods (Table 3.2). Mean scale density increased in the Emmet region during all three annual sample time frames. Scale density on 39 to 80% of trees increased, while scale density only decreased on 3 to 22 % of trees. In contrast, the Ludington region showed an overall decrease in scale density during every sample period. In this region, density on 0-8% of trees increased while density on 92-96% of trees decreased. The regions in the Upper Peninsula (U.P.) were only sampled annually during July, and showed an overall increase in beech scale density from 2007 to 2008.

In the eastern and central U.P., scale density increased on 67% and 74% of trees, respectively and decreased on 33% and 21% of trees, respectively.

Analysis of scale densities on individual trees using a general linear model produced a significant result ($p < 0.001$), explaining approximately 24% of the variation in annual change (Table 3.3). Changes in beech scale abundance were affected by region ($p < 0.001$), initial scale abundance ($p = 0.01$), and the interaction of region and initial scale abundance ($p = 0.033$). The interaction reflected a positive relationship between change in scale densities and initial scale abundance in the Emmet population, while all other regions showed a negative relationship. DBH was not related to change in scale density and was not included in the model.

Qualitative Analysis of Scale Density on Individual Trees

In most cases, qualitative estimates were similar to quantitative estimates, but some differences occurred (Table 3.2; Figure 3.3). A majority of tree samples (64%) resulted in constant qualitative rankings (Table 3.4). Of the samples that did change, 96% changed one visual rank, while the remaining four percent changed two ranks (Table 3.4). In addition, 81% of samples that changed increased in scale density, while only 19% decreased (Table 3.4). On several occasions (i.e. 324 of the 3,072 samples), the qualitative technique showed beech scale presence when the quantitative rank did not.

Trends from the qualitative assessment of beech scale density for each of the three sample periods, March 2008 to 2009, October 2007 to 2008 and July 2007 to 2008 were similar, but changes in scale density varied among regions ($p < 0.001$) (Table 3.2; Table 3.4). In the Cadillac region, the qualitative scale density remained the same for

72 to 86% of trees, increased for 10 to 25% of trees, and decreased for 3 to 4% of trees. The net result of these changes was a slight overall increase in qualitative ranks for scale density. Scale density in the Emmet region remained consistent on 29 to 69% of trees, increased on 39 to 71% of trees, and decreased on only 3% of the trees. In the E.U.P region, 58% of trees had no change in scale density but density increased on 42%, resulting in an overall increase in scale ranking. In the C.U.P region, we observed constant rankings on 24% of trees while density on 76% of trees increased. Trends in the Ludington region differed from other regions ($p < 0.001$); a nearly equal number of trees increased and decreased in scale density (Table 3.2; Table 3.4). Qualitative rankings for 50 to 78% of trees remained constant.

Plot Level Analysis of Beech Scale

The two plots that were initially uninfested in 2007 remained uninfested in 2008 despite the presence of infested trees within 200 m. These plots were not included in further analyses.

Overall, the plot level general linear model was significant ($p = 0.002$) and explained approximately 81% of the variation in annual change of beech scale density. Changes in beech scale populations varied among regions ($p = 0.008$) (Table 3.5). Scale density changed more dramatically in the two regions in the Upper Peninsula than in the other regions. Interactions of regions and other variables were not used as independent variables due to the low number of samples per region. Initial scale abundance and the log transformation of beech tree basal area and mean DBH were not significant (Table 3.5). Basal area of all non-beech trees was explored as an independent variable but showed no relationship with change in beech scale density. A new model was created without regions to focus on specific biological factors affecting change in beech scale densities. This model was significant ($p = 0.04$), explaining 41% of variation in annual change of beech scale density. The log transformation of beech basal area was the only significant variable ($p = 0.01$), while initial scale abundance and mean DBH of trees (log transformed) were not significant ($p = 0.74$ and $p = 0.17$, respectively). To reduce complexity, a final model was selected with beech basal area as the only significant variable ($p = 0.01$). The model explained 32% of variation in annual change of beech scale density (Table 3.5).

Discussion

Although our study design and sampling techniques differ from previous studies of beech scale dynamics, our results showed similar trends. Houston (1994) used a 40 point qualitative rank system to compare annual change of beech scale density in a stand of newly infested American beech trees (first decade of infestation) and a stand where scale populations were present for over 50 years. He found that the newly infested site generally increased in scale density annually over a ten year period, while the long-affected stand had scale densities that remained lower and fluctuated less than those in the newly infested stand. Our data shows similar results, where the more recently infested regions, Emmet, C.U.P., and E.U.P. showed large increases in scale density, while the other regions showed lower and more stable densities of beech scale (Table 2). Wainhouse and Gate (1988) used a 6 point qualitative rank system in their study of beech scale populations over a seven year period. Their results showed that beech scale populations on most European beech trees remained constant and those populations that did change showed a relatively small difference in density. Gora et al.

(1994) also looked at long term changes in beech scale densities using a qualiative five point ranking system (i.e. *uninfested* < *very slight* < *slight* < *medium* < *severely*). When control trees were observed, a decrease of 96% of trees classified as *very slight*, *medium* and no infestation occurred. A large increase in trees classified as *slight* infestations also occurred (127 %). Our qualitative assessments over a two year period also showed most populations of beech scale remained relatively constant from year to year. Also, similar to Gora et al. (1994), our results showed a large percentage of trees that were uninfested or had a trace of scale in the first year increased in scale density in the second year. Houston et al. (1979) used a five point qualitative ranking system to estimate scale density over three years following the inoculation of 40 of 80 European beech trees in a plantation. Once infested, a majority of trees increased one ranking per year. Of the trees that did not increase in scale density, most retained a constant rank while one tree actually went from a small infestation to being uninfested. The year to year results were similar to our findings; the trees in the Emmet, C.U.P. and E.U.P regions, all started with low beech scale densities. Scale density on most trees in these areas remained constant or increased one rank after one year. Also similar to Houston et al. (1979), only two of the 275 trees we sampled were initially infested and became uninfested after a year. This indicates that once infested with beech scale, a tree is likely to remain infested.

Our sample design and sampling techniques allowed us to analyze with-in year population dynamics of beech scale. The patterns we observed (Figure 3.2) appear to be largely driven by beech scale reproduction. Adults lay eggs and then die in the early summer (Ehrlich 1934). Their offspring do not secrete waxy coats until becoming 2nd

instars in late summer to early fall. Scales remain dormant through winter until early summer, when they begin feeding again (Ehrlich 1934). These events should cause the amount of wax generated by actively feeding to decrease during late summer and increase during fall. Consistent with this, data from our photos showed a slight decrease in scale density from June to July and a general increase in density during October sampling (Figure 3.2). During the winter of 2007-2008, beech scale density estimated by wax abundance decreased, suggesting that mortality occurred. Mortality during these months is most likely from exogenous stresses such as weather. From March 2008 to May 2008, a substantial increase in scale density occurred in the Emmet region. This trend is unexplained by scale biology, although this result may be influenced by scales losing wax during their dormant winter stage and replenishing wax in the spring after breaking dormancy.

In addition to with-in year data, our technique of using digital photography to measure scale density allowed us to more precisely quantify beech scale densities rather than qualitative measures used in previous studies. Unlike visual assessments, digital photography provided a lasting record of beech scale which allowed for more precise comparisons of infestation over time. In addition, digital photography provided concrete and reproducible results, unlike the subjective results of visual assessments. These qualities allowed us to produce reliable with-in year estimates of scale density and investigate more subtle changes in beech scale densities.

Our study is also the first to sample beech scale dynamics in several regions. Past studies have suggested beech scale dynamics are dependent on the stage of BBD (Shigo 1972; Houston 1994). These studies proposed that in early stages, when only beech scale is present, the populations of scale can reach higher densities. Once the *Neonectria* fungus is established, the phloem dies and scale density decreases. Our results suggest this may have occurred in our study in one region. Ludington has been infested with scale and fungi since at least 2000 (O'Brien et al. 2001) and overall this region showed decreases in annual scale density. Our other sample regions were in areas where beech scale has more recently invaded (Schwalm 2009), and all of these populations demonstrated annual increases in density. Different regions also have different exogenous factors acting on scale populations. For example, weather patterns and populations of insect predators may differ between regions. Gora et al. (1994) also suggested scale populations are sensitive to environmental conditions such as stand light and climate.

The use of both qualitative and quantitative methods of estimating beech scale density was valuable for detecting change in beech scale populations over time. In most cases, the directionality of change in mean scale density of photos was similar to that of qualitative mean scale density (Table 3.2), although the October sample period in Cadillac showed a decrease in scale density with photos and an increase in scale density with qualitative ratings. This difference is likely caused by the different precisions of the two methods. The quantitative method was more precise so it detected changes in beech scale densities that were missed with qualitative sampling (Figure 3.3). As a result, the percentage of trees with constant beech scale density was higher when reviewing qualitative results than quantitative (Figure 3.3). In contrast, qualitative methods enabled us to sample the entire visible portion of the tree, increasing the likelihood of detecting low densities or scattered scales, while photos sub-sampled only the truck and could fail to capture low densities of scale.

Our data suggest that density dependence may occur in beech scale populations. In particular, general linear models showed initial scale abundance to be a significant predictor variable of change in beech scale density. Also, on several occasions the digital photographs yielded an overall decrease in population density from Year 1, yet results from the qualitative method showed scale density on the same tree increased. These situations show that the beech scale densities in specific locations of a tree may decrease even though the tree's overall level of infestation increases. Such scenarios could be caused by density dependence, if crawlers move to areas of bark (not in the photograph) where scale density was lower. Another likely explanation for such scenarios involves *Neonectria* killing tree tissue in photographed areas, causing scale mortality. In addition, it is possible that disproportional predation of scale occurred on areas photographed and areas not photographed.

Our study increased knowledge of beech scale population dynamics, but several questions still need to be addressed. A similar study conducted over a longer timeframe would allow comparison of within year and annual trends of beech scale populations. Both qualitative and quantitative methods of estimating scale populations are useful to ensure trends on both individual trees and plots are captured. In addition, several plots within infested and uninfested areas of a single stand should be monitored over time to assess stand level dynamics of beech scale.

Table 3.1: Number of plots visited in each region during each sampling time frame. Annual density refers to the number of plots we revisited after one year (± 30 days) and within year density refers to the number of plots we revisited in the given month and year.

	# Sites						
	Cadillac	Central U.P.	Eastern U.P.	Emmet	Ludington	Benzie	Total
Annual Density							
March 2008-2009	7	0	0	3	3	0	13
July 2007-2008	7	4	6	4	3	2	26
October 2007-2008	7	0	0	4	3	0	14
Within Year Density							
July 2007	7	0	0	4	3	0	14
October 2007	7	0	0	4	3	0	14
December 2007	5	0	0	0	3	0	8
January 2008	1	0	0	4	0	0	5
March 2008	7	0	0	4	3	0	14
May 2008	7	0	0	4	3	0	14
June 2008	7	0	0	4	3	0	14
July 2008	7	0	0	4	3	0	14
October 2008	7	0	0	4	3	0	14
March 2009	7	0	0	3	3	0	13
June 2009	7	0	0	4	3	0	14

Table 3.2: Results from annual photo analysis (% area infested) and visual assessment of beech scale density, separated by region and sample timeframe. For photo analysis, Year 1 and Year 2 represent mean % of bark covered by wax per tree. For visual assessments, Year 1 and Year 2 were mean visual assessment. Visual assessments were 0 = no beech scale, 1 = trace populations, 2 = patchy populations and 3= heavy populations. Time refers to sampling timeframe including March 2008 to 2009, July 2007 to 2008, and October 2007 to 2008. Number of trees per sample = n, Year 1 represents mean beech scale density per tree in initial visits, Year 2 represents mean beech scale density per tree in revisits, CUP = Central Upper Peninsula, and EUP = Eastern Upper Peninsula. Ratio represents scale density in Year1/Year2. The percentage of trees in the region with increasing beech scale abundance (Percent Increase), decreasing abundance (Percent Decrease) and no change in abundance (Percent Constant) are also reported.

Annual Scale Density Estimated with Photos

Region	Time	n	Year 1	Year 2	Ratio	Percent Increase	Percent Decrease	Percent Constant
Cadillac	March	72	0.158	0.174	1.268 ± *0.21*	44	36	20
Cadillac	July	80	0.321	0.500	8.551 ± *1.94*	11	70	19
Cadillac	October	79	0.352	0.133	2.747 ± *0.77*	34	49	17
Emmet	March	25	0.002	0.008	0.396 ± *0.08*	76	4	20
Emmet	July	30	0.003	0.005	2.689 ± *1.16*	39	22	39
Emmet	October	30	0.001	0.009	0.228 ± *0.08*	80	3	17
Ludington	March	25	0.202	0.080	3.491 ± *0.45*	8	92	0
Ludington	July	26	0.590	0.063	26.864 ± *7.95*	0	96	4
Ludington	October	27	0.614	0.155	5.557 ± *1.55*	4	93	3
CUP	July	34	0.013	0.032	0.871 ± *0.26*	74	21	5
EUP	July	69	0.532	0.825	1.097 ± *0.17*	67	33	0

Annual Scale Density using Visual Assessment Ranks

Region	Time	n	Year 1	Year 2	Percent Increase	Percent Decrease	Percent Constant
Cadillac	March	69	1.246	1.406	19	3	78
Cadillac	July	80	1.225	1.288	10	4	87

Table 3.2 cont

Cadillac	October	79	1.076	1.291	25	3	72
Emmet	March	23	0.783	1.174	39	0	61
Emmet	July	34	0.382	0.794	41	3	56
Emmet	October	35	0.514	1.257	71	0	29
Ludington	March	23	2.174	1.957	0	22	78
Ludington	July	21	2.190	2.143	14	14	72
Ludington	October	24	2.000	1.917	21	29	50
CUP	July	38	0.092	1.711	76	0	24
EUP	July	69	1.783	2.217	42	0	58

Table 3.3: General linear model results evaluating relationship between percent change in beech scale on individual trees (n = 325), as measured by photographs. The model was significant ($p < 0.001$) and explained approximately 24 % of variation in change of scale density. Initial was Year 1 scale density measurements, from photographs. Five regions were included (i.e. Cadillac, Emmet, Ludington, C.U.P, and E.U.P.). Model included the two-way interaction between initial scale and region.

Source	Degrees of Freedom	Squares	Mean Squares	F Value	Pr > F
Model	9	18116165	2012907	10.8	< 0.001
Error	315	58695128	186333		
Initial	1	1240327	1240327	6.66	0.01
Regions	4	16586161	4146540	22.25	< 0.001
Initial * Regions	4	1974567	493641	2.65	0.033

Table 3.4: Annual change matrices, representing number of individual trees with each initial (rows) and revisited (columns) qualitative ranking of scale density where 0 = no beech scale, 1 = trace populations, 2 = patchy populations and 3= heavy populations.

a) **All Regions**

Year 1 Scale Rank	Year 2 Scale Rank: 0	1	2	3
0	50	52	2	0
1	7	151	63	2
2	1	7	63	25
3	0	2	17	53

b) **Cadillac**

Year 1 Scale Rank	Year 2 Scale Rank: 0	1	2	3
0	33	12	0	0
1	6	95	13	0
2	0	6	30	5
3	0	1	5	22

c) **Emmet**

Year 1 Scale Rank	Year 2 Scale Rank: 0	1	2	3
0	16	30	2	0
1	1	26	13	0
2	0	0	0	3
3	0	0	0	1

d) **Ludington**

Year 1 Scale Rank	Year 2 Scale Rank: 0	1	2	3
0	0	1	0	0
1	0	12	4	0
2	1	1	20	3
3	0	1	12	13

e) **Central U.P.**

Year 1 Scale Rank	Year 2 Scale Rank: 0	1	2	3
0	1	9	0	0
1	0	6	15	1
2	0	0	1	4
3	0	0	0	1

f) **Eastern U.P.**

Year 1 Scale Rank	Year 2 Scale Rank: 0	1	2	3
0	0	0	0	0
1	0	12	18	1
2	0	0	12	10
3	0	0	0	16

Table 3.5: General linear model results evaluating relationship between percentage change in beech scale at the plot level (n = 19), as measured by photographs. Model 1 was significant (p = 0.003) and explained approximately 81 % of variation in change of scale density. Model 2 was significant (p = 0.01) and explained approximately 32% of variation in change of scale density. Initial was the mean scale density measurements of each plot for Year 1 (calculated from photographs), other BA was the basal area of all trees except beech in Year 1, and beech BA was the basal area of all beech trees. The model also included the two-way interaction between initial scale and region. Five regions were included (i.e. Cadillac, Emmet, Ludington, C.U.P, and E.U.P.).

Model 1					
Source	**Degrees of Freedom**	**Coefficient**	**Mean Squares**	**F Value**	**Pr > F**
Model	7		652,922	8.02	0.0115
Error	11		81,384		
Log(10) Beech Basal Area	1	-352.0	28214	0.81	0.388
Initial	1	0.24	0.2695	0.00	0.998
Log(10) DBH	1	315.0	28528	0.82	0.385
Locations	4		206462	5.92	0.009

Model 2					
Source	**Degrees of Freedom**	**Coefficient**	**Mean Squares**	**F Value**	**Pr > F**
Model	1		652922	8.02	0.0115
Error	17		81384		
Log(10) Beech Basal Area	1	-1215.0	652922	8.02	0.0115

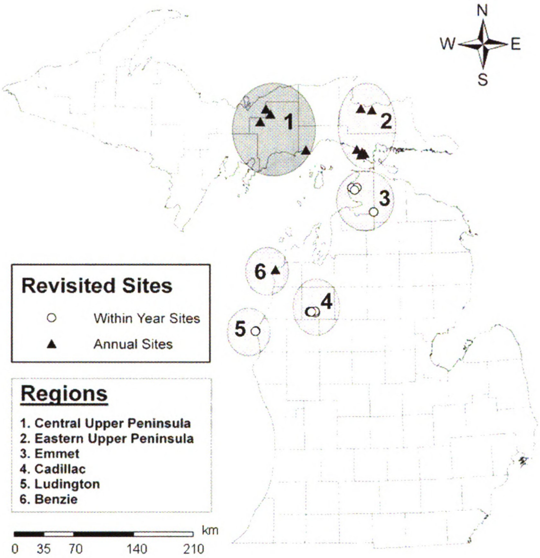

Figure 3.1: Plot locations by region used for bimonthly and annual sampling of scale density. Bimonthly plots (n=14) were used to determine bimonthly and annual changes in scale density, while annual plots (n=12) were only used in annual analysis.

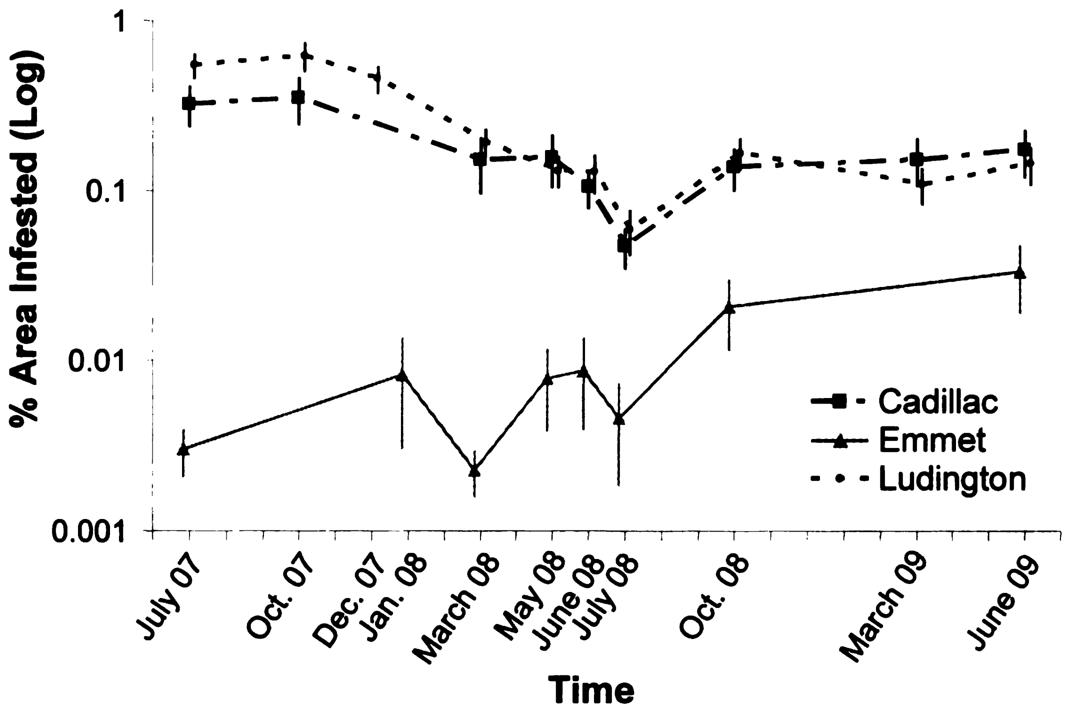

Figure 3.2: Within year change in beech scale densities by region from July 2007 to June 2009. Percent area infested refers to average percent of bark infested with scale per tree. Cadillac (n = 84 trees), Emmet (n = 36 trees), Ludington (n = 28 trees).

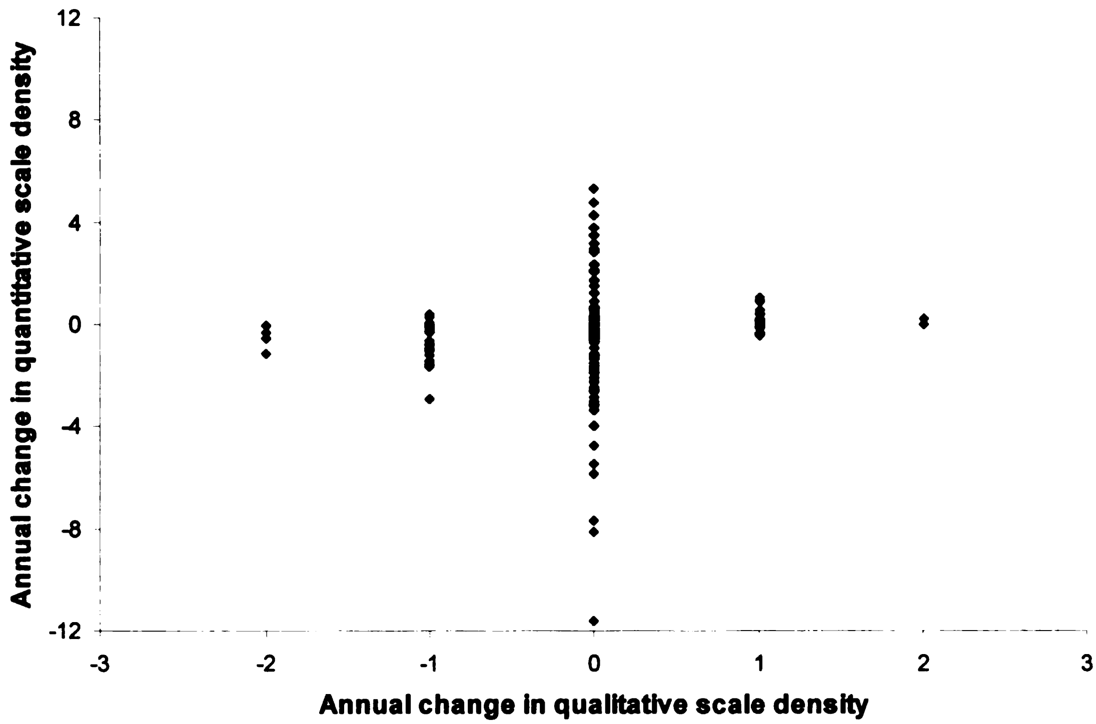

Figure 3.3: Comparison of visual qualitative assessment and quantitative assessment of change in beech scale density per tree. Change in qualitative scale density was a difference of visual ranking from Year 1 to Year 2. Photos on each tree were averaged for each year and then the difference between Year 1 and Year 2 was used to represent quantitative scale density.

APPENDICES

APPENDIX A: Site Coordinates

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
11	7/1/2007	-86.5118	43.639	Whitewashed	OCEANA
25	8/8/2005	-86.4083	43.617	No Scale	OCEANA
25	6/26/2007	-86.4083	43.617	Trace	OCEANA
31	8/8/2005	-86.3826	43.6453	No Scale	OCEANA
37	8/8/2005	-86.492	43.5413	No Scale	OCEANA
40	8/8/2005	-86.4158	43.5448	No Scale	OCEANA
43	8/8/2005	-86.4617	43.5312	No Scale	OCEANA
44	7/10/2006	-86.4523	43.5449	Whitewashed	OCEANA
49	8/8/2005	-86.3777	43.583	No Scale	OCEANA
60	7/10/2006	-86.3745	43.7685	Trace	OCEANA
76	8/9/2005	-86.3571	43.5101	No Scale	OCEANA
76	7/10/2006	-86.3571	43.5101	No Scale	OCEANA
83	8/9/2005	-86.3382	43.7979	No Scale	OCEANA
83	7/10/2006	-86.3382	43.7979	No Scale	OCEANA
115	5/30/2009	-85.7991	44.2012	No Scale	WEXFORD
122	5/30/2009	-86.0143	44.0816	No Scale	LAKE
123	6/19/2007	-86.1202	44.2697	No Scale	MANISTEE
128	5/17/2005	-86.4127	43.6797	No Scale	OCEANA
129	5/17/2005	-86.3694	43.6591	No Scale	OCEANA
130	5/19/2005	-84.4771	42.7177	No Scale	INGHAM
131	5/19/2005	-84.5112	42.6892	No Scale	INGHAM
132	5/19/2005	-84.5912	42.6092	No Scale	INGHAM
133	5/19/2005	-84.7582	42.5779	No Scale	EATON
134	5/19/2005	-84.7598	42.7594	No Scale	EATON
135	5/23/2005	-84.4714	42.5307	No Beech	INGHAM
136	5/23/2005	-84.3637	42.5267	No Beech	INGHAM
137	5/23/2005	-84.279	42.5964	No Beech	INGHAM
138	5/23/2005	-84.3692	42.7054	No Scale	INGHAM
139	5/23/2005	-84.4076	42.7552	No Beech	INGHAM
140	5/23/2005	-84.3895	42.8125	No Beech	CLINTON
141	5/24/2005	-86.2667	43.1315	No Scale	MUSKEGON
141	5/22/2008	-86.2667	43.1315	No Scale	MUSKEGON
141	5/29/2009	-86.2667	43.1315	No Scale	MUSKEGON
142	5/24/2005	-86.3586	43.2633	No Scale	MUSKEGON
142	5/22/2008	-86.3586	43.2633	No Scale	MUSKEGON
142	5/22/2008	-86.3586	43.2633	No Scale	MUSKEGON
142	5/29/2009	-86.3586	43.2633	No Scale	MUSKEGON
143	5/24/2005	-86.3961	43.3447	No Beech	MUSKEGON
144	5/25/2005	-86.2662	43.4546	No Scale	MUSKEGON
144	6/18/2007	-86.2653	43.4573	No Scale	MUSKEGON

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
145	5/25/2005	-86.3595	43.4854	No Beech	OCEANA
146	5/25/2005	-86.4395	43.5306	No Beech	OCEANA
147	5/25/2005	-86.4377	43.5348	No Scale	OCEANA
148	5/25/2005	-86.3589	43.5438	No Scale	OCEANA
148	7/10/2006	-86.3589	43.5438	Trace	OCEANA
149	5/25/2005	-86.4311	43.615	No Scale	OCEANA
150	5/25/2005	-86.4683	43.6144	No Scale	OCEANA
150	7/10/2006	-86.4683	43.6144	No Scale	OCEANA
151	5/25/2005	-86.4971	43.6608	Trace	OCEANA
152	5/25/2005	-86.4981	43.649	No Scale	OCEANA
152	7/10/2006	-86.4981	43.649	Trace	OCEANA
153	5/25/2005	-86.483	43.6641	Patchy	OCEANA
154	5/25/2005	-86.4681	43.6676	Whitewashed	OCEANA
155	5/25/2005	-86.4544	43.6963	No Scale	OCEANA
156	5/25/2005	-86.4874	43.6915	No Scale	OCEANA
157	5/25/2005	-86.4713	43.7335	No Beech	OCEANA
158	5/26/2005	-86.4963	44.0401	Whitewashed	MASON
159	5/26/2005	-86.4632	43.9931	Whitewashed	MASON
160	5/26/2005	-86.4583	43.9713	Whitewashed	MASON
161	5/26/2005	-86.3985	43.9447	No Beech	MASON
162	5/26/2005	-86.2849	43.8906	No Beech	MASON
163	5/26/2005	-86.3317	43.8765	Whitewashed	MASON
164	5/26/2005	-86.3683	43.8767	Patchy	MASON
165	5/26/2005	-86.4	43.8688	Whitewashed	MASON
166	5/26/2005	-86.3928	43.6972	Patchy	OCEANA
167	5/26/2005	-86.3715	43.4958	No Scale	OCEANA
168	5/31/2005	-86.2143	43.7588	No Scale	OCEANA
169	5/31/2005	-86.1286	43.7721	No Scale	OCEANA
169	6/19/2007	-86.1286	43.7721	Patchy	OCEANA
170	5/31/2005	-86.0871	43.8027	No Scale	OCEANA
170	6/19/2007	-86.0871	43.8027	No Scale	OCEANA
170	5/25/2008	-86.0871	43.8027	Trace	OCEANA
171	5/31/2005	-86.0773	43.8481	No Beech	MASON
172	5/31/2005	-86.1025	43.8719	No Scale	MASON
173	5/31/2005	-86.1107	43.8741	No Scale	MASON
173	7/13/2006	-86.1107	43.8741	No Scale	MASON
173	5/25/2008	-86.1107	43.8741	Patchy	MASON
174	5/31/2005	-86.135	43.8737	No Scale	MASON
175	5/31/2005	-86.1909	43.8747	No Scale	MASON
176	5/31/2005	-86.2315	43.8754	Patchy	MASON
177	5/31/2005	-86.2277	43.8743	Patchy	MASON
178	5/31/2005	-86.2298	43.8899	No Scale	MASON

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
179	5/31/2005	-86.2278	43.89	Patchy	MASON
180	5/31/2005	-86.2185	43.9045	Patchy	MASON
181	5/31/2005	-86.1033	43.9754	Patchy	MASON
182	6/1/2005	-85.8945	44.3473	No Scale	MANISTEE
182	6/1/2009	-85.8945	44.3473	Whitewashed	MANISTEE
183	6/1/2005	-85.9973	44.4387	No Scale	MANISTEE
183	6/1/2009	-85.9973	44.4387	Trace	MANISTEE
184	6/1/2005	-86.2434	44.4792	No Scale	MANISTEE
185	6/1/2005	-86.2304	44.4306	No Scale	MANISTEE
186	6/1/2005	-86.2259	44.4037	Trace	MANISTEE
187	6/1/2005	-86.2274	44.4009	Whitewashed	MANISTEE
188	6/1/2005	-86.1965	44.389	Patchy	MANISTEE
189	6/1/2005	-86.1648	44.3885	Trace	MANISTEE
190	6/1/2005	-86.1673	44.4031	No Scale	MANISTEE
191	6/1/2005	-86.1944	44.4064	Trace	MANISTEE
192	6/1/2005	-86.1451	44.3589	No Scale	MANISTEE
193	6/1/2005	-86.125	44.3876	No Scale	MANISTEE
194	6/1/2005	-86.1224	44.3714	No Scale	MANISTEE
195	6/1/2005	-86.1477	44.3298	No Scale	MANISTEE
196	6/1/2005	-86.1727	44.3091	Whitewashed	MANISTEE
197	6/2/2005	-86.1677	44.3158	Patchy	MANISTEE
198	6/2/2005	-86.1622	44.3401	No Scale	MANISTEE
199	6/2/2005	-86.1558	44.3813	No Scale	MANISTEE
200	7/14/2005	-86.0096	46.666	Patchy	ALGER
208	7/25/2006	-86.5464	46.4193	No Scale	ALGER
214	7/17/2009	-86.7166	46.3078	No Scale	ALGER
222	6/28/2006	-86.2718	46.5025	Patchy	SCHOOLCRAFT
223	6/28/2006	-86.3618	46.4282	No Scale	SCHOOLCRAFT
223	7/23/2007	-86.3618	46.4284	Whitewashed	SCHOOLCRAFT
224	7/26/2006	-86.2914	46.3717	Trace	SCHOOLCRAFT
224	7/2/2007	-86.2914	46.3717	Trace	SCHOOLCRAFT
228	7/26/2006	-86.2595	46.2777	No Scale	SCHOOLCRAFT
229	7/26/2006	-86.2299	46.2206	No Scale	SCHOOLCRAFT
231	7/26/2006	-86.228	46.1251	No Scale	SCHOOLCRAFT
231	7/3/2007	-86.228	46.1251	No Scale	SCHOOLCRAFT
231	7/17/2009	-86.228	46.1251	No Scale	SCHOOLCRAFT
236	7/3/2007	-86.0826	46.0431	No Scale	SCHOOLCRAFT
236	7/20/2008	-86.0826	46.0431	No Scale	SCHOOLCRAFT
236	7/19/2009	-86.0826	46.0431	Trace	SCHOOLCRAFT
245	6/27/2006	-85.9283	46.1858	No Scale	SCHOOLCRAFT
257	7/18/2009	-86.8372	46.1419	No Scale	DELTA
500	6/2/2005	-86.172	44.3585	No Scale	MANISTEE

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
501	6/2/2005	-86.2025	44.3497	No Scale	MANISTEE
502	6/2/2005	-86.1979	44.3315	Patchy	MANISTEE
503	6/2/2005	-86.1879	44.3313	No Scale	MANISTEE
504	6/2/2005	-86.1921	44.3168	Whitewashed	MANISTEE
505	6/2/2005	-86.1816	44.2627	No Scale	MANISTEE
506	6/2/2005	-86.1773	44.2671	Trace	MANISTEE
507	6/6/2005	-86.3585	43.8165	Trace	OCEANA
508	6/6/2005	-86.2982	43.7984	No Beech	OCEANA
509	6/6/2005	-86.2922	43.7877	Trace	OCEANA
510	6/6/2005	-86.2689	43.8175	No Scale	OCEANA
511	6/6/2005	-86.2482	43.8721	No Scale	MASON
512	6/6/2005	-86.2014	43.8389	No Scale	MASON
512	7/13/2006	-86.2014	43.8389	Trace	MASON
513	6/6/2005	-86.1755	43.8357	No Scale	MASON
513	7/13/2006	-86.1755	43.8357	Trace	MASON
514	6/6/2005	-86.1617	43.837	Whitewashed	MASON
515	6/6/2005	-86.1749	43.7907	No Scale	OCEANA
515	7/10/2006	-86.1749	43.7907	No Scale	OCEANA
516	6/6/2005	-86.2449	43.7934	Trace	OCEANA
517	6/7/2005	-86.1531	43.9113	No Beech	MASON
518	6/7/2005	-86.1634	43.9141	Trace	MASON
519	6/7/2005	-86.1907	43.9038	Trace	MASON
520	6/7/2005	-86.1751	43.9021	Trace	MASON
521	6/7/2005	-86.05	43.9376	No Scale	MASON
521	5/25/2008	-86.05	43.9376	No Scale	MASON
522	6/7/2005	-86.0546	43.9848	No Scale	MASON
522	5/25/2008	-86.0546	43.9848	No Scale	MASON
523	6/7/2005	-86.0801	44.0178	Trace	MASON
524	6/7/2005	-86.1159	44.0163	Trace	MASON
525	6/7/2005	-86.0772	44.0322	No Scale	MASON
525	6/19/2007	-86.0772	44.0322	Whitewashed	MASON
526	6/7/2005	-86.1204	44.0418	Whitewashed	MASON
527	6/7/2005	-86.1324	44.0663	Trace	MASON
528	6/7/2005	-86.1254	44.1049	Trace	MASON
529	6/7/2005	-86.2211	44.1457	Trace	MASON
530	6/7/2005	-86.2007	44.2509	Patchy	MANISTEE
531	6/7/2005	-86.1033	44.1707	No Scale	MANISTEE
531	6/19/2007	-86.1033	44.1707	No Scale	MANISTEE
531	5/26/2008	-86.1033	44.1707	No Scale	MANISTEE
532	6/8/2005	-86.1411	44.3129	Trace	MANISTEE
533	6/8/2005	-86.1023	44.305	Trace	MANISTEE
534	6/8/2005	-86.2683	44.345	Patchy	MANISTEE

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
535	6/8/2005	-86.1054	44.5358	No Scale	BENZIE
535	6/27/2007	-86.1054	44.5358	No Scale	BENZIE
535	6/18/2008	-86.1054	44.5358	No Scale	BENZIE
535	6/11/2009	-86.1054	44.5358	Trace	BENZIE
536	6/8/2005	-86.1024	44.5901	Trace	BENZIE
537	6/8/2005	-86.1136	44.6833	No Scale	BENZIE
538	6/8/2005	-86.0622	44.7207	No Scale	BENZIE
538	6/11/2009	-86.0622	44.7207	No Scale	BENZIE
539	6/8/2005	-86.0746	44.764	No Scale	BENZIE
539	6/11/2009	-86.0746	44.764	No Scale	BENZIE
540	6/8/2005	-86.0359	44.8459	No Scale	LEELANAU
540	7/17/2006	-86.0359	44.8459	No Scale	LEELANAU
540	6/18/2008	-86.0359	44.8459	No Scale	LEELANAU
540	6/11/2009	-86.0359	44.8459	No Scale	LEELANAU
541	6/8/2005	-86.021	44.897	No Scale	LEELANAU
541	7/10/2007	-86.0198	44.897	No Scale	LEELANAU
541	6/11/2009	-86.021	44.897	No Scale	LEELANAU
542	6/8/2005	-85.9252	44.9354	No Scale	LEELANAU
542	7/17/2006	-85.9252	44.9354	No Scale	LEELANAU
542	6/11/2009	-85.9252	44.9354	No Scale	LEELANAU
543	6/8/2005	-85.9147	44.8771	No Scale	LEELANAU
543	6/26/2007	-85.9147	44.8771	No Scale	LEELANAU
544	6/8/2005	-85.9698	44.8428	No Scale	LEELANAU
545	6/9/2005	-85.9991	44.7575	No Scale	BENZIE
545	6/11/2009	-85.9991	44.7575	No Scale	BENZIE
546	6/9/2005	-85.9572	44.8073	No Scale	LEELANAU
547	6/9/2005	-85.8857	44.7182	No Scale	BENZIE
548	6/9/2005	-85.9796	44.6449	No Scale	BENZIE
548	6/27/2007	-85.9796	44.6449	No Scale	BENZIE
548	6/18/2008	-85.9796	44.6449	No Scale	BENZIE
549	6/9/2005	-85.9579	44.6801	No Scale	BENZIE
550	6/9/2005	-85.9091	44.6171	No Scale	BENZIE
551	6/9/2005	-86.0463	44.6175	No Scale	BENZIE
552	6/9/2005	-86.2307	44.6958	No Scale	BENZIE
553	6/9/2005	-86.13	44.531	Trace	BENZIE
554	6/9/2005	-85.9588	44.5255	Patchy	BENZIE
555	6/13/2005	-84.356	44.5362	No Beech	OSCODA
556	6/13/2005	-84.5993	44.9391	No Scale	OTSEGO
557	6/13/2005	-84.447	44.9712	No Scale	OTSEGO
558	6/13/2005	-84.5902	45.0157	No Scale	OTSEGO
559	6/13/2005	-84.3713	44.9602	No Scale	MONTMORENCY
560	6/13/2005	-84.6779	44.8802	No Scale	OTSEGO

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
560	6/12/2009	-84.6779	44.8802	Trace	OTSEGO
561	6/13/2005	-84.1987	44.8682	No Scale	MONTMORENCY
562	6/14/2005	-85.8552	44.8104	No Scale	LEELANAU
563	6/14/2005	-85.5197	44.5122	No Scale	GRAND TRAVERSE
563	6/12/2009	-85.5197	44.5122	No Scale	GRAND TRAVERSE
564	6/14/2005	-85.8537	44.8788	No Scale	LEELANAU
565	6/14/2005	-85.6081	44.4971	No Scale	WEXFORD
566	6/14/2005	-85.8644	44.922	No Scale	LEELANAU
566	7/17/2006	-85.8644	44.922	No Scale	LEELANAU
567	6/14/2005	-85.6775	44.5467	No Scale	GRAND TRAVERSE
568	6/14/2005	-85.7447	44.8916	No Scale	LEELANAU
569	6/14/2005	-85.8185	44.5473	No Scale	BENZIE
570	6/14/2005	-85.727	44.9822	No Scale	LEELANAU
571	6/14/2005	-85.7979	44.6045	No Scale	GRAND TRAVERSE
571	6/12/2009	-85.7979	44.6045	Trace	GRAND TRAVERSE
572	6/14/2005	-85.7599	44.9944	No Scale	LEELANAU
573	6/14/2005	-85.8419	44.6781	No Scale	BENZIE
574	6/14/2005	-85.7764	44.9805	No Scale	LEELANAU
575	6/14/2005	-85.8584	44.7399	No Scale	BENZIE
575	6/12/2009	-85.8584	44.7399	No Scale	BENZIE
576	6/14/2005	-85.7964	44.959	No Scale	LEELANAU
577	6/14/2005	-85.6759	44.6681	No Scale	GRAND TRAVERSE
578	6/14/2005	-85.6331	45.0063	No Scale	LEELANAU
579	6/14/2005	-85.599	44.6355	No Scale	GRAND TRAVERSE
580	6/14/2005	-85.6436	45.1028	No Scale	LEELANAU
581	6/14/2005	-85.5567	44.6278	No Scale	GRAND TRAVERSE
581	6/12/2009	-85.5567	44.6278	No Scale	GRAND TRAVERSE
582	6/14/2005	-85.6745	44.8873	No Scale	LEELANAU
583	6/14/2005	-85.4943	44.7124	No Scale	GRAND TRAVERSE
584	6/14/2005	-85.6522	44.8025	No Scale	LEELANAU
585	6/15/2005	-85.423	44.8818	No Scale	ANTRIM
586	6/15/2005	-85.4031	44.763	No Scale	GRAND TRAVERSE
587	6/15/2005	-85.3532	44.8632	No Scale	ANTRIM
588	6/15/2005	-85.3457	44.5878	No Scale	GRAND TRAVERSE

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
589	6/15/2005	-85.1893	44.8577	No Scale	KALKASKA
590	6/15/2005	-85.3167	44.5267	No Scale	KALKASKA
591	6/15/2005	-85.1347	44.9898	No Scale	ANTRIM
592	6/15/2005	-85.178	44.5839	No Scale	KALKASKA
593	6/15/2005	-85.0506	44.8394	No Scale	KALKASKA
594	6/15/2005	-85.1434	44.641	No Scale	KALKASKA
595	6/15/2005	-85.1933	44.7925	No Scale	KALKASKA
596	6/15/2005	-85.1964	44.6549	No Scale	KALKASKA
597	6/15/2005	-85.2683	44.7829	No Scale	KALKASKA
597	6/12/2009	-85.2683	44.7829	No Scale	KALKASKA
598	6/15/2005	-85.1545	44.67	No Scale	KALKASKA
599	6/15/2005	-85.1347	44.9612	No Scale	ANTRIM
600	6/15/2005	-85.0738	44.6987	No Scale	KALKASKA
601	6/15/2005	-85.0714	44.7282	No Scale	KALKASKA
602	6/15/2005	-85.2118	44.5726	No Scale	KALKASKA
603	6/15/2005	-85.0727	44.7286	No Scale	KALKASKA
604	6/16/2005	-84.6458	44.8014	No Scale	CRAWFORD
605	6/16/2005	-84.6467	44.6805	No Beech	CRAWFORD
606	6/16/2005	-84.7067	44.9582	No Scale	OTSEGO
606	6/13/2009	-84.7067	44.9582	No Scale	OTSEGO
607	6/16/2005	-84.7771	44.7539	No Scale	CRAWFORD
608	6/16/2005	-84.7767	44.9211	No Scale	OTSEGO
609	6/16/2005	-84.8845	44.7709	No Scale	KALKASKA
609	6/12/2009	-84.8845	44.7709	No Scale	KALKASKA
610	6/16/2005	-84.7874	44.888	No Scale	OTSEGO
611	6/16/2005	-84.976	44.7134	No Scale	KALKASKA
611	6/23/2008	-84.976	44.7134	No Scale	KALKASKA
611	6/12/2009	-84.976	44.7134	No Scale	KALKASKA
612	6/16/2005	-84.7811	44.7769	No Scale	CRAWFORD
613	6/16/2005	-84.9144	44.6353	No Scale	KALKASKA
614	6/20/2005	-84.7514	45.1867	No Scale	CHARLEVOIX
615	6/16/2005	-84.9558	44.5399	No Scale	KALKASKA
616	6/20/2005	-84.9352	45.1467	No Scale	CHARLEVOIX
617	6/16/2005	-84.7657	44.5981	No Scale	CRAWFORD
618	6/20/2005	-84.9074	45.0646	No Scale	ANTRIM
619	6/20/2005	-84.5911	45.2052	No Scale	CHEBOYGAN
620	6/20/2005	-84.8164	45.113	No Scale	OTSEGO
620	6/13/2009	-84.8164	45.113	No Scale	OTSEGO
621	6/20/2005	-84.6669	45.2444	No Scale	CHEBOYGAN
621	6/21/2008	-84.6669	45.2444	No Scale	CHEBOYGAN
621	6/13/2009	-84.6669	45.2444	Trace	CHEBOYGAN
622	6/20/2005	-84.7556	45.0276	No Scale	OTSEGO

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
623	6/20/2005	-84.9356	45.2778	No Scale	CHARLEVOIX
624	6/20/2005	-84.699	45.0996	No Scale	OTSEGO
625	6/20/2005	-84.8166	45.3524	No Scale	EMMET
626	6/20/2005	-84.6235	45.0618	No Scale	OTSEGO
627	6/20/2005	-84.7418	45.3263	No Scale	EMMET
628	6/21/2005	-84.5762	45.505	No Scale	CHEBOYGAN
629	6/21/2005	-84.7666	45.4417	No Scale	EMMET
630	6/21/2005	-84.7159	45.5509	No Scale	CHEBOYGAN
630	6/20/2008	-84.7159	45.5509	No Scale	CHEBOYGAN
630	6/14/2009	-84.7159	45.5509	Patchy	CHEBOYGAN
631	6/21/2005	-84.762	45.5161	No Scale	EMMET
632	6/21/2005	-84.6316	45.5749	No Scale	CHEBOYGAN
632	6/14/2009	-84.6316	45.5749	No Scale	CHEBOYGAN
633	6/21/2005	-84.7925	45.6287	No Scale	EMMET
633	6/25/2007	-84.7925	45.6287	Patchy	EMMET
634	6/21/2005	-84.7282	45.6916	No Scale	CHEBOYGAN
634	6/25/2007	-84.7282	45.6916	No Scale	CHEBOYGAN
634	6/20/2008	-84.7282	45.6916	No Scale	CHEBOYGAN
634	6/15/2009	-84.7282	45.6916	Patchy	CHEBOYGAN
635	6/21/2005	-84.7728	45.7192	No Scale	EMMET
635	7/27/2006	-84.7728	45.7192	No Scale	EMMET
635	6/25/2007	-84.7728	45.7192	No Scale	EMMET
635	6/15/2009	-84.7728	45.7192	No Scale	EMMET
636	6/21/2005	-84.6681	45.7463	No Scale	CHEBOYGAN
636	7/27/2006	-84.6681	45.7463	No Scale	CHEBOYGAN
637	6/21/2005	-84.7695	45.7668	Whitewashed	EMMET
638	6/21/2005	-84.6507	45.6832	No Scale	CHEBOYGAN
638	6/15/2009	-84.6507	45.6832	Whitewashed	CHEBOYGAN
640	6/21/2005	-84.6386	45.6646	No Scale	CHEBOYGAN
640	6/15/2009	-84.6386	45.6646	Patchy	CHEBOYGAN
641	6/21/2005	-85.0146	45.6507	No Scale	EMMET
641	6/25/2007	-85.0146	45.6507	Trace	EMMET
642	6/21/2005	-84.3282	45.5795	No Scale	CHEBOYGAN
642	6/15/2009	-84.3282	45.5795	Trace	CHEBOYGAN
643	6/21/2005	-85.0851	45.6066	No Scale	EMMET
643	6/25/2007	-85.0851	45.6066	Trace	EMMET
644	6/21/2005	-84.3963	45.5387	No Scale	CHEBOYGAN
645	6/21/2005	-85.0161	45.5511	No Scale	EMMET
645	7/27/2006	-85.0161	45.5511	Trace	EMMET
646	6/21/2005	-84.4542	45.5692	No Scale	CHEBOYGAN
647	6/21/2005	-84.9358	45.5503	No Scale	EMMET
647	6/25/2007	-84.9358	45.5503	No Scale	EMMET

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
648	6/21/2005	-84.508	45.319	No Scale	CHEBOYGAN
649	6/21/2005	-84.9296	45.6138	No Scale	EMMET
650	6/21/2005	-84.4773	45.2542	No Scale	CHEBOYGAN
650	6/15/2009	-84.4773	45.2542	No Scale	CHEBOYGAN
651	6/21/2005	-84.8495	45.6367	Trace	EMMET
652	6/22/2005	-85.1664	45.3495	No Scale	CHARLEVOIX
653	6/21/2005	-84.8457	45.5513	No Scale	EMMET
654	6/22/2005	-85.1781	45.3109	No Scale	CHARLEVOIX
655	6/21/2005	-84.8522	45.4711	No Scale	EMMET
656	6/22/2005	-85.0586	45.3123	No Scale	CHARLEVOIX
657	6/21/2005	-84.927	45.4568	No Scale	EMMET
658	6/22/2005	-85.0429	45.2419	No Scale	CHARLEVOIX
658	6/13/2009	-85.0429	45.2419	No Scale	CHARLEVOIX
659	6/21/2005	-84.7996	45.377	No Scale	EMMET
660	6/22/2005	-85.0933	45.2373	No Scale	CHARLEVOIX
661	6/21/2005	-84.9063	45.4078	No Scale	EMMET
661	6/25/2007	-84.9063	45.4078	Patchy	EMMET
662	6/22/2005	-85.131	45.1718	No Scale	CHARLEVOIX
663	6/22/2005	-85.2265	45.1685	No Scale	ANTRIM
664	6/22/2005	-85.0401	45.1282	No Scale	CHARLEVOIX
665	6/22/2005	-85.2017	45.2155	No Scale	CHARLEVOIX
666	6/22/2005	-85.154	45.0499	No Scale	ANTRIM
666	6/13/2009	-85.154	45.0499	No Scale	ANTRIM
667	6/22/2005	-85.2546	45.2793	No Scale	CHARLEVOIX
668	6/22/2005	-85.1387	45.0907	No Scale	ANTRIM
669	6/22/2005	-85.3218	45.2556	No Scale	CHARLEVOIX
670	6/22/2005	-84.5121	45.1591	No Scale	OTSEGO
670	6/21/2008	-84.5121	45.1591	No Scale	OTSEGO
670	6/15/2009	-84.5121	45.1591	No Scale	OTSEGO
671	6/22/2005	-85.3766	45.1822	No Scale	ANTRIM
672	6/23/2005	-84.4175	45.1562	No Scale	OTSEGO
672	6/15/2009	-84.4175	45.1562	No Scale	OTSEGO
673	6/22/2005	-85.3612	45.0757	No Scale	ANTRIM
674	6/28/2005	-85.3596	44.2518	No Scale	WEXFORD
675	6/22/2005	-85.2998	45.1593	No Scale	ANTRIM
676	6/28/2005	-85.3245	44.1487	No Scale	OSCEOLA
677	6/22/2005	-85.2994	45.0487	No Scale	ANTRIM
678	6/28/2005	-85.3825	44.0734	No Scale	OSCEOLA
678	5/31/2009	-85.3825	44.0734	No Scale	OSCEOLA
679	6/22/2005	-85.2172	45.0297	No Scale	ANTRIM
680	6/28/2005	-85.1871	44.1101	No Scale	OSCEOLA
681	6/22/2005	-85.1446	45.103	No Scale	ANTRIM

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
682	6/29/2005	-85.5007	44.2179	No Scale	WEXFORD
682	5/31/2009	-85.5007	44.2179	Patchy	WEXFORD
683	6/23/2005	-84.4708	45.4356	No Scale	CHEBOYGAN
684	6/29/2005	-85.6039	44.2225	No Scale	WEXFORD
684	8/5/2007	-85.6035	44.2227	Trace	WEXFORD
685	6/23/2005	-84.4319	45.3439	No Scale	CHEBOYGAN
686	6/29/2005	-85.7037	44.2464	No Scale	WEXFORD
686	7/12/2006	-85.7037	44.2464	Trace	WEXFORD
687	6/23/2005	-84.2249	45.4358	No Scale	PRESQUE ISLE
687	6/15/2009	-84.2249	45.4358	No Scale	PRESQUE ISLE
688	6/29/2005	-85.7081	44.1856	No Scale	WEXFORD
689	6/23/2005	-84.1525	45.3567	No Scale	PRESQUE ISLE
690	6/29/2005	-85.5945	44.1322	No Scale	LAKE
690	6/17/2008	-85.5945	44.1322	No Scale	LAKE
691	6/23/2005	-84.3077	45.274	No Scale	CHEBOYGAN
691	6/15/2009	-84.3077	45.274	No Scale	CHEBOYGAN
692	6/29/2005	-85.5031	44.0558	No Scale	OSCEOLA
693	6/27/2005	-84.9725	44.4634	No Scale	MISSAUKEE
694	6/29/2005	-85.6089	44.2658	No Scale	WEXFORD
695	6/27/2005	-84.9941	44.3058	No Scale	MISSAUKEE
696	6/29/2005	-85.6197	44.2759	No Scale	WEXFORD
696	7/12/2006	-85.6197	44.2759	Trace	WEXFORD
697	6/27/2005	-84.8695	44.0693	No Scale	CLARE
698	6/29/2005	-85.6403	44.2807	Trace	WEXFORD
699	6/27/2005	-84.6929	44.1067	No Scale	CLARE
700	6/29/2005	-85.6415	44.2841	Trace	WEXFORD
701	6/28/2005	-85.4071	44.3305	No Scale	WEXFORD
702	6/29/2005	-85.6099	44.3291	Trace	WEXFORD
703	6/28/2005	-85.4121	44.454	No Scale	WEXFORD
704	6/30/2005	-84.147	44.4457	No Scale	OGEMAW
705	6/28/2005	-85.3733	44.4252	No Scale	WEXFORD
705	6/1/2009	-85.3733	44.4252	No Scale	WEXFORD
706	6/30/2005	-84.3072	44.2722	No Scale	OGEMAW
707	6/28/2005	-85.2401	44.4542	No Scale	MISSAUKEE
707	6/1/2009	-85.2401	44.4542	No Scale	MISSAUKEE
708	7/5/2005	-86.4477	46.2917	No Scale	SCHOOLCRAFT
708	7/23/2007	-86.4482	46.2915	Trace	SCHOOLCRAFT
709	6/28/2005	-85.3112	44.3599	No Scale	MISSAUKEE
709	6/17/2008	-85.3112	44.3599	No Scale	MISSAUKEE
709	6/1/2009	-85.3112	44.3599	Trace	MISSAUKEE
710	7/6/2005	-86.4682	46.0681	No Scale	SCHOOLCRAFT
711	6/28/2005	-85.3362	44.2602	No Scale	WEXFORD

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
711	5/31/2009	-85.3362	44.2602	No Scale	WEXFORD
712	7/6/2005	-86.364	45.9671	No Scale	SCHOOLCRAFT
712	7/26/2006	-86.364	45.9671	No Scale	SCHOOLCRAFT
713	6/28/2005	-85.135	44.295	No Scale	MISSAUKEE
714	7/6/2005	-86.5997	45.7672	No Scale	DELTA
715	6/28/2005	-85.0749	44.445	No Scale	MISSAUKEE
715	6/1/2009	-85.0749	44.445	No Scale	MISSAUKEE
716	7/6/2005	-86.6639	45.7006	No Scale	DELTA
717	6/28/2005	-85.1354	44.4518	No Scale	MISSAUKEE
718	7/6/2005	-86.4699	45.7857	No Scale	DELTA
719	6/28/2005	-85.2034	44.3674	No Scale	MISSAUKEE
719	6/1/2009	-85.2034	44.3674	No Scale	MISSAUKEE
720	7/6/2005	-86.3689	45.8402	No Scale	SCHOOLCRAFT
721	6/28/2005	-85.0349	44.3076	No Scale	MISSAUKEE
721	5/31/2009	-85.0349	44.3076	No Scale	MISSAUKEE
722	7/6/2005	-86.1364	45.9813	No Scale	SCHOOLCRAFT
722	7/26/2006	-86.1364	45.9813	Whitewashed	SCHOOLCRAFT
723	6/29/2005	-85.4894	44.3035	No Scale	WEXFORD
724	7/6/2005	-86.0585	46.0717	No Scale	SCHOOLCRAFT
724	7/26/2006	-86.0585	46.0717	No Scale	SCHOOLCRAFT
725	6/29/2005	-85.536	44.3781	No Scale	WEXFORD
726	7/12/2005	-85.6004	46.5893	Whitewashed	LUCE
727	6/29/2005	-85.6191	44.4065	No Scale	WEXFORD
727	6/1/2009	-85.6191	44.4065	No Scale	WEXFORD
728	7/12/2005	-85.745	46.6517	Whitewashed	LUCE
729	6/29/2005	-85.6975	44.4436	No Scale	WEXFORD
730	7/12/2005	-85.8316	46.6697	Whitewashed	LUCE
731	6/29/2005	-85.771	44.4691	No Scale	WEXFORD
731	6/1/2009	-85.771	44.4691	No Scale	WEXFORD
732	7/12/2005	-85.929	46.6552	Whitewashed	ALGER
733	6/29/2005	-85.7388	44.3525	No Scale	WEXFORD
733	7/11/2006	-85.7388	44.3525	Trace	WEXFORD
734	7/12/2005	-85.9279	46.165	Patchy	SCHOOLCRAFT
735	6/29/2005	-85.661	44.2515	Patchy	WEXFORD
736	7/12/2005	-85.7829	46.1008	Whitewashed	MACKINAC
737	6/29/2005	-85.6997	44.2512	No Scale	WEXFORD
737	7/29/2007	-85.7007	44.2511	No Scale	WEXFORD
738	7/12/2005	-85.6968	46.0355	No Scale	MACKINAC
738	7/26/2006	-85.6968	46.0355	Patchy	MACKINAC
739	6/29/2005	-85.6446	44.2517	No Scale	WEXFORD
739	7/12/2006	-85.6446	44.2517	Patchy	WEXFORD
740	7/12/2005	-85.572	46.2224	Whitewashed	MACKINAC

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
741	6/30/2005	-84.5205	44.0165	No Scale	GLADWIN
742	7/12/2005	-85.7831	46.3359	Whitewashed	LUCE
743	7/6/2005	-86.5525	46.4673	No Scale	ALGER
743	7/25/2006	-86.5525	46.4673	No Scale	ALGER
743	7/2/2007	-86.5525	46.4673	No Scale	ALGER
743	7/17/2008	-86.5525	46.4673	No Scale	ALGER
744	7/13/2005	-85.7073	46.4623	Whitewashed	LUCE
745	7/6/2005	-86.5744	46.4072	No Scale	ALGER
746	7/13/2005	-85.8014	46.4506	Whitewashed	LUCE
747	7/6/2005	-86.6157	46.3195	No Scale	ALGER
749	7/6/2005	-86.6358	46.1574	No Scale	DELTA
750	7/14/2005	-86.3638	46.5573	No Scale	ALGER
750	7/24/2006	-86.3638	46.5573	Trace	ALGER
751	7/6/2005	-86.5572	46.0739	No Scale	DELTA
752	7/12/2005	-85.9278	46.5641	Whitewashed	ALGER
753	7/6/2005	-86.8632	45.7883	No Scale	DELTA
754	7/12/2005	-84.254	42.5778	No Scale	INGHAM
755	7/6/2005	-86.8571	46.036	No Scale	DELTA
756	7/20/2005	-87.3038	45.6258	No Scale	DELTA
756	7/18/2009	-87.3038	45.6258	No Scale	DELTA
757	7/6/2005	-86.8376	46.1347	No Scale	DELTA
757	7/19/2008	-86.8376	46.1347	No Scale	DELTA
758	7/20/2005	-87.1111	45.8409	No Scale	DELTA
758	7/18/2009	-87.1111	45.8409	No Scale	DELTA
759	7/6/2005	-87.3669	45.7718	No Scale	MENOMINEE
759	7/18/2009	-87.3669	45.7718	No Scale	MENOMINEE
760	7/25/2005	-86.7992	46.3333	No Scale	ALGER
761	7/7/2005	-86.3635	46.5069	No Scale	ALGER
761	7/25/2006	-86.3635	46.5069	Trace	ALGER
762	7/26/2005	-85.5391	45.7479	Whitewashed	CHARLEVOIX
763	7/7/2005	-86.2687	46.5208	Patchy	ALGER
764	7/26/2005	-85.5569	45.734	No Scale	CHARLEVOIX
764	7/18/2006	-85.5569	45.734	Trace	CHARLEVOIX
765	7/7/2005	-86.2525	46.5356	Whitewashed	ALGER
766	7/26/2005	-85.5643	45.7254	Whitewashed	CHARLEVOIX
767	7/7/2005	-86.1504	46.5524	No Scale	ALGER

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
767	7/25/2006	-86.1504	46.5524	Whitewashed	ALGER
768	7/26/2005	-85.5591	45.688	No Scale	CHARLEVOIX
768	7/18/2006	-85.5591	45.688	Trace	CHARLEVOIX
769	7/7/2005	-86.0626	46.5475	Trace	ALGER
770	7/27/2005	-85.4914	45.6467	Patchy	CHARLEVOIX
770	7/18/2006	-85.4914	45.6467	Whitewashed	CHARLEVOIX
771	7/7/2005	-86.1709	46.4591	Trace	SCHOOLCRAFT
772	7/27/2005	-85.4963	45.606	No Scale	CHARLEVOIX
772	7/18/2006	-85.4963	45.606	No Scale	CHARLEVOIX
773	7/7/2005	-86.1575	46.4194	No Scale	SCHOOLCRAFT
773	7/25/2006	-86.1575	46.4194	Whitewashed	SCHOOLCRAFT
774	7/27/2005	-85.5706	45.5755	No Scale	CHARLEVOIX
774	7/18/2006	-85.5706	45.5755	No Scale	CHARLEVOIX
775	7/11/2005	-85.076	46.4314	Whitewashed	CHIPPEWA
776	7/27/2005	-85.5537	45.6597	No Scale	CHARLEVOIX
777	7/11/2005	-85.1153	46.6344	Whitewashed	CHIPPEWA
778	7/27/2005	-85.5794	45.6593	No Scale	CHARLEVOIX
778	7/18/2006	-85.5794	45.6593	No Scale	CHARLEVOIX
779	7/11/2005	-85.2524	46.5779	Whitewashed	LUCE
780	7/27/2005	-85.5831	45.6473	No Scale	CHARLEVOIX
780	7/18/2006	-85.5831	45.6473	No Scale	CHARLEVOIX
781	7/11/2005	-85.3701	46.5537	Whitewashed	LUCE
782	7/27/2005	-85.5924	45.6087	No Scale	CHARLEVOIX
782	7/18/2006	-85.5924	45.6087	No Scale	CHARLEVOIX
783	7/11/2005	-85.3076	46.6656	Whitewashed	LUCE
784	7/27/2005	-85.5965	45.5846	No Scale	CHARLEVOIX
784	7/18/2006	-85.5965	45.5846	No Scale	CHARLEVOIX
785	7/11/2005	-85.5337	46.6572	Patchy	LUCE
786	8/1/2005	-86.1343	45.0035	No Scale	LEELANAU
787	7/11/2005	-85.5973	46.454	Whitewashed	LUCE
788	8/2/2005	-85.986	45.1082	No Scale	LEELANAU
789	7/12/2005	-85.4269	46.4948	Whitewashed	LUCE
790	8/3/2005	-86.0538	45.1199	No Scale	LEELANAU
791	7/12/2005	-85.6342	46.4144	Whitewashed	LUCE
792	8/3/2005	-86.0474	45.1381	No Scale	LEELANAU
793	7/12/2005	-85.1447	46.3496	Whitewashed	CHIPPEWA
794	8/3/2005	-86.0197	45.1429	No Scale	LEELANAU
795	7/12/2005	-85.2394	46.477	Whitewashed	LUCE
797	7/12/2005	-85.0123	46.2614	Whitewashed	CHIPPEWA
798	8/3/2005	-85.9896	45.1228	No Scale	LEELANAU
799	7/12/2005	-85.1849	46.1745	Whitewashed	MACKINAC
800	8/1/2005	-86.1395	45.0028	No Scale	LEELANAU

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Site	Date	Longitude	Latitude	Scale	County
801	7/12/2005	-85.4465	46.1105	Whitewashed	MACKINAC
802	8/1/2005	-86.113	45.0057	No Scale	LEELANAU
803	7/12/2005	-85.1123	46.0393	Patchy	MACKINAC
804	8/4/2005	-85.0694	45.508	No Scale	EMMET
805	7/12/2005	-84.6688	46.4622	Trace	CHIPPEWA
806	8/4/2005	-85.0154	45.5891	Trace	EMMET
807	7/14/2005	-84.9256	45.9883	Whitewashed	MACKINAC
808	8/2/2005	-85.9805	45.1167	No Scale	LEELANAU
809	7/14/2005	-84.8069	45.8928	No Scale	MACKINAC
809	7/24/2006	-84.8069	45.8928	Patchy	MACKINAC
810	8/2/2005	-86.0062	45.0979	No Scale	LEELANAU
811	7/14/2005	-84.7614	45.9665	No Scale	MACKINAC
811	7/27/2006	-84.7614	45.9665	No Scale	MACKINAC
811	7/1/2007	-84.7614	45.9665	Trace	MACKINAC
812	8/3/2005	-86.0592	45.111	No Scale	LEELANAU
813	7/25/2005	-85.6046	44.2088	No Scale	WEXFORD
813	7/12/2006	-85.6046	44.2088	No Scale	WEXFORD
814	8/3/2005	-86.0474	45.0989	No Scale	LEELANAU
815	7/25/2005	-85.6575	44.2028	No Scale	WEXFORD
815	7/12/2006	-85.6575	44.2028	No Scale	WEXFORD
815	8/5/2007	-85.658	44.2029	No Scale	WEXFORD
816	8/3/2005	-86.0296	45.0809	No Scale	LEELANAU
817	7/25/2005	-85.6405	44.206	No Scale	WEXFORD
817	7/12/2006	-85.6405	44.206	No Scale	WEXFORD
818	8/3/2005	-86.0073	45.0734	No Scale	LEELANAU
819	7/25/2005	-85.6233	44.237	No Scale	WEXFORD
819	8/4/2007	-85.6224	44.2367	Whitewashed	WEXFORD
820	8/3/2005	-85.9896	45.08	No Scale	LEELANAU
821	7/25/2005	-85.6478	44.2404	Whitewashed	WEXFORD
822	8/3/2005	-85.9898	45.0909	No Scale	LEELANAU
823	7/25/2005	-85.7075	44.2772	No Scale	WEXFORD
823	7/12/2006	-85.7075	44.2772	No Scale	WEXFORD
824	8/3/2005	-85.9851	45.1034	No Scale	LEELANAU
825	7/25/2005	-85.6759	44.344	No Scale	WEXFORD
825	7/11/2006	-85.6759	44.344	Whitewashed	WEXFORD
826	8/4/2005	-85.067	45.4581	No Scale	EMMET
827	7/25/2005	-85.6756	44.3441	Trace	WEXFORD
828	8/4/2005	-84.8929	45.6803	No Scale	EMMET
828	7/27/2006	-84.8929	45.6803	No Scale	EMMET
828	6/25/2007	-84.8929	45.6803	Trace	EMMET
829	7/25/2005	-85.6164	44.3813	No Scale	WEXFORD
829	7/13/2006	-85.6164	44.3813	No Scale	WEXFORD

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
830	8/4/2005	-84.7741	45.6557	No Scale	EMMET
831	7/25/2005	-85.567	44.3534	No Scale	WEXFORD
831	6/17/2008	-85.567	44.3534	Trace	WEXFORD
832	8/8/2005	-86.6256	41.8394	No Scale	BERRIEN
833	7/25/2005	-85.5596	44.3035	No Scale	WEXFORD
833	7/12/2006	-85.5596	44.3035	No Scale	WEXFORD
834	8/8/2005	-86.6018	41.9044	No Scale	BERRIEN
835	8/25/2005	-85.6097	44.2227	Trace	WEXFORD
836	8/8/2005	-86.3045	42.3306	No Scale	VAN BUREN
837	8/8/2005	-86.3069	42.337	No Scale	VAN BUREN
837	5/28/2009	-86.3069	42.337	No Scale	VAN BUREN
838	8/8/2005	-86.1972	42.703	No Scale	ALLEGAN
838	5/28/2009	-86.1972	42.703	No Scale	ALLEGAN
842	5/29/2009	-86.3573	43.5099	No Scale	OCEANA
847	6/1/2005	-86.2214	44.3962	No Scale	MANISTEE
1000	5/8/2006	-84.5906	42.9144	No Beech	CLINTON
1001	5/8/2006	-85.014	43.2902	No Scale	MONTCALM
1002	5/8/2006	-85.0844	43.4275	No Scale	MONTCALM
1003	5/8/2006	-85.4433	43.6048	No Scale	MECOSTA
1004	5/8/2006	-85.2007	43.7035	No Scale	MECOSTA
1005	5/8/2006	-85.2662	43.9706	No Scale	OSCEOLA
1005	5/31/2009	-85.2662	43.9706	No Scale	OSCEOLA
1006	5/9/2006	-85.7033	44.2468	No Scale	WEXFORD
1007	5/9/2006	-85.6746	44.2481	Trace	WEXFORD
1008	5/9/2006	-86.0371	44.1948	No Scale	MANISTEE
1009	5/9/2006	-86.1783	44.2673	Whitewashed	MANISTEE
1010	5/9/2006	-86.4185	44.1118	Whitewashed	MASON
1011	5/9/2006	-86.4355	44.0855	Whitewashed	MASON
1012	5/9/2006	-86.3872	44.0852	Whitewashed	MASON
1013	5/9/2006	-86.3668	44.0921	Whitewashed	MASON
1014	5/10/2006	-86.4963	44.0425	Whitewashed	MASON
1015	5/10/2006	-86.4966	44.0447	Whitewashed	MASON
1016	5/10/2006	-86.5049	44.0378	Whitewashed	MASON
1017	5/10/2006	-86.5192	43.6482	Patchy	OCEANA
1018	5/10/2006	-86.3315	43.6301	Trace	OCEANA
1019	5/10/2006	-86.2782	43.6147	Patchy	OCEANA
1020	5/10/2006	-86.2664	43.5998	No Scale	OCEANA
1020	6/18/2007	-86.2664	43.5998	No Scale	OCEANA
1020	5/25/2008	-86.2664	43.5998	No Scale	OCEANA
1020	5/29/2009	-86.2664	43.5998	Trace	OCEANA
1021	5/10/2006	-86.1788	43.6206	Whitewashed	OCEANA
1022	5/10/2006	-86.1393	43.6728	No Scale	OCEANA

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Site	Date	Longitude	Latitude	Scale	County
1022	6/18/2007	-86.1393	43.6728	No Scale	OCEANA
1023	5/10/2006	-85.9112	43.7793	No Beech	NEWAYGO
1024	5/10/2006	-85.8247	43.8499	No Beech	LAKE
1025	5/10/2006	-85.7641	43.923	No Beech	LAKE
1026	5/10/2006	-85.6431	43.8153	No Scale	NEWAYGO
1026	5/30/2009	-85.6431	43.8153	No Scale	NEWAYGO
1027	5/10/2006	-85.6275	43.6638	No Scale	NEWAYGO
1028	5/23/2006	-85.0139	43.408	No Beech	MONTCALM
1029	5/23/2006	-84.8865	43.4607	No Scale	MONTCALM
1030	5/23/2006	-84.9093	43.4808	No Scale	ISABELLA
1031	5/23/2006	-85.0472	43.5246	No Scale	ISABELLA
1032	5/23/2006	-85.0099	43.8427	No Scale	CLARE
1033	5/23/2006	-85.4338	43.8948	No Scale	OSCEOLA
1033	5/31/2009	-85.4338	43.8948	No Scale	OSCEOLA
1034	5/24/2006	-85.8705	44.1405	No Beech	LAKE
1035	5/24/2006	-86.0812	44.0804	No Scale	MASON
1036	5/24/2006	-86.0156	44.0322	No Scale	LAKE
1037	5/24/2006	-85.9852	43.8877	No Scale	LAKE
1038	5/24/2006	-85.9705	43.8233	No Beech	LAKE
1039	5/24/2006	-86.0188	43.7421	No Scale	NEWAYGO
1039	6/19/2007	-86.0188	43.7421	No Scale	NEWAYGO
1039	5/25/2008	-86.0188	43.7421	Whitewashed	NEWAYGO
1040	5/24/2006	-86.1672	43.7318	No Scale	OCEANA
1040	6/19/2007	-86.1672	43.7318	Trace	OCEANA
1041	5/24/2006	-86.1263	43.6255	No Scale	OCEANA
1041	6/18/2007	-86.1263	43.6255	No Scale	OCEANA
1041	5/24/2008	-86.1263	43.6255	No Scale	OCEANA
1042	5/24/2006	-86.153	43.5877	No Scale	OCEANA
1042	6/18/2007	-86.153	43.5877	No Scale	OCEANA
1043	5/24/2006	-86.1136	43.5322	No Scale	OCEANA
1043	6/18/2007	-86.1136	43.5322	No Scale	OCEANA
1043	5/23/2008	-86.1136	43.5322	No Scale	OCEANA
1044	5/24/2006	-85.9	43.5883	No Scale	NEWAYGO
1045	5/25/2006	-85.89	43.6691	No Beech	NEWAYGO
1046	5/25/2006	-85.8128	43.6992	No Beech	NEWAYGO
1047	5/25/2006	-85.7611	43.6107	No Scale	NEWAYGO
1047	5/23/2008	-85.7611	43.6107	No Scale	NEWAYGO
1048	5/25/2006	-85.6621	43.5588	No Scale	NEWAYGO
1049	5/25/2006	-85.5228	43.558	No Scale	MECOSTA
1050	5/25/2006	-85.4027	43.5156	No Scale	MECOSTA
1051	5/25/2006	-85.3436	43.4323	No Scale	MONTCALM
1052	5/25/2006	-85.5821	43.4589	No Beech	NEWAYGO

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
1053	5/25/2006	-85.5353	43.3297	No Scale	MONTCALM
1054	5/25/2006	-85.6973	43.2529	No Scale	KENT
1055	5/25/2006	-85.7882	43.4802	No Scale	NEWAYGO
1055	5/23/2008	-85.7882	43.4802	No Scale	NEWAYGO
1056	5/25/2006	-86.0994	43.4318	No Scale	MUSKEGON
1057	5/25/2006	-86.0823	43.3372	No Scale	MUSKEGON
1058	5/25/2006	-86.189	43.3648	No Scale	MUSKEGON
1058	5/29/2009	-86.189	43.3648	No Scale	MUSKEGON
1059	5/25/2006	-86.0874	43.14	No Scale	MUSKEGON
1059	5/29/2009	-86.0874	43.14	No Scale	MUSKEGON
1060	5/25/2006	-86.1849	43.0019	No Scale	OTTAWA
1061	5/25/2006	-86.1264	42.9355	No Scale	OTTAWA
1062	5/25/2006	-86.1789	42.8752	No Scale	OTTAWA
1063	5/25/2006	-85.8986	42.6472	No Beech	ALLEGAN
1064	5/25/2006	-85.8988	42.636	No Scale	ALLEGAN
1064	5/28/2009	-85.8988	42.636	No Scale	ALLEGAN
1065	5/26/2006	-86.0105	42.4851	No Scale	ALLEGAN
1066	5/26/2006	-85.9957	42.553	No Scale	ALLEGAN
1067	5/26/2006	-85.4656	42.5947	No Scale	BARRY
1068	5/26/2006	-85.4087	42.7855	No Beech	KENT
1069	5/26/2006	-85.312	42.949	No Beech	KENT
1070	5/26/2006	-85.4849	43.0436	No Beech	KENT
1071	5/26/2006	-85.2832	43.1275	No Beech	MONTCALM
1072	5/26/2006	-85.2558	43.2854	No Scale	MONTCALM
1073	5/29/2006	-84.0553	45.3962	No Beech	PRESQUE ISLE
1074	5/29/2006	-83.8863	45.4131	No Scale	PRESQUE ISLE
1075	5/29/2006	-83.6219	45.2225	No Beech	PRESQUE ISLE
1076	5/29/2006	-83.4835	45.2607	No Scale	PRESQUE ISLE
1077	5/29/2006	-84.1211	45.1354	No Scale	MONTMORENCY
1078	5/29/2006	-83.7311	45.1762	No Scale	ALPENA
1079	5/29/2006	-83.5633	45.0421	No Beech	ALPENA
1080	5/29/2006	-83.617	44.9827	No Scale	ALPENA
1081	5/29/2006	-83.6682	44.8986	No Beech	ALPENA
1082	5/30/2006	-83.4451	44.8465	No Scale	ALCONA
1083	5/30/2006	-83.404	44.7798	No Scale	ALCONA
1084	5/30/2006	-83.4037	44.6838	No Scale	ALCONA
1085	5/30/2006	-83.3682	44.5698	No Beech	ALCONA
1086	5/30/2006	-83.592	44.5668	No Beech	ALCONA
1087	5/30/2006	-83.666	44.6928	No Scale	ALCONA
1088	5/30/2006	-83.7664	44.4563	No Beech	IOSCO
1089	5/30/2006	-83.9449	44.4701	No Scale	OGEMAW
1090	5/30/2006	-84.217	44.707	No Scale	OSCODA

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Site	Date	Longitude	Latitude	Scale	County
1091	5/30/2006	-84.1296	44.616	No Scale	OSCODA
1092	5/30/2006	-83.9411	44.6323	No Beech	OSCODA
1093	5/30/2006	-83.8321	44.7845	No Scale	ALCONA
1094	5/30/2006	-84.0606	44.754	No Scale	OSCODA
1095	5/30/2006	-84.0063	44.9572	No Beech	MONTMORENCY
1096	5/31/2006	-84.738	45.2738	No Scale	CHARLEVOIX
1097	5/31/2006	-84.7468	45.3132	No Scale	EMMET
1098	5/31/2006	-84.8821	45.3103	No Scale	EMMET
1099	5/31/2006	-84.8767	45.493	No Scale	EMMET
1099	6/20/2008	-84.8767	45.493	Trace	EMMET
1100	5/31/2006	-84.8559	45.5471	No Scale	EMMET
1101	6/5/2006	-84.9134	45.9289	Whitewashed	MACKINAC
1102	6/5/2006	-84.9128	45.9286	No Scale	MACKINAC
1102	7/1/2007	-84.9128	45.9286	Patchy	MACKINAC
1103	6/5/2006	-84.8983	45.9619	Patchy	MACKINAC
1104	6/5/2006	-84.3697	46.086	No Scale	MACKINAC
1105	6/5/2006	-84.1858	46.0036	No Scale	CHIPPEWA
1106	6/5/2006	-84.0213	45.9618	No Scale	CHIPPEWA
1106	7/20/2009	-84.0213	45.9618	Trace	CHIPPEWA
1107	6/6/2006	-83.7247	46.0894	No Beech	CHIPPEWA
1108	6/6/2006	-83.619	46.0724	No Beech	CHIPPEWA
1109	6/6/2006	-83.6734	46.0312	No Scale	CHIPPEWA
1110	6/6/2006	-83.7031	46.0131	No Scale	CHIPPEWA
1110	7/14/2008	-83.7031	46.0131	No Scale	CHIPPEWA
1110	7/20/2009	-83.7031	46.0131	Trace	CHIPPEWA
1111	6/6/2006	-83.6675	45.9987	No Scale	CHIPPEWA
1111	7/14/2008	-83.6675	45.9987	No Scale	CHIPPEWA
1111	7/20/2009	-83.6675	45.9987	No Scale	CHIPPEWA
1112	6/6/2006	-83.5455	45.9434	No Scale	CHIPPEWA
1112	7/14/2008	-83.5455	45.9434	No Scale	CHIPPEWA
1112	7/20/2009	-83.5455	45.9434	Trace	CHIPPEWA
1113	6/6/2006	-83.5367	46.0024	No Scale	CHIPPEWA
1113	7/14/2008	-83.5367	46.0024	No Scale	CHIPPEWA
1113	7/20/2009	-83.5367	46.0024	No Scale	CHIPPEWA
1114	6/6/2006	-83.6119	45.9599	No Scale	CHIPPEWA
1114	7/14/2008	-83.6119	45.9599	Trace	CHIPPEWA
1114	7/20/2009	-83.6119	45.9599	Trace	CHIPPEWA
1115	6/6/2006	-83.6973	45.9752	No Scale	CHIPPEWA
1115	7/14/2008	-83.6973	45.9752	No Scale	CHIPPEWA
1115	7/20/2009	-83.6973	45.9752	No Scale	CHIPPEWA
1116	6/6/2006	-83.7876	45.9844	No Scale	CHIPPEWA
1116	7/14/2008	-83.7876	45.9844	No Scale	CHIPPEWA

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Site	Date	Longitude	Latitude	Scale	County
1116	7/20/2009	-83.7876	45.9844	No Scale	CHIPPEWA
1117	6/7/2006	-84.0726	45.9946	No Scale	CHIPPEWA
1117	7/20/2009	-84.0726	45.9946	No Scale	CHIPPEWA
1118	6/7/2006	-84.1751	46.159	No Beech	CHIPPEWA
1119	6/7/2006	-84.2713	46.2129	No Beech	CHIPPEWA
1120	6/7/2006	-84.3535	46.3758	No Beech	CHIPPEWA
1121	6/7/2006	-84.7391	46.4096	No Scale	CHIPPEWA
1121	7/24/2007	-84.739	46.4102	Whitewashed	CHIPPEWA
1122	6/7/2006	-84.6976	46.4318	Patchy	CHIPPEWA
1123	6/7/2006	-84.6773	46.4507	Trace	CHIPPEWA
1124	6/7/2006	-84.9389	46.4037	Trace	CHIPPEWA
1125	6/7/2006	-84.9088	46.4229	Patchy	CHIPPEWA
1126	6/7/2006	-84.8351	46.4135	Trace	CHIPPEWA
1127	6/7/2006	-84.5917	46.3028	No Beech	CHIPPEWA
1128	6/7/2006	-84.7871	46.1868	No Beech	CHIPPEWA
1129	6/8/2006	-85.1466	46.0631	Whitewashed	MACKINAC
1130	6/8/2006	-85.0267	46.066	Trace	MACKINAC
1131	6/8/2006	-84.9189	46.0284	No Scale	MACKINAC
1132	6/8/2006	-84.88	46.1023	No Scale	MACKINAC
1133	6/8/2006	-84.7655	46.0736	No Scale	MACKINAC
1133	7/1/2007	-84.7655	46.0736	Trace	MACKINAC
1134	6/12/2006	-84.4092	43.2516	No Beech	GRATIOT
1135	6/12/2006	-84.2099	43.9791	No Beech	GLADWIN
1136	6/13/2006	-84.6053	45.8559	No Beech	MACKINAC
1137	6/13/2006	-84.6241	45.8776	No Beech	MACKINAC
1138	6/13/2006	-84.629	45.8795	No Scale	MACKINAC
1139	6/13/2006	-84.6242	45.8711	Whitewashed	MACKINAC
1140	6/13/2006	-84.6355	45.874	No Scale	MACKINAC
1141	6/13/2006	-84.6437	45.8729	Trace	MACKINAC
1142	6/13/2006	-84.6453	45.8715	Patchy	MACKINAC
1143	6/13/2006	-84.6462	45.8708	Whitewashed	MACKINAC
1144	6/13/2006	-84.645	45.8656	Whitewashed	MACKINAC
1145	6/13/2006	-84.6376	45.8586	No Scale	MACKINAC
1146	6/13/2006	-84.6335	45.8628	No Scale	MACKINAC
1147	6/13/2006	-84.6254	45.8618	Patchy	MACKINAC
1148	6/13/2006	-84.61	45.8577	Trace	MACKINAC
1149	6/14/2006	-84.571	45.809	Whitewashed	MACKINAC
1150	6/14/2006	-84.5364	45.7945	Trace	MACKINAC
1151	6/14/2006	-84.5208	45.7906	Patchy	MACKINAC
1152	6/14/2006	-84.5131	45.7707	Trace	MACKINAC
1153	6/14/2006	-84.4931	45.7524	No Scale	MACKINAC
1154	6/14/2006	-84.3847	45.779	No Beech	MACKINAC

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Site	Date	Longitude	Latitude	Scale	County
1155	6/14/2006	-84.3859	45.7432	No Beech	MACKINAC
1156	6/14/2006	-84.4244	45.7619	No Scale	MACKINAC
1157	6/14/2006	-84.4519	45.7728	No Scale	MACKINAC
1158	6/20/2006	-86.1139	45.0117	No Scale	LEELANAU
1159	6/20/2006	-86.1138	45.0191	No Scale	LEELANAU
1160	6/20/2006	-86.1126	45.0327	No Scale	LEELANAU
1161	6/20/2006	-86.1129	45.0342	No Beech	LEELANAU
1162	6/20/2006	-86.1207	45.0255	No Scale	LEELANAU
1163	6/21/2006	-86.1399	44.9989	No Scale	LEELANAU
1164	6/22/2006	-84.9847	45.5764	No Scale	EMMET
1165	6/22/2006	-85.0572	45.5757	No Scale	EMMET
1165	6/25/2007	-85.0572	45.5757	No Scale	EMMET
1166	6/26/2006	-85.5945	46.0818	Patchy	MACKINAC
1167	6/26/2006	-85.7001	45.9837	No Scale	MACKINAC
1168	6/27/2006	-87.3756	45.4333	No Scale	MENOMINEE
1169	6/27/2006	-87.7568	45.5153	No Beech	MENOMINEE
1171	6/27/2006	-85.7952	46.1772	Whitewashed	MACKINAC
1172	6/28/2006	-86.6583	46.4368	No Scale	ALGER
1172	7/2/2007	-86.6583	46.4368	No Scale	ALGER
1172	7/18/2008	-86.6583	46.4368	Trace	ALGER
1173	6/28/2006	-86.9282	46.396	No Scale	ALGER
1173	7/16/2009	-86.9282	46.396	No Scale	ALGER
1174	6/28/2006	-87.086	46.3813	No Scale	ALGER
1174	7/17/2009	-87.086	46.3813	No Scale	ALGER
1175	7/2/2007	-86.3618	46.4282	Whitewashed	SCHOOLCRAFT
1177	6/28/2006	-86.272	46.5022	Whitewashed	SCHOOLCRAFT
1178	6/28/2006	-86.2616	46.4611	Whitewashed	SCHOOLCRAFT
1179	6/28/2006	-86.083	46.4267	No Beech	SCHOOLCRAFT
1180	6/29/2006	-84.8598	45.9459	Whitewashed	MACKINAC
1181	6/29/2006	-84.8413	45.6807	No Scale	EMMET
1182	6/29/2006	-84.9101	45.7079	Trace	EMMET
1183	6/29/2006	-84.8683	45.7169	Patchy	EMMET
1184	6/30/2006	-84.8905	44.2917	No Beech	MISSAUKEE
1185	6/30/2006	-84.8722	44.205	No Beech	MISSAUKEE
1186	6/29/2006	-84.9744	46.332	No Beech	CHIPPEWA
1187	7/5/2006	-84.9275	42.8204	No Beech	IONIA
1188	7/5/2006	-85.1296	42.9363	No Scale	IONIA
1189	7/5/2006	-85.7901	42.2984	No Scale	VAN BUREN
1190	7/5/2006	-85.7695	41.9487	No Scale	CASS
1191	7/5/2006	-85.3275	42.0861	No Beech	KALAMAZOO
1192	7/5/2006	-84.4736	41.8333	No Beech	HILLSDALE
1193	7/6/2006	-84.5867	43.6552	No Beech	MIDLAND

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Site	Date	Longitude	Latitude	Scale	County
1194	7/6/2006	-83.9089	43.6686	No Beech	BAY
1195	7/6/2006	-83.3659	43.4599	No Beech	TUSCOLA
1196	7/6/2006	-83.3789	43.1668	No Scale	LAPEER
1197	7/6/2006	-83.3462	42.9426	No Scale	LAPEER
1198	7/6/2006	-83.5099	42.7943	No Scale	OAKLAND
1199	7/6/2006	-83.5497	42.6447	No Scale	OAKLAND
1200	7/7/2006	-83.5198	42.4317	No Scale	WAYNE
1201	7/7/2006	-83.6958	41.8786	No Beech	MONROE
1210	7/10/2006	-86.1789	43.7909	Trace	OCEANA
1211	7/10/2006	-86.1526	43.8253	Whitewashed	MASON
1216	7/12/2006	-85.6171	44.2372	Trace	WEXFORD
1218	7/12/2006	-85.6227	44.2543	Patchy	WEXFORD
1219	7/12/2006	-85.6035	44.2226	No Scale	WEXFORD
1220	6/17/2008	-85.6046	44.2087	No Scale	WEXFORD
1225	7/12/2006	-85.6878	44.2486	Trace	WEXFORD
1226	7/13/2006	-85.8637	44.2841	No Scale	MANISTEE
1226	6/20/2007	-85.8637	44.2841	No Scale	MANISTEE
1226	5/26/2008	-85.8637	44.2841	No Scale	MANISTEE
1227	7/13/2006	-85.7065	44.3519	No Scale	WEXFORD
1227	7/28/2007	-85.7064	44.3533	Whitewashed	WEXFORD
1234	7/17/2006	-85.8749	44.9176	No Scale	LEELANAU
1234	6/11/2009	-85.8749	44.9176	No Scale	LEELANAU
1236	7/17/2006	-85.3066	45.3077	No Scale	CHARLEVOIX
1236	6/19/2008	-85.3066	45.3077	No Scale	CHARLEVOIX
1237	7/17/2006	-85.3111	45.3074	Whitewashed	CHARLEVOIX
1237	6/19/2008	-85.3111	45.3074	Trace	CHARLEVOIX
1239	7/18/2006	-85.4914	45.6145	Whitewashed	CHARLEVOIX
1247	7/18/2006	-85.539	45.7498	Whitewashed	CHARLEVOIX
1249	7/19/2006	-85.5026	45.6942	No Beech	CHARLEVOIX
1250	7/19/2006	-85.5138	45.6093	No Beech	CHARLEVOIX
1251	7/19/2006	-85.5696	45.6339	No Scale	CHARLEVOIX
1252	7/19/2006	-85.5279	45.6559	No Beech	CHARLEVOIX
1257	7/25/2006	-86.4462	46.5399	Trace	ALGER
1259	7/25/2006	-86.428	46.4745	No Scale	ALGER
1259	7/17/2008	-86.428	46.4745	Trace	ALGER
1260	7/25/2006	-86.1468	46.4137	Whitewashed	SCHOOLCRAFT
1262	7/26/2006	-86.2913	46.3716	No Scale	SCHOOLCRAFT
1271	7/26/2006	-85.7492	45.9879	Patchy	MACKINAC
1273	6/15/2009	-84.6704	45.7442	No Scale	CHEBOYGAN
1277	7/27/2006	-85.083	45.6088	No Scale	EMMET
2007011	6/19/2007	-86.1107	43.874	No Scale	MASON
2007012	6/19/2007	-86.053	43.9868	No Scale	MASON

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Site	Date	Longitude	Latitude	Scale	County
2007013	6/19/2007	-86.016	44.0325	No Scale	LAKE
2007015	6/19/2007	-86.0811	44.0802	No Scale	MASON
2007015	5/26/2008	-86.0811	44.0802	No Scale	MASON
2007019	6/20/2007	-85.6956	44.2722	No Scale	WEXFORD
2007020	6/20/2007	-85.6195	44.1866	No Scale	WEXFORD
2007020	6/16/2008	-85.6195	44.1866	No Scale	WEXFORD
2007020	5/31/2009	-85.6195	44.1866	Trace	WEXFORD
2007022	6/20/2008	-84.7722	45.7197	No Scale	EMMET
2007023	6/25/2007	-84.7122	45.7463	No Scale	CHEBOYGAN
2007023	6/20/2008	-84.7122	45.7463	No Scale	CHEBOYGAN
2007023	6/15/2009	-84.7122	45.7463	Whitewashed	CHEBOYGAN
2007024	6/25/2007	-84.8434	45.6821	Patchy	EMMET
2007029	6/25/2007	-84.9861	45.5768	Trace	EMMET
2007030	6/20/2008	-84.9358	45.5506	No Scale	EMMET
2007031	6/25/2007	-84.8536	45.55	Whitewashed	EMMET
2007033	6/25/2007	-84.7162	45.5504	No Scale	CHEBOYGAN
2007035	6/26/2007	-84.6877	45.4922	No Scale	CHEBOYGAN
2007035	6/20/2008	-84.6877	45.4922	No Scale	CHEBOYGAN
2007035	6/14/2009	-84.6877	45.4922	No Scale	CHEBOYGAN
2007036	6/26/2007	-84.6502	45.3317	No Scale	CHEBOYGAN
2007036	6/20/2008	-84.6502	45.3317	No Scale	CHEBOYGAN
2007037	6/26/2007	-84.7427	45.3157	No Scale	EMMET
2007038	6/26/2007	-85.3058	45.3073	No Scale	CHARLEVOIX
2007039	6/26/2007	-85.8753	44.9171	No Scale	LEELANAU
2007041	6/26/2007	-85.97	44.8426	No Scale	LEELANAU
2007043	6/26/2007	-85.9683	44.6016	No Scale	BENZIE
2007043	6/18/2008	-85.9683	44.6016	No Scale	BENZIE
2007043	6/11/2009	-85.9683	44.6016	No Scale	BENZIE
2007044	6/27/2007	-86.0711	44.5735	No Scale	BENZIE
2007046	6/27/2007	-85.9588	44.5288	No Scale	BENZIE
2007046	6/18/2008	-85.9588	44.5288	No Scale	BENZIE
2007051	7/1/2007	-84.7522	46.075	Trace	MACKINAC
2007052	7/1/2007	-84.8799	46.1024	Trace	MACKINAC
2007053	7/1/2007	-84.6966	46.0906	No Scale	MACKINAC
2007053	7/12/2008	-84.6966	46.0906	Trace	MACKINAC
2007054	7/2/2007	-86.4479	46.2918	No Scale	SCHOOLCRAFT
2007057	7/2/2007	-86.4231	46.4762	No Scale	ALGER
2007058	7/2/2007	-86.5503	46.4923	No Scale	ALGER
2007059	7/2/2007	-86.5465	46.4736	No Scale	ALGER
2007059	7/17/2008	-86.5465	46.4736	No Scale	ALGER
2007061	7/2/2007	-86.5871	46.4207	No Scale	ALGER
2007062	7/2/2007	-86.5796	46.407	Trace	ALGER

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Site	Date	Longitude	Latitude	Scale	County
2007064	7/2/2007	-86.7595	46.397	No Scale	ALGER
2007064	7/18/2008	-86.7595	46.397	No Scale	ALGER
2007064	7/16/2009	-86.7595	46.397	No Scale	ALGER
2007065	7/2/2007	-86.6155	46.3194	Whitewashed	ALGER
2007066	7/2/2007	-86.7125	46.3028	No Scale	ALGER
2007066	7/2/2007	-86.712	46.3044	No Scale	ALGER
2007066	7/18/2008	-86.7125	46.3028	No Scale	ALGER
2007067	7/2/2007	-86.6241	46.217	No Scale	ALGER
2007067	7/18/2008	-86.6241	46.217	No Scale	ALGER
2007069	7/3/2007	-86.3644	45.967	No Scale	SCHOOLCRAFT
2007069	7/18/2008	-86.3644	45.967	Patchy	SCHOOLCRAFT
2007070	7/18/2008	-86.0738	46.0434	No Scale	SCHOOLCRAFT
2007073	6/20/2007	-85.701	44.2708	Patchy	WEXFORD
2007083	7/10/2007	-84.7386	45.3126	Whitewashed	EMMET
2007083	6/25/2009	-84.7386	45.3126	Whitewashed	EMMET
2007084	7/10/2007	-84.7497	45.199	No Scale	CHARLEVOIX
2007085	7/10/2007	-86.0365	44.8482	No Scale	LEELANAU
2007086	7/10/2007	-86.101	44.6229	Trace	BENZIE
2007088	7/10/2007	-85.9487	44.9347	No Scale	LEELANAU
2007090	7/16/2007	-86.2075	44.7027	Patchy	BENZIE
2007091	7/16/2007	-86.2091	44.7009	No Scale	BENZIE
2007091	6/18/2008	-86.2091	44.7009	No Scale	BENZIE
2007100	7/22/2007	-84.9752	45.9896	Whitewashed	MACKINAC
2007108	7/27/2007	-86.1203	44.2701	Patchy	MANISTEE
2007109	7/27/2007	-86.0356	44.2617	Patchy	MANISTEE
2007114	7/7/2008	-85.7007	44.2511	No Scale	WEXFORD
2007114	6/25/2009	-85.7007	44.2511	No Scale	WEXFORD
2007116	8/3/2007	-85.6857	44.2789	Trace	WEXFORD
2007127	8/6/2007	-86.6445	46.3467	Trace	ALGER
2007128	8/6/2007	-86.7854	46.4264	Trace	ALGER
2008032	5/30/2009	-86.2664	43.5998	No Scale	OCEANA
2008033	5/30/2009	-85.7879	43.4802	No Scale	NEWAYGO
2008034	5/23/2008	-86.2124	43.4745	No Scale	OCEANA
2008035	5/29/2009	-86.1132	43.5324	No Scale	OCEANA
2008035	5/29/2009	-86.1132	43.5324	No Scale	OCEANA
2008036	5/23/2008	-86.1194	43.5799	No Scale	OCEANA
2008036	5/29/2009	-86.1194	43.5799	No Scale	OCEANA
2008037	5/29/2009	-86.1263	43.6255	No Scale	OCEANA
2008042	5/25/2008	-86.1299	43.7866	Trace	OCEANA
2008044	5/25/2008	-86.0983	43.845	No Scale	MASON
2008044	5/30/2009	-86.0983	43.845	No Scale	MASON
2008046	5/30/2009	-86.05	43.9377	No Scale	MASON

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
2008049	5/30/2009	-86.1033	44.1707	No Scale	MANISTEE
2008052	5/30/2009	-85.8637	44.2849	Trace	MANISTEE
2008057	5/22/2008	-86.4027	43.3443	No Scale	MUSKEGON
2008057	5/11/2009	-86.4027	43.3443	No Scale	MUSKEGON
2008100	5/31/2009	-85.658	44.2029	Trace	WEXFORD
2008107	5/31/2009	-85.6046	44.2082	Trace	WEXFORD
2008108	5/31/2009	-85.5953	44.1326	No Scale	LAKE
2008111	6/17/2008	-85.795	44.4262	No Scale	WEXFORD
2008111	6/1/2009	-85.795	44.4262	Patchy	WEXFORD
2008118	6/18/2008	-86.0644	44.7128	No Scale	BENZIE
2008120	6/18/2008	-85.9754	44.8452	No Scale	LEELANAU
2008120	6/11/2009	-85.9754	44.8452	No Scale	LEELANAU
2008121	6/14/2009	-85.3066	45.3077	No Scale	CHARLEVOIX
2008123	6/19/2008	-84.8465	45.2926	No Scale	EMMET
2008123	6/13/2009	-84.8465	45.2926	No Scale	EMMET
2008132	6/20/2008	-84.714	45.2997	Trace	CHEBOYGAN
2008135	8/3/2008	-87.011	46.4954	No Scale	ALGER
2008302	7/13/2008	-84.6914	46.0611	Whitewashed	MACKINAC
2008303	7/13/2008	-84.4354	46.0715	Whitewashed	MACKINAC
2008304	7/13/2008	-84.441	46.0392	Whitewashed	MACKINAC
2008309	7/14/2008	-83.6996	45.9813	No Scale	CHIPPEWA
2008309	7/20/2009	-83.6996	45.9813	No Scale	CHIPPEWA
2008312	7/14/2008	-83.6864	45.9955	Whitewashed	CHIPPEWA
2008327	7/18/2008	-86.636	46.1465	Trace	DELTA
2008328	7/18/2008	-86.6412	46.0725	No Scale	DELTA
2008328	7/17/2009	-86.6412	46.0725	Trace	DELTA
2008330	7/19/2008	-86.8611	46.0307	No Scale	DELTA
2008330	7/18/2009	-86.8611	46.0307	No Scale	DELTA
2008338	7/15/2008	-84.0919	46.0526	No Scale	CHIPPEWA
2008339	7/18/2008	-86.719	46.358	No Scale	ALGER
2009016	5/11/2009	-85.78	43.025	No Scale	KENT
2009017	5/28/2009	-84.73	42.8	No Scale	CLINTON
2009018	5/28/2009	-86.1688	42.7054	No Beech	ALLEGAN
2009022	5/28/2009	-86.1854	42.9775	No Scale	OTTAWA
2009029	5/29/2009	-86.2862	43.5704	No Scale	OCEANA
2009046	5/31/2009	-85.7126	44.1644	No Scale	LAKE
2009050	5/31/2009	-85.3523	43.8845	No Scale	OSCEOLA
2009053	5/31/2009	-85.3048	44.1314	No Scale	OSCEOLA
2009061	6/1/2009	-85.56	44.3927	No Scale	WEXFORD
2009067	6/2/2009	-85.2541	44.3612	No Scale	MISSAUKEE
2009073	6/11/2009	-86.0458	44.7991	No Scale	LEELANAU
2009079	6/11/2009	-85.9974	44.5291	Trace	BENZIE

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
2009080	6/12/2009	-85.1574	44.7856	Trace	KALKASKA
2009086	6/12/2009	-85.3739	44.7322	No Scale	GRAND TRAVERSE
2009090	6/12/2009	-84.7867	44.7657	Trace	CRAWFORD
2009092	6/12/2009	-84.7059	44.752	No Scale	CRAWFORD
2009093	6/13/2009	-84.6699	44.8877	No Scale	OTSEGO
2009096	6/13/2009	-84.9392	45.0854	No Scale	ANTRIM
2009101	6/14/2009	-85.3418	45.2835	No Scale	CHARLEVOIX
2009105	6/14/2009	-84.6863	45.5556	Whitewashed	CHEBOYGAN
2009106	6/14/2009	-84.6418	45.5719	Trace	CHEBOYGAN
2009114	6/15/2009	-84.5778	45.6921	No Beech	CHARLEVOIX
2009117	6/15/2009	-84.0562	45.3951	No Scale	PRESQUE ISLE
2009119	6/15/2009	-84.4082	45.2462	No Scale	CHEBOYGAN
2009122	6/15/2009	-84.4723	45.2255	No Scale	CHEBOYGAN
2009124	6/16/2009	-84.6897	45.1069	No Scale	OTSEGO
2009137	6/25/2009	-85.6882	44.2485	Patchy	WEXFORD
2009139	6/26/2009	-84.7578	44.5148	No Beech	CRAWFORD
2009140	6/26/2009	-84.675	44.423	No Beech	ROSCOMMON
2009141	7/16/2009	-84.705	44.6124	No Beech	CRAWFORD
2009144	7/16/2009	-86.7895	46.3419	No Scale	ALGER
2009145	7/16/2009	-86.8658	46.3127	No Beech	ALGER
2009147	7/16/2009	-86.931	46.4553	No Scale	ALGER
2009148	7/17/2009	-87.2215	46.4651	No Beech	MARQUETTE
2009149	7/17/2009	-87.0428	46.3117	No Scale	ALGER
2009150	7/17/2009	-87.4077	46.3626	No Beech	MARQUETTE
2009151	7/17/2009	-87.3613	46.2842	No Beech	MARQUETTE
2009157	7/18/2009	-86.7304	46.1733	No Beech	ALGER
2009160	7/18/2009	-87.0764	45.7977	Whitewashed	DELTA
2009161	7/18/2009	-87.1831	45.805	No Beech	DELTA
2009163	7/18/2009	-87.3667	45.7054	No Beech	MENOMINEE
2009164	7/18/2009	-87.3647	45.3952	No Scale	MENOMINEE
2009165	7/18/2009	-87.5968	45.4059	No Beech	MENOMINEE
2009166	7/18/2009	-87.5238	45.6583	No Beech	MENOMINEE
2009167	7/18/2009	-87.603	45.7155	Trace	MENOMINEE
2009168	7/18/2009	-87.8391	45.7762	No Beech	DICKINSON
2009169	7/18/2009	-87.8746	45.7844	Patchy	DICKINSON
2009170	7/18/2009	-87.9787	45.8061	No Beech	DICKINSON
2009171	7/18/2009	-88.0385	45.9585	No Beech	DICKINSON
2009172	7/19/2009	-88.247	46.0844	No Beech	IRON
2009173	7/19/2009	-88.4671	46.3042	No Beech	IRON
2009174	7/19/2009	-88.5329	46.5373	No Beech	BARAGA
2009175	7/19/2009	-88.34	46.5751	No Beech	BARAGA
2009176	7/19/2009	-87.9571	46.5082	No Beech	MARQUETTE

Appendix A : Site Coordinates

Site	Date	Longitude	Latitude	Scale	County
2009177	7/19/2009	-87.6273	46.5088	No Beech	MARQUETTE
2009178	7/19/2009	-87.4615	46.565	No Beech	MARQUETTE
2009179	7/19/2009	-87.675	46.6602	No Scale	MARQUETTE
2009180	7/19/2009	-87.5481	46.3864	No Beech	MARQUETTE
2009181	7/19/2009	-87.2989	46.2553	No Beech	MARQUETTE
2009182	7/19/2009	-87.1993	46.1162	No Beech	DELTA
2009183	7/19/2009	-87.0862	45.9783	No Beech	DELTA
2009184	7/19/2009	-86.8913	45.8975	No Beech	DELTA
2009197	7/3/2009	-83.2702	44.7065	No Beech	ALCONA
2009198	8/1/2009	-84.0075	43.3841	No Beech	SAGINAW
2009199	8/1/2009	-84.1036	43.4139	No Scale	SAGINAW
2009200	8/4/2009	-84.7555	42.348	No Beech	CALHOUN
2009201	8/4/2009	-84.2443	42.3194	No Scale	JACKSON
2009202	8/4/2009	-84.1982	42.3277	No Beech	JACKSON
2009203	8/4/2009	-84.0445	42.4187	No Beech	WASHTENAW
2009204	8/4/2009	-83.9614	42.4071	No Beech	WASHTENAW
2009205	8/4/2009	-83.8643	42.506	No Beech	LIVINGSTON
2009206	8/17/2009	-82.7945	44.0182	No Scale	HURON
2009207	8/17/2009	-82.5271	43.2692	No Beech	SANILAC
2009208	8/17/2009	-82.61	43.7166	No Beech	HURON
2009209	8/17/2009	-82.4883	43.1078	No Scale	ST. CLAIR
2009210	8/18/2009	-84.3646	42.8071	No Scale	CLINTON
2009211	8/18/2009	-84.3563	42.8086	No Scale	SHIAWASSEE

Appendix B: ImageJ Photo Analysis Protocol

Opening / Setting Up Program

1) Open a picture
    a. Select *File* => *Open*
2) Setting the Scale by selecting Analyze => *Set Scale*
    a. Set *Distance in Pixels* to 267.01
    b. Set *Known* Distance to 1
        -note must recalculate if new stabilizer is used (different distance from the tree)
    c. Change *Unit of Length* to: Inch
    d. Check the *Global* option

Analyzing Photos / Data Collection

1) Open Photo
2) Record Sampling Event, Tag Number and Photo Aspect
3) Visually asses photo for location of beech scale.
4) Select *Image* => *Type* => *8-bit*
5) Select Image => Adjust => Threshold
    Adjust the Threshold using the top bar (be sure the bottom bar is set to 255) *Note: do not hit apply*
6) If needed apply paint to increase contrast of scale from remaining photo (Reapply Threshold)
7) Use polygon selection tool to select the tree
8) Select *Analyze* => *Measure* (Record Calculated Area)
9) Select *Analyze* => *Analyze Particles* (Uncheck show results) (Record *Total Pixel Area)*
10) Make notes if needed (e.g. used paint and cropped tree)
11) Save changes of new copy of photo
12) Repeat process

*Note: To minimize extra pixels when little scale is present, paint is usually needed.

APPENDIX C: Beech Scale Photo Datasheets

Sampling Event	Site Number

Year	Month	Day	Time

Recorded By:__________
Measured By:__________

Circle Appropriate
Sunny Overcast Rain

Latitude	Longitude	Plot Area	Total # Beech	Total # Other	Road Name	Side of Road (N, S, W, E)	Approx. Distance from Rd. (meter)

Individual Beech Tree Data

Beech Scale Code: 0 = none, 1 = trace, 2 = patchy, 3=whitewashed, 4=dead/declining

Tag # ____ Scale ____ DBH ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ Scale ____ DBH ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ Scale ____ DBH ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ Scale ____ DBH ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ Scale ____ DBH ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ Scale ____ DBH ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Appendix C: Continued

Tag # ____ **Scale** ____ **DBH** ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ **Scale** ____ **DBH** ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ **Scale** ____ **DBH** ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ **Scale** ____ **DBH** ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ **Scale** ____ **DBH** ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Tag # ____ **Scale** ____ **DBH** ____

Photo #			
Photo Height			
Direction (N,S)			
Notes			
Duplicate Pic #			

Other Tree Information

Other Tree ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Species														
DBH														
Cavity														

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Literature Cited

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