Ecological Monitoring at ***rare*** Charitable Research Reserve
2011

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Executive Summary

The ***rare*** Charitable Research Reserve is a not-for-profit environmental organization that preserves over 900 acres of land along the Grand River in Cambridge, Ontario. In 2006, ***rare*** joined Environment Canada's Ecological Monitoring and Assessment Network (EMAN) to establish long-term ecological monitoring programs for the property with the objective of determining the status of ***rare***'s ecosystems and tracking how they change over time. Since 2006, monitoring programs established at ***rare*** include butterfly monitoring, plethodontid salamander monitoring, benthic invertebrate monitoring, forest canopy tree biodiversity and health monitoring and soil humus decay rate monitoring. All of these programs are ongoing. In accordance with the monitoring schedule for the property, the monitoring conducted in 2011 included all of the above, except benthic invertebrate monitoring, which is scheduled for 2012.

Butterfly Monitoring

In 2006, Jessica Grealey was contracted by ***rare*** and Environment Canada to develop a long-term butterfly transect monitoring protocol for EMAN; using ***rare*** as the initial protocol site. Two transects were established: one in the Cliffs and Alvars area, and one in the South field/Sparrow field. The monitoring program was dormant in 2007 and 2008, but resumed in 2009 – whereupon a third transect was added to the monitoring initiative; it was established in the Thompson Tract. Monitoring continued in 2010, and a fourth transect was established in Blair Flats. Monitoring transects involved walking at a controlled pace and recording number of individuals of each species observed. In 2011, butterfly monitoring continued in all four transects, marking the fifth year of monitoring at the ***rare*** Charitable Research Reserve.

A total of 3808 individual butterflies were counted during transect walks in 2011. Over half of these individuals (n=2215) were two non-native species: the Cabbage White (*Pieris rapae*) and the European Skipper (*Thymelicus lineola*). The transects that represented the highest butterfly abundance also had the highest counts of Cabbage Whites and European Skippers, which could indicate that the non-native species were able to exploit the resources available in these landscapes best. Trends in overall butterfly richness and abundance were similar between monitoring years in each of the four transects. Shannon diversity scores between years across the same transects were generally close in range, although transects 1 and 2 in year 2010 marked notably different Shannon indices than in 2009 and 2011. Weather could be a factor in the changes in abundance of butterflies across the years, however, there are likely a complex and variable events that influence butterfly abundance.

Plethodontid Salamander Monitoring

The 2011 field season was the 5th year of monitoring at the Indian Woods salamander plot (which was previously monitored in 2006, 2008, 2009, and 2010) and the 4th year of monitoring at the Hogsback salamander plot (which was previously monitored in 2008, 2009, and 2010). Each plot is composed of a series of wooden boards (32 in Indian Woods, 20 in the Hogsback) placed on the forest floor to act as artificial cover objects (ACO) for plethodontid salamanders. Once weekly for nine weeks, the plots were monitored by turning over the ACOs and quantifying species, snout-vent length (SVL), vent-tail length, and weight of the salamanders underneath the boards. Environmental data including soil temperature, soil moisture, soil pH, air temperature, wind speed, relative humidity, and precipitation from the previous 24 hours were also collected.

Eastern Red-backed salamanders (*Plethodon cinereus*) were the most abundant species in both Indian Woods and the Hogsback; in fact, they were the only species detected in 2011 in the Indian Woods monitoring plot. In Indian Woods, mean weekly Eastern Red-backed salamander abundance (measured as weekly catch per ACO) has declined every year since the start of monitoring, with statistically significant decline detected between 2008 and 2010, and 2008 and 2011. The pattern of salamander abundance in the Hogsback was not similar to that of Indian Woods: mean weekly Eastern Red-backed salamander catch per ACO was highest in 2009, significantly greater than that of 2008. The 2011 mean abundance fell between the abundances of 2008 and 2009, with no significant difference between either years.

To examine the factors influencing salamander abundance in the forest plots, a selection of soil parameters (including mean weekly soil temperature, mean weekly soil moisture, and mean soil pH) and temporal parameters (including the week and the year) were regressed on weekly salamander abundance (measured as catch per ACO). In Indian Woods, we detected significant relationships between salamander abundance and year and soil moisture. Similarly in the Hogsback, year, soil moisture, and additionally, soil pH were found to have a significant positive effect on the salamander abundance under the ACOs.

Finally, the size-class distribution (measured as SVL) of the salamanders observed under the ACOs was analyzed for each plot. In 2011, the greatest proportion of Eastern Red-backed salamanders in both Indian Woods and the Hogsback fell within the SVL size class 35mm to 40mm. Juvenile salamanders (less than 25mm SVL) were underrepresented under the ACOs in both plots. In the Hogsback, we detected a trend towards greater mean SVL in Eastern Red-backed salamanders measured in 2011 compared to previous monitoring years. This could indicate that the same salamanders may be returning to the boards each year. In Indian Woods, there was a trend for increasing mean SVL over the monitoring years, with mean salamander size in 2010 significantly exceeding that in 2006 and 2008. However, 2011 marked a significantly smaller mean SVL of Eastern Red-backed salamanders than 2010. These findings may indicate recruitment of juvenile salamanders to the monitoring plot.

Forest Biodiversity Plot Monitoring

In 2009, permanent 20m x 20m Forest Biodiversity and Health Monitoring plots were established in Indian Woods (three plots) and the Cliffs and Alvars forest (three plots). In

2010, three additional forest plots were established in the Hogsback, and the complete monitoring data (including tree health assessments) for all nine plots was collected. During annual monitoring, the following information was collected for each tree: diameter at breast height, tree height, and tree condition (first classified as either alive or dead and then classified as standing, leaning, fallen, broken, or dead top). Tree health was monitored by recording stem defects, crown class (which indicates the level of dominance or suppression in the canopy), crown rating (which indicates the percent of crown dieback) and any other health notes.

The three plots within each forest were pooled for the calculations of the stand characteristics, and the diversity of each stand was calculated using the Shannon index and Evenness measures. The Importance Value for each species monitored within the stand was calculated as the sum of that species' relative density, relative frequency and relative dominance in the plots. The Indian Woods plots had the lowest tree species diversity (Shannon index= 0.75, Evenness= 0.54) of the three forests, while the Hogsback plots were the most diverse (Shannon index= 2.08, Evenness= 0.90). The diversity of the Cliffs and Alvars forest plots was high (Shannon index = 1.47, Evenness = 0.75), with one plot containing an endangered Butternut tree (*Juglans cinerea*). Sugar Maple (*Acer saccharum*) and American Beech (*Fagus grandifolia*) were the most dominant tree species in each stand.

Soil Humus Decay Rate Monitoring

Soil Humus Decay Rate Monitoring plots were established at the Cliffs and Alvars forest plot 1 in 2009 and additional plots were established at Indian Woods forest plot 1 and the Hogsback forest plot 1 in 2010. For each forest plot being monitored, three annual decay rate (ADR) monitoring plots were set up on each of the four plot corners. At each ADR plot, three pre-weighed tongue depressors were installed in the ground parallel to the soil surface at a depth of 5 cm, and one pre-weighed tongue depressor was positioned on the soil surface. In 2010, sticks were placed in nylon mesh bags to facilitate excavation. The decay sticks were excavated and re-weighed one year after installation, and decay rate was calculated by measuring and averaging the weight loss of excavated sticks.

The decay rate of sticks in the Cliffs and Alvars forest monitoring plot from 2010-2011 was not significantly different from the decay rate from 2009-2010 ($p=0.363$). This could indicate that the nylon mesh bags did not impact the soil decay rate of sticks in the Cliffs and Alvars. As long as mesh bags are used for the duration of the monitoring years, we will be able to accurately and confidently track changes in decay rates in rare forests. The results can be charted over time to detect trends in the decay rate.

In both the Cliffs and Alvars and Indian Woods decay monitoring plots, we found a significant difference between the decay rates of sticks that had been buried beneath the soil, and sticks that had been placed on the soil surface beneath the leaf litter ($p<0.001$). Interestingly, we found no significant difference between decay rates of sticks above (0.437) and below (0.477) ground for the Hogsback monitoring plots. The lack of oxygen and presence of water could account for the low decay rates below ground in some of the sticks in the Hogsback.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Ecological Monitoring

Ecological monitoring measures changes in ecosystems over time through the regular observation and evaluation of organisms, populations and communities (Parks Canada 2009; McCarter 2009). It is impractical and often impossible to monitor every single species within an ecosystem, and ecological monitoring therefore relies on the study of a few carefully selected indicator species. These species are selected because they are convenient to study and because they are particularly sensitive to changes in their environment. Changes in indicator species abundance or population structure indicates change in the ecosystem in general and provides an early warning of environmental stress or ecosystem function decline (Parks Canada 2007).

Ecological responses to changes in the environment occur on longer time scales (i.e. decades, Vaughn *et* al. 2001) than most academic funding packages or political initiatives, and consequently there is a paucity of long-term monitoring datasets for ecosystems in Canada. The findings of long-term ecological monitoring programs are essential in determining priority issues for ecological management and stewardship, and play an important role in informing environmental regulations and policies (Environment Canada 2011).

1.2 Ecological Monitoring Assessment Network (EMAN)

In 1994, Environment Canada established the Ecological Monitoring and Assessment Network (EMAN) as a Canada-wide network of ecological monitoring organizations, including various levels of government, academic institutions, private organizations and community groups (Environment Canada 2011). The objective of the EMAN Coordinating Office was to develop a series of standardized protocols for ecological monitoring, so that data collected by these diverse organizations could be easily compared or even compiled into meta-datasets. Since 1994, the EMAN coordinating office has developed a large variety of monitoring protocols for terrestrial, freshwater and marine ecosystems (Environment Canada 2011). All protocols are available without cost and, until recently, members of the network were encouraged to upload and share their monitoring data so that meta-analyses examining larger-scale patterns in ecosystem change could be conducted.

The EMAN coordinating office was closed in September 2010, and at present it is not clear as to whether the EMAN program will continue in any form. The monitoring protocols are still available online at the Environment Canada website, but it is no longer possible to access or upload monitoring data. According to Environment Canada (2011), some aspects of the work done by the EMAN coordinating office will now be handled by the Wildlife and Landscape Science Directorate in the Landscape Science and Technology Division.

1.3 Ecological monitoring at *rare* Charitable Research Reserve

The ***rare*** Charitable Research Reserve is a not-for-profit environmental organization that preserves over 900+ acres of land along the Grand River in the village of Blair in Cambridge, Ontario. The vision of ***rare*** is to offer the community a healthy natural area preserved intact and in perpetuity. The ***rare*** lands are ecologically diverse, with cold-water streams, floodplains, alvars, old-growth forests, pine plantations, and tall-grass prairies counted among the many habitat types on the property. The land use surrounding the ***rare*** property is likewise diverse; our neighbours include subdivisions, aggregate pits, busy roads, residential estates, and conventional agricultural fields. In keeping with ***rare***'s vision for healthy lands intact and in perpetuity, a number of ecological monitoring programs have been established on the property to determine the health of ***rare***'s ecosystems and to study the responses of these ecosystems to the environmental stresses presented by the changing world.

In 2006, ***rare*** joined EMAN to establish a monitoring program including butterfly monitoring in Cliffs and Alvars and the South Field, plethodontid salamander monitoring in Indian Woods, and benthic invertebrate monitoring in Bauman and Cruickston creeks. Plethodontid salamander monitoring was expanded to the Hogsback forest in 2008. In 2009, both the butterfly and benthic invertebrate monitoring programs were expanded to include more sites, and forest canopy tree biodiversity plots were established in Indian Woods and the Cliffs and Alvars forests. Annual soil humus decay rate monitoring plots were established as well in 2009 at the Cliffs and Alvars forest plot. In 2010, the forest canopy tree monitoring program was expanded to include the Hogsback forest, and annual soil humus decay rate monitoring began in Indian Woods and the Hogsback. The findings of the 2011 butterfly monitoring, plethodontid salamander monitoring, forest canopy tree biodiversity and health monitoring, and annual soil humus decay rate monitoring will be discussed in this report.

2.0 Butterfly Monitoring

2.1 Introduction

2.1.1 Butterflies, Skippers, and Moths

The order Lepidoptera is generally divided in to three laymen categories: Butterflies, Skippers, and Moths. Skippers are considered an intermediate form between Butterflies and Moths, though they are often lumped with the Butterflies in systematics/phenology. There is no single or absolute character by which Butterflies and Moths can be separated (Klots 1979) - although, there are generalizations that can be applied to their identification. **Butterflies** are characterized by having a slender body (head, thorax, and abdomen) and long antennae cumulating in a club at the apex. Their flight is generally languid, but can be also be swift – although it lacks power and the blurring wing strokes as seen in skippers. **Skippers** have a relatively stout body with antennae that have a club short of the apex and culminate in a tapered hook. Their flight is swift and darting, with fast-beating blurred wings. **Moths** are typically nocturnal, although there are some day-flying exceptions. They are characterized by having either simple (no club/hook) or feathery tapering antennae.

2.1.2 Why Monitor Butterfly Populations?

Insects are the most species-rich group of animals, representing over 50% of the world's biodiversity (Groombridge 1992). Unlike most groups of insects, butterflies are well-documented, easy to recognize, and popular within the public perspective. Thomas (2005) concluded that butterflies may be considered representative indicators of trends observed in most other terrestrial insects.

At its core, butterfly monitoring provides objective data on changes in butterfly abundance over time. However, butterflies are also valuable indicators of changes in environmental and community health. Butterflies are susceptible to climatic changes (Van Swaay *et* al. 2006; Wikström *et* al. 2009), anthropogenic pressures (Van Dyck *et* al. 2008), and resource availability (Dennis and Sparks 2006; Aviron *et* al. 2007) – monitoring their populations may provide us with a form of early detection of changes in our environment. For example, some butterfly larvae are monophagous, and their persistence depends exclusively on the presence and health of a particular host plant.

2.1.3 Monitoring Butterflies at *rare* Charitable Research Reserve

Our main objective is to document both general population trends and species-specific trends for butterflies detected on ***rare*** Charitable Research Reserve property.

Reliable estimates of trends used to identify early warning signs should be based on long series of distributional data (Van Swaay *et* al. 2008) and monitoring protocols with standardized sampling efforts. To this effect, Jessica Grealey was contracted by ***rare*** and Environment Canada in 2006 to develop a long-term butterfly transect monitoring protocol for the EMAN. In 2006, Jessica established two transects: one in the Cliffs and Alvars area, and one in the South field/Sparrow field. The monitoring program was dormant in 2007 and 2008, but resumed in 2009 – whereupon a third transect was added to the monitoring initiative; it was established in the Thompson Tract. Monitoring continued in 2010, and a fourth transect was established in Blair Flats. In 2011, butterfly monitoring continued in all four transects.

2.2 Methods

2.2.1 Transect Locations

There are four established butterfly monitoring transects at ***rare*** Charitable Research Reserve (APPENDIX B: Figure B.1).

Cliffs and Alvars is primarily composed of mature hardwood stands (dominated by American Beech (*Fagus grandifolia*) and Sugar Maple (*Acer saccharum*)), deciduous swamps, and limestone cliffs. The 3.5 km monitoring transect passes through an extensive floodplain, mature forest, and open alvar habitat (APPENDIX B: List B.1).

South Field/Sparrow Field is a 70.05 acre property and comprises the southern-most parcel of ***rare***. The east field of the parcel is in agriculture, and the south field is in perennial hay. The remaining acreage have been restored to native vegetation, and are considered conservation lands. The monitoring transect is 3.4 km in length and follows the edge of fields, hedgerows, an old lane, and a Maple-Beech forest (APPENDIX B: List B.2).

Thompson Tract is a 93-acre section of land located on the western boundary of ***rare*** property. It is characterized by a combination of meadows, plantations, lowland forests, and upland forests - which are highly dominated by Sugar Maple and American Beech. The monitoring transect follows established trails in a 2.2 km counter-clockwise loop through all four habitat types (APPENDIX B: List B.3).

Blair Flats was pulled out of agriculture and planted as tallgrass prairie in 2010 as part of a long-term restoration study. The monitoring transect starts at the singular large Bur Oak (*Quercus macrocarpa*) off of Blair road, and forms a 1.3 km loop which traverses the field and follows a hedgerow to the west (APPENDIX B: List B.4). Currently the prairie is dominated by Canada Goldenrod (*Solidago canadensis*), Quackgrass (*Elymus repens*), and Smooth Bedstraw (*Gallium mollugo*).

2.2.2 Monitoring Protocol

Butterfly monitoring at ***rare*** Charitable Research Reserve is conducted using transect methodology – popularized in Europe (Van Swaay *et* al. 2008) and used widely by institutions that conduct butterfly monitoring (Van Swaay *et* al. 2008). The transect method involves walking a fixed route (transect) over a defined amount of time, while recording the number and species of butterflies observed within a certain radius.

The ideal butterfly monitoring season is approximately 26 weeks (Layberry 1998), beginning the first week of April and ending the last week of September. Due to time and monetary constraints, the monitoring period at ***rare*** was reduced to 14 weeks – from mid-May to mid-August. Transects were monitored from late-morning to early-afternoon, coinciding with the ideal conditions for butterfly activity (Layberry 1998). In the summer months the observer should avoid monitoring during peak afternoon hours, as butterfly activity has been known to decrease when temperatures are too high.

It is essential that the observer carries a butterfly net to facilitate identification of unknown species through immobilization and digital photograph records. A list of suggested field equipment is available in APPENDIX C: List C.1. If a butterfly cannot be identified in the field, the observer should record defining features and acquire macro and micro digital images to be sent to local experts[1] for identification. In the absence of experts or images, the observer should assume the butterfly observed was the most common of all possibilities.

Prior to the start of monitoring, all transects were walked by the observer. Transects are made up of a series of sections that separate the different habitat types that are encountered (APPENDIX B: Figure B.1). The observer flagged transects where appropriate (to delineate sections and routes), and practiced pacing throughout the length of each transect.

Each transect was walked once per week from mid-May to late August, for a total of 14 consecutive weeks. To minimize observer bias, all transects were monitored by one person for the duration of the season. Occasionally, the primary observer was accompanied by one or two volunteers. At the beginning of each transect, the observer recorded the start time, measured the temperature using a hand-held Kestrel 3000© (Nielsen-Kellerman, Boothwyn, PA, USA), recorded wind-speed using Beauford's wind scale (Appendix D: Table D.1), and evaluated the percent cloud cover (0-100). All of these factors were documented on a

[1] Jessica Grealey (NRSI, Waterloo), Larry Lamb (Retired), and Glenn Richardson (Hamilton Field Naturalists).

transect-specific field datasheet, which was also used to record all butterfly observations (APPENDIX D: Figure D.1). While walking the transect, the observer recorded all butterflies within 10 metre radius – adding a 10 minute stop halfway through each section for stationary recording of butterflies. Temporary stops were permitted to properly identify butterflies.

2.2.3 Data Analysis

The purpose of the butterfly monitoring program at ***rare*** is to record number of individuals, investigate species diversity, and acquire data to evaluate overall population health. To this extent, data accumulated across the monitoring years is presented graphically to facilitate comparisons between those years. Due to extreme variation in the number of individuals of species recorded, the graphs for each transect are divided in to species with less than 50 observations, and species with greater than 50 observations.

In addition, for the years 2009-2011, we calculated the Shannon Indices[2] for each transect (Figure 2.1). From this calculation, we also derived the species Evenness[3] (Figure 2.2) for each transect in each year.

Shannon index:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Where:

p_i is the proportion of individuals belonging to the *i*th species

Figure 2.1 Formula for calculating the Shannon index.

[2] The Shannon index is a measure of the uncertainty in predicting what species an individual chosen at random from a collection will belong.

[3] Species Evenness refers to how close in number each species in an environment are; values closer to 1 represent more even populations.

Evenness:

$$E_H = H/\ln(S)$$

Where:

H is the Shannon index

S is the number of species

Figure 2.2 Formula for calculating species Evenness.

In 2006, the inaugural monitoring year, the monitoring season was truncated due to the observer's contract length. In 2009 a third monitoring transect was established mid-season, and it includes only seven weeks of late-season data. As we have accumulated more data, we are most interested in comparing full-season datasets. For the purpose of this report, all data from all years is presented graphically (years with less than 14 week monitoring period are marked with a * in the figure heading), while only 2009-2011 Shannon indices for each transect with full monitoring period (14 weeks) are compared.

A list of common and scientific names of all butterfly species listed in this report can be found in APPENDIX A: Table A.2.

2.3 Results

2.3.1 Transect 1 – Cliffs and Alvars

Thirty-five Lepidopteran species (1453 individuals) were recorded while walking transect 1 during the 2011 monitoring season (Table 2.1). Figure 2.3 shows the total yearly count (2006, 2009, 2010, and 2011) of butterfly species with less than 50 observations in transect 1. Figure 2.4 shows the total yearly count of butterfly species with more than 50 observations. In 2011, the five most abundant species in transect 1 were: Cabbage Whites (*Pieris rapae*) (n=885), European Skippers (*Thymelicus lineola*) (n=115), Northern Crescents (*Phyciodes selenis*) (n=66), Little Wood-Satyrs (*Megisto cymela*) (n=60), and Monarchs (*Danaus plexippus*) (n=46).

Table 2.2 gives the Shannon index values which were calculated for 2009, 2010, and 2011 in transect 1. In 2011, the Shannon index value was 1.77, and species Evenness was 1.15.

Table 2.1 Number of individual butterflies observed in 2011, listed by species and transect. Including status of species in Waterloo Region.

	Transects					
Species	**1**	**2**	**3**	**4**	**Total**	**Regional Status**
Appalachian Brown	2	-	-	-	**2**	Uncommon
Banded Hairstreak	-	1	-	-	**1**	Uncommon
Black Swallowtail	5	48	3	7	**63**	Very Common
Cabbage White	885	726	197	219	**2027**	Very Common
Clouded Sulphur	8	88	24	6	**126**	Very Common
Common Sooty Wing	-	1	-	-	**1**	Rare
Common Wood Nymph	19	14	41	5	**79**	Very Common
Compton's Tortoiseshell	-	1	-	-	**1**	Uncommon
Delaware Skipper	-	4	2	1	**7**	Common
Dun Skipper	11	-	1	2	**14**	Very Common
Eastern Comma	11	1	1	-	**13**	Very Common
Eastern Tailed Blue	-	2	-	1	**3**	Uncommon
Eastern Tiger Swallowtail	16	19	10	4	**49**	Very Common
European Skipper	115	18	49	6	**188**	Very Common
Eyed Brown	9	1	10	-	**20**	Very Common
Giant Swallowtail	23	10	5	7	**45**	Uncommon
Great Spangled Fritillary	-	-	11	-	**11**	Very Common
Harvester	-	-	1	-	**1**	Rare
Hobomok Skipper	5	18	13	1	**37**	Common
Inornate Ringlet	40	27	194	5	**266**	Common
Juvenal's Duskywing	9	1	19	-	**29**	Rare
Least Skipper	13	-	3	-	**16**	Uncommon
Little Glassywing	1	-	-	-	**1**	Uncommon
Little Wood Satyr	60	5	26	-	**91**	Very Common
Long Dash	1	-	1	-	**2**	Uncommon
Milbert's Tortoiseshell	-	-	1	-	**1**	Uncommon
Monarch	46	85	67	18	**216**	Very Common
Mourning Cloak	2	5	3	-	**10**	Very Common
Mustard White	1	-	-	-	**1**	Possibly Extirpated
Northern Broken Dash	2	-	-	-	**2**	Common
Northern Crescent	66	14	64	3	**147**	Uncommon
Northern Pearly Eye	33	6	89	1	**129**	Common
Orange Sulphur	2	21	3	-	**26**	Very Common
Pearl Crescent	20	7	29	-	**56**	Common

Table 2.1 Continued.

Species	Transects					Regional Status
	1	2	3	4	Total	
Peck's Skipper	-	-	3	-	**3**	Very Common
Question Mark	1	1	1	-	**3**	Very Common
Red Admiral	4	-	1	-	**5**	Very Common
Red Spotted Purple	12	12	6	1	**31**	Common
Silver-Spotted Skipper	-	-	11	-	**11**	Uncommon
Spring Azure	10	-	8	1	**19**	Common
Striped Hairstreak	1	1	-	-	**2**	Uncommon
Summer Azure	15	6	6	5	**32**	Very Common
Tawny Emperor	1	2	-	1	**4**	Uncommon
Tawny-edged Skipper	1	-	-	-	**1**	Common
Viceroy	3	1	7	4	**15**	Very Common
White Admiral	-	-	1	-	**1**	Uncommon
TOTAL	**1453**	**1146**	**911**	**298**	**3808**	

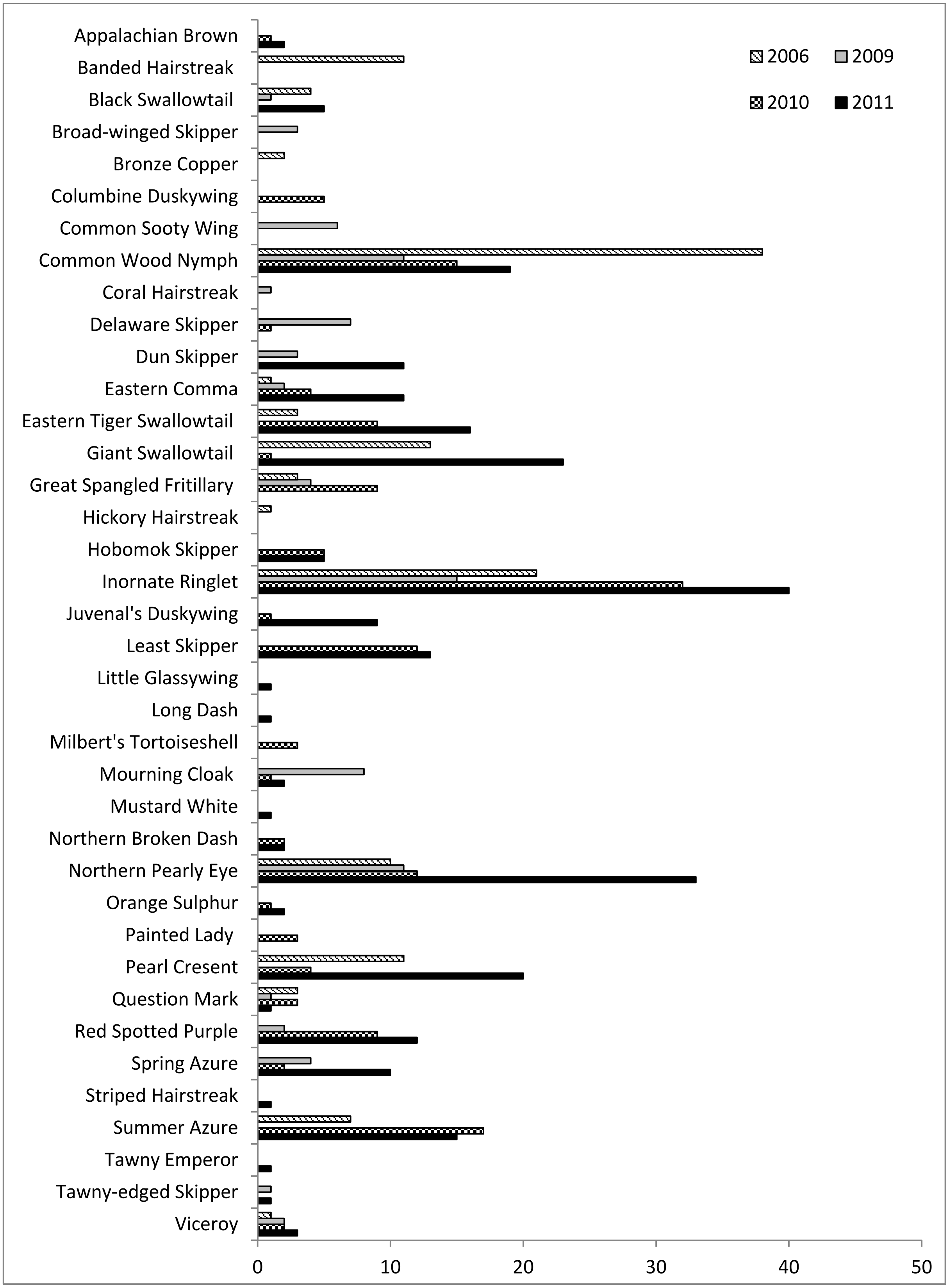

Figure 2.3 Number of butterflies observed by species (<50 observations) in transect 1, May through August 2006*, 2009, 2010, and 2011.

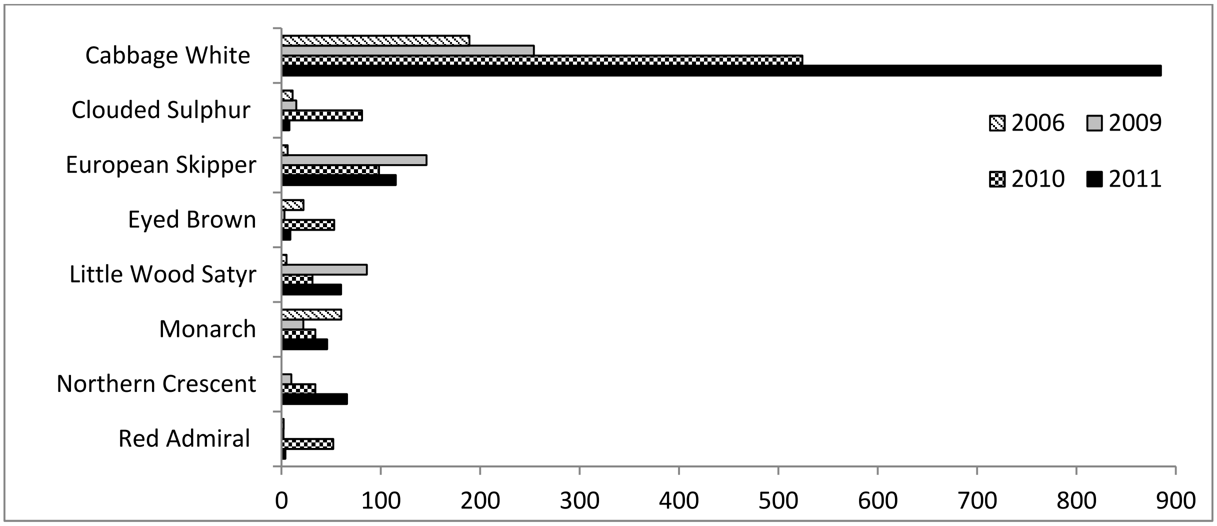

Figure 2.4 Number of butterflies observed by species (>50 observations) in transect 1, May through August 2006*, 2009, 2010, and 2011.

Table 2.2 Comparison of Abundance (n), number of species (S), Shannon index (H), and species Evenness (E) of butterflies observed in years with full 14 week monitoring schedules.

Measures	Transect 1			Transect 2			Transect 3		Transect 4	
	2009	2010	2011	2009	2010	2011	2010	2011	2010	2011
Number of individuals (n)	620	1063	1453	717	1778	1146	938	911	270	298
Species richness (S)	25	33	35	24	26	30	30	35	14	20
Shannon-Wiener index (H)	1.90	2.07	1.77	1.65	1.42	1.60	2.37	2.56	1.30	1.26
Evenness (E)	0.59	0.59	0.50	0.52	0.44	0.47	0.70	0.72	0.49	0.42

2.3.2 Transect 2 – South Field/Sparrow Field

Thirty Lepidopteran species (1146 individuals) were recorded while walking transect 2 during the 2011 monitoring season (Table 2.1). Figure 2.5 shows the total yearly count (2006, 2009, 2010, and 2011) of butterfly species with less than 50 observations in transect 2. Figure 2.6 shows the total yearly count of butterfly species with more than 50 observations. In 2011, the five most abundant species in transect 2 were: Cabbage Whites (n=726), Clouded Sulphurs (*Colias philodice*) (n=88), Monarchs (n=85), Black Swallowtails (*Papilio polyxenes*) (n=48), and Inornate Ringlets (*Coenonympha tullia inornata*) (n=27).

Table 2.2 gives the Shannon index values which were calculated for 2009, 2010, and 2011 in transect 2. In 2011, the Shannon index value was 1.60, and species Evenness was 1.08.

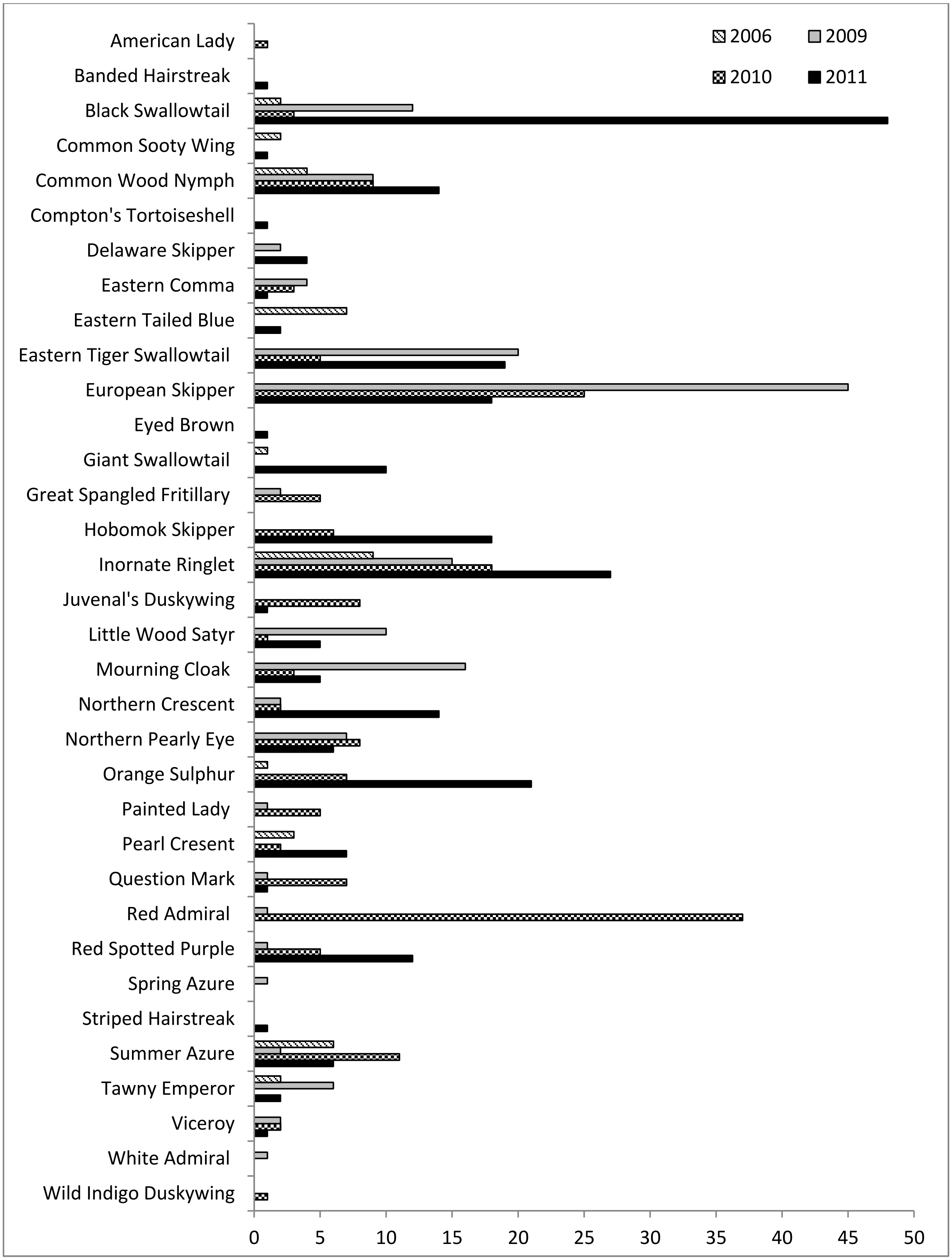

Figure 2.5 Number of butterflies observed by species (<50 observations) in transect 2, May through August 2006*, 2009, 2010, and 2011.

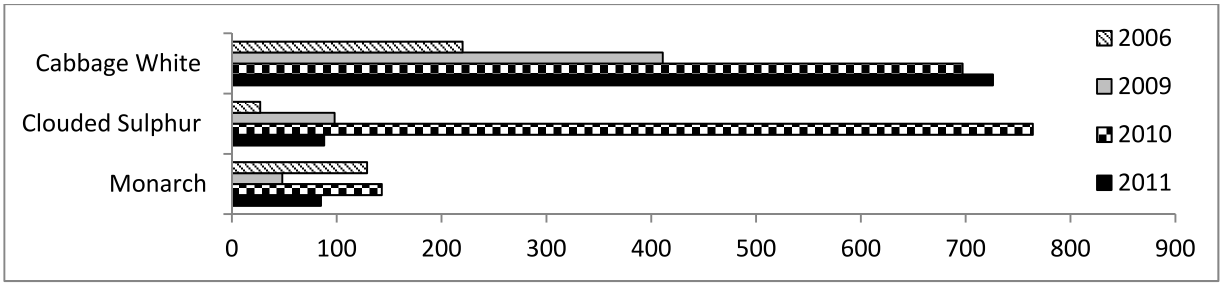

Figure 2.6 Number of butterflies observed by species (>50 observations) in transect 2, May through August 2006*, 2009, 2010, and 2011.

2.3.3 Transect 3 – Thompson Tract

Thirty-five Lepidopteran species (911 individuals) were recorded while walking transect 3 during the 2011 monitoring season (Table 2.1). Figure 2.7 shows the total yearly count (2009, 2010, and 2011) of butterfly species with less than 50 observations in transect 3. Figure 2.8 shows the total yearly count of butterfly species with more than 50 observations. In 2011, the five most abundant species in transect 3 were: Cabbage Whites (n=197), Inornate Ringlets (n=194), Northern Pearly-eyes (*Enodia anthedon*) (n=89), Monarchs (n=67), and Northern Crescents (n=64).

Table 2.2 gives the Shannon index values which were calculated for 2010 and 2011 in transect 3. In 2011, the Shannon index value was 2.56, and species Evenness was 1.66.

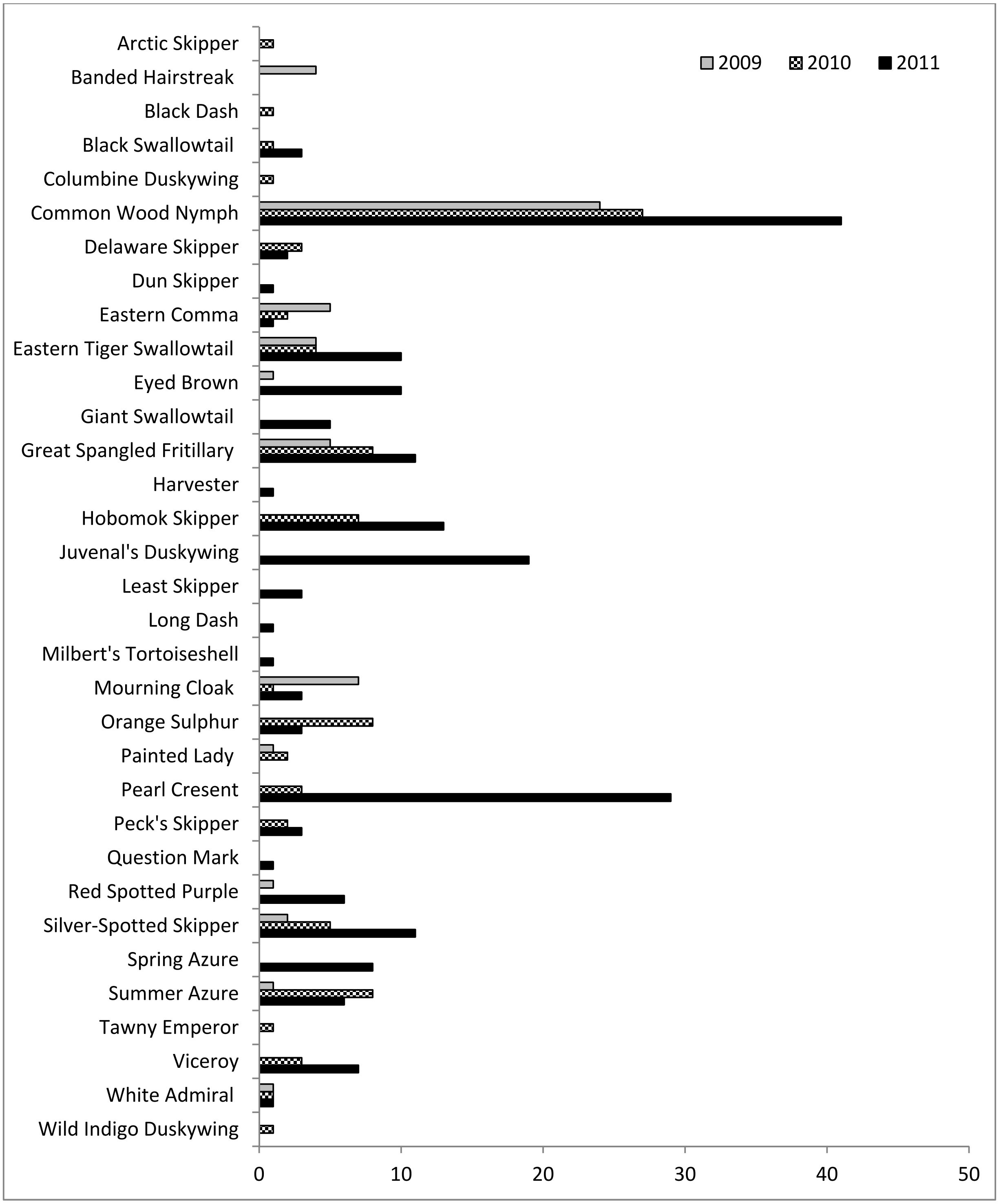

Figure 2.7 Number of butterflies observed by species (<50 observations) in transect 3, May through August 2009*, 2010, and 2011.

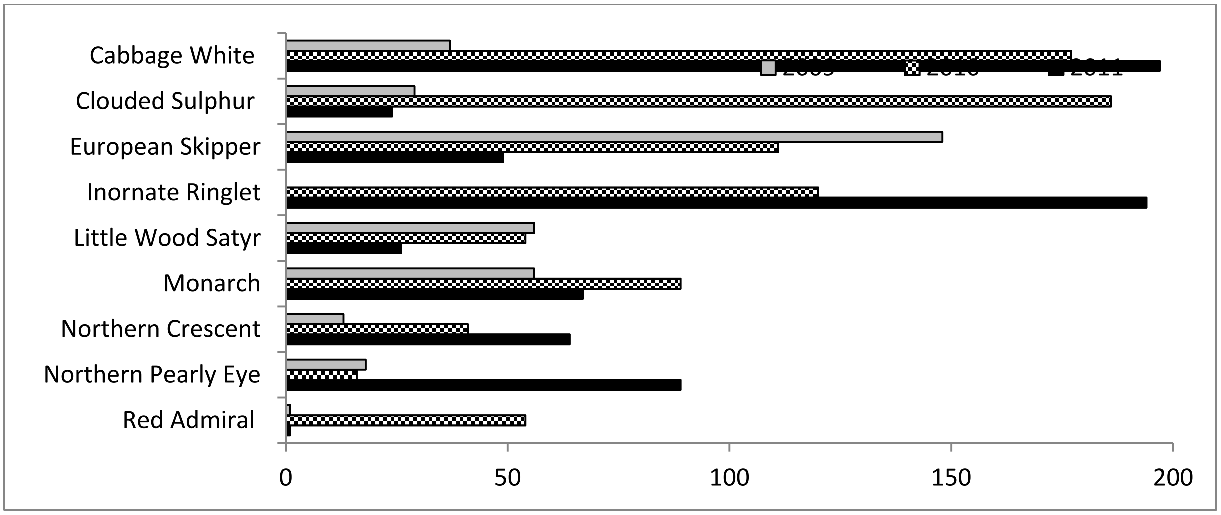

Figure 2.8 Number of butterflies observed by species (>50 observations) in transect 3, May through August 2009*, 2010, and 2011.

2.3.4 Transect 4 – Blair Flats

Twenty Lepidopteran species (298 individuals) were recorded while walking transect 4 during the 2011 monitoring season (Table 2.1). Figure 2.9 shows the total yearly count (2010 and 2011) of butterfly species with less than 50 observations in transect 4. Figure 2.10 shows the total yearly count of butterfly species with more than 50 observations. In 2011, the five most abundant species in transect 4 were: Cabbage Whites (n=219), Monarchs (n=18), Black Swallowtails (n=7), Giant Swallowtails (*Papilio cresphontes*) (n=7), and Clouded Sulphurs (n=6).

Table 2.2 gives the Shannon index values which were calculated for 2010 and 2011 in transect 4. In 2011, the Shannon index value was 1.26, and species Evenness was 0.97.

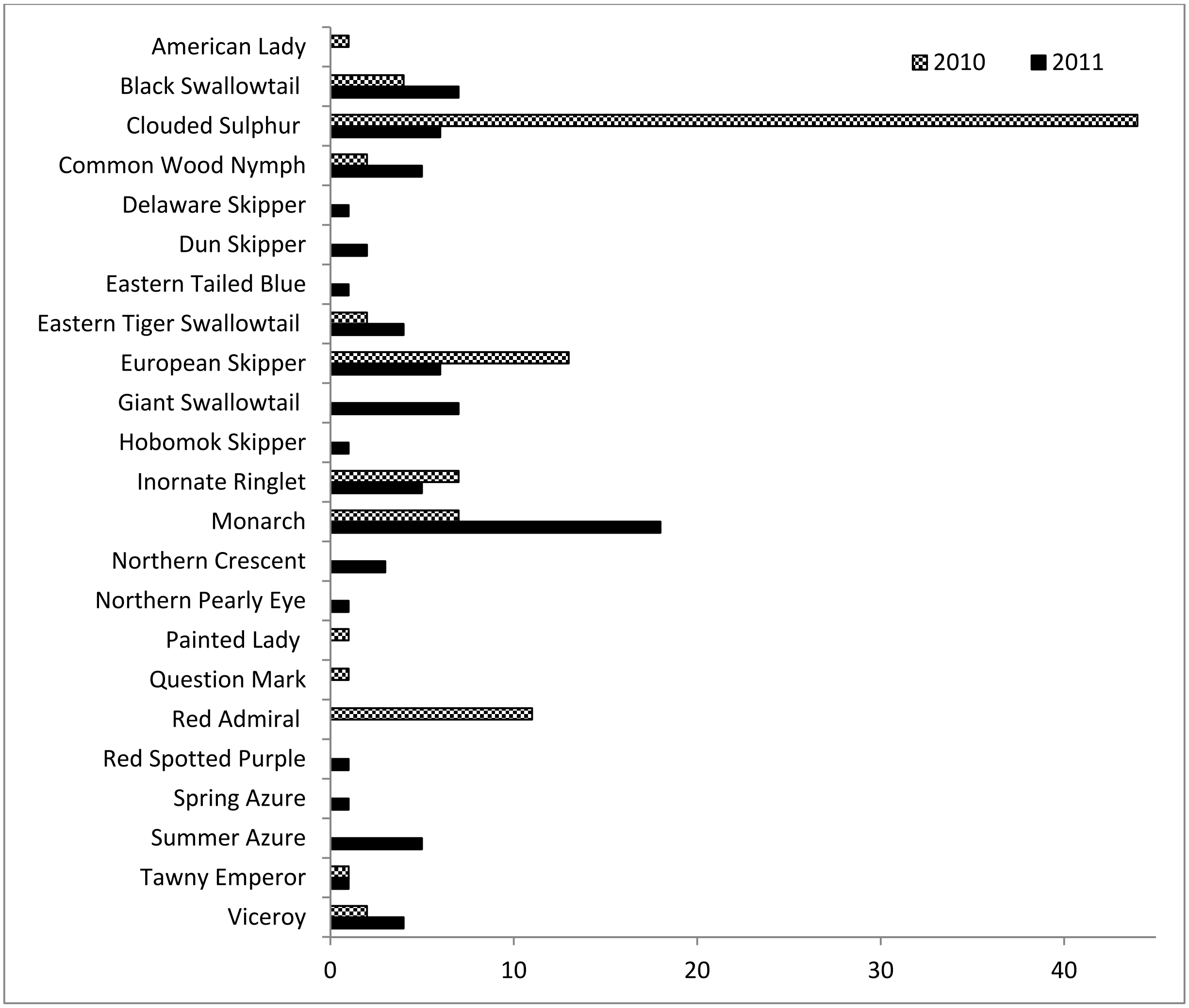

Figure 2.9 Number of butterflies observed by species (<50 observations) in transect 4, May through August 2010 and 2011.

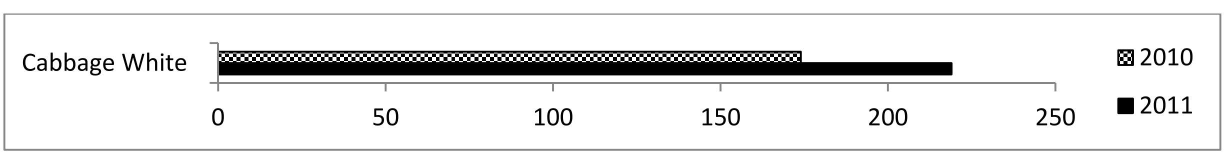

Figure 2.10 Number of butterflies observed by species (>50 observations) in transect 4, May through August 2010 and 2011.

2.3.5 Weather and Climate Data

The monitoring season of 2011 was characterized by a cool wet start to the spring, followed by a hot, dry summer. Monthly mean temperatures for the four monitoring years are displayed in Figure 2.11, and total rainfall for each monitoring month is shown in Figure 2.12.

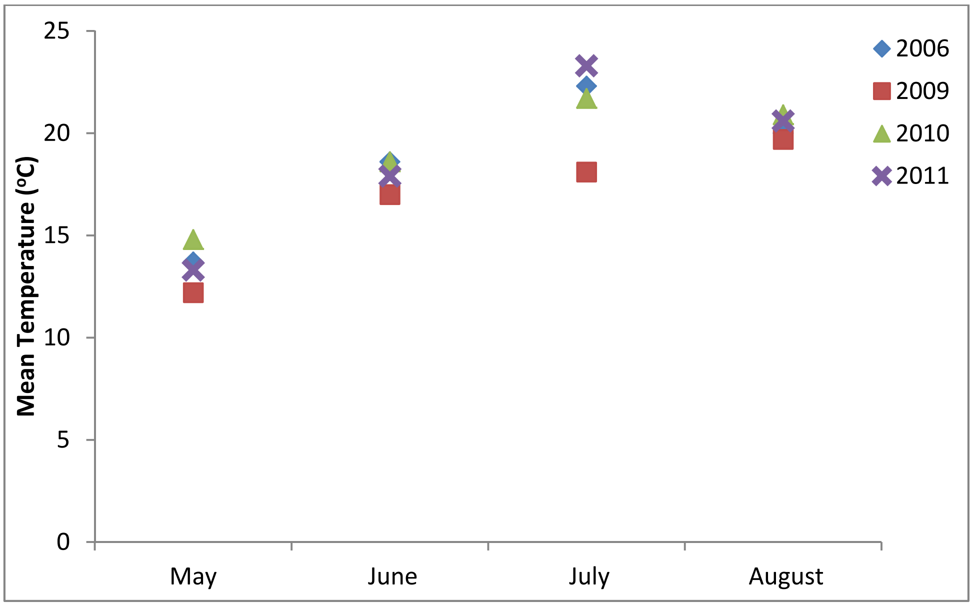

Figure 2.11 Mean monthly temperatures for Waterloo region May through August 2006, 2009, 2010, and 2011 (Environment Canada 2012).

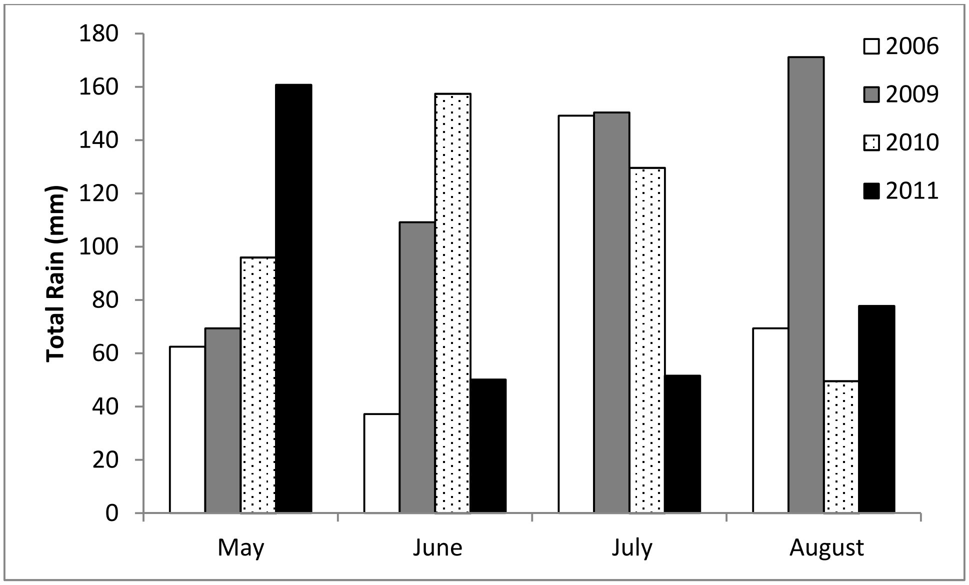

Figure 2.12 Total monthly rainfall for Waterloo region May through August 2006, 2009, 2010, and 2011 (Environment Canada 2012).

2.4 Discussion

2.4.1 Butterfly Diversity and Abundance

A total of 3808 individual butterflies were counted during transect walks in 2011. Table 2.1 displays individual species and the number of individuals observed within each transect. Over half of these individuals (n=2215) were two non-native species: the Cabbage White and the European Skipper. The Cabbage White butterfly is nearly ubiquitous in Canada. It was first introduced to North America (Quebec) in the 1860s, and spread rapidly across the continent over the next few decades (Layberry 1998). It favours plants from the Mustard (*Brassicaceae*) family, which are abundant and well-represented at ***rare*** (Draft ***rare*** Environmental Management Plan 2012). The European Skipper was introduced to North America in 1910 via contaminated imported Timothy Grass (*Phleum pratense*) seeds near London, Ontario. Today, its range covers Eastern Canada, and its range is only thought to be restricted by lack of suitable habitat to the North. The European Skipper flourishes in agricultural and grassy areas (Layberry 1998); ***rare*** is comprised of approximately 17.7% agriculture lands, and more than 5.3% regenerating native grassland (Draft ***rare*** Environmental Management Plan 2012) – making it an ideal and suitable habitat for the European Skipper.

Trends in overall butterfly richness and abundance were similar between monitoring years in each of the four transects. Dates of first emergence of each species were recorded for each monitoring season and can be found in APPENDIX A: Table A.1. Shannon diversity scores between years across the same transects were generally close in range, although transects 1 and 2 in year 2010 marked notably different Shannon indices than in 2009 and 2011. Weather could be a factor in the changes in abundance of butterflies across the years. In 2011, the highest species richness was observed in transects 1 (n=35) and 3 (n=35), followed by transect 2 (n=30), and transect 4 (n=20). Abundance was observed to be highest in transect 1 (n=1453), followed by transect 2 (n=1146), transect 3 (911), and transect 4 (n=298). The transects that represented the highest butterfly abundance also had the highest counts of Cabbage Whites and European Skippers, which could indicate that the non-native species were able to exploit the resources available in these landscapes best. Transect 3 had the fewest Cabbage White butterflies recorded, both proportionally and numerically. The majority of Transect 3 is a managed woodlot and old growth forest, whereas transect 1 boasts more open forest and field habitat. The results of our monitoring indicate that although transect 1 and 3 tend to be characterized by forested habitat, they still support the highest diversity of butterfly species. This is likely due to their relatively intact native plant communities and the open edge communities that are often formed as a result of walking trails.

In general, causes of observed patterns in distribution and abundance of butterflies are difficult to isolate and are likely the result of a combination of multiple interacting factors. Higher overall butterfly richness has been observed in areas with more naturalized habitats and richer plant communities (Linton 2012). The ***rare*** Charitable Research Reserve provides wildlife with abundant naturalized habitats which act as an oasis in the expanding urban centre of Waterloo Region. Butterfly monitoring will continue to provide valuable information on the health of ***rare***'s lands, and will serve as an indicator of ecological integrity in the region.

2.4.2 New and Noteworthy Records at *rare* Charitable Research Reserve.

Based on the regional status assignment (Table 2.1) (Linton 2012), 19 of all butterfly species observed during transect counts are considered very common. Species designated as very common were observed within each of the four monitoring transects. Species designated as rare were observed in each of transect 1, transect 2, and transect 3.

In 2010, there were 1075 individual Clouded sulphurs observed in the monitoring transects (Moore 2010); whereas in 2011, only 126 were observed across all four transects. Similarly, in 2009, there were only 142 Clouded Sulphurs recorded in the monitoring transects (Moore 2009). Transect 2 had the most drastic differences in observations, from 98 in 2009, to 764 in 2010, and 88 in 2011. The absence of Clouded Sulphurs in 2011 is surprising, and could be a result of the wet start to the season. Alternatively, butterfly populations are known to have dramatic population fluctuations, and 2011 could be an off year.

Another species that was noticeably absent from the 2011 monitoring season was the Red Admiral (*Vanessa atalanta*). In 2010, 154 individuals were observed throughout the four transects; whereas in 2011, only five individuals were recorded. The records for 2009 are most similar to 2011, with only four Red Admiral butterflies recorded in the monitoring season (Moore 2009). The differences in abundance could result from changes in weather patterns, as 2009 was an extremely wet summer.

Conversely, in 2011, there was a dramatic increase in Giant Swallowtail abundance recorded across Ontario (Ontario Butterflies 2011). Giant Swallowtails are the largest butterflies found in Canada. During the 2009 monitoring season, no Giant Swallowtails were observed (Moore 2009); in 2010, one individual was recorded in transect 1 (Moore 2010); in 2011, 45 Giant Swallowtails were observed across all four transects – with the majority being recorded in transect 1. The larval host plant for Giant Swallowtails is the Northern Prickly Ash (*Zanthoxylum americanum*), a shrub that is abundant in certain areas of ***rare***, most notably in the Cliffs and Alvars. Northern Prickly Ash has been spreading across Ontario, outside of its normal southern range; the spread of host plant in combination with changes in climate may account for the greater abundance of Giant Swallowtails in 2011.

Species new to ***rare*** in 2011 were: Compton Tortoiseshell (*Nymphalis vaualbum*), Harvester (*Feniseca tarquinius*), and Mustard White (*Pieris napi*).

On August 12th 2011 a *Pieris* species was netted at the heading of the rail trail in the Cliffs and Alvars transect, and was identified as a Mustard White butterfly. This species is listed as possibly extirpated in Waterloo Region, and is provincially rare. This butterfly is often confused with the West Virginia White (*Pieris virginiensis*); however, we were able to confirm identification by flight season – West Virginia Whites have only one flight season, in the spring May through early June (Layberry 1998). Following the introduction of the Cabbage White in North America, the Mustard White population saw a dramatic decrease in abundance – a pattern some researchers attribute to intense competition for habitat (Linton 2012). It has not been recorded in Waterloo Region since 1986. While this species is listed as possibly extirpated in the region and declining in number in general, it is still considered common throughout its range in Canada (Layberry 1998). In Waterloo Region, the lack of sightings could be a consequence of weak search effort – In flight and in the field they are nearly indistinguishable from Cabbage Whites unless identified at rest or in hand.

August 2nd 2011, a Harvester butterfly was netted in the Thompson Tract at the trail junction with Grand Allée. It was flying erratically and low to the ground in an area with slow moving water and alder bushes. The Harvester is the only butterfly with carnivorous larvae in North America. Larvae feed on Woolly Aphids (*Eriosomatidae* spp.) and adults feed on the honeydew produced from these same aphids. The Harvester butterfly is considered widespread throughout its range in Eastern Canada however, in Waterloo Region it is considered rare. The last record for the Harvester butterfly in Waterloo region was in 1990. Because this species often occurs singly, is a fast, erratic flyer, and tends to be extremely local, it may be easily overlooked (Layberry 1998; Linton 2012).

August 4th 2011, a Common Sootywing (*Pholisora catullus*) was netted in South Field, which is in perennial hay. The Common Sootywing can be locally common in southern Ontario, but is considered provincially 'imperilled' and rare in the region of Waterloo (Layberry 1998, NHIC 2010). In recent years, it has been recorded by local experts at ***rare*** Charitable Research Reserve (Linton 2012).

The data collected in 2009 represents butterfly abundance and richness in an uncharacteristically cool and wet year, while the data in 2010 represents a long, warm season where a noticeable influx of seasonal colonists and immigrants was observed. The 2011 monitoring season started off cold and wet, and then progressed into a dry, hot field season. (Figure 2.10, Figure 2.11). It is evident that we are gaining valuable insight in to the yearly peculiarities of butterfly diversity, building a strong baseline dataset for future comparisons. Clearly certain species fluctuate dramatically each year, and with more observations and monitoring seasons, combined with the collection of temperature, rainfall, and other potential variables, we will be able to identify patterns in butterfly abundance and model suitable management plans. The collection of plant species-level data for each section of each transect could benefit the monitoring program by identifying possible associations between butterflies and host/nectaring plant abundance. New (1997) argued that butterflies act as effective umbrella species[4] for guiding conservation management because of their dependence on plants.

[4] Umbrella species occupy expansive tracts of habitat or specific types of habitat so that conserving such a species automatically saves many other species occupying the same area (Simberloff 1998).

3.0 Plethodontid Salamander Monitoring

3.1 Introduction

3.1.1 Plethodontid Salamanders

In Ontario, salamanders fall into two major categories: the lungless salamanders (Plethodontidae) and the mole salamanders (Ambystomatidae). Mature mole salamanders are larger than their lungless counterparts, burrow, and lay eggs in ephemeral ponds. Examples of mole salamanders include: Spotted salamander (*Ambystoma maculatum*), Blue-spotted salamander (*Ambystoma laterale*), and the provincially and federally endangered Jefferson's salamander (*Ambystoma jeffersonianum*). In contrast, lungless salamanders are small, slender salamanders characterized by the absence of lungs, and the presence of chemoreceptor-lined naso-labial grooves used for hunting prey (Conant and Collins 1998). Examples of lungless salamanders include: Eastern Red-backed salamander (*Plethodon cinereus*) and the Four-toed salamander (*Hemidactylium scutatum*). Plethodontidae is the largest salamander family in the world, with 27 genera representing 376 recognized species (Larson *et* al. 2006). Most members of the Plethodontidae family have both an aquatic juvenile stage and a terrestrial adult stage, although there are a number of species that exhibit only one the terrestrial or aquatic phase (Larson *et* al. 2006).

Most plethodontids live in moist areas, generally in or under decaying logs or stumps, leaf litter, fallen bark, or large stones (Welsh and Droege 2001). They receive oxygen exclusively through cutaneous respiration, relying on gas exchange across the moist surfaces of their skin and the roof of their mouth (Conant and Collins 1998). This feature of their biology makes them particularly sensitive to changes in the environment that may alter the air and water conditions of their micro-habitat (Zorn *et* al. 2004). Cutaneous gas exchange can only occur when skin is moist (Welsh and Droege 2001), and the highly absorptive nature of their skin makes plethodontid salamanders susceptible to contaminants in the soil. Of the five species of Plethodontidae in Ontario, the Eastern Red-backed salamander is the most common (Zorn et al. 2004).

Eastern Red-backed salamanders are terrestrial and do not require ponds or vernal pools for their development. They are most often found in moist soil under downed woody debris in mature forests (Conant and Collins 1998). There are two major colour variants of Eastern Red-backed salamander; the red-backed phase has dark grey sides with a red, rough-edged stripe down its back, whereas the lead-backed phase lacks the red stripe and is completely grey.

The normally aggressive and territorial Eastern Red-backed salamanders breed from October to December, at which point they can be found in breeding pairs in suitable habitat (Ransom and Jaeger 2006; Bishop 1943). Eggs are inseminated in the spring and females lay a cluster of up to a dozen eggs throughout June and July, which they subsequently attach to the roofs or sides of small terrestrial cavities (Lang and Jaegar 2000; Bishop 1943). Females guard and tend their eggs, periodically turning them to prevent mildew from forming, until the eggs hatch in August or early September (Zorn et al. 2004). Juvenile Eastern Red-backed salamanders complete their larval stages within their eggs and emerge as intact adults; save for a set of gills that are present at emergences which are absorbed in to the skin within a week (Ontario Nature 2012).

3.1.2 Monitoring Eastern Red-backed salamanders

While monitoring Eastern Red-backed salamanders provides beneficial information on the abundance and diversity of their population, it can also highlight trends that are representative of the greater ecosystem (Van Wieren 2003). Salamanders are significant components of many forest ecosystems, and their decline may have consequences that affect a variety of associated plant and animal species. A number of life history characteristics of the Eastern Red-backed salamander make it a valuable indicator species when monitoring ecosystem health.

Eastern Red-backed salamanders are abundant in North America's temperate forests (Welsh and Droege 2001). In a study of Eastern Red-backed salamander abundance in the Hubbard Brook forest in New Hampshire, Burton and Likens (1975) estimated that the biomass of this species surpassed that of any other vertebrate group, and exceeded the biomass of all small mammals in the forest combined. Given this impressive abundance, the importance of this species in the nutrient cycling of the forest is clear. Eastern Red-backed salamanders are among the top predators of invertebrates in the soil and leaf litter, feeding on springtails, earthworms, ants and many other detritivores of the forest floor (Casper 2011). The Eastern Red-backed salamander in turn provides an ample food source for predators such as snakes, rodents, rove beetles, and birds - all while moving energy and nutrients into the higher trophic levels (Casper 2011; Zorn *et* al. 2004).

Given their low mortality and reproductive rates and their relatively long lifespan (which may reach nine years in some cases (Zorn *et* al. 2004; LeClair *et* al. 2006)), Eastern Red-backed salamanders typically have stable population sizes under normal conditions (Zorn *et* al. 2004). This is an essential characteristic species used in long-term monitoring programs: the year-to-year fluctuations in population size are low or negligible for the Eastern Red-backed salamander, therefore large changes in abundance likely indicate changes to the ecosystem and not just normal population cycling (Welsh and Droege 2001; Zorn *et* al. 2004). Eastern Red-backed salamanders are also known to have small home ranges, and they often return to the same cover objects year after year (Welsh and Droege 2001), therefore, it is unlikely that changes in salamander abundance are the result of shifting home ranges. Finally, Eastern Red-backed salamanders are known to readily use artificial cover objects (ACOs) added to the forest floor, allowing for simple, repeatable, and non-destructive monitoring

(Zorn *et* al. 2004). In addition, they are easy to identify; this reduces observer bias and maintains the integrity of the data collected. The Eastern Red-backed Salamander is therefore a highly suitable study system for long-term monitoring of the forest ecosystem.

3.1.3 EMAN Plethodontid Salamander Monitoring at *rare*

The Ecological Monitoring and Assessment Network and Parks Canada published a joint National Monitoring Protocol for plethodontid salamanders in 2004. This protocol outlines the establishment of permanent forest monitoring plots containing a series of wooden ACOs spaced evenly across the forest floor (Zorn *et* al. 2004). To achieve the best results, the plots should be monitored in the spring and fall of every year to detect changes in plethodontid salamander abundance and community structure (Zorn *et* al. 2004) as an indicator of forest health. Due to monetary and time constraints, plethodontid salamander monitoring at ***rare*** takes place exclusively in the fall.

The salamander monitoring program at the ***rare*** Charitable Research Reserve began in 2006 with the installation of 29 ACOs in the Indian Woods. Monitoring was not conducted in 2007, but resumed in 2008 and has continued every fall to 2011. In 2009, three additional ACOs were installed in the Indian Woods plot, bringing the total number of ACOs to 32. The Hogsback monitoring plot was established in 2008 with the introduction of 20 ACOs; it has been monitored each fall season from 2008-2011.

The salamander monitoring program at ***rare*** has been successful to date in that salamanders started using the ACOs within weeks of establishing plots; and they continue to use the boards despite the disturbance resulting from monitoring protocol. The monitoring data collected in these early monitoring years will provide valuable baseline data to which the data from future years can be compared in order to determine how ***rare***'s salamander populations are changing over time. In addition, upon the creation of the monitoring plots, research questions were identified by McCarter (2009) specific to ***rare*** and its goals and mandates:

1. What is the current state (species diversity, abundance, age structure) of the salamander populations in ***rare***'s forests, and how do they compare to one another?
2. What are the long-term trends in Eastern Red-backed salamander abundance and population structure taking place within Indian Woods and the Hogsback?
3. Is the ecosystem integrity[5] of Indian Woods and the Hogsback being maintained or improved under ***rare*** management?
4. Is either the ecological health[6] or integrity of Indian Woods and the Hogsback being affected by on-site and nearby changes in land use (i.e. restoration, agriculture, residential development and aggregate extraction)?

[5] Ecosystem integrity is defined by Parks Canada (2009) as an ecosystem that has its native components intact (abiotic, biodiversity, and ecosystem processes).

These data will provide the basis for the long-term plethodontid salamander monitoring program at ***rare***. The data accumulated from this long-term study will be beneficial in the development of new land management plans, restoration projects, and current and future research projects.

3.2 Methods

3.2.1 Monitoring Locations

Indian Woods is an old-growth Sugar Maple-American Beech dominated forest located on the western side of the ***rare*** property, south of Blair Road, and north of Whistle Bare road. The forest encompasses approximately 20 acres and contains trees as old as 240 years. The Indian Woods salamander monitoring plot is located on the east side of the ephemeral pond near the south end of the forest (APPENDIX B: Figure B.2 and Table B.1). The plot is accessed by parking at the South Gate on Whistle Bare road, and walking north along the Grand Allée until a second path merges from the west (left) (marked by a post with a blue square and white arrow, and a large downed cottonwood on the left). From this point, walk east (right) into the forest towards a large ephemeral pond (approximately 100m). The 32 ACOs of the monitoring plot are distributed in large square – made up of four lines of eight ACOs each. Each board is identified with a writeable aluminum tag, and an adjacent shrub/tree is flagged with orange. Boards 5, 6, and 7 were missing from the 2006 and 2008 monitoring years, but were re-admitted to the plot in 2009.

The Hogsback is a 57 acre forest located approximately 700m southeast of Indian Woods, south of Blair Road and just west of the Newman Drive subdivision. It is comprised of mixed swamp interspersed with ridges of upland forest characterized by Red Maple (*Acer rubra*) and White Pine (*Pinus stroba*). The Hogsback salamander plot is accessed through the South Gate, off of Whistle Bare road, and heading east along the lane to where it turns as it hits the Hogsback (APPENDIX B: Figure B.2 and Table B.1). From there, keep left and walk north and then east along the edge of the forest, finally heading south into the stand (over the fallen tree that lowers the fence) for 50m to the monitoring plot. The Hogsback monitoring plot was established in 2008 and is comprised of 20 ACOs distributed in a large rectangle with eight ACOs on each of the long (north-south) sides.

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[6] Ecosystem health is defined as when an ecosystem has the capacity to resist and recover from a range of disturbances, while maintaining its functions and processes (Styers *et* al. 2010; Twery and Gottschalk 1996)

3.2.2 Monitoring Protocol

One month prior to the start of monitoring, all ACOs in both Indian Woods and the Hogsback were visited to ensure proper positioning and clear labelling. If necessary, the boards were re-positioned so that they were flush against the soil. Any holes in the board were packed with soil to prevent salamanders from hiding during monitoring.

Each plot was monitored once a week for nine successive weeks from the end of August to the end of October. Indian Woods was monitored for only five weeks in 2006, and the Hogsback was monitored for five weeks in 2008.

Prior to commencing daily monitoring protocol, the soil moisture meter (Lincoln Irrigation Corporation, Lincoln, Nebraska, USA) was calibrated in pond water from the education pond behind Lamb's Inn. To calibrate, the meter was adjusted with a screw driver so that it read a moisture rating of "10: saturated" when the probe was completely immersed in water. Precipitation was recorded on the datasheet for the 24 hours prior to monitoring (as reported by the Environment Canada Weather Office for the Region of Waterloo Airport). And in Indian Woods, the pond depth was recorded using the metre-stick which was previously planted in the ephemeral pond. The first 5cm of the stick are submerged in mud, so 5cm were subtracted from the measured depth to get the true water level.

At the beginning of each monitoring session, Beaufort's wind and sky codes (Appendix D, Tables D.1 and D.2) were recorded for the entire monitoring plot. Sample data sheets are available in APPENDIX D: Tables D.2 and D.3) and on the ***rare*** server. The start time of the monitoring session was recorded and each board was then visited in sequential order. Soil temperature (ºC) (Ashcroft® Thermometers, USA) and moisture measurements were collected for each ACO by inserting the probes of the soil thermometer and the soil moisture meter to a depth of 10 cm (marked with white tape on the probes) in the soil beside the board. The ACO board was then gently turned over and any salamanders underneath were collected by observers wearing nitrile gloves and placed into a plastic container with a sponge dampened with pond water (from the education pond). Each salamander was identified to species (colour phase was indicated for Eastern Red-backed salamander), and any noticeable physical defects were recorded. A list of common and scientific names for all salamanders observed at ***rare***, and their abbreviated codes is available in APPENDIX A: Table A.3. Snout-vent length (SVL) and vent-tail lengths were recorded for each individual using a set of digital calipers (TuffGrade IDI, Commercial Solutions, Alberta, Canada). To ensure that measurements were recorded accurately from the vent, individuals were measured through a clear lid – either raised above the head to see the ventral side of the salamander, or pressed up against sponges in the base of the container to secure the salamander and view the ventral side. Salamanders were weighed on a digital scale (Equal Digital Scale, model #23-D-50, capacity 50g, measures to 0.01g) and then released next to the board. Disturbances under or near the boards (e.g. snakes, ant nests, turkey scratches, or an ACO moved from its proper location) were also recorded. A complete list of required equipment is available in APPENDIX C: List C.2.

Weather variables such as average wind speed (taken as the average after ten seconds), air temperature (degrees Celsius) and percent relative humidity were collected for a subsample of the ACOs called weather stations. Tables 3.1 and 3.2 provide a list of the boards represented by the measurements at the weather stations for Indian Woods and the Hogsback, respectively

Soil samples for pH testing were collected on November 23, 2011 for both Indian Woods and the Hogsback. Three samples were collected from a depth of 10 cm from the ground adjacent to the ACO weather stations. Equipment needed for soil pH testing is listed in APPENDIX C: List C.3. The soil samples were refrigerated at 4ºC for two months (while waiting for pH kit to arrive). Samples were placed in individual open deli containers and left to dry for one week prior to pH testing. A Hellige-Truog Soil pH Tester kit (Forestry Suppliers Inc., Jackson, MS, USA) was used to determine the pH for each sample. The pHs for the three samples from the same ACO were averaged to give a mean weather station board pH.

Table 3.1 List of weather stations in Indian Woods and the artificial cover objects which they represent.

Weather Station	Associated ACOs
3	1 2 3 4
7	5 6 7 8
11	9 10 11 12
15	13 14 15 16
18	17 18 19 20
23	21 22 23 24
27	25 26 27 28
31	29 30 31 32

Table 3.2 List of weather stations in the Hogsback and the artificial cover objects which they represent.

Weather Station	Associated ACOs
2	1 2 3 4 5
7	6 7 8 9 10
12	11 12 13 14 15
17	16 17 18 19 20

3.2.3 Data Analysis

Statistical analyses were performed with Excel (Microsoft Office 2010) or STATA 10.

Salamander Abundance

Each salamander monitoring plot (Indian Woods/Hogsback) was interpreted as representing a unique population, and each ACO within that plot was interpreted as representing a sample of that population. A handful of boards in Indian Woods were missing in 2006 and 2008, meaning that fewer samples were taken at each monitoring season during those years. To enable comparison between years with variable trap-effort, abundance was transformed into “catch per unit effort” (CPUE) for each monitoring session, as is commonly used in fisheries science (Krebs 2001). To calculate the CPUE, the total salamander count for each monitoring day was divided by the number of ACOs in the plot to get the mean weekly catch per ACO. Only Eastern Red-backed salamanders were included in the abundance comparison calculations.

As only five weeks of monitoring data were collected for both Indian Woods in 2006 and the Hogsback in 2008, only these five weeks (the last week of September to the last week of October) were compared between years. A t-test (paired by week) was used to determine whether any two years were significantly different in salamander abundance (measured as mean weekly catch per ACO). Because multiple comparisons were made, the p-values were corrected with a sequential Bonferroni adjustment (Rice 1989, $\alpha = 0.05$).

Relationships between Salamander Abundance and Environmental Parameters

Data for a large number of environmental parameters were collected during monitoring, including soil variables like soil moisture, soil temperature and soil pH and climatic variables like air temperature, wind speed, and relative humidity. While we would ideally test for relationships between salamander abundance and each of these variables, the dataset is currently too small to provide the necessary degrees of freedom, and many of these variables would be highly correlated anyway. As such, a subset of variables was selected based upon our knowledge of salamander biology. Observations with missing data points were not included in this regression analysis (All of the Indian Woods 2006 data and the first week of 2008 as they were missing soil pH and temperature values).

Plethodontid salamanders live in the soil (Conant and Collins 1998), and soil parameters were therefore included as these are assumed to be the environmental conditions most relevant to salamander occurrence under the boards. Mean weekly soil temperature, mean weekly soil moisture and mean yearly soil pH were calculated for each plot by taking the average of the ACO values. These parameters were then included in a multiple linear regression on the mean weekly catch per ACO (CPUE) of the plot. Monitoring week was included in the regression, as ACO use by the salamanders is predicted to change across the season with changes in behaviour (i.e. mating, egg-guarding, hunting, and departure for hibernacula). Finally, the year was also included in the analysis to account for any yearly environmental changes beyond the soil parameters. By including each of these variables in the regression, we will be able to determine their relationship with salamander abundance independent of the effects of the other variables that are included in the regression. Only Eastern Red-backed salamanders were included in this analysis. All weeks of monitoring data were included, except those with missing data points, which were: all of 2006 monitoring in Indian Woods and the first week in 2008 of monitoring in Indian Woods.

Eastern Red-backed Salamander Size

Two measurements were collected for salamander size: SVL and vent-tail length. As Eastern Red-backed salamanders are capable of tail autonomy[7] (Wise and Jaeger 1998), only SVL was used to indicate salamander size. Salamander SVL is known to a have a significant positive correlation with Eastern Red-backed salamander age (for salamanders four years old or younger, LeClair *et* al. 2006), which allows us to estimate the approximate age structure of the population under the boards using size-class distribution. To test for differences in mean salamander SVL between years, non-parametric independent 2-group Mann-Whitney U tests were used because many of the SVL distributions were non-normal. Because multiple comparisons were made, the *p*-values were corrected with a sequential Bonferroni adjustment

3.3 Results

3.3.1 Salamander Abundance

Figure 3.1 shows the weekly count of plethodontid salamanders for each monitoring year in Indian Woods. There was a significant difference in salamander abundance between 2008 and 2010 (p=0.0074) and between 2008 and 2011 (p=0.0029). The mean catch per ACO in 2008 was nearly twice that of 2010, and three times that of 2011 (Table 3.3). Figure 3.3 shows the number of each individuals of each species trapped in Indian Woods throughout the monitoring years.

Figure 3.2 shows the weekly count of plethodontid salamanders for each monitoring year in the Hogsback. There was a significant difference in salamander abundance between 2008 and 2009 (p=0.0011). The mean catch per ACO in 2009 was nearly twice that of 2008 (Table 3.4). After sequential Bonferroni correction for multiple comparisons, no significance was detected between weekly salamander counts in 2011 and weekly salamander counts from

[7] Dropping their tails.

previous monitoring years. Figure 3.4 shows the number of each individuals of each species trapped in the Hogsback throughout the monitoring years.

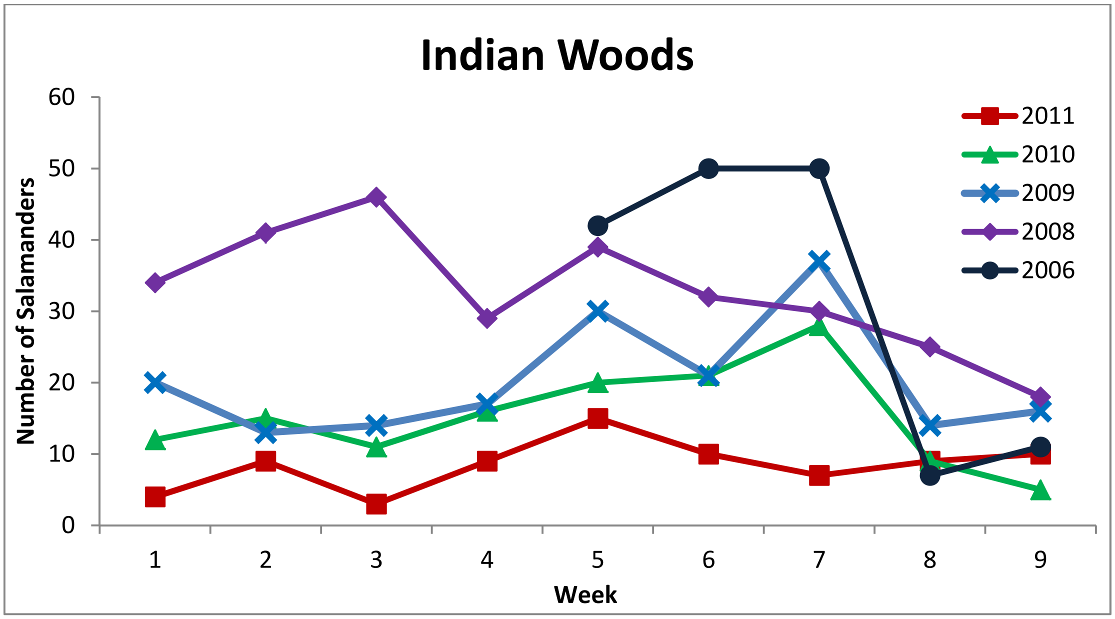

Figure 3.1 Total weekly salamander counts for each monitoring year in the Indian Woods monitoring plot.

Table 3.3 Mean weekly salamander catch per unit (unit = one artificial cover object) and standard error for each monitoring year in Indian Woods. Statistically significant differences between years are indicated with superscript letters.

Year	2006	2008	2009	2010	2011
Mean CPUE	1.103	0.993[ab]	0.738	0.519[a]	0.319[b]
S.E.	0.328	0.121	0.136	0.131	0.041

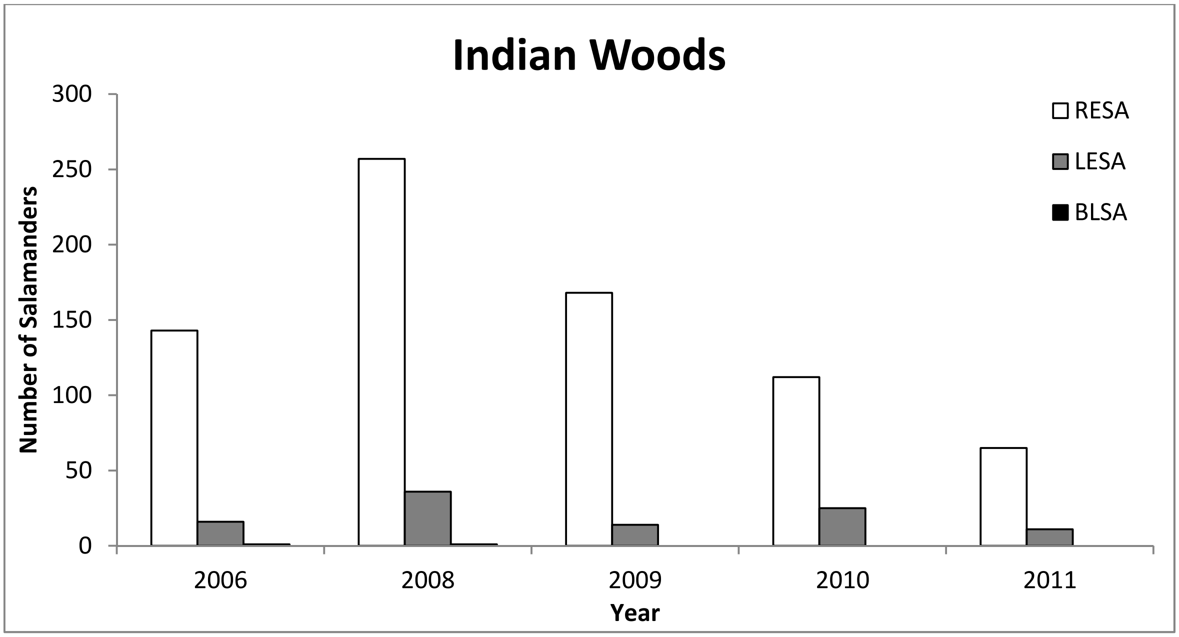

Figure 3.3 Salamander abundance by species for each monitoring year in Indian Woods. Species codes: BLSA = Blue-spotted salamander (*Ambyostoma laterale*), LESA = Lead-backed phase of Eastern Red-backed Salamander (*Plethodon cinereus*), and RESA = Red-backed phase of Eastern Red-backed salamander.

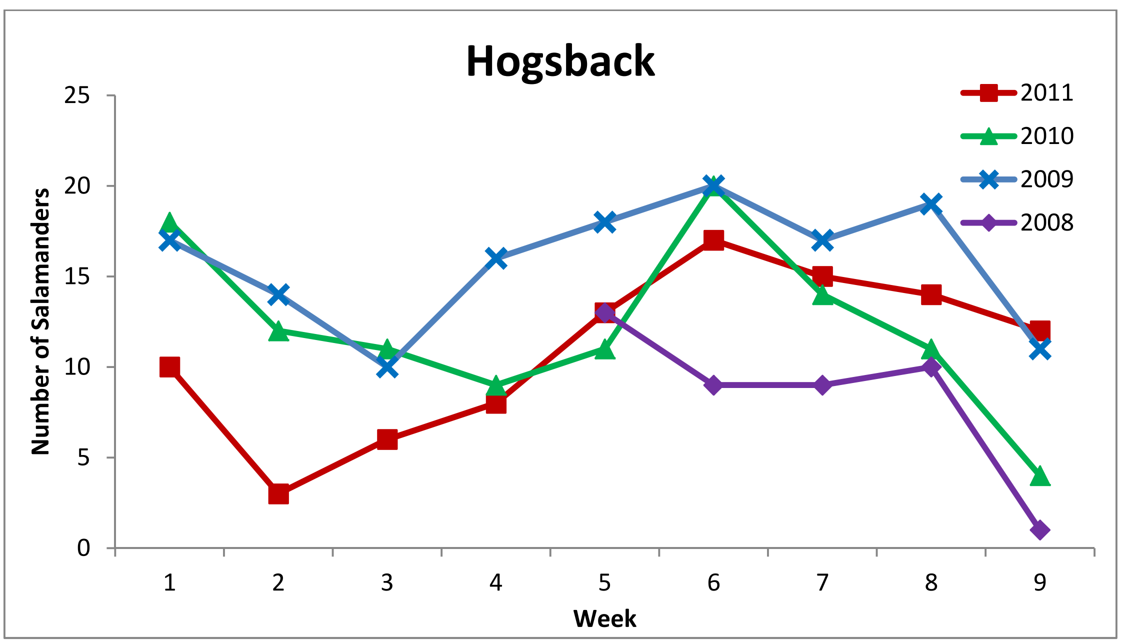

Figure 3.2 Total weekly salamander counts for each monitoring year in the Hogsback monitoring plot.

Table 3.4 Mean weekly salamander catch per unit (unit = one artificial cover object) and standard error for each monitoring year in the Hogsback. Statistically significant differences between years are indicated with superscript letters.

Year	2008	2009	2010	2011
Mean CPUE	0.420[a]	0.850[a]	0.600	0.710
S.E.	0.099	0.079	0.129	0.043

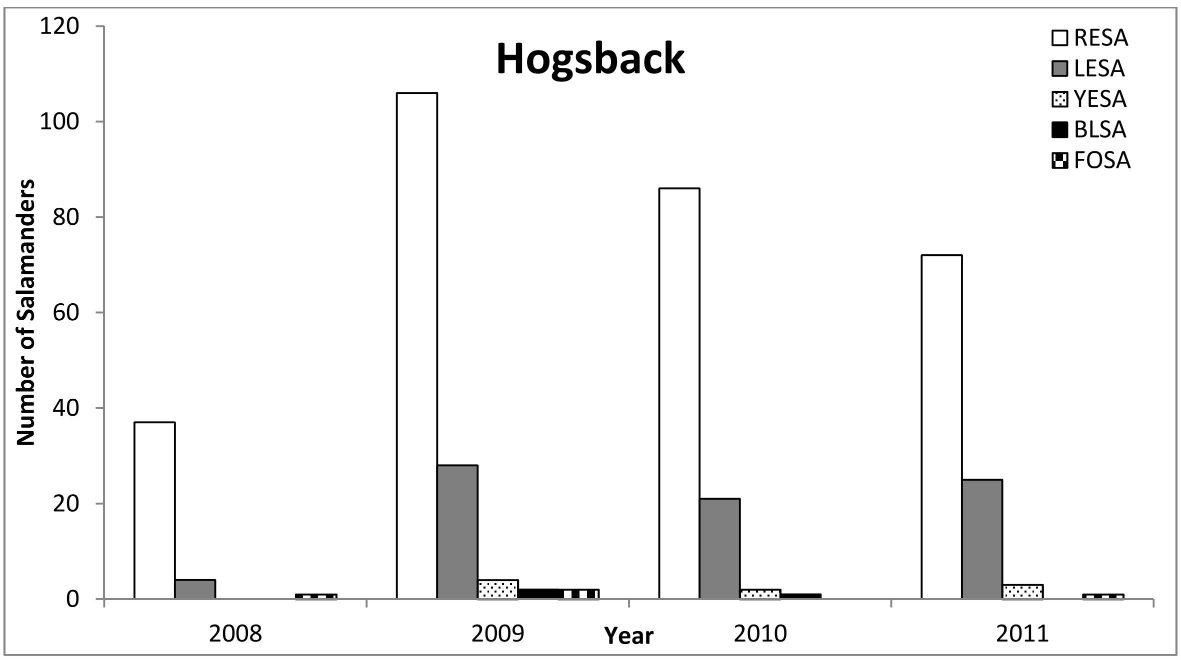

Figure 3.4 Salamander abundance by species for each monitoring year in the Hogsback. Species codes: BLSA = Blue-spotted salamander (*Ambyostoma laterale*), FOSA = Four-toed salamander (*Hemidactylium scutatum*), YESA = Spotted salamander (*Ambystoma maculatum*), LESA = Lead-backed phase of Eastern Red-backed Salamander (*Plethodon cinereus*), and RESA = Red-backed phase of Eastern Red-backed salamander.

3.3.2 Salamander Abundance and Environmental Parameters

Table 3.5 shows the selection coefficients (β), standard error, and *p* value generated from the multiple linear regression of soil and temporal variables on salamander abundance (measured as mean weekly catch per ACO) at the Indian Woods monitoring plot. Both year and soil moisture variables had significant effects on the mean abundance of Eastern Red-backed salamander abundance.

Table 3.6 shows the selection coefficients (β), standard error, and *p* value generated from the multiple linear regression of soil and temporal variables on salamander abundance (measured as mean weekly catch per ACO) at the Hogsback monitoring plot. The variables year, soil moisture, and soil pH were found to have a significant positive effect on weekly CPUE in the Hogsback.

Table 3.5 Selection coefficients for the multiple linear regression of temporal and soil parameters on weekly salamander abundance (measured as weekly catch per artificial cover object) for Indian Woods.

	β	**S.E.**	***p***
Year	-0.163	0.049	0.002*
Week	-0.025	0.027	0.363
Mean soil temperature	-0.005	0.017	0.773
Mean soil moisture	0.12	0.039	0.005*
Mean soil pH	1.31	0.720	0.079

Table 3.6 Selection coefficients for the multiple linear regression of temporal and soil parameters on weekly salamander abundance (measured as weekly catch per artificial cover object) for the Hogsback.

	β	**S.E.**	***p***
Year	0.325	0.117	0.010*
Week	-0.044	0.031	0.167
Mean soil temperature	-0.002	0.023	0.937
Mean soil moisture	0.132	0.050	0.015*
Mean soil pH	0.794	0.286	0.010*

3.3.3 Eastern Red-backed Salamander Size

Figure 3.5 shows the SVL size class distributions for Eastern Red-backed salamanders for each of the monitoring years in Indian Woods. Statistically significant differences between mean plethodontid salamander SVL during different monitoring years can be found in Table 3.7. For the 2011 monitoring season in Indian Woods, the mean SVL of plethodontid salamanders was significantly different from the 2010 mean SVL (p<0.001); the mean SVL of plethodontid salamanders in 2010 was over 2.0mm greater than in 2011. The mean SVL in 2010 was also significantly greater than both the mean SVLs in 2006 (p<0.001) and 2008 (p<0.001). In 2009, mean plethodontid salamander SVL was significantly greater than mean SVL in 2006 (p<0.001).

Figure 3.6 shows the SVL size class distribution for Eastern Red-backed salamanders for each of the monitoring years in the Hogsback. We detected no significant differences in mean SVL between years in the Hogsback monitoring plot (Table 3.8).

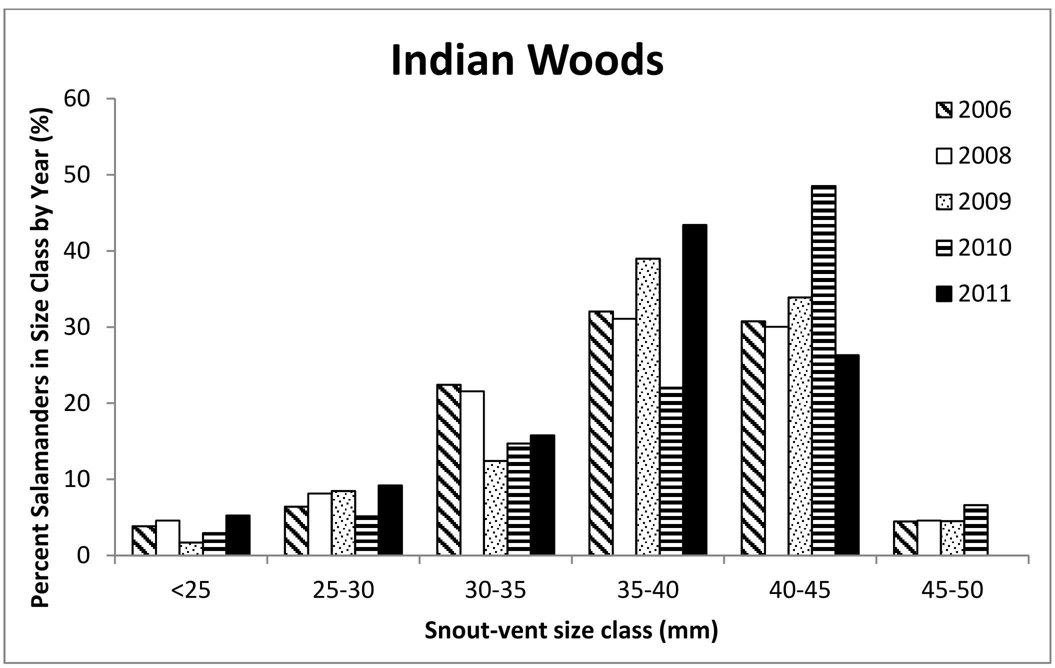

Figure 3.5 Percent of Eastern Red-backed salamanders in each snout-vent size class in Indian Woods for each monitoring year.

Table 3.7 Mean snout-vent length (SVL) (mm) and standard error (S.E) of Eastern Red-backed salamanders during four monitoring years in Indian Woods. Statistically significant differences between years are indicated with superscript letters.

year	2006	2008	2009	2010	2011
Mean SVL	35.827^{ab}	36.466^{c}	37.830^{a}	38.486^{bcd}	36.190^{d}
S.E.	0.492	0.382	0.415	0.519	0.685

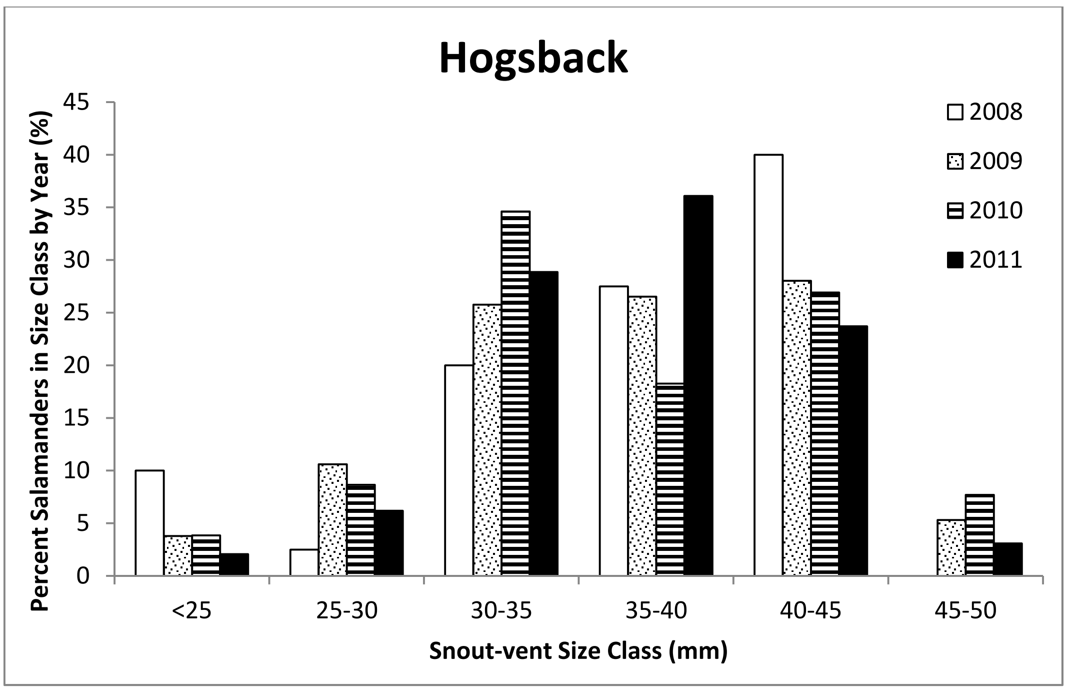

Figure 3.6 Percent of Eastern Red-backed salamanders in each snout-vent size class in the Hogsback for each monitoring year.

Table 3.8 Mean snout-vent length (SVL) (mm) and standard error (S.E) of Eastern Red-backed salamanders during four monitoring years in the Hogsback. Statistically significant differences between years are indicated with superscript letters.

year	2008	2009	2010	2011
Mean SVL	36.24	36.23	36.13	37.39
S.E.	1.106	0.582	0.631	0.577

3.4 Discussion

3.4.1 Salamander Abundance

The primary objective of plethodontid salamander monitoring at ***rare*** is to detect changes in the salamander populations, which may in turn indicate changes in the forest ecosystem (Zorn *et* al. 2004). We are most interested in exploring whether salamander abundance in the two forest monitoring plots is changing significantly over time. In the EMAN protocol, Zorn *et* al. (2004) suggest setting the monitoring thresholds at "a statistically significant change in plethodontid counts at plot level over five or more years". This year, 2011, marked the 5th monitoring year in the Indian Woods forest (monitoring began in 2006, was not pursued in 2007, then continued yearly from 2008 to present). In 2011, the Hogsback forest marked its 4th year of plethodontid salamander monitoring. Monitoring the plethodontid salamander population at ***rare*** began immediately after the placement of ACOs in both Indian Woods and the Hogsback; whereas Zorn *et* al. (2004) suggest that the ACO boards weather in situ for a winter prior to monitoring because the disturbance of plot establishment may skew abundance estimates. All data surrounding salamander abundance and diversity is of great value to ***rare***; while information gathered on salamander populations in the inaugural years (2006 in the Indian Woods and 2008 in the Hogsback) contributes to our knowledge of the property, it does not contribute to EMAN protocol for testing monitoring thresholds. Therefore, following the EMAN protocol, we will not be able to test whether the five year monitoring threshold has been surpassed until 2012 in Indian Woods and 2013 in the Hogsback. We can, however, compare the yearly salamander abundance data collected to date.

In Indian Woods, mean weekly salamander abundance (measured as weekly catch per ACO) has declined every year since the first year that monitoring was implemented (Table

3.3), with a significant difference (decline) detected between 2008 and 2010, and 2008 and 2011. These findings dispute the prediction that the first year of monitoring (2006) would have the lowest salamander abundance due to the disruptions caused by plot establishment and the time lag for the salamanders to begin using the ACO boards. This may suggest that competition for natural cover objects was a factor that influenced the weekly salamander abundance in 2006. The trend of declining abundance in the plethodontid salamander population in Indian Woods is concerning. However, variation observed in mean weekly salamander abundance from year to year is high. Following the 2012 monitoring season and the subsequent analysis of EMAN's suggested five-year data minimum, ***rare*** will have a better understanding of the significance of the variation in the salamander population in the Indian Woods.

The pattern of plethodontid salamander abundance in the Hogsback did not follow the same yearly trend in salamander decline as did Indian Woods. The mean weekly Eastern Red-backed salamander catch per ACO was highest in 2009 (Table 3.4), which varied significantly (greater) than that of 2008, the year that the plot was established. Both 2010 and 2011 saw mean weekly trends in abundance which fell between the 2008 and 2009 values. The mean weekly abundance observed in 2006 (the first year of monitoring) supports Zorn et al. (2004)'s prediction that salamanders may need a season to acclimate to newly placed ACOs.

Indian Woods and the Hogsback forest stands are separated by as little as 600m of productive farm land. The variation in trends in abundance could indicate that the factors influencing Eastern Red-backed salamander populations are highly localized. In fact, Welsh and Droege (2001) suggest that plethodontid salamanders are ideal for monitoring forest health because of their elevated sensitivity to the within-stand microclimatic conditions of the forest floor (like soil moisture and temperature) created by fine-scale characteristics of the stand such as canopy layering and gaps, soil type, and the quantity and type of downed woody debris and leaf litter.

3.4.2 Species Diversity

While the EMAN salamander protocol was designed for monitoring the Plethodontidae family of salamanders (Zorn *et* al. 2004), a variety of salamander species have been observed over the monitoring years. During the 2011 monitoring season, the Eastern Red-backed salamander was the only species detected in Indian Woods, with the red-backed phase making up 85.5% of the population, and the lead-backed 14.5%. Moreno (1989) found that the different phases of the Eastern Red-backed salamander appeared to experience differential predation pressures as indicated by more frequent tail autonomy in the lead-backed phase. This observation was further supported by Venesky and Anthony (2007) who showed in an experimental setting that the lead-backed phase was more likely to flee from predators and were generally more mobile than the red-backed phase. This indicates that the lower abundance of the lead-backed phase of the Eastern-Red-backed salamander observed in both

Indian Woods and the Hogsback could be a result of preferential predation on the darker phase, and in turn, positive genetic selection of the more abundant red-backed phase. Interestingly, a more general observation is that the proportion of red-backed phase salamanders tends to be proportionally higher than lead-backed phase salamanders in higher altitudes and latitudes (Harding 1997).

Salamander species diversity was particularly low in Indian Woods, where there have only been two non-Eastern Red-backed salamander observations over the five monitoring years (Blue-spotted salamanders recorded in 2006 and 2008, Figure 3.3). However, Blue-spotted salamanders are more easily found in the spring (J. Paterson - Ontario Nature, personal communication, February 6, 2012; DNR 2012); therefore, it would be to ***rare***'s benefit to monitor salamanders in both the spring and fall to capture true species diversity in the forest stands.

The Hogsback monitoring plot was similarly dominated by Eastern Red-backed salamanders (red-backed phase: 71.3%, lead-backed phase: 24.8%), although the diversity of other salamander species observed was greater than that of Indian Woods (Figure 3.4). Four-toed salamanders were observed in 2008, 2009, and 2011. This species belongs to the same family as the Eastern Red-backed salamander (lungless salamanders: Plethodontidae) and is usually associated with sphagnum moss or boggy woodlands (Conant and Collins 1998), the latter of which is found in the Hogsback forest. Mole salamanders belonging to the family Ambystomatidae have been observed in the Hogsback, with both Blue-spotted salamanders observed in both 2009 and 2010, and Spotted salamanders observed in 2009, 2010, and 2011. This may suggest that the ACOs are suitable habitat for mole salamanders as well as plethodontid salamanders, and that some salamanders may exhibit board fidelity from year to year. There are multiple accounts of Spotted salamanders in the Hogsback, however, it is possible that these observations were of one individual (of a consistent weight and size) who was observed under the same ACO (#11) during multiple times during 2009, 2010, and 2011 monitoring. Researchers at Algonquin Provincial Park have been developing a software application that will allow for identification of individual Spotted salamanders based on pattern recognition of spots (P. Moldowan, personal communication, February 9, 2012); ***rare*** would benefit from this technology in the future to aid in quantifying the Spotted salamander populations on the property.

3.4.3 Salamander Abundance and Environmental Parameters

For plethodontid salamanders in Indian Woods, our multiple linear regression detected a significant positive association between weekly salamander abundance (catch per ACO) and soil moisture, and a significant negative association between salamander abundance and year (Table 3.5). We did not detect any significant associations between weekly salamander abundance and the other independent variables, week, mean soil temperature, and mean soil pH. In the Hogsback forest, we detected a significant positive association between weekly salamander abundance and year, mean soil moisture, and mean soil pH (Table 3.6).

The temporal variables "Year" and "Week" were included in the analysis to determine if there were any temporal effects beyond the soil parameters that may influence salamander abundance. Interestingly, year had a significant negative effect on mean weekly salamander abundance in Indian Woods, and a positive effect on salamander abundance in the Hogsback. plethodontid salamanders typically have high population stability (Welsh and Droege 2001; Zorn *et* al. 2004), but it is possible that some form of population cycling could account for the observed effect of year on abundance. Additionally, Eastern Red-backed salamanders are aggressive predators of soil invertebrates (Casper 2011), and are capable of significantly reducing soil detrivore numbers (Wyman 1998), which suggests that predator-prey cycling could occur – which would support the significance of year on salamander abundance.

Plethodontid salamanders require moist skin to facilitate gas exchange across their cutaneous membrane for respiration. To this extent, plethodontid salamanders are highly dependent on receiving moisture from their micro-environments. Water loss influences the way in which plethodontids forage and use energy. It stands to reason that plethodontids must either remain in moist microhabitats, or drastically limit their time in dry microhabitats (Feder 1983). We found a significant correlation between soil moisture and mean weekly salamander catch per ACO in both Indian Woods (p=0.005) and the Hogsback (p=0.015) monitoring plots. Eastern Red-backed salamanders are terrestrial and spend the majority of their lives underground or under a variety of cover objects – oftentimes in contact with soil. Heatwole (1962) estimated that Eastern Red-backed salamanders cannot tolerate soil with interstitial humidity less than 85%. Soil moisture is dependent on several factors: size of soil particles, compactness, organic and mineral content. The variation in soil moisture in the Indian Woods and Hogsback monitoring plots could be affected by the variety of soils in the plots.

Salamander abundance/presence and associated soil pH has been well studied in the Eastern Red-backed salamander; Wyman and Hawksley-Lescault (1987) determined that salamanders would avoid soil of pH less than 3.7, and Heatwole (1962) reported that their preferred range of soil pH was 6.0 to 6.8. In the Hogsback monitoring plot, we found a significant association between mean weekly salamander abundance and soil pH. Soil pH values ranged from 6.5 to 7.5. Wyman and Hawksley-Lescault (1987) suggest that salamanders may serve as "canaries in the coal mine" should any significant changes occur in the soil pH of the forest, like, for example, soil acidification resulting from acid rain. In an experimental study manipulating soil pH, soil moisture and light intensity, Sugalski and Claussen (1997) found that *Plethodon cinereus* distribution was most affected by pH, even though inadequate soil moisture can be immediately lethal to the salamanders. It is interesting to note that in 2011 Indian Woods soil had the same average yearly pH as the Hogsback soil, although no significant associations were detected between salamander abundance in Indian Woods and soil pH (p=0.079); there is however a trend towards correlation which may become stronger with the accumulation of data over the years.

3.4.4 Eastern Red-backed Salamander Size

In both Indian Woods and the Hogsback, the SVL class category that had the greatest proportion of Eastern Red-backed salamanders in 2011 was 35 mm – 40 mm (Figure 3.5 and Figure 3.6). Salamanders measured in the Hogsback had a slightly higher mean SVL (37.39 mm) than salamanders in Indian Woods (36.19 mm). Using skeletochronology[8], LeClair *et* al. (2006) calculated the mean SVLs of Eastern Red-backed salamanders aged 0 (neonates) to seven years in Quebec, and found a significant positive association between salamander size and age. Salamanders growth starts to slow around four years of age, and the strength of the association between size and age becomes weak after that point (LeClair et al. 2006). Assuming that the Eastern Red-backed salamanders at ***rare*** have similar growth rates to those in Quebec, then the large majority of salamanders found under the ACOs in Indian Woods and the Hogsback would be adults aged three years and older.

Individuals with SVLs less than 15 mm are likely neonates (LeClair *et* al. 2006; Zorn *et* al. (2004) classify individuals with S-V lengths less than 25 mm as juveniles), an age demographic that appears to be underrepresented by ACO sampling. In Indian Woods, individuals with SVLs <25 mm make up 5% of the sampled population. In the Hogsback, individuals with SVLs <25 mm make up 2% of the sampled population. Marsh and Goicochea (2003) propose a number of possible reasons for low proportion of juveniles under ACOs compared to natural cover objects: 1. adults may be better dispersers and territory defenders, so they are able to reach and secure the new cover objects more quickly than juveniles; 2. larger salamanders may prefer the wider cover provided by the ACOs; 3. reproductive success may be lower under ACOs than natural cover objects and therefore there are fewer hatchlings and juveniles under the new boards. While these findings indicate that ACO sampling method does not provide a complete representation of all age demographics of the population of Eastern Red-backed salamanders in the ***rare*** forests, the data obtained from the monitoring is valuable for within-site, between-year comparisons.

In the Hogsback in 2011, we observed a trend towards an increase in mean SVLsince monitoring in 2010. The salamander monitoring years 2008-2010 were otherwise stable (Table 3.8). Parker (2003) detected a similar trend for salamander size increasing over the monitoring years at the Long Point World Biosphere Reserve. These findings could suggest that the same individual salamanders are returning to the boards each year, and we are detecting the increasing size of the co-hort. Interestingly, mean SVL of Eastern Red-backed salamanders in Indian Woods was found to be significantly lower than mean SVL in 2010 (Table 3.7). If the same salamanders are securing the same ACOs each year, this could indicate a shift in the population structure towards a younger group of salamanders. Alternatively, a mark-recapture study of Eastern Red-backed salamanders by Monti *et* al.

[8] Age estimation from growth rings of long bones

(2000) found both recapture rates and ACO fidelity to be low. Eastern Red-backed salamander trends could be further examined using non-invasive mark-recapture procedures.

4.0 Forest Canopy Tree Biodiversity Monitoring

4.1 Introduction

4.1.1 Forest Biodiversity Monitoring

Forests are critical to environmental health and stability. They house a significant amount of the world's biodiversity of flora and fauna, providing habitats for numerous ecosystems (Butt 2011). They are also an integral part of soil conversion, water cycling, and air quality mediation (Butt 2011). Globally, initiatives establishing policy and protocol related to the safeguarding of forests are a high priority. In southern Ontario, forests have experienced a great deal of change in the past 200 years. Prior to European settlement, southern Ontario was largely covered by a patchwork of deciduous and mixed hardwood forests (OMNR 1999). Due to the rapid development in southern Ontario and a change in land use, forest species have been removed and land cover has been significantly altered. What remains are forests that are highly fragmented and smaller in size than in previous years (Waldron 2003). These forests face significant pressures from both abiotic and biotic factors.

Establishing long term monitoring of biodiversity across a network of sites can aid in developing an improved understanding of baseline levels of variability and health in natural systems (Gardner 2011). Monitoring crown conditions and stem defects is essential in providing an early warning system to recognise changes in tree health of Canadian forests and urban areas (EMAN 2006). Records of cause and effect of tree damage will help to identify the cause of tree and forest decline. In addition to satisfying scientific inquiry, the baseline data collected from surveying forest biodiversity monitoring can also be used as an aid to conservation (Gardner 2011). Information on population or species decline can be used as a platform to launch conservation initiatives, and may influence management objectives when considering human-impact on forest tracts.

4.1.2 EMAN Forest Monitoring at *rare*

rare Charitable Research Reserve is a significant ecological landscape that harbours trees more than 240 years old and hosts a diversity of habitats that support rich biodiversity. The oldest trees can be found in ***rare***'s remnant old-growth forest on the property (Indian Woods), a Sugar Maple-American Beech dominated forest. In addition to the Indian Woods old-growth forest, ***rare*** boasts the Cliffs and Alvars forest, a mixed deciduous stand that was partially grazed by cattle within the last century, and the Hogsback, a relatively undisturbed mixed swamp forest. All of these forest ecosystems contribute invaluable services to the region by sequestering carbon dioxide and improving air and water quality (Führer 2000), as well as providing habitat to countless plants and animals that require mature forest interior (OMNR 1999).

These forests face diverse challenges in the landscape of Waterloo Region; ***rare*** is bordered by conventional farm fields, aggregate mining operations, subdivisions, and busy roads. Many of these neighbouring lands are scheduled for drastic changes and development within the next few years. By acquiring baseline records of conditions of the ***rare*** forests and continuing long-term monitoring, we may be able to track changes in the forest ecosystems, and use those changes develop an effective management plan to protect ***rare*** forest ecosystems.

The research questions that we hope to address with long-term forest canopy tree monitoring were identified at the establishment of the program (McCarter 2009):

1. What is the current state (biodiversity, composition, health) of ***rare***'s forests, and how to they compare to one another?
2. What are the long-term trends in tree mortality, recruitment and replacement taking place within the forests at ***rare***?
3. Is the ecosystem integrity of the forests being maintained or improved under ***rare*** management?
4. Is either the ecological health or integrity of ***rare*** forests being affected by on-site and nearby changes in land use (i.e. restoration, agriculture, residential development and aggregate extraction)?

4.2 Methods

4.2.1 Forest Plot Locations

Forest biodiversity monitoring plots are established in three forest stands on ***rare*** property. Each of these stands houses three monitoring plots, which together are used to describe their respective stands.

Cliffs and Alvars: is a mature Sugar Maple - American Beech dominated forest located on the north side of Blair Road, bordered by Cruickston Creek on the West, Newman Creek on the East and the Grand River to the North. The three plots in the Cliffs and Alvars forest are located approximately 50m north of the Grand Trunk Trail, arranged parallel to the trail (APPENDIX B: Figure B.2 and Table B.2). To access these plots, walk from the Slit Barn to the Grand Trunk Trail. Follow the trail to the East (right) until the forest opens up to the North, approximately 200m from the Slit Barn access trail. Follow the small seasonal trail past the large fallen trees - the plots are located to the left and right of this trail. They corners of the plots are clearly labelled with pigtails and orange/pink flagging tape.

Indian Woods: is a remnant old-growth forest located south of Blair road and North of Whistle Bare road on the west side of the property. The three forest plots in Indian Woods are oriented in a north-south line in the centre of the forest, approximately 100m east of the Grand Allée. The third plot can be accessed by turning east into the forest off the Grand Allée towards the salamander monitoring plot and continuing to the top of the hill overlooking the pond (see further directions in section 3.2.1). The second and first plots can then be found by heading north from the third plot (APPENDIX B: Figure B.2 and Table B.2). The plots are approximately 30m apart and the flagging tape on the corners of each plot should be visible from the adjacent plot.

The Hogsback: is located at the south-west corner of the property, bisected by Cruickston Creek and bordered by the Newman Drive subdivision to the west. The Hogsback is a mixed swamp forest with upland ridges dominated by White Pine, Red Maple, American Beech and Sugar Maple. The three forest biodiversity plots were established on these elevated ridges as the lower areas will likely be too swampy to access in wetter years. The second forest plot overlaps with the Hogsback salamander monitoring plot and can be reached by following the directions given in section 3.2.1. The first plot is found approximately 30m north of the second plot on the same elevated ridge, and the third plot is located 30m southwest of the second plot (and separated by a small boggy area) (APPENDIX B: Figure B.2 and Table B.2).

4.2.2 Monitoring Protocol

At each annual monitoring session the following variables should be recorded for each tree in the monitoring plot: diameter at breast height (DBH) (using Woven Fibre Glass Diameter Tape, Richter Measuring Tools, Commercial Solutions Inc., Alberta, Canada), tree height (using one of two clinometers: SUUNTO Co., Helsinki, Finland and/or HAGLÖF Sweden, Långsele, Sweden), and tree condition (first classified as either alive or dead and then as standing, leaning, fallen, broken, dead top). A list of equipment required to complete monitoring protocol is listed in Appendix C: List C.4. Sample data sheets are available both on the ***rare*** server and in Appendix D: Figures D.5 and D.6. Tree health was monitored by recording stem defects, crown class (indicates level of dominance or suppression in the canopy), crown rating (indicates percent of crown dieback), and any other health notes (e.g. leaf damage, animal scratching, woodpecker excavations). During each monitoring session, marginal trees should be checked to see if they have graduated into the 10cm DBH size class (minimum for inclusion). If so, they should be tagged in a manner consistent with their plot and measured into the plot using distance from two adjacent corners. In this plotting technique, one observer stands with their back to the tree, facing the nearest line of the plot. The line number was recorded, and using a hand-held fiberglass tape measure (Mastercraft©, Commercial Solutions, Alberta, Canada) the "A" distance was measured from the tree to the corner to the right-hand side of the observer facing the line, while the "B" distance was measured from the tree to the corner to the left hand side of the observer (Figure 4.1). Subsequently, these distances were plotted into BioMon (BioMon *for* Windows Suite Version 2), a biodiversity monitoring software package, to generate tree species maps for each forest plot (APPENDIX B: Figures B.3 through B.11).

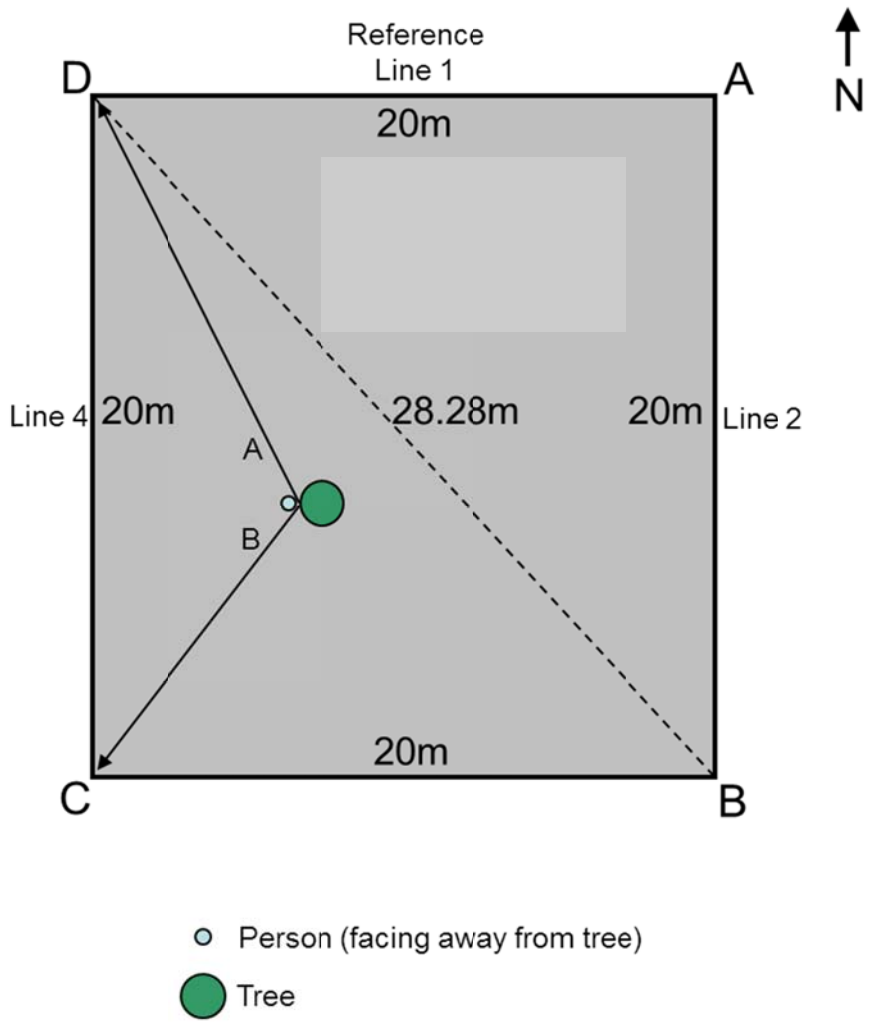

Figure 4.1 Diagram of an EMAN forest canopy tree biodiversity plot (from McCarter 2009). The A and B distances are used to map the position of the tree within the plot. The A distance is measured from the tree to the corner to the right of an observer standing facing the reference line. The B distance is measured to the corner on the left side of the observer.

4.2.3 Data Analysis

For each forest (Cliffs and Alvars, Indian Woods, Hogsback), summary statistics were calculated by combining the data for the three plots, which represent the same stand. For each forest stand, we recorded the number of species present, the number of trees present, the mean DBH (cm) for the stems included in the plots (i.e. stems >10cm DBH), and the total basal area (m^2ha^{-1}) for the three plots combined. Basal area was calculated as the cross sectional area of all tagged tree stems in the plot and was determined using the DBH data.

The Cliffs and Alvars and Indian Woods forest plots were established in 2009, making this year the third monitoring season. The Hogsback forest monitoring plots were established in 2010, which makes this the second year of monitoring. The stand summary statistics from all three years are presented side by side for comparison (two years for the Hogsback). To determine whether there was a significant increase in mean stand DBH over the years, a paired Wilcoxon signed rank test was used. This non-parametric analysis was used because the DBH distribution for both stands in both years were right skewed towards an abundance of smaller trees.

Species diversity, tree abundance, and size class (DBH) distribution were plotted and compared between the forest plots to give a general idea of differences in stand composition between the forests. The size class (DBH) distribution for each species was graphed for the three forests as an examination of recruitment and replacement patterns.

Mean stem DBH and standard deviation were calculated for all three forest stands. Species diversity and Evenness were calculated using the Shannon index. In previous years diversity was measured with the Brillouin Index, which correlates with the Shannon index (Magurran 2004). The Shannon index was used in 2011 because plots were considered random samples of the forest stands.

Additionally, for each forest, the relative density (Figure 4.2), relative frequency (Figure 4.3), relative dominance (Figure 4.4), and Importance Value (IV) (Figure 4.5) were calculated for each species (Roberts-Pichette and Gillespie 1999).

$$\textbf{Relative Density} = \frac{\text{\# of trees of species A in the sample}}{\text{Total \# of trees of all species in the sample}} \times 100$$

where trees with multiple stems are counted as single individuals

Figure 4.2 Formula for calculating the Relative Density of tree species in a forest stand.

$$\textbf{Relative Frequency} = \frac{\text{frequency of species A in the sample}}{\text{Total frequency of all species in the sample}} \times 100$$

$$\text{where frequency} = \frac{\text{\# of plots with species A}}{\text{Total \# of plots in stand}}$$

Figure 4.3 Formula for calculating the Relative Frequency of tree species in a forest stand.

$$\textbf{Relative Dominance} = \frac{\text{basal area of species A } (m^2)}{\text{Total basal area of all species } (m^2)} \times 100$$

Figure 4.4 Formula for calculating the Relative Dominance of tree species in a stand.

Species Importance Value = Relative Density + Relative Frequency + Relative Dominance

Figure 4.5 Formula for calculating the Species Importance Value of tree species in a stand.

4.3 Results

4.3.1 Tree Species Diversity

Figures 4.6, 4.7, and 4.8 show tree species diversity and abundance for the three monitoring plots used to quantify the biodiversity of the Cliffs and Alvars forest stand. A list of scientific and common names for tree species and shorthand codes can be found in Appendix A: List A.4. The Cliffs and Alvars forest monitoring plots contain seven species, and the stand is largely co-dominated by Sugar Maple and American Beech. The Shannon index for the Cliffs and Alvars forest stand is 1.47 and the Evenness index of 0.75 (Table 4.1).

APPENDIX B: Figures B.3 through B.5 show the distribution of tree species and proportional trunk size in each of the Cliffs and Alvars forest monitoring plots.

Figures 4.9, 4.10, and 4.11 show tree species diversity and abundance for the three monitoring plots used to quantify the biodiversity of the Indian Woods forest stand. The Indian Woods forest monitoring plots contain four species, and the stand is largely dominated by Sugar Maple. The Shannon index for the Indian Woods forest stand is 0.75 and the Evenness index is 0.54 (Table 4.2). APPENDIX B: Figures B.6 through B.8 show the distribution of tree species and proportional trunk size in each of the Indian Woods forest monitoring plots.

Figures 4.12, 4.13, and 4.14 show tree species diversity and abundance for the three monitoring plots used to quantify the biodiversity of the Hogsback forest stand. The Hogsback forest monitoring plots contain 10 species, and the stand is largely dominated by Sugar Maple. The Shannon index for the Hogsback forest stand is 2.08 and the Evenness index is 0.90 (Table 4.3). APPENDIX B: Figures B.9 through B.11 show the distribution of tree species and proportional trunk size in each of the Hogsback forest monitoring plots.

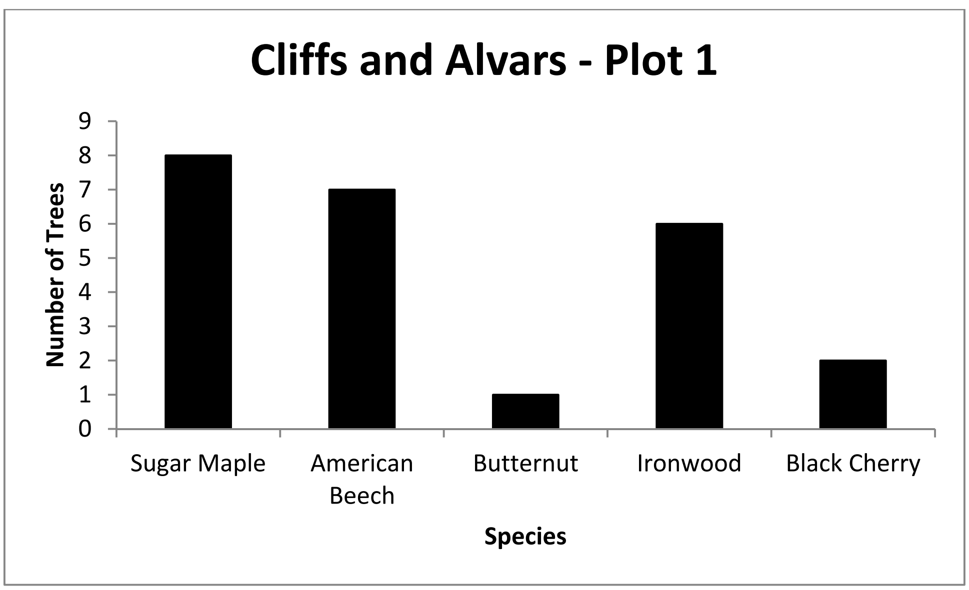

Figure 4.6 Tree species diversity and abundance for plot 1 in the Cliffs and Alvars forest stand.

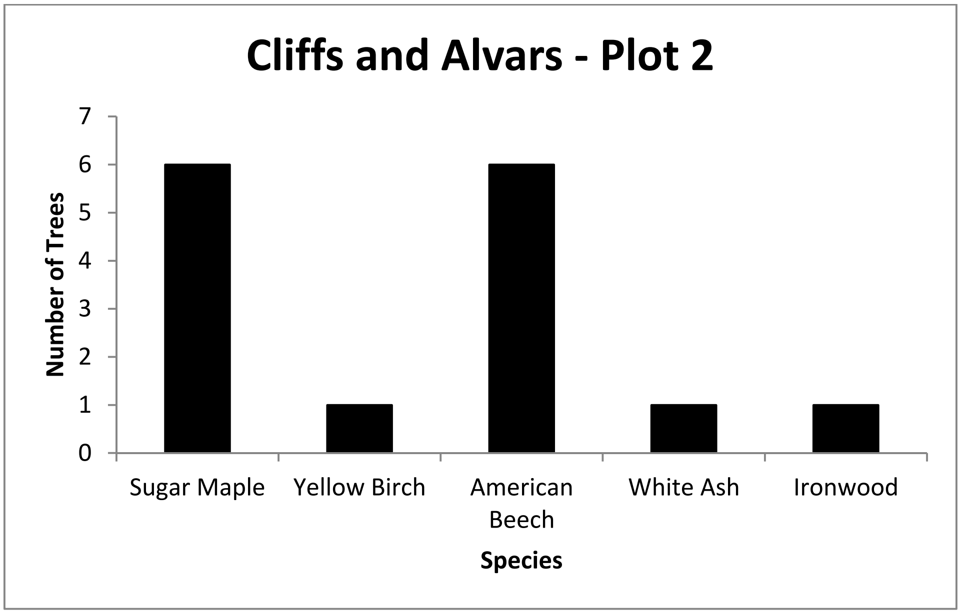

Figure 4.7 Tree species diversity and abundance for plot 2 in the Cliffs and Alvars forest stand.

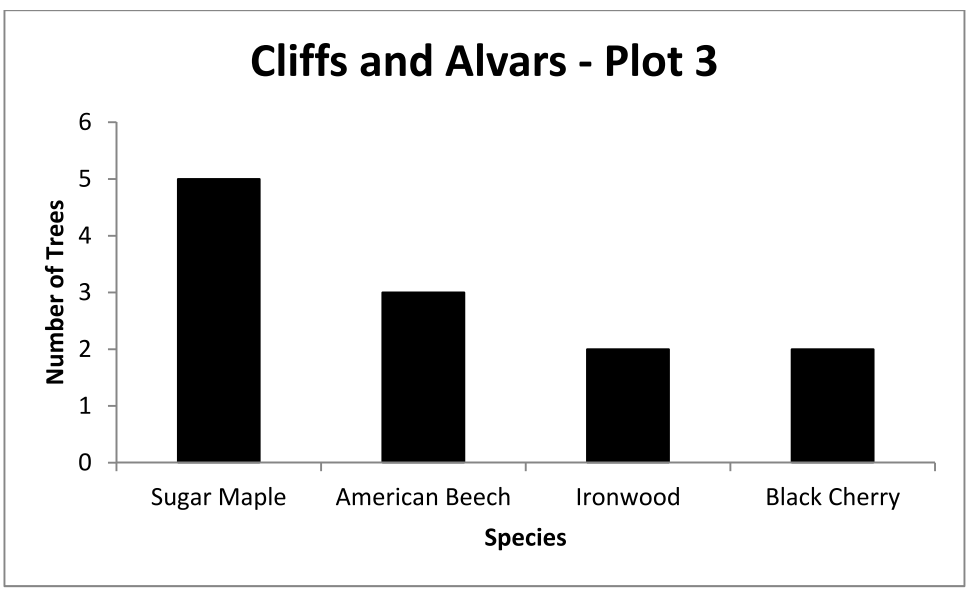

Figure 4.8 Tree species diversity and abundance for plot 3 in the Cliffs and Alvars forest stand.

Table 4.1 Summary statistics of stand characteristics for the Cliffs and Alvars forest stand in 2009, 2010, and 2011. The data from the three forest monitoring plots in Cliffs and Alvars were pooled to calculate the stand values.

Cliffs and Alvars	2009	2010	2011
Number of Live Stems[9]	49	52	51
Number of Dead Stems	7	7	9
Number of Species	7	7	7
Shannon Index	1.51	1.56	1.47
Evenness Index	0.84	0.80	0.75

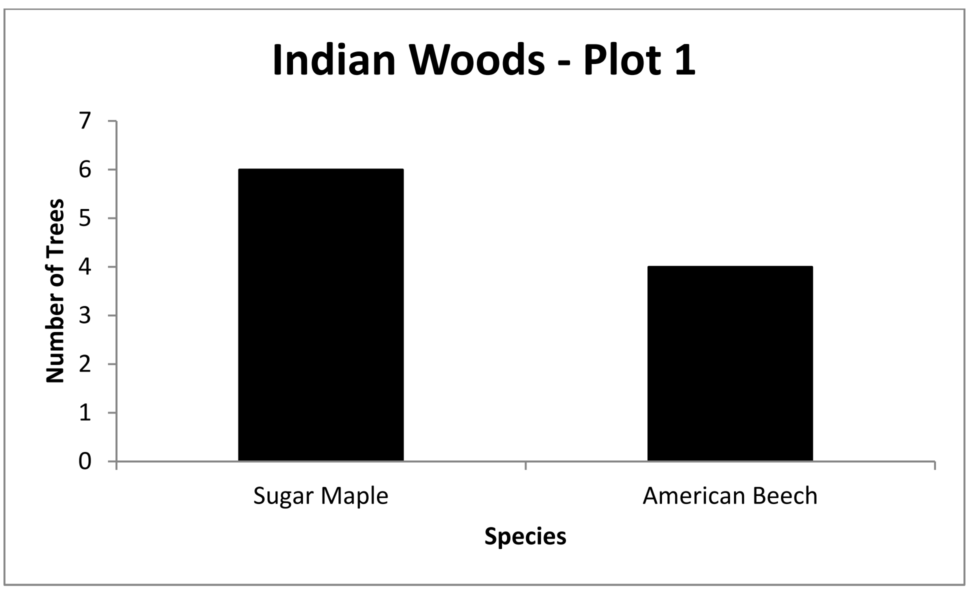

Figure 4.9 Tree species diversity and abundance for plot 1 in the Indian Woods forest stand.

[9] Where stems are tree trunks with DBH greater than 10.0 cm. One tree may have multiple stems (trunks).

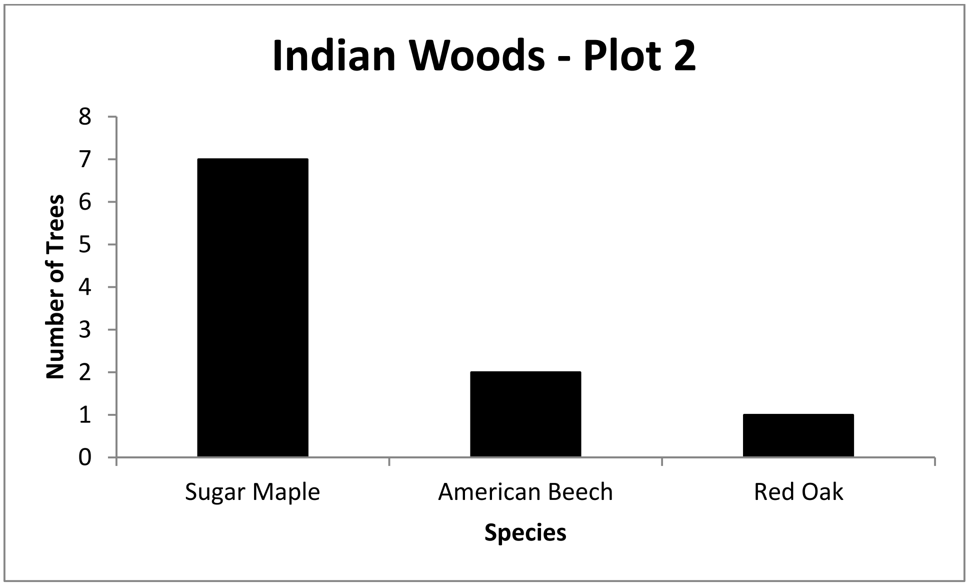

Figure 4.10 Tree species diversity and abundance for plot 2 in the Indian Woods forest stand.

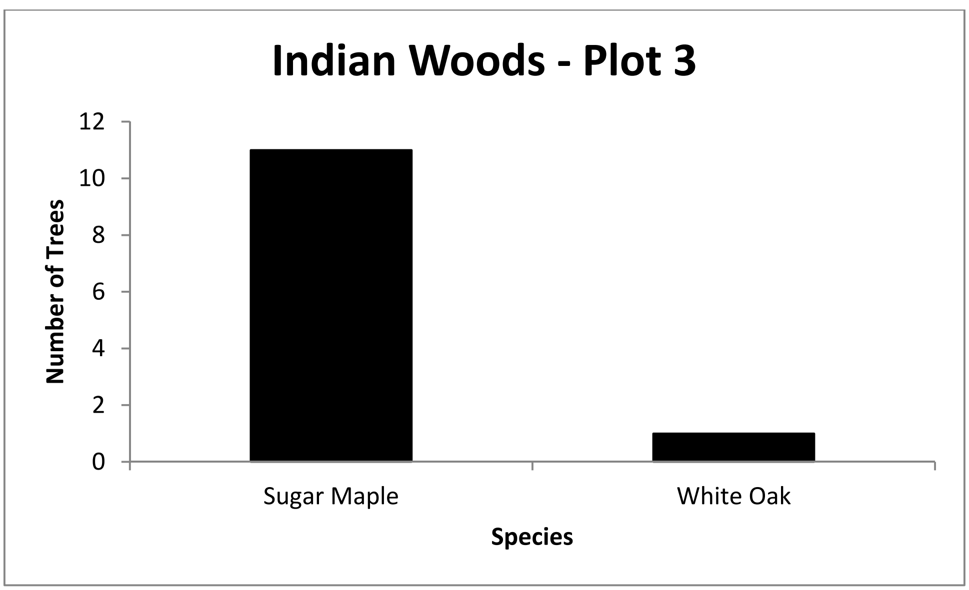

Figure 4.11 Tree species diversity and abundance for plot 3 in the Indian Woods forest stand.

Table 4.2 Summary statistics of stand characteristics for the Indian Woods forest stand in 2009, 2010, and 2011. The data from the three forest monitoring plots in Indian Woods were pooled to calculate the stand values.

Indian Woods	2009	2010	2011
Number of Live Stems	34	32	32
Number of Dead Stems	4	7	7
Number of Species	5	4	4
Shannon Index	0.80	0.75	0.75
Evenness Index	0.58	0.54	0.54

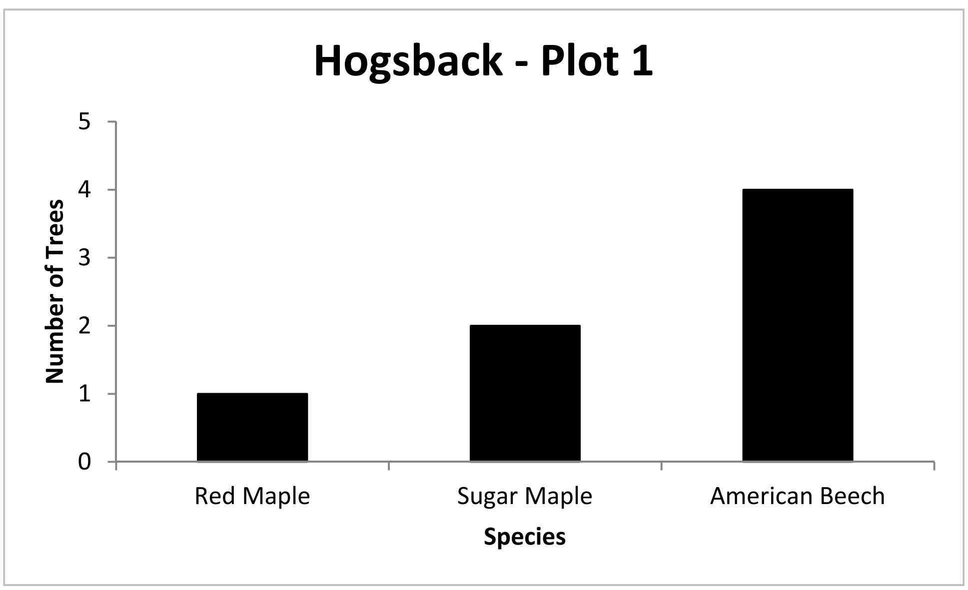

Figure 4.12 Tree species diversity and abundance for plot 1 in the Hogsback forest stand.

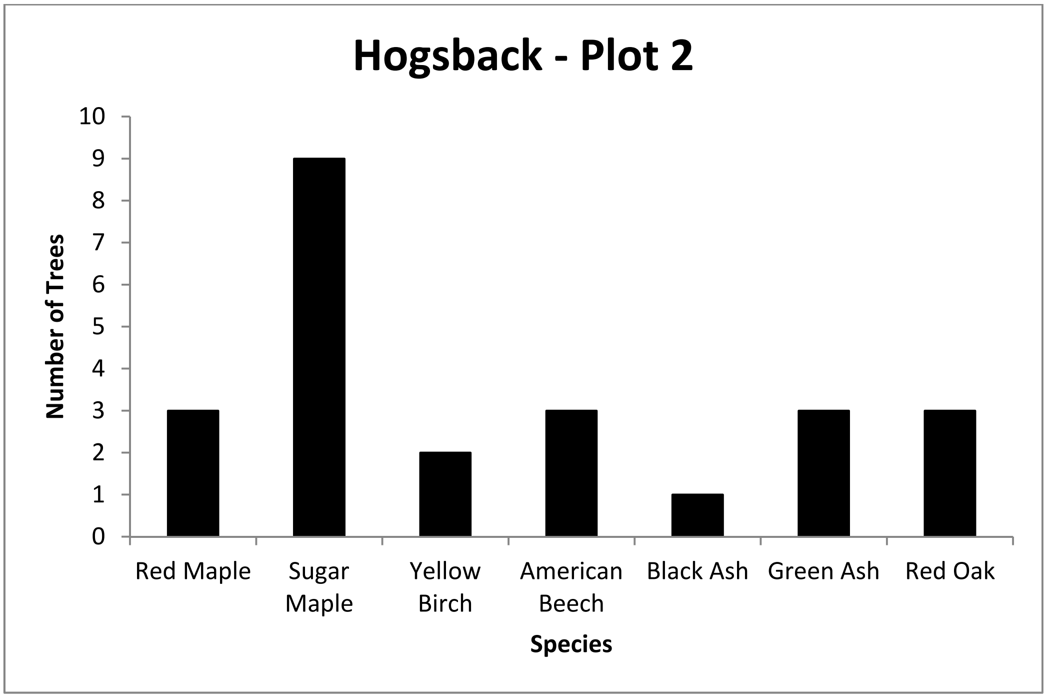

Figure 4.13 Tree species diversity and abundance for plot 2 in the Hogsback forest stand.

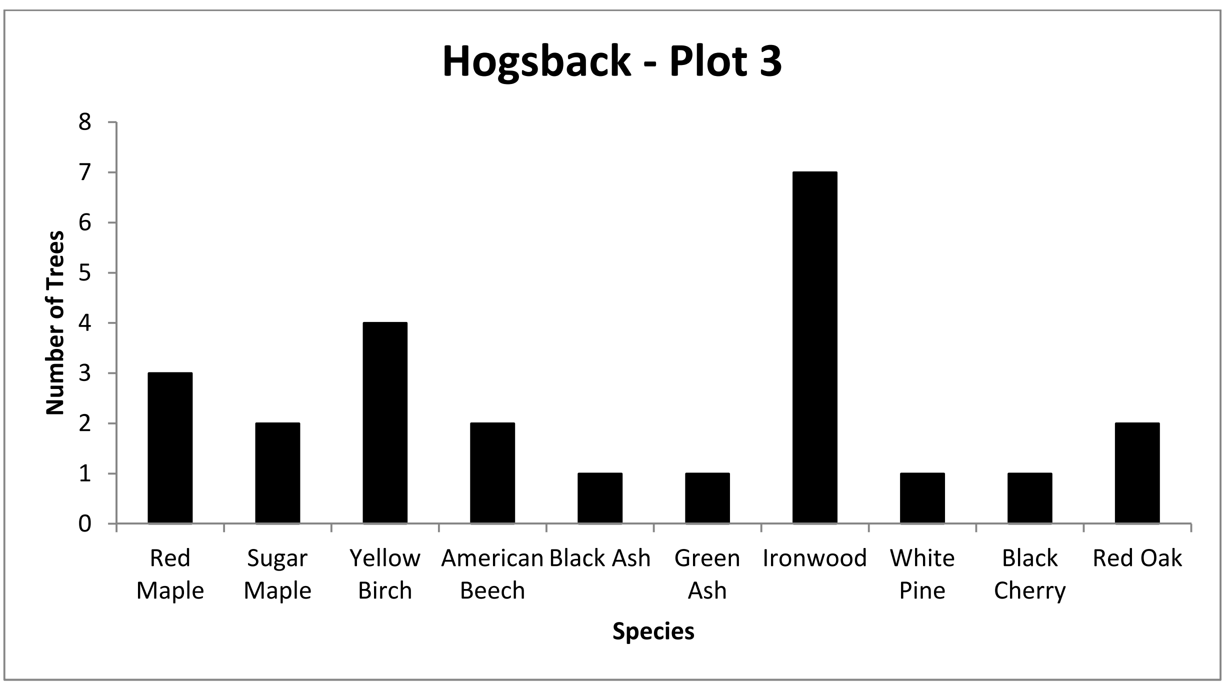

Figure 4.14 Tree species diversity and abundance for plot 3 in the Hogsback forest stand.

Table 4.3 Summary statistics of stand characteristics for the Hogsback forest stand in 2010 and 2011. The data from the three forest monitoring plots in the Hogsback were pooled to calculate the stand values.

Hogsback	2010	2011
Number of Live Stems	55	55
Number of Dead Stems	6	6
Number of Species	10	10
Shannon Index	2.05	2.08
Evenness Index	0.89	0.90

4.3.2 Stand Characteristics and Size Classes

Figure 4.15 shows the size class distribution of tagged trees in the Cliffs and Alvars forest stand. The mean stem DBH in Cliffs and Alvars in 2011 was 23.3 cm (SD ± 15.73 cm). In 2011, the stand recruited one new tree, while two trees were found newly deceased. Tree species composition for the Cliffs and Alvars forest stand for the years 2009, 2010, and 2011 can be found in Table 4.4.

Figure 4.16 shows the size class distribution of tagged trees in the Indian Woods forest stand. Mean stem DBH in Indian Woods in 2011 was 32.3 cm (SD ± 20.07 cm). In 2011, the stand did not recruit any new trees, nor did it experience any new mortalities. Tree species composition for the Indian Woods forest stand for the years 2009, 2010, and 2011 can be found in Table 4.5.

Figure 4.17 shows the size class distribution of tagged trees in the Hogsback forest stand. Mean stem DBH in the Hogsback in 2011 was 25.1 cm (SD ± 16.49 cm). In 2011, the stand did not recruit any new trees, nor did it experience any new mortalities. Tree species composition for the Hogsback forest stand for the years 2010 and 2011 can be found in Table 4.6.

Using a paired Wilcoxon signed rank test, we found significant differences in the mean stand DBH between the monitoring years 2009 and 2010 in both Cliffs and Alvars (p<0.001) and Indian Woods (p<0.001). In both forest stands, the 2010 mean DBH was significantly greater than that measured in 2009. We found no significant difference in mean DBH in any of the forest stands between the 2011 and 2010 monitoring years.

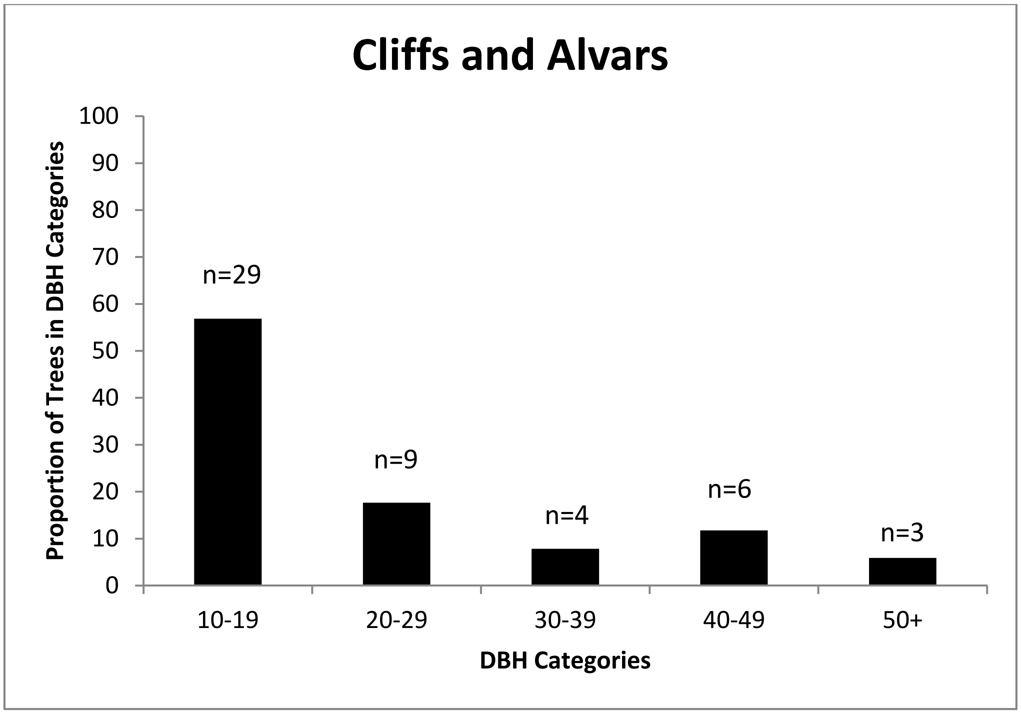

Figure 4.15 Tree trunk size distribution measured at breast height (DBH) for the Cliffs and Alvars forest stand.

Table 4.4 Tree species composition for the Cliffs and Alvars forest in 2011. Data from the three forest monitoring plots in Cliffs and Alvars were pooled and only living trees were included in these calculations.

	Abundance			Basal area (m^2)			Relative Density			Relative Frequency			Relative Dominance			Importance Value		
Species	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
Acer saccharum	18	18	19	1.37	1.43	1.50	36.73	36.00	37.25	18.75	18.75	21.43	44.48	44.79	47.53	99.96	99.54	69.33
Betula alleghaniensis	1	1	1	0.15	0.16	0.15	2.04	2.00	1.96	6.25	6.25	7.14	4.94	4.91	4.91	13.23	13.16	12.07
Fagus grandifolia	14	14	16	1.05	1.08	1.09	28.57	28.00	31.37	18.75	18.75	21.43	34.16	33.88	34.54	81.48	80.63	56.28
Fraxinus americana	3	3	1	0.13	0.13	0.02	6.12	6.00	1.96	18.75	18.75	7.14	4.08	3.95	0.49	28.95	28.70	7.65
Juglans cinerea	1	1	1	0.06	0.07	0.07	2.04	2.00	1.96	6.25	6.25	7.14	2.08	2.03	2.10	10.37	10.28	9.26
Ostrya virginiana	8	9	9	0.09	0.10	0.10	16.33	18.00	17.65	18.75	18.75	21.43	2.89	3.11	3.17	37.97	39.86	24.77
Prunus serotina	4	4	4	0.23	0.23	0.23	8.16	8.00	7.84	12.50	12.50	14.29	7.37	7.33	7.27	28.03	27.83	21.63

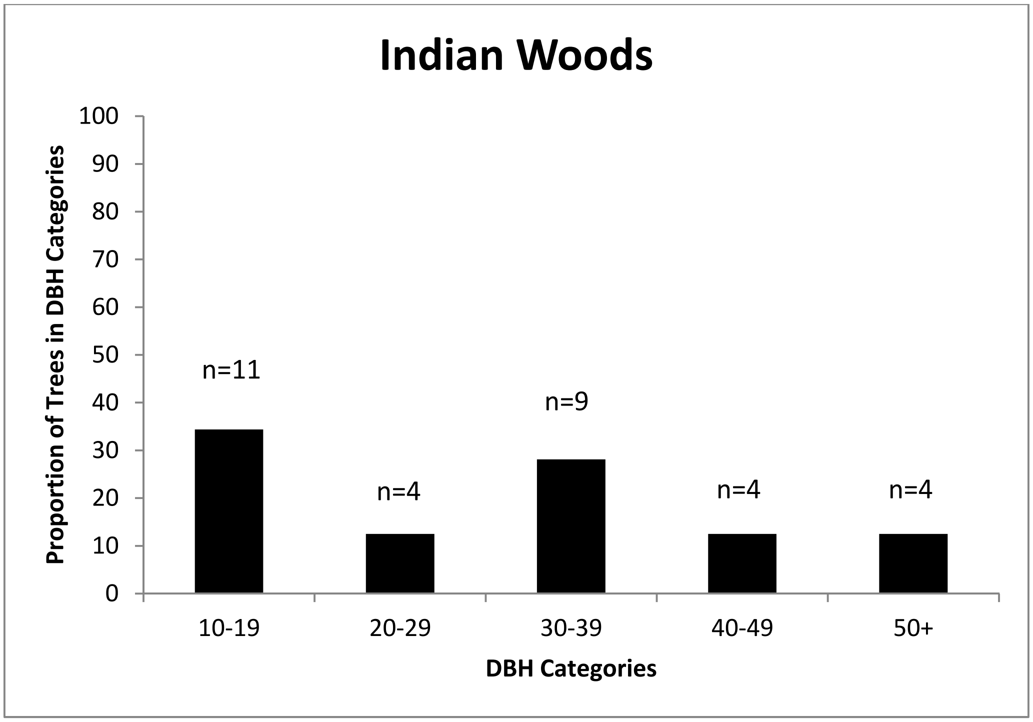

Figure 4.16 Tree trunk size distribution measured at breast height (DBH) for the Indian Woods forest stand.

Table 4.5 Tree species composition for the Indian Woods forest in 2011. Data from the three forest monitoring plots in Indian Woods were pooled and only living trees were included in these calculations.

Species	Abundance			Basal area (m^2)			Relative Density			Relative Frequency			Relative Dominance			Importance Value		
	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
Acer rubrum	2	-	-	0.23	-	-	5.88	-	-	22.22	-	-	5.98	-	-	34.08	-	-
Acer saccharum	24	24	24	2.53	2.60	2.61	70.59	75.00	75.00	33.33	42.86	42.86	66.24	73.02	72.35	170.16	190.88	190.21
Fagus grandifolia	6	6	6	0.37	0.21	0.21	17.65	18.75	18.75	22.22	28.57	28.57	9.66	5.83	5.88	49.53	53.15	53.20
Quercus rubra	1	1	1	0.15	0.16	0.17	2.94	3.13	3.13	11.11	14.29	14.29	3.99	4.62	4.61	18.04	22.03	22.02
Quercus alba	1	1	1	0.54	0.59	0.62	2.94	3.13	3.13	11.11	14.29	14.29	14.14	16.53	17.16	28.19	33.94	34.57

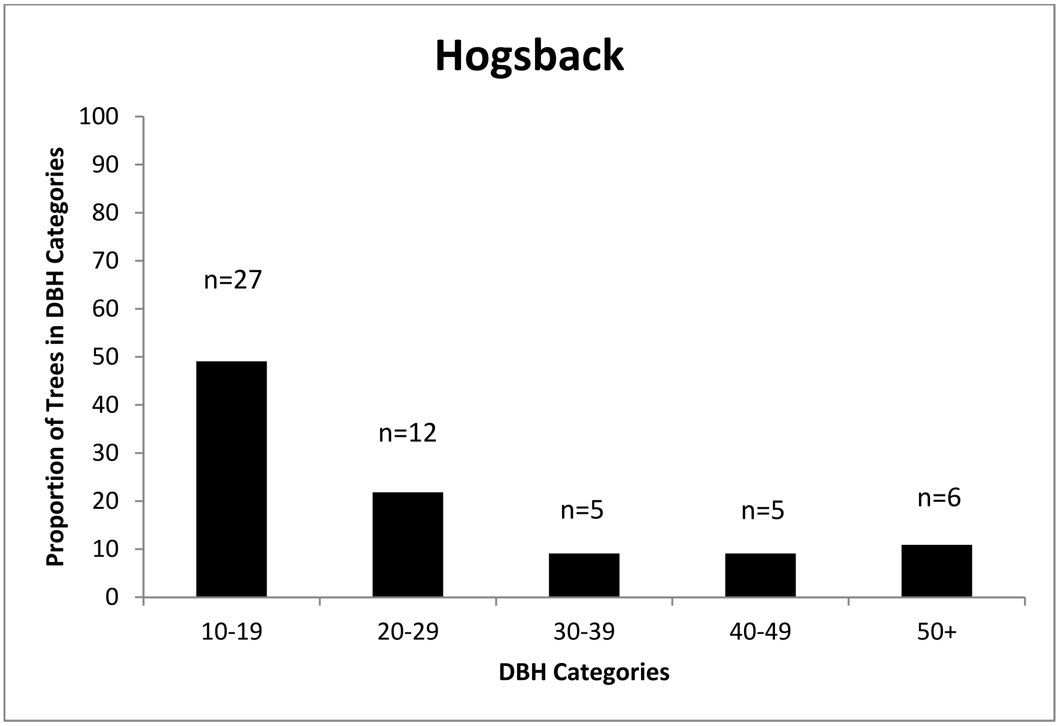

Figure 4.17 Tree trunk size distribution measured at breast height (DBH) for the Hogsback forest stand.

Table 4.6 Tree species composition for the Hogsback forest in 2011. Data from the three forest monitoring plots in the Hogsback were pooled and only living trees were included in these calculations.

	Abundance		Basal area (m^2)		Relative Density		Relative Frequency		Relative Dominance		Importance Value	
Species	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Acer rubrum	6	7	1.07	1.11	11.11	12.73	15.79	15.00	28.14	28.63	55.04	56.36
Acer saccharum	13	13	0.84	0.85	24.07	23.64	15.79	15.00	21.94	22.01	61.80	60.64
Betula alleghaniensis	6	6	0.15	0.15	11.11	10.91	10.53	10.00	3.84	3.80	25.48	24.71
Fagus grandifolia	10	9	1.16	1.15	18.52	16.36	15.79	15.00	30.35	29.62	64.66	60.98
Fraxinus nigra	1	2	0.01	0.03	1.85	3.64	5.26	10.00	0.26	0.66	7.37	14.30
Fraxinus pennsilvanica	5	4	0.18	0.16	9.26	7.27	10.53	10.00	4.63	4.18	24.41	21.45
Ostrya virginiana	6	7	0.11	0.11	11.11	12.73	5.26	5.00	2.81	2.76	19.19	20.49
Pinus strobus	1	1	0.01	0.01	1.85	1.82	5.26	5.00	0.27	0.26	7.38	7.08
Prunus serotina	1	1	0.05	0.06	1.85	1.82	5.26	5.00	1.37	1.47	8.49	8.28
Quercus rubra	5	5	0.24	0.26	9.26	9.09	10.53	10.00	6.39	6.60	26.17	25.69

4.4 Discussion

4.4.1 Tree Species Diversity

The Cliffs and Alvars forest is a mature stand co-dominated by Sugar Maple and American Beech. The sampled population was found to be more even than Indian Woods, but less even than the Hogsback, and had a Shannon index that also fell between the other two forest stands (1.47). This indicates that the Cliffs and Alvars population is reasonably even, and has high species diversity. While most of the trees observed in this forest stand favour dry, upland habitats, we did record Yellow Birch (*Betula alleghaniensis*), which favours wet soils. While most of Cliffs and Alvars boasts limestone and upland habitat, there are pockets of low-lying areas that are host to vernal pools and perpetually wet habitat that is ideal for Yellow Birch (Sibley 2009).

Indian Woods is an eastern deciduous old-growth remnant forest dominated by Sugar Maple; an ecosystem that is rare in the region and to southwestern Ontario (Draft ***rare*** Environmental Management Plan 2012). The diversity of the Indian Woods forest plots was the lowest of the three forest stands examined (Table 4.2), and had the smallest Evenness index – meaning there was high variability between numbers of species. American Beech was the second most important tree species in the forest (Table 4.4), while Red and White Oak (*Quercus rubra* and *alba* respectively) were each recorded only once in the forest monitoring plots. Old-growth forests are often viewed as a final stage in forest succession, representing a climax community that will persist in a state of dynamic equilibrium in the prevailing environmental conditions (Krebs 2001). As succession progresses and the canopy becomes more closed, the composition of canopy trees shifts towards more shade tolerant species such as Sugar Maple and American Beech (for eastern deciduous forests) (Fox 1977). These species are able to grow suppressed in the understory and they are then primed to exploit canopy gaps when they occur, outcompeting other shade-sensitive species (Weiskittel and Hix 2003).

The Hogsback forest monitoring plots were distributed over a greater range of habitats than the Cliffs and Alvars and Indian Woods, with plots positioned on upland ridges bordered by wet bog. The Hogsback had the greatest species diversity, and highest Shannon and Evenness index ratings (Table 4.3) – which indicates that the forest has high species diversity, and similar numbers of each species present. The wet margins of the plots are likely the source of increased species diversity in the Hogsback, as Yellow Birch, Black Ash (*Fraxinus nigra*), Green Ash (*Fraxinus pennsylvanica*), and Red Maple all thrive in wet soils (Sibley 2009).

4.4.2 Stand Characteristics and Size Classes

The tree DBH distributions of the three forests were plotted in Figures 4.15 through 4.17 to give a visual representation of the size-class composition of the stands. This information will be useful as baseline data to which the monitoring data from future years may be compared to examine the recruitment and replacement patterns of the stand (Parker 2003, Forrester and Runkle 2000). It is interesting to note that while the Hogsback exhibits the classic distribution of trunk size in a young forest stand (fewer trees in bigger size classes) Cliffs and Alvars and the Hogsback forests have different distributions tree sizes. The Cliffs and Alvars area at ***rare*** was historically grazing grounds for cattle. The past use of the land could account for the increased number of trees we see in the 40-49 cm DBH category vs. the 30-39 cm DBH category. It could be that trees in the 40-49 cm DBH category were large enough at the time of grazing that they were not stripped by cattle. Whereas trees that are now in the 30-39 cm DBH category may have been more likely to have been targets for grazing due to their smaller size. Whereas in Indian Woods, we see a more even distribution across the DBH categories, indicating that while there is regeneration occurring in the old growth forest, it is settling as a climax community forest, where dominant trees are stable in the canopy and not permitting succession by smaller trees. Smaller trees can remain in the understory for many years using a series of gaps to reach the canopy (Forrester and Runkle 2000). From this, we could also predict that in a century, Indian Woods will be increasingly dominated by American Beech and Sugar Maple, likely at the expense of species richness (which is already low in Indian Woods). Long-term monitoring of the plots will allow predictions such as these to be tested.

For each forest stand we calculated the IV for each species. The IV incorporates relative density, relative frequency, and relative dominance to determine dominance in forest stands and summarize the influence that an individual species may have within the community (Brower *et* al. 1997). Cliffs and Alvars, Indian Woods, and the Hogsback were similar in that the two tree species with the highest IVs were the same in each stand - Sugar Maple and American Beech. However, the Hogsback stand had a close third, Red Maple, with an IV similar to both the co-dominant species. While Sugar Maple and American Beech had 13 and 10 individuals respectively, Red Maple had six – indicating that the fewer number of Red Maple have strong influence on the community. Importance values are weighted toward density, in that the number of trees present exerts a greater effect on the index than does their size. A critical assumption of calculating IVs is that we have adequately sampled the area. If the area is homogeneous in terms of diversity it would require fewer transects and plots than if it is heterogeneous in terms of diversity. Because of the variety of habitat within each of the forest stands, establishing more forest plots will only improve our description of the ecological community and may reveal different habitats and niches that were missed with our small sample size.

4.4.3 Tree Health and Future Recommendations

Of the 12 known Butternut (*Juglans cinerea*) trees on the ***rare*** property, one individual fell within the forest monitoring plot 1 in the Cliffs and Alvars. Butternut is classified as Endangered by the Ontario Ministry of Natural Resources Species at Risk in Ontario (OMNR 2010). The decline of Butternut in Ontario is attributed to Butternut Canker (*Sirococcus clavigignenti-juglandacearum*), an introduced fungal disease that has been present in Ontario since the early 1990s. Symptoms of the disease are elongated, sunken cankers, which commonly originate at leaf scars, buds, or wounds (Davis and Meyer 1997). Eventually, cankers spread around branches and the trunk, girdle, and kill the tree. There is currently no prevention, control, or treatment for the disease and most Butternut conservation efforts are focussed on the detection of resistant individuals for seed banking and grafting (FGCA 2012). One strategy for reducing inoculum load from a forest stand is to remove ailing Butternut – however, as a Species at Risk in Ontario, there are strict guidelines surrounding the management of Butternut Trees. Unfortunately, the Butternut surveyed in the Cliffs and Alvars stand was found to be in severe decline: it had been classified as dead-standing in the 2009 monitoring season, however, it was found to be living in 2010 and 2011, albeit with severe crown dieback and extensive wounds covering the trunk.

Severe decline was also detected in a large proportion of the Ash trees included in the plots. Of the four White Ash (*Fraxinus americana*) trees included in the Cliffs and Alvars forest plots, three were dead, and the remaining tree had extensive crown dieback. In the Hogsback monitoring plots, one Black Ash was found newly dead in 2011. The remaining three Green Ash trees, and one Black Ash, were found to be in severe decline. The Ash trees in both Cliffs and Alvars and the Hogsback are rapidly declining in health according to our EMAN data. The high proportion of declining Ash trees is of particular concern given the recent discovery of the Emerald Ash Borer beetle (EAB - *Agrilus planipennis*) in the Waterloo region (CFIA 2010). Emerald Ash borer colonize and lay eggs on and in the bark, trunk, and branches of Ash trees. Larvae tunnel beneath the bark and feed on the cambium[10], whereby they develop extensive galleries that girdle the trunk cutting off transport of nutrients and water. The ash tree then starts to die from the top down (Davis and Meyer 1997). Not all of the Ash declines observed in southern Ontario are thought to be caused by the Emerald Ash Borer; inspection of failing trees has pinned some of the blame on fungal root rot, bacterial infection (Pokorny and Sinclair 1994), other pest insects such as the Redheaded Ash Borer (*Neoclytus acuminatus*) and the Lilac Borer (*Podosesia syringae*) (Lyons *et* al. 2007). Should ***rare*** choose to supplement the EMAN forest biodiversity plots with an Ash specific monitoring program, the Canadian Food and Inspection Agency has developed a number of protocols for the detection and monitoring of EAB (Ryall *et* al. 2010). At the very least, the current forest plots will allow us to estimate the rate of Ash decline and to detect any resistance or resiliency in our tagged trees.

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[10] Layer of living cells between the bark and sapwood.

A number of American Beech trees in all three forest stands had early stage lesions that indicated the presence of Beech Bark Disease (*Nectria coccinea*). Some trees were noted as having Beech Scale insects (*Cryptococcus fagisuga*), which are vectors of the fungus that kills the bark and causes extensive lesions. The disease is best identified by the presence of red fruiting bodies in the fall (Davis and Meyer 1997). Management of Beech Bark disease in Beech dominated forests is tricky. The MNR recommends reducing the amount of overstory Beech while retaining vigorous trees with smooth bark. In infected stands, the spread of disease may be slowed by selective cutting and removal of infested and infected stems. Most importantly, ***rare*** should consider identifying, marking, and retaining resistant trees for the purpose of controlled Beech regeneration in the future.

In 2011, observers also noted extensive colonization of American Beech by the Woolly Aphid (*Eriosomatinae spp.*). While this insect is unrelated to Beech Bark Disease, some speculate that it may have deleterious effects on tree health because the insects feed on leaves and blanket small stems. Woolly Aphids produce honeydew that attracts sooty mold (*Capnodium spp*.), which can further cover foliage and reduce transpiration and photosynthesis (Davis and Meyer 1997). It can reduce vigor in young trees, affecting growth and possibly survival. The fungus declines once the insect infestation with which it is associated ceases. It is highly unlikely that the Woolly Aphid or the associated sooty mold have any serious effects on the decline in health of the Beech trees at ***rare***.

5.0 Soil Humus Decay Rare Monitoring

5.1 Introduction

5.1.1 Soil Characteristics and Functions

Decomposition is defined as the physical, chemical and biological breakdown of organic material into simpler matter, and it is a significant producer of carbon dioxide, as well as methane and nitrogen gases (Berg and McClaugherty 2008). Soil humus, the stable organic layer remaining after initial decomposition, acts as a reservoir for the carbon that was not released during decay, as well as storage for the nutrients that support plant growth and the microbial and fungal communities of the soil (Berg and McClaugherty 2008). The rate at which decomposition occurs is dependent on many factors, including the composition of the material being decomposed, the ecology (species composition and abundance) of the decomposer organisms available in the soil, and a suite of environmental variables, including soil temperature, moisture, pH and aeration (Tenney and Waksman 1929).

5.1.2 Soil Humus Decay Rate Monitoring at *rare*

The first EMAN soil humus decay rate monitoring plots at ***rare*** were established on November 9, 2009 at the Cliffs and Alvars forest plot 1. The success of the first monitoring year encouraged us to expand the study in 2010 by establishing monitoring plots at Indian Woods forest plot 1 and the Hogsback forest plot 1.

In response to concerns that climate change may affect soil decomposition, Natural Resources Canada (NRC) developed the Canadian Intersite Decomposition Experiment (NRC 2007) to examine the long-term litter decomposition rates and nutrient mineralization of forests across Canada. The moderate temperate zone of southwestern Ontario is the one area excluded from NRC's long-term decomposition study. Long-term monitoring of soil decay rates can provide valuable information on the relationship between soil decomposition and environmental factors, and it may serve to inform management decisions. For example, we currently can only guess at the effects that nearby aggregate mining or pesticide application may have on the health of our forests; decay rate monitoring, together with the other biological monitoring protocols in place at ***rare*** such as forest tree biodiversity and plethodontid salamander monitoring, can provide us with a greater understanding of the integrity and stability of our forest ecosystems.

At ***rare***, the objective of the EMAN soil humus decay rate monitoring procedure is to contribute to the overall assessment of forest ecosystem integrity by monitoring yearly mass loss in standardized decay sticks as a representation of soil decomposition. The EMAN (2006) decay rate protocol suggests locating the Annual Decay Rate (ADR) plots at the corners of the permanent Forest Canopy Tree Biodiversity plots. The information gained from decay monitoring can then be directly linked to the forest health and productivity data.

We predict that the mean mass loss of the sticks positioned on the surface of the soil will be less than the mean mass loss of the sticks placed below the soil; where they are more accessible to soil microorganisms responsible for decomposition. We also expect that decay rates will remain relatively stable across monitoring years.

5.2 Methods

5.2.1 Soil Humus Decay Plot Locations

For the 2011 soil decay monitoring, ADR plots were established on all four corners of three forests plots involved in the forest biodiversity monitoring (Figure 5.1). Monitoring took place adjacent to plot 1 from each of the three different stands (Cliffs and Alvars, Indian Woods, Hogsback). Each of these plots had 12 ADR plots established along its perimeter – three at each corner. Section 4.2.1 provides detailed descriptions of the Cliffs and Alvars, Indian Woods, and Hogsback forest stands, and includes instructions to access the plots. A map of the forest monitoring plots which correspond to the soil decay monitoring plots is available in APPENDIX B: Figure B.2, and UTMs of the NE corners of plot 1 of each of the forest monitoring plots can be found in APPENDIX B: Table B.2.

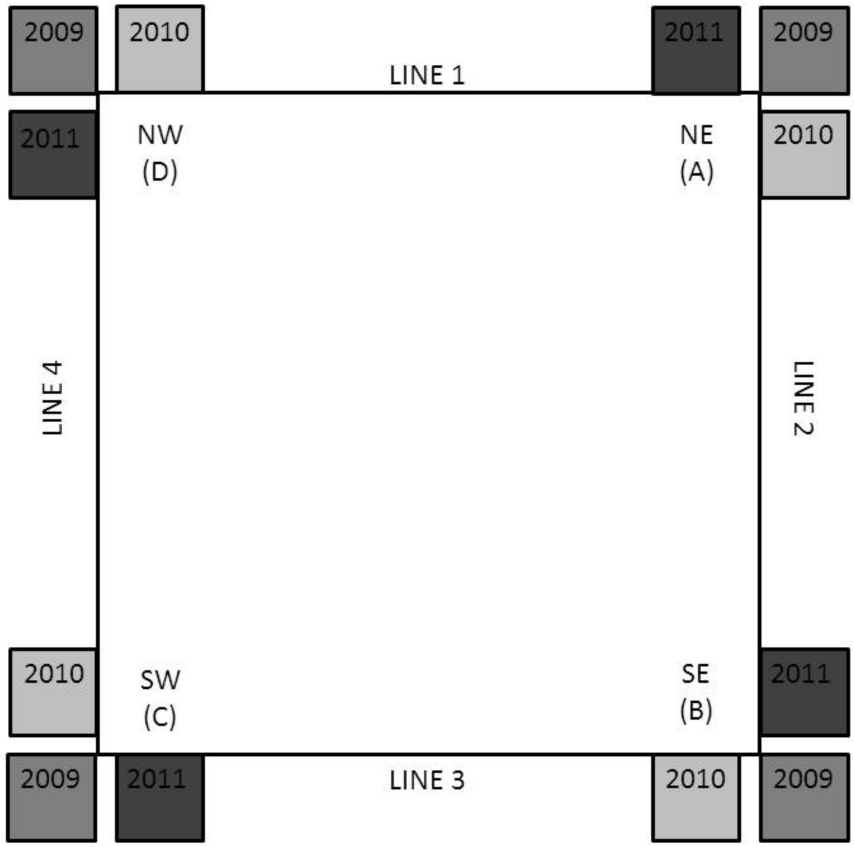

Figure 5.1 Spatial location of annual soil hummus decay rate plots relative to forest canopy tree biodiversity plot. Adapted from McCarter (2009).

5.2.2 Monitoring Protocol

Decay Stick Installation

Decay sticks must be prepared in-house prior to ground installation. The first step was to drill a 2mm hole at the end of each tongue depressor (MedPro, 100% natural birch wood, ultra smooth finish). We prepared 160 tongue depressors for installation (err on the side of caution) although only 144 are required for the three plots (48 sticks per plot). The tongue depressors were then transported to the University of Guelph (Dr. Brian Husband's Research Laboratory) and oven-dried at 70˚C for 48 hours. Following the oven-drying, the sticks were let to sit for 24 hours at room temperature before being weighed (to ±0.001g) on a Sartorius 1265MP balance. A sample datasheet used to record stick weights pre and post decay is available in APPENDIX D: Figure D.6. After their mass was recorded, the tongue depressors were tagged with pre-labelled aluminum tags attached with approximately 30cm of extra-strong (40LB) fishing line. For the 2010 and 2011 installations, depressors were placed in 100% vinyl mesh bags (total dimensions were 17cm x 4cm with an approximate pocket size of 16cm x 3cm and hole size of 3mm x 2mm) that were tied closed with fishing line. A complete list of equipment required for installation of decay sticks is available in APPENDIX C: List C.5). Many of the 2009 decay sticks extracted in 2010 were broken and missing pieces due to forces other than decay (e.g. hasty extraction or shifting due to ground freeze); the mesh bags were added to the protocol in an attempt to keep all the stick's pieces together and increase the number of decay sticks excavated intact.

A 1 m^2 quadrat was marked on each corner of the forest plots, and three ADR plots were positioned on the corners not touching the forest plot. At each ADR plot, a 30cm x 30cm hole was excavated with the soil plug removed intact if possible and placed to the side. In the 2011 installation, the quadrat at each corner was shifted approximately 1 m counter-clockwise from the forest plot corner to ensure that the soil was undisturbed by the excavation of the previous year's sticks (Figure 5.1). Three slots were made (using a knife or chisel) parallel to the forest floor in the north face of the initial 30 cm x 30 cm hole, deep enough to accommodate the bagged sticks. These slots were made 5 cm below the forest floor, and were each 10 cm apart. The decay sticks in their mesh bags were then inserted into the slots made in the soil. The pre-numbered aluminum forestry tags (attached to the sticks with fishing line) were then placed on the soil surface. Each stick was also individually attached by fishing line to a galvanized steel pigtail that was flagged and labelled with the ADR plot number and inserted into the middle of the ADR hole. A fourth stick (similarly strung, tagged, and bagged) was placed on the soil surface (Figure 5.2). Insertion depth of each stick was recorded using a standard ruler (cm). The main, large hole was then refilled with the previously excavated soil and the tags were covered with leaf litter to prevent tampering by wildlife or the public.

Decay Stick Excavation

Decay sticks should be excavated close to the same date one year after their installation; however, this date should be moved forward if there is a risk of the ground freezing. The tags and fishing line help to indicate the position of the sticks in the soil. Using a trowel, gradually remove soil the area suspected to contain the sticks. Because the sticks are bagged and attached by fishing line, they can be gently pulled from the ground once a hole has been dug. Place each stick and its tag together in individual plastic bags or paper envelopes. A complete list of equipment required for decay stick excavation is available in APPENDIX C: List C.5).

To remove any dirt adhered to the sticks, each stick was gently brushed with a dry paintbrush and then gently scrubbed with a different paintbrush in water. The sticks were placed in labelled paper envelopes and then oven-dried (Dr. Brian Husband's Research

Laboratory) at 70˚C for 48 hours and then let to sit for 24 hours at room temperature before being weighed (to ±0.001g) on a Sartorius 1265MP balance. Weights were recorded on a datasheet available both on the ***rare*** server and in APPENDIX D: Figure D.6).

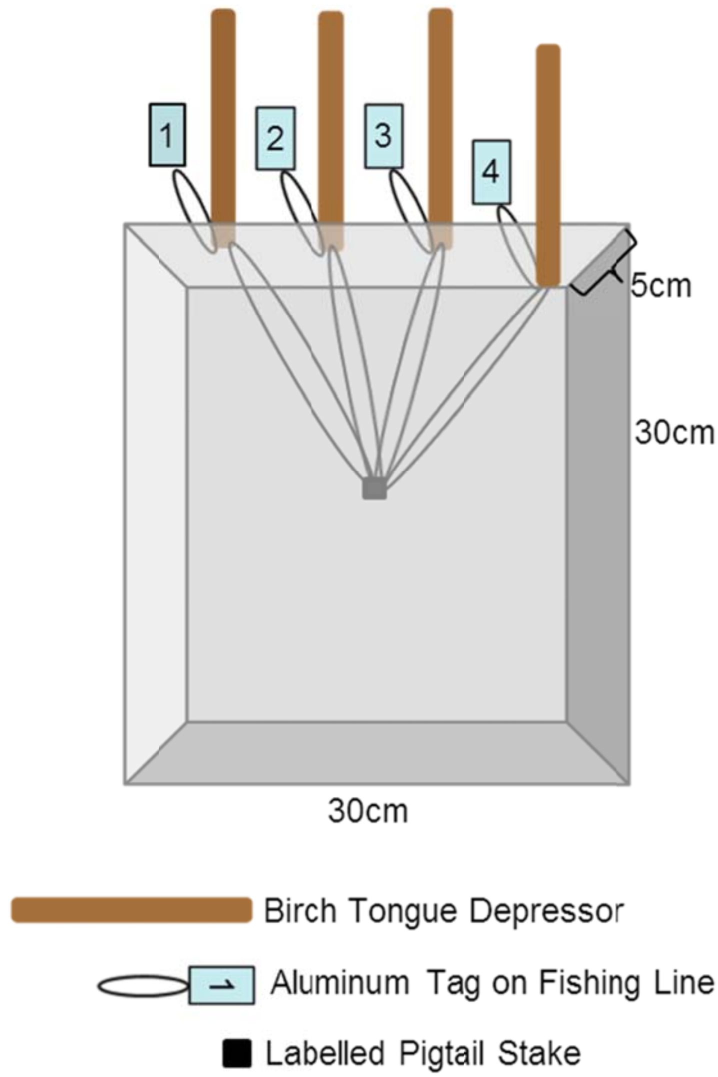

Figure 5.2 Diagram of one corner hole in an annual soil humus decay rate monitoring plot, looking down into the hole. Sticks 1-3 are below the surface, while stick 4 rests on the forest floor. Figure taken from Robson (2010).

5.2.3 Data Analysis

The annual soil decay rate is calculated as the mean percent mass loss of the decay sticks.

We used a non-parametric paired Wilcoxon signed rank test to compare yearly decay rates between 2009-2010 and 2010-2011 in the Cliffs and Alvars soil plots. This calculation was not performed for either Indian Woods or the Hogsback because the soil decay monitoring plots were newly established in 2010 for these locations.

To test the difference in decay rates for below and above ground decay sticks recovered in 2010 and 2011, we used a non-parametric independent 2-group Mann-Whitney U test. For the purpose of our comparisons, we included all decay sticks (Set 1, see Robson 2010) from 2010.

5.3 Results

In 2011, we installed new decay monitoring sticks adjacent to the plots from 2010 in an attempt to shift the extraction date forward in the season to avoid encountering frozen ground. In Cliffs and Alvars, the sticks were installed on November 2, 2011, in Indian Woods they were installed on November 3, 2011, and in the Hogsback they were installed on November 7, 2011. They should be removed from the ground as close to these dates as possible in 2012.

The sticks that were installed on November 15-16, 2010 at Cliffs and Alvars forest plot 1 were excavated November 15, 2011. The annual soil decay rate was 0.646 for all sticks in the plot. We compared decay rates of sticks situated above and below ground (Table 5.1), and found a significant difference ($p<0.001$) in mean soil decay rate – sticks below ground had, on average, greater decay rates than sticks that spent the year above ground.

We compared annual soil decay rates of all sticks (both above and below ground) in the Cliffs and Alvars soil monitoring plots between 2009-2010 and 2010-2011 and found no significant difference ($p=0.363$).

The sticks installed on November 18, 2010 at Indian Woods forest plot 1 were excavated November 18 2011. The annual soil decay rate was 0.644 for all sticks in the plot. We compared decay rates of sticks situated above and below ground (Table 5.1), and found a significant difference ($p<0.001$) in mean soil decay rate – sticks below ground had, on average, greater decay rates than sticks that spent the year above ground.

The sticks installed on November 19, 2010 at Hogsback forest plot 1 were excavated November 21 2011. The annual soil decay rate was 0.468 for all sticks in the plot. We compared decay rates of sticks situated above and below ground (Table 5.1). There was no significant difference detected between mean ADRs in sticks above and below ground.

Table 5.1 Annual soil decay rates for Cliffs and Alvars (CA), Indian Woods (IW), and the Hogsback (HB). Decay rates were calculated for all sticks, sticks that were buried below ground, and sticks that were placed on top of the soil, under leaf litter. Statistically significant differences between years are indicated with superscript letters.

	CA	IW	HB
All Sticks	0.646	0.644	0.468
Sticks Below Ground	0.801[a]	0.796[b]	0.477
Sticks Above Ground	0.181[a]	0.188[b]	0.437

5.4 Discussion

In 2009, the first annual soil humus decay rate plots were established (Cliffs and Alvars). Upon excavation of the sticks in 2010, it was discovered that modifications had to be made to the protocol. The decay sticks were difficult to find, and had decayed to such a stage that there was no way to ensure the collection of all materials. Because of these difficulties, sticks installed in 2010 were placed in a nylon mesh bag, with the hopes that it would facilitate excavation in future years. While the sticks may continue break during extraction, the nylon mesh bag served to prevent any pieces from being lost in the soil. Mesh bags are often used in studies of leaf litter decay rate (Moore *et* al. 2005, Albers *et* al. 2004, Gallardo *et* al. 1995).

The decay rate of sticks in the Cliffs and Alvars forest monitoring plot from 2010-2011 was not significantly different from the decay rate from 2009-2010 (p=0.363). This could indicate that the nylon mesh bags did not impact the soil decay rate of sticks in the Cliffs and Alvars. As long as mesh bags are used for the duration of the monitoring years, we will be able to accurately and confidently track changes in decay rates in ***rare*** forests. The results can be charted over time to detect trends in the decay rate.

In the soil decay monitoring plots, sticks are placed both above and below ground to quantify both decay rates below the soil, and above soil but below the surface litter in the woods. In both the Cliffs and Alvars and Indian Woods decay monitoring plots, we found a significant difference between the decay rates of sticks that had been buried beneath the soil, and sticks that had been placed on the soil surface beneath the leaf litter (p<0.001). Sticks that were placed underground were more accessible to soil microorganisms, fungi, and moisture – which could explain the higher decay rate. Rates of decay can be influenced by many factors including: climate, temperature, moisture, substrate type, nutrient concentrations and availability, litter type and size, and soil organisms (EMAN 2006). Moisture and temperature, which vary greatly with local conditions, are the principal factors that affect rate of decay

(USDA 2007). Interestingly, we found no significant difference between decay rates of sticks above (0.437) and below (0.477) ground for the Hogsback monitoring plots. In fact, decay rate of below ground sticks was markedly lower than the other two forest plots and markedly higher for the above ground sticks (Table 5.1). The Hogsback forest is a mixture of upland and low-lying land with swampy features that were incorporated in to the soil decay monitoring plots – one soil decay plot was placed in an especially swampy corner. If wood is kept continuously submerged in water, even for long periods of time, it does not decay significantly by the common decay fungi. Bacteria and certain soft-rot fungi can attack submerged wood, but the resulting deterioration is very slow (USDA 2007). The lack of oxygen and presence of water could account for the low decay rates below ground in some of the sticks in the Hogsback. As for the elevated decay rate of above ground sticks relative to the other monitoring plots, it has been hypothesized that above-ground mass loss may be due to abiotic factors such as wind, high temperature, leaching, and UVB breakdown (Montana 1998). It is possible that above ground sticks in the Hogsback were left more exposed to the elements than in the other monitoring plots.

6.0 Summary of Monitoring at *rare* Charitable Research Reserve

Together, these four monitoring programs provide a broad picture of the function and health of the landscapes (especially forests) at ***rare***. As each program is relatively new, the data collected to date will serve to build a valuable baseline to which future years can be compared. Waterloo Region continues to grow around ***rare***, with golf courses, housing developments, and aggregate pits comprising the majority of the abutting lands. Within a few years, it is likely that ***rare*** will become an island of greenspace in an industrialized landscape. Continuation of this long-term monitoring will allow for the early detection of changes in the health and structure of ecosystems at the ***rare*** Charitable Research Reserve.

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APPENDIX A – SPECIES LISTS

Table A.1 Records of date of first observation of each species for each monitoring year, and earliest observation during the annual butterfly counts.

	Earliest Record by Year					
Species	**2006**	**2009**	**2010**	**2011**	**Annual Butterfly Counts**	**Earliest Record at *rare***
Acadian Hairstreak					July 13	July 13
American Lady			May 20		July 10	May 20
American Snout					July 10	July 10
Appalachian Brown				July 6	July 2	July 2
Arctic Skipper			June 3		July 10	June 3
Banded Hairstreak	July 18	July 16		July 12	July 2	July 2
Black Dash			June 8		July 10	June 8
Black Swallowtail	July 24	May 20	May 4	May 30	July 10	May 4
Broad-winged Skipper		July 24			July 10	July 10
Bronze Copper	Aug 18				July 2	July 2
Cabbage White	July 18	May 12	May 3	May 19	July 2	May 3
Clouded Sulphur	July 18	May 22	May 4	May 31	July 10	May 4
Columbine Duskywing			May 19			May 19
Common Buckeye				Sept 15		Sept 15
Common Sooty Wing	July 21	June 2		Aug 4	July 10	June 2
Common Wood Nymph	July 18	June 16	June 25	June 14	July 2	June 14
Compton Tortoiseshell				July 12		July 12
Coral Hairstreak		July 16			July 2	July 2
Crossline Skipper					July 2	July 2
Delaware Skipper		June 2	May 24	July 11	July 10	May 24

Table A.1 Continued.

Species	Earliest Record by Year 2006	2009	2010	2011	Annual Butterfly Counts	Earliest Record at *rare*
Dion Skipper					July 13	July 13
Dun Skipper		July 24		July 6	July 11	July 6
Eastern Comma	Aug 2	June 30	May 14	June 1	July 10	May 14
Eastern Tailed Blue	Aug 18			July 27	July 11	July 13
Eastern Tiger Swallowtail	July 18	May 21	May 19	June 1	July 2	May 19
European Skipper	July 18	June 24	May 24	June 14	July 2	May 24
Eyed Brown	July 18	July 30	June 15	July 5	July 2	June 15
Giant Swallowtail	July 24			June 8	July 11	June 8
Gray Comma					July 19	July 19
Great Spangled Fritillary	July 18	July 24	June 21	July 11	July 10	June 21
Harvester				Aug 19		Aug 19
Hickory Hairstreak	July 18				July 11	July 13
Hobomok Skipper			May 26	June 1	July 2	May 26
Inornate Ringlet	Aug 2	June 2	May 19	June 6	July 2	May 19
Juvenal's Duskywing			May 26	May 25		May 25
Least Skipper				Aug 5		Aug 5
Little Wood Satyr	July 18	June 10	June 3	June 8	July 2	June 3
Little Glassywing				July 6	July 2	July 2
Little Yellow					July 11	July 11
Long Dash				June 14	July 2	June 14
Meadow Fritillary					July 10	July 10

Table A.1 Continued

	Earliest Record by Year					
Species	**2006**	**2009**	**2010**	**2011**	**Annual Butterfly Counts**	**Earliest Record at *rare***
Milbert's Tortoiseshell			June 21	July 19		June 21
Monarch	July 18	June 22	June 25	May 30	July 2	May 30
Mourning Cloak		May 25	May 4	June 7	July 10	May 4
Mustard White				Aug 12		Aug 12
Northern Broken-Dash					July 10	July 10
Northern Crescent		May 21	June 3	June 7	July 2	May 21
Northern Pearly Eye	July 18	June 30	June 3	June 20	July 2	June 3
Orange Sulphur	Aug 24		June 30	July 19	July 10	June 30
Painted Lady		June 4	May 4			May 4
Pearl Crescent	July 18			May 25	July 2	May 25
Peck's Skipper				July 11	July 2	July 2
Question Mark	July 18	June 10	May 19	June 7	July 10	May 19
Red Admiral	Aug 18	May 14	May 3	May 25	July 10	May 3
Red Spotted Purple		June 16	June 1	June 14	July 10	June 1
Silver-bordered Fritillary					July 2	July 2
Silver Spotted Skipper		July 30	June 8	June 20	July 10	June 8
Spring Azure		May 13	May 4	May 20		May 4
Striped Hairstreak				July 26	July 11	July 13
"Summer" Spring Azure	Aug 2	July 22	June 8	July 5	July 2	June 8
Tawny Emperor	July 21	July 30		Aug 4	July 2	July 2

Table A.1 Continued

Species	Earliest Record by Year				Annual Butterfly Counts	Earliest Record at *rare*
	2006	2009	2010	2011		
Tawny-edged Skipper		July 16		July 22	July 2	July 2
Viceroy	Aug 2	June 10	June 8	June 20	July 2	June 8
White Admiral		July 14		June 14	July 11	June 14
Wild Indigo Duskywing			May 17		July 2	May 17

Table A.2 Common and scientific names of all butterflies observed at *rare* Charitable Research Reserve since 2006.

Common Name	Scientific Name
Acadian Hairstreak	*Satyrium acadica*
American Lady	*Vanessa virginiensis*
American Snout	*Libytheana carinenta*
Appalachian Brown	*Lethe appalachia*
Arctic Skipper	*Carterocephalus palaemon*
Banded Hairstreak	*Satyrium calanus*
Black Dash	*Euphyes conspicua*
Black Swallowtail	*Papilio polyxenes*
Broad-winged Skipper	*Poanes viator*
Bronze Copper	*Lycaena hyllus*
Cabbage White	*Pieris rapae*
Clouded Sulphur	*Colias philodice*
Columbine Duskywing	*Erynnis lucilius*
Common Buckeye	*Junonia coenia*
Common Sooty Wing	*Pholisora catullus*
Common Wood Nymph	*Cercyonis pegala*
Compton Tortoiseshell	*Nymphalis l-album*
Coral Hairstreak	*Satyrium titus*
Crossline Skipper	*Polites origenes*
Delaware Skipper	*Anatrytone logan*
Dion Skipper	*Euphyes dion*
Dun Skipper	*Euphyes vestris*
Eastern Comma	*Polygonia comma*
Eastern Tailed Blue	*Cupido comyntas*
Eastern Tiger Swallowtail	*Papilio glaucus*
European Skipper	*Thymelicus lineola*
Eyed Brown	*Lethe eurydice*
Giant Swallowtail	*Papilio cresphontes*
Gray Comma	*Polygonia progne*
Great Spangled Fritillary	*Speyeria cybele*
Harvester	*Feniseca tarquinius*
Hickory Hairstreak	*Satyrium caryaevorus*
Hobomok Skipper	*Poanes hobomok*
Inornate Ringlet	*Coenonympha tullia*
Juvenal's Duskywing	*Erynnis juvenalis*
Least Skipper	*Ancyloxypha numitor*
Little Wood Satyr	*Megisto cymela*

Little Glassywing	*Pompeius verna*
Little Yellow	*Pyristia lisa*
Long Dash	*Polites mystic*
Meadow Fritillary	*Boloria bellona*
Milbert's Tortoiseshell	*Aglais milberti*
Monarch	*Danaus plexppus*
Mourning Cloak	*Nymphalis antiopa*
Mustard White	*Pieris oleracea*
Northern Broken-Dash	*Wallengrenia egeremet*
Northern Crescent	*Phyciodes cocyta*
Northern Pearly Eye	*Enodia anthedon*
Orange Sulphur	*Colias eurytheme*
Painted Lady	*Vanessa cardui*
Pearl Crescent	*Phyciodes tharos*
Peck's Skipper	*Polites peckius*
Question Mark	*Polygonia interrogationis*
Red Admiral	*Vanessa atalanta*
Red Spotted Purple	*Limenitis arthemis astyanax*
Silver-bordered Fritillary	*Boloria selene*
Silver Spotted Skipper	*Epargyreus clarus*
Spring Azure	*Celastrina lucia*
Striped Hairstreak	*Satyrium liparops*
"Summer" Spring Azure	*Celastrina neglecta*
Tawny Emperor	*Asterocampa clyton*
Tawny-edged Skipper	*Polites themistocles*
Viceroy	*Limenitis archippus*
White Admiral	*Limenitis arthemis arthemis*
Wild Indigo Duskywing	*Erynnis baptisiae*

Table A.3 Common and scientific names with shorthand abbreviations of all salamander species observed at *rare* Charitable Research Reserve since 2006.

Common Name	Scientific Name	Abbreviation
Spotted Salamander	*Ambystoma maculatum*	YESA
Blue-spotted Salamander	*Ambystoma laterale*	BLSA
Four-toed Salamander	*Hemidactylium scutatum*	FOSA
Eastern Red-backed Salamander	*Plethodon cinereus*	RESA/LESA

Table A.4 Common and scientific names with shorthand abbreviations of all tree species observed in forest biodiversity monitoring plots at *rare* Charitable Research Reserve since 2009.

Common Name	**Scientific Name**	**Abbreviation**
American Beech	*Fagus grandifolia*	FAGUGRAN
Black Ash	*Fraxinus nigra*	FRAXNIGR
Black Cherry	*Prunus serotina*	PRUNSERO
Butternut	*Juglans cinerea*	JUGLCINE
Green Ash	*Fraxinus pennsilvanica*	FRAXPENN
Ironwood	*Ostrya virginiana*	OSTRVIRG
Red Maple	*Acer rubrum*	ACERRUBR
Red Oak	*Quercus rubra*	QUERRUBR
Sugar Maple	*Acer saccharum*	ACERSACC
White Ash	*Fraxinus americana*	FRAXAMER
White Oak	*Quercus alba*	QUERALBA
White Pine	*Pinus strobus*	PINUSTRO
Yellow Birch	*Betula alleghaniensis*	BETUALLE

APPENDIX B – MAPS AND COORDINATES

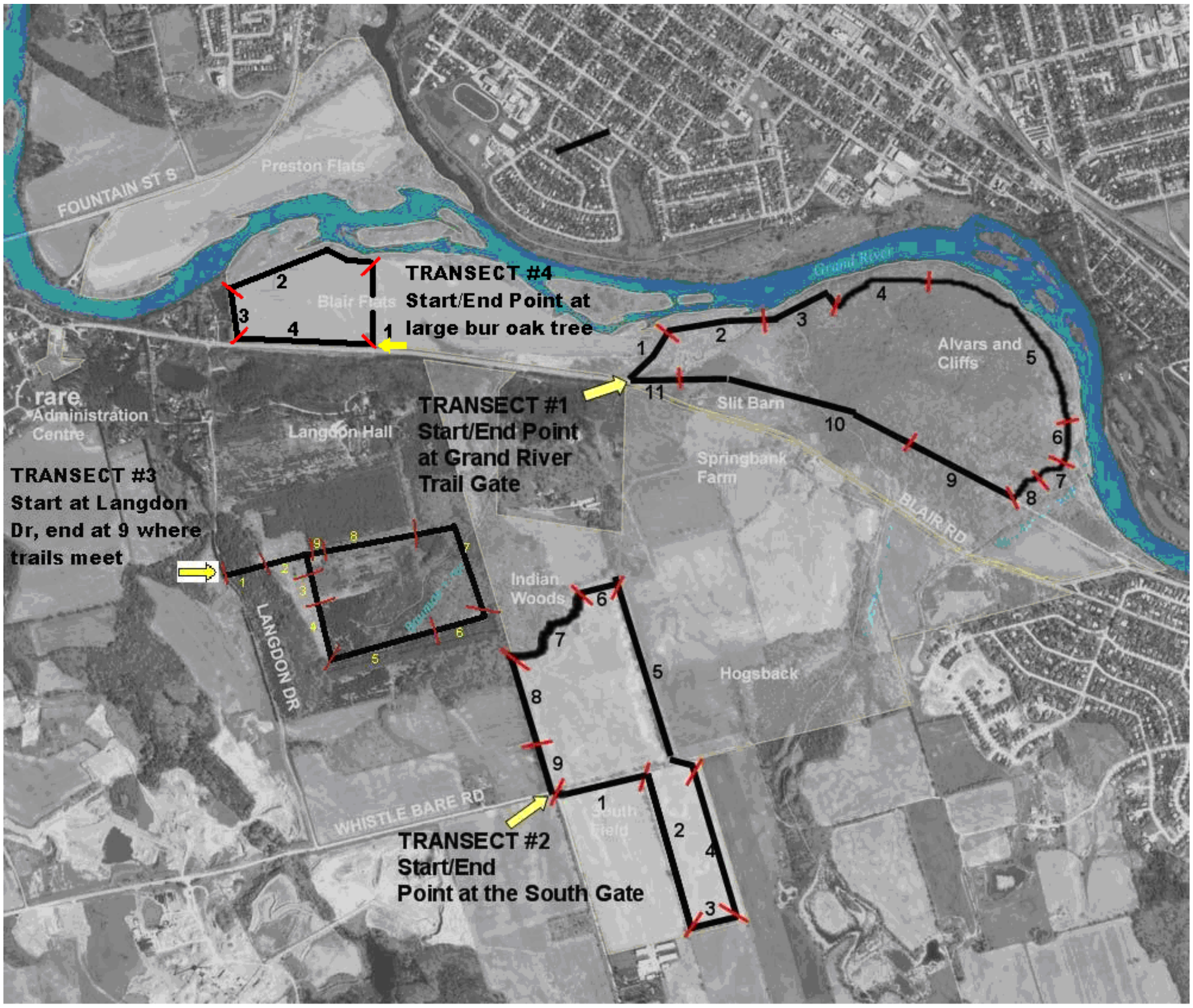


Figure B.1 Location and start/end descriptors of butterfly monitoring transects at *rare* Charitable Research Reserve (Moore 2010).

List B.1 Transect 1 - Butterfly section descriptions with coordinates (Moore 2010).

Section one (N 43° 22.980' W 80° 21.475')
- Grasslands
- Milkweeds
- Goldenrod

Section two (N 43° 23.053' W 80° 21.254')
- Riparian Meadow
- South side of transect- shrubs and trees

Section three (N 43° 23.053' W 80° 21.254')
- Riparian area with trees on south side
- Grasses/sedges
- Small shrubs
- Goldenrods

Section four (N 43° 23.119' W 80°21.037')
- Forest trail with open canopy areas
- Mainly conifers
- On cliffs

Section five (N 43° 22.966' W 80°20.605')
- Deciduous forest trail

Section six (N 43° 22.767' W 80°20.625'
- Open shrub land

Section seven (N 43° 23.016' W 80° 20.650')
- Deciduous forest trail

Section eight (N 43° 22.709' W 80° 20.694')
- Open shrub land

Section nine (N 43° 22.812' W 80° 20.892')
- Grand Trunk trail-deciduous forest

Section ten (N 43° 22.912' W 80° 21.303')
- Grand Trunk trail-dense shrub growth on both sides of trail

Section eleven (N 43° 22.927' W 80° 21.552')
- Wetland on either side of trail

List B.2 Transect 2 - Butterfly section descriptions with coordinates (Moore 2010).

Section one (N 43° 22.192’ W 080° 21.703’)

- Meadow-south side of transect
- Deciduous trees & shrubs- north side of transect
- Bordering a mix of alfalfa, red fescue, perennial wild rye, buckwheat, winter wheat, and oats field.

Section two (N 43° 22.043’ W 080° 21.555’)

- Hedgerow along a soy bean field edge
- Mostly open with some shrubs

Section three (N 43° 21.915’ W 080° 21.411’)

- Hedgerow of deciduous trees along a soy bean field edge

Section four (N 43° 22.058’ W 080° 21.401’)

- Open soy bean field

Section five (N 43° 22.359’ W 080° 21.585’)

- Deciduous hedgerow of mostly Oak spp.
- Bordering corn field on east side
- Bordering soy bean on west side

Section six (N 43° 22.551’ W 080° 21.735’)

- Hedgerow with deciduous trees, grapevines and tall grasses
- North of the transect is corn and south of transect is soy bean

Section seven (N 43° 22.459’ W 080° 21.855’)

- Meadow bordered by deciduous trees (Indian Woods) to the North and natural regeneration and soy bean to the south

Section eight (N 43° 22.296’ W 080° 21.888’)

- Hedgerow of deciduous trees, mostly maple bordering soy bean field
- Shady areas

Section nine (N 43° 22.215’ W 080° 21.861’)

- Hedgerow of shrubs, vines, and grasses bordering soy bean field

List B.3 Transect 3 - Butterfly section descriptions with coordinates (Moore 2010).

Section one (N 43° 22.342' W 080° 22.374')
- Coniferous forest – cedar, shrubs, ash
- Stop by swamp

Section two (N 43° 22.358' W 080° 22.282')
- Meadow species – milkweed, golden rod, grasses, sedges
- Stop at junction of trails

Section three (N 43° 22.324' W 080° 22.272')
- Black locust plantation and meadow
- Stop halfway

Section four (N 43° 22.280' W 080° 22.253')
- Meadow – milkweed, golden rod, grasses and sedges
- Spruce forest on east side
- Stop near single coniferous tree on west side

Section five (N 43° 22.254' W 080° 22.172')
- Spruce and deciduous forest
- Stop where wet area ends (will change from year to year)

Section six (N 43° 22.288' W 080° 22.230)
- Meadow – grasses and sedges
- Walnut plantation
- Stop halfway

Section seven (N 43° 22.374' W 080° 22.390')
- Langdon Hall trail
- Deciduous forest – sugar maple, beech and oak
- Woodland plants/flowers – may apple, solomon's seal, trillium, ferns
- Stop on cement bridge over Bauman Creek

Section eight (N 43° 22.373' W 080° 22.189')
- Laneway
- Deciduous forest – sugar maple, shrubs
- Stop near pile of logs

Section nine (N 43° 22.362' W 080° 22.267')
- Meadow – vetch, grasses and sedges
- Scattered trees and shrubs, golden rod

Stop halfway before the junction of trails

List B.4 Transect 4 - Butterfly section descriptions with coordinates (Moore 2010).

Section 1: (N 43° 23.470’ W 080° 22.187’)

- Weedy meadow planted for tall grass prairie, recovering from agricultural use
- Horseweed, Black-eyed Susan, goldenrod

Section 2: (N 43° 23.910’ W080° 22.294’)

- North side regeneration area, south side planted for tall grass prairie
- Horseweed, milkweed, goldenrod, thistles and burdock

Section 3 (N 43° 23.330’ W 080° 22.384’)

- East side planted for tall grass prairie, west side hedgerow of shrubs and trees

Section 4 (N 43° 23.020’ W 080° 22.283’)

- North side planted for tall grass prairie, south side hedgerow along Blair Road
- Horseweed, thistles, poison ivy, shrubs, Manitoba maple

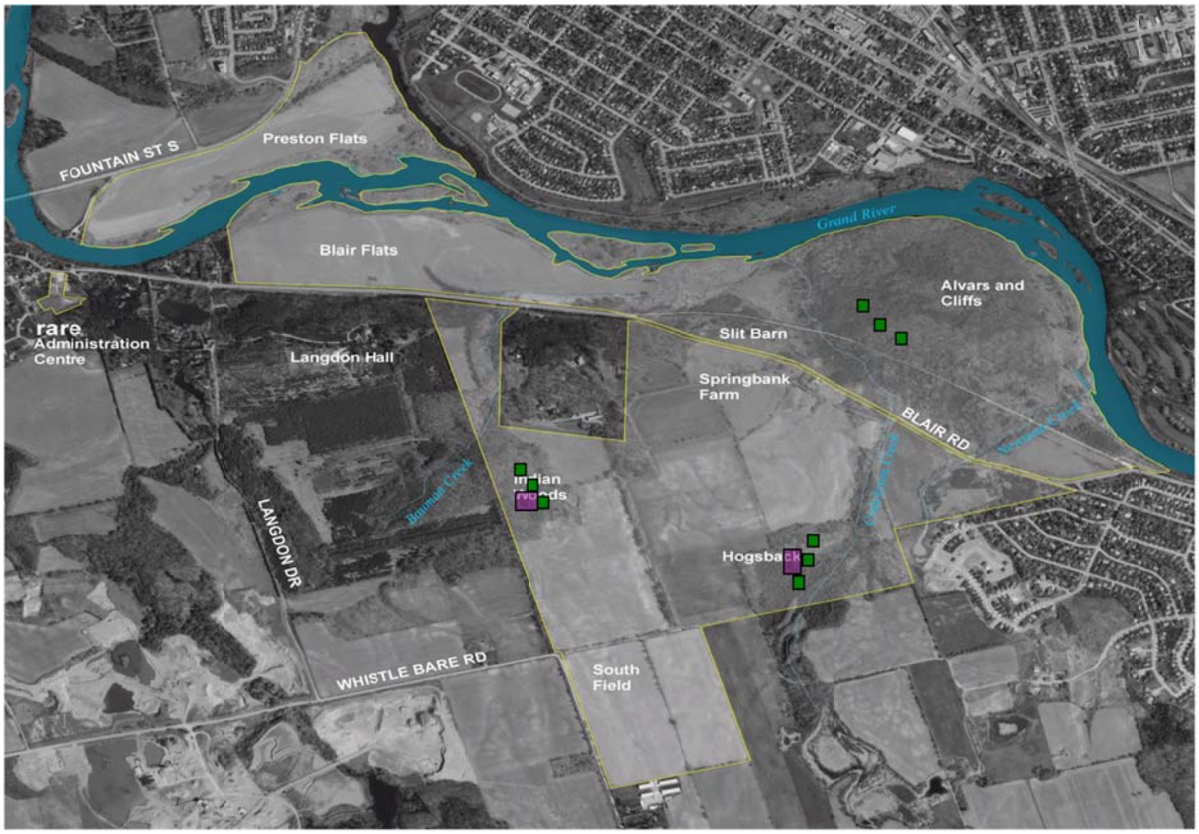


Figure B.2 Map of ***rare*** Charitable Research Reserve with locations of monitoring plots. Green squares represent forest canopy tree biodiversity and health monitoring plots. Purple rectangles represent the plethodontid salamander monitoring plots. Annual soil humus decay monitoring plots are associated with Cliffs and Alvars forest plot 1, Indian Woods forest plot 1, and Hogsback forest plot 1. Scale = 1:20,000.

Table B.1 Geographic coordinates of artificial cover objects used for plethodontid salamander monitoring in Indian Woods and the Hogsback (from McCarter, 2009).

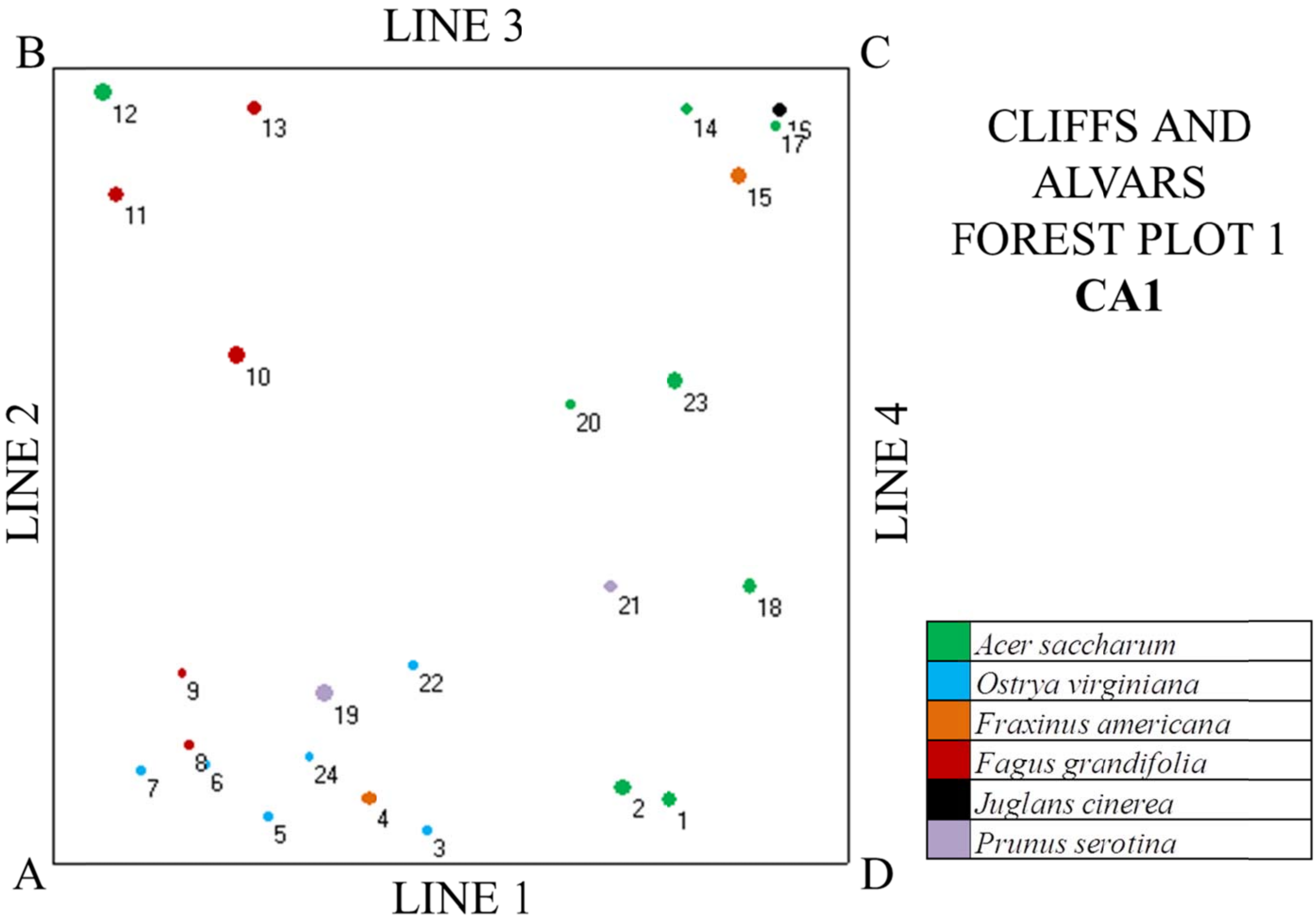
Monitoring Plot	ACO	Latitude and Longitude	UTM (zone 17T)
Indian Woods	1	N43°22'32.05" W80°21'55.49"	551408E 4802718N
	9	N43°22'31.97" W80°21'53.71"	551448E 4802716N
	17	N43°22'30.97" W80°21'53.63"	551450E 4802685N
	25	N43°22'30.85" W80°21'55.37"	551411E 4802681N
Hogsback	1	N43°22'23.93" W80°21'12.74"	552372E 4802475N
	8	N43°22'22.99" W80°21'13.32"	552359E 4802446N
	11	N43°22'22.44" W80°21'12.84"	552370E 4802429N
	18	N43°22'23.57" W80°21'12.30"	552382E 4802464N

Table B.2 Geographic coordinates of the forest canopy tree biodiversity and health monitoring plots in Cliffs and Alvars, Indian Woods, and the Hogsback (from Robson 2010). The coordinates describe the location of the northwest corner of each plot. The annual soil decay rate monitoring plots are located on all four corners of forest plot 1 in each of: Cliffs and Alvars, Indian Woods, and the Hogsback.

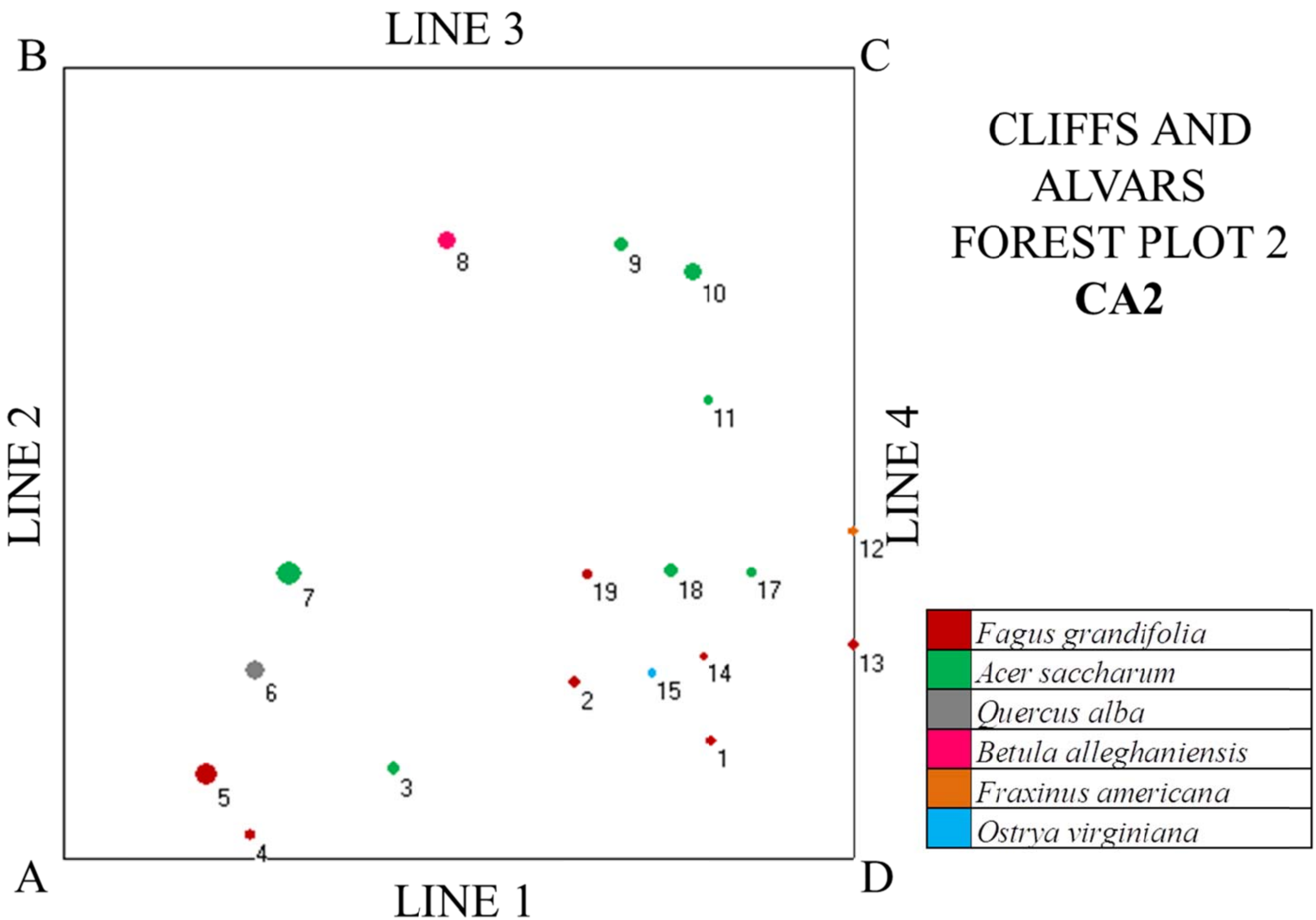
Forest	Plot	Latitude and Longitude	UTM (zone 17T)
Cliffs and Alvars	1	N43˚22’46.30” W80˚21’1.34”	552623E 4803167N
	2	N43˚22’44.64” W80˚21’0.21”	552649E 4803116N
	3	N43˚22’43.72” W80˚20’57.91”	552701E 4803088N
Indian Woods	1	N43˚22’27.27” W80˚21’51.45”	551500E 4802571N
	2	N43˚22’26.12” W80˚21’56.08”	551396E 4802535N
	3	N43˚22’23.62” W80˚21’54.78”	551426E 4802458N
Hogsback	1	N43˚22’24.18” W80˚21’11.10”	552409E 4802483N
	2	N43˚22’23.28” W80˚21’12.66”	552374E 4802455N
	3	N43˚22’22.08” W80˚21’14.46”	552334E 4802418N

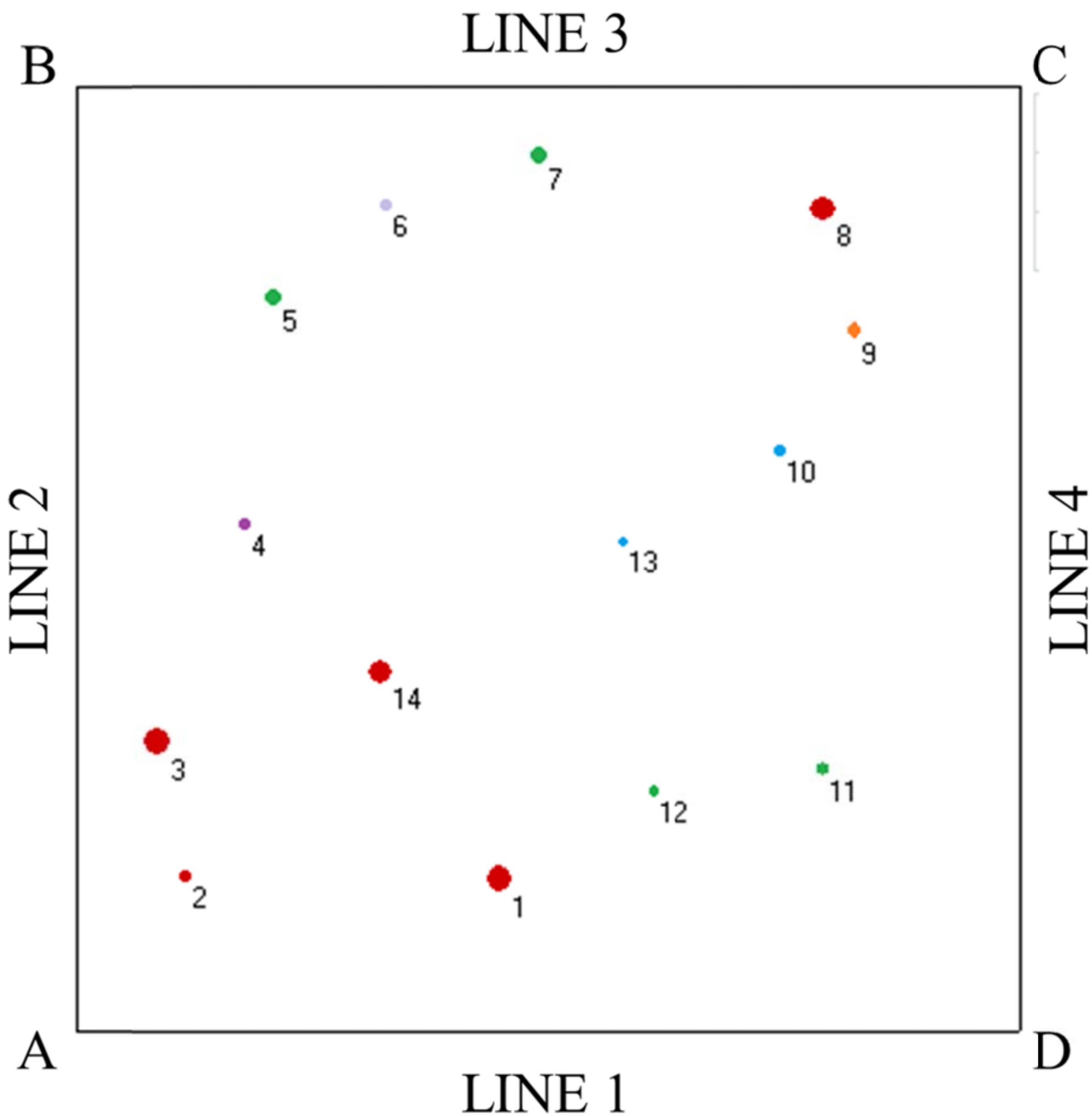
Figures B.3 through B.11 Maps of Cliffs and Alvars, Indian Woods, and the Hogsback forest biodiversity monitoring plots showing location of all standing, live trees with DBH > 10.0 cm (Pages 96-104). Sizes of circles are proportional to real tree diameters, colours indicate different species.

CLIFFS AND ALVARS FOREST PLOT 1
CA1

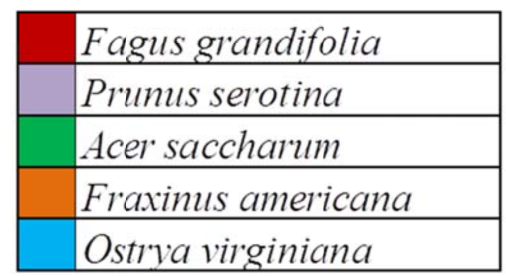


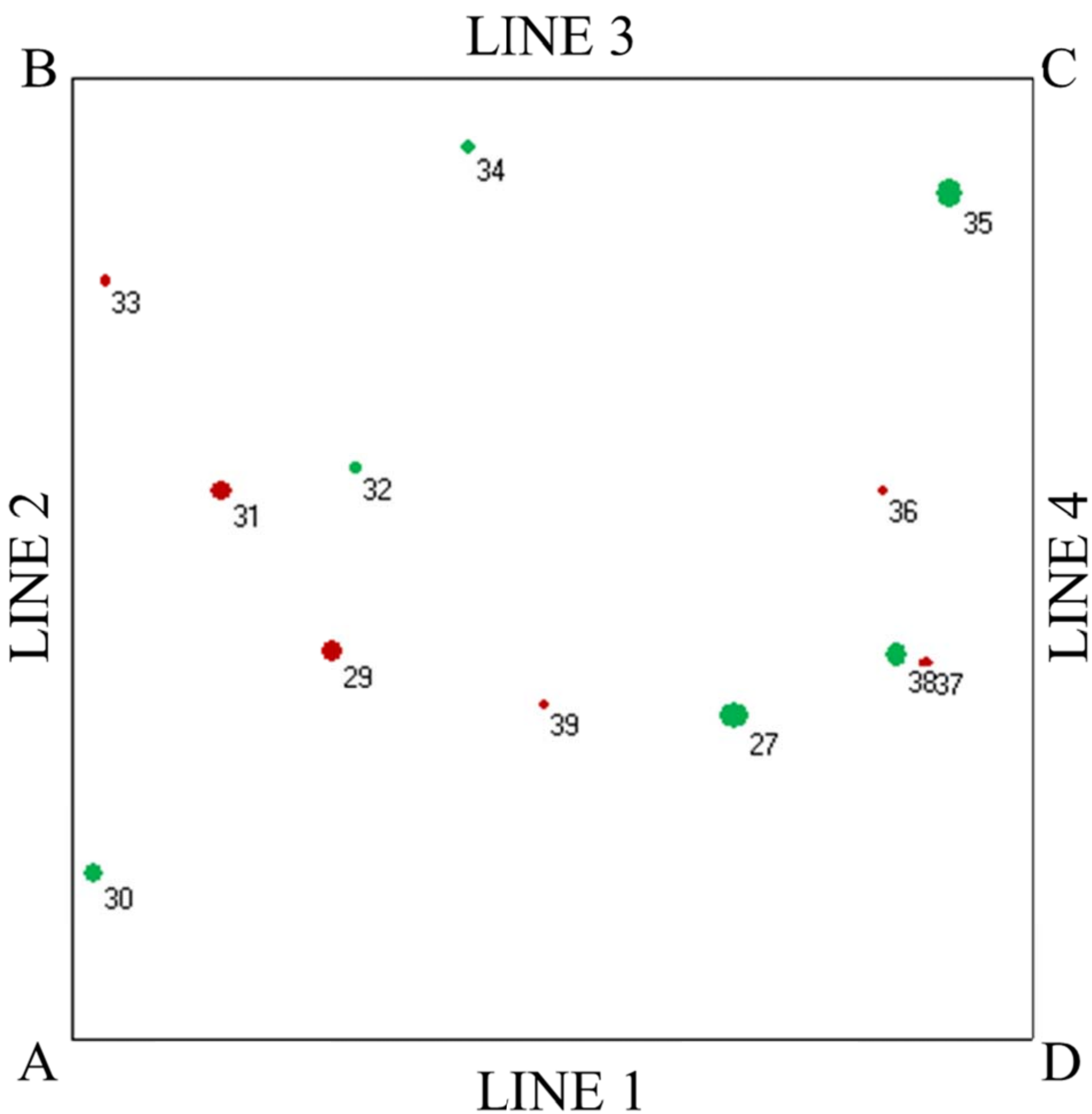
CLIFFS AND ALVARS FOREST PLOT 2
CA2





CLIFFS AND ALVARS FOREST PLOT 3
CA3

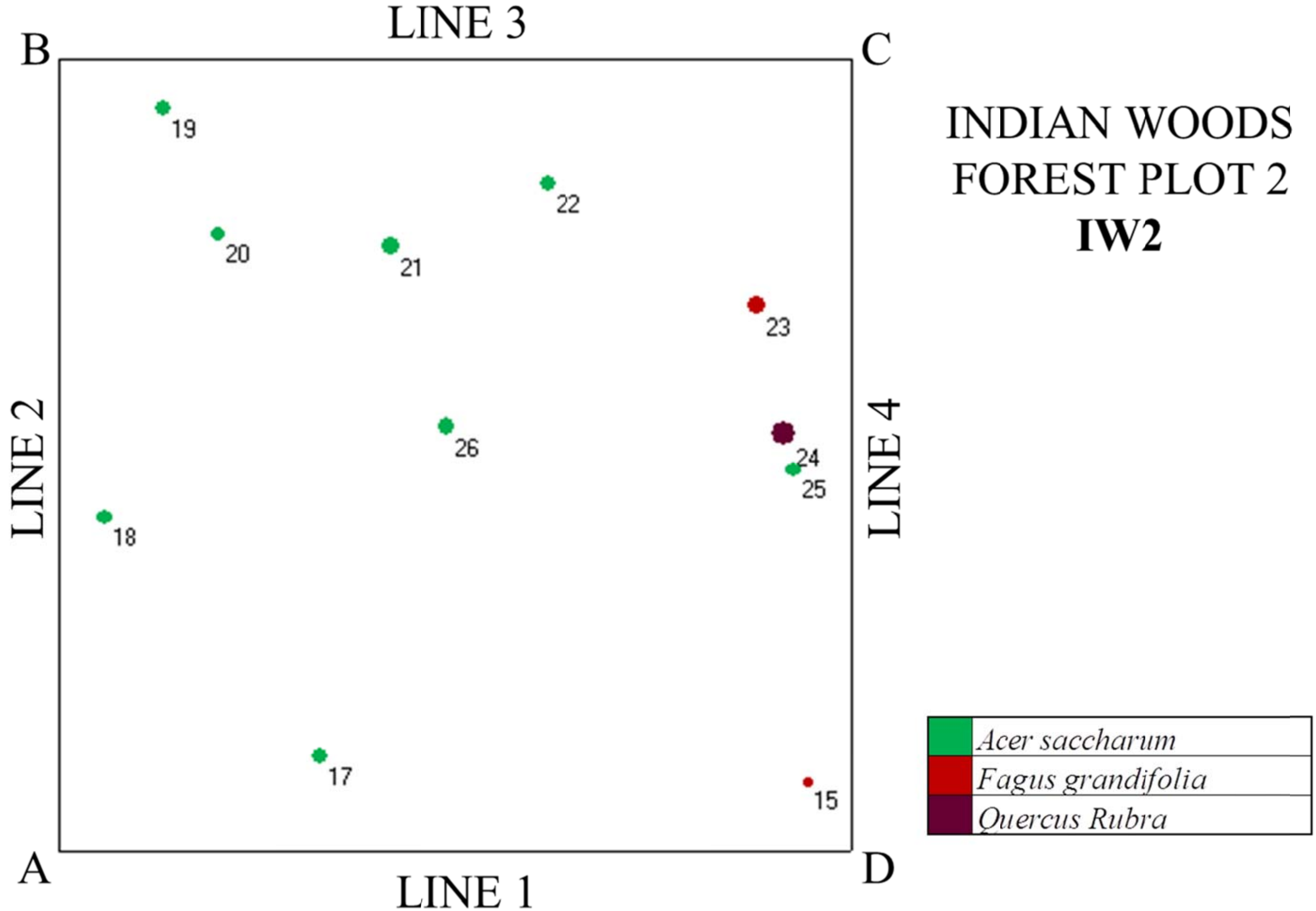




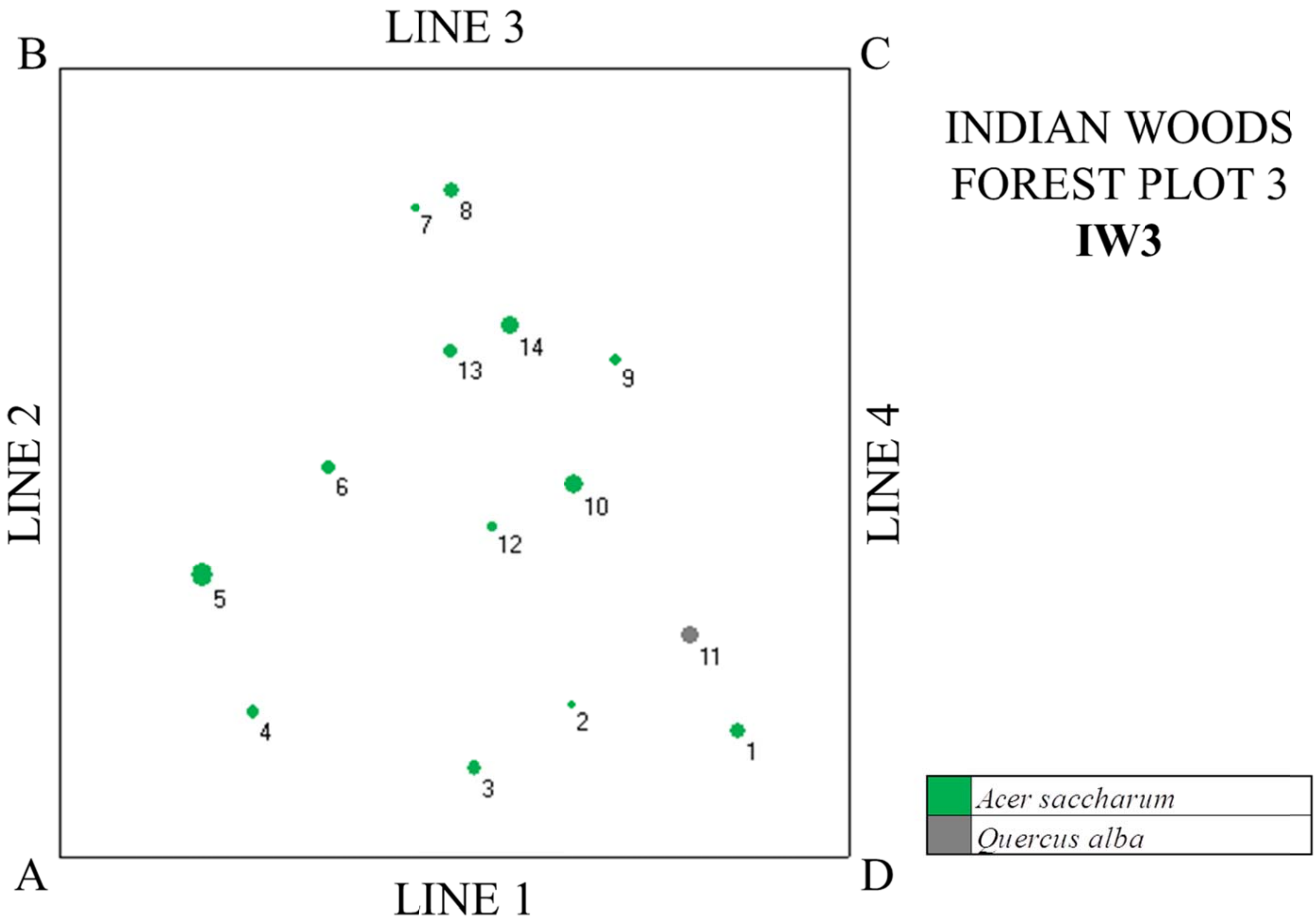
INDIAN WOODS
FOREST PLOT 1
IW1

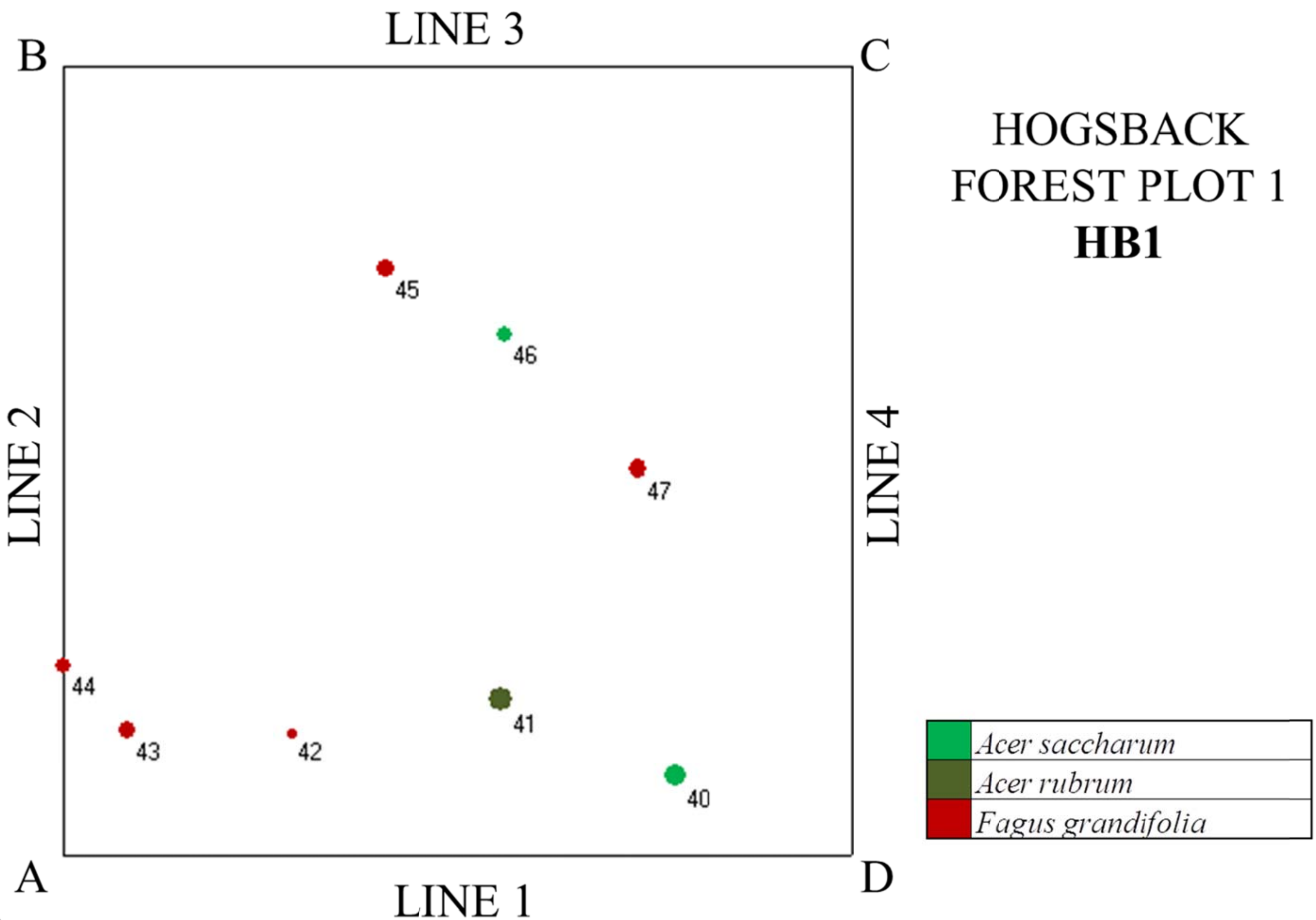
INDIAN WOODS FOREST PLOT 2

IW2

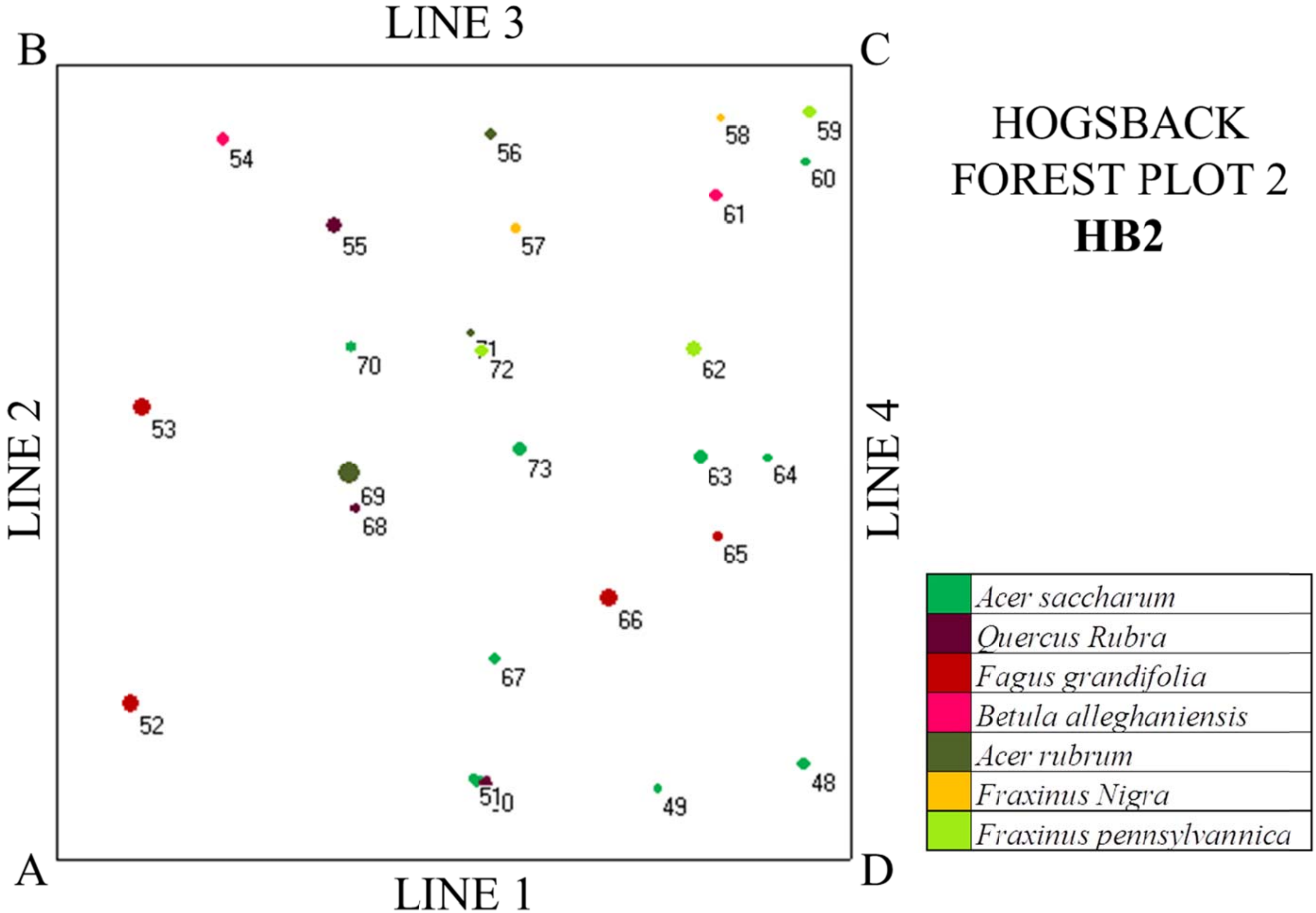


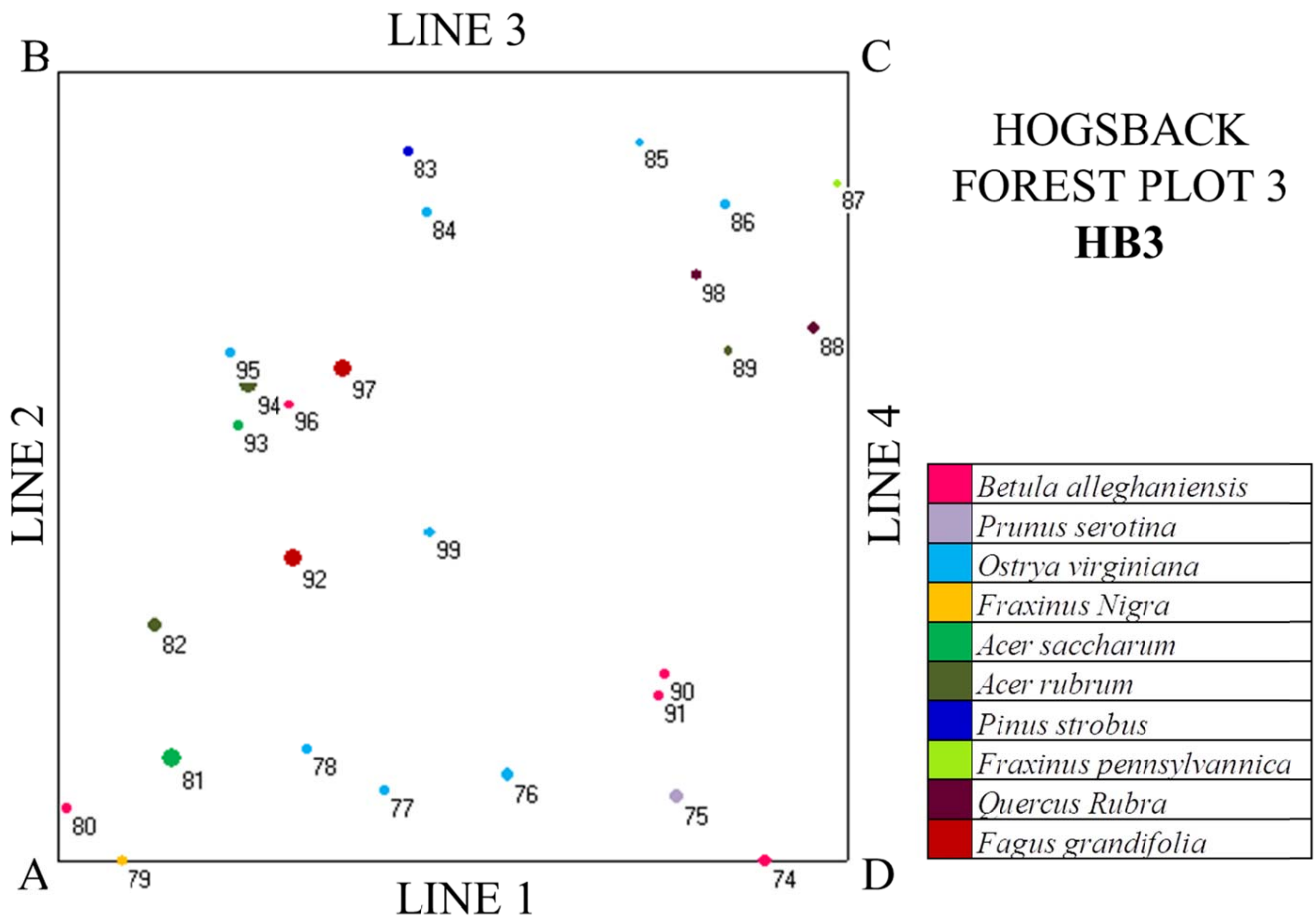
INDIAN WOODS FOREST PLOT 3
IW3




HOGSBACK
FOREST PLOT 1
HB1
LINE 3
LINE 2
LINE 4
LINE 1
A
B
C
D
45
46
47
44
43
42
41
40
Acer saccharum
Acer rubrum
Fagus grandifolia

HOGSBACK FOREST PLOT 2
HB2




HOGSBACK
FOREST PLOT 3
HB3
LINE 3
LINE 2
LINE 4
LINE 1
B
C
A
D
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
Betula alleghaniensis
Prunus serotina
Ostrya virginiana
Fraxinus Nigra
Acer saccharum
Acer rubrum
Pinus strobus
Fraxinus pennsylvannica
Quercus Rubra
Fagus grandifolia

APPENDIX C – EQUIPMENT LIST

List C.1 Butterfly Monitoring Equipment List

- Field Data Sheets (x1) and Clipboard
- Pencils
- Binoculars
- Field guides
- Jar with mesh lid
- Butterfly net
- Digital camera

List C.2 Salamander Monitoring Equipment List

- Field Data Sheets (x2) and Clipboard
- Pencils
- Nitrile gloves
- Kestral 3000 pocket weather station
- Soil moisture metre
- Screw driver to calibrate soil moisture metre
- Soil thermometer
- Digital calipers
- Ruler
- Digital pocket scale
- Spare batteries
- Sandwich sized tupperware filled with moist sponges
- Larger Tupperware with some moist sponges for salamander 'holding tank'
- Bottle of pond water from education pond behind Lamb's Inn
- Flagging tape
- Aluminum tags if ACOs need to be re-labelled
- Camera

List C.3 Soil pH Testing Equipment List

- Plastic ziplock bags (x36)
- Trowel
- Spoon
- Nitrile gloves
- Soil pH testing (don't need in field)

List C.4 Forest Canopy Tree Monitoring Equipment List

- Fresh Field Data Sheets (x2) and clipboard
- Past years Data Sheets to use as reference
- Pencils
- Flagging tape
- DBH tape
- Two nylon tape measures (30m)
- Field guide
- Binoculars
- Clinometer
- Pre-labelled tags and steel pigtails for new trees

List C.5 Decay Rate Monitoring Equipment List

Extraction

- Nitrile gloves
- Trowel
- Scissors
- Utility knife
- Envelopes or baggies to store sticks

Installation

- Nitrile gloves
- Shovel
- Field Data Sheets and clipboard
- Trowel
- Chisel
- Pigtails (x12/plot)
- Tongue depressors ('sticks') – pre-weighed and dried.
- Fishing line

APPENDIX D – FIELD DATA SHEETS AND CODES

Table D.1 Beaufort Wind Codes (Zorn et al. 2004)

Beaufort Scale	Wind Speed (mph)	Wind Speed (km/h)	Description
0	1	1.6	Calm. Smoke rises vertically
1	2	3.2	Light. Smoke drifts
2	5	8	Light breeze. Leaves rustle
3	10	16	Gentle breeze. Lighter branches sway
4	15	24	Moderate breeze. Dust rises. Branches move
5	21	33.6	Fresh breeze. Small trees sway
6	28	44.8	Strong breeze. Larger branches move
7	35	56	Moderate gale. Trees move
8	42	67.2	Fresh gale. Twigs break
9	50	80	Strong gale. Branches break
10	59	94.4	Whole gale. Trees fall
11	69	110.4	Storm. Violent blasts
12	75	120	Hurricane. Structures shake

Table D.2 Beauford Sky Codes (Zorn et al. 2004)

Sky Code	Description
0	Clear. No clouds at any level
1	Partly cloudy. Scattered or broken clouds
2	Cloudy (broken) or overcast
3	Sandstorm, dust storm, or blowing snow
4	Fog, thick dust or haze
5	Drizzle
6	Rain
7	Snow, or snow and rain mixed
8	Shower(s)
9	Thunderstorm(s)

Figure D.1 Sample of butterfly monitoring field sheet (available on server).

DATE:				START:			TEMP_START:		
TRANSECT:				FINISH:			TEMP_END:		
1				SUN:	2				SUN:
				WIND:					WIND:
3				SUN:	4				SUN:
				WIND:					WIND:
5				SUN:	6				SUN:
				WIND:					WIND:
NOTES:									

Figure D.2 Sample of salamander monitoring field sheet A (available on server).

Field Data Sheet A		
Plot Name:	Group Name: rare Charitable Research Reserve	
Observer Name(s):		
Pond depth (mm; Indian Woods):	Date:	Time:
Precip.(last 24hrs):	Beaufort Sky Code:	Beaufort Wind Code:

ACO			ACO		Soil		ACO
Number	Species	Count	Type	Age	Temp	Moisture	Disturbance
Additional Comments:							

	North Perimeter		**East Perimeter**		**South Perimeter**		**West Perimeter**	
ACO #								
WS (mph)								
RH (%)								
AT (°C)								

WS = Wind Speed RH = Relative Humidity AT = Air Temperature

Figure D.3 Sample of salamander monitoring field sheet B (available on server).

<table>
<tr><td colspan="8">Field Data Sheet B</td></tr>
<tr><td colspan="4">Plot Name:</td><td colspan="4">Group Name: rare Charitable Research Reserve</td></tr>
<tr><td colspan="8">Observer Name(s):</td></tr>
<tr><td colspan="4">Pond depth (Indian Woods):</td><td colspan="2">Date:</td><td colspan="2">Time:</td></tr>
<tr><td colspan="3">Precip.(last 24hrs):</td><td colspan="3">Beaufort Sky Code:</td><td colspan="2">Beaufort Wind Code:</td></tr>
<tr><td rowspan="2">ACO Number</td><td rowspan="2">Cumulative Number of Salamanders</td><td rowspan="2">Species</td><td colspan="3">Length (mm)</td><td rowspan="2">Weight (g)</td><td rowspan="2">Comments</td></tr>
<tr><td>S-V</td><td>V-T</td><td>Total</td></tr>
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<tr><td colspan="8">Additional Comments:</td></tr>
</table>

Figure D.4 Sample of forest canopy tree biodiversity monitoring sheet (available on server).

Canopy-Tree Sample: Field Data Sheet (20m x 20m stand-alone quadrats) Stand name: Date:

Stand Location: Plot no.: Avg. stand height:

Identification Manual: Observer(s):

Tag #	Species Name	Number of Stems	DBH (cm)	Line (1,2,3,4)	A distance (m)	B distance (m)	Height (m)	Condition	Notes

Figure D.5 Sample of forest canopy tree health monitoring field sheet (available on server).

Tree Condition Data Sheet

Site Name:	Date:	Observation Area Name and Description
Stand Location (lat/long):	Nearest Named Place:	
County/Township:	Province:	
Observer(s):	Observer Address: Telephone:	

Tree #	Species	DBH (cm)	Tree Status	Stem Defect 1		Stem Defect 2		Crown Class	Crown Rating	Comments
				Type	Location	Type	Location			

Figure D.6 Sample of annual soil humus decay rate monitoring field sheet (available on server).

Forest Plot ID:

Forest Plot Location (lat/long from NW corner):

Observer(s):

Stand	Plot	ADR Station	Tag #	Original weight (g)	Placement (s/ b)	Humus depth (cm)	Buried depth (cm)	Date Buried	Date Retrieved	Decayed weight (g)	% Stick Missing	Comments