

# **Habitat characteristics associated with redroot (*Lachnanthes caroliniana*) in Nova Scotia**

ENVS 4902 Environmental Science Undergraduate Honours Thesis

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## Abstract

Redroot (*Lachnanthes caroliniana* Lam.) is a member of the Atlantic Coastal Plain Flora (ACPF), a group of taxonomically unrelated plants occupying similar habitat types along the eastern coast of North America. These species are typically poor competitors, and thus thrive in very specific nutrient-poor and high-disturbance environments. Redroot has been listed as “threatened” under the Nova Scotia Endangered Species Act and as a COSEWIC Species of Special Concern, and gaining a greater understanding of its habitat is one of the key conservation goals listed in management plans for the species. Therefore, this study examined the shoreline characteristics, vegetation structure, and interspecific interactions associated with redroot. In the summer of 2015, transects and grids were established at seven lakes in southwestern Nova Scotia, measuring the abundance of redroot and other vegetation, as well as substrate type and elevation. Redroot was found to grow in patches along the first 5 m of shorelines, well within the zone of disturbance from periodic flooding, wave action and ice scour. These disturbances limit the encroachment of woody species which would otherwise outcompete redroot. Redroot abundance increased significantly with decreasing lake area, increasing watershed area to lake area ratio, and increasing amounts of gravel on shorelines. Since flowering is rare in Nova Scotia, and the species is limited to asexual reproduction through rhizome fragmentation, lake connectivity is also thought to be a critical habitat component. The covariation of redroot with other species of ACPF was highly variable between sites, but showed that the direction and magnitude of redroot’s interspecific interactions change depending on the spatial scale at which they are examined. This study confirms habitat trends described in the 2010 COSEWIC status report and complements them through an increased understanding of redroot’s habitat characteristics on the microhabitat scale. These findings can be used to determine suitable regions which could be protected in order to prevent the extirpation of the species.

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## 1.0 Introduction

The Atlantic Coastal Plain Flora (ACPF) are a unique group of taxonomically unrelated plants including flowering plants, shrubs, and herbs that occupy similar habitat types along the Atlantic Coastal Plain (Wisheu and Keddy 1989, 1994). They are fundamental in maintaining healthy and functional ecosystems, as well as delivering ecosystem services such as the provision of clean air and water, flooding regulation, the reduction of sediment erosion and the provision of food and habitat for many species of wildlife (Hill et al. 1998; Belliveau 2011). ACPF are thought to be weak competitors, but well-adapted to disturbance and stress, and so typically only occur in low nutrient and/or high natural disturbance environments (Wisheu and Keddy 1994; Hill and Keddy 1992). Because of their low competitive ability, their continued survival depends on the availability and preservation of habitats that meet their specific environmental requirements.

The range of ACPF extends along the Atlantic Coast, from Florida north to Maine (Wisheu and Keddy 1989; Fig. 1). There are also disjunct populations which occur in Michigan, Wisconsin, Ontario, and Nova Scotia (Fig. 1). The intensifying development of the eastern seaboard of the United States has led to the destruction of about 50% of ACPF habitat, creating a mounting threat to American populations (Wisheu and Keddy 1989, 1994; Francis and Munro 1994). This amplifies the importance of the contribution to ACPF conservation that can be made by Nova Scotia, which has one of the last large, relatively undisturbed populations of ACPF in the world (Francis and Munro 1994; Wisheu et al. 1994). As intensifying development threatens the remaining American populations, conservation of suitable habitat in Nova Scotia becomes increasingly essential to the preservation of ACPF.

Nova Scotia is home to 90 ACPF species, 11 of which are legally listed under the Species at Risk Act (SARA) and the Nova Scotia Endangered Species Act (NS ESA) (Environment Canada and Parks Canada 2010). Among these is the species *Lachnanthes caroliniana* (Lam.) Dandy, commonly known as redroot, which has been listed as “threatened” under the NS ESA and as a SARA species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Species At Risk 2015). One factor in redroot’s conservation status designations is its limited distribution; the entire Canadian range of redroot consists of only 8 lakes within Queens County, Nova Scotia (Fig. 2). The main threat to redroot comes from continuing shoreline modification of these lakes due mainly to cottage and residential development (COSEWIC 2002), highlighting the importance of designating protected areas free of human interference to conserve redroot’s remaining habitat.



**Figure 1.** The distribution of Atlantic Coastal Plain Flora (Nova Scotia's Atlantic Coastal Plain Flora Recovery and Stewardship 2010).

In its recovery plan, Environment Canada and Parks Canada (2010) state that continued information acquisition is one of the most important components of preserving redroot. Within information acquisition, two high priority goals are: updated assessments of abundance, distribution and habitat suitability, and research on key habitat characteristics required to identify critical habitat (Environment Canada and Parks Canada 2010). Recognizing habitat characteristics is imperative because the various habitat components dictate where a plant can and cannot grow, both as limitations to a plant's distribution as well as a source of resources necessary to a plant's survival (Smith and Smith 2001). To conserve and to promote the growth of redroot, we need a greater understanding of the plant and its relationship to the environmental features of the sites at which it is found. Therefore, this study examines the associations of redroot with both biotic and abiotic habitat characteristics in southwestern Nova Scotia.



**Figure 2.** The Canadian range of redroot (*Lachnanthes caroliniana*), as indicated by the red lakes. The grid lines represent 0.25 degrees of latitude by 0.5 degrees of longitude (COSEWIC 2009).



The objective of my study is to further the understanding of the habitat characteristics associated with redroot populations in Nova Scotia. Identification of the biotic and abiotic environmental components most strongly associated with redroot can help distinguish key elements that should be present in protected areas designated for species conservation, and identify possible sites where redroot might thrive in the future, whether by natural dispersal or by human introduction.

The research question of this study is: What abiotic and biotic characteristics are associated with redroot distribution in Nova Scotia? Sub-questions include:

A: What forms of vegetation structure are associated with redroot?

B: What soil and lakeshore attributes are associated with redroot?

C: Which other ACPF species have positive or negative associations with redroot, and at which spatial scales?

The abiotic and biotic characteristics associated with redroot in Nova Scotia were explored at different spatial scales through spatial pattern analysis of data collected in the summer of 2015. These findings will facilitate a better appreciation of the habitat that needs to be conserved in order to safeguard redroot populations in Nova Scotia.

## **2.0 Literature Review**

There is a fairly extensive existing body of knowledge regarding Atlantic Coastal Plain Flora and their habitat, yet there is little published research focusing specifically on redroot. Conservation status reports are therefore the main sources of information regarding redroot distribution in Nova Scotia. There are several shortcomings, however, in these reports'

evaluation of redroot habitat, such as a lack of inclusion of biological components and a lack of examination of the microhabitat scale. This review should help illuminate the current understanding of ACPF, redroot, and their habitats, while identifying some of the key knowledge gaps where a further understanding of redroot and its habitat characteristics could be achieved.

## **2.1 Atlantic Coastal Plain Flora**

Redroot is a member of the Atlantic Coastal Plain Flora (ACPF), a group of unrelated flowering plants, herbs and shrubs that share common lakeshore and wetland habitat types along the eastern coast of North America. ACPF are both an important source of biodiversity and key components in the provision of ecosystem goods and services (Environment Canada and Parks Canada 2010). ACPF play a fundamental role in maintaining healthy and functional ecosystems; they assist in providing clean air and water, regulating flooding, reducing soil erosion and cycling nutrients throughout the ecosystem (Hill et al. 1998; Belliveau 2011). Many species of ACPF are flowering plants, providing millions of flowers for pollinators (Belliveau 2011). ACPF also offer important sources of food, shelter and reproductive sites to numerous species of invertebrates, fish, reptiles, amphibians, and migratory birds (Environment Canada and Parks Canada 2010). The presence of ACPF not only increases biodiversity, but also contributes to a myriad of ecological processes such as water filtration and nutrient retention and cycling, which benefit the ecosystem as a whole.

Populations of ACPF species have been extensively recorded over the years, both in their native range as well as in peripheral populations. A variety of research has documented ACPF species in the center of their natural range, which is typically considered to extend along the eastern coast of the United States from Florida to Maine (Wisheu and Keddy 1989; Estill and Cruzan 2001); ACPF communities have been examined in Virginia (Carr 1965; Plunkett and

Hall 1995), in coastal ponds in New England (Sorrie 1994), along pondshores in New York (Zaremba and Lamont 1993) and in regions of North Carolina (Elam et al. 2009). Furthermore, ACPF populations have been noted in multi-state inventories of plant communities conducted throughout the southeastern United States, including Florida, Georgia, North and South Carolina, Alabama, West Virginia, and Tennessee (Estill and Cruzan 2001; McMillan et al. 2002).

Although many studies have recorded the prevalence of ACPF throughout their typical coastal range, there are also numerous directed investigations of disjunct populations of the floral group. Reznicek (1994) provides an excellent summary of the findings within the Great Lakes region, which includes certain populations of ACPF within central and northern Wisconsin (McLaughlin 1932; Tans 1983), as well as within the southern Canadian Shield just east of southern Georgian Bay, Ontario (Reznicek and Whiting 1976; Keddy 1981; Keddy and Reznicek 1982; Keddy and Sharp 1989). The first survey of ACPF populations in Nova Scotia was conducted in 1989 by Wisheu and Keddy (1989). Since then, many studies have expanded on their work, and have found ACPF to be quite prevalent within forested wetlands, salt marshes, and, most commonly, along forested lakeshores in the southwestern part of the province (Hill and Keddy 1992; Wisheu and Keddy 1994; Wisheu et al. 1994; Good-Avila et al. 2006; Environment Canada and Parks Canada 2010). Whereas ACPF populations have been recorded incidentally in many vegetation surveys within the eastern United States, targeted studies of ACPF have been the source of information regarding their peripheral populations in the Great Lakes and Nova Scotia.

The study of these disjunct populations is invaluable to the conservation of the species because of their divergence from central populations. Peripheral populations are expected to diverge from central populations as a result of the mix of isolation, genetic drift, and natural selection (Lesica and Allendorf 1995). Good-Avila et al. (2006) found that divergent selection

pressures were operating in ACPF species between northern and southern populations. For example, individuals at the southern portion of their ranges invest more in sexual reproduction and are therefore selected based on their ability to entice pollinators, whereas those at the northern end of their range tend to be selected based on their ability to withstand harsh conditions. These conflicting selection pressures can often lead to genetic and morphological differences between disjunct and central populations (Lesica and Allendorf 1995). Since these genetically distinct populations can help generate future evolutionary diversity, their protection is crucial to the long-term conservation of the species (Lesica and Allendorf 1995; Environment Canada and Parks Canada 2010). Moreover, disjunct populations are potentially important sites of future speciation events (Lesica and Allendorf 1995) which may result from diverging selection pressures. Thus, it is clear that understanding the populations and ecosystem dynamics of peripheral populations of ACPF is critical to their conservation.

## **2.2 Role of Disturbance**

In Nova Scotia, ACPF are most often encountered along the shores of lakes in the southwestern region of the province. In these lakeshore habitats, many processes affect plant community structure (Hill and Keddy 1992); lakeshores experience physical disturbance from fluvial processes such as water level fluctuations, periodic flooding, wave action, wind action, alluvial deposition, mass soil movement, and ice movement (Fetherston et al. 1995; Morris et al. 2002). Exposure to waves, wind, and ice can damage plants directly, or hinder them indirectly due to resulting processes such as soil erosion and soil impoverishment (Schneider 1994; Morris et al. 2002). Since physical disturbance from fluvial processes is known to influence vegetation characteristics (Fetherston et al. 1995), and most fluvial processes are related to lake size and watershed area (Morris et al. 2002), both lake area and the watershed area to lake area ratio are

essential components in determining habitat suitability. Similarly, Nilsson and Wilson (1991) found that water depth could be considered a principal factor controlling the structure of lakeshore plant communities. Hill and Keddy (1992) concurred, but expanded on these findings, suggesting that species richness was most highly correlated with both watershed area and shoreline width. The amount of water present in a region and the associated physical processes clearly have a large role in determining the vegetation that inhabit lakeshores.

Lakeshore disturbances have been proven to be a crucial habitat characteristic for ACPF species. ACPF are known to typically be weak competitors in the acquisition of light and nutrients, but compensate for this with a high tolerance to both stress and disturbance (Wisheu and Keddy 1989, 1994). Since they are such poor competitors, ACPF are commonly found in areas with high disturbance and/or high stress that prevent the establishment of competitive dominants (Keddy 1985; Wisheu and Keddy 1989; Hill and Keddy 1991). Wave action and ice-scour limit the encroachment of woody plants into these habitats, protecting rare coastal plain species from being crowded out by more competitive species (Hill and Keddy 1992). Additionally, high wave action, ice scour, and periodic flooding all contribute to the removal of organic matter and the creation of low-nutrient habitats, which many competing species cannot tolerate (Hill and Keddy 1992; Schneider 1994; Wisheu and Keddy 1994; Wisheu et al. 1994). Disturbance- and stress-adapted ACPF thrive in these environments where they no longer have to vie for light or nutrients with more competitive but less tolerant species. Thus, disturbance is critical in creating an ecological niche for ACPF species. Moreover, the fluvial processes of the lakes aid in ACPF propagation. Wave action and ice scour can dislodge and transport pieces of soil, seeds and plants, allowing them to colonize new shorelines and establish additional populations (Hill et al. 1998; Environment Canada and Parks Canada 2010). Although

disturbance is most important for ACPF in terms of its elimination of competitors, disturbance also facilitates the reproduction and dispersal of ACPF populations. Understanding disturbances and their influence on ACPF is therefore critical in promoting their conservation.

### **2.3 Spatial Patterns**

Vegetation spatial patterns are the physical arrangements in space of patches of or individual plants which display a certain amount of predictability, where predictability is defined as some form of periodicity (Dale 1999). The spatial association of two species of plants occupying the same shoreline can be positive, where they tend to be found together, or it can be negative where they tend to be found apart. These spatial associations can have a variety of causes, including influence and ecological coincidence (Smith and Smith 2001; Fortin et al. 2002). Ecological coincidence refers to cases in which similar or divergent ecological requirements or tolerances drive plants of different species to grow either close together or far apart. Influence refers to the phenomenon where the presence of one species alters the environment sufficiently to have a direct impact on the occurrence of other species.

Influence can be positive, such as nurse plants which provide habitat for other plants, or negative, such as plants which compete for nutrients in the soil (Smith and Smith 2001). These associations can vary depending on the scale under which they are examined. For example, competition between species that are ecologically similar would result in the species being negatively associated at small distances (due to local competition effects), but positively associated at greater distances, since they flourish under similar environmental conditions (Dale 2002; Callaway 2007). It is therefore beneficial to evaluate relationships at multiple spatial scales when possible.

Because the spatial pattern of one species can have many impacts on the distribution of concomitant species, spatial pattern analysis is crucial for understanding the species of interest as well as other associated species. The structure and organization of plant communities depends on plants' locations in space, and thus, spatial pattern is a critical part of understanding the underlying mechanisms of ecosystems (Rees et al. 1996). Therefore, spatial pattern analysis is an integral process in determining critical habitat.

## **2.4 Redroot**

Redroot, or *Lachnanthes caroliniana* (Lam.) Dandy, is one of the 90 species of ACPF found in Nova Scotia. Redroot is the only species in the genus *Lachnanthes*, and is also the only species in the Haemodoraceae family that occurs in North America (Keddy 1994). It is an herbaceous perennial with yellow-green basal leaves that grow 10 to 80 cm in height, and is easily identified by its bright red rhizomes (Scoggan 1978). Although the plant can reproduce sexually, flowering is very rare in the Nova Scotia subpopulation (Wisheu et al. 1994). Instead, asexual reproduction through new growths from its namesake rhizomes is the most common form of propagation in the harsher Nova Scotia environment (Keddy 1994). This divergence in reproductive strategy is common of peripheral populations (Lesica and Allendorf 1995; Good-Avila et al. 2006). Redroot is easily recognizable and, despite differences in reproductive strategy, there has never been any dispute regarding its taxonomic status as a single but distinct species (COSEWIC 2009).

Very little of the published literature considers redroot directly. It has, however, frequently been recorded incidentally as part of floristic studies of wetlands along the eastern coast of the United States. Studies documenting populations of redroot have found them on shorelines in the Carolina Bays (Landers et al. 1976; Tyndall et al. 1990; Tyndall 2000), in deep

and shallow marshes of the Okefenokee swamp in northern Florida and southern Georgia (Cypert 1972), and in seasonal ponds and “cypress domes” in Florida (Robertson et al. 1998; Landman and Menges 1999). Redroot has also been recorded along ponds and in flatwood savannas in Louisiana (Keddy et al. 2006), and along shorelines of Long Island (Zaremba and Lamont 1993) and Cape Cod (Craine and Orians 2004). In a completely different perspective, some of the existing literature focuses on redroot and its classification as a weed. For example, redroot is considered a troublesome weed in New Jersey cranberry bogs (Meggitt and Aldrich 1959) and in North Carolina blueberry fields (Meyers et al. 2013). It is also considered problematic in terms of its ability to invade and to take over newly established or disturbed pastures in Florida (Ferrell et al. 2009). Although rare and protected in Nova Scotia, it is clear that many studies have found redroot to be quite prevalent, and even overly abundant, in other parts of its range.

In terms of its Canadian range, the published literature contains only one detailed description of redroot and its habitat in Nova Scotia. This report was prepared by Wisheu et al. (1994) from surveys of the Ponhook Lake and Molega Lake populations. It established that redroot could be found on a variety of shoreline substrates from boulder to pebble beaches (Wisheu et al. 1994), but was most common on southwest-facing windward shores of cobble or peat. The orientation of the shorelines was found to be quite important, as increased wind and wave action made broader shores, decreased soil fertility, reduced competition, and increased exposure to sunlight, a crucial feature for a southern species such as redroot (Keddy and Reznicek 1982; Wisheu et al. 1994). Along these shores, redroot most commonly grew 15-100 cm above the August water line and more than 50 cm horizontally from the water’s edge. Although they counted tens of thousands of individual plants, the report authors found only 200



plants in flower; these rare flowering individuals were always found near the upper limit of the shoreline distribution (Wisheu et al. 1994). The study also found that redroot abundance was dependent on shoreline width, with larger populations occurring on broader, more gently sloping shores. Wisheu et al. (1994) reported that plants typically associated with redroot included isoetids, carnivorous species, *Cladium mariscoides*, and other rare species such as *Lophiola aurea* and *Scirpus longii*. Although redroot was thoroughly assessed in this study, there is little else in the published literature to corroborate the findings.

Government reports regarding the conservation status of redroot, however, provide an updated source of insight into redroot abundance in Nova Scotia. Most of Wisheu et al.'s (1994) findings were confirmed in the most recent evaluation of redroot and its habitat characteristics, which occurred as part of the 2009 COSEWIC report that determined the legislative status of redroot (COSEWIC 2009). This report confirmed the presence of redroot on the large Ponhook and Molega lakes, as well as on several nearby smaller lakes including Little Ponhook, First Christopher, Beartrap, Cameron, Hog, and Beavertail lakes (COSEWIC 2009). Across these eight lakes, the extent of occurrence was 117 km<sup>2</sup>, but the plants themselves occupied less than 1.24 km<sup>2</sup> of actual habitat (COSEWIC 2009). Like Wisheu et al. (1994), the 2009 COSEWIC report observed that larger populations tend to occur on broader, more gently sloping lake shores. Similarly, both the COSEWIC (2009) report and the Atlantic Coastal Plain Recovery Strategy (Environment Canada and Parks Canada 2010) found that in Nova Scotia, redroot is most commonly found in nutrient-poor soil on windward shores made up of cobble, gravel, or peat. They also found that natural disturbance, particularly fluctuating water levels, were integral to the presence of the species. Finally, the COSEWIC (2009) report included a much more extensive list of all the species with which redroot was commonly found. Although not a peer

reviewed article, the COSEWIC (2009) report on the status of redroot provides the most extensive and in-depth understanding of redroot and the habitat in which it is found.

Redroot's small distribution in Nova Scotia may be due to its limited dispersal abilities. As mentioned, flowering individuals are extremely rare in Nova Scotia (Wisheu et al. 1994). On flowering individuals, the small seeds possess no features to indicate that they are dispersed by animal vectors or carried by the wind (COSEWIC 2009). Thus, the seeds are likely locally dispersed by gravity and possibly carried by water. Limited seed production due to the infrequency of flowering and poor seed dispersal mechanisms is likely a restrictive factor in redroot's ability to colonize new territory. Instead, redroot in Nova Scotia likely relies on wave action and ice scouring to dislodge and transport intact plants or viable rhizome fragments to new locations (Environment Canada and Parks Canada 2010). While this may somewhat impede redroot's ability to spread to new habitats, it can also be considered an opportunity for viable transplantation. Populations of redroot in Nova Scotia clearly rely heavily on propagation through asexual reproduction and dispersal by water, which may be a limiting factor in their distribution (Wisheu et al. 1994; COSEWIC 2009). Nonetheless, adaptation to disturbance and the regenerative ability of the rhizomes may also present a conservation opportunity by facilitating transplantation of the species to previously unoccupied habitats.

Within the small body of literature, there is nothing to suggest that herbivory is a major component of the ecological restrictions of the plant within Nova Scotia. In other regions, where redroot is much more abundant, the species is known to be an important food source for ducks (Landers et al. 1976). However, no signs of substantial herbivory were detected during field surveys of the species in Nova Scotia (COSEWIC 2009). The lack of herbivory is likely due to photodynamic toxins contained within the plant, which presumably limit herbivory by insects

and at least some vertebrates (Kornfeld and Edwards 1972; Edwards and Weiss 1974). These toxins do not, however, seem to have any effects on waterfowl (Landers et al. 1976). These findings seem to indicate that something other than herbivory limits redroot abundance in the province.

Whereas herbivory does not seem to be threatening redroot populations, anthropogenic influence certainly is a threat. Activities such as off-road vehicle use, agricultural and forest harvesting practices, and dam construction and operation cause habitat loss and degradation as well as perturbations to natural ecological processes (Environment Canada and Parks Canada 2010). Nevertheless, the greatest threat to redroot in Nova Scotia is shoreline development. In Nova Scotia, lakeshores are being altered by the construction of cottages and their associated docks, boat launches, patios, and swimming areas (COSEWIC 2009). Based on the location of the redroot populations, there are likely several hundred cottages with redroot on their properties, and the increasing levels of development mean that this number will continue to rise. The COSEWIC (2009) report estimates that 89% of available redroot habitat is owned privately. Where redroot populations and development coincide, there is most often some loss of redroot populations and habitat (Francis and Munro 1994). New development and the intensification and expansion of existing development are both likely to continue, causing a slow decline in redroot populations and habitat quality throughout the foreseeable future (Environment Canada and Parks Canada 2010). Fortunately, in many cases, relatively undisturbed portions of shoreline are left between adjacent cottages. Due to this spacing of developments and the resilience of the plant, shoreline development is unlikely to entirely eliminate redroot from any of the lakes on which it occurs (COSEWIC 2009). Redroot habitat seems to coincide with the ideal cottage location, and whereas several human activities such as farming may degrade redroot habitat,

continued recreational development of shorelines poses the most significant threat to redroot populations in Nova Scotia.

## **2.5 Knowledge gaps**

Although several studies have described how disturbance prevents redroot from being out-competed by more competitive species (e.g., shrubs, Hill and Keddy 1992; Schneider 1994), little else has been done to examine the roles of other forms of vegetation in determining habitat suitability. There is very little research that investigates the role of vegetation structure in modifying abiotic characteristics of redroot habitat, such as shading provided by trees. Additionally, little has been done to categorize redroot's ecological interactions such as competition or facilitation with other species of ACPF. Past studies have noted a wide range of plants that coexist with redroot, including *Drosera spp.* and *Sarracenia purpurea* (Wisheu et al. 1994), *Cladium mariscoides*, *Euthamia caroliniana*, *Viola lanceolata*, *Xyris difformis* and *Lycopodiella appressa* (COSEWIC 2009), but their relative abundance and influence on redroot have not been quantified in any way. Uncovering these species associations could determine how protecting the habitat of other plants might be beneficial or detrimental to the continued survival of redroot. Whereas many existing studies have examined abiotic characteristics such as soil type or distance from the water's edge (Hill and Keddy 1992; Wisheu et al. 1994; Keddy 1994; Hill et al. 1998), further research should be conducted regarding the influence of vegetation structure, which can be as important as abiotic factors in determining habitat suitability.

Further evaluation of different habitat scales is also needed. As explained by Fortin et al. (2002), ecological processes often operate at more than one spatial scale, and various patterns and processes at different scales are not necessarily linear or additive. As affirmed by Environment Canada and Parks Canada (2010), an integrated evaluation of the habitat features at

both the site and individual scales will deliver the most comprehensive approach to understanding of ecological processes and patterns and determining critical habitat. Numerous surveys have evaluated redroot at the site level and have determined general lakeshore habitat characteristics such as their preference for wide, gently sloping shores made of coarser substrates (Keddy 1994; Wisheu et al. 1994; COSEWIC 2009; Environment Canada and Parks Canada 2010). In contrast, very little research has focused on the individual scale. A greater understanding of this most basic, microhabitat scale is needed because it is possible for individuals to occur in areas that do not fit the description of the site scale (Environment Canada and Parks Canada 2010). Since ecological processes operate on multiple spatial scales, the knowledge gap regarding the microhabitat scale needs to be filled by examining conditions and organisms in the immediate vicinity of the redroot plants.

This literature review has examined the Atlantic Coastal Plain Flora as a whole, as well as their common habitat characteristics, before focusing on the existing body of knowledge surrounding the species of interest, *L. caroliniana*. As their name suggests, ACPF are found on lakeshores along the Atlantic Coast of the United States, and the disturbance experienced by these lakeshores is a critical component of their established habitat. Redroot itself has been mainly studied in the grey literature of government reports, although it does appear in numerous vegetation surveys of the southeastern United States, where it is much more abundant. The Nova Scotia population of redroot can be considered a peripheral population which exhibits differences in reproductive strategies. This population is particularly threatened by the development of recreational properties along lakeshores. To understand the dynamics and potential for the Nova Scotia population, there is a need for increased study at the finer microhabitat scale, as well as a need to evaluate the role of vegetation structure in determining habitat suitability. A greater

understanding of the plant and the habitat characteristics with which it is associated in Nova Scotia is needed in order to conserve and to promote the growth of this locally rare species.

## **3.0 Methods**

### **3.1 Overview**

Data on the abundance of redroot and other species of ACPF, as well as vegetation and habitat structure, were collected through quantitative, non-probabilistic sampling techniques at specific lakes in southwestern Nova Scotia, where ACPF populations were known to be located (Fig. 3). The percent cover of various functional groups and a select set of ACPF species were measured in contiguous quadrats in transects and grids along selected lakeshores. The data on redroot and its surrounding habitat components were analyzed using simple regression and chi square analysis. In order to assess spatial patterns of redroot and possible associated habitat components at different spatial scales, univariate and bivariate wavelet analysis was also conducted using the PASSaGE software package.

### **3.2 Species of study**

Redroot is a perennial herb with long, narrow, yellow-green leaves that are oriented vertically (Keddy 1994). The leaves are up to 40 cm long and 1 cm wide and most occur close to the base of the stem (Scoggan 1978). Flowering, though rare in Nova Scotia (Wisheu et al. 1994), typically occurs from August to September (Environment Canada and Parks Canada 2010). Flowering plants bear a cluster of 10 to 30 light yellow flowers at the crown of a 20 to 40 cm tall flowering stem. Pale, dense yellow hairs cover both the top of the stem and the flower cluster (Scoggan 1978). The capsule contains reddish-brown seeds that have a diameter of 2 to 3

mm. Since redroot habitat is nutrient poor and growth rates are slow, generation time is estimated to be about 3 to 5 years (Environment Canada and Parks Canada 2010). Redroot gets its name from the plant's slender, blood-red rhizomes, which are integral to the asexual reproduction that is the most common form of propagation in Nova Scotia (Keddy 1994). Redroot's typical range extends from Massachusetts, south along the coast to Florida (Roland and Zinck 1998). In Nova Scotia, redroot occurs along the shorelines of eight lakes in Queens County, and has an estimated population of over 5000 individuals (COSEWIC 2009). Redroot grows on the shorelines of lakes on substrates such as peat, sand and gravel (Keddy 1994), but abundance is highest on windward cobble or peat beaches that face southwest (Keddy 1994; Wisheu et al. 1994).

### **3.3 Study Area**

Sampling was conducted in southwestern Nova Scotia, which has been found to be a prevalent location for many species of ACPF (Wisheu and Keddy 1989, 1994). The study was restricted to the Medway and Mersey watersheds, as they contain numerous critical habitats (Francis and Munro 1994) and have been less extensively studied than the Tusket watershed (Environment Canada and Parks Canada 2010). The study area is located within the LaHave Drumlins ecodistrict, which occupies approximately 16% of the province's land area (Webb and Marshall 1999). This region experiences fairly mild winters, warm, early springs, and a relatively long growing season of just over 200 days (Webb and Marshall 1999; Neily et al. 2005). Mean daily temperatures vary from -5°C in January to 18°C in July, and the region receives approximately 1400 mm of precipitation annually (Neily et al. 2005; Parks Canada 2012).

The LaHave Drumlins ecodistrict is dominated by shallow and stony till from the underlying slate of the region, and the majority of soils can be classified as well-drained,

shallow, sandy loams (Webb and Marshall 1999; Neily et al. 2005). Coniferous forests of black spruce, white pine and hemlock dominate the landscape, although tolerant hardwoods such as sugar maple and beech can also be found (Webb and Marshall 1999; Neily et al. 2005). Wetlands and lakes are common between the drumlins, and the area of freshwater occupies 27,634 hectares, or 10% of the ecodistrict (Neily et al. 2005).

The largest settlement within the ecodistrict is the town of Bridgewater, which, according to the 2011 census, had a population of 8,241 (Statistics Canada 2015). However, within the regional subset of the ecodistrict chosen for the project, the largest settlement is the community of Caledonia, which has a population of approximately 1,500 (Discover Caledonia n.d.). The region is also home to 3 reserves for the Acadia First Nation Mi'kmaw community (*Indian Lands Act*. R.S., c. 219, s. 1.): the Ponhook Lake, Medway River and WildCat Reserves. Forestry is by far the dominant land use in the ecodistrict, but other land uses include agriculture and cottage residential development, particularly along lakeshores.

### **3.4 Sampling Design**

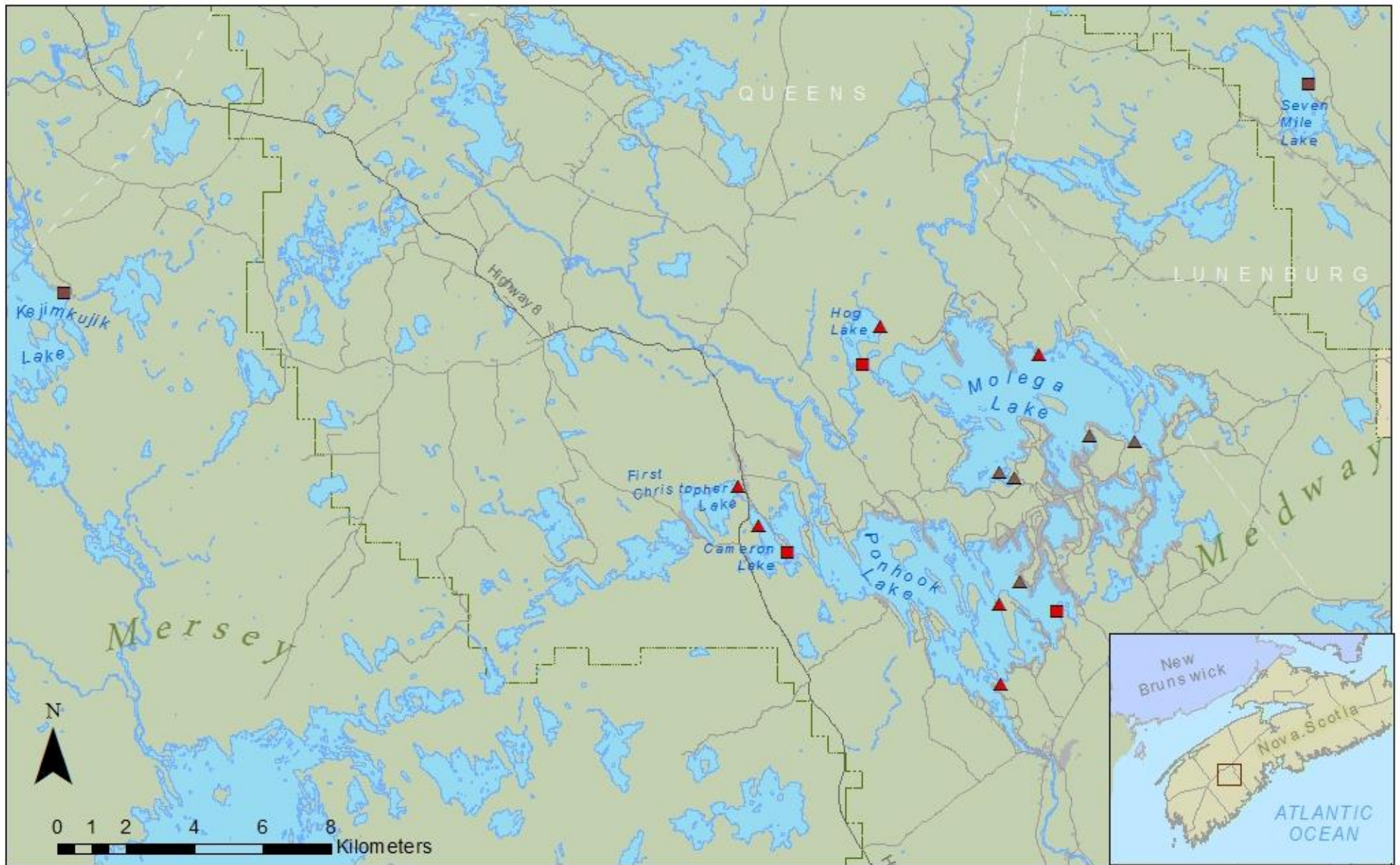
Saint Mary's University MSc. candidate Natasha Dazé Querry selected seven different lakes within the Mersey and Medway watersheds, based on accessibility and previously measured ACPF abundance. The chosen lakes were Cameron Lake, First Christopher Lake, Hog Lake, Kejimkujik Lake, Molega Lake, Ponhook Lake, and Seven Mile Lake (Fig. 3). Along these seven lakes, Dazé Querry chose sixteen sites for vegetation transects based on previous findings of high richness and diversity of ACPF species (A. Belliveau, personal communication). Wherever possible, Dazé Querry selected sites on westward- or southwestward-facing shorelines, to maintain the consistency of associated environmental factors such as sunlight, wave energy, and wind exposure (Lusk and Reekie 2007).



Data were collected from July to September 2015. To determine the distribution of redroot and its associated habitat characteristics along the lakeshore gradient, I established 20 m long transects of 0.2 by 0.2 m contiguous quadrats at each of the selected 16 sites (Fig. 4). I placed the transects where the density and variety of species were highest so as to incorporate the most ACPF possible. The transects originated in the lake where vegetation began to appear, and extended perpendicular to the shoreline for at least 20 m, and at least 5 m into the forest (Fig. 4). To capture variation in shape and width of habitat sites caused by the interplay of ecological and geophysical processes and properties, Hukfens et al. (2009) advocate two dimensional sampling. Therefore, I sampled 5 by 5 m grids of 0.2 by 0.2 m contiguous quadrats in addition to the linear transects in order to capture the second dimension of spatial patterns (Fig. 4; Camarero et al. 2006). I established these grids at the five sites with the highest diversity of ACPF species. The grids originated at the first incidence of ACPF within or near the lake, and ran parallel to the lakeshore in an area of high ACPF richness.

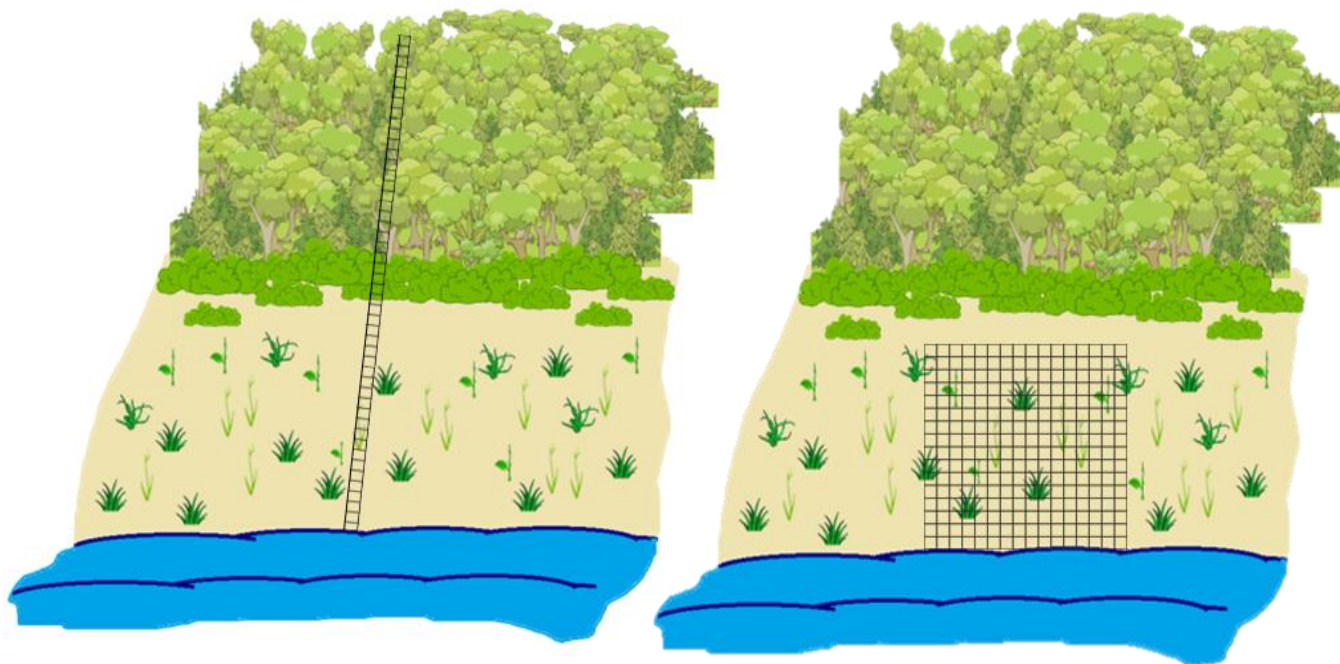
Dazé Querry chose the 0.2 m by 0.2 m quadrat size to avoid missing small scale patterns (Dale 1999), and as a suitable size for microhabitat analysis (Environment Canada and Parks Canada 2010). The quadrats were placed contiguously so as to be able to distinguish non-random spatial patterns that may not otherwise appear evident. Furthermore, using contiguous quadrats was especially advantageous in that I was able to examine associations at a range of scales using only one data set (Dale 1999; Fortin et al. 2002).

Within each quadrat, I estimated the percent cover of 19 different ACPF species according to the following classes: 0.01-5%, 5-25%, 25-50%, 50-75%, and 75-100%. The inequality of the smallest cover classes was used to better be able to differentiate mere presence from low abundance. The 19 species, which includes *L. caroliniana*, were selected for their



**Figure 3.** The location of sampling sites within southwestern Nova Scotia. Sites sampled with transects and grids are denoted with squares, whereas those sampled only with transects are represented by triangles. Sampling sites where redroot was found are coloured red, whereas those without redroot are coloured brown. Urban areas are shown in grey and watershed boundaries are shown in green. Base map created from data from the Nova Scotia Topographic Database.

abundance and ease of identification. Additionally, I measured the percent cover of different functional groups of plants (e.g., grasses, flowering plants, ferns, mosses, carnivorous plants) and structural elements (e.g., leaf and needle litter, snags, logs) according to the same classification system. The herbaceous species, ferns, deciduous species, and coniferous species functional groups were also divided into 0.2 m high vertical layers from 0 to 2 m. I then estimated the percent cover of the functional group within each 0.2 m horizon. I also estimated the percent cover of conifer and deciduous tree species within the height ranges of 2 to 3 m, 3 to 5 m and above 5 m. Furthermore, I recorded the dominant substrate type within each quadrat (NSDNR 2010). Finally, I measured the relative change in elevation every 0.2 m along each transect and through the middle of each grid. To do this, a bubble level 20 cm in length was laid flush against the highest point of the substrate, and the height of the end of the level not touching the ground was measured with a ruler.



**Figure 4.** An illustration of the two sampling techniques used in the study. The figure on the left depicts the 20 m long transect running perpendicular to the water's edge, and extending at least 5 m into the forest. The figure on the right depicts the 5 by 5 m grids placed along the shorelines. Both the transects and the grids were composed of 0.2 by 0.2 m contiguous quadrats.

### 3.5 Data Analysis

In order to have a single representative value for the percent cover measurements, I converted all percent cover classes to the midpoint value of the category (e.g. the cover class 0.01-5% was assigned a value of 2.5%). From these values, I calculated the frequency, total abundance and average abundance of redroot on each shoreline. I also calculated the average shrub and tree cover at each distance by finding the sum of the cover values in all height horizons at that distance, and dividing by the number of height horizons. For example, for total tree cover, I added the cover values for 2 to 3 m, 3 to 5 m, and above 5 m, and then divided by 3 at each distance along the transect. These values were then averaged across all shorelines, and compared to the average cover of redroot at all distances along the transects.

I then evaluated redroot's relationship with different substrate types. In Excel, I determined the frequency of different types of substrate both with and without redroot, and identified the shoreline's dominant substrate as the most commonly occurring substrate type found in the first 5 m. I performed chi square testing to determine whether there was a non-random association between redroot and the different substrate types. I then used Minitab Statistical Software 17.0 (2010) to perform simple regression analysis to determine if there was any significant correlation between the frequency of each of the different substrates and the abundance or frequency of redroot along lakeshores.

Within Excel, I also converted the relative elevation values into absolute elevation values, and calculated the elevation change that occurred over the first 5 m of the shoreline. To determine shoreline width, I used the start of the transect as the lower bound, and the distance at which deciduous species were first recorded at a cover of 38.5% or greater at a height of 0.8 m as

the upper bound, as adapted from Schneider (1994)'s recommendations for pond-shore delineation.

I calculated lake area and watershed area from GIS layers acquired from the Nova Scotia Topographic Database and Nova Scotia Environment. I calculated easternness by calculating the sine of the aspect (MacLeod et al. 2008). To determine if there was any significant correlation between the abundance or frequency of redroot and the various shoreline characteristics including lake area, elevation change, shoreline width, watershed area to lake area ratio, easternness, and the frequencies of various substrate types I used Minitab Statistical Software 17.0 (2010) to perform multiple stepwise regression ( $\alpha=0.05$  to enter and to remove variables) for all variables. I also conducted simple linear regression analysis with each of the variables independently to identify any non-significant trends that would not have appeared in the previous regression analysis (Gonzalez et al. 2009).

### **3.6 Spatial Pattern Analysis**

Spatial pattern analysis was performed using the PASSaGE 2.0 software package (Rosenberg and Anderson 2011). In plant ecology, spatial analysis consists of determining the predictability of the arrangement of plants in space (Dale and Mah 1998); this was determined using wavelet analysis.

Wavelet analysis assesses patterns at different spatial scales by repeatedly passing a template of increasing size over the data set and assessing the similarity between the pattern of the data and the wavelet template at each point along the transect (Dale and Mah 1998; James et al. 2011; Fig. 5). The degree of fit is quantified in the form of wavelet coefficients, which have a high value if the data matches the template or a value close to 0 if it does not (Bradshaw and



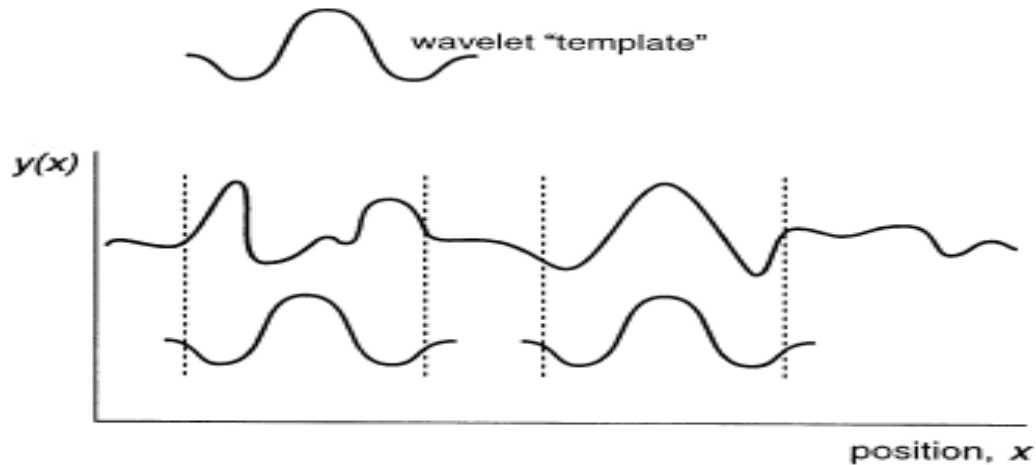
Spies 1992; Dale and Mah 1998). A match between the data and the template indicates a non-random spatial association. At all locations, the degree of fit is calculated from a variety of template sizes to find wavelet coefficients at various spatial scales (James et al. 2010, 2011). Wavelet scale variance is calculated as the average square of wavelet coefficients at all positions for a given scale, while wavelet position variance is calculated as the average square of wavelet coefficients at all scales for a given position (Bradshaw and Spies 1992). Finally, the scale x position variance ( $W$ ) can be calculated for each point at each spatial scale. The variance at position  $p_x$ , at scale  $b_k$ , is equal to:

$$W(b_k, p_x) = \frac{1}{b_k} \sum_{i=1}^{n_x} d(p_i) g\left[\frac{f(p_x, p_i)}{b_k}\right]$$

where  $g(z)$  is the function of the wavelet template,  $d(p)$  is the value of the data at position  $p$  and  $f(p_x, p_i)$  is the signed displacement between positions  $p_x$  and  $p_i$  (Rosenberg and Anderson 2011).

To understand the spatial distribution of redroot over an environmental gradient, univariate wavelet analysis was used to determine the spatial variability of redroot's cover across the shoreline transects. The Haar wavelet template was selected since it is the simplest wavelet and most appropriate for observing discontinuities in spatial data (Bradshaw and Spies 1992; Camarero et al. 2006). The data were examined to determine where the shape of the Haar wavelet function was similar to the shape of the underlying redroot data by observing where high wavelet position and scale variance occurred. High variance values indicated an abrupt change in redroot abundance, thereby signalling the start or end of a patch. The distance between peaks of position variance was measured in order to determine the width of individual redroot patches, and the distance from the start of the first patch to the end of the last patch was recorded as the

overall patch width. The distance between the end of the last patch and the end of the shoreline as measured above was recorded as distance to the forest.



**Figure 5.** A simple representation of how wavelet analysis assesses the match between a wavelet template and the data. In this example, the Mexican hat wavelet template is being used to analyze spatial pattern. In the window on the left, the template matches the data series poorly, however in the window on the right, the template matches the data matches well, indicating non-random spatial variation, or that a significant pattern is present at this scale. Diagram from Dale and Mah (1998).

To investigate the phytosociological associations in the grids between redroot and other species of ACPF, as well as certain functional groups of vegetation, I used two-dimensional bivariate wavelet analysis (Kembel and Dale 2006), which examines the covariance of two separate variables measured over the same area (Dale and Blundon 1991; James et al. 2011). The Boater wavelet template was used, as it is the two-dimensional equivalent of the Haar wavelet (Rosenberg and Anderson 2011). Using wavelet analysis to determine the peaks and valleys of covariance at different scales takes into account spatial autocorrelation, as well as the lack of independence between the varying sizes of spatial scales, and any inherent spatial patterns each of the species possesses (Dale and Blundon 1991; Camarero et al. 2006). The cover density data

were converted into presence/absence data, and the covariance curves of both sets of data were evaluated at the three grid sites at which redroot was present. The magnitude and direction of interspecific associations were determined by examining the shape of the covariance curves for both presence/absence and density data at increasing spatial scales. The covariance of species' densities was used to examine the more subtle effects of species on each other, whereas the covariance of presence/absence of the species was used to detect more strict effects. Where one species is replaced by another, there can either be sharp exclusion or gradual replacement (Fortin et al. 2002). Gradual replacement through reduced biomass would be detected using the density data, whereas sharp competitive exclusion would be noted in the presence/absence data.

The results from both univariate and bivariate wavelet analysis were compared to null models that represent spatial stochasticity in order to determine the positions and scales at which patterns could be considered significant (James et al. 2011). These randomization tests involved 999 iterations of randomly reshuffling the data using a 95% confidence interval, where scales at which the wavelet variance were higher than the 95th percentile from the null distribution were considered significant.

### **3.7 Potential Limitations**

This study is limited due to time constraints placed on data collection. As mentioned, data were collected during only three months of the summer of 2015. This meant that rather than being randomly designated, study sites were purposively selected from known ACPF habitats (Wisheu et al. 1994; Environment Canada and Parks Canada 2010) to ensure that enough data on ACPF and their habitat would be collected. With more time, locations could have been chosen more randomly such that the sampling was probabilistic, allowing the results to be more widely applicable to the entire redroot population. Nonetheless, as the sites were chosen so as to



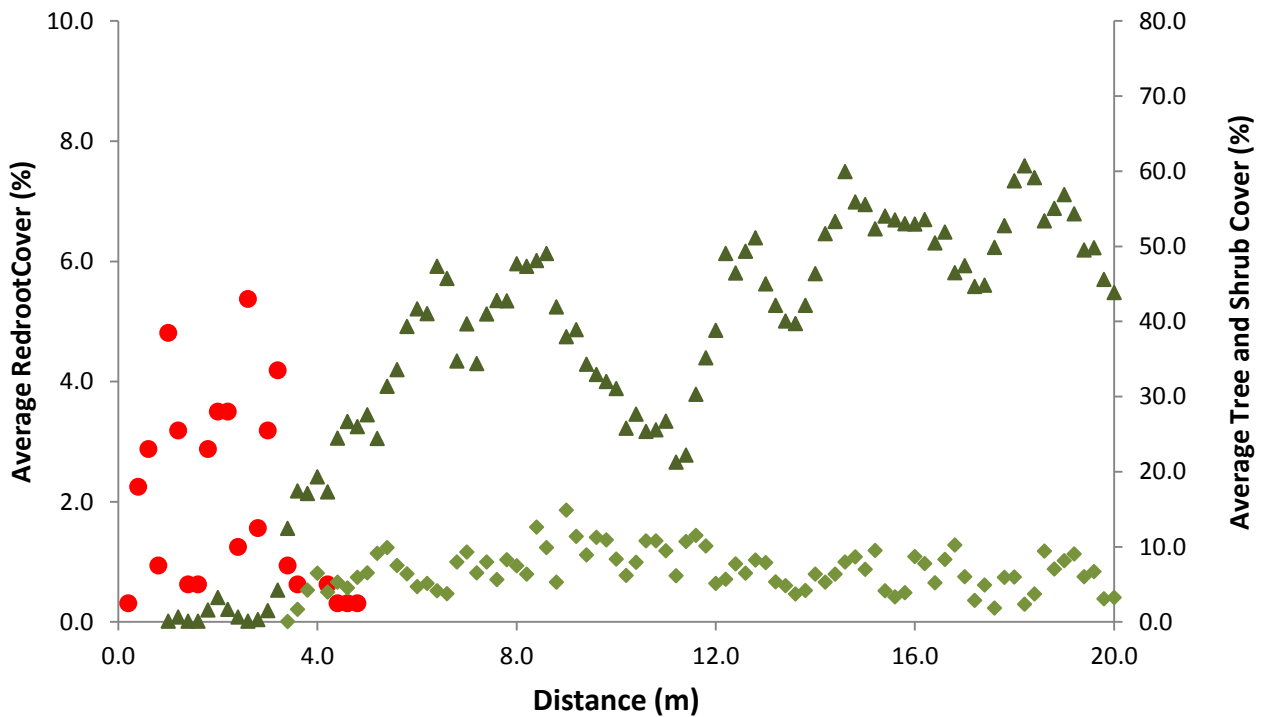
incorporate the highest diversity and abundance of ACPF, but without specifically taking redroot into account, it is possible to draw inferences from the results to a wider population of redroot at sites of high ACPF abundance. Thus, although not an entirely random study, it will be possible to use both inferential and descriptive statistics.

The limited span of data collection leads to another drawback; since the data were only collected over one summer, it is hard to know if the findings are truly representative of the species distribution in a typical year. Future studies could compare the temperature, precipitation and water level data to past climate and water level values, and examine and interpret any significant discrepancies. The distribution found for redroot in this study was compared to previous findings to ascertain that no drastic changes in redroot distribution occurred, which could be an indication of a strong climate impact. This comparison was difficult, however, because of the different methodologies used in data collection and the limited scale of this study. To truly capture the demographics of the species, this study should be repeated over multiple years to track any changes in redroot abundance.

## **4.0 Results**

Redroot was found along at least one shoreline of five of the seven lakes chosen for this study (Fig. 3). The five lakes at which redroot was found (Cameron Lake, First Christopher Lake, Hog Lake, Molega Lake, and Ponhook Lake) are all in some way connected, and can all be found in neighbouring tertiary watersheds within the same primary watershed (Medway watershed). Redroot was not found at either of the two geographically isolated lakes (Kejimkujik Lake and Seven Mile Lake), both of which are located in different watersheds.

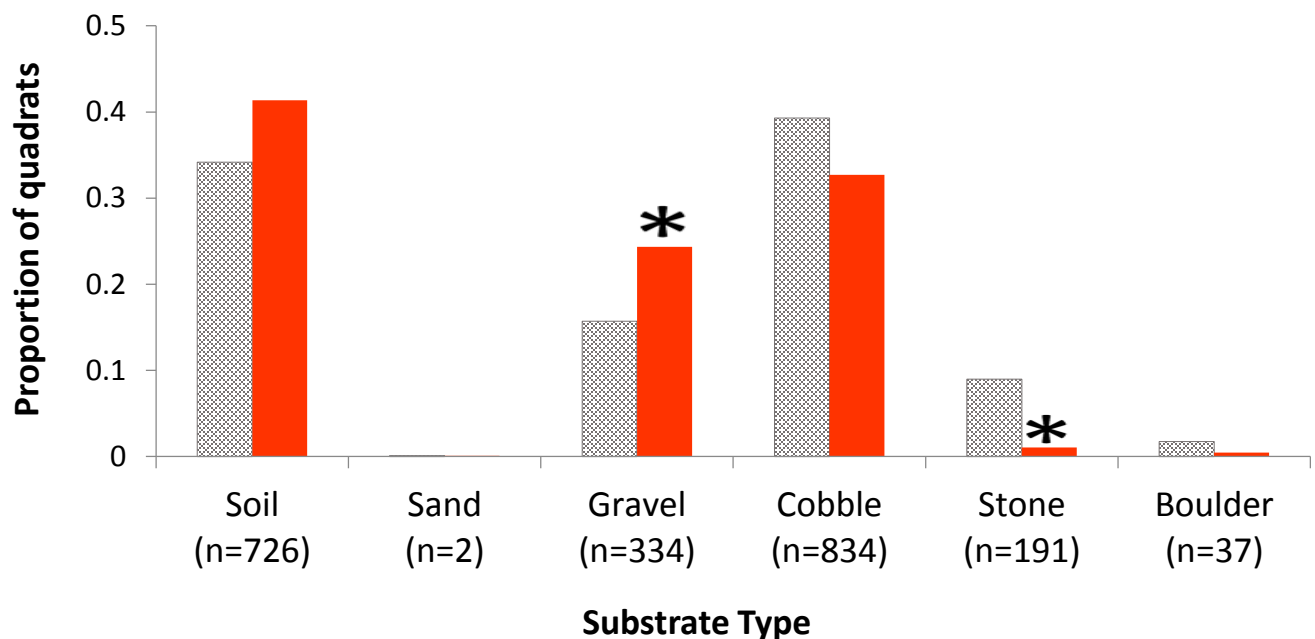
Redroot was only found growing within the first 5 m of the shoreline, and had the highest abundance where there was a lack of shrubs or cover from either deciduous or coniferous trees (Fig. 6). Tree cover increased with increasing distance from the lake edge, whereas shrub cover typically increased until a peak at approximately 8 to 10 m from the lake edge, and then decreased slightly. Individual redroot plants tended to be fairly spread out within the quadrats and rarely grew densely enough to cover an area of more than 5% (20 cm<sup>2</sup>) of a 400 cm<sup>2</sup> quadrat (Fig. 6). Redroot was most commonly found at shoreline elevations of 0 to 30 cm above the water level, although the plant was recorded as high as 90 cm above the water level. The mean and median elevations at which redroot was present were 24.9 cm and 24.4 cm, respectively. The relatively low elevations at which redroot was recorded may be due to the position along the shoreline rather than elevation itself.



**Figure 6.** The average abundance of redroot (red circles) along the transects (n=16) with increasing distance from the lake edge, as compared to the average total tree cover (deciduous and coniferous above 2 m; dark green triangles), and the total shrub cover (deciduous species 0.8 to 1.8 m; light green diamonds).

#### 4.1 Substrate

Redroot was most commonly found in substrates classified as soil, followed by cobble and gravel. Redroot occurred minimally on substrates classified as sand, stone, and boulder (Fig. 7). Chi-square testing showed that the frequency of redroot on gravel ( $\chi^2=5.605$ ) and on stone ( $\chi^2=7.712$ ) both were significantly different ( $p<0.05$ ) than what would be expected if there was no relationship between redroot presence and substrate type. Redroot occurs more frequently on gravel, and less frequently on stone, than would be expected if redroot was distributed evenly amongst all substrate types (Fig. 7).



**Figure 7.** The difference in proportion of quadrats of each substrate type between all quadrats and only redroot-containing quadrats. The hatched bars represent the proportion of quadrats with each type of substrate amongst all quadrats along shorelines where redroot is present. The red bars represent the proportion of all redroot-containing quadrats that occur on each of the types of substrates. Asterisks represent a significant difference ( $p<0.05$ ) in proportion than would be expected if there was no relationship between redroot presence and substrate type.

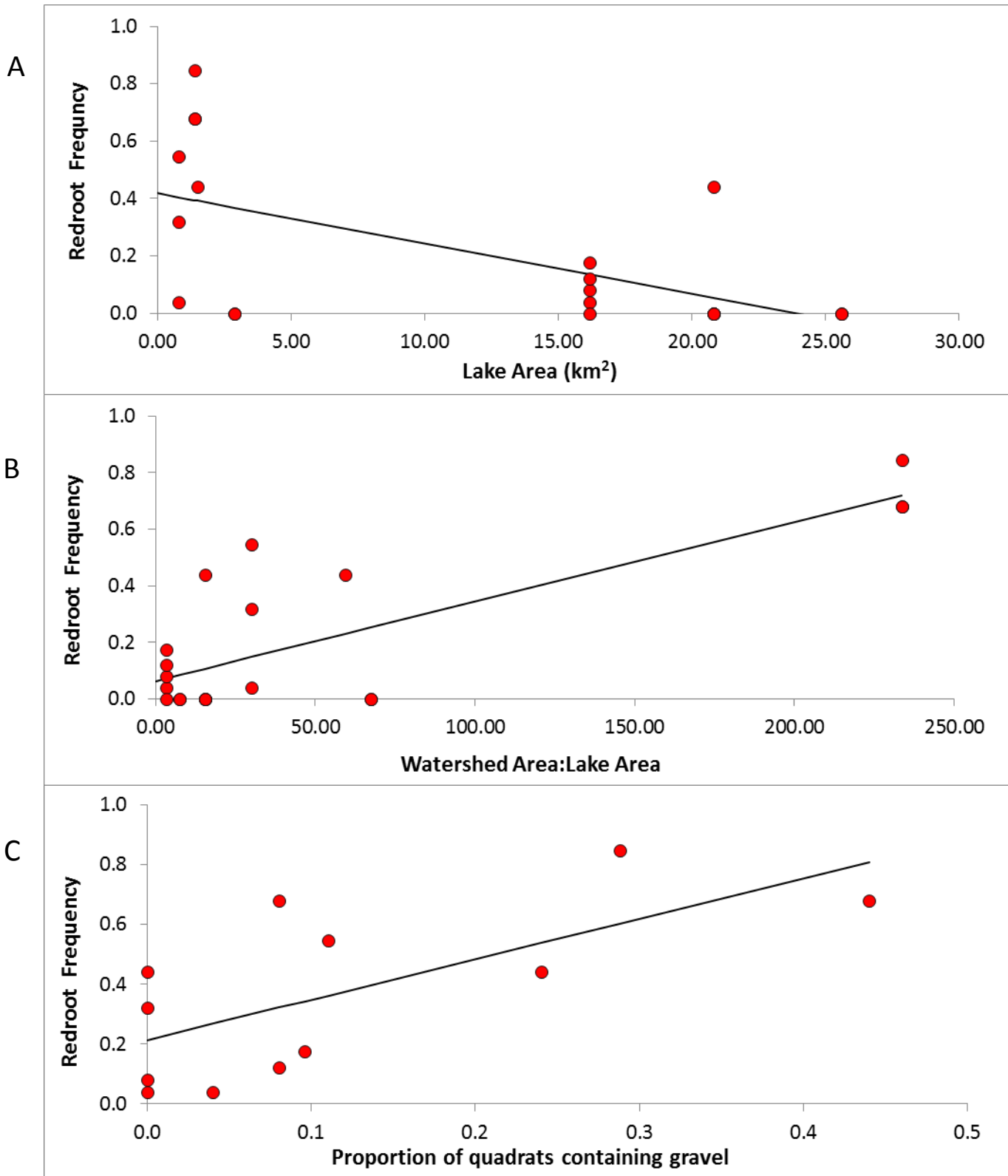
## 4.2 Lakeshore Attributes

Redroot was found on the shorelines of lakes ranging from 0.8 km<sup>2</sup> to 20.8 km<sup>2</sup>, and multiple sites on the same lake typically had somewhat similar frequencies of redroot occurrence (Table 1). All sites except one were eastern-facing, though to varying degrees. The width of the shorelines varied from 2.4 m to 10.8 m. Redroot grew in patches from 1.2 m to 5 m in width, and occurred at varying distances from the forest edge (Table 1).

In simple regression analysis, only two variables were found to have a significant effect on the occurrence of redroot: lake area, and watershed area to lake area ratio. Larger lakes tended to have a smaller frequency of redroot ( $R^2=32.8\%$ ; Fig 8a), while lakes with larger watershed area to lake area ratios tended to have a higher frequency of redroot ( $R^2=62.7\%$ ; Fig 8b). Both shoreline width and easternness had a non-significant positive correlation with redroot abundance, whereas elevation change had a non-significant negative correlation. Of the different types of substrate, only the proportion of gravel along shorelines had a somewhat significant relationship with redroot abundance ( $p<0.1$ ). However, when only the sites at which redroot was recorded were included in a stepwise regression model, the proportion of gravel became the only significant association. Redroot frequency increased with higher frequency of gravel along the shoreline ( $R^2 = 44.6\%$ ; Fig. 8c) at sites with redroot present.

**Table 1.** General descriptive characteristics of the different shorelines along which redroot abundance was measured. Elevation change is the difference between elevation values at 0 and 5 m along the shoreline. Shoreline width is the distance from the lake edge to the first significant occurrence of shrubs, as described in the methods. Easternness was calculated as  $\sin(\text{aspect})$ . Patch width is the distance between the start of the first patch and end of the last patch as determined through wavelet analysis. Distance to forest is the distance from the end of patch to the end of the shoreline. See Methods for more detailed explanations.

Location	Elevation Change (cm)	Shoreline Width (m)	Lake Area (km <sup>2</sup> )	Watershed Area (km <sup>2</sup> )	Easternness	Dominant Substrate	Patch Width (m)	Distance to Forest (m)	Average Redroot Cover (%)	Frequency of Redroot
<b>Transects</b>										
Cameron Mineral	119.3	3.6	0.8016	24.062	0.819	Cobble	3	0.1	0.80	0.32
Cameron Organic	30.3	2.4	0.8016	24.062	-0.545	Soil	1.24	-0.22	0.10	0.04
First Christopher Mineral	81.2	5.4	1.5159	89.802	0.988	Soil	1.62	3.28	2.14	0.44
Hog Mineral 1	84	5.2	1.3817	322.676	0.988	Soil	3.2	2	4.30	0.68
Hog Mineral 2	49.7	10.8	1.3817	322.676	0.829	Soil	2.3	6.8	5.20	0.68
Kejimkujik Mineral	63.1	9	25.5884	192.469	0.326	Gravel	N/A	N/A	0	0
Molega Mineral 1	26.8	4.6	20.8141	322.676	0.988	Soil	3.95	-0.15	1.10	0.44
Molega Mineral 2	21.3	4	20.8141	322.676	0.242	Soil/Cobble	N/A	N/A	0	0
Molega Mineral 3	40.2	6.2	20.8141	322.676	0.995	Soil	N/A	N/A	0	0
Molega Mineral 4	22.6	6	20.8141	322.676	0.993	Soil	N/A	N/A	0	0
Molega Mineral 5	24.4	8.2	20.8141	322.676	0.777	Soil	N/A	N/A	0	0
Ponhook Mineral 1	148.3	3.8	16.1732	52.212	0.985	Cobble	1.25	2	0.10	0.04
Ponhook Mineral 2	165	3.8	16.1732	52.212	0.707	Cobble	N/A	N/A	0	0
Ponhook Mineral 3	49.5	6.8	16.1732	52.212	0.990	Cobble	1.2	1.5	0.20	0.08
Ponhook Organic	42.7	7.4	16.1732	52.212	0.643	Cobble	1.9	4	0.30	0.12
Seven Mile Mineral	14.3	8.8	2.8904	194.682	0.438	Gravel	N/A	N/A	0	0
<b>Grids</b>										
Cameron Mineral	119.3		0.8016	24.062	0.857	Cobble			5.57	0.55
Hog Mineral 2	49.7		1.3817	322.676	0.326	Soil			10.69	0.85
Kejimkujik Mineral	63.1	N/A	25.5884	192.469	0.454	Gravel	N/A	N/A	0	0
Ponhook Mineral 3	49.5		16.1732	52.212	0.956	Cobble			1.78	0.18
Seven Mile Mineral	47.3		2.8904	194.682	0.326	Cobble			0	0



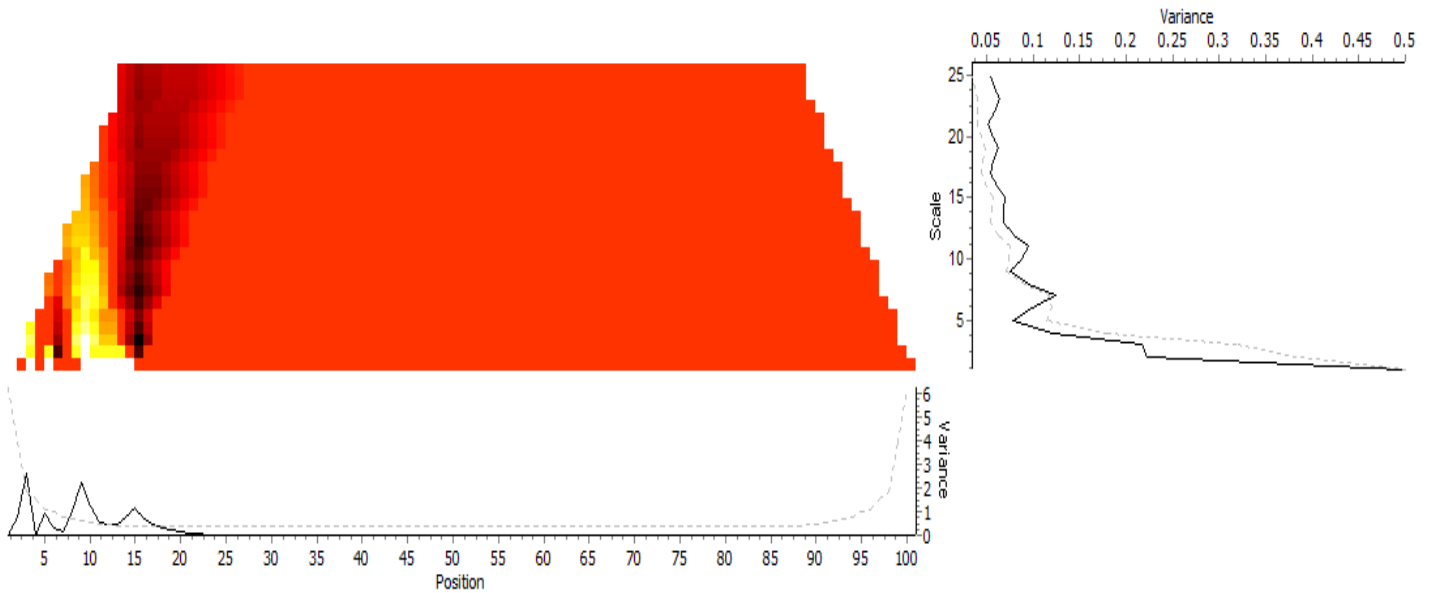
**Figure 8.** The relationship between frequency of redroot and **A**) lake area, as modeled by the equation:  $y = 0.419 - 0.0175x$  ( $R^2=32.8\%$ ;  $p=0.004$ ), **B**) watershed to lake area ratio, as modeled by the equation:  $y = 0.064 + 0.0028x$  ( $R^2=62.7\%$ ,  $p=0.014$ ), and **C**) the proportion of quadrats containing gravel along shorelines at sites where redroot is present ( $n=12$ ), as modeled by the equation:  $y = 0.213 + 1.348x$  ( $R^2=44.6\%$ ;  $p=0.018$ ).

### 4.3 Spatial Patterns

The position variance of redroot, which indicates the locations along the transect at which there is an abrupt change in redroot, was at its highest within the first 20% (5 m) of the lake edge along the transects. Each transect typically contained one to six abrupt changes in redroot abundance, indicating the presence of one to three distinct patches of redroot (Fig. 9).

Individual clusters varied in width from 0.4 to 1.6 m, and the total width of the patchy area typically ranged between from 1.2 and 3.5 m (Table 1). The scale variance was always highest, and usually significant, at scales of less than 1.0 m, and was also occasionally significant around scales of 1.6 to 2.4 m (Fig. 9). The scale x position variance was always greatest at small to medium scales at early positions along the transect, and was typically negative at large scales at early positions. At positions further along the transect, the scale x position variance was generally 0.0 at all scales.

The covariance of redroot and other species of Atlantic Coastal Plain Flora, measured using the Boater wavelet, was fairly variable, but usually involved significant ( $p < 0.05$ ) covariation at a scale of 0.20 m, and occasionally at a scale of 0.80 m as well (Appendix Fig. 1). For example, redroot and the lance-leaved violet (*Viola lanceolata*) were found to have significant positive covariation at a scale of 0.2 m at all sites. The size of any further scale at which the covariance between these two species was significant varied between each of the sites. For other species, such as old switch panic grass (*Panicum virgatum*) and southern clubmoss (*Lycopodiella appressa*), a lack of significant covariance with redroot occurred at almost every scale. The covariance between redroot and total tree cover and total shrub cover varied tremendously between each of the three sites (Appendix Fig. 1).



**Figure 9.** An example of the result of the Haar wavelet analysis generated by the PASSaGE software. The depicted site is Cameron Mineral. The bottom graph shows the position variance of redroot along the transect. The graph to the right shows the variance of redroot at different spatial scales, ranging from 1% (0.2 m) to 25% (5 m) of the total transect length (20 m). In both graphs, the dotted line represents a 95% confidence interval of no specific geographic relationships. Spatially significant clusters begin and end where the observed peak in variance exceeds the expectation generated from the randomization test. The heat map represents the scale  $\times$  position variance, where red represents a value of zero, black represents a large negative value, white represents a large positive value, and the degree of yellow represents the transition from 0 to the large positive values.

## 5.0 Discussion

This study has determined some of the habitat components associated with redroot distribution in Nova Scotia. In terms of vegetation structure, redroot was found in patches within the first 5 m of the shoreline with the highest abundance where there was little to no shrub and tree cover. The abiotic characteristics which were associated with greater redroot abundance include smaller lakes with relatively large watersheds, and shorelines with prevalent gravel substrate. The interspecific interactions that redroot experienced with other species of ACPF were highly variable both at different spatial scales and between sampling sites.



## 5.1 General Trends and Associated Vegetation Structure

Like Wisheu et al. (1994), I found that redroot was most abundant more than 50 cm from the water's edge, though it could be found right at the August water line. Most redroot plants were found within the zone of seasonal or periodic inundation (COSEWIC 2009). Since redroot is a poor competitor (Wisheu and Keddy 1994), it does best where it does not have to contend with more competitive species such as woody plants. Close to the water, the disturbance caused by wave action and ice scour limits the encroachment of shrubs. Few species can tolerate this disturbance, and those that can tend to be small, leading to the deposition of very little organic matter in the area. Furthermore, wave action, ice scour, and periodic flooding prevent any organic matter from accumulating, rendering the shoreline too nutrient poor for many woody species (Schneider 1994; Morris et al. 2002). Redroot is able to survive in nutrient-poor environments, and is either able to persist through disturbance or reestablish itself through rhizome fragments once the disturbance recedes (Keddy 1994; Wisheu et al. 1994). Redroot thus thrives near the water's edge, where water action protects redroot from being crowded out by more competitive species (Hill and Keddy 1992). Herbaceous ACPF species, including redroot, are sensitive to shading from shrubs (Wisheu and Keddy 1994) and the increased sunlight exposure from the lack of tree and shrub cover is likely even more important for a southern species such as redroot which is used to receiving higher levels of insolation (Keddy and Reznicek 1982; Wisheu et al. 1994).

Although redroot was most common at an elevation of about 25 cm, which falls within Wisheu et al. (1994)'s range of 15 to 100 cm above the August water line, my findings found redroot to be common at elevations of 0 to 30 cm, and rather rare at elevations of 55 cm above the August water line. It is possible that the large snowfall and late spring experienced by Nova Scotia

in 2015 (Bolduc 2015) may have contributed to higher lake water levels. Since redroot can persist through flooding (Wisheu et al. 1994), the species is unlikely to have shifted despite higher water levels, and thus would appear to grow closer to the August water line. Ideally, this study would be replicated in multiple years to so as to determine redroot's distance from the edge for average water levels.

The low average cover of redroot, its patchiness and personal observation all indicate that redroot typically grows sparsely throughout its habitat. This corroborates the 2009 COSEWIC report's findings that though the extent of occurrence was 117 km<sup>2</sup>, the plants themselves occupied less than 1.24 km<sup>2</sup> of actual habitat (COSEWIC 2009). Additionally, no flowering redroot individuals were observed during this study, which mirrors the findings from previous surveys where less than 200 flowering individuals were counted amongst tens of thousands of individual plants (Wisheu et al. 1994). Populations of redroot in Nova Scotia therefore clearly rely heavily on propagation through asexual reproduction, which may be a naturally limiting factor in their distribution (Wisheu et al. 1994; COSEWIC 2009). The low rate of flowering and therefore seed production, which is very different from the more southern American portion of its range, may be attributable to a Nova Scotian climate that is marginal for redroot. Populations of redroot in the southern United States also grow at much higher densities (Landman and Menges 1999; McMillan et al. 2002; Ferrell et al. 2009). Thus, it may be that the climate in Nova Scotia limits both the abundance and dispersal of redroot.

## **5.2 Associated Substrate**

This study confirmed previous findings that redroot is most abundant on shorelines dominated by cobble and soil (Keddy 1994; Wisheu et al. 1994; COSEWIC 2009), but can also

appear on a variety of shoreline substrates ranging from boulders to soil. This validates my findings of some redroot presence on each type of substrate measured. Whereas both this study and previous studies have found highest redroot abundance on shorelines dominated by cobble and soil, this study showed that on a finer scale, gravel was the most important substrate for redroot, and was the only substrate type that was significantly correlated with the species.

Redroot's association with gravel is likely due to the fact that gravel represents a level of disturbance that is suitable for redroot. Wave action leads to the physical weathering of rocky substrate, while also washing out finer substrate particles (Keddy 1984; Wisheu et al. 1994). This results in an infertile substrate of intermediate coarseness in which redroot can thrive due to a lack of competitors (Keddy 1984; Wisheu et al. 1994).

Since there were shorelines with abundant gravel that contained no redroot, the presence of gravel does not necessarily ensure that redroot will grow on that shoreline. This lack of occupation of seemingly suitable habitat may be due to the inaccessibility of the site caused by redroot's limited dispersal capabilities. Additionally, redroot was still found to be relatively abundant at sites that contained little to no gravel. Nevertheless, at sites where redroot is present, more gravel typically leads to higher abundances of redroot. This significant correlation indicates that the presence of gravel is an important, although not necessary, feature of suitable redroot habitat.

### **5.3 Associated Lakeshore Characteristics**

Previous research has found redroot to be most common on broad and gently sloping shorelines (Keddy 1994; Wisheu et al. 1994; COSEWIC 2009). Although there were trends of increasing redroot abundance with increasing shoreline width and decreasing elevation change, they were not statistically significant, likely due to a small sample size. Evaluating redroot abundance on

a greater number of shorelines could potentially provide more significant trends to confirm previous findings. The habitat preference for wide, gently sloping shorelines is important to highlight since these types of shorelines are some of the preferred characteristics for recreational cottage development, which poses a threat to redroot (Wisheu et al 1994; COSEWIC 2009). A better survey of these shorelines is necessary in order to determine their importance to redroot and to implement optimal habitat conservation.

Prior studies also found the orientation of shorelines to be quite important, as increased wind and wave action make broader shores, decrease soil fertility, reduce competition, and increase exposure to sunlight. Though I found the easternness of shorelines (the degree to which they face west) to be positively correlated with redroot abundance, the relationship was not significant. The lack of significance is likely due to a small sample size as well as an inherent shoreline bias; the study sites chosen were known locations of high ACPF abundance, and ACPF are known to be more prevalent on western-facing shorelines. Since only one of the sites faced east, it is difficult to make comparisons between eastern and western facing shorelines, and the influence of orientation on redroot itself. Future studies could randomly sample along similar shoreline types facing both east and west, and compare the frequency and abundance of redroot between the two orientations. Alternatively, information could be gleaned from an existing data set amassed by the Mersey Tobeatic Research Institute (MTRI) and the Atlantic Canada Conservation Data Centre (ACCDC). This data set, collected by researchers, botanists, and volunteers, includes the distribution and abundance of at-risk ACPF species, human-induced threats, and macrohabitat shoreline features along 36 high-priority lakes in Southwest Nova Scotia (Blaney 2010), and could therefore potentially be consulted as a source of further information. The inconsistency in data collection,

however, may render some of the results questionable, and therefore this data set should be used more as secondary evidence to corroborate findings.

Large lakes tend to have higher wind velocities, which leads to greater wave action and ice scour (Fetherston et al. 1995; Morris et al. 2002), and the shorelines of large lakes therefore tend to experience more disturbance. Since disturbance plays such a critical role in ensuring the abundance of redroot for both dispersal and elimination of competitors (Schneider 1994; COSEWIC 2009), I would expect to find a higher abundance of redroot on the shorelines of larger lakes. In my study, however, the opposite trend was found, as redroot frequency declined significantly with increasing lake area. However, only seven lakes were considered in this study, which is likely too small a sample size to draw meaningful conclusions about lake size. Furthermore, it is probable that a finer scale characteristic such as the degree of shelter or exposure of the shoreline, which was not measured in this study, has a more significant influence on redroot abundance. The shape of the lake might therefore be of greater importance than its size. Future studies could investigate the lake perimeter to area ratio and the lake shape complexity as possible larger scale explanatory variables, as well as the degree of shoreline exposure as an explanatory variable at a finer scale (Keddy 1984; Mitchell et al. 2001).

Similar to the importance of lake shape, lake connectivity is likely a critical factor that was not directly measured in my study. On a very large scale, redroot tends to exhibit spatial autocorrelation: redroot is more likely to be found near other populations of redroot. Since the species depends on asexual reproduction through rhizome fragment transportation (Keddy 1994), the connectivity of lakes, especially with those that have existing populations of redroot, is likely extremely important for the establishment and propagation of the species. A lack of connectivity

renders it very unlikely that there will be redroot, since the species has very little chance of being transported there naturally (COSEWIC 2009).

The presence of redroot within only the five connected lakes that share a primary watershed gives further credence to the importance of connectivity. Kejimikujik Lake and Seven Mile Lake, however, only had one study site each, whereas most of the other lakes had at least two study sites, which may have had a slight bias on the probability of sampling at a site containing redroot. Nevertheless, previous literature has never documented redroot at either Kejimikujik Lake or Seven Mile Lake, but has previously found it at the five other studied lakes as well as other small connected lakes located within the Medway watershed (Keddy 1994; Wisheu et al. 1994; COSEWIC 2009). More study sites at all lakes, particularly those with few existing study sites, would determine whether connectivity amongst the lakes is a meaningful factor in determining redroot abundance. The MTRI and ACCDC dataset (Blaney 2010) could once again be a useful tool to supplement this research.

A higher degree of connectivity can sometimes be indicated by a larger watershed area to lake area ratio since larger catchment areas have more numerous bodies of water (Brandt-Williams et al. 2012). Thus, redroot may have a better chance of establishing itself from an existing colony through rhizome transport in lakes that are located in larger watersheds. On the other hand, productivity is known to increase with increasing watershed area to lake area, since the lake receives a relatively greater nutrient influx as the ratio increases (Brandt-Williams et al. 2012; Schlesinger and Bernhardt 2013). An increase in productivity seems like it should have a negative effect on redroot growth, since productive environments tend to have increased biomass of dominant species, such as shrubs, which would outcompete redroot (Callaway 2007). Nevertheless, several studies in Nova Scotia have found that overall species richness, as well as the frequency and

diversity of rare species tend to be higher on lakes with relatively large catchment areas (Hill and Keddy 1992; Morris et al 1992). The increased water input from larger watersheds likely contributes to increased flooding, thereby limiting shrub encroachment and creating open expanses of shoreline that can support a high diversity of species (Hill and Keddy 1992). The increased wave action and exposed shoreline created by the larger watershed may therefore justify the trend of increasing redroot with increasing watershed area to lake area ratio. Future research could seek to quantify the nutrient transport and water level fluctuation of various watersheds and determine the degree to which they may impede or enhance redroot growth.

#### **5.4 Spatial Patterns**

The patterns of the distribution of a species arise from the interaction of the physiology of the species, its interspecific relationships with other species, and the effects of diverse environmental gradients. The abiotic environmental gradient determines the potential distribution of redroot, while its biotic interactions with other species determine its actual distribution. Combining these factors gives us the best insight into redroot's ecological niche, and can help determine the critical habitat for the species.

Wavelet analysis using the Haar wavelet detected several abrupt changes in cover along the lakeshore gradient, thereby indicating the existence of patches. The patches were all within the first 5 m of the lakeshore, within the zone of exposure to wave action (COSEWIC 2009), which fits with my previous findings. The width of the patches themselves, as well as the width of the extent of the patches, was quite variable, which could be due to the fact that there is no general pattern of even dispersal through sexual reproduction, since flowering redroot plants are extremely rare in Nova Scotia (Wisheu and Keddy 1994). The existence of multiple patches, rather than a continuous

presence of redroot, may also be attributable to the variable disturbance of ice-scouring (Holt et al. 1995). This variability in ice scouring creates not only different patterns of disturbance, but also different opportunities for redroot fragmentation and asexual propagation.

Significantly abrupt changes typically occurred at the smallest scales of below 1.0 m, and often again at around 2.0 m. The high variance at less than 1.0 m is natural given redroot's low density; at small scales, any increase in the density of redroot is significant and easily detected. In contrast, by encompassing a greater area, larger scales are more likely to appear to have an even distribution of redroot and fewer abrupt changes. However, the width of redroot occurrence along shorelines measured by position variance was frequently found to be around 2.2 m, complementing previous findings of a width of occurrence of 2 to 3 m (COSEWIC 2009), and thus the wavelet variance would again be significant at this scale as there is an abrupt change between areas of patchy redroot presence, and no redroot presence whatsoever. Further along the transect, the lack of position variance confirmed the absence of redroot where environmental conditions for redroot were no longer suitable, due to a lack of gravel substrate and the growth of competitive woody species.

## **5.5 Interspecific Interactions**

Redroot's habitat occupancy may also be explained by its phytosociological associations; the interactions within a community that cause the plants of different species to grow close together or far apart (Fortin et al. 2002). In my study, the covariance curves for presence/absence and cover density were not identical. This discrepancy indicates that some of the relationships between redroot and other species are subtle, affecting the amount of biomass, rather than being strong interactions that affect presence outright (Dale and Blundon 1991). Furthermore, the variation along the curve,



typically involving both positive and negative correlation values, shows that the direction and magnitude of interspecific interaction depends on the scale at which it is examined. Nevertheless the high degree of variability points to the influence of other habitat characteristics that must be considered in addition to the interaction between plants. Therefore, future studies should examine covariance in relation to other abiotic habitat components to determine the extent of their effect on each species and their interaction. Additionally, the first scale in wavelet analysis is often considered less accurate than the rest of the results since it is the first frame over which the template passes (Dale and Blundon 1991; Dale 2002). Thus, while most of the consistently significant results occurred at the smallest scale, it is difficult to give these results much credence. When examining the covariance curves at the remaining scales, no species or vegetative component seemed to display a consistent trend across all sites.

Based on previous findings and personal observation of ecological coincidence, I would have expected significant positive covariance at a minimum of medium to large scales between redroot and Yellow-Eyed Grass (*Xyris difformis*), Golden Pert (*Gratiola aurea*), Southern Clubmoss (*Lycopodiella appressa*) and sundews (*Drosera spp.*), since they tend to occupy similar habitat types fairly close to the water's edge (Wisheu et al. 1994; COSEWIC 2009; Environment Canada and Parks Canada 2010). *Drosera spp.* are known to live in nutrient poor environments (Wisheu and Keddy 1994), and thus would likely grow in similar places to the stress tolerant redroot. For presence/absence data, redroot and *Drosera spp.* tended to experience significant positive covariance at the smallest scale, and then a negative covariance at a larger scale, which Dale and Blundon (1991) would characterise as enhancement, though the variability of their covariance curves and the literature suggests that ecological coincidence may be the real driver of the trend (Keddy 1994; COSEWIC 2009). Like redroot, *X. difformis* and *G. aurea* both inhabit portions of the

shoreline that are periodically to regularly inundated, but these species occurred at much higher densities than redroot, and were found in a wider range along the shoreline. The variability in the covariance curves for these species between shorelines was too large as to give any insight into whether these species experience ecological coincidence or even competition.

I would also have expected redroot to show negative covariance with grassy species such as Old Switch Panic Grass (*Panicum virgatum* var. *spissum*), and the total shrub cover and total tree cover. *P. virgatum* tends to be found at greater distances from the lake edge than redroot, in the zone of only occasional inundation, where competition from shrubs begins to intensify (Wisheu and Keddy 1994). Therefore, I would have expected to see a significant negative covariation at small scales. I would also expect an increasingly positive covariation at larger scales since they would still be located along the same shoreline, though this trend would be at scales larger than those captured in this study. This trend was not evident in any of the covariation curves, though yet again, the between-site variability was quite large. Similarly, due to woody species' competitive nature and shade cover, I would have expected them to display a strong negative covariance at the small scales captured in my analysis, which could become a positive covariance at larger scales not measured in this study. Once again, the variability between the sites was too great to draw any meaningful conclusions.

Due to the diversity and variability of the covariance curves between each site, I conclude that patterns of covariance are a product not only of the interactions of the two species, but also a product of the different characteristics of the environment and their spatial heterogeneity. Furthermore, several more shorelines should be sampled, and at finer scales, in order to truly gain a better understanding of redroot's interactions with other species.

## 5.6 Future Recommendations

Using the Boater wavelet for bivariate wavelet analysis in the PASSaGE 2.0 software only allows a maximum scale of 25% of the total length of the data, which with my sampling design, can therefore only calculate the covariance at scales of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 m. If the first scale is taken to be inaccurate, this leaves only five data points per grid, from which it is difficult to interpret significant results. Therefore, future studies would be much improved with increased sampling grid sizes and the use of finer quadrats. The grid size of 5.0 by 5.0 m typically captured the natural shoreline well, but increasing its size would enable covariance curves to detect covariance trends at scales as large as the shoreline itself. A different form of analysis with a larger block size capacity could also be considered (Camarero et al. 2006). Additionally, much greater insight into species interactions at the microhabitat scale would also be gleaned by using a smaller quadrat size. 0.05 by 0.05 m quadrats would be ideal to observe competition or enhancement relationships operating at too fine a scale to have been captured in this study, and would also provide more data for wavelet analysis. Such a fine quadrat size would of course take much longer to survey, but the increased precision of the results could justify the additional effort. If time was very limited, a quadrat size of 0.1 by 0.1 m could be considered as the optimal size for both efficient sampling and precise results (Dale and Blundon 1991).

Wavelet analysis can be a useful tool for plant ecologists in order to capture and analyse spatial patterns of plants at multiple scales with one data set, and without a strong bias from spatial autocorrelation. However, the limitations of the wavelet calculation in terms of maximum scale must be taken into consideration when designing the methodology for data collection, to ensure that sufficient data are collected to be able to detect meaningful patterns in the spatial distribution of the vegetation. This study could have been improved with measurements along more lakeshores,

especially at sites chosen more randomly, and by using a finer quadrat size to more precisely capture the microhabitat conditions and interactions experienced by redroot.

## **6.0 Conclusions and Implications for Conservation**

Redroot has a limited distribution in Nova Scotia, and only grows at low densities throughout its range. Its lakeshore habitat is undergoing steady decline due to new and intensified lakeshore development in recent years, and thus, in order to conserve the species, its critical habitat must be identified and protected. This study therefore set out to better understand the distribution of redroot and examine the abiotic and biotic habitat characteristics that are associated with the species in Nova Scotia.

Redroot grows best in a vegetation structure with other herbs and grasses, and with a lack of shrub and tree cover. These woody species outcompete redroot, and prevent it from obtaining the insolation it needs to thrive. By impeding the development of woody species through physical disturbance and the removal of organic matter, the processes of wave action, periodic flooding, and ice scour are therefore essential components of redroot habitat. Other herbaceous ACPF species, which are also tolerant of disturbance and low nutrient levels, experience ecological coincidence with redroot along these exposed shorelines. Redroot itself grows in multiple patches within an extent of occurrence about 2 m wide within the zone of periodic inundation, starting about 50 cm above the August water line. This niche is determined both by its tolerance to environmental gradients as well as its interactions with competing woody species.

As a highly tolerant plant, redroot is able to grow in all substrate types. At a finer microhabitat scale, however, abundant redroot is best associated with gravel, a substrate formed by levels of disturbance suitable for redroot growth.

Similar to previous findings, my study indicates that redroot's critical habitat includes wider, gently sloping, western-facing shorelines of smaller, more connected lakes that have large watersheds relative to the size of the lake. These larger watersheds provide an influx of water essential for creating the periodic flooding and wave action that provide the optimal shoreline habitat for redroot. The low rate of flowering, and therefore reliance on asexual propagation, may be a natural limiting factor and emphasizes the importance of lake connectivity for suitable redroot habitat in Nova Scotia. A network of protected areas made up of shorelines with these characteristics would thus be the optimal conservation measure to protect this threatened species. Furthermore, because redroot seems to grow in positive association with most species of ACPF at a minimum of one spatial scale, protecting the habitat for one species can simultaneously aid in the conservation of many other species of ACPF.

The scope of this study was limited by the time constraints placed on data collection. Future studies could randomly sample a much greater number of shorelines on a larger number of lakes, in order to increase the sample size and variability of the independent variables, and to be able to draw statistically significant conclusions about the entire Nova Scotia redroot population. Additional variables such as shoreline exposure, lake shape complexity, water level fluctuations and nutrient input could also be recorded to provide greater insight into the processes that shape optimal redroot habitat. Finer quadrats could also be used to better detect interspecific interactions. Furthermore, data collection could also occur over the course of several years to ensure that the findings do not simply represent the growth patterns in an anomalous year of unusual temperatures or water levels.

Finally, the analysis methods used in this study can be replicated for other rare species of ACPF to further the understanding of their critical habitat characteristics and develop a more comprehensive and scientifically-derived conservation strategy for ACPF species.

## 7.0 References

- Belliveau A. 2011. Characterizing freshwater lakeshore habitat for rare Atlantic coastal plain flora (*Coreopsis rosea* and *Sabatia kennedyana*) in southwest Nova Scotia [M.R.E.M. report]. [Halifax (NS)]: Dalhousie University.
- Blaney S. 2010. Atlantic coastal plain flora shoreline inventory [Standardized protocol]. Nova Scotia: Atlantic Canada Conservation Data Centre.
- Bolduc J. 2015 Apr 8. Halifax snowfall sets records over past two months. The Chronicle Herald [Internet]. [cited 2016 Mar 12]; Available from: <http://thechronicleherald.ca/metro/1279409-halifax-snowfall-sets-records-over-past-two-months>
- Bradshaw GA, Spies TA. 1992. Characterizing canopy gap structure in forests using wavelet analysis. *J Ecol.* 80(2): 205-215.
- Brandt-Williams S, Wigand C, Campbell DE. 2012. Relationships between watershed emergy flow and coastal New England salt marsh structure, function, and condition. *Environ Monit Assess.* 185(2): 1391–1412.
- Callaway RM. 2007. Positive interactions and interdependence in plant communities. Dordrecht (Netherlands): Springer. 415 p.
- Camarero JJ, Guitierrez E, Fortin MJ. 2006. Spatial patterns of plant richness across treeline ecotones in the Pyrenees reveal different locations for richness and tree cover boundaries. *Global Ecol Biogeogr.* 15(2): 182-191.
- Carr LGK. 1965. Floristic elements in southwestern Virginia: A phytogeographical consideration. *Castanea.* 30(2): 105-145.
- COSEWIC. 2009. COSEWIC assessment and status report on the redroot, *Lachnanthes caroliniana*, in Canada. Ottawa(ON): Committee on the Status of Endangered Wildlife in Canada. vii + 34 pp.
- Craine SI, Orians CM. 2004. Pitch pine (*Pinus rigida Mill.*) invasion of Cape Cod pond shores alters abiotic environment and inhibits indigenous herbaceous species. *Biol Conserv.* 116(2): 181-189.
- Cypert E. 1972. The origin of houses in the Okefenokee Prairies. *Am Midl Nat.* 87(2): 448-458.
- Dale MRT. 1999. Spatial pattern analysis in plant ecology. Cambridge (UK): Cambridge University Press; Cambridge Studies in Ecology. 326 pp.
- Dale MRT, Blundon DJ. 1991. Quadrat covariance analysis and the scales of interspecific association during primary succession. *J Veg Sci.* 2(1): 103–112.
- Dale MRT, Mah M. 1998. The use of wavelets for spatial pattern analysis in ecology. *J Veg Sci.* 9(6): 805-814.
- Discover Caledonia [Internet]. [date unknown]. Caledonia (NS): North Queens Board of Trade; [modified 2015 Jun 24; cited 2015 Dec 4]. Available from: [http://www.registrelep-sararegistry.gc.ca/species/speciesDetails\\_e.cfm?sid=229](http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=229)
- Edwards JM, Weiss U. 1974. Phenalenone pigments of the root system of *Lachnanthes tinctoria*. *Phytochemistry.* 13(8): 1597–1602.

- Environment Canada, Parks Canada. 2010. Recovery strategy and management plan for multiple species of Atlantic Coastal Plain Flora in Canada. Ottawa (ON): Environment Canada and Parks Canada Agency. 96 pp. + appendices. Species at Risk Act recovery strategy series.
- Elam CE, Stucky JM, Wentworth TR, Gregory JD. 2009. Vascular flora, plant communities, and soils of a significant natural area in the middle Atlantic coastal plain (Craven County, North Carolina). *Castanea*. 74(1): 53-77.
- Estill JC, Cruzan MB. 2001. Phyto geography of rare plant species endemic to the southeastern United States. *Castanea*. 66 (1/2): 3-23
- Ferrell J, Sellers B, Walter J. 2009. Control of Redroot (*Lachnanthes caroliniana*) in pastures. Gainesville, FL: University of Florida Cooperative Extension Service. SS Agr 290. 2 p.
- Fetherston KL, Naiman RJ, Bilby RE. 1995. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. *Geomorphology*, 13(1): 133-144.
- Fortin MJ, Dale MRT, ver Hoef J. 2002. Spatial analysis in ecology. In: *Encyclopedia of Environmetrics Volume 4*. Chichester: John Wiley & Sons. pp 2051–2058.
- Francis G, Munro N. 1994. A biosphere reserve for Atlantic Coastal Plain flora, south-western Nova Scotia. *Biol Conserv*. 68(3): 275-279.
- Gonzalez M, Deconchat M, Balent G. 2009. Woody plant composition of forest layers: The importance of environmental conditions and spatial configuration. *Plant Ecol*. 201(1): 305–318.
- Good-Avila SV, Sutton J, Wood S, Ferrer M. 2006. Conservation of Atlantic Coastal Plain Flora Species at Risk and important lakeshore habitat in the Tusket River Watershed. Nova Scotia Habitat Conservation Fund. 34 pp.
- Harper KA, Danby RK, De Fields D L, Lewis KP, Trant AJ, Starzomski BM, Savidge R, Hermanutz L. 2011. Tree spatial pattern within the forest-tundra ecotone: a comparison of sites across Canada. *Can J Forest Res*. 41(3): 479-489.
- Hill NM, Keddy PA. 1992. Prediction of rarities from habitat variables: coastal plain plants on Nova Scotian lakeshores. *Ecology*. 73(5): 1852–1859.
- Hill NM, Keddy PA, Wisheu IC. 1998. A hydrological model for predicting the effects of dams on the shoreline vegetation of lakes and reservoirs. *Environ Manage*. 22 (5): 723-736.
- Hufkens KP, Scheunders P, Ceulemans R. 2009. Ecotones in vegetation ecology: methodologies and definitions revisited. *Ecol Res*. 24(5): 977-986.
- James, PMA, Fleming RA, and Fortin MJ. 2010. Identifying significant scale-specific spatial boundaries using wavelets and null models: spruce budworm defoliation in Ontario, Canada as a case study. *Landscape Ecol*. 25(6): 873–887.
- James, PMA, Sturtevant BR, Townsend P, Wolter P, Fortin MJ. 2011. Two-dimensional wavelet analysis of spruce budworm host basal area in the Border Lakes landscape. *Ecol Appl*. 21(6): 2197-2209.
- Keddy C. 1994. Status report on the redroot, *Lachnanthes caroliniana*, in Canada. Ottawa (ON): Committee on the Status of Endangered Wildlife in Canada (COSEWIC).
- Keddy CJ, Sharp MJ. 1989. Atlantic coastal plain flora conservation in Ontario. Toronto (ON): Report for the World Wildlife Fund and Ontario Heritage League.



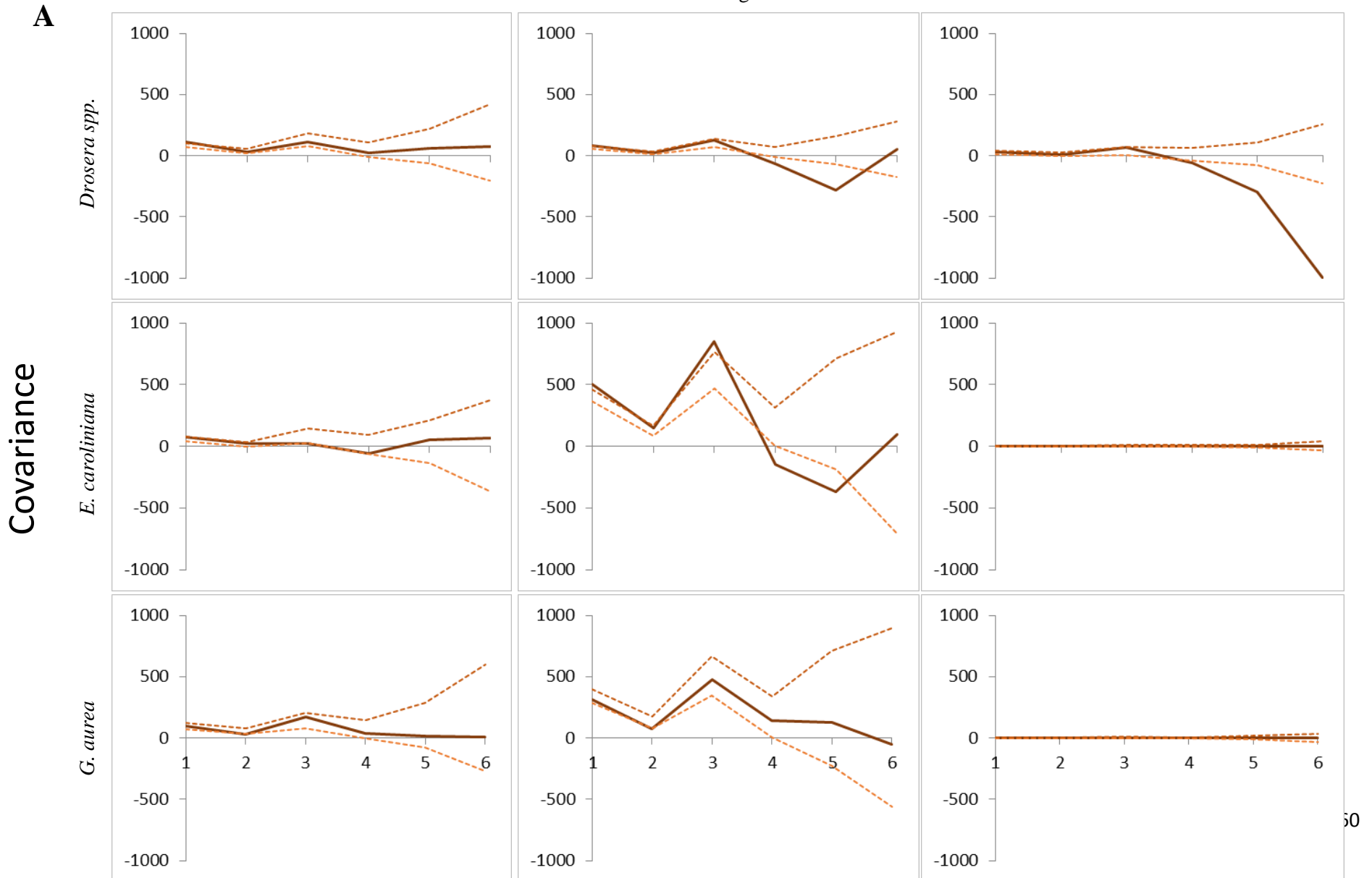
- Keddy, PA. 1981. Vegetation with Atlantic coastal plain affinities in Axe Lake, near Georgian Bay, Ontario. *Can Field Nat.* 95(3): 241-248.
- Keddy PA. 1984. Quantifying a within-lake gradient of wave energy in Gillfillan Lake Nova Scotia. *Can J Bot.* 62: 301–309.
- Keddy PA. 1989. Effect of competition from shrubs on herbaceous wetland plants: a 4 year field experiment. *Can J Bot.* 67(3):708–716.
- Keddy PA, Reznicek AA. 1982. The role of seedbanks in the persistence of Ontario's coastal plain flora. *Am J Bot.* 69(1): 13-22.
- Keddy PA, Smith L, Campbell DR, Clark M, Montz G. 2006. Patterns of herbaceous plant diversity in southeastern Louisiana pine savannas. *J Veg Sci.* 9(1): 17-26.
- Kembel SW, Dale MRT. 2006. Within-stand spatial structure and relation of boreal canopy and understory vegetation. *J Veg Sci.* 17(6): 783-790.
- Kornfeld JM, Edwards JM. 1972. Investigation of photodynamic pigments in extracts of *Lachnanthes tinctoria*. *BBA-Gen Subjects.* 286(1):88-90.
- Landers JL, Johnson AS, Morgan PH, Baldwin WP. 1976. Duck foods in managed tidal impoundments in South Carolina. *J Wildlife Manage.* 40(4): 721-728.
- Landman GB, Menges ES. 1999. Dynamics of woody bayhead invasion into seasonal ponds in south central Florida. *Castanea* 64(2): 130-137.
- Lesica P, Allendorf FW. 1995. When are peripheral populations valuable for conservation?. *Conserv Biol.* 9(4): 753-760.
- Lusk JM, Reekie EG. 2007. The effect of growing season length and water-level fluctuations on growth and survival of two rare and at risk Atlantic Coastal Plain flora species, *Coreopsis rosea* and *Hydrocotyle umbellata*. *Can J Bot.* 85(2): 119-131.
- MacLeod CD, Mandleberg L, Schweder C, Bannon SM, Pierce GJ. 2008. A comparison of approaches for modelling the occurrence of marine animals. *Hydrobiologia.* 612(1): 21–32.
- McMillan PD, Peet RK, Porcher, RD, Sorrie BA. 2002. Noteworthy botanical collections from the fire-maintained pineland and wetland communities of the coastal plain of the Carolinas and Georgia. *Castanea.* 67(1): 61-83
- McLaughlin WT. 1932. Atlantic coastal plain plants in the sand barrens of Wisconsin. *Ecol Monogr.* 2(3): 335-383.
- Meggitt WF, Aldrich RJ. 1959. Amitrol for control of redroot in cranberries. *Weeds.* 7(3): 271-276.
- Meyers SL, Jennings KM, Monks DW, Jordan DL, Ballington JR. 2013. Effect of PRE and POST herbicides on Carolina Redroot (*Lachnanthes caroliniana*) growth. *Weed Technol.* 27 (3): 747–751.
- Minitab 17 Statistical Software [Computer software]. 2010. State College (PA): Minitab, Inc. Available from: [www.minitab.com](http://www.minitab.com)
- Mitchell SJ, Hailemariam T, Kulis Y. 2001. Empirical modeling of cutblock edge windthrow risk on Vancouver Island, Canada, using stand level information. *Forest Ecol Manag.* 154(1–2): 117–130.

- Morris PA, Hill NM, Reekie EG, Hewlin HL. 2002. Lakeshore diversity and rarity relationships along interacting disturbance gradients: catchment area, wave action and depth. *Biol Conserv.* 106 (1): 79-90.
- Neily PD, Quigley E, Benjamin L, Steward B, Duke T. 2005. Ecological land classification for Nova Scotia. Nova Scotia: Nova Scotia Department of Natural Resources Renewable Resources Branch. Report DNR 2005. 71 pp + appendix.
- Nova Scotia Department of Natural Resources. 2011. Forest ecosystem classification for Nova Scotia part II: Soil types. Nova Scotia: Nova Scotia Department of Natural Resources Renewable Resources Branch. Report for 2011-3.88 pp + appendices.
- Parks Canada. 2012. Kejimikujik National Park and National Historic Site of Canada: Weather [Internet]. Ottawa (ON): Parks Canada; [updated 2012 Feb 27; cited 2015 Nov 6]. Available from: <http://www.pc.gc.ca/eng/pn-np/ns/kejimikujik/visit/visit5.aspx>
- Plunkett GM, Hall GW. 1995. The vascular flora and vegetation of western Isle of Wight County, Virginia. *Castanea.* 60(1): 30-59.
- Rees M, Grubb PJ, Kelly D. 1996. Quantifying the impact of competition and spatial heterogeneity on the structure and dynamics of a four-species guild of winter annuals. *Am Nat.* 147 (1): 1-32.
- Reznicek AA. 1994. The disjunct coastal plain flora in the Great Lakes region. *Biol Conserv.* 68(3): 203-215.
- Reznicek AA, Whiting RE. 1976. *Bartonia* (Gentianaceae) in Ontario. *Can Field Nat.* 90(1): 67-69.
- Roland AE, Zinck M. 1998. Roland's flora of Nova Scotia. 3rd ed. Halifax (NS): Nova Scotia Museum and Nimbus Publishing. 2 vols.
- Rosenberg MS, Anderson CD. 2011. PASSaGE: Pattern Analysis, Spatial Statistics and Geographic Exegesis [Computer software]. Version 2. *Method Ecol and Evol.* 2(3): 229-232.
- Schneider R. 1994. The role of hydrological regime in maintaining rare plant communities of New York's coastal plain pond shores. *Biol Conserv.* 68 (3): 253-260.
- Scoggan HJ. 1978. The flora of Canada. Ottawa (ON): National Museums of Canada. 4 vol.
- Schlesinger WH, Bernhardt ES. 2013. Biogeochemistry: An analysis of global change. 3<sup>rd</sup> ed. San Diego (CA): Academic Press (Elsevier). 688 pp.
- Shmida A, Whittaker RH. Pattern and biological microsite effects in two shrub communities, Southern California. *Ecology.* 62 (1): 234-251.
- Smith RL, Smith TM. 2001. Ecology and field biology. 6th ed. New York: Benjamin Cummings. 771 p.
- Sorrie BA. 1994. Coastal-plain ponds in New England. *Biol Conserv.* 68(3):225-233.
- Species at Risk Public Registry. [date unknown]. Species profile: Redroot [Internet]. Ottawa (ON): Government of Canada; [modified 2015 Aug 14; cited 2015 Sept 21]. Available from: [http://www.registrelep-sararegistry.gc.ca/species/speciesDetails\\_e.cfm?sid=229](http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=229)
- Statistics Canada. 2015. Focus on geography series, 2011 census: Census subdivision of Bridgewater, T, Nova Scotia [Internet]. Ottawa (ON): Government of Canada; [modified 2015 Nov 12; cited 2015 Dec 4]. Available from:

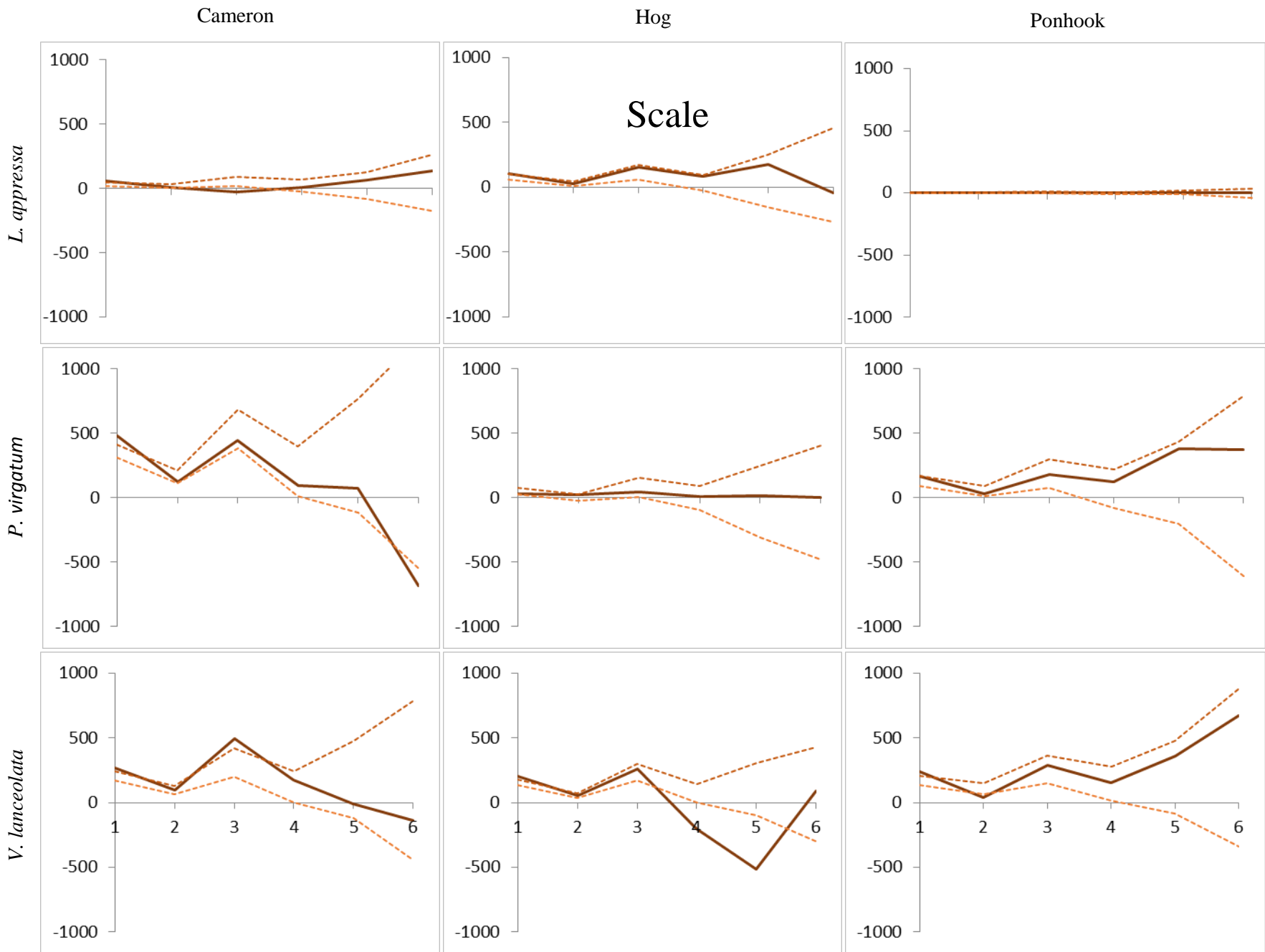
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- Tans WE. 1983. Recent Wisconsin records for some interesting vascular plants in the western Great Lakes region II. *Mich Bot.* 22(1): 11-18.
- Tyndall RW, McCarthy KA, Ludwig JC, Rome A. 1990. Vegetation of six Carolina bays in Maryland. *Castanea.* 55(1): 1-21.
- Tyndall RW 2000. Vegetation change in a Carolina Bay on the Delmarva Peninsula of Maryland during an eleven-year period (1987-1997). *Castanea.* 65(2): 155-164.
- Webb KT, Marshall IB. 1999. Ecoregions and ecodistricts of Nova Scotia. Truro (NS) and Hull (QC): Crops and Livestock Research Centre, Research Branch, Agriculture and Agri-Food Canada and Assessment Office, Environmental Quality Branch, Environment Canada. 39 pp. + 1 map.
- Wisheu IC, Keddy PA. 1989. The conservation and management of a threatened coastal plain plant community in eastern North America (Nova Scotia, Canada). *Biol Conserv.* 48 (3): 229-238.
- Wisheu IC, Keddy PA. 1994. The low competitive ability of Canada's Atlantic coastal plain shoreline flora: implications for conservation. *Biol Conserv.* 68 (3): 247-252.
- Wisheu IC, Keddy CJ, Keddy PA, Hill NM. 1994. Disjunct Atlantic Coastal Plain species in Nova Scotia: distribution, habitat and conservation priorities. *Biol Conserv.* 68 (3): 217-224.
- Zaremba RE, Lamont EE. 1993. The status of the Coastal Plain pondshore community in New York. *B Torrey Bot Club.* 120:180-187.

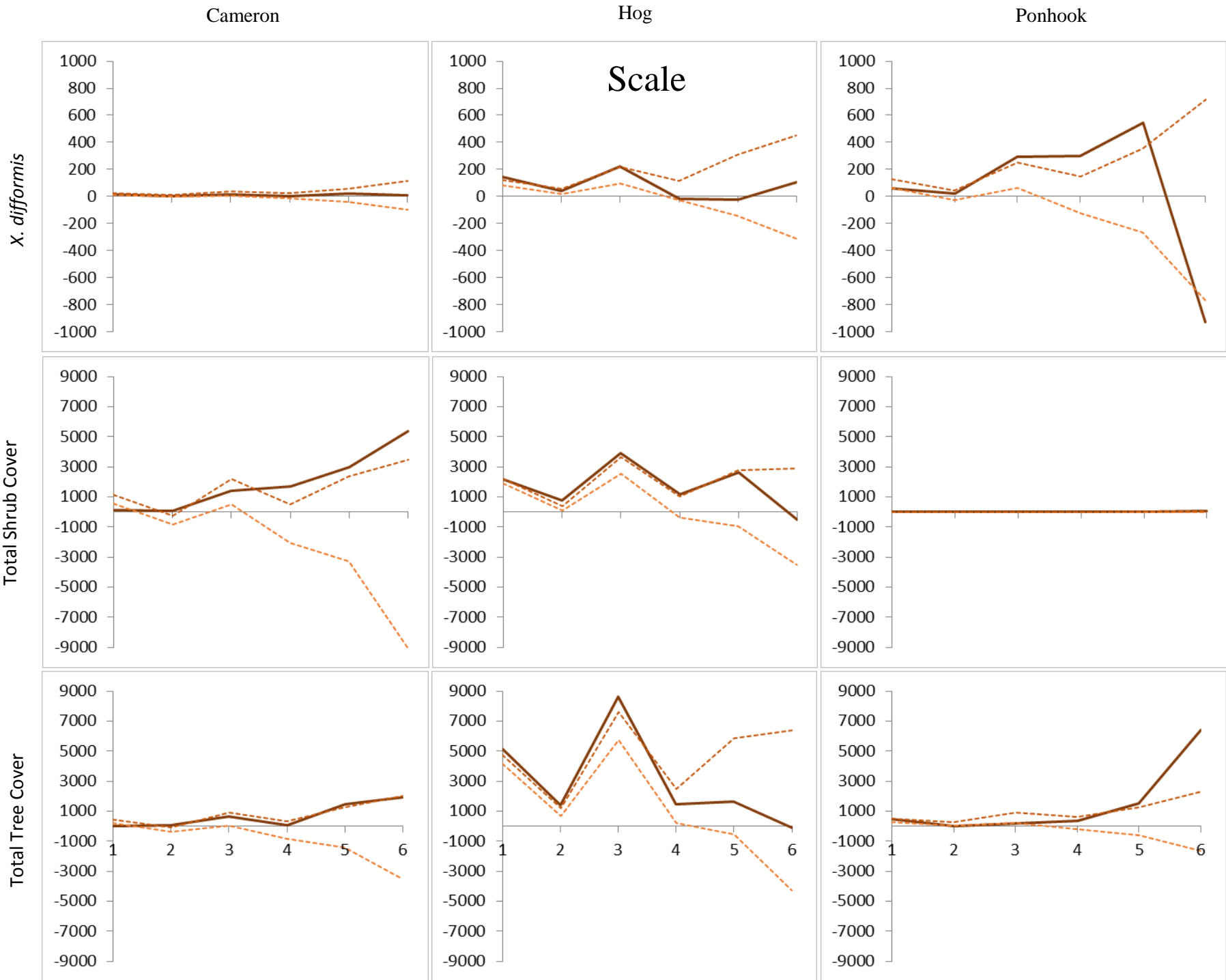
## 8.0 Appendix 1 – Redroot covariance with other species of Atlantic Coastal Plain Flora and other vegetation

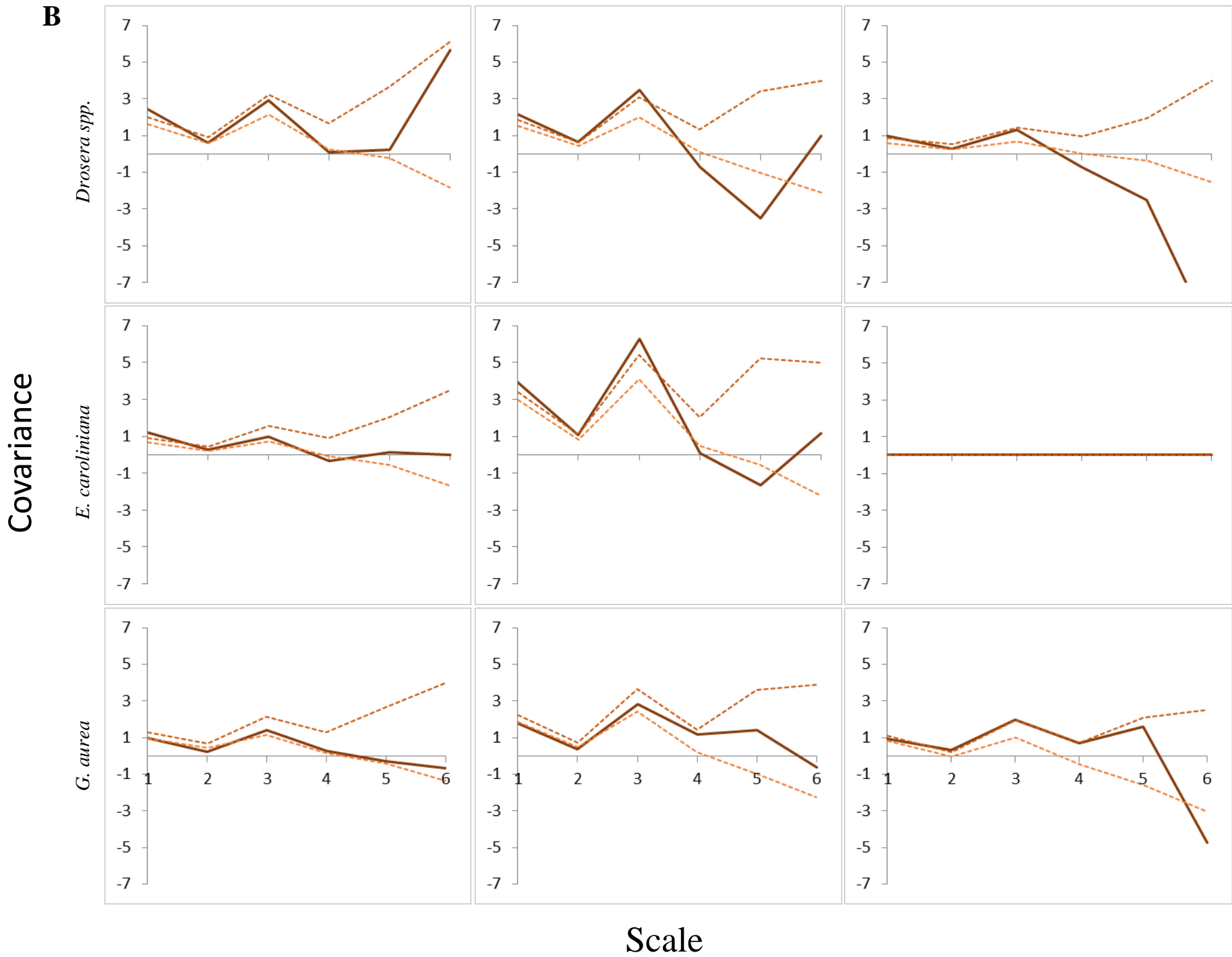


Covariance



# Covariance





# Covariance

Cameron

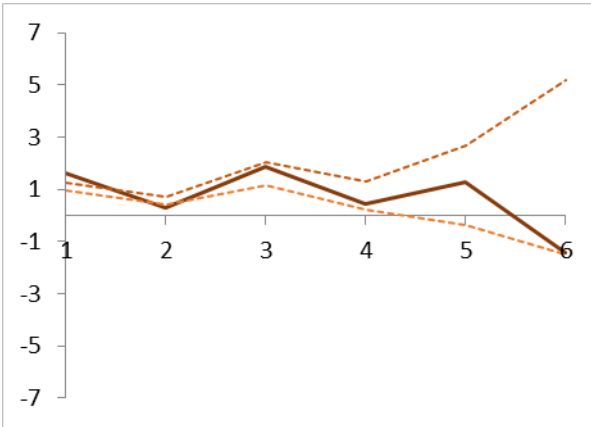
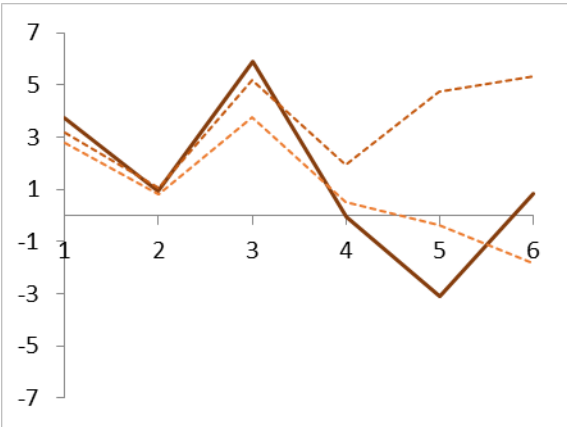
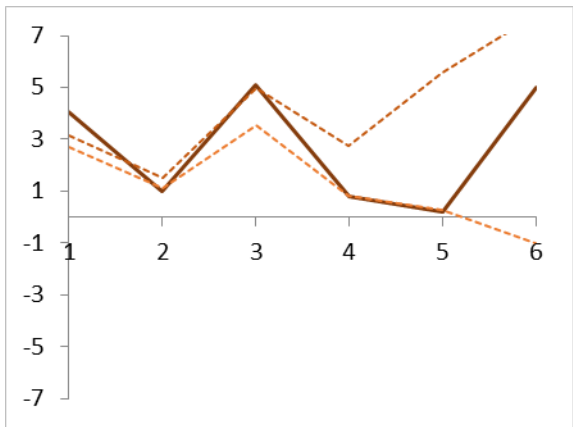
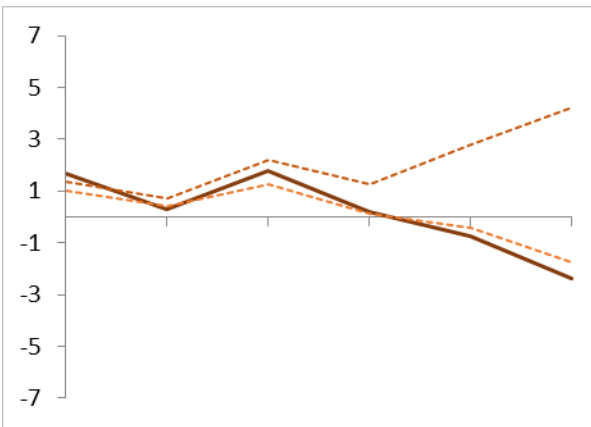
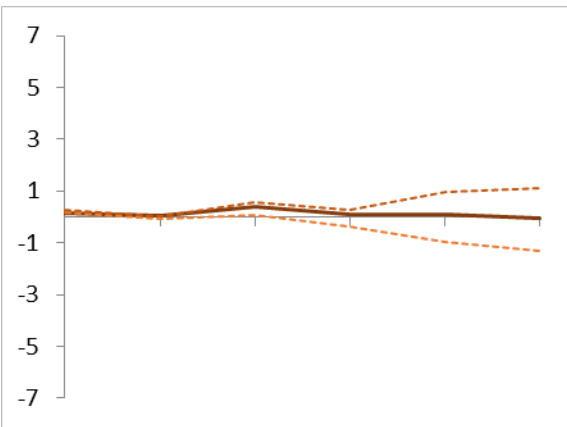
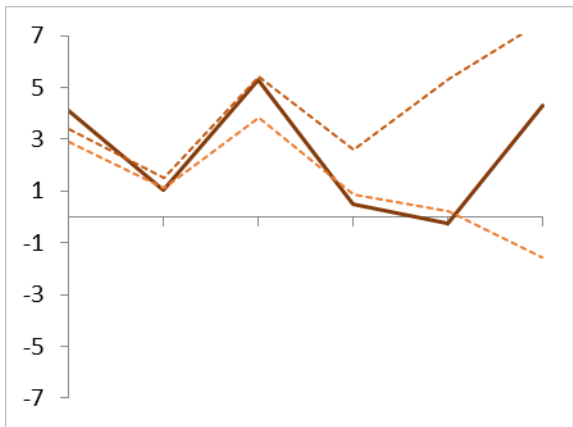
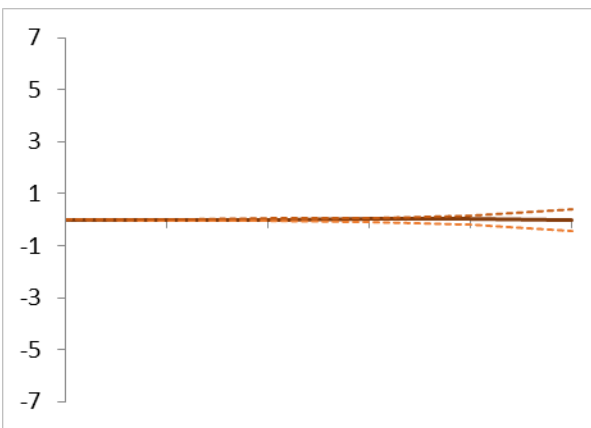
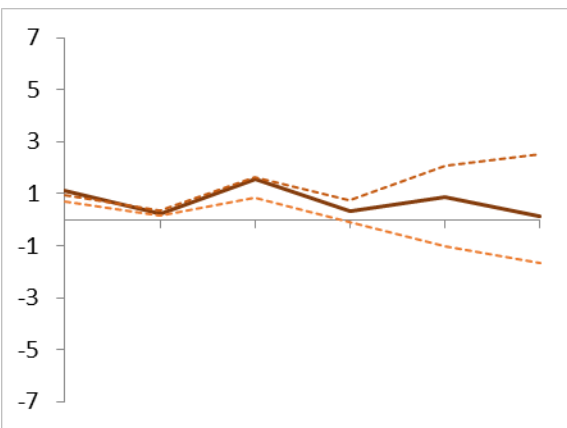
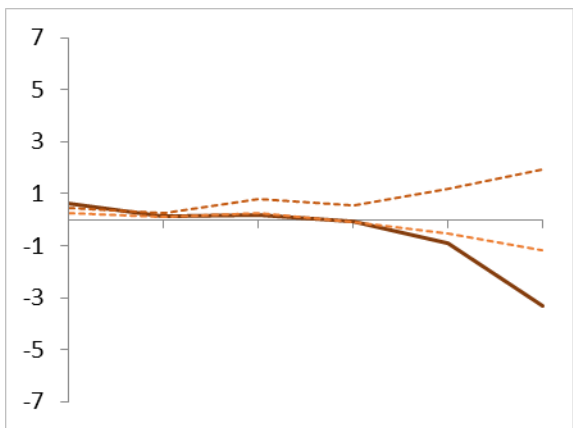
Hog

Ponhook

*L. appressa*

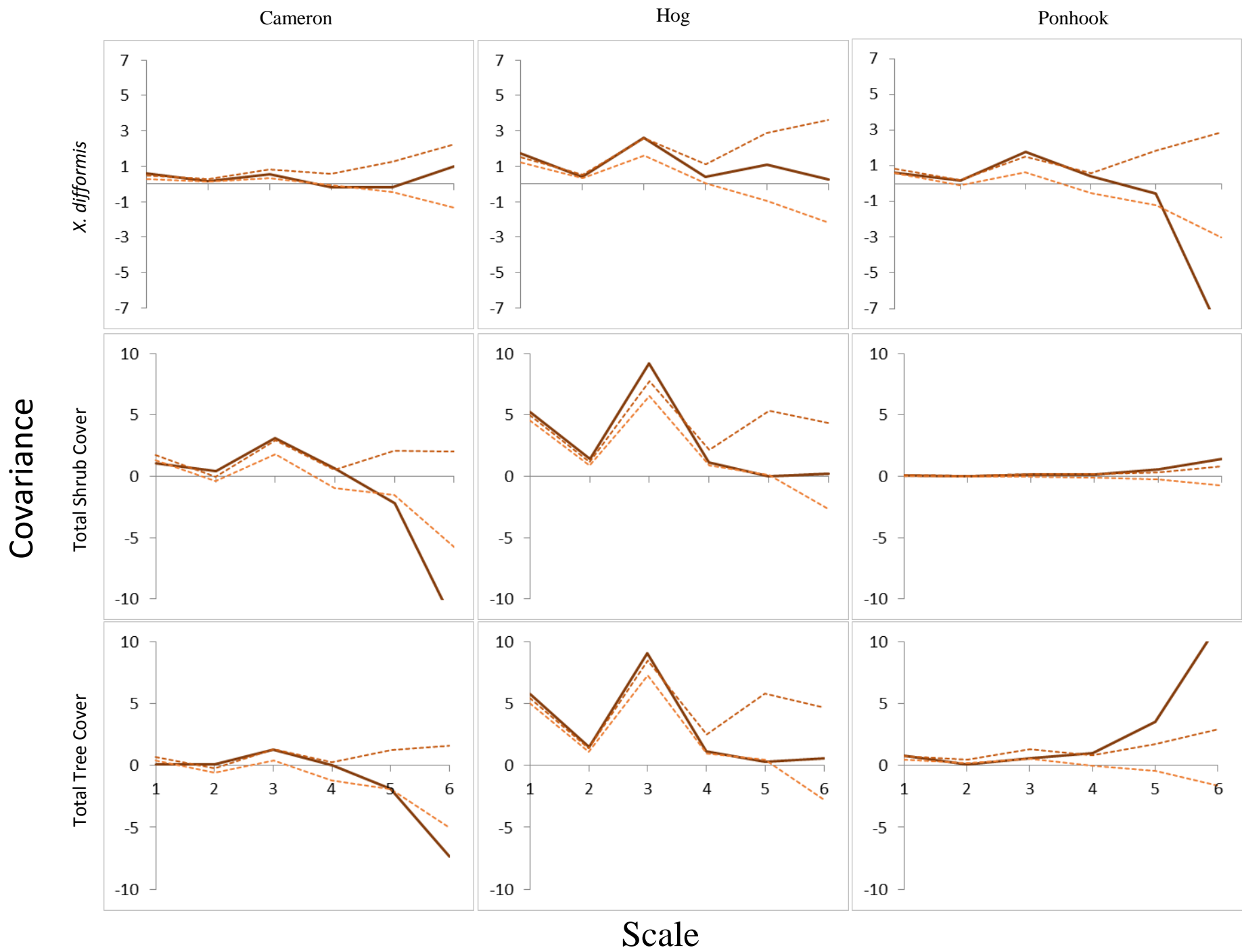
*P. virgatatum*

*V. lanceolata*



Scale





**Figure 1.** The curves of covariance of redroot and different species of ACPF and vegetation groups at various spatial scales. The spatial scales are in multiples of 0.2 m, where 1 is 0.2 m and 6 is 1.2 m. A. The covariance curves for density data. B. The covariance curves for presence/absence data.