An Inventory and Recommendations for the Management of High Priority Invasive Alien Plants in Point Pelee National Park

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including and required final revisions, as accepted by my examiners.

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Abstract

Point Pelee National Park in Ontario, Canada has been affected by a long history of human activity. This activity has encouraged the establishment of approximately 276 exotic invasive plant species. These plants decrease biodiversity and effective function of ecosystems within the Park. Plant biodiversity is important for maintaining ecosystem integrity through supporting a diversity of other species and increasing the ecosystems resilience. A 5 Year Exotic Plant Species Management Plan for the Park was written in 1990, at which time 43 species were deemed a priority. Since that time inventories have been done on some of the species but a monitoring of all the high priority exotic invasive plants has not. The lack of temporal data prevents the assessment of trends of these species as well. As part of this study an inventory of the high priority exotic invasive plants and their spatial extent in the Park, was created. Emphasis was on methods that are relevant and physically and economically feasible in the Park. This will provide a standard inventory method that can be repeated in future years and the data comparable among inventories. Comparing results in future years will help the Park monitor the success of management. From May to September, 2011 a comprehensive inventory took place within a 5.5km stretch in the terrestrial area at the southern end of the Park. Systematic belt transects were performed, on foot, from west to east at 100 m intervals. Belt transects were a combination of frame quadrats (2 x 2 m) along transects. The quadrats were placed randomly one within every 100 m of transect. Within the quadrats percent cover of each plant species was determined. This assured that the frequency and density of each species was recorded with respect to the native plants. Observations that the species composition differed along the road and trails, led to additional random quadrat placement along them. The data collected in the field were compiled using geographic information systems (GIS), resulting in maps of the extent of the most abundant species studied. Analysis as part of this study included using the data to determine which plants and areas are higher priorities for management within the Park. Quadrats were analysed for diversity using the Simpson Index and, since the data was non-parametric, comparisons were made across diversity and native richness using the Kruskal Wallis test. The Kruskal Wallis test was also used to test differences between the road and trails data and base data that was greater than 100m from the road and trails. *Alliaria officinalis* is the only non-native species that is widespread within the study area. Other non-native species with a high potential for invasiveness were observed but only consisted of a few individuals along roads and paths. *Vinca minor*, *Bromus inermis*, *Convallaria majalis* and *Hemerocallis fulva* were present along or near roads and paths in denser patches (17-100% plot coverage). *Osmorhiza longistylis*, a native species, was observed to be dominating in some areas and was widespread throughout the study area. The continued existence of non-native species and the dominance of some native species is likely a symptom of the low diversity, caused by the history of disturbance. Recommendations include removal of some non-native species deemed to be a potential threat to native richness and diversity, followed by re-vegetation with native species, and continued monitoring. Future restoration efforts are best directed at the area around DeLaurier, along west beach and at the Tip. These areas have the lowest diversity and native richness and therefore need the most improvement. Recent budget cuts will make it difficult to employ some of these recommendations but the maps of high priority species make it possible to focus remaining resources in those areas.

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Chapter 1 Introduction

Invasive Plants

When discussing invasive plants it is important to establish first what is meant by the term. Non-native, alien, or exotic plants are all terms used interchangeably to represent a plant species that has been introduced as a result of human activity (Richardson et al., 2000). Plant species have been introduced intentionally for agriculture, forestry, recreation and horticulture and accidentally as seed contaminants (Elton, 1958). An invasive plant species can produce a great number of offspring at considerable distances from the parent, making it easy for the species to spread its range. A considerable number of invasive plants are non-native but native plants can also be invasive. Attributes of non-native plants that make them good invaders are not always unique to those species. Co-occurring native species can also share these attributes (Thompson et al., 1995). The term weed describes an invasive plant that is increasing its range at the expense of native plants, resulting in negative effects on biodiversity and ecosystem functioning (Richardson et al., 2000). For the purposes of this study the term invasive plant species will be used to describe a plant that is non-native and expanding its range at the expense of native plants in the ecosystem, unless otherwise stated.

Not all introduced plants will become invasive. There are four stages for a plant species to go through before it becomes invasive and only about 10% pass from each transition to the next stage. The stages are dispersal by human activity, introduction to the wild, establishment and finally becoming invasive (Williamson & Fitter, 1996). Reasons for failure to reach the next stage include competition, predation and inappropriate abiotic conditions. Successful invasion depends on plant species traits as well as the characteristics of the habitat being invaded, and timing or chance (Lodge, 1993). Human disturbances like agriculture and urban development can provide an opportunity for invasion to occur if timed with the introduction of a plant with invasive traits. Invasive plants are usually opportunistic and generalists, allowing them to colonize and spread in an area under disturbance better than the native species (Elton, 1958; Hobbs & Huenneke, 1992).

When more than one plant species invades an ecosystem they can in turn facilitate successive invasions. This can accelerate and increase the effect of the invasive plants on the ecosystem in what is called an invasion meltdown (Elton, 1958). When the physical structure of the plant community is altered by the invasion of one or more non-native plants, new disturbance regimes and successional paths may be formed. It can be difficult to determine if the change in disturbance is related to the invasive plants only, or the disturbance that introduced them (Woods, 1997).

Succession in plant communities refers to the way in which the community changes and develops. It never reaches an end point but instead experiences a rise and fall in importance of plant species in the community. The establishment and maturity of the late successional species tends to depend on the senescence of the early successional species. Species availability and performance are two causes of succession and are driven by dispersal, resources, plant physiology, life history, and competition. Invasive plants tend to have characteristics that favour these drivers and can alter the trajectory of succession (Luken, 1997).

Invasive plants not only cause succession to occur but can also change the rate and direction it takes. Human disturbance provides an opportunity for invasive plants to enter an ecosystem, but also creates a stress for the native plant community, making it easier for the non-native plants to outcompete them. If the non-native plant lacks natural predators in the new habitat and has traits that make it a better competitor for resources, it can quickly establish itself, outgrowing the native plants (Luken, 1997). This dominance can be short lived and in some cases the invasive plants will be replaced by native plants. If the invasive plant is a good colonizer as well as able to persist it will change succession and the species may dominate long term (D'Antonio & Meyerson, 2002).

The IUCN lists invasive species as the second largest threat to biodiversity globally, after habitat loss and degradation (International Union for Conservation of Nature, 2010). The overall effect of an invasive plant depends on the amount of area occupied, the abundance, and the impact per individual plant (Parker et al., 1999)**.** If an invasive plant dominates long term it will displace the native vegetation in an ecosystem as well as the organisms that depend on that vegetative community (Canadian Food Inspection Agency, 2008). This decreases biodiversity in the ecosystem and a diverse ecosystem is more resilient to disturbances. Displacement of native species can have a negative effect on species that are already at risk; in Canada there are 44 species at risk that are threatened by invasive plants. This not only includes plants but also birds, amphibians, insects and one reptile (Canadian Food Inspection Agency, 2008). Invasive plants can also negatively affect fire regimes, biogeochemical cycling, geomorphological processes, hydrological cycles, recruitment or reproduction of native plants, and human health. (Blossey, 1999).

Globalization of trade has increased the number of species being introduced around the world. Humans have been responsible for spreading species around the globe throughout history, including when they first came to North America and brought plants and animals with them. Once Europeans reached North America introductions increased and today, as trade and transportation increases around the globe, so do introductions of plants and animals. Some of these introductions are intentional because of their benefits for humans. This is especially true of agricultural introductions. Some introductions are unintentional and are the result of non-native species stowing away in shipping containers, fruits, seeds and vegetables. These introductions do not always result in decreased biodiversity. In central Europe plant diversity has increased as a result of human-introduced plant invasions. This does not outweigh the negative effects, which invasive species have on a global scale. Instead there is a homogenization of species taking place, which could result in unpredictable long term effects (McNeely, 1999).

The economic costs of invasive plants are large as well. In Canada they cost the agricultural community $2.2 billion annually as a result of damage to crops and control efforts. While this sector is the most affected, other economic sectors are affected by invasive plants as well (Canadian Food Inspection Agency, 2008). The estimated costs of invasive plants are difficult to determine and have been criticized for being inaccurate. This is because indirect costs like the alteration of ecosystem services, non-market values and external costs can be difficult to determine. There is a lack of data for all invasive species in Canada including the extent of their effects and the associated costs. Overlapping effects of other environmental stressors like habitat loss and climate change can make it difficult to determine how much cost can be associated with just invasive species. Cost estimates are usually modest as a result of these difficulties but are important to determine because of the important implications such costs can have for environmental policy and management (Colautti et al., 2006).

Carolinian Zone and Point Pelee National Park

The Carolinian Zone (Figure 1), otherwise known as the Eastern Deciduous Forest, is restricted in Canada to Southern Ontario. The moderate climate, flat terrain and glacial soils, of this zone result in high primary productivity. It experiences the highest average temperatures in

Canada and the longest frost free season. It composes only 1% of Canada's land mass but is the most species rich.

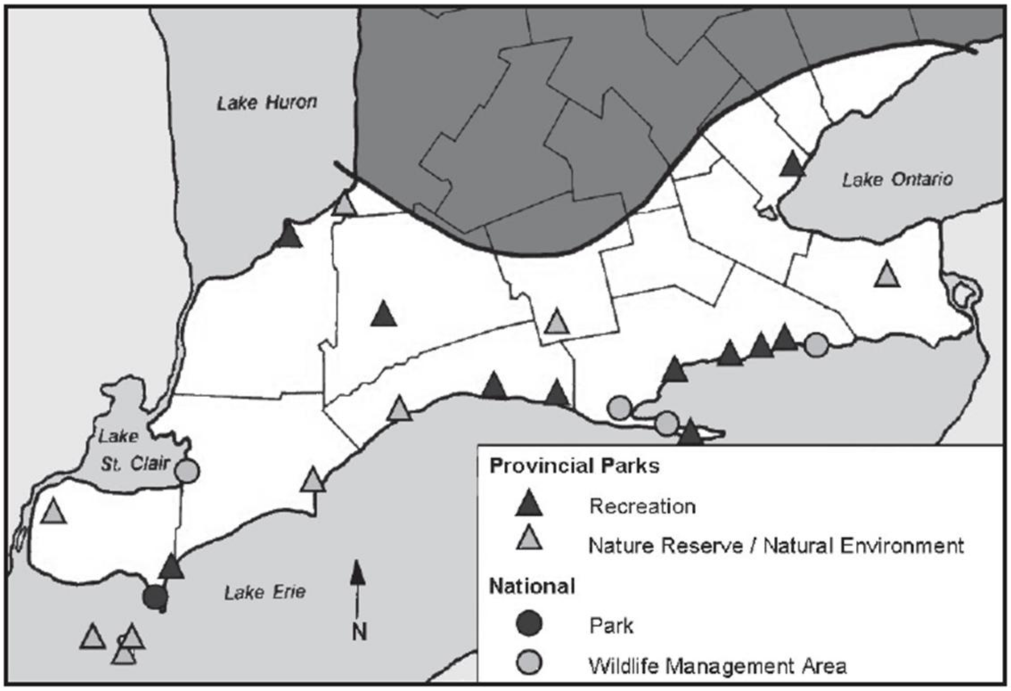

Figure 1. Map showing the Carolinian Zone and protected areas within it (Kanter, 2005)

This zone continues south into the United States, so many of the species that exist in this zone in Canada are at the northern most part of their range (Allen et al., 1990). Point Pelee National Park (PPNP) is the only Canadian National Park located in the Carolinian Zone and protects a number of these species. There are 66 Species at Risk within PPNP that are supported by the diversity of ecosystem types that are present. PPNP is a 15.5km^2, 10 km long peninsula that juts into Lake Erie east of Windsor, Ontario and is the southernmost point of Canada. Lake Erie is productive and diverse itself and moderates the climate while also being a source of disturbance for PPNP. There are five ecosystem types in PPNP; wetland (72%), savannah (2%), Great Lakes Shore (4%) and dryland and swamp forest that together take up 21% (Figure 1). The forest habitat types are present in a range of successional stages and the Great Lakes Shore consists of open beach, grass covered dunes, meadows and shrub thickets. PPNP boasts the second greatest diversity of native plants per square kilometer, out of the Canadian National Parks, at 750 species of vascular plants. It is also where 370 species of birds and insects come before or after crossing Lake Erie during their migrations (Parks Canada, 2010, Dobbie et al., 2006). The high productivity of the Carolinian Zone has led to 80-90% of the area outside PPNP to be cleared for agricultural development (Kanter, 2005). It is now an island of protection with only 6% of the original forest and 3% of the original wetland still existing in the area surrounding PPNP (Dobbie et al., 2006; Parks Canada, 2010). PPNP is part of a Greater Park Ecosystem in Southern Ontario, which is situated in one of the most highly populated and developed areas in Canada. Approximately 46 million people live within a 450 km radius, including the United States, of PPNP. Farming development continues up to PPNP's boundary and as a result there is no buffer habitat available for species to take temporary refuge from any stressors in the Park. The fragmented nature of protected areas in Southern Ontario has also resulted in impaired ecological processes in the area (Dobbie et al., 2006).

Figure 1b. Ecosystem types in the study area of PPNP, as of 2004

National Parks protect ecosystem integrity within their borders but also provide an opportunity for the public to interact with nature. This interaction has caused various amounts of disturbance within Canada's National Parks. Over the years there have been intentional introductions of non-native plants and the installation of infrastructure in the parks has provided opportunities for invasive species to spread. Though PPNP protects important ecosystems and species within the Carolinian Zone it is not composed of pristine wilderness but instead has had a long human history associated with it. PPNP is the traditional homeland for the Caldwell First Nation and Walpole Island First Nation. They were expelled by the British by the 20th Century and the area was used as a Naval Reserve, protecting the timber for use as masts on ships. In the 1830s families began to settle the area for farming purposes and by 1891 there were 22 fisheries located along its shores. The first cottage went up in 1910 and by 1939 the area resembled a carefully manicured urban landscape popular as a recreational area. The marsh also made the area popular among duck hunters. Agriculture peaked around the 1950s, with about 40% of PPNP being used as orchards. By 1963 a large portion of PPNP was being used for housing and recreation, and visitors to the park peaked at 781,000. There were about 600 cottages and numerous roads present at this time (McLachlan and Bazely, 2003). Concerns were raised at this time by management as to what effect human disturbance was having on the ecosystem within PPNP. This began an effort, in the 1970s, to remove the buildings and roads and allow ecological processes to reclaim area. (Parks Canada, 2010; Rodger, 1997). The extent and change in land use from 1920 to 1959 can be seen in Figure 2. The map centers on the area that was part of this study to show that most of the land was affected by human activity. The past human disturbance, within PPNP, has had a lasting effect on native plant communities in the form of invasive plants. Non-native plants were introduced intentionally and accidentally as ornamentals or for agricultural purposes. Large scale clearing of the original vegetation also took place. Some of these plants have persisted in PPNP. Other lasting impacts include the presence of feral animals and altered hydrological and fire regimes. Today human stressors that are being managed for in PPNP are vegetation trampling, road wildlife mortality and the collection of plants, animals and natural objects. The State of the Park report, produced in 2006, listed invasive species as stressor to all habitat types in PPNP (Dobbie et al., 2006)

Objectives of the Thesis

The main objective of this study was to determine the extent and threat, to native species richness and diversity, of non-native plant species in PPNP. The results of a comprehensive inventory of the study area will be used to prioritize species for management based on their threat to ecosystems and at risk species in the park. The final objective will be to make recommendations for management of these species.

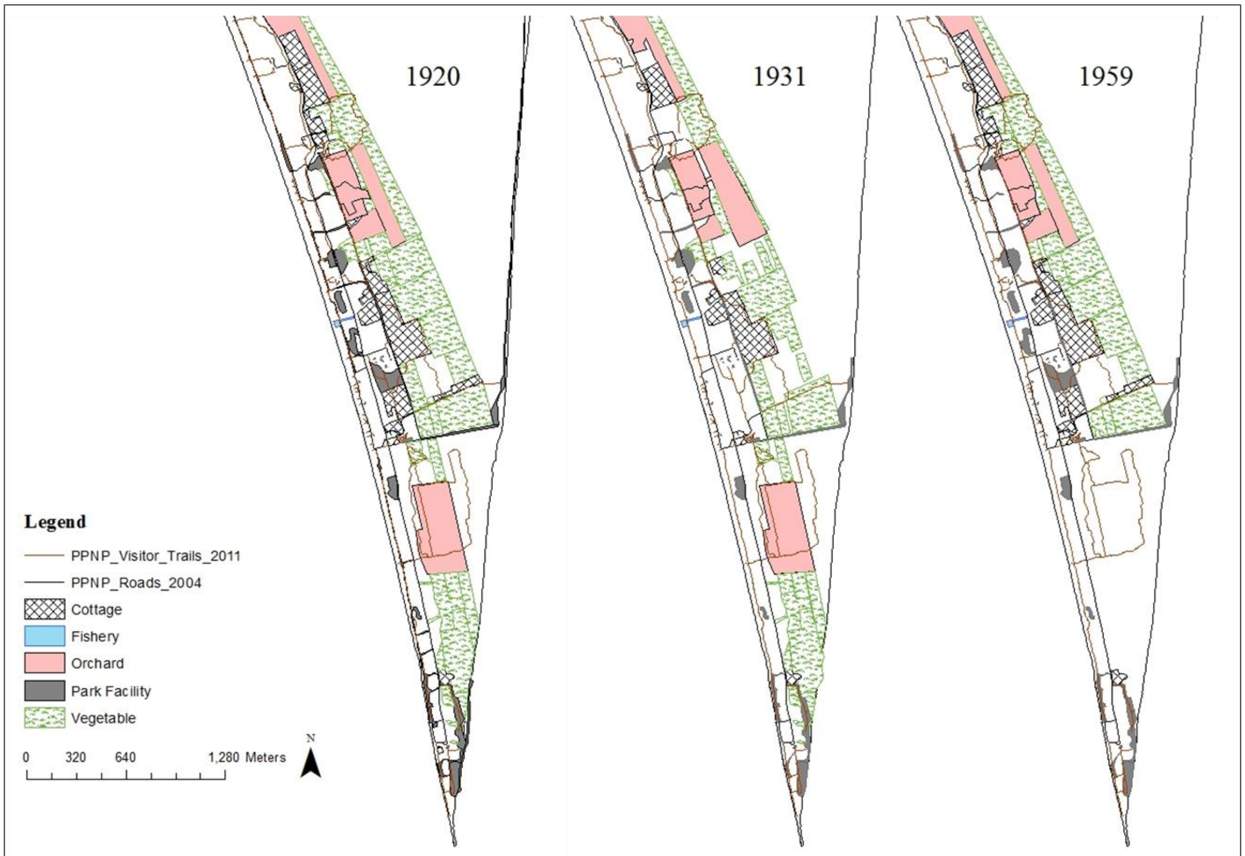

Figure 2. Land use from 1920 to 1959 in PPNP

Chapter 2 Literature Review

Traditional Management Methods.

The following management options are the most commonly used to remove or control invasive plants.

Manual

Manual removal includes hand-pulling, mowing, grubbing and bulldozing (DiTomaso, 2000). The impact of this option can vary from minor, with hand-pulling, to extensive with bulldozing. Proper monitoring and restoration involving the replanting of native plants is required to reduce these impacts (Hobbs & Humphries, 1995). The success of manual removal varies depending on the invasive plant being managed. Hand pulling has proven effective for the control of the South African shrub, *Chrysanthemoides monilifera*, in urban parks in southern Australia, but ineffective for controlling species of *Rhododendron* in British nature reserves (Groves, 1989). This type of removal can be very labour intensive and is usually only a treatment for small areas. For larger areas there are other treatment options (Hobbs & Humphries, 1995).

Herbicides

The use of herbicides is a commonly used management option. Application can be done by aircraft or on the ground. The timing of herbicide application is important and must coincide with the most susceptible stage of the target species life cycle in order to be the most effective (DiTomaso, 2000; Hobbs & Humphries, 1995). Herbicides can have non target effects on native plants and can contaminate water bodies which would be a concern in protected areas (Flory & Clay, 2009). When an invasive plant has become widespread it may have produced a seed bank in the soil. Herbicides may decrease the plant base allowing for native species to return but if the seeds from the invasive plant remain in the soil it could regenerate making herbicide application a short term solution only. Herbicide application over large areas can also be expensive (Groves, 1989).

Biological

Biological management is more controversial because it involves introducing a predator from the species' native range. This carries its own risks and therefore requires a great deal of study about the target species, the predator and what effect it will have on the ecosystem (Hobbs & Humphries, 1995). The moth *Cactoblastis cactorum* is an example of how an introduced biological agent can have unforeseen negative effects on non-target plants. It was introduced to the Lesser Antilles in 1957 to control some species of *Opuntia*. It then spread either naturally by island hopping or inadvertently on imported, ornamental cacti, to the Florida Keys. There it infested *Opuntia spinosissima*, which only consisted of a few individuals within the Torch Wood Hammock Preserve of the Nature Conservancy. The moth decreased the number of *O. spinosissima* to the point that it only exists currently in botanical gardens. It has also infested the rare jumping prickly pear cactus *Opuntia triacantha.* This demonstrates the importance of considering the effects that the introduced species will have on the ecosystem locally as well as at the landscape scale (Simberloff & Stiling, 1996). Over the past 100 years 165 biological agents have been introduced in Canada and the United States. Most introduced predators are arthropods but others include nematodes, pathogens and vertebrates. Fewer attempts at biological control have succeeded then failed, but when it does succeed it can be long term, cost-effective and self-sustaining. While biological control does not eradicate the invasive plant it can reduce its dominance in the ecosystem (DiTomaso, 2000).

Fire

The use of fire to control invasive plants is another common method, especially in prairie and savannah habitats. Fire can be cheaper than some of the other methods and can help maintain the natural element of an ecosystem while removing the invasive species (Groves 1989). Depending on the species, timing is important in order to target the appropriate life stage and be most effective (Emery and Gross, 2005). Fire, if not used appropriately, can be a disturbance that encourages invasive plants so needs to be applied carefully. In about 80% of studies using prescribed burning to control an invasive plant, the plant either increased or was unaffected by the burning. Before using fire as a tool it is important to understand how the invasive and the native, non-target species will react, on a case by case basis. In California fire is being used to decrease invasive plants and promote native plants, but in the western United States fire can promote invasive European grasses (D’Antonio, 2000).

Issues and Concerns

The weed control industry has, in the past, focused on control options for agricultural land, which is a completely different ecosystem than natural areas. Natural ecosystems are more complex and care must be taken to protect the native species; therefore some of these options may not be reasonable solutions in natural areas (White et al., 1993). Managers of invasive plants in natural areas face many unknowns; the effects of the species being managed, and the cost and feasibility of the control methods. Often they are managing for multiple species which can further complicate the matter. It is important for managers to be able to determine the threat, possible threat, and feasibility of control of the species they are managing.

Typically a combination of the above methods needs to be applied to be effective and should be followed with monitoring of the target species as well as the native components of the ecosystem. After removal of the target species re-vegetation with native species can also improve the effectiveness of the program. Predicting what the plant community will look like, after invasive plant removal, can often be done by looking at the seed bank in the soil. However, if the plant is removed, the seed bank still remains, and the plant will return. This is especially true when an invasive has dominated for a long period of time changing the seed bank by keeping native plants from contributing. Manipulating the factors that would stimulate the germination of those seeds could discourage this and make the management program more successful (D'Antonio and Meyerson, 2002).

Invasive plants are typically prioritized for management and those that are both good colonizers and can persist, should be a high priority. It is especially important to prioritize species in parks and protected areas, because funding for expensive management programs can be at a minimum (D'Antonio and Meyerson, 2002). Priority can range from high priority species that will have a high impact and are easy to control, to low priority species that are difficult to control. Prioritization is based on the significance of their impact and the practicality of control. The significance of the species impact is determined by considering the current level of impact as well as the ability of that species to become invasive. The current level of impact depends on how that species responds to disturbances, how many populations exist in the park, what effects it has on ecological processes and structure, which park resources are threatened by it and what its visual impact is. Control practicality is determined based on the abundance of the species in the park, how easy it is to control, side effects of the control options, and how effective community management will be for controlling the species (Hiebert, 1997).

In parks and protected areas, management of invasive plants has focused on stopping continued introduction of new species and reclaiming already invaded communities. The goal is to conserve plant communities that existed before European settlement. Invasive plants threaten this because most were introduced as a result of European settlement in North America. Efforts to prevent further introductions in parks has been somewhat successful but management of areas, where invasive plants have been present for many years and are changing ecological processes, is a more difficult problem to address. Changes in processes and interactions, in a vegetative community, that are caused by invasive plants, creates an opportunity to reassess conservation goals, especially if the non-native plants are providing an ecosystem service. Non-native species can facilitate native species. In PPNP, *Centaurea maculosa* Lam. (spotted knapweed) and *Saponaria officinalis* L. (bouncing bet) are used as a food source by species of butterflies and moths (Roger, 1997). This can create problems for conservation and restoration management. The threat to native species must be weighed against whether the non-native species facilitates at risk species or provides a critical ecosystem service (Rodriguez, 2006). The success of traditional methods of control, whether physical, biological or chemical, is measured in terms of a decrease or removal of the species (Luken, 1997). There is still little evidence that management focused on the target species has a positive effect on the native plant community (Reid et al., 2009). As a result management has more recently moved its focus to improving the native plant community and making ecosystems more resilient to future invasions.

New Directions in Management

When an invasion occurs and there is little pre-invasion baseline information it makes it more difficult to manage. There can also be lag times between when a non-native is introduced and when it becomes invasive. It is important therefore to have a monitoring and rapid response system as part of the management program. Spending money on this in the short term, will hopefully avoid future widespread invasions that can be more costly in the long term. It is also important to consider the effect the surrounding area can have on the protected area. If the park is fragmented, surrounded by highly disturbed land, isolated from other protected habitat, has a history of human disturbance within the park and/or is subject to high human traffic within the park, then it is more likely to be influenced by invasive plants. If this is the case then management goals should be realistic and the complete control or removal of all invasive species may not be practical. Invasive plants do not obey park boundaries and a successful management plan must take into consideration the surrounding environment (D'Antonio and Meyerson, 2002).

Ecologically Based Management

The ways in which invasive plants change how succession occurs and cause other community level effects, have important implications for management. Predicting what and when changes will occur in the new community and what effects management will have, are important to determine (Luken, 1997). Research on the community level effects of invasion is still limited. Direct management of the invading species may have no or little effect if invasion is the result of disturbance. Addressing the disturbance would be a more practical management option but may not be enough to restore the community, if invasive plants have changed the early successional response of the community (Woods, 1997).

Ecological systems tend to be dynamic. Therefore in order for management to be successful it must focus on how they change. There has been little attempt to do this in the area of invasive plant management; instead management has focused on plant control measures, aimed at decreasing population numbers. Management that takes into account how the system changes and between species interactions, is more complicated, but can be more successful. Most importantly the characteristics of the ecosystem that allowed and will continue to allow invasion to occur must be addressed, otherwise invasive plants will continue to invade. Managing succession by controlling disturbance, colonization and species performance would be more successful than traditional control methods. It would create a community better able to resist non-native plant invasions and support a greater diversity of native plants (Luken, 1997).

Monitoring and careful study of the effects of invasive plant removal on the native plant community is important for determining which methods or combination of methods is most effective. Another option that considers the integrity of the ecosystem in question, instead of individual species, is Ecologically Based Invasive Plant Management (EBIPM). This involves integrating different types of ecological models to create a framework that can then help managers with decision making (Sheley et al., 2010). Without taking a broad ecosystem based approach to management any combination of the traditional control measures can fail. Invasive plants have shown that they affect ecological processes; therefore repairing these processes can often correct the cause of invasion, instead of continuously treating the symptom of invasion by removing the invasive plant (Sheley et al., 2010). With EBIPM the emphasis is on addressing ecological processes and modifying them to encourage native plant assemblages rather than invasive (Krueger-Mangold et al., 2006).

Predicting how vegetation communities will respond to invasive plant management can be useful for determining how successful management has been, and for making future management decisions. EBIPM addresses the underlying cause of vegetation dynamics by integrating different types of ecological models into a framework for managers to use when predicting the effects of various management options. The usefulness of EBIPM has been limited by how complex the ecological models tend to be. Emphasis needs to be on determining ecological principles based on what is known already about ecological processes and successional dynamics. This will make EBIPM more useful because it will inform managers on how assessment, ecological process, vegetation dynamics and management practices are linked to one another (Sheley et al., 2010).

Successional management has been used on range lands as a form of EBIPM. By modifying one of the three causes of succession (site availability, species availability and species performance), successional transitions are created, that will lead to predictable and desirable plant communities. (Sheley and Krueger-Mangold, 2003). Site availability can be facilitated by reducing standing vegetation cover, re-establishing past hydrological, nutrient and disturbance regimes and eliminating non-native species. Species availability can be promoted by reintroducing native species, increasing structural complexity, constructing bird perches, and introducing fruit bearing shrubs that attract vertebrate seed dispersers. When monitoring restored areas, changes in species composition must be studied as well as diversity. Any differences in successional species or native versus non-native status cannot be determined from diversity alone (McLachlan and Bazely, 2003).

Use of successional management can improve the presence of native desired species, by improving processes that are already occurring naturally at inadequate levels. Relying on already occurring processes can result in lower management inputs. The high economic costs associated with high management inputs have already been discussed; therefore successional management may offer a more economic option for land managers. With lower management inputs such as herbicides or biological controls, the unintended impacts on native vegetation can also be minimized (Sheley et al., 2009).

Sheley et al. (2010) have created a step by step framework for land managers to refer to when solving invasive plant problems. They also provide case studies as an example of how the framework can be applied. The design of the framework was based on previous research that had been done on management of invasive plants in rangelands, with the intention that it could be applied elsewhere. The first step involves assessing the condition of the ecological processes present and collecting data that will aid in further decision making. The second step involves determining which processes are favouring invasive plants. Determining which processes favour desired species and are not functioning properly and processes that are presently favouring invasive species, allows land managers to focus their efforts. The third step involves ecological principles that provided targets for land managers to work towards. These principles have been derived from already existing literature and allow land managers to make more scientifically informed decisions. Based on the principles determined in step three, step four involves choosing tools and strategies that are predicted to have the desired effect on the ecological process being managed. The final step involves adaptive management in order to determine the effectiveness of the chosen tools and strategies. Variables that most effectively tell whether an ecological process is improving should be chosen and experiments kept simple initially, with only a few variables and a control. Including researchers in the management program can help with experimental design and analysis of the data during this step (Sheley et al., 2010).

Current Management in Canada

In 1992 Canada ratified the United Nations Convention on Biological Diversity (UNCBD) which states that all parties are required to prevent the introduction of, control or eradicate alien species that are threatening native ecosystems, habitats or species. Despite this there is still no federal invasive species act in Canada. Instead invasive plants are addressed under a number of acts listed below along with when they were established (CFIA, 2008).

Plant Protection Act (1990)

Seeds Act (1985)

Wild Animal and Plant Protection and regulation of International and Inter-provincial Trade Act and Regulations (1992)

Species at Risk Act (2002)

Canadian Environmental Protection Act (1999)

Canada National Parks Act (2000)

Pest Control Products Act (2002)

Customs Act (1985)

In 2004, Canada produced An Invasive Alien Species Strategy for Canada. The purpose of this strategy is to address invasive alien species and protect Canada's natural resources. The strategy uses a hierarchy of approaches listed in order of priority. The first is prevention followed by early detection and rapid response and finally management of established invasive species. Management includes eradication, containment, and control. The Strategy also addresses the prevention of invasive species introduction from other countries or from one ecosystem to another within Canada. Throughout the strategy there is emphasis on risk analysis, prioritization and research, to ensure that the most effective and appropriate methods are used (Government of Canada, 2004). As part of the Strategy, a Canadian Invasive Plant Framework (CIPF) is being created. It is still in draft form, evolving as it receives input from federal, provincial and territorial governments, industry, academia and non-government organisations. When complete it will provide a basis for a nationally coordinated response to invasive plants. It will be multi-jurisdictional and will involve both regulatory and non-regulatory methods (Dobbie, 2011).

A Variety of Efforts

Across Canada there are provincial, territorial and municipal governments, universities, colleges, botanical gardens, non-government organisations, youth groups, businesses and First Nations Groups that have responded to the threat of invasive plants. This response has consisted of surveys, mapping, management programs, monitoring and regulations (CFIA, 2008). British Columbia, in an effort to map invasive plants in the province, created the invasive alien plant program in 2005. It includes a data base that allows agencies and non-government organisations to share information collected while conducting various invasive plant management programs. It maps where and what kind of surveys, treatment and monitoring are taking place throughout the province, and has become a tool managers can use to assist in planning (Province of British Columbia, 2011).

Many provinces and territories have formed invasive plant councils. The Ontario Invasive Plant Council is a non-profit, multiagency organisation that was founded in 2007. The council focuses on communication, policy, research and control and horticultural outreach (Ontario Invasive Plant Council, 2009). The other provincial councils have similar mandates and are the response to a need for coordinated response, within the provinces, to invasive plants. The Canadian weed Science Society is the Canada wide equivalent to these councils. It began in 2002 with the main objective of bringing together research and information on science and management of invasive plants (Canadian Weed Science Society, 2011).

Parks Canada

Parks Canada's mandate states "On behalf of the people of Canada, we protect and present nationally significant examples of Canada's natural and cultural heritage and foster public understanding, appreciation and enjoyment in ways that ensure their ecological and commemorative integrity for present and future generations." (Parks Canada, 2011). It has been shown that invasive plants pose a threat to ecological integrity; therefore management of invasive plants is required by the mandate. Under the Guiding Principles and Operational Policies for Parks Canada it is stated that "all practical efforts will be made to prevent the introduction of exotic plants and animals into national parks, and to eliminate or contain them where they already exist." (Parks Canada, 2009). Parks Canada currently has a Directive on the Management of Alien Species in Canada's National Parks that is in draft form (Dobbie, 2011). The strategy of the directive is similar to those of the Invasive Alien Species Strategy for Canada. Prioritization of non-native species for management and options for control are similar to what was already mentioned. Restoration is suggested for areas where non-native species have become abundant but few have entered the natural areas of the Park. This should include encouraging native species, which will help prevent reinvasions. Monitoring, educating the public and co-operating with other organisations are also listed as important parts of management (Parks Canada, draft).

Management Plans have been produced for some parks, including PPNP and Waterton Lakes National Park (WLNP) (Dunster, 1990; Achuff et al., 1990; Duncan, 2003). The WLNP produced a Non-native Plant Management Strategy as part of a management program that began in the 1980's. This program successfully reduced some populations of invasive plants but some have expanded their range and there have been new invasions. A review of the Strategy found that there was a need for more monitoring and adaptive management including continued reprioritization of invasive species. It also recommended increased public education and involvement, within and outside WLNP, as well as well as partnerships with surrounding parks, counties and provinces (Duncan, 2003).

Many protected areas are surrounded by lands that are infested with invasive plants and the agencies that manage protected areas usually lack the funds to stop those plants at the property line. Proper management of invasive plants requires cooperation with those responsible for the neighbouring lands. Resources can also be limited for conducting research on the extent and effects of potential and existing invasive plants. When there is a lack of a National coordinated effort to effectively manage invasive plants, invasive plant councils can help improve cooperation between different land managers. They also serve as a tool for raising awareness and promoting policy and national management programs (Campbell, 1997).

Invasive Management in Point Pelee National Park

Efforts that began in the 1970s to restore the Park to its previous state have focused on creating an inventory, testing control techniques, and developing a strategic approach. In 1989 a program was initiated to remove the non-native plants and rehabilitate those areas affected. Removal focused on *Hesperis matronalis* L. (dame's rocket), *Lunaria annua* L. (silver dollar), *Centaurea maculosa* (spotted knapweed), *Hemerocallis fulva* L. (daylily), *Rosa rugosa* Thunb. (rugosa rose), *Sedum acre* L. (creeping stonecrop), Yucca glauca Nutt. (soapweed) and *Ambrosia artemisiifolia* L. (common ragweed). *Ambrosia artemisiifolia* is native but was thought not to exist in the Park before human settlement. The area where removal took place was mainly around the Visitor Center (VC), the trails and road to the tip and the access to the east and west beach. Removal included hand pulling and snapping off the stems. Rehabilitation in the form of native plantings took place in the same area. The plants that were planted included *Ptelea trifoliata* L. (hoptree), *Prunus virginiana* L. (chokecherry), *Celtis occidentalis* L. (common hackberry), *Juniperus virginiana* L. (eastern red cedar), *Cornus drummondii* C.A. Meyer (rough-leaved dogwood), *Rhus typhina* L. (staghorn sumac), *Gleditsia tricanthos* L. (honey locust), *Juglans nigra* L. (black walnut), *Gymnocladus dioicus* (L.) K. Koch. (Kentucky coffee tree), *Rosa setigera* Michx. (prairie rose) and *Rubus occidentalis* L. (raspberry) (Leggo, 1990). An exotic plant species management plan that was prepared in 1990, which stated, that 276 out of 755 plant species in PPNP are non-native. It also listed 43 of the non-native plants as high priority invasive. This plan was produced with the intention that it be revisted every five years (Dunster, 1990). These values are an approximation and were determined using difference sampling protocol than this study.

From 1990 to 1996 volunteers spent 105.5 hours removing around 90,060 stems of non-native plants from the Park. Removal efforts cost Parks Canada $146,350 and Friends of Point Pelee $20,215. *Alliaria officinalis* (Bieb) Cav. & Gran. (garlic mustard) has received some study in the Park, since its establishment in the tip area in the late 1960s to early 1970s. It is believed that, while it is so widespread that total removal is unlikely, there is little evidence indicating that garlic mustard is a direct factor in the suppression of native species. It may instead be an indication of other disturbances that are causing native plant decline (Firanski et al., 2002). It was determined in the 1990s that manual and chemical removal of *Hemerocallis fulva* was ineffective at decreasing numbers in the Park (Roger, 1997). Former cottage and road sites were studied, in the 1990s, to determine if managed or unmanaged regeneration was more effective for restoration. Decreases in non-native plant diversity were associated with an increase in time since disturbance, canopy cover and soil moisture. This indicates that succession management is effective in the Park, as the majority of the non-natives were found to be shade intolerant (Roger, 1997).

A study produced in 1997 reviewed the management of non-native plants during the 1990s. It recommended that *Saponaria officinalis* be given lower priority because it was considered naturalized and well used by various butterfly species. *Vinca minor* L. (periwinkle) and *Convallaria majalis* L. (lily-of-the-valley) were both found to be effective ground cover, eliminating other species. The 1990 report recommended manual removal but the 1997 report states this has not been done because of the destructiveness and labour intensity of that removal technique. It also suggests more study is needed to determine the threat of these two species as well as trial removal sites to determine which removal techniques are most effective (Roger, 1997). Most work in the 1990s focused on the removal of low priority horticultural plants, because it was likely they could be completely removed and removal methods for the higher ranked species were still undetermined. Observations throughout the 1990s indicate removal efforts have resulted in a decline in non-natives within the Park, but better data collection methods are needed to allow statistical analysis that would confirm these observations (Roger, 1997).

The 1997 report made many recommendations for future management efforts. This included priority designation changes based on ecological information, such as the usefulness of *Centaurea maculosa* and *Saponaria officinalis* for species of butterflies and moths. It also recommended that removal sites be revisited annually and removal should focus on a small number of species. This would ensure that seed sources are eliminated and reserves for vegetative propagation are decreased over time. Focus should also be on pro-active work, targeting species that may become widespread but have not yet. Finally a switch from population based management to landscape based management was recommended. This would involve encouraging succession and work should be carried out as experimental trials so that the success of the trials can be assessed. Furthermore there is a need for baseline data and data collection protocol so that the annual data collected can be compared (Roger, 1997).

Another study looking at old cottage sites over a four year period determined that there were no significant changes in species composition but one site had fewer non-native plants. The reintroduction of native plants to these cottage sites was successful, as canopies developed, but native understory plants failed to recolonize from neighbouring undisturbed sites. Reintroduction of these plants was recommended but proper light and protection from grazing would be necessary for successful recolonization. The reintroduction of native plants like yellow violet and Virginia Waterleaf was suggested. Drier sites were open and dominated by grasses and sedges. It was suggested that they would continue to remain this way and that they be allowed to do so. Transects were also completed and in Oak Savannah sites it was observed that succession proceeded to more closed canopy. Any further recovery would then depend on the seed banks and dispersal rates of desirable species (Hynes et al, 2001). Another study looking at the recovery of Red Cedar and Oak Savanna plant communities also supports the dependence of recovery on seed bank and availability of seed sources. It was observed that burning in plots south of the VC had little long term effect on the plant community and the reintroduction of desirable native plants was recommended to aid in the recovery of these areas (Tagliavia et al, 2001).

McLachlan and Bazely (2003) found that 5 years after active restoration occurred in some sites, non-native ruderal species still dominated and native ephemeral species, that are dispersal restricted, remained absent. These species include *Trillium grandiflorum* (Michx.) Salisb. (white trillium), *Arisaema triphyllum* (L.) Schott. (jack-in-the-pulpit) and *Dicentra cucullaria* (L.) Bernh. (Duchman's breeches). They also point out that the long term disturbance in PPNP has left the soil with a poor seed bank, dominated by non-native species. It is possible to successfully restore highly degraded areas as long as there are viable seed sources present. They recommended that future restoration should include the planting of valuable ephemeral and dispersal restricted herbaceous species, since they are unlikely to recolonize restored areas naturally. Specifically this would include *Aquilegia Canadensis* L. (wild columbine), *Trillium grandiflorum*, *Arisaema triphyllum*, *Dicentra cucullaria*, *Hepatica acutiloba* DC. (sharp-lobed hepatica), *Allium tricoccum* Ait. (wild leek), *Viola pubescens* Ait. (downy yellow violet), *Podophyllum peltatum* L. (may apple), *Acer nigrum* L. (black maple), *Polygonatum biflorum* (Walt.) Ell. (great solomon's seal) and *Hydrophyllum appendiculatum* Michx. (appendaged waterleaf). In order to determine success of the reintroduction, monitoring of the sites would need to be completed. This can be quite costly. Therefore additional efforts should be made to identify high quality forest remnants and protect them from further degradation (McLachlan and Bazely, 2001).

PPNP actively works on the management of regional stressors with Frist Nations, the Essex County Conservation Authority, the Windsor Essex County and Pelee Island Convention and Visitors Bureau and the US National Park Service at Cuyahoga Valley National Park in Ohio. Monitoring programs that were summarized in the State of the Park report produced in 2006 listed the key stressors impacting PPNP's ecosystems as habitat loss, fragmentation and alteration, shoreline erosion, and regional sources of pollution. It notes that PPNPs small size and the intensive land use in the Greater Park Ecosystem leave it highly susceptible to these stressors. Other significant stressors that were listed were invasive exotic species, hyper-abundant species and altered disturbance regimes (Dobbie et al., 2006).

Chapter 3 Materials and Methods

The extent and threat of high priority invasive plant species in PPNP was determined through a comprehensive inventory of the study area.

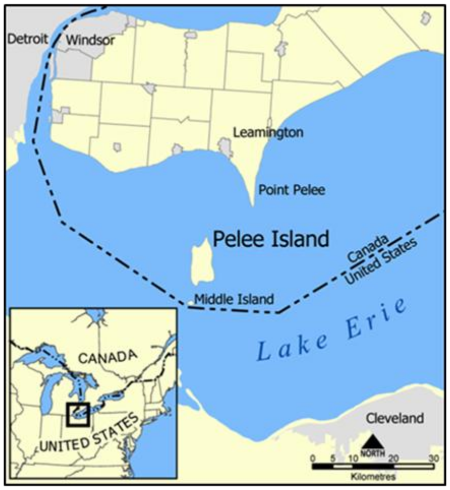

Figure 3. Geographic location of the study area. (Wikipedia, 2011)

Study Site

PPNP is located in Essex County, Ontario, which is the southernmost area of Canada (Figure 3). The study area for this project is the mostly terrestrial area of PPNP within 5.5 km from the tip (Figure 4). This area was chosen to refine the project to a practical size considering the time restrictions of one field season and because it has been the site of previous study and restoration.

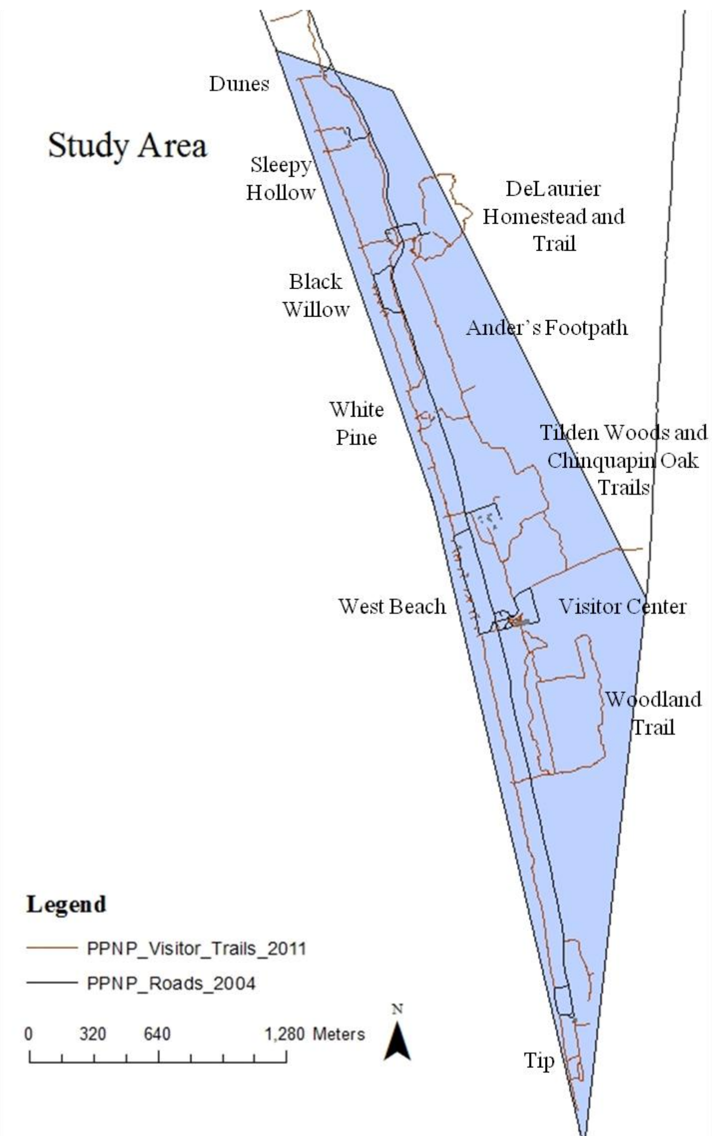

Figure 4. Study area within PPNP.

Field Study

From May to October, 2011 a comprehensive inventory was taken of the plant species present within the study area. Systematic belt transects were performed on foot from west to east at 100 m intervals, within a 5.5 km stretch in the terrestrial area, at the southern end of the Park (Figure 4). West to east transects were chosen in order to intersect all the terrestrial ecosystem types, that trend north to south (Figure 1). Belt transects consisted of a combination of frame quadrats (2 x 2 m) along transects. A quadrat was placed randomly within every 100 m of transect. The number and size of belt transects were chosen in order to provide a large enough data set for statistical and mapping purposes. Additional subjective quadrat placement was done in areas of dense invasion, no invasion or potential high risk of invasion. This was done based on observations in the field in order to assure areas of unique interest to the study were not missed. Quadrats were constructed from bamboo stakes and rope for ease of set up in dense brush and in order to create as small a disturbance as possible (Figure 5). The southwest corner of each quadrat was geo referenced (Falkenberg, 2000). Within the quadrats percent cover of each plant species was determined. This was done to assure that the frequency and density of each non-native species is recorded with respect to the native plants (Barnett, 2005). Percent cover was determined using a comparison chart to ensure consistency between quadrats (BC Ministry of Forests, 1998). A photo was taken of each quadrat as well as any species that was unidentifiable in the field along with a sample. Throughout the sampling North American Weed Managers Association Standards were followed to allow for replication in future years as part of a monitoring program.

Figure 5. Photo of a quadrat laid out with rope and bamboo poles.

The same belt transects and mapping were completed twice throughout the growing season, once in the spring and once in late summer, to account for plant species that lay dormant at different times of the year. It should be noted that because of the time necessary to visit all quadrats the species of plants that were in season at the beginning and the end of each survey differed. To account for this, transects were not completed from north to south consecutively but instead a few would be completed at the north end then the south end followed by the middle of the study area. Based on observations made during the spring round of sampling quadrats were selected for permanent marking. This was done for 137 out of the 620 randomly placed quadrats (base data) and 3 out of the 32 subjectively placed quadrats, during the late summer round of sampling. Quadrats were chosen for marking in an attempt to evenly represent what was observed on during the surveys, both geographically and based on species composition. Not every quadrat was marked because it is unlikely that it would be feasible for park staff to revisit them all as a part of future monitoring (see Appendix A for maps). Quadrat markers consist of a metal pig tail marker with metal tag and identification number (Figure 6). The beginning of each transect was also marked with a similar marker on the west beach. The exception to this are transects at the very southern tip of the Park. There is a rock berm on the west beach; as a result markers were placed on the eastern end of the transect on the East Beach. It was observed during the spring round of quadrats that species composition appeared to differ along the trails and road compared to those greater than 100 m away from these features. Trails and roads also cover a considerable amount of area within the study area and represent a source of disturbance. To determine if there was a significant difference, additional random quadrats (257) were completed along the road and some of the main trails and footpaths within the study area. These quadrats were also revisited in late summer.

Figure 6. One of the markers used to mark some of the random plots to aid in revisitation

Analysis

The non-parametric test Kruskal-Wallis was used to test for differences among groups because it does not assume normal distribution of the data. The data was collected randomly and is not normally distributed. The Kruskal-Wallis test is performed on ranked data, the smallest value gets a rank of 1 and the next largest a rank of 2 and so on (Zar, 2010). Data were grouped based on natural breaks in species diversity (inverse Simpson index) and native species richness, both indicators of ecosystem integrity. The most abundant species populations and non-native richness and area were then compared across the groups to determine if there were any significant differences. Scatter plots were also produced to display the trends present in the data. Since the objective of the study was to determine if any of the non-native species are dominating and becoming invasive the Simpson's Dominance index was used to determine the diversity. It accounts for probability that any two individuals sampled will be the same species (Booth et al., 2003). Diversity, the most abundant species, and native and non-native richness and density were compared between base data greater than 100m away from road and trails and road and trail data, using Kruskal Wallis. The statistical program R was used to perform the Kruskal-Wallis test, Simpson's Dominance index and the scatter plots. Specifically the package BiodiversityR was used. It provides a user interface and some functions for statistical analysis of biodiversity and ecological communities.

Lists of native and non-native species were composed based on abundance and those of highest abundance mapped using geographic information systems (GIS). Diversity, native and non-native richness and density were also mapped, for both base and trail and road data. Other species of interest that were mapped include non-native species which are high priority for immediate removal and native species that should be protected and used for restoration purposes.

These data will then be used to determine which plants and which areas are higher priorities for management within the Park. Prioritization will be based on which species are at high risk for further invasion in PPNP, what the ecological role of each species is, the species aggressiveness and practicality of removal strategies. Emphasis will be on methods that are physically and economically feasible in the Park.

Chapter 4 Results

Some non-native species were observed that have the ability to be invasive but were only present as a few individuals while others were observed to be dense in localized areas. *Alliaria officinalis* was observed throughout the study area. Native species covered much more area then even the top occurring non-native species. For example, *Osmorhiza longistylis* (Torr.) DC. (aniseroot) occurred in three times as many quadrats and covered twelve times more area than the most abundant non-native *Alliaria officinalis*. The area north and east of the Tilden Woods and Chinquapin Oak trails and east of the west beach parking have the highest diversity and native richness. The area around and north of DeLaurier and at the Tip have the lowest diversity and highest non-native richness. There is a significant difference of native and non-native richness across diversity and a few non-native species differed significantly across native richness and diversity.

Observations

During the spring survey 183 species of plants were observed, 41 of which were non-native species. The late summer survey had similar results with 37 non-native out of 184 species. In the road and trail quadrats 158 species were observed in the spring, 36 of which were non-native and 152 species were observed during the late summer survey, 31 of which were non-native. Some non-natives species, such as *Polygonum cuspidatum* Sied. & Zucc. (japanese knotweed) and *Euonymus fortunei* (Turcz.) Hand.-Mazz. (wintercreeper) were observed in the trail and road quadrats but not the base quadrats and vice versa (Table 1). These two species consisted of only one individual in the quadrats they were observed in. Species observed in base quadrats and not trail or road quadrats include *Convallaria majalis* L. (Lily-of-the-valley) and *Narcissus psedonarcissus* L. (daffodil). Only one quadrat contained *Narcissus psedonarcissus* and that was in the form of one individual. Another non-native species of note is *Lonicera japonica* Thunb. (japanese honeysuckle), which was observed in quadrats near trails and west beach. Four quadrats contained *Lonicera japonica* with only a few individuals per quadrat.

In quadrats where *Hemerocallis fulva*, *Vinca minor*, *Bromus inermis* Leyss. (smooth brome), and *Convallaria majalis* were observed, the plants were quite dense. During the late summer plots only the quadrats with *Vinca minor* had other species growing in them, mostly *Solidago altissima* L. (tall goldenrod). In quadrats where *Osmorhiza longistylis* and *Laportea Canadensis* (L.) Wedd. (wood nettle) were observed they were also quite dense. Spring species such as *Dicentra cucullaria*, *Claytonia virginica* L. (spring beauty), and *Trillium grandiflorum* had very short growing seasons and were finished by mid to late May. When *Podophyllum peltatum* was observed it shaded out other species and was quite dense, not usually seen growing with either *Osmorhiza longistylis* or *Alliaria officinalis.* It should also be noted that *Urtica gracilis* Aiton (slender nettle) and *Urtica dioica* L. (stinging nettle) grew so tall and *Vitis aestivalis* Michx. (summer grape) so dense, in the area southeast of DeLaurier, that is was difficult to impossible to traverse during the late summer survey. *Urtica gracilis* in particular was 2-3m high. As a result four plots were not revisited.

Table 1. List of all the non-native plants observed in quadrats, in order from most to least occurring.

Base		Trails and Road	
Common Name	**Latin Name**	**Common Name**	**Latin Name**
Garlic Mustard	*Alliaria officinalis*	Garlic Mustard	*Alliaria officinalis*
Dame's Rocket	*Hesperis matronalis*	Smooth Brome	*Bromus inermis*
Smooth Brome	*Bromus inermis*	Bouncing Bet	*Saponaria officinalis*
Stinging Nettle	*Urtica dioica*	Annual Bluegrass	*Poa annua*
Ground Ivy	*Glechoma hederacea*	Spotted Knapweed	*Centaurea maculosa*
Bouncing Bet	*Saponaria officinalis*	Orchard Grass	*Dactylis glomerata*
Common Dandelion	*Taraxacum officinale*	Stinging Nettle	*Urtica dioica*
Spotted Knapweed	*Centaurea maculosa*	Dame's Rocket	*Hesperis matronalis*
Motherwort*	*Leonurus cardiaca**	Hoary Alyssum	*Berteroa incana*
Purple Dead Nettle*	*Lamium purpureum**	White Sweet Clover	*Melilotus alba*
Lily-of-the-valley*	*Convallaria majalis**	Day Lily	*Hemerocallis fulva*
White Sweet Clover	*Melilotus alba*	Ground Ivy	*Glechoma hederacea*
Hoary Alyssum	*Berteroa incana*	Downy Brome	*Bromus tectorum*
Multiflora Rose	*Rosa multiflora*	Multiflora Rose	*Rosa multiflora*
Thyme-leaved Sandwort	*Arenaria serpyllifolia*	Giant Red Top	*Agrostis gignatea*
Japanese Honeysuckle	*Lonicera japonica*	Thyme-leaved Sandwort	*Arenaria serpyllifolia*
Common Mullein	*Verbascum thapsus*	Perennial Ryegrass	*Lolium perenne*
Yellow Goatsbeard	*Tragopogon pratensis*	White Campion	*Lychnis alba*
White Mulberry	*Morus alba*	Curled Dock	*Rumex crispus*
Whitlow Grass	*Draba verna*	Japanese Honeysuckle	*Lonicera japonica*
Day Lily	*Hemerocallis fulva*	White Mulberry	*Morus alba*
Downy Brome	*Bromus tectorum*	Asparagus	*Asparagus officinalis*
Yellow Sweet Clover	*Melilotus tinctoria*	White Clover*	*Trifolium repens**
Common Reed*	*Phragmites australis**	Yellow Sweet Clover	*Melilotus tinctoria*
Perennial Ryegrass	*Lolium perenne*	Quack Grass	*Elytrigia repens*
Common Chickweed*	*Stellaria media**	Norway Maple	*Acer platanoides*
Rough-fruited Cinquefoil	*Potentilla recta*	Common Mullein	*Verbascum thapsus*
Mossy Stonecrop*	*Sedum acre**	Bittersweet Nightshade	*Solanum dulcamara*
Asparagus	*Asparagus officinalis*	Periwinkle	*Vinca minor*
White Campion	*Lychnis alba**	Cow Vetch	*Vicia cracca*
Manitoba Maple*	*Acer negundo**	Common Dandelion	*Taraxacum officinale*
Norway Maple	*Acer platanoides*	Yellow Goatsbeard	*Tragopogon pratensis*
Moneywort*	*Lysimachia nummularia**	Wintercreeper*	*Euonymus fortunei**
Queen Anne's Lace	*Daucus carota*	Rough-fruited Cinquefoil	*Potentilla recta*
Cow Vetch	*Vicia cracca*	Smooth Crabgrass*	*Digitaria ischaemum**
Annual Bluegrass	*Poa annua*	Timothy Grass*	*Phleum pratense**
Hop Clover*	*Trifolium agrarium*	European Gromwell*	*Lithospermum officinale**
Daffodil*	*Narcissus psedonarcissus**	Japanese Knotweed*	*Polygonum cuspidatum**
Curled Dock	*Rumex crispus*	Black Nightshade*	*Solanum nigrum**
Orchard Grass	*Dactylis glomerata*	Queen Anne's Lace	*Daucus carota*
Quack Grass	*Elytrigia repens*	Canada Thistle	*Cirsium arvense*
Stink Grass*	*Eragrostis cilianensis**	Whitlow Grass	*Draba verna*
Hemp Nettle*	*Galeopsis tetrahit**		
Bittersweet Nightshade	*Solanum dulcamara*		
Periwinkle	*Vinca minor*		
Giant Red Top	*Agrostis gignatea*		
Canada Thistle	*Cirsium arvense*		
Wild Madder*	*Galium mollugo**		
Yarrow*	*Achillea millefolium**		
* species unique to that set of plots			

Transects

Diversity, Richness and Density

Native and non-native species were listed based on their occurrence for both spring and late summer data (Table 2). Native plant species occur in more quadrats and cover more area than non-native plants for both surveys. The most abundant native species, *Osmorhiza longistylis* occurred in almost 3 times as many quadrats and covers 12 times as much area as the most abundant non-native species, *Alliaria officinalis*. Diversity data for both surveys were negatively skewed but, maps of how diversity varies across the study area show there are some areas of higher diversity that stand out (Figure 7). The area north and east of the Tilden woods and Chinquapin oak trails and the area east of the west beach parking had higher diversity for both surveys. There are other quadrats with higher diversity but they are more scattered throughout

Table 2. Top ten occuring species, in order from most to least, base data. Number of plots each species occurred in and the total area (m^2).

Spring Pass					
Native			Non-Native		
Common Name	Latin name	# Plots (area)	Common Name	Latin Name	# Plots (area)
Aniseroot	*Osmorhiza longistylis*	448 (409)	Garlic Mustard	*Alliaria officinalis*	162 (34)
Star-flowered Solomons Seal	*Smilacina stellata*	306 (92)	Dame's Rocket	*Hesperis matronalis*	60 (17)
Virginia Creeper	*Parthenocissus quinquefolia*	245 (103)	Smooth Brome	*Bromus inermis*	43 (39)
Cleavers	*Galium aparine*	232 (74)	Stinging Nettle	*Urtica dioica*	31 (5)
Rough-leaved Dogwood	*Cornus drummondii*	190 (53)	Purple Dead Nettle	*Lamium purpureum*	25 (4)
Poison Ivy	*Rhus radicans*	152 (49)	Bouncing Bet	*Saponaria officinalis*	24 (6)
Choke Cherry	*Prunus virginiana*	140 (37)	Spotted Knapweed	*Centaurea maculosa*	21 (5)
Prickly Gooseberry	*Ribes cynosbati*	131 (80)	Common Dandelion	*Taraxacum officinale*	20 (2)
Tall Goldenrod	*Solidago altissima*	118 (42)	Ground Ivy	*Glechoma hederacea*	15 (6)
Wavy-leaved Aster	*Aster undulatus*	117 (26)	Lily-of-the-valley	*Convallaria majalis*	13 (5)
Late Summer Pass					
Native			**Non-Native**		
Common Name	**Latin Name**	**# Plots (area)**	**Common Name**	**Latin Name**	**# Plots (area)**
Aniseroot	*Osmorhiza longistylis*	376 (238)	Garlic Mustard	*Alliaria officinalis*	100 (29)
Virginia Creeper	*Parthenocissus quinquefolia*	369 (166)	Dame's Rocket	*Hesperis matronalis*	46 (15)
Rough-leaved Dogwood	*Cornus drummondii*	247 (76)	Ground Ivy	*Glechoma hederacea*	41 (19)
Poison Ivy	*Rhus radicans*	246 (100)	Stinging Nettle	*Urtica dioica*	28 (5)
White Avens	*Geum canadense*	206 (34)	Bouncing Bet	*Saponaria officinalis*	27 (9)
Wavy-leaved Aster	*Aster undulatus*	144 (37)	Smooth Brome	*Bromus inermis*	24 (36)
Star-flowered Solomons Seal	*Smilacina stellata*	138 (26)	Spotted Knapweed	*Centaurea maculosa*	18 (11)
Tall Goldenrod	*Solidago altissima*	137 (52)	White Sweet Clover	*Melilotus alba*	14 (6)
Choke Cherry	*Prunus virginiana*	135 (37)	Motherwort	*Leonurus cardiaca*	14 (3)
Jumpseed	*Tovara virginianum*	132 (32)	Lily-of-the-valley	*Convallaria majalis*	9 (3)

the study area. Distribution maps of native species richness show that areas of high species richness correspond with areas of higher diversity (Figure 8).

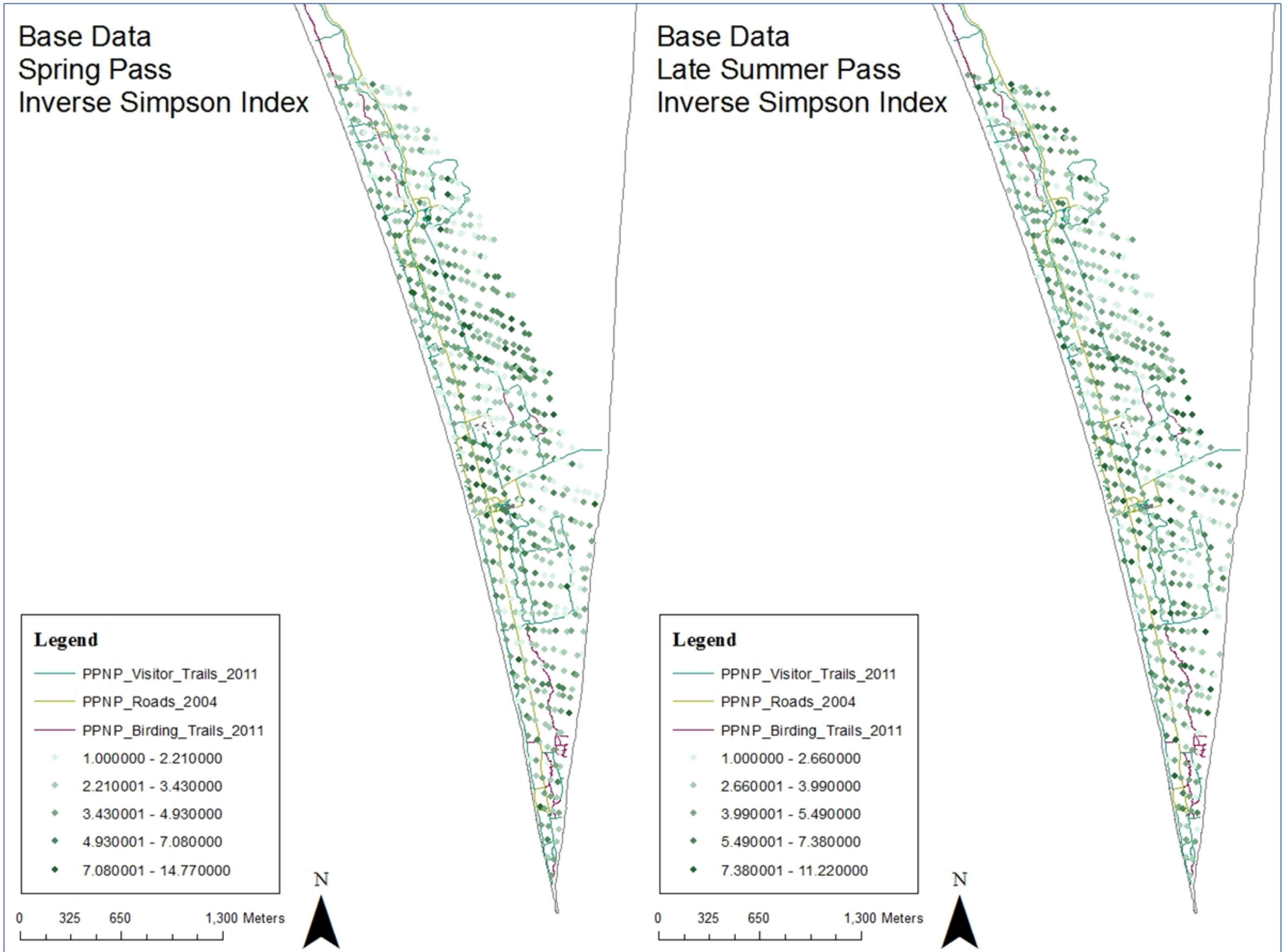

Figure 7. Maps showing how diversity varies across the study area for both spring and late summer surveys

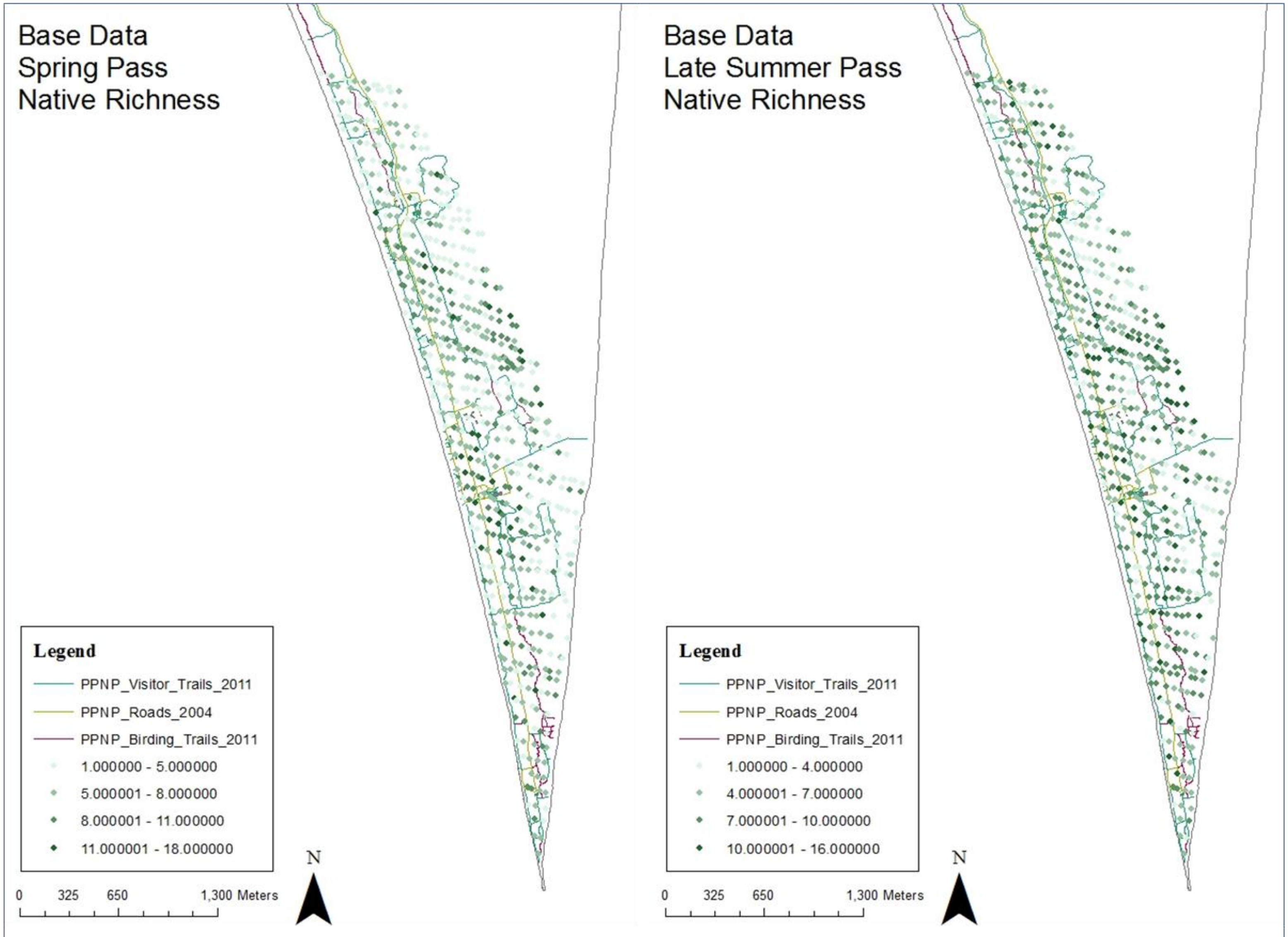

Figure 8. Maps showing how native species richness varies across the study area for both surveys

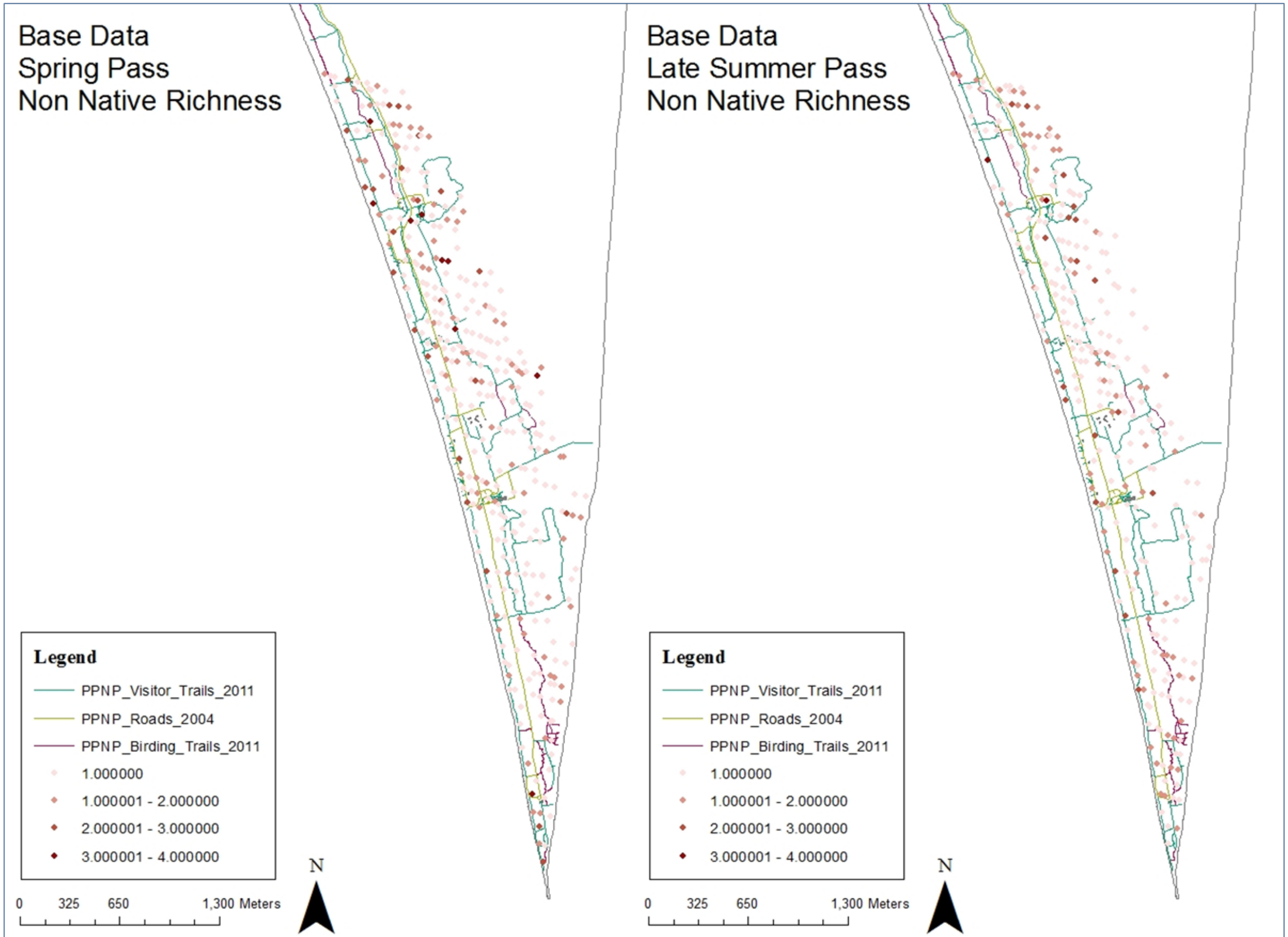

Figure 9. Maps showing how non-native species richness varies across the study area for both surveys.

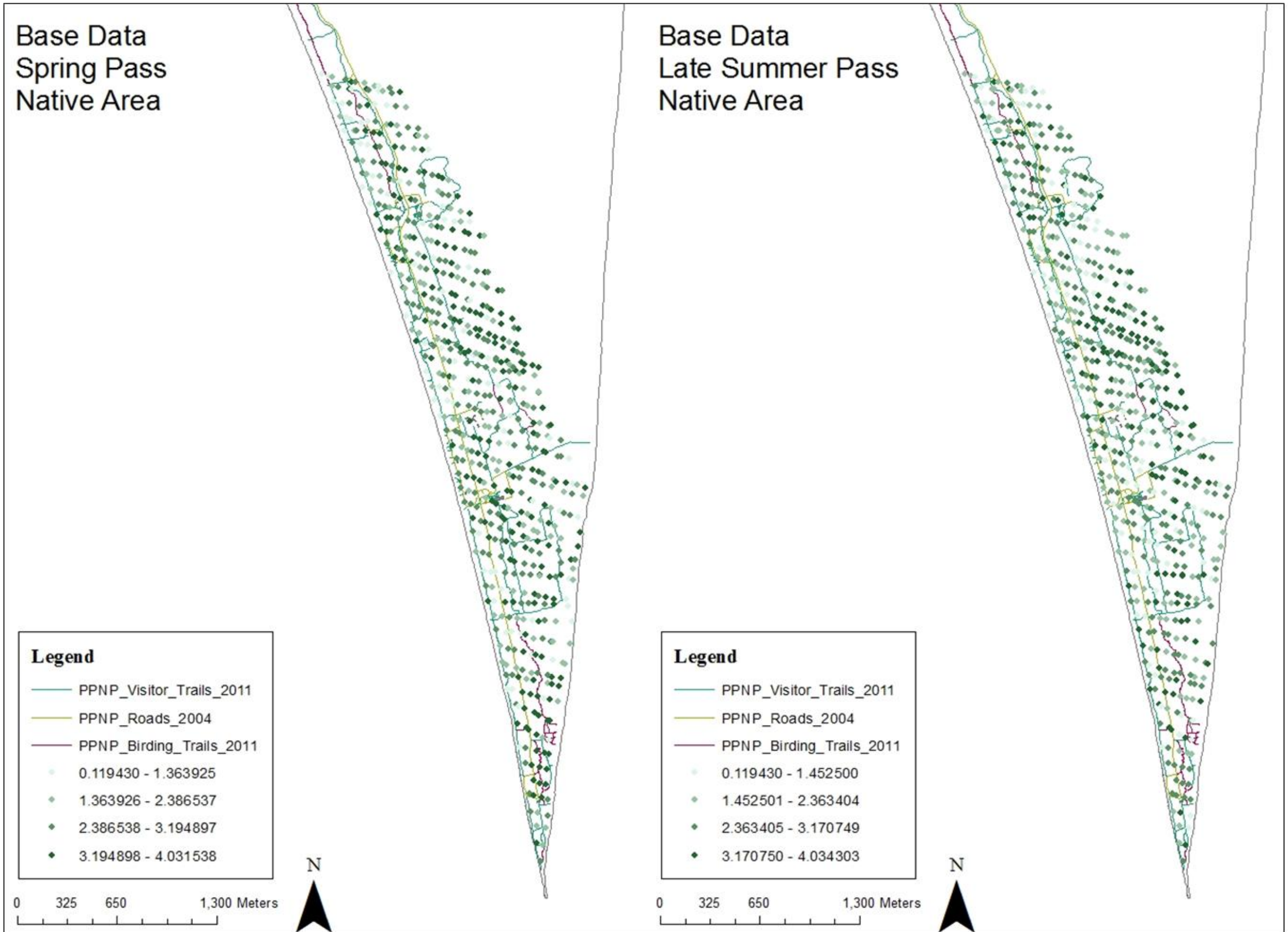

Figure 10. Maps showing how native species density differs across the study area for both surveys.

Distribution maps of non-native species richness show that the areas around and north of the DeLaurier Trail and at the tip have lower diversity and higher non-native species richness, during both surveys. The other areas with lower diversity do not appear to correspond with higher non-native richness (Figure 9); instead they appear to correspond with areas of high native species density (Figure 10). This includes the area southeast of DeLaurier Trail, the area north of west beach parking and the area surrounding and north of the woodland trail. It should be noted that the area north of DeLaurier had higher diversity and native species richness during the late summer survey, compared to the spring survey. Scatter plots of native and non-native species richness versus diversity, for both surveys, reveal that there is a significant positive trend for native richness and a significant difference of non-native richness across diversity. The significance of these trends is higher for native species richness (Figures 11). Most of the quadrats have mid levels of native species richness while for non-native species richness it is more spread out. Native and non-native density also differs significantly with diversity, for both surveys (Figures 12). Quadrats with high native species density tend to have low diversity and for most, native species cover over half the quadrat. Quadrats with high non-native density also have low diversity but for most non-native species cover less than half the quadrat.

Non-Native Species

The ten top occurring native and non-native species were compared across diversity and native richness for both surveys (Table 3). The occurrence of *Alliaria officinalis* differs significantly across diversity but not across native richness for the spring data. It did not differ across either for the late summer data. A scatter plot shows that quadrats with the highest occurrence of *Alliaria officinalis* also have low diversity values (See Appendix B for scatter plots of species, that differed significantly). Maps of the density of *Alliaria officinalis*, for the spring data, show that it occurs all over the study area and in most quadrats covers less than 25% of the quadrat. The areas where it covers up to 75% correspond with areas of low diversity. *Alliaria officinalis* is a spring flowering plant but in some areas of the study area it was observed to have a second season. Occurrence was not as high as the spring season and a map of the data shows that the areas of second growth correspond with areas of lower diversity (See Appendix A for species maps).

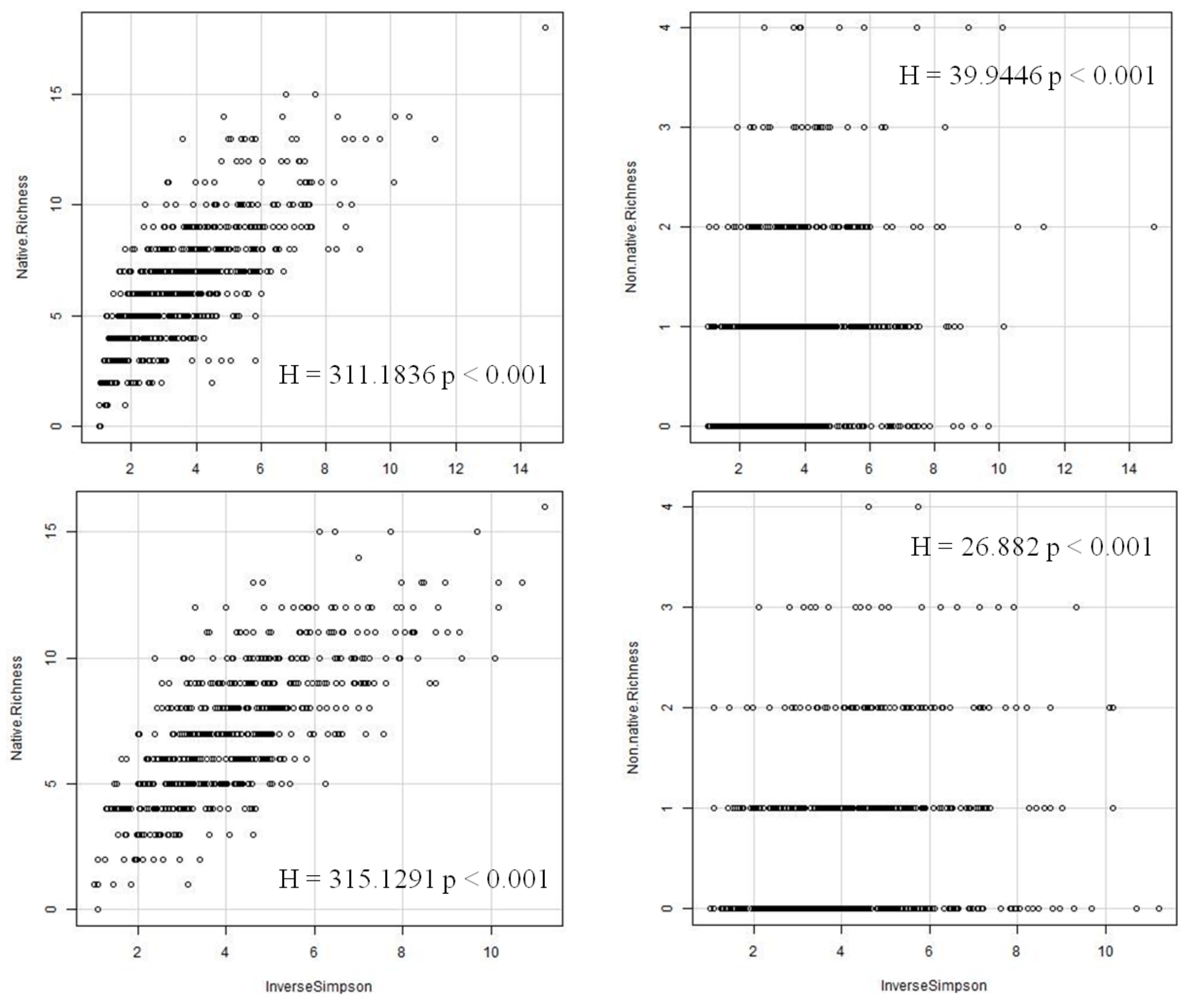

Figure 11. Scatter plots of native and non-native species richness versus Inverse Simpson index base data, spring survey (top), late summer survey (bottom), with corresponding Kruskal Wallis results.

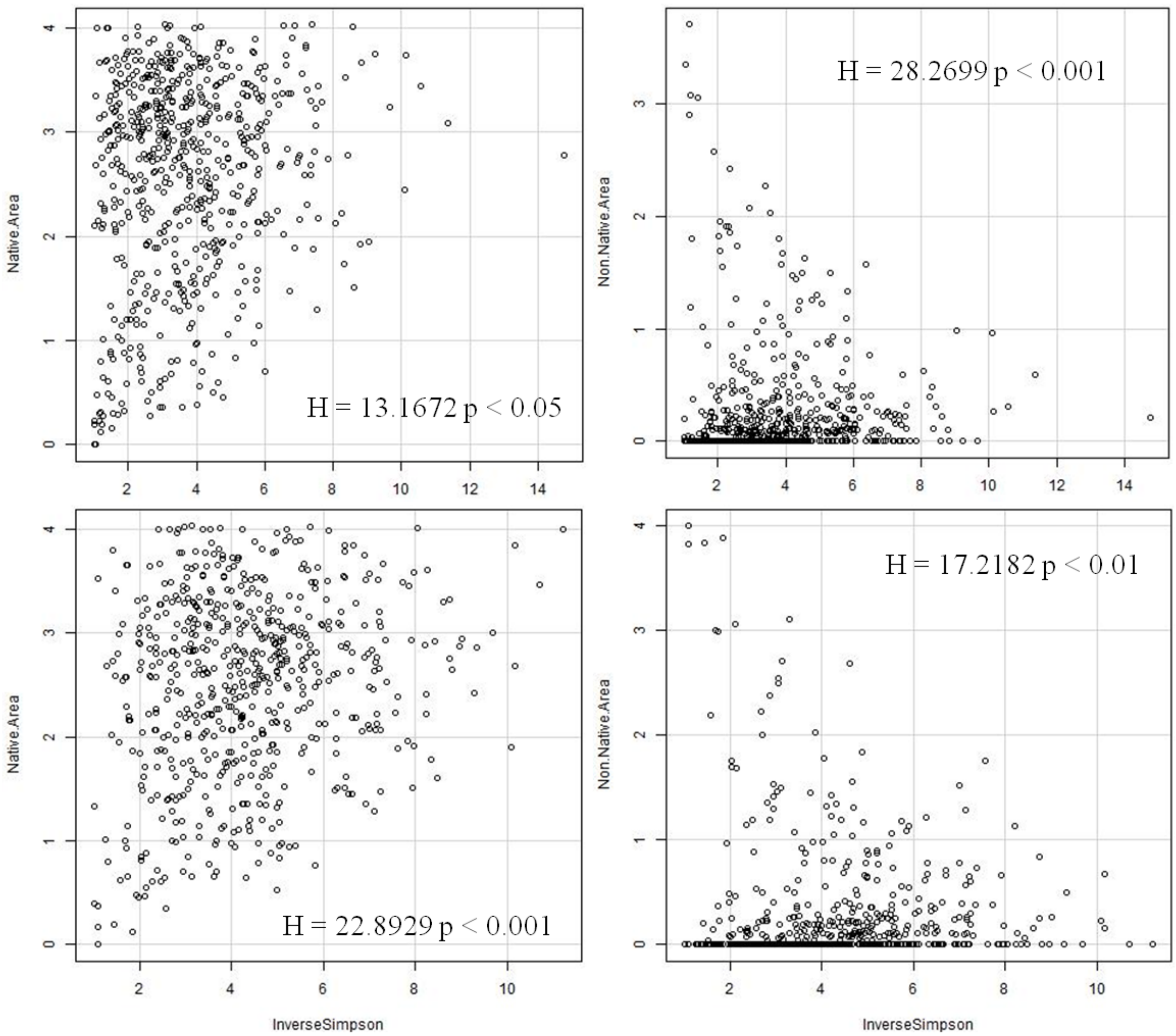

Figure 12. Scatter plots of native and non-native species area versus Inverse Simpson index, base data, spring survey (top), late summer survey (bottom), with corresponding Kruskal Wallis results.

Table 3. Top ten occurring native and non-native species Kruskal Wallis values, base data.

Spring Survey		Versus Inverse Simpson Index	Versus Native Species Richness
Native			
Aniseroot	*Osmorhiza longistylis*	4.7632	46.7481**
Star-flowered Solomons Seal	*Smilacina stellata*	37.8399**	67.6231**
Virginia Creeper	*Parthenocissus quinquefolia*	77.2104**	94.3536**
Cleavers	*Galium aparine*	25.2301**	30.6893**
Rough-leaved Dogwood	*Cornus drummondii*	9.9717*	11.3935*
Poison Ivy	*Rhus radicans*	38.0228**	36.2009**
Choke Cherry	*Prunus virginiana*	7.6395	15.4446*
Prickly Gooseberry	*Ribes cynosbati*	3.9449	24.648**
Tall Goldenrod	*Solidago altissima*	37.0899**	36.3076**
Wavy-leaved Aster	*Aster undulatus*	50.1723**	87.8033**
Non-Native			
Garlic Mustard	*Alliaria officinalis*	20.949**	7.0189
Dame's Rocket	*Hesperis matronalis*	6.6189	9.2930
Smooth Brome	*Bromus inermis*	1.4582	33.7675**
Stinging Nettle	*Urtica dioica*	1.2239	4.1213
Purple Dead Nettle	*Lamium purpureum*	3.9149	6.0092
Bouncing Bet	*Saponaria officinalis*	10.4972*	4.1505
Spotted Knapweed	*Centaurea maculosa*	4.6890	14.4393*
Common Dandelion	*Taraxacum officinale*	8.7103	3.4977
Ground Ivy	*Glechoma hederacea*	14.5456*	8.3096
Lily-of-the-valley	*Convallaria majalis*	2.8350	3.3178
Late Summer Survey			
Native			
Aniseroot	*Osmorhiza longistylis*	21.8441**	27.8766**
Virginia Creeper	*Parthenocissus quinquefolia*	35.0166**	62.7505**
Rough-leaved Dogwood	*Cornus drummondii*	5.4568	3.2590
Poison Ivy	*Rhus radicans*	25.0664**	33.578**
White Avens	*Geum canadense*	36.9179**	67.7757**
Wavy-leaved Aster	*Aster undulatus*	56.8127**	103.0036**
Star-flowered Solomons Seal	*Smilacina stellata*	15.1561*	14.7638*
Tall Goldenrod	*Solidago altissima*	31.8073**	57.8736**
Choke Cherry	*Prunus virginiana*	7.3762	7.4541
Jumpseed	*Tovara virginianum*	43.2223**	78.0487**
Non-Native			
Garlic Mustard	*Alliaria officinalis*	8.1475	2.2934
Dame's Rocket	*Hesperis matronalis*	19.4629**	5.4865
Ground Ivy	*Glechoma hederacea*	17.2016*	4.5130
Stinging Nettle	*Urtica dioica*	4.0094	2.3973
Bouncing Bet	*Saponaria officinalis*	4.0765	1.6237
Smooth Brome	*Bromus inermis*	5.0184	43.146**
Spotted Knapweed	*Centaurea maculosa*	1.3707	8.1065
White Sweet Clover	*Melilotus alba*	5.6246	9.8854*
Motherwort	*Leonurus cardiaca*	13.8731*	4.9141
Lily-of-the-valley	*Convallaria majalis*	4.1115	3.6675

* $p < 0.05$
** $p < 0.001$

Occurrence also differed significantly across diversity but not across native richness for *Saponaria officinalis* and *Glechoma hederacea* L. (ground ivy), for the spring data. Scatter plots show quadrats with higher values for these two species have mid level diversity values. *Glechoma hederacea* shows the same trend for the late summer data. Occurrence did not differ significantly across diversity but did across native richness for *Bromus inermis* and *Centaurea maculosa*, for the spring data. Scatter plots show that higher values for these two species correspond with quadrats with low native species richness. *Bromus inermis* shows the same trend for the late summer data. Occurrence differs significantly across diversity but not native richness for *Hesperis matronalis* and *Leonurus cardiac* L. (motherwort), for the late summer data. Scatter plots reveal that quadrats with higher values for these two species have mid level diversity values. Occurrence did not differ significantly across diversity but did across native richness for *Melilotus alba* Desr. (white sweet clover). A scatter plot reveals that quadrats with high *Melilotus alba* occurrence also have low values of native species diversity.

Maps of the species that differed significantly confirm the trends shown by the scatter plots. All these species, except *Saponaria officinalis* and *Bromus inermis*, covered less than 25% of most of the quadrats they occurred in. *Saponaria officinalis* covered less than 10% and *Bromus inermis* covered 50-100% of most of the quadrats they occurred in. *Bromus inermis* is most dense at north and south of DeLaurier and at the Tip. *Centaurea maculosa* and *Melilotus alba* occurred only along the west beach and trails, while *Hesperis matronalis* mostly occurred in the area between Ander's footpath and the road. *Saponaria officinalis* was observed mostly along the west beach, at DeLaurier and the Tip, *Glechoma hederacea* at DeLaurier, the Visitor Center and the Tip and *Leonurus cardiac* along trails and the road and west beach.

Native Species

Occurrence differed significantly across diversity and native species richness for all top ten native species for the spring survey, except *Osmorhiza longistyli*, *Prunus virginiana* and *Ribes cynosbati* L. (prickly gooseberry), which only differed significantly across native richness. Scatter plots revealed that quadrats with high occurrences of these three species also had low native species richness. They also revealed that quadrats with high occurrences of *Smilacina stellata* (L.) Desf. (star-flowered solomon's seal), *Parthenocissus quinquefolia* (L.) Planch. (virginia creeper), *Galium aparine* L. (cleavers), *Cornus drummondii* and *Aster undulates* L.

(Wavy-leaved Aster) also had low diversity but mid level native species richness. Quadrats with high occurrence of *Solidago altissima* also had mid levels of both diversity and native richness. Quadrats with high occurrence of *Rhus radicans* L. (poison ivy) also had low diversity and native species richness.

Occurrence differed significantly across diversity and native species richness for all top ten native species, for the late summer data, except *Cornus drummondii* and *Prunus virginiana*. Scatter plots revealed that quadrats with high occurrence of *Osmorhiza longistyli* also had low diversity and native species richness. They also revealed that quadrats with high occurrences of *Parthenocissus quinquefolia*, *Rhus radicans* and *Geum canadense* Jacq. (white avens) also had low diversity and mid level native species richness. High occurrences of *Aster undulates*, *Smilacina stellata*, *Solidago altissima*, and *Tovara virginianum* (L.) Raf. (jumpseed) have mid levels of both diversity and native species richness.

Maps of the species that differed significantly confirm the trends observed in the scatter plots. All species covered less than 25% of most of the quadrats they occurred in, except for *Osmorhiza longistyli*, which covered 25-50% of the quadrats it occurred in. It flowers in the spring and observations made during the late summer survey were of second growth and less dense. *Smilacina stellata*, *Prunus virginiana* and *Ribes cynosbati* occurred mostly in the area along and west of the road. *Smilacina stellata* occurred more in the spring than the summer, which is to be expected since it flowers in the spring. *Cornus drummondii* occurred mostly east of Ander's footpath and other trails. *Parthenocissus quinquefolia* occurred mostly in the areas that were high in native species richness. The other native species were spread out in the study area.

Out of the species McLachlan and Bazely (2003) listed as valuable, dispersal restricted, native species, *Trillium grandiflorum*, *Aquilegia canadensis*, *Arisaema triphyllum*, *Dicentra cucullaria*, *Viola pubescens*, *Podophyllum peltatum*, *Polygonatum biflorum* and *Hydrophyllum appendiculatum* were observed. *Trillium grandiflorum* was observed in one subjective plot along the Woodland trail and consisted of one individual. The rest were mostly observed in quadrats close to trails and the road, not necessarily in areas of higher diversity or native species richness (Appendix A). This is confirmed when compared across diversity and native richness only *Aquilegia Canadensis* showed a significant difference (Kruskal Wallis $H = 10.4554$ $p < 0.05$). Quadrats with the highest values of *Aquilegia Canadensis* had mid to high values of diversity.

Only *Arisaema triphyllum* (Kruskal Wallis H = 10.0154 $p < 0.05$) and *Viola pubescens* (Kruskal Wallis H = 23.0128 $p < 0.001$) showed significant differences across native species richness. Quadrats with high values of both these species had mid to high values of native richness (Appendix B).

Road and Trails

Diversity, Density and Richness

Native and non-native species were listed based on their occurrence for both spring and late summer data (Table 4). The top ten native and non-native species composition is similar to the base data with a few exceptions. Non-native species *Dactylis glomerata* L. (orchard grass), *Bromus tectorum* L. (downy brome) and *Poa annua* L. (annual bluegrass) were observed in greater numbers along the trails and road. Similar to the base data native species occur in more quadrats and cover more area than non-native plants for both surveys. Distribution maps for diversity reveal the trails have lower diversity than the road and the area around DeLaurier, the west beach and along the eastern side of the Woodland trail have the lowest (Figure 13).

Table 4. Top ten occurring species, in order from most to least, trail and road data. Number of plots each species occurred in and the total area (m^2).

Spring Pass					
Native			**Non-Native**		
Common Name	**Latin name**	**# Plots (area)**	**Common Name**	**Latin Name**	**# Plots (area)**
Virginia Creeper	*Parthenocissus quinquefolia*	163 (88)	Garlic Mustard	*Alliaria officinalis*	59 (13)
Aniseroot	*Osmorhiza longistylis*	154 (72)	Smooth Brome	*Bromus inermis*	40 (47)
Poison Ivy	*Rhus radicans*	107 (46)	Annual Bluegrass	*Poa annua*	35 (18)
Star-flowered Solomons Seal	*Smilacina stellata*	105 (35)	Bouncing Bet	*Saponaria officinalis*	32 (10)
Wavy-leaved Aster	*Aster undulatus*	100 (21)	Stinging Nettle	*Urtica dioica*	23 (5)
White Avens	*Geum canadense*	89 (14)	Orchard Grass	*Dactylis glomerata*	23 (9)
Tall Goldenrod	*Solidago altissima*	89 (57)	Spotted Knapweed	*Centaurea maculosa*	22 (14)
Common Hackberry	*Celtis occidentalis*	74 (19)	Dame's Rocket	*Hesperis matronalis*	11 (2)
Rough-leaved Dogwood	*Cornus drummondii*	71 (25)	Hoary Alyssum	*Berteroa incana*	9 (2)
Choke Cherry	*Prunus virginiana*	69 (20)	Downy Brome	*Bromus tectorum*	8 (3)
Late Summer Pass					
Native			**Non-Native**		
Common Name	**Latin Name**	**# Plots (area)**	**Common Name**	**Latin Name**	**# Plots (area)**
Aniseroot	*Osmorhiza longistylis*	152 (111)	Garlic Mustard	*Alliaria officinalis*	41(10)
Poison Ivy	*Rhus radicans*	128 (55)	Smooth Brome	*Bromus inermis*	34 (54)
Wavy-leaved Aster	*Aster undulatus*	103 (27)	Bouncing Bet	*Saponaria officinalis*	23 (6)
Virginia Creeper	*Parthenocissus quinquefolia*	97 (24)	Spotted Knapweed	*Centaurea maculosa*	20 (12)
Rough-leaved Dogwood	*Cornus drummondii*	89 (30)	Annual Bluegrass	*Poa annua*	15 (15)
Common Hackberry	*Celtis occidentalis*	88 (22)	White Sweet Clover	*Melilotus alba*	13 (6)
Choke Cherry	*Prunus virginiana*	74 (17)	Orchard Grass	*Dactylis glomerata*	12 (4)
Tall Goldenrod	*Solidago altissima*	72 (34)	Stinging Nettle	*Urtica dioica*	11 (4)
White Avens	*Geum canadense*	67 (11)	Dame's Rocket	*Hesperis matronalis*	9 (1)
Common Greenbriar	*Smilax rotundifolia*	53 (8)	Ground Ivy	*Glechoma hederacea*	9 (3)

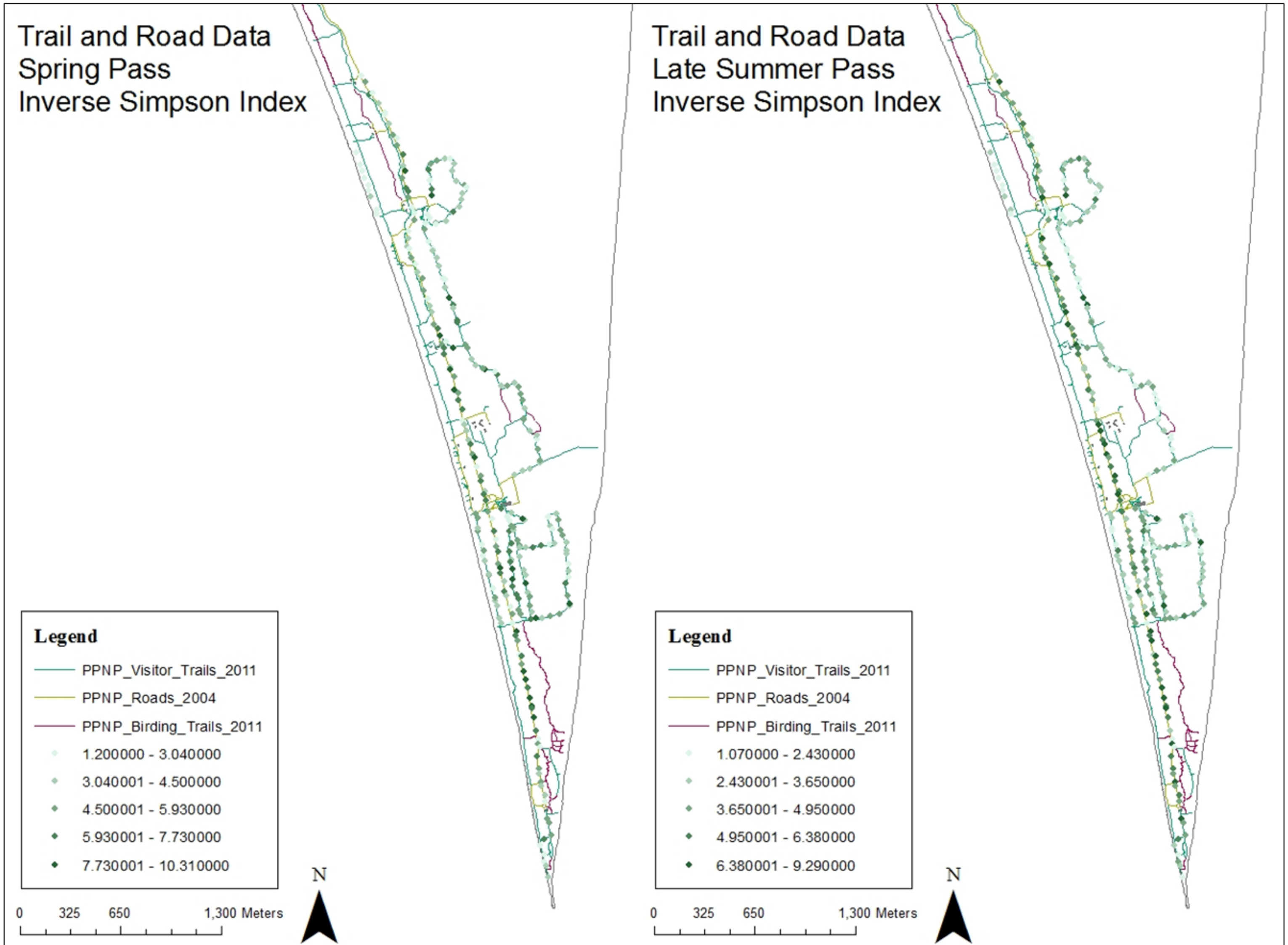

Figure 13. Maps showing how diversity differs along the road and trails in the study area.

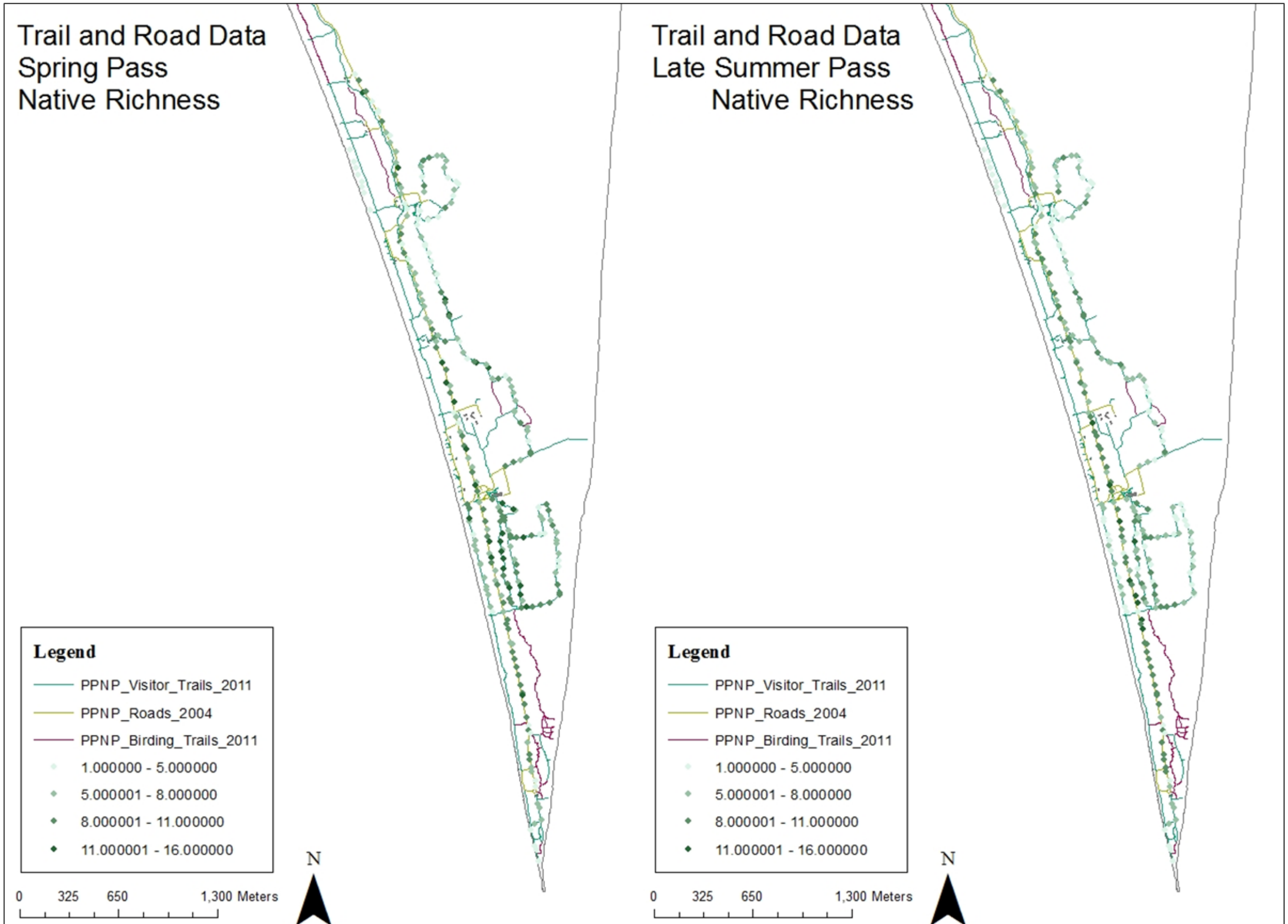

Figure 14. Maps showing how native species richness varies along the road and trails in the study area.

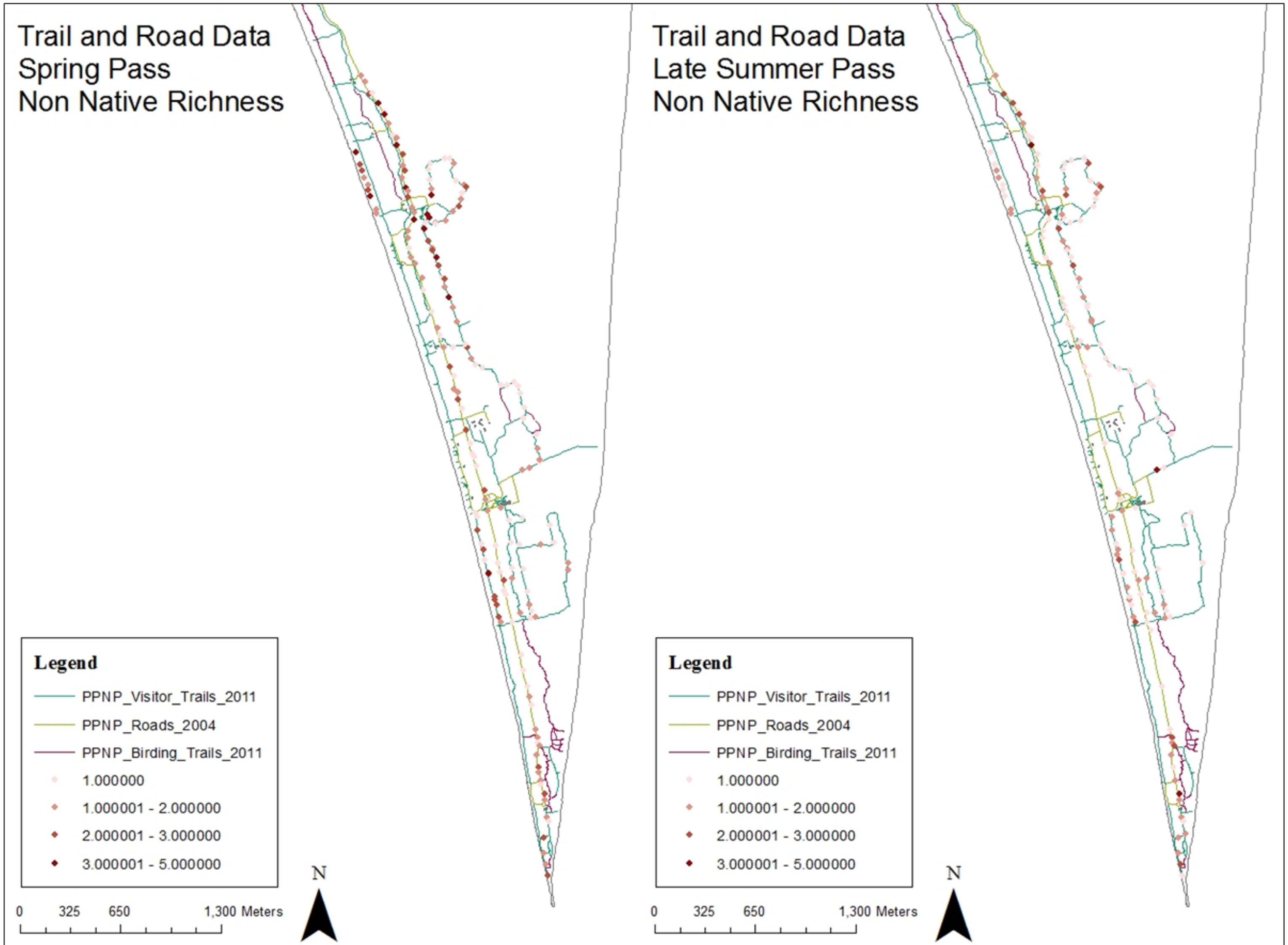

Figure 15. Maps showing how non-native species richness varies along the road and trails in the study area.

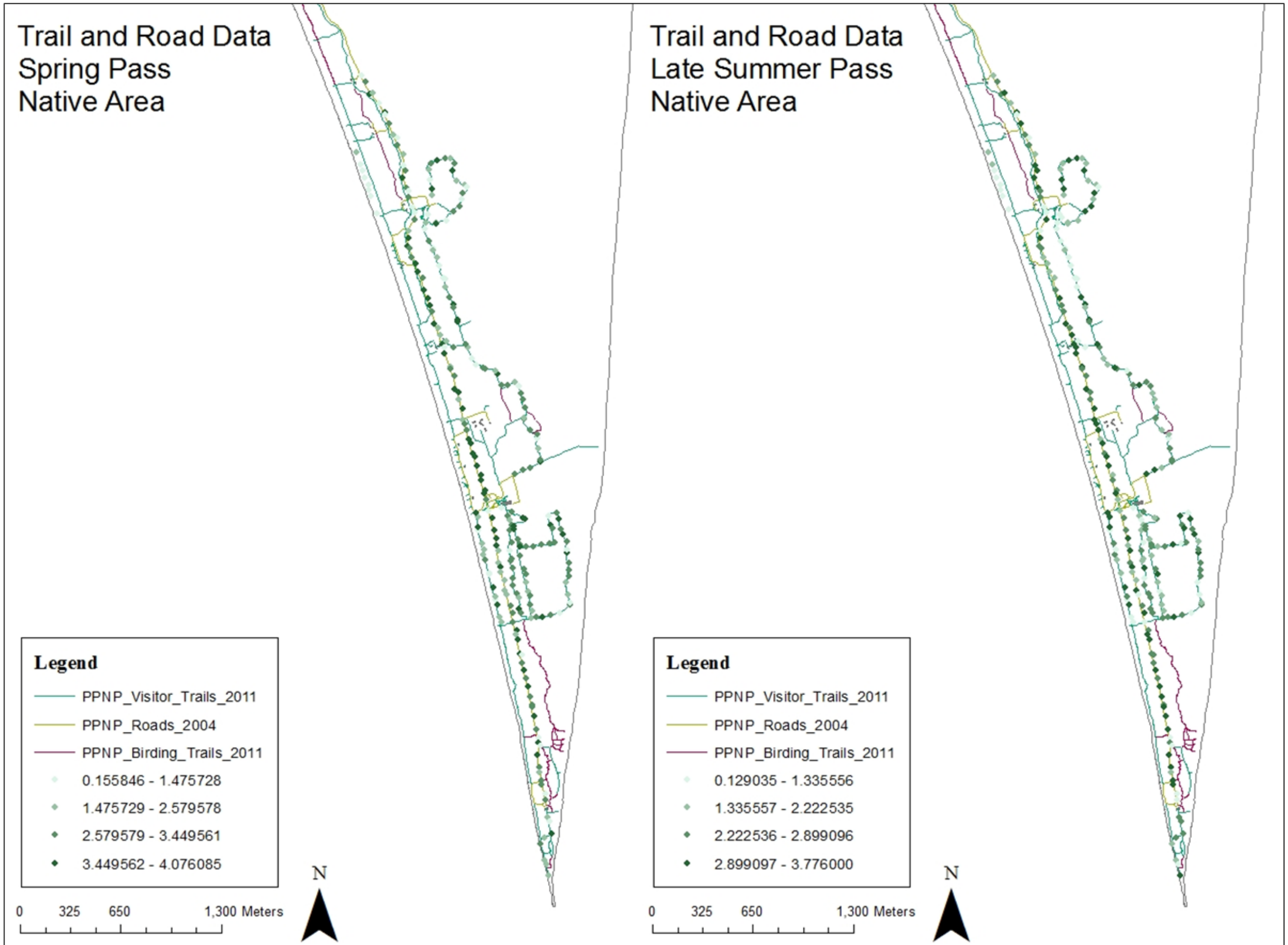

Figure 16. Maps showing how native species area varies along the road and trails in the study area

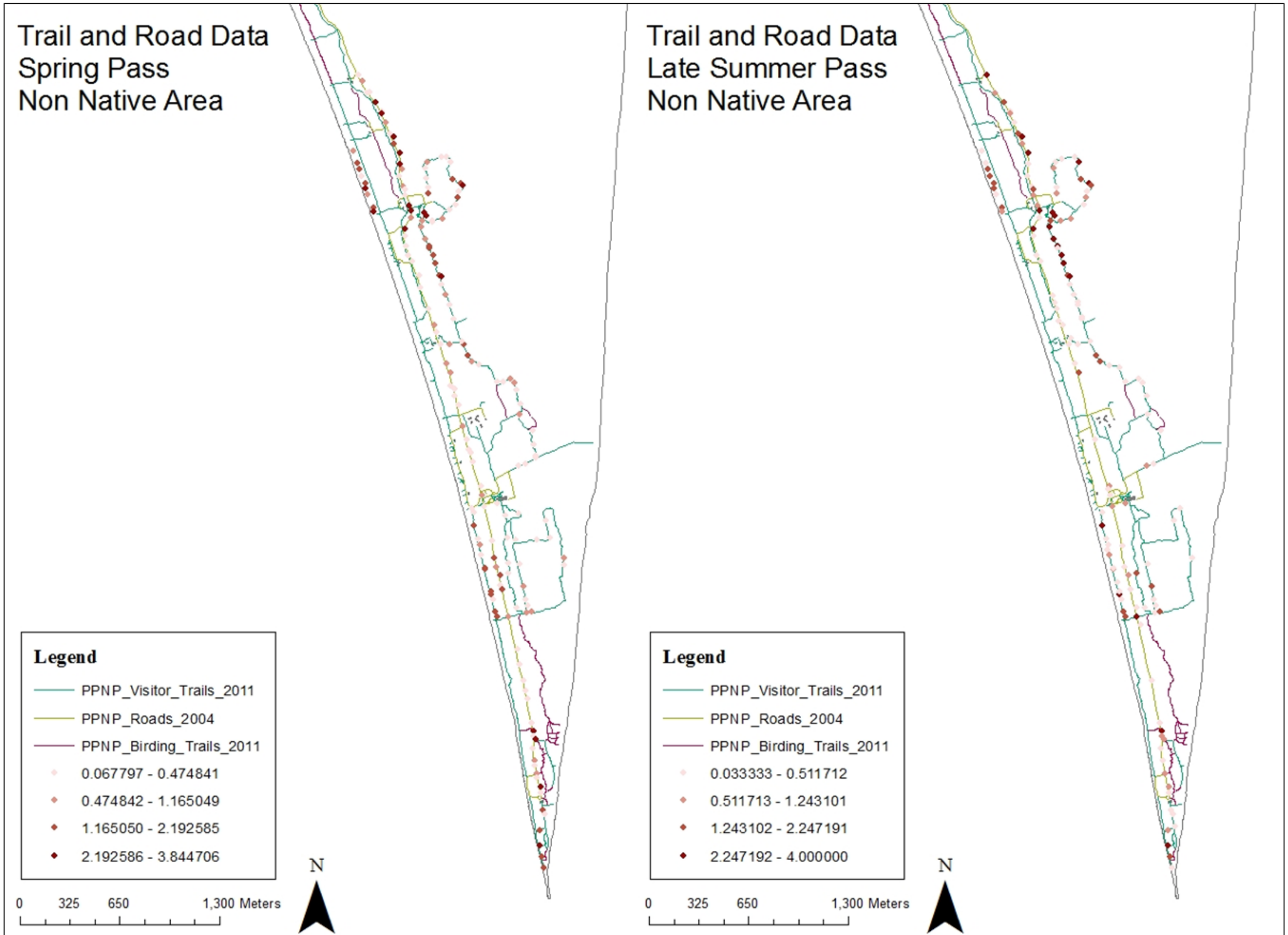

Figure 17. Maps showing how non-native area differs along the road and trails in the study area.

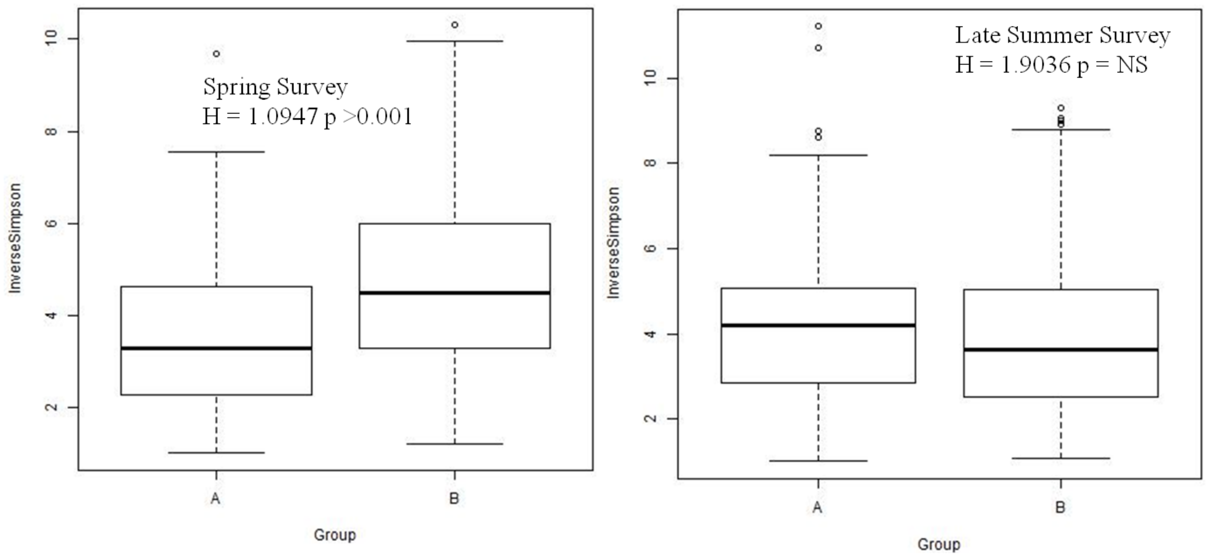

Figure 18. Box plots of Inverse Simpson index for base data >100m from trails or road (A) and trail and road data (B), both surveys, with Kruskal Wallis values.

Distribution maps of native richness reveal that high native richness occurs where there is high diversity and is lowest in the area around DeLaurier and along the east side of the Woodland trail (Figure 14). Distribution maps of non-native richness reveal it is highest along the west beach and in the area around DeLaurier (Figure 15). Distribution maps of native density reveal that it is mostly spread out but is highest along the woodland trail and lowest along Ander's footpath (Figure 16). Maps of non-native density show that the area around DeLaurier and Ander's field have the highest values and west beach the lowest (Figure 17). Box plots reveal that the diversity for the quadrats greater than 100m away from road or trails (group A) is significantly different and lower than for the road and trail quadrats (group B), for the spring survey (Figure 18). There is no significant difference between the two for the late summer survey. Box plots for native and non-native area comparisons reveal group A is significantly lower in all cases, except native area, in the late summer, which is higher (Figure 19). Box plots of native and non-native species richness reveal that non-native richness is significantly higher for group B. Native richness is higher for group A in the spring but there is no significant difference in the late summer (Figure 20).

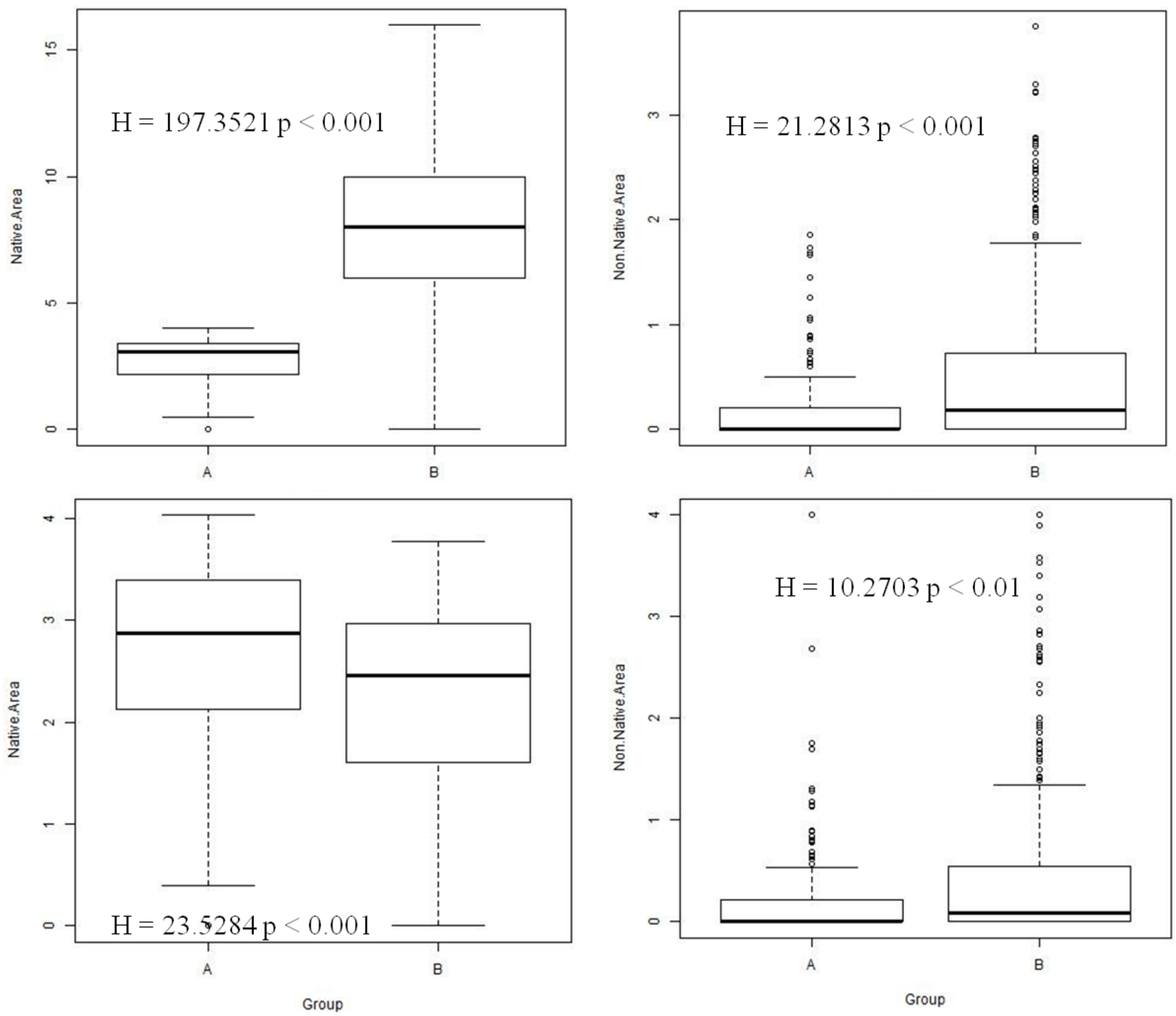

Figure 19. Box plots of native and non-native area for base data >100m from trails or road (A) and trail and road data (B), spring survey (top) late summer survey (bottom), with Kruskal Wallis values.

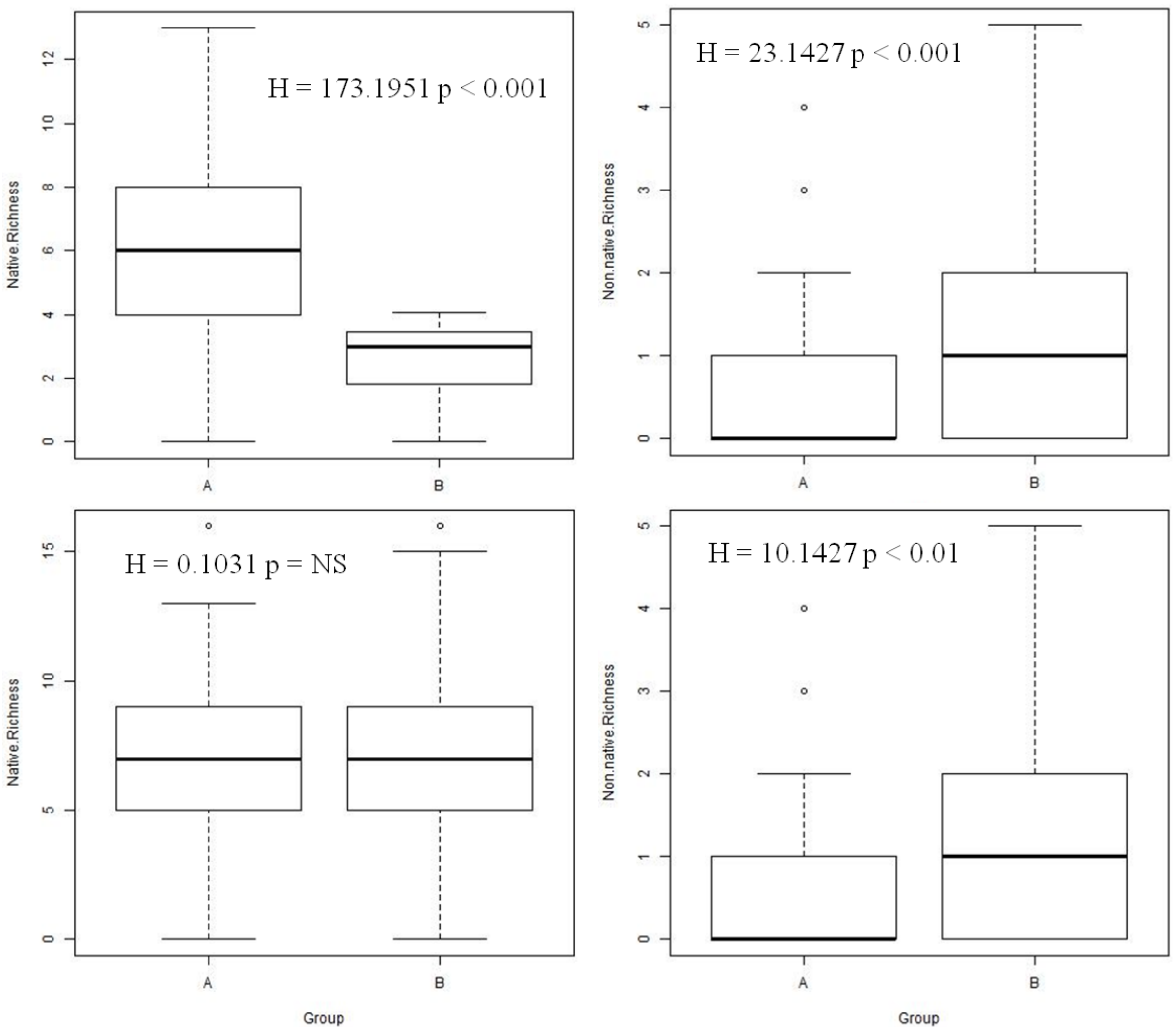

Figure 20. Box plots of native and non-native richness for base data >100m from trails or road (A) and trail and road data (B), spring pass (top) late summer pass (bottom), with Kruskal Wallis values.

Non-native Species

Occurrence was compared across diversity and native species richness for the top ten non-native species (Table 5). Occurrence differed significantly across diversity and native richness for both *Bromus inermis* and *Centaurea maculosa*, for both surveys. Scatter plots reveal quadrats with high values of either species also had low diversity and native species richness. The spring survey results show *Bromus tectorum* differs significantly across diversity and native richness. Quadrats containing high values of *Bromus tectorum* also had low values of both variables. The late summer survey results show *Saponaria officinalis* and *Melilotus alba* differ significantly across native richness and quadrats containing high values of either have low native richness. *Alliaria officinalis* differed significantly across diversity for the late summer data and quadrats with high values also have mid level diversity values.

Maps of the species that differed significantly show the same associations. Distribution maps for *Bromus tectorum* reveal that it mostly occurs around DeLaurier and near the Tip and in most quadrats covers less than 25%. *Alliaria officinalis* covered less than 10% of most of the quadrats it occurred in and was quite spread out along the road and trails. *Centaurea maculosa* and *Melilotus alba* mostly occurred along the west beach and for most quadrats covered less than 25%. *Saponaria officinalis* also covered less than 25% of the quadrats it occurred in and was observed mostly around DeLaurier and at the Tip. Other species that occurred mostly around DeLaurier were *Dactylis glomerata*, *Bromus tectorum* and *Hesperis matronalis* and all covered less than 25% of most of the quadrats they occurred in.

The occurrence of the top ten non-native species were compared between the two groups using the Kruskal Wallis test (Table 6). Species that did not occur in group A were *Saponaria officinalis*, *Centaurea maculosa*, *Poa annua*, *Dactylis glomerata*, *Berteroa incana* (L.) DC. (hoary alyssum), and *Melilotus alba*. Species that did not occur in group B were *Lamium purpureum* L. (purple dead nettle), and *Convallaria majalis*. *Bromus inermis* differed significantly between the two groups for both surveys and box plots revealed that group B had higher values. *Alliaria officinalis* differed significantly between the two groups during the late summer survey and a box plot revealed that group A had the higher values.

Table 5. Top ten occurring native and non-native species Kruskal Wallis values, trail and road data.			
Spring Survey		**Versus Inverse Simpson Index**	**Versus Native Species Richness**
Native			
Virginia Creeper	*Parthenocissus quinquefolia*	20.5512**	37.6863**
Aniseroot	*Osmorhiza longistylis*	40.1372**	48.8466**
Poison Ivy	*Rhus radicans*	12.5335*	20.9524**
Star-flowered Solomons Seal	*Smilacina stellata*	11.0462*	27.9932**
Wavy-leaved Aster	*Aster undulatus*	15.8644*	28.2382**
White Avens	*Geum canadense*	21.0172**	53.9952**
Tall Goldenrod	*Solidago altissima*	8.3768	13.0968*
Common Hackberry	*Celtis occidentalis*	15.0003*	17.6491*
Rough-leaved Dogwood	*Cornus drummondii*	6.3164	7.9180
Choke Cherry	*Prunus virginiana*	20.2576**	27.0397**
Non-Native			
Garlic Mustard	*Alliaria officinalis*	6.7938	9.0784
Smooth Brome	*Bromus inermis*	9.6117*	25.0935**
Annual Bluegrass	*Poa annua*	1.1908	9.7931*
Bouncing Bet	*Saponaria officinalis*	3.0408	2.8793
Stinging Nettle	*Urtica dioica*	7.4594	9.1120
Orchard Grass	*Dactylis glomerata*	0.9063	6.0810
Spotted Knapweed	*Centaurea maculosa*	13.0366*	62.8164**
Dame's Rocket	*Hesperis matronalis*	8.0184	4.6378
Hoary Alyssum	*Berteroa incana*	1.4160	6.9601
Downy Brome	*Bromus tectorum*	15.3344*	62.215**
Late Summer Survey			
Native			
Aniseroot	*Osmorhiza longistylis*	2.9905	25.6115**
Poison Ivy	*Rhus radicans*	45.3608**	49.9844**
Wavy-leaved Aster	*Aster undulatus*	35.8266**	51.3262**
Virginia Creeper	*Parthenocissus quinquefolia*	63.6248**	56.8609**
Rough-leaved Dogwood	*Cornus drummondii*	4.2306	10.7088*
Common Hackberry	*Celtis occidentalis*	11.0808*	16.2415*
Choke Cherry	*Prunus virginiana*	32.919**	24.4918**
Tall Goldenrod	*Solidago altissima*	27.9944**	18.9199**
White Avens	*Geum canadense*	10.4122*	24.3927**
Common Greenbriar	*Smilax rotundifolia*	25.9275**	51.2155**
Non-Native			
Garlic Mustard	*Alliaria officinalis*	11.0786*	7.8075
Smooth Brome	*Bromus inermis*	24.6739**	19.4934**
Bouncing Bet	*Saponaria officinalis*	4.9290	13.1689*
Spotted Knapweed	*Centaurea maculosa*	14.1818*	45.7982**
Annual Bluegrass	*Poa annua*	5.2007	4.8995
White Sweet Clover	*Melilotus alba*	2.6629	21.0995**
Orchard Grass	*Dactylis glomerata*	8.4145	4.2143
Stinging Nettle	*Urtica dioica*	3.1132	3.5424
Dame's Rocket	*Hesperis matronalis*	1.1731	6.8121
Ground Ivy	*Glechoma hederacea*	6.3628	2.4534

* $p < 0.05$
** $p < 0.001$

Table 6. Top 10 non-native species for both base and trail and road data, Kruskal Wallis values comparing trail and road data to base data > 100m from trails and roads, both surveys		
Species - Spring Survey		**H**
Garlic Mustard	*Alliaria officinalis*	0.2334
Dame's Rocket	*Hesperis matronalis*	1.6421
Smooth Brome	*Bromus inermis*	4.6347*B
Stinging Nettle	*Urtica dioica*	0.0358
Purple Dead Nettle	*Lamium purpureum*	none on trails or road
Bouncing Bet	*Saponaria officinalis*	none >100m away
Spotted Knapweed	*Centaurea maculosa*	none >100m away
Common Dandelion	*Taraxacum officinale*	0.4323
Ground Ivy	*Glechoma hederacea*	0.6411
Lily-of-the-valley	*Convallaria majalis*	none on trails or road
Annual Bluegrass	*Poa annua*	none > 100m away
Orchard Grass	*Dactylis glomerata*	none > 100m away
Hoary Alyssum	*Berteroa incana*	none > 100m away
Downy Brome	*Bromus tectorum*	2.2141
Species - Late Summer Survey		**H**
Garlic Mustard	*Alliaria officinalis*	5.7511*A
Dame's Rocket	*Hesperis matronalis*	0.0401
Ground Ivy	*Glechoma hederacea*	3.433
Stinging Nettle	*Urtica dioica*	3.8439
Bouncing Bet	*Saponaria officinalis*	none > 100m away
Smooth Brome	*Bromus inermis*	9.9878*B
Spotted Knapweed	*Centaurea maculosa*	none > 100m away
White Sweet Clover	*Melilotus alba*	none > 100m away
Motherwort	*Leonurus cardiaca*	0.7608
Lily-of-the-valley	*Convallaria majalis*	none on trails or road
Annual Bluegrass	*Poa annua*	none > 100m away
Orchard Grass	*Dactylis glomerata*	none > 100m away

* $p < 0.05$
** $p < 0.001$
A base data > 100m away from trails or road had higher values
B trail and road data had higher values

Native Species

Occurrence was compared across diversity and native species richness for the top ten native species (Table 5). All differed significantly across both and quadrats with high values for those species also had mid to high values for diversity and native richness, with the following exceptions. *Osmorhiza longistyli* did not differ significantly across diversity during the late summer survey, *Cornus drummondii* only differed significantly across native richness during the late summer survey and *Solidago altissima* did not differ significantly across diversity during the spring survey. Maps of the species that differed significantly confirm the trends observed. Scatter plots confirm the trends discussed for the base data. It should be noted that *Osmorhiza longistyli* occurred mostly along the Woodland and Tilden trails and *Smilax rotundifolia* L. (Common Greenbriar) was observed mostly south of the Visitor Center. The occurrence of the top ten native species were compared between the two groups using the Kruskal Wallis test (Table 7). Most species differed significantly between the two groups, except for *Solidago altissima* and *Geum canadense* during the late summer survey. Most had higher values for group B except for *Osmorhiza longistyli*, *Cornus drummondii* (both surveys), *Galium aparine* (spring survey), *Parthenocissus quinquefolia* and *Tovara virginianum* (late summer survey).

Table 7. Top 10 native species for both base and trail and road data, Kruskal Wallis values comparing trail and road data to base data > 100m from trails and roads, both surveys

Species - Spring Survey		H
Aniseroot	*Osmorhiza longistylis*	26.9854**A
Star-flowered Solomons Seal	*Smilacina stellata*	16.0981**B
Virginia Creeper	*Parthenocissus quinquefolia*	41.6949**B
Cleavers	*Galium aparine*	28.3679**A
Rough-leaved Dogwood	*Cornus drummondii*	21.9679**A
Poison Ivy	*Rhus radicans*	9.1344*B
Choke Cherry	*Prunus virginiana*	14.4978**B
Prickly Gooseberry	*Ribes cynosbati*	6.4291*B
Tall Goldenrod	*Solidago altissima*	9.8734*B
Wavy-leaved Aster	*Aster undulatus*	21.66**B
White Avens	*Geum canadense*	14.9907**B
Common Hackberry	*Celtis occidentalis*	27.693**B
Species - Late Summer Survey		**H**
Aniseroot	*Osmorhiza longistylis*	5.565*A
Virginia Creeper	*Parthenocissus quinquefolia*	8.463*A
Rough-leaved Dogwood	*Cornus drummondii*	28.6834**A
Poison Ivy	*Rhus radicans*	9.2529*B
White Avens	*Geum canadense*	0.9028
Wavy-leaved Aster	*Aster undulatus*	16.3544**B
Star-flowered Solomons Seal	*Smilacina stellata*	6.984*B
Tall Goldenrod	*Solidago altissima*	0.5701
Choke Cherry	*Prunus virginiana*	26.3509**B
Jumpseed	*Tovara virginianum*	32.1294**A
Common Hackberry	*Celtis occidentalis*	20.4312**B
Common Greenbriar	*Smilax rotundifolia*	14.4204**B

* $p < 0.05$
** $p < 0.001$
A base data > 100m away from trails or road had higher values
B trail and road data had higher values

Chapter 5 Discussion and Recommendations

Non-native Species

The most important question this study set out to answer was, are any non-native plant species expanding at the expense of native plants, making them invasive. There are very few species that are exhibiting this or have the ability to do so. Most non-native species covered less than half of the quadrats they were observed in. *Vinca minor*, *Bromus inermis*, *Convallaria majalis* and *Hemerocallis fulva* were observed to be very dense in the quadrats they occurred in but did not differ significantly across density (Figure 21). Only *Bromus inermis* varied significantly across native species richness. All four species were found in localized areas and did not appear to be spreading throughout the study area. Most non-native species did not differ significantly across diversity or native richness. *Lonicera japonica, Rosa multiflora* Thunb ex Murray (Multiflora Rose), *Morus alba* L. (white mulberry), *Euonymus fortunei* and *Polygonum cuspidatum* were observed and have the ability to become invasive, based on how they have invaded in areas outside PPNP (Figure 22) (Swearingen et al., 2002). It is likely that human disturbance, in the form of agriculture and cottages, created the disturbance that lowered diversity first. This makes it difficult to determine if the non-native species that are significantly associated with areas of low diversity and native richness are causing or are a symptom of it (Bazely et al. 2004).

Figure 21. Photos of *Vinca minor* (top left), *Bromus inermis* (top right), *Convallaria majalis* (bottom left) and *Hemerocallis fulva* (bottom right).

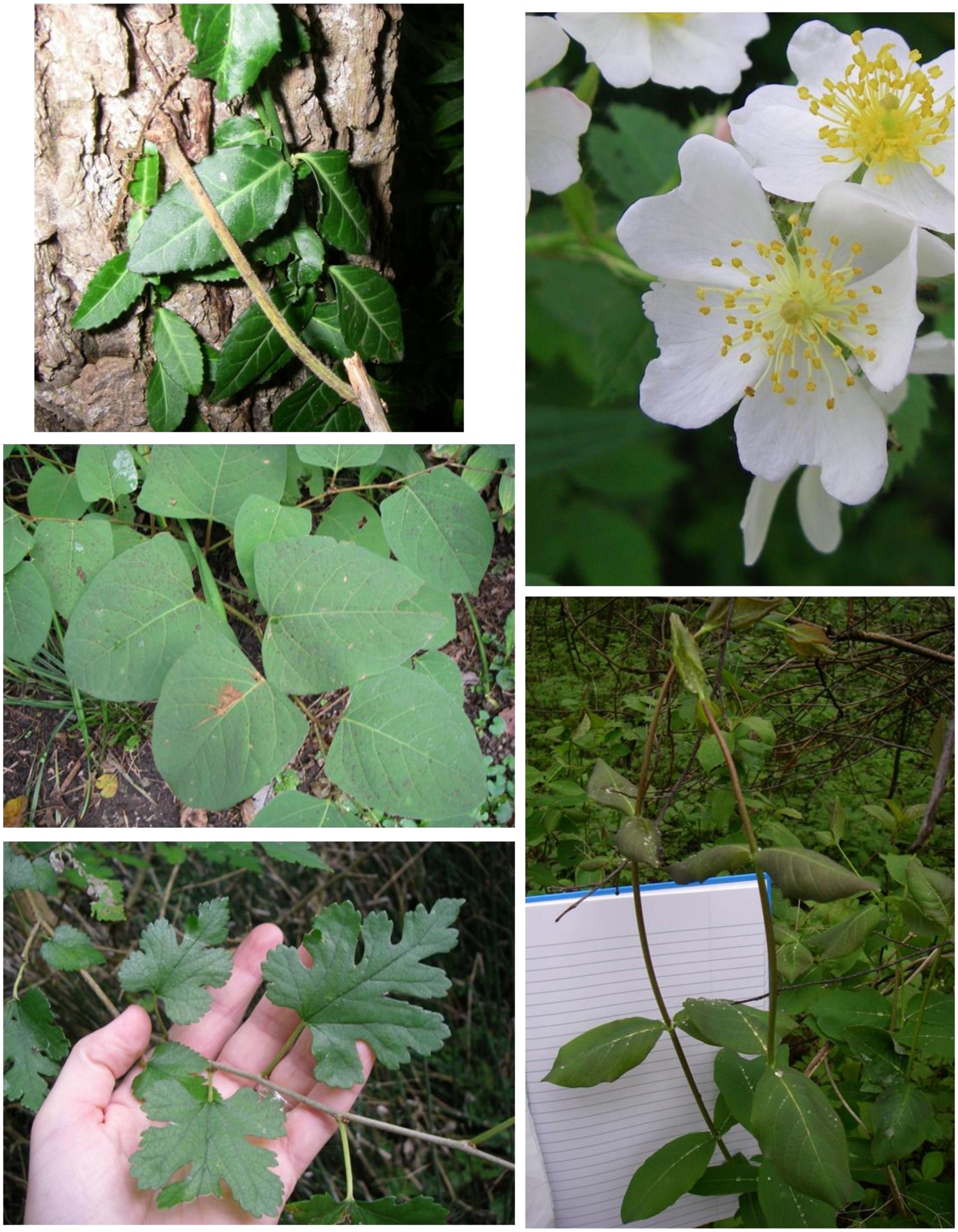

Figure 22. Photos of *Euonymus fortunei* (top left), *Polygonum cuspidatum* (center left), *Morus alba* (bottom left), *Rosa multiflora* (top right) and *Lonicera japonica* (bottom right).

Future monitoring of diversity should show diversity increasing with time since disturbance if they are only a symptom. Non-native richness has decreased in PPNP since the 1990 management plan. At that time non-natives made up 37% of the plant species and this study found it was closer to 20%. This could indicate that there has been some improvement as the result of passive and active restoration that has taken place. Future regular monitoring, using the sampling methods used in this study, of diversity and non-native richness will give a more accurate indication of improvement.

Non-native richness was significantly higher along the road and trails therefore they could provide an opportunity for non-natives to introduce and become established (Alston and Richardson, 2006). Monitoring, along the road in particular, for any new non-native plants will allow for quick response and removal before they get the opportunity to become invasive.

Native Species

Disturbance that is currently being managed for in PPNP include the road, trails and visitor use. This may be having an impact on native richness in those areas as it is significantly lower than over 100m away from these features, in the spring. It is significant that this is the case in the spring but not the summer, since that is when species that are known to be vulnerable to disturbance are present. Native species may be denser along the trails and road but so are non-native species and this can be attributed to there being less shade in those areas. This allows more shade intolerant species to become denser.

The results indicate that high native density does not equal high native richness. It was observed that some areas of high native density were diversity poor. Most native species covered over half the quadrats they occurred in. This indicates that some native species may be dominating. Invasive species are opportunistic and generalists, *Osmorhiza longistylis* has shown these characteristics even though it is a native species. This is supported by how it varies significantly with diversity and native richness and by how widespread it is in the study area. It is also much denser and more widespread in the study area than any of the non-native species. It is an excellent disperser and was observed to have two growing seasons. The results indicate that it is likely dominating some areas. The road and trails data show low diversity and native richness along the east side of the Woodland trail. This is also an area where *Osmorhiza longistylis* and

Laportea canadensis are the densest (Figure 23). It is well shaded in this area and these species are shade tolerant.

Laportea canadensis can be used as valuable cover for wildlife. Caterpillars of some butterfly species feed on the foliage and the caterpillars of *Papilio polyxenes* (Black Swallowtail) will feed on the foliage of *Osmorhiza longistylis* (Hilty, 2012). Removal of these species is not recommended even though they are so dense where they occur. The most abundant native species are early successional and those that are dispersal restricted are not as widespread

Figure 23. Photos of *Osmorrhiza longistylis* (top) and *Laportea canadensis* (bottom).

Recommendations for Management

Land development surrounding PPNP make is susceptible to future introductions and invasions of non-native plants. It will be important to continue working with other groups in the area as well as local landowners and the public. Educating the local landowners about how to identify and manage non-natives on their own properties may decrease future introductions. Engaging volunteers in removal and re-vegetation programs will make management more economical. There is also a need to make ecosystems in PPNP harder to invade. This means increasing diversity and native richness, making them more resilient and carefully managing disturbance. Making ecosystems more resilient should be the top priority for management. This is more important than returning them to what they were before human disturbance, which might be impossible to achieve considering the level of disturbance that has occurred.

Novel ecosystems are produced when species occur in combinations and relative abundances, which have not occurred previously in a given area, as a result of human actions. Invasion of native ecosystems by non-native species and the abandonment of intensively managed systems are two ways in which novel ecosystems are created, that apply to PPNP. Human impact in PPNP has introduced a number of plant species not previously present in that region, cultivated and degraded landscapes around PPNP create dispersal barriers for many native animal and plant species and past agricultural use of PPNP may have decreased the native plant seed bank in the soil, making it difficult for pre-existing species to re-establish. These three issues have contributed to new plant species combinations in PPNP (Hobbs et al., 2006). Management that involves removing undesirable features, such as non-native species, can create a disturbance that perpetuates novel ecosystems. When these novel ecosystems are stable it can be difficult to restore them to their historical state financially and technically. In order to encourage desirable species, management efforts are best directed at maintaining genetic and species diversity. When management focuses on the invasive species only, native species do not necessarily benefit. In the United States rangelands, knapweeds (*Centaurea spp*.) are actively being managed through various removal strategies. Some studies suggest that new dominant plant species are replacing the knapweeds and are increasing in abundance (Hobbs et al., 2009 and Seastedt et al., 2008). Based on the biotic alteration that has occurred at PPNP, restoration of ecosystem structure and/or function is likely and is occurring already. Restoration of the historical state depends on the removal of non-native species and is therefore only achievable if the definition of historic state is broadened to include some modification and new species (Hobbs et al., 2009).

Manual (hand pulling) and fire are likely the best control options for those species being removed. Fire is recommended as it is already being practiced by PPNP management and the results of this study indicate that it will likely be useful for restoring disturbance regimes. Fire is currently being used in an attempt to restore Red Cedar Savanna habitat (Smith and Bishop, 2002). Caution with this method is needed. When employed in areas where the seed bank is dominated by non-native species, they could become invasive (Marchante et al., 2011). Re-vegetation with native desired species is recommended to control for this. Monitoring will be important, test restoration sites should be revisited annually and the marked quadrats that were part of this study should be revisited also. This will help managers determine if diversity and native richness improve as a result of restoration efforts and help them detect any newly introduced non-native species. Native and non-native species composition should be monitored as well. It will help managers determine if there are any changes in successional species (McLachlan and Bazely, 2001).

The 2012 Federal budget and Bill C-38 have resulted in a 10% budget cut for Parks Canada over 3 years and the laying off of approximately 1680 staff. Previous to Bill C-38 the state of the National Parks was reported every two years and management plans reviewed every five years. Changes that will be made to the Parks Canada Agency Act as part of Bill C-38 will result in State of the Parks reports being produced every 5 years and Management Plans being reviewed every 10 years (Parliament of Canada, 2012). This change will make it difficult to annually monitor and make changes to management activities, which was recommended as part of this study.

If recent cutbacks to Parks Canada also make these recommendations difficult to achieve priority should be on decreasing the amount of disturbance as much as possible. Human disturbance creates a stress to the native plant community and provides an opportunity for non-native plants to enter (Luken, 1997). Clothing can be a significant vector of non-native seeds and contributes to unintended human mediated seed dispersal (Mount & Pickering, 2009). Recreation areas, such as parks and protected areas, can be especially prone to invasions by plants that spread by these means. A large number of visitors travel to PPNP from geographically diverse areas making it too prone to invasions by these means. Visitors can bring with them species of plants that otherwise would be unable to propagate over such long distances (Tobin et al., 2010). Studies have shown that in general the number and abundance of non-native plants is higher at habitat edges such as roads and trails. The decline in the amount of invasion towards the center of fragmented landscape can be dramatic. Smaller isolated fragments will also be more susceptible to invasion than larger more continuous fragments. In general the average distance of influence by a road or trail is about 80 meters (Merriam, 2003; Vila, 2011). Other studies have shown that the number of non-native species generally decreases with distance from trail heads and trails with higher use have a greater number of non-native plants at further distances from the trail head (Bella, 2011). Canopy disturbance and herbivory by white-tailed deer can also contribute to invasions by non-native plants (Eschtruth & Battles, 2007). Non-native plant diversity in forest sites generally increases with a decrease in canopy cover and with an increase in the amount of open habitat in the surrounding landscape. This is especially the case with non-native plants that are open habitat species (Charbonneau & Fahrig, 2004). In PPNP the history of agriculture has introduced mainly open habitat species, so the importance of canopy cover would apply. Edges from roads or trails through grasslands or open habitat can be more susceptible to invasion than forest habitats (Hansen & Clevenger, 2005). This is the case along some areas of the road near DeLaurier and along parts of the trail at DeLaurier.

The roads and trails in the Park could facilitate the introduction of non-native plants by providing a location for non-native plants to establish once introduced. Roads and trails are also vectors for introduction as seeds can be transported on people's clothing or on vehicles. The more edges that are present, the higher the invisibility of the Park (Bartuszevige et al., 2006). Vehicles can also aid in seed dispersal by causing air turbulence (Hansen & Clevenger, 2005). It is important to remove any non-native plants that could spread early and to minimize the maintenance of these passage ways during the time that these plants may be producing seeds (Merriam, 2003).

Roads and trails are the first point of contact for fluxes of non-native plants. These edges can affect the magnitude and direction of the fluxes, based on their structure, and therefore can influence the dynamics of the forest interior. For wind dispersed seeds, a dense intact edge will physically inhibit seed transmission. The presence of branches, twigs and leaf mass is particularly important for decreasing an edge's permeability. Dense plantings of native shrubs, vines and understory trees along edges can decrease the permeability of the forest to non-natives.

Combined with the removal of non-natives already existing can prevent the spread of non-native plants into the forest (Cadenasso & Pickett, 2008). It was observed as part of this study that edges along the road and trails were quite dense in a lot of areas, particularly along the eastern part of the woodland trail and in some southern areas of the DeLaurier trail. Edges like those should be encouraged.

The areas greater than 100m away from roads and trails have higher native plant diversity, showing that, as succession proceeds, these areas are becoming more resistant to invasion. If succession is allowed to continue more non-native species will succeed to native species (D'Antonio & Meyerson, 2002). Tracts of forest with less edge should be preserved to minimize invasion (Yates et al., 2004). These areas in PPNP require little to no management except for periodic monitoring by revisiting the plots that were marked as part of this study. In PPNP a number of trails and roads have been removed already. This has likely contributed to a decrease of non-native plants within the interior of the Park. The trails that still exist within the Park still present an opportunity for future invasions. Decreasing the number or extent of the trails could aid in the control of non-native plant introductions. Emphasis should be on protecting, as large as possible tracts of forest and decreasing the amount of fragmentation in the park. The shape of the woodland trail, the area of north of the Visitor Center, the area around DeLaurier and along the western coast of the Park between the road and the water are highly fragmented with trails, footpaths and roads. These areas were identified in this study as areas with higher non-native species richness. Removing trails and footpaths in these areas and allowing succession to take over would create larger, more continuous forest habitats.

Another concern is the restoration of savannah habitat by burning. This is being done near the Tip and this area also contains a dense amount of trails. These trails fragment an already small habitat, that combined with the disturbance from burning could increase the amount of non-native plants in this area. This study shows that non-native richness is already high in this area that combined with the fragmentation and disturbance could lead to invasions by the non-native plants. In areas where there are open habitats, near DeLaurier and at the Tip, roads and trails will likely have an effect on distances up to 120m because of the greater effect these edges have on open habitats.

Re-vegetation with native species should be another important part of restoration efforts, when there is removal taking place and in areas of disturbance. Maps show where species listed by McLachlan and Bazely (2003) were observed (Figure 24 and 25). These areas should be protected and these species encouraged, so that they can then serve as a source for transplants. Construction of a nursery for native plant transplants would also be useful for re-vegetating restored areas. Using these species for re-vegetation will give them some advantage and should improve native diversity and richness. Native species planting can also be done in areas dominated by *Osmorhiza longistylis* to improve native richness. Species like *Podophyllum peltatum* were observed to shade out other early spring species and could be planted to help control *Osmorhiza longistylis* and *Alliaria officinalis*.

It is also recommended that a seed bank study be completed particularly in areas that receive restoration efforts (before and after). This will help give a picture of what the plant community might look like after restoration. Where non-native species dominate the seed bank, these species should be suppressed and native species replanted (Marchante et al., 2011). A seed bank study could be done in the marked quadrats and that data compared to the data of this study.

Removal of high priority non-native species, re-establishment of disturbance regimes, native re-vegetation, monitoring, and a seed bank study would be key components of an EBIPM system that should have better success than just removal of non-native species. When revisiting marked quadrats it might be more effective to do 3 surveys, early spring, summer and late summer. The early spring species were ephemeral and this might provide more information on their extent.

Figure 24. Photos of *Aquilegia canadensis* (top left), *Trillium grandiflorum* (center left), *Dicentra cucullaria* (bottom left), Viola pubescens (top right) and *Arisaema triphyllum* (bottom right).

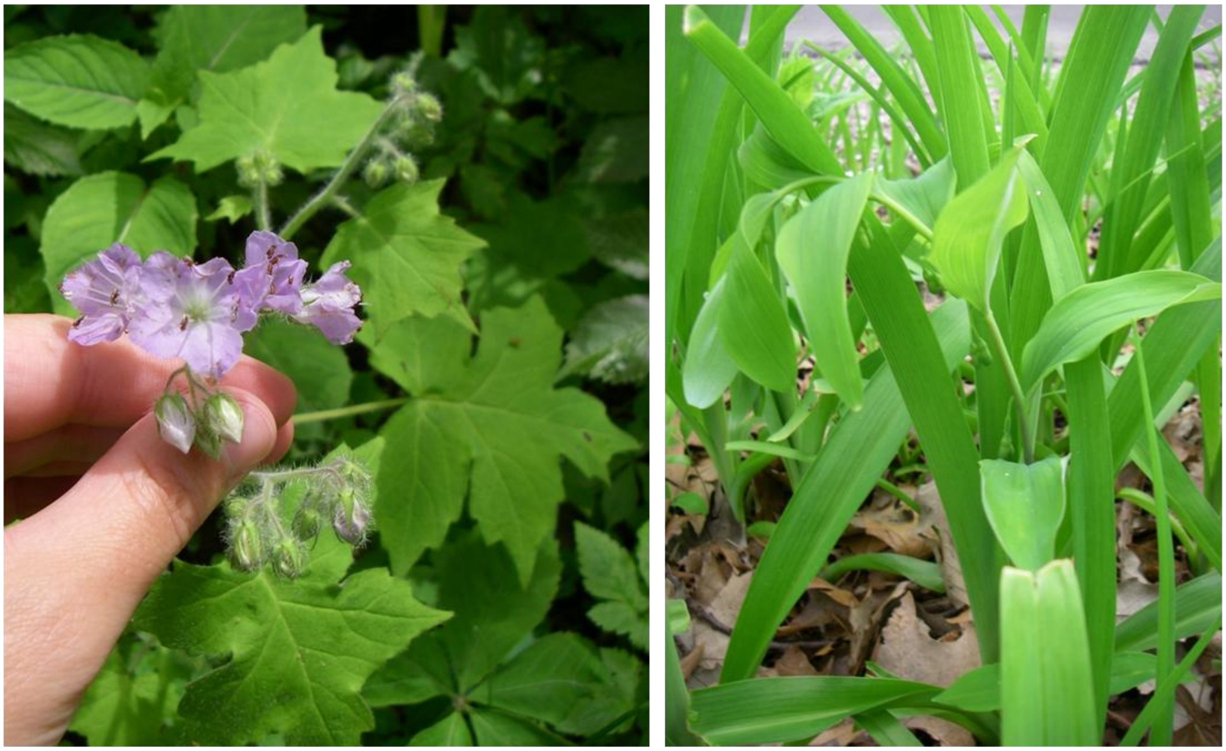

Figure 25. Photos of *Hydrophyllum appendiculatum* (top left), *Polygonatum biflorum* (top right) and *Podophyllum peltatum* (bottom left).

Areas that have the highest diversity, northeast of the Tilden Woods and Chinquapin oak trails and east of west beach parking, should be properly protected and disturbance minimized. This might include limiting visitor traffic or the removal of trails and footpaths. Protecting these areas will help maintain the diversity of these areas and provide a source of species richness and resilience for the rest of the areas surrounding them. These areas have experienced the most time since disturbance and are a good reference for where succession should be heading for other areas. Areas with the lowest diversity and highest non-native richness, DeLaurier, west beach and the Tip, are the best area to focus restoration efforts, in the form of non-native removal and native planting. It should be noted that the area north of DeLaurier had higher native richness and diversity during the late summer survey because the non-native plants that were observed in that area were mostly spring flowering species.

PPNP is currently in a novel state and ideally management would focus on removing the non-native species in an effort to restore it to its historic state. As was discussed a large amount of financial and technical input would be needed to do so and those efforts may not even be successful. In light of the recent budget cuts and changes to the Parks Canada Agency Act there is a need to prioritize management efforts so that what resources Parks Canada has left are put to best use. The following is a list of high and low priority targets for management. The targets listed as low priority are not meant to be left out of management plans but instead included as budget and resources allow.

Currently *Euonymus fortune* and *Polygonum cuspidatum* only consist of a couple of individuals, along the road and it is recommended they be removed, manually (hand pulling), immediately. *Lonicera japonica* is also present in only a few individuals and is a good candidate for manual removal as it can become invasive. When infestations are small as with these species hand-pulling can be very effective at preventing further infestation (DiTomaso, 2000). Complete removal of all roots and runners, especially for *Polygonum cuspidatum*, is required to ensure there is no re-sprouting (Swearingen et al., 2002).

Only one individual of *Narcissus psedonarcissus* was observed, while it is unlikely to become invasive and is likely a remnant ornamental plant, it is also easy to remove manually and so this is recommended.

Areas with *Vinca minor*, *Bromus inermis*, *Convallaria majalis* and *Hemerocallis fulva* are good candidates for test restoration plots. Treatment with glyphosate of these species would likely be most effective. Care should be taken to only apply the herbicide to the target plants as it will also kill native plants. This can be done using disposable paint brushes to apply the chemical directly to the plant foliage. It should be applied in the fall and during dry conditions to ensure rainfall does not wash it off (Malik et al., 1989 and Twyford & Baxter, 1999). Quadrat RQ0066 had both *Vinca minor* and *Convallaria majalis* occurring densely. It would be an excellent quadrat in which to perform this sort of restoration. Multiple applications of glyphosate may be necessary to ensure no re-growth of *Vinca minor*, *Convallaria majalis* and *Hemerocallis fulva*. Re-vegetation after removal can include *Lilium canadense* L. (Canada lily) and *Parthenocissus quinquefolia* (Swearingen et al., 2002). *Bromus inermis* prefers sunny, disturbed areas and therefore does not pose a threat of invasion if disturbance is minimized. Re-vegetation with competitive native grasses like those observed through this study should be used. Other recommendations include *Panicum virgatum* L. (switchgrass) and *Schizachyrium scoparium* (Michx.) Nees (little bluestem). Fire control can be effective as well, as long as the seed bank is not dominated by *Bromus inermis* and burning is timed correctly so as to not promote growth of *Poa pratensis* L. (Kentucky bluegrass), which can become invasive and is present in PPNP. *Bromus inermis* will also re-sprout from rhizomes so complete removal of them is recommended. Care should also be taken not to fragment them during removal as even the smallest piece can re-sprout (Otfinowski et al., 2007).

Rosa multiflora and *Morus alba* can become invasive and removal is recommended. Cutting is required to remove them and *Rosa Multiflora* may need repeated cutting. *Rosa Multiflora* can be replanted with *Rubus alleghensis* Porter. (common blackberry), *Rosa carolina* L. (pasture rose) and *Rubus odoratus* L. (flowering raspberry) and *Morus alba* with *Celtis occidentalis* and *Sassafras albidum* (Nutt.) Ness (Sassafras) (Swearingen et al., 2002). The quadrats where removal takes place should be monitored to confirm complete removal.

Melilotus alba and *Centaurea maculosa* benefit from high disturbance so decreasing the amount of human disturbance in that area would limit site availability for them to spread. This is especially important in areas where they have not spread; human traffic can help spread the seeds of both into these areas. *Centaurea maculosa* was burned along the west beach, the same summer as this study was conducted. Using fire to control *Centaurea maculosa* is not always effective. If it is a low intensity fire re-sprouting can occur from the undamaged crowns and viable seeds that remain in the soil. Burning followed by the application (spraying) of the herbicide picloram can be effective in decreasing the amount of re-growth. This should be done during active growth of *Centaurea maculosa* and before it goes to seed, in early July. Large scale cultivation (grubbing) in late fall, followed by re-vegetation with dormant native grass seeds could also be effective. The least labour and resource intensive management option would include planting competitive native plants that can also serve as a nectar source for those species currently using *Centaurea maculosa*. These species could include *Monarda fistulosa* L. (Wild

Bergamot), *Rudbeckia hirta* L. (Black-eyed Susan), *Oenothera biennis* L. (Evening Primrose), *Asclepias tuberose* L. (Butterfly weed), and *Lupinus perennis* L. (Wild Lupine). *Monarda fistulosa* and *Oenothera biennis* were both observed in the study area and may be the most successful; replanting with these species would enhance the already established population (NANPS, 1999). Test plots of the different techniques should be studied to determine which technique works best for this location (Sheley et al., 1998). It is likely a combination of the above techniques will be required and should be used in the immediate future. While *Centaurea maculosa* is widespread along the west beach, it is still concentrated in that area and has not spread to the rest of the study area. It has the ability to spread easily and could dominate in areas of disturbance. Immediate management could prevent such spread, but if it is not properly managed and spread occurs it will be more difficult or impossible to manage in the future. It is likely that a north to south transect would reveal that *Centaurea maculosa* differs significantly across diversity which would make it invasive in that area. This could be the case for other non-native species in other ecosystem types. Future research could include transects that run north to south. This would account for species that are concentrated in particular ecosystem types and give a clearer indication of how invasive they are.

It is important to consider the usefulness of *Saponaria officinalis* and *Hesperis matronalis* by other species, particularly long-tongued bees, moths and butterflies, when considering management (Figure 26) (Hilty, 2012). PPNP is an important stopping point for migrations of moths and butterflies so removal of plants they depend on could be extremely detrimental. Re-vegetation using native plants that are also important for these species, would improve native richness in those areas, while not removing the present food source. The invasive threat of *Saponaria officinalis,* and *Hesperis matronalis* are low and they will likely decrease as diversity and native richness improve, as the result of native species planting and encouragement.

Figure 26. Photos of *Hesperis matronalis* (top left), *Saponaria officinalis* (bottom left) and *Centaurea maculosa* (right).

It is unlikely that complete removal of *Alliaria officinalis* will be possible given that it is widespread throughout the study area (Figure 27) (Firanski et al., 2002). This may not even be necessary since there is little evidence, from this study, that it is having an effect on diversity or native richness. It is an excellent seed disperser and seeds can stay dormant in the soil, giving it the potential to be very invasive (Cavers et al., 1979). While removal is not recommended caution stills needs to be used with other management programs because of the invasiveness of *Alliaria officinalis*. *Alliaria officinalis* had significantly higher occurrence greater than 100m away from road and trails indicating it may be dominating in the seed bank. If this is correct, even as native species succeed it will remain, as it has the competitive advantage of coming up and going to seed before most of the native plants. Management should include a seed bank study to determine what areas, if disturbed, could become invaded and improving the native species community by replanting, as was mentioned already.

Figure 27. Photo of *Alliaria petiolata*.

Improvements to Invasive Plant Management

There are good invasive plant management programs being carried out across the country, but without an inclusive management strategy for the entire country it is difficult to coordinate efforts and data. Invasive plants are borderless, and this raises two problems. Invasive plants will continue to invade natural areas in Canada unless an appropriate country wide effort is made to prevent introduction. Secondly strategies that are developed in one area of the country by a provincial government or non-government organisation may not actually apply to the entire species range. While it may prove effective in the short term in that one specific area, reinvasion could occur unless the invasive species is managed across its range. This would require not only a Canada wide effort, but also an International effort in cooperation with the United States, as many of the invasive plants that threaten Canadian ecosystems are also present south of the border. There is need for a Federal act that helps govern and give guidance to the provinces. It would provide a means for sharing knowledge across the provinces as well as provide a national stance on invasive plants when International concerns are raised. This would address the threat of invasive plants across their range, as this usually crosses provincial and international borders. The CIPF and the Directive on the Management of Alien Species in Canada's National Parks, that are still being developed, will hopefully create a cohesive country wide effort. Recent changes to the Parks Canada Agency Act as part of Bill C-38 as well as budget cuts to Parks Canada is a step in the opposite direction and will make it difficult to go forward with annual monitoring and management.

Public education and involvement is an underused resource in Canada. Given the costs associated with the control of invasive plants volunteer public organisations represent a large labour force, that can assist with control efforts. The public are also responsible for the introduction of invasive plants, either unintentionally or intentionally, through the use of non-native horticultural plants. Proper education on which plants pose a threat to native ecosystems could help decrease future introductions.

McNeely (1999) suggests bringing the issues of invasive species to the attention of the World Trade Organization. In an attempt to make an economic argument for the control and prevention of invasive species, a partnership between economists and ecologists could be beneficial. Given the large costs associated already with invasive species this may be an effective way of convincing decision makers and governments to create appropriate programs for managing invasive species. This would require more accurately determining cost estimates that would enable governments to decide where to focus management efforts.

Mooney (1999) calls for a globally coordinated invasive species program. He recommends further research is required to improve understanding of invasive species and their effects. Globally shared data systems would distribute this research among countries and improve their ability to predict the invasiveness of a species. This is important for early and quick response to unintentional introductions. International agreements and programs have been created that deal with the control of invasive species; the International Plant Protection Convention, The Convention on Biological Diversity, the Convention on the Law of the Sea and GISP. Not all countries have signed these agreements and their effectiveness needs to be assessed. Finally, further public education of the effects of invasive species is required. Informing travellers and people in the horticultural and pet trade could decrease the number of unintentional introductions that occur through these pathways.

The framework presented by Sheley et al. (2010) while useful still presents some potential problems when being applied. The framework requires a great deal of data collection as part of the assessment in step one. The ability to produce a sound management plan is dependent on this first step. The collection of the appropriate data may be labour and resource intensive for the land managers. If the ecological processes are not assessed properly poor decisions could be made that will lead to further damage to the ecosystem. Including adaptive management in the framework will help the managers assess if they have made poor decisions based on poor data, but by this point it may be too late to reverse the damage.

The framework is aimed at restoring pre-European settlement conditions. This is assuming that the ecological processes present at that time are still present and only need to be improved. This does not account for instances where the ecosystem has been so affected by invasive plants or human development, that a new type of ecosystem is now present. In this case it might be inappropriate to assume that the pre-European settlement conditions can be restored.

The need to incorporate EBIPM is growing and it can provide solutions where more traditional methods of management have failed. This area needs further research in order to develop it and make it more practical for managers. Current management plans and plans being developed are slow to incorporate EBIPM and with more research in this field hopefully this will change.

Specifically research should focus on how managers can create communities that are resistant to future invasions. Some work has been done already, studying what effects diversity has on invasion potential and what the mechanisms of invasion are. This needs to be expanded on in order to help management programs have longer lasting effects. Researchers also need to incorporate their findings with information gathered from successful and unsuccessful restoration attempts (D'Antonio and Meyerson, 2002). This will add to a network of knowledge that will allow managers to make more informed decisions in the future.

Conclusion

There are few non-native species dominating the area studied in PPNP. *Alliaria officinalis* is the only one that is widespread and complete removal is not likely. Given its invasive ability in areas outside PPNP and ability to dominate in the soil seed bank, caution needs to be taken when disturbance is used as part of other management plans. If it is not monitored properly it has the ability to become more invasive within PPNP. *Lonicera japonica, Rosa multiflora*, *Morus alba*, *Euonymus fortunei* and *Polygonum cuspidatum* are currently localized but can become invasive and recommendations have been made for their removal. The presence of other non-native species that differed significantly in diversity and native richness are likely symptoms of low diversity and richness, given the history of disturbance within PPNP. Areas with *Vinca minor*, *Bromus inermis*, *Convallaria majalis* and *Hemerocallis fulva* are recommended for restoration efforts because of how densely they occur in the few locations where they are located. Management of *Centaurea maculosa* is highly recommended while it is still localized along the west beach. This will likely involve a combination of burning, use of herbicide and planting with native species. If it goes unmanaged it could continue to spread and be more difficult to impossible to manage.

Some native species appear to be dominating in the study area, particularly *Osmorhiza longistylis*. Planting of *Trillium grandiflorum*, *Aquilegia Canadensis*, *Arisaema triphyllum*, *Dicentra cucullaria*, *Viola pubescens*, *Podophyllum peltatum*, *Polygonatum biflorum* and *Hydrophyllum appendiculatum* is recommended to aid in succession since these species are dispersal restricted and to improve native richness. This should be done in areas where diversity and native richness is low and will make them more resilient to future invasions.

Removal techniques that were recommended include hand pulling (where populations are small), cutting, grubbing and fire. Re-vegetation should follow removal efforts as well as monitoring to determine success. The quadrats marked as part of this study should be monitored, to determine if there are improvements across the study area. Roads and trails should be monitored for any new non-native species that might be introduced along them and subsequent removal of these species before they can become invasive. A seed bank study should be completed before restoration efforts and in areas of low diversity. If there are non-native species dominating the seed bank they can become invasive once disturbed by restoration efforts. This will make re-vegetation with native species even more important. Educating and engaging the public and other organisations can help aid in restoration efforts and help prevent future introductions. These are all integral parts of an EPIBM program which is most likely to give the desired results of a more resilient and diverse Park.

Restoration efforts are best directed at the area around DeLaurier, along west beach and at the Tip. These areas have the lowest diversity and native richness and therefore need the most improvement. Protection of the areas of higher diversity and richness, by minimizing disturbance is also highly recommended. Less human disturbance along west beach is recommended as it is likely helping the spread of plants like *Centaurea maculosa* and providing site availability.

Future research should focus on continued monitoring, a seed bank study and sampling programs that attempt to cover areas missed by this study.

Non-native plants are a legacy of the human disturbance that has occurred within PPNP in the past. Efforts have been made to restore much of the park and it has had a positive effect on diversity and richness. With more focused restoration efforts in the future hopefully diversity and richness can continue to improve, avoid future invasions, establishing a more resilient plant community.

References

Achuff, P. L., Bailey, A. W., & Brusnyk, L. M. (1990). *Non-native plant management in western region national and historic parks: issue analysis and recommendations*. Prepared by D.A. Westworth and Associates Ltd. For Parks Canada, Ottawa ON

Allen, G. M., Eagles, P. F. J., & Price, S. D. (Eds.). (1990). *Conserving carolinian canada*. Waterloo, ON: University of Waterloo Press.

Alston, K.P. & Richardson, D.M. (2006). The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the cape peninsula, south Africa. *Biological Conservation*, 132, 183-198

Barnett, D., Stohlgren, T., Lusk, M., & Ericson, J. (2005). Iterative sampling of non-native plant species at hart mountain national antelope refuge. U.S. Fish and Wildlife Service, National Wildlife Refuge System. Retrieved from http://www.fws.gov/invasives/staffTrainingModule/assessing/inventory.html

Bartuszevige, A.M., Gorchov, D.L., & Raab, L. (2006). The relative importance of landscape and community features in the invasion of an exotic shrub in a fragmented landscape. *Ecography*, 29, 213-222.

Bazely, D.R., Firanski, J.C., & Koh, S. (2004). Invasive plants of Canadian woodlands-scientific challenges. *Proceedings of the 6th Parks Research Forum of Ontario, 2004*. pp125-132. Waterloo, ON

Bella, E.M. (2011). Invasion prediction on alaskan trails: distribution, habitat, and trail use. *Invasive Plant Science and Management*, 4, 296-305.

Blossey, B. (1999). Before, during and after: The need for long-term monitoring in invasive plant species management. *Biological Invasions, 1*(2-3), 301-311.

Booth, B. D., Murphy, S. D., & Swanton, C. J. (2003). Weed ecology in natural and agricultural systems. Wallingford, Oxon, UK: CABI Pub.

British Columbia Ministry of Forests (1998). *Field manual for describing terrestrial ecosystems*. BC

Cadenasso, M.L., & Pickett, S.T.A. (2008). Effect of edge structure on the fluxof species into forest interiors. *Conservation Biology*, 15(1), 91-97.

Campbell, F. T. (1997). Exotic pest plant councils: cooperating to assess and control invasive nonindigenous plant species. In: Luken, J. O., & Theiret, J. W. (eds) *Assessment and Management of Plant Invasions*, pp 228-243. Springer. New York

Canadian Food Inspection Agency. (2008). *Invasive alien plants in Canada: Summary report.* Ottawa, ON: CFIA.

Canadian Weed Science Society. (2011). *Canadian weed science society*. Retrieved March 8, 2011, from http://www.weedscience.ca/home

Cavers, P.B., Heagy, M.I., & Kokron, R.F. (1979). The biology of Canadian weeds. 35. *Alliaria petiolata* (M. Bieb.) Cavara and Grande. *Canadian Journal of Plant Science*, 59, 217-229

Charbonneau, N.C., & Fahrig, L. (2004). Influence of canopy cover and amount of open habitat in the surrounding landscape on proportion of alien plant species in forest sites. *Ecoscience*, 11(3), 278-281.

Colautti, R. I., Bailey, S. A., Van Overdijk, C. D. A., Amundsen, K., & MacIsaac, H. J. (2006). Characterised and projected costs of nonindigenous species in canada. *Biological Invasions, 8*(1), 45-59.

D'Antonio, C. M. (2000). Fire, plant invasions, and global changes. In: Mooney, H. A., & Hobbs, R.J. (eds) Invasive Species in a Changing World, pp 65-93. Island Press. Washington DC.

D'Antonio, C. M., & Meyerson, L. A. (2002). Exotic plant species as problems and solutions in ecological restoration: a synthesis. *Restoration Ecology*, 10(4), 703-713.

DiTomaso, J. M. (2000). Invasive weeds in rangelands: Species, impacts, and management. *Weed Science*, *48*(2), 255-265.

Dobbie, T., McFadyen, T., Zorn, P., Keitel, J., & Terra Ecological Consulting. (2006). *Point pelee national park of canada state of the park report.*Parks Canada. Retrieved from http://www.pc.gc.ca/eng/pn-np/on/pelee/plan.aspx

Dobbie, T., Point Pelee National Park (2011). Personal communication on May 2, 2011

Duncan, C. (2003). *Waterton lakes national park non-native plants management strategy review*. Prepared by Weed Management Services for Waterton Lakes National Park

Dunster, K. (1990). *Exotic plant species management plan: Point pelee national park.* Leamington, ON: Parks Canada.

Elton, C. S. (1958). *The ecology of invasions by plants and animals*. Chicago, Illinois: University of Chicago Press.

Emery, S. M, & Gross, K. L. (2005). Effects of timing of prescribed fire on the demography of an invasive plant, spotted knapweed centaurea maculosa. *Journal of Applied Ecology, 42,* 60-69.

Eschtruth, A.K., & Battles, J.J. (2009). Assessing the relative importance of disturbance, herbivory, diversity and propagule pressure in exotic plant invasion. *Ecological Monographs*, 79(2), 265-280.

Falkenberg, N. (2000). Restoration of a savanna habitat in point pelee national park, southwestern ontario. Master thesis at York University.

Firanski, J.C., Falkenburg, N., Koh, S., & Bazely, D.R. (2002). Characteristics of expanding and stable populations of garlic mustard in carolinian parks. In: Porter, J. et al. (eds) *Proceedings of the 4th Parks Research Forum of Ontario, 2001*, pp243-250. Waterloo, ON

Flory, S. L., & Clay, K. (2009). Invasive plant removal method determines native plant community responses. *Journal of Applied Ecology*, *46*, 434-442.

Government of Canada, Environment Canada. (2004). *An invasive alien species strategy for Canada*. Ottawa, ON.

Groves, R. H. (1989). Ecological control of invasive terrestrial plants. In: Drake, J. A., Mooney, H. A., di Castri, F., Groves, R. H., Kruger, F. J., Rejmanek, M., & Williamson, M. (eds) *Biological Invasions a Global Perspective*, pp 437-461. J. Wiley and Sons. New York.

Hansen, M.J., & Clevenger, A.P. (2005). The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. *Biological Conservation*, 125, 249-259.

Hiebert, R. D. (1997). Prioritizing invasive plants and planning for management. In: Luken, J. O., & Theiret, J. W. (eds) *Assessment and Management of Plant Invasions*, pp 195-212. Springer. New York

Hilty, J. (2012). *Illinois wildflowers*. Retrieved February, 2012, from http://www.illinoiswildfloers.info/

Hobbs, R. J., & Huenneke, L. F. (1992). Disturbance, diversity, and invasion - implications for conservations. *Conservation Biology*, *6*(3), 324-337.

Hobbs, R. J., & Humphries, S. E. (1995). An integrated approach to the ecology and management of plant invasions. *Conservation Biology*, *9*(4), 761-770.

Hobbs, R.J., Arico, S.A., Aronson, J., Baron, J.S., Bridgewater, P., Cramer, V.A., Epstein, P.R., Ewel, J.J., Klink, C.A., Lugo, A.E., Norton, D., Ojima, D., Richardson, D.M., Sanderson, E.W., Valladares, F., Vila, M., Zamora, R., & Zobel, M. (2006). Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, 15, 1-7.

Hobbs, R.J., Higgs, E., & Harris, J.A. (2009). Novel ecosystems: implications for conservation and restoration. *Trends in Ecology and Evolution*, 24(11). 599-605.

Hynes, K. Tagliavia, C. & Bazely, D.R. (2001). *Restoring disturbed Carolinian plant communities*. Report to the Endangered Specis Recovery Fund, World Wildlife Fund, Toronto, ON

International Union for Conservation of Nature. (2010). *Why is biodiversity in crisis?* Retrieved March 28, 2011, from http://www.iucn.org/iyb/about/biodiversity_crisis/

Kanter, M. (2005). The future of species and ecosystems at risk in carolinian Canada: are we on the right track? *Parks Research Forum of Ontario Species and Ecosystems at Risk: Theme Papers*. London, ON: Carolinian Canada Coalition

Krueger-Mangold, J. M., Sheley, R. L., & Svejcar, T. J. (2006). Toward ecologically-based invasive plant management on rangeland. *Weed Science, 54*(3), 597-605.

Leggo, J. (1990). *Sumary of exotic plant removal and site rehabilitation 1989 point pelee national park*. Leamington, ON: Environment Canada Parks Service

Lodge, D. M. (1993). Biological invasions - lessons for ecology. *Trends in Ecology & Evolution, 8*(4), 133-137.

Luken, J. O. (1997) Management of plant invasions: implicating ecological succession. In: Luken, J. O., & Theiret, J. W. (eds) *Assessment and Management of Plant Invasions*, pp 133-144. Springer. New York.

Malik, J., Barry, G., & Kishore, G. (1989). The herbicide glyphosate. *BioFactors*, 2(1), 17-25

Marchante, H., Freitas, H., & Hoffman, J.H. (2011). The potential role of seed banks in the recovery of dune ecosystems after removal of invasive plant species. *Applied Vegetation Science*. 14, 107-119

McLachlan, S.M., & Bazely, D.R. (2001). Recovery patterns of understory herbs and their use as indicators of deciduous forest regeneration. *Conservation Biology*, 15(1), 98-110

McLachlan, S.M., & Bazely, D.R., (2003). Outcomes of longterm deciduous forest restoration in southwestern Ontario, Canada. *Biological Conservation*. 113, 159-169

McNeely, J.A. (1999). The great reshuffling: how alien species help feed the global economy. In: Sandlund, O. T., Schei, P. J., & Viken, A. (eds) *Invasive Species and Biodiversity Management*, pp 11-31. Kluwer Academic Publishers. Netherlands

Merriam, R.W. (2003). The abundance, distribution and edge associations of six non-indigenous harmful plants across north Carolina. *Journal of the Torrey Botanical Society*, 130(4), 283-291.

Mooney, H. A. (1999). A global strategy for dealing with alien invasive species. In: Sandlund, O. T., Schei, P. J., & Viken, A. (eds) *Invasive Species and Biodiversity Management*, pp 407-418. Kluwer Academic Publishers. Netherlands

Mount, A., & Pickering, C.M. (2009). Testing the capacity of clothing to act as a vector for non-native seed in protected areas. *Journal of Environmental Management*, 91, 168-179.

North American Native Plant Society. (1999). Butterfly Gardening. Retrieved July 30, 2012, from http://www.nanps.org/

Ontario Invasive Plant Council. (2009).*Ontario invasive plant council*. Retrieved March 8, 2011, from http://www.ontarioinvasiveplants.ca/

Otfinowski, R., Kenkel, N.C. & Catling, P.M. (2007). The biology of Canadian weeds. 134. *Bromus inermis* Leyss. *Canadian Journal of Plant Science*, 87, 183-198

Parker, I. M., Simberloff, D., Lonsdale, W. M., Goodell, K., Wonham, M., Kareiva, P. M., Williamson, M. H., Von Holle, B., Moyle, P. B., Byers, J. E.,& Goldwasser, L. (1999). Impact: Toward a framework for understanding the ecological effects of invaders. *Biological Invasions, 1*(1), 3-19.

Parks Canada. (2009). Part II – activity policies: national parks policy. Retrieved March 8, 2011, from http://www.pc.gc.ca/docs/pc/poli/princip/sec2/part2a/part2a5.aspx

Parks Canada. (2010). *Point pelee national park of canada management plan.* (Management Plan Leamington. Ontario: Point Pelee National Park of Canada. Retrieved from http://www.pc.gc.ca/eng/pn-np/on/pelee/plan/plan8.aspx

Parks Canada (2011). *Directive on the management of alien species in Canada's national parks*. Draft: Parks Canada

Parks Canada. (2011). *Parks Canada's mandate*. Retrieved March 8, 2011 from http://www.pc.gc.ca/eng/agen/index.aspx

Parliament of Canada. (2012). Bill C-38. Retrieved July 22 from http://parl.gc.ca/HousePublications/Publication.aspx?Language=E&Mode=1&DocId=5524772

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Province of British Columbia. (2011). *Invasive Alien Plant Program*. Retrieved March 8, 2011, from http://www.for.gov.bc.ca/hra/plants/index.htm

Reid, A. M., Morin, L., Downey, P. O., French, K., & Virtue, J. G. (2009). Does invasive plant management aid the restoration of natural ecosystems? *Biological Conservation, 142*, 2342-2349.

Richardson, D. M., Pyšek, P., Rejmánek, M., Barbour, M. G., Dane Panetta, F., & West, C. J. (2000). Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions, 6*(2), 93-107.

Rodriguez, L.F. (2006). Can invasive species facilitate native species? Evidence of how, when, and why these impacts occur. *Biological Invasions*, 8, 927-939

Roger, L. (1997). *Review of the exotic plant species management plan and 1990 to 1996 activities*. Point Pelee National Park

Seastedt, T.R., Hobbs, R.J., & Suding, K.N. (2008). Management of novel ecosystems: are novel approaches required? *Frontiers in Ecology and the Environment*, 6(10), 547-553.

Sheley, R.L., Jacobs, J.S., & Carpinelli, M.F. (1998). Distribution, biology, and management of diffuse knapweed (centaurea diffusa) and spotted knapweed (centaurea maculosa). *Weed Technology*. 12(2), 353-362.

Sheley, R., James, J.J., & Bard, E.C. (2009). Augmentative restoration: repairing damaged ecological processes during restoration of heterogeneous environments. *Invasive Plant Science and Management*. 2(1) 10-21

Sheley, R., James, J., Smith, B., & Vasquez, E. (2010). Applying ecologically based invasive-plant management. *Rangeland Ecology & Management, 63*(6), 605-613.

Sheley, R., & Krueger-Mangold, J. (2003) Principles for restoring invasive plant infested rangeland. *Weed Science, 51*, 260-265.

Simberloff, D., & Stiling, P. (1996). How risky is biological control? *Ecology, 77*(7), 1965-1974.

Smith, M., & Bishop, H. (2002). Red cedar savanna: a disappearing habitat at point pelee national park. In: Porter, J. et al.(eds) *Proceedings of the 4th Parks Research Forum of Ontario, 2001*, pp 283-292, Waterloo, ON

Swearingen, J., Reshetiloff, K., Slattery, B., & Zwicker, S. (2002). *Plant invaders of mid-atlantic natural areas*. US: National Park Service and U.S. Fish and Wildlife Service

Tagliavia, C., Koh, S. & Bazely, D.R. (2001). *Recovery of red cedar savanna and oak savanna plant communities*. Report to Point Pelee National Park and Pinery Provincial Park

Thompson, K., Hodgson, J.G., & Rich, C.G. (1995). Native and alien invasive plants: more of the same? *Ecography*, 18(4), 390-402

Tobin, P.C., VanStrappen, J., & Blackburn, L.M. (2010). Human visitation rates to the apostle islands national lakeshore and introduction of the non-native species lymantria dispar. *Journal of Environmental Management*, 9, 1991-1996.

Twyford, K.L. & Baxter, G.S. (1999). Chemical control of blue periwinkle (vinca major L.) in creajingolong national park, Victoria. *Plant Protection Quarterly*, 14(2), 47-50.

United Nations Convention on Biological Diversity. (2002). *COP6 decision VI/23.* Retrieved March 16, 2011, from http://www.cbd.int/decision/cop/?id=7197

Vila, M., & Ibanez, I. (2011). Plant invasions in the landscape. *Landscape Ecology,* 26, 461-472.

White, D. J., Haber, E., & Keddy, C. (1993). Invasive plants of natural habitats in canada an integrated review of wetland and upland species and legislation governing their control. *Canadian Wildlife Service*.

Wikipedia. (2011). Pelee Island map. Retrieved March 28, 2011 from http://en.wikipedia.org/wiki/File:Pelee_Island_map.png

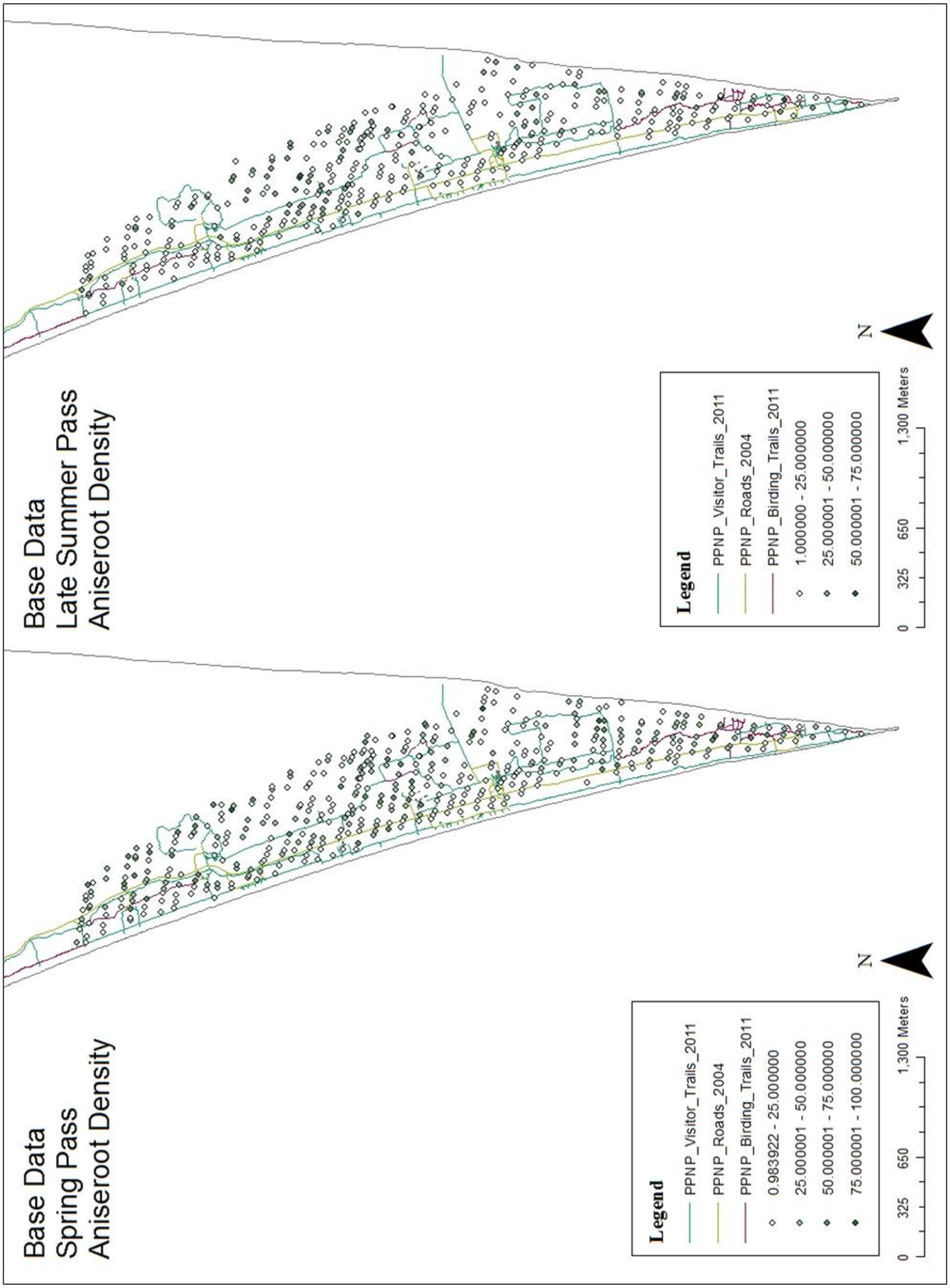
Williamson, M. H., & Fitter, A. (1996). The characters of successful invaders. *Biological Conservation, 78*(1-2), 163-170.

Wittenburg, R., & Cock, M. J. W. (eds) (2001). Invasive alien species: a toolkit of best prevention and management practices. pp. xvii-228. CAB international. Wallingford, Oxon, UK.

Woods, K. D. (1997). Community response to plant invasion. In: Luken, J. O., & Theiret, J. W. (eds) *Assessment and Management of Plant Invasions*, pp 56-68. Springer. New York

Zar, J.H. (2010). Biostatistical Analysis. Upper Saddle River, New Jersey, US: Prentice Hall Inc.

Appendix A Maps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25.000001 - 50.000000
50.000001 - 75.000000
75.000001 - 100.000000
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N
Base Data
Late Summer Pass
Aniseroot Density
Legend
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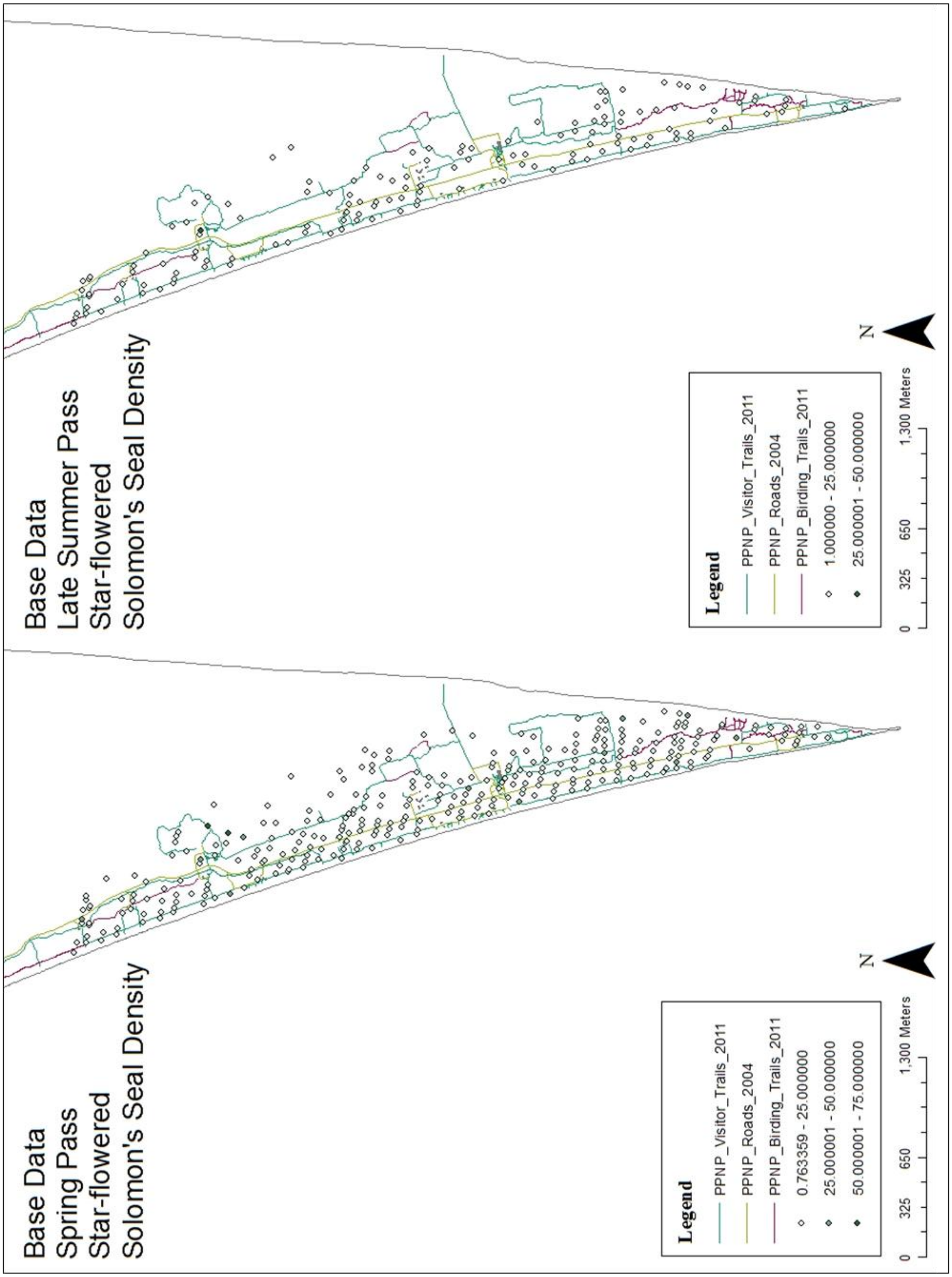
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Solomon's Seal Density
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Spring Pass
Star-flowered
Solomon's Seal Density
Legend
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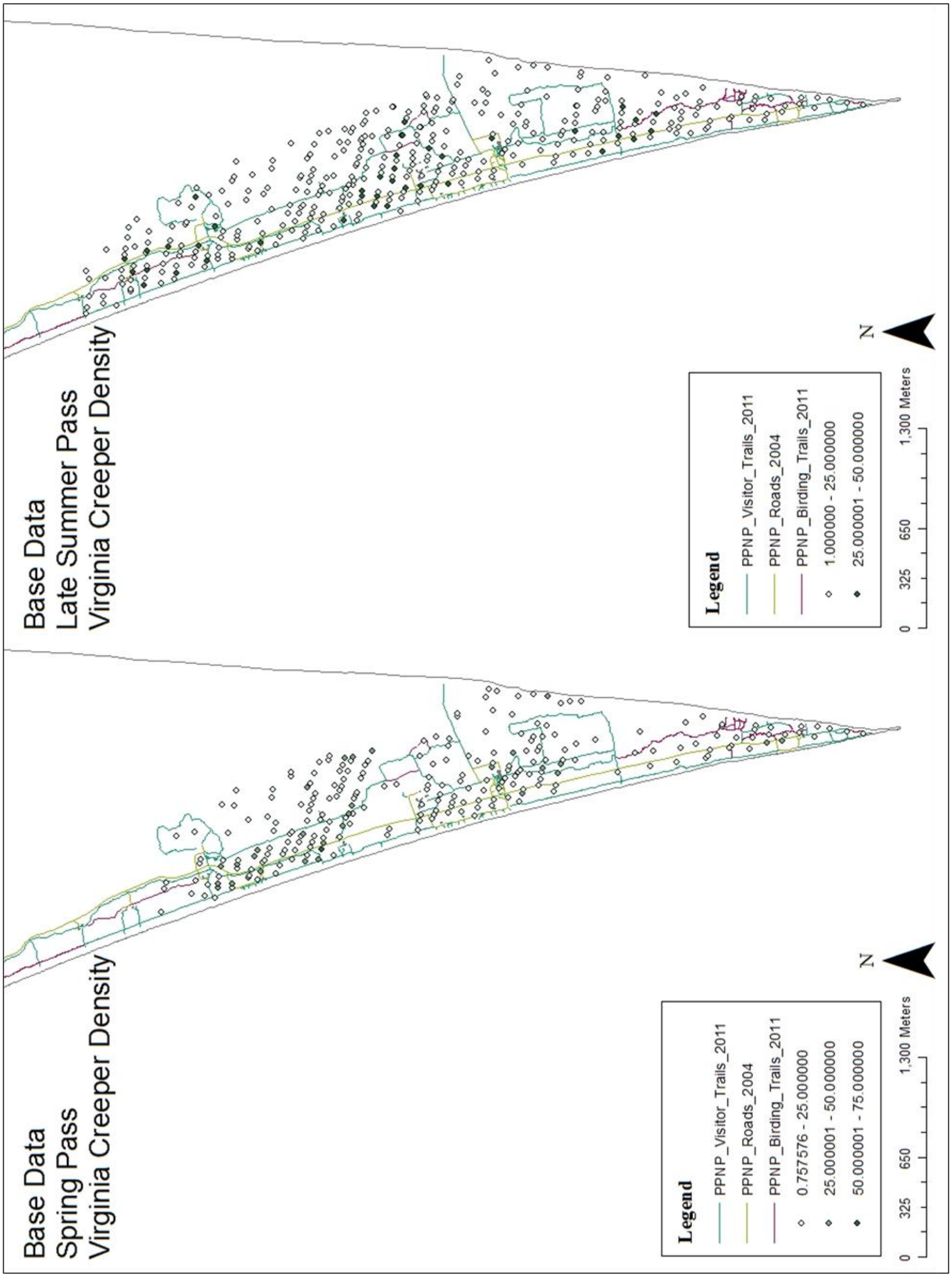
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Virginia Creeper Density
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25.000001 - 50.000000
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N
Base Data
Spring Pass
Virginia Creeper Density
Legend
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PPNP_Roads_2004
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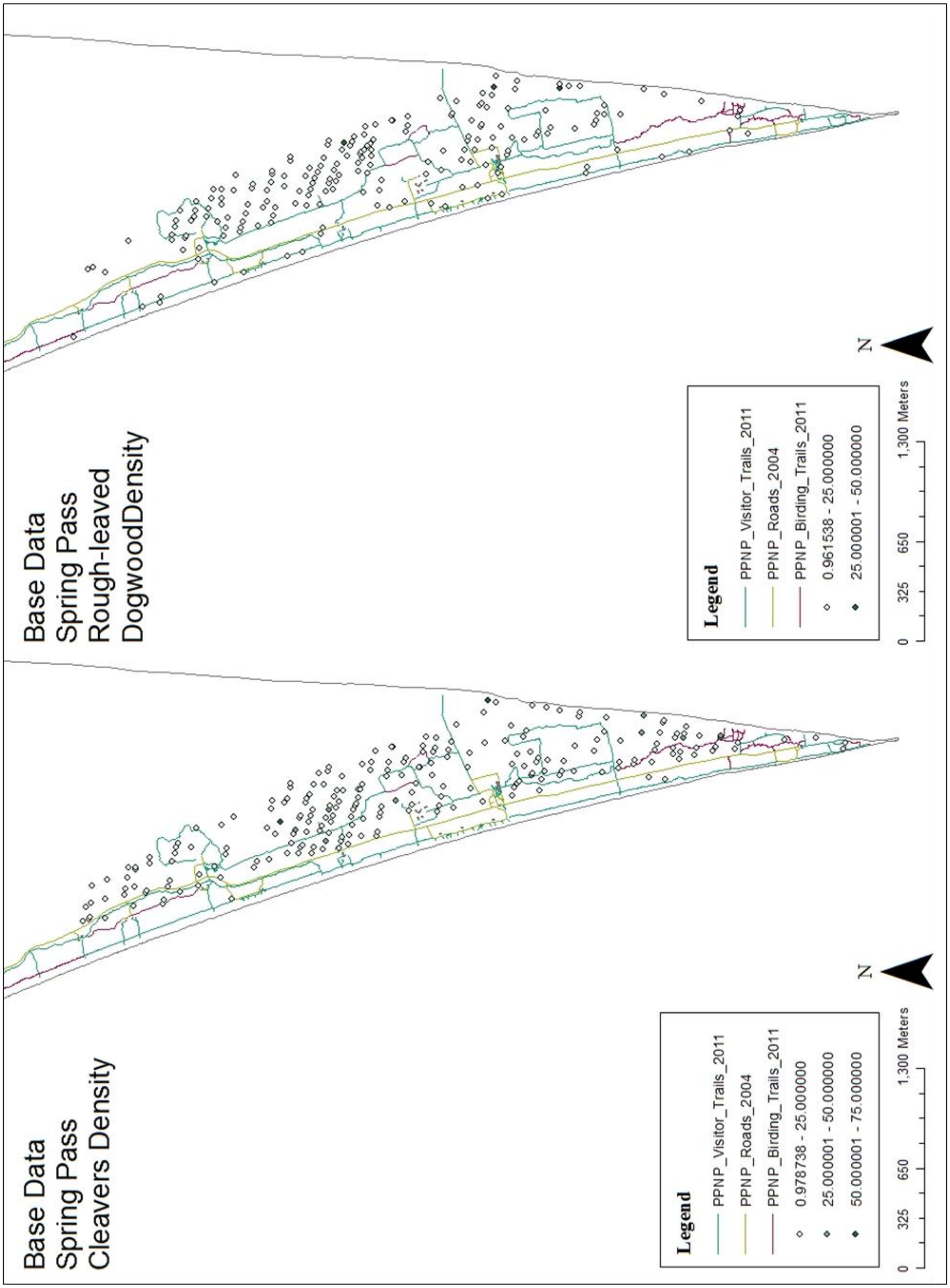
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50.000001 - 75.000000
0
325
650
1,300 Meters
N
Base Data
Spring Pass
Rough-leaved
DogwoodDensity
Legend
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1,300 Meters
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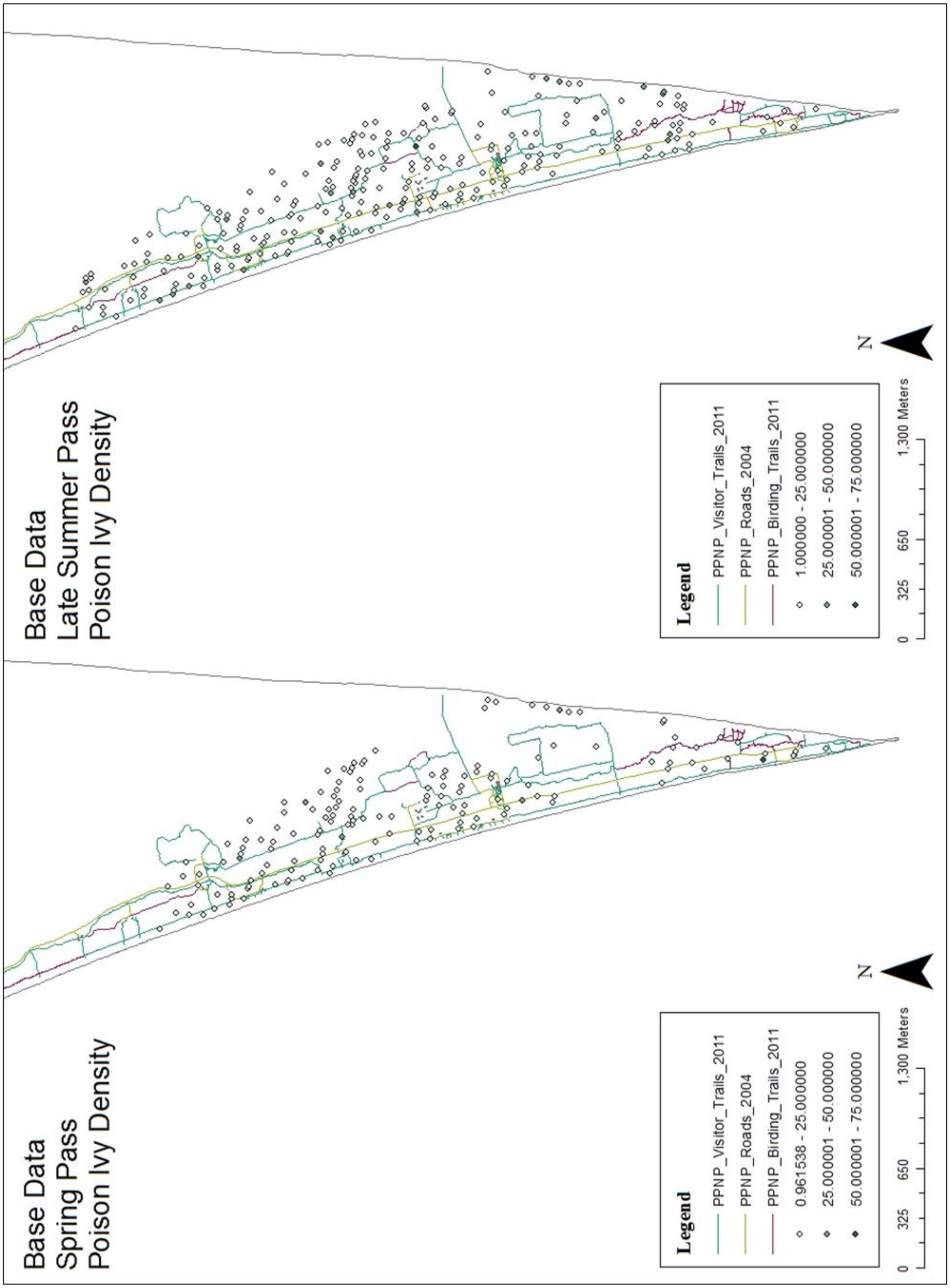
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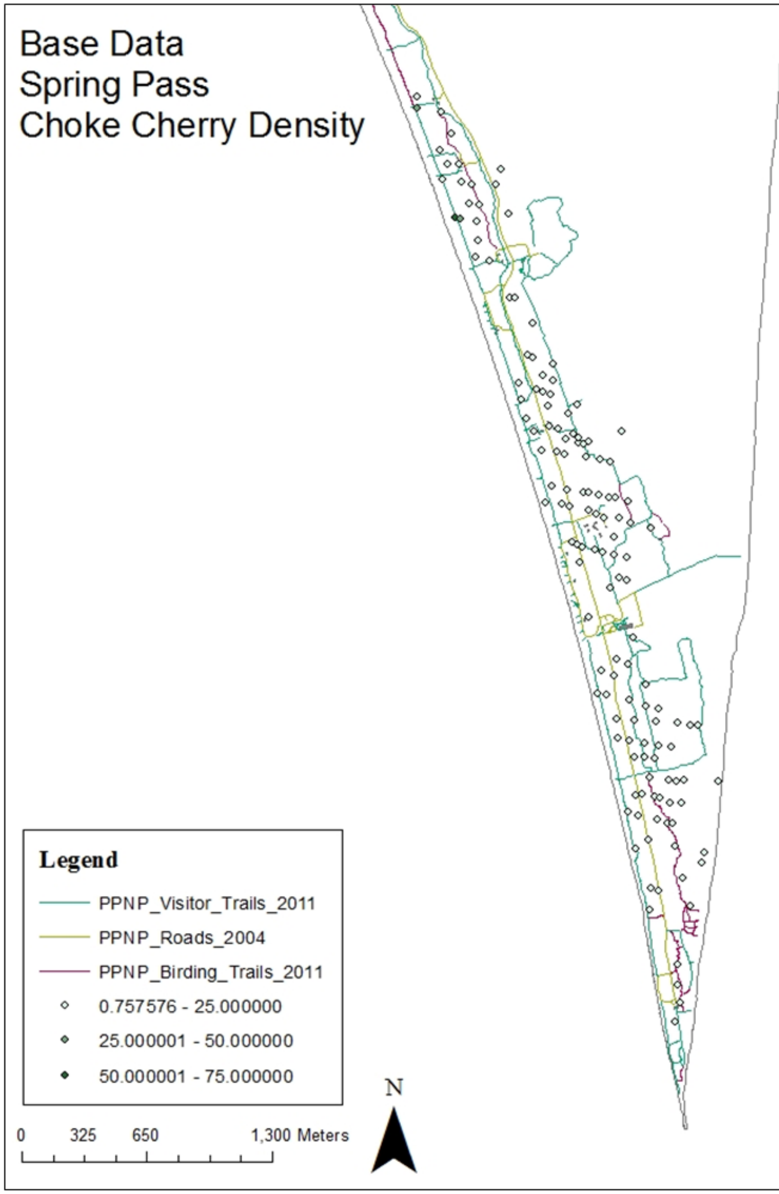
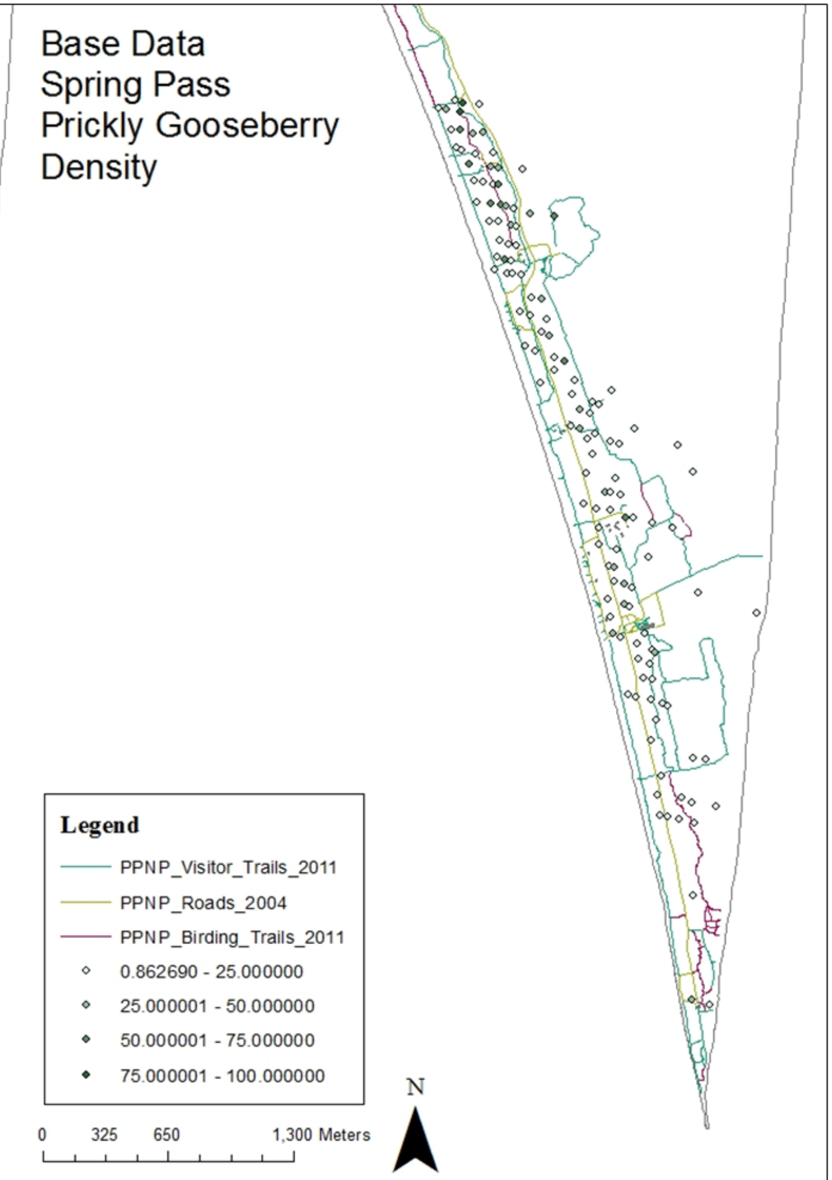
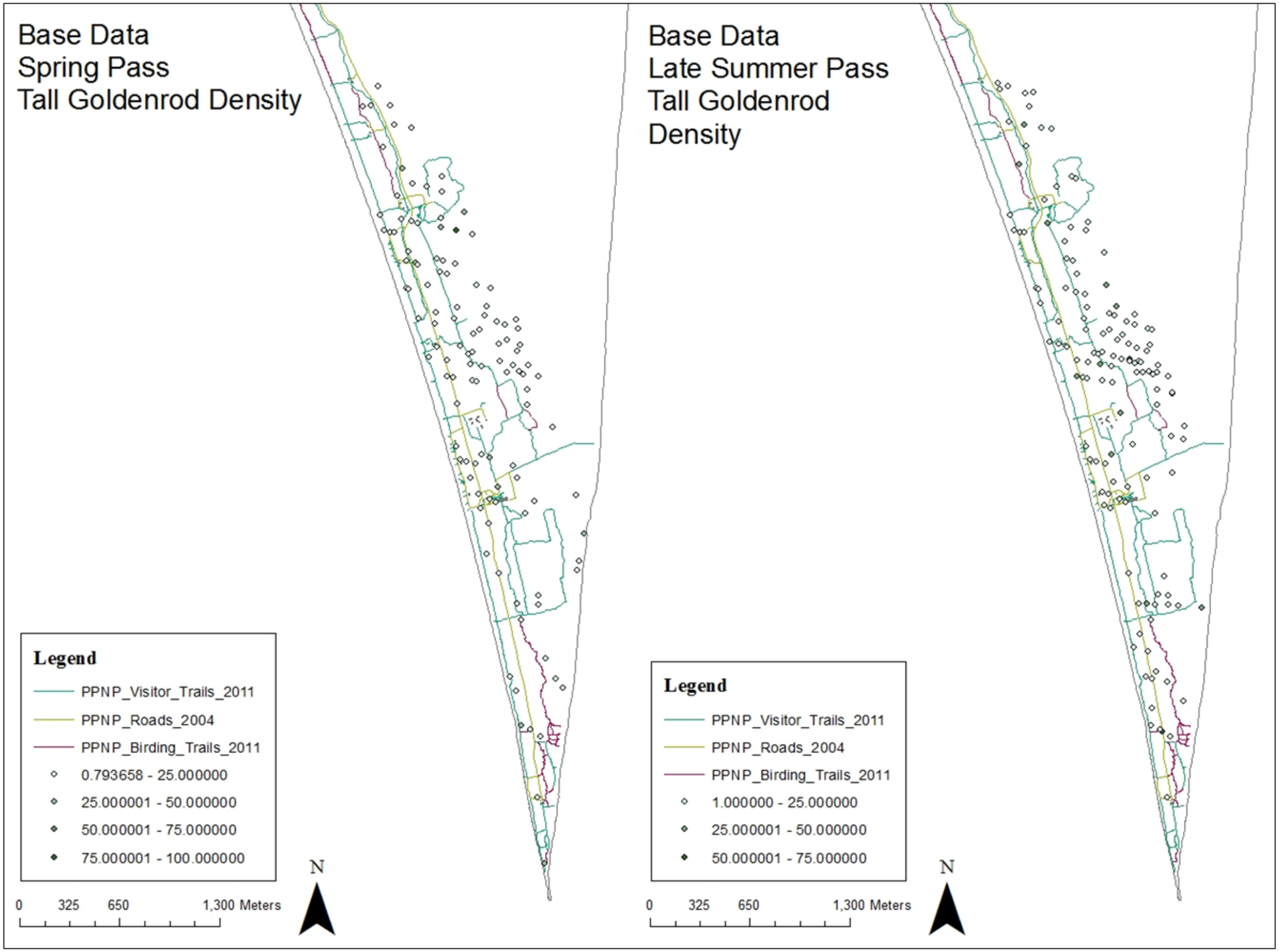
25.000001 - 50.000000
50.000001 - 75.000000
0 325 650 1,300 Meters
N
Base Data
Late Summer Pass
Poison Ivy Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.000000 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
0 325 650 1,300 Meters
N

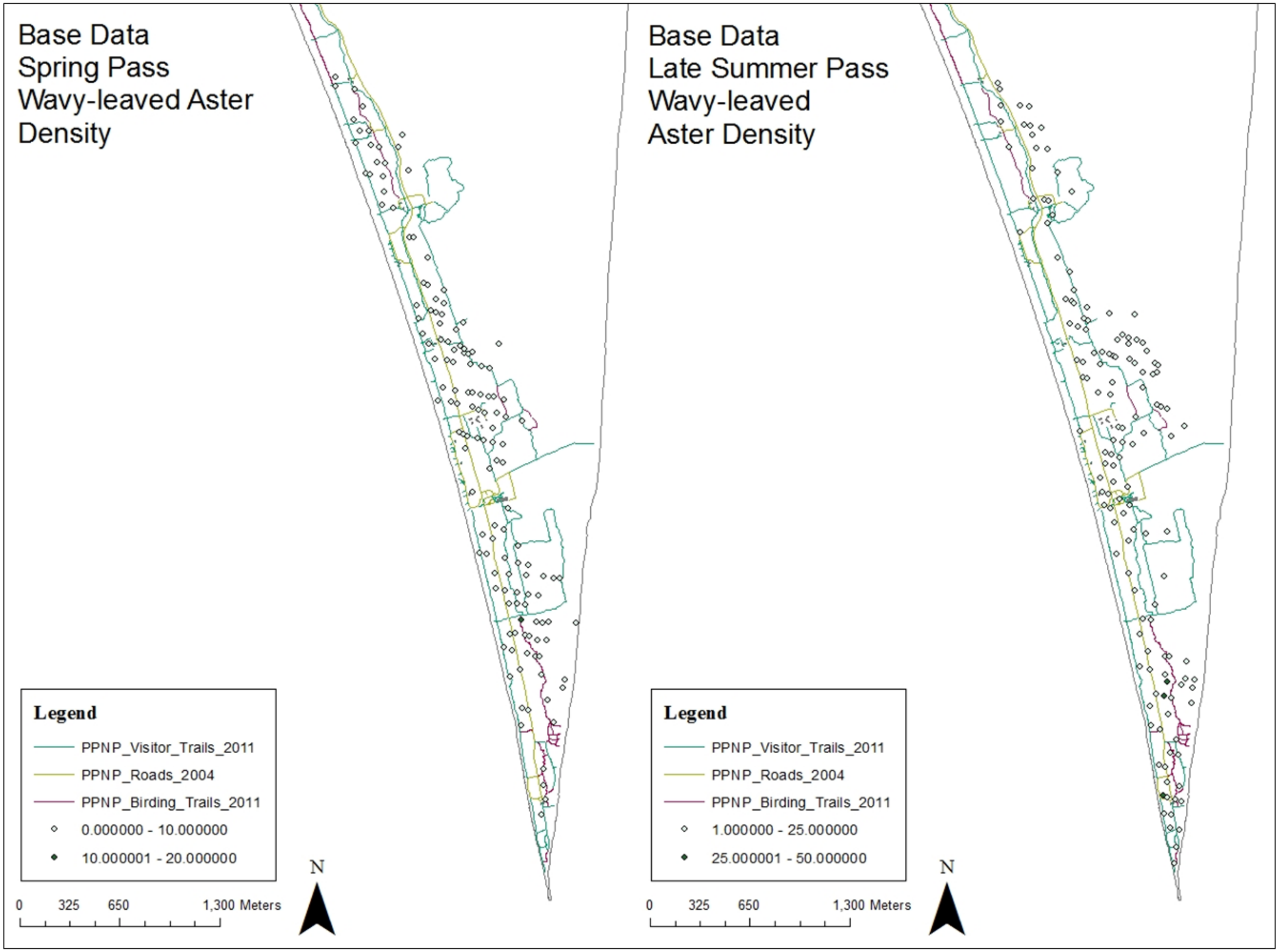


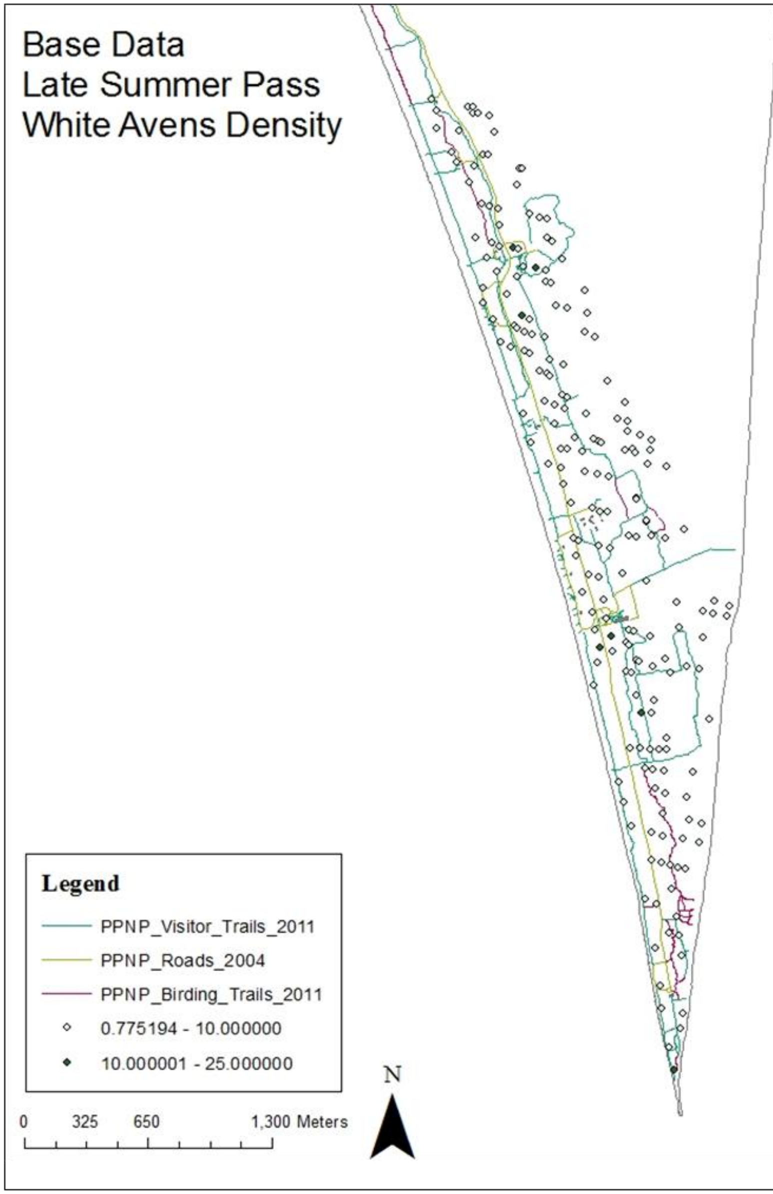
Base Data
Spring Pass
Choke Cherry Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.757576 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
0
325
650
1,300 Meters
N

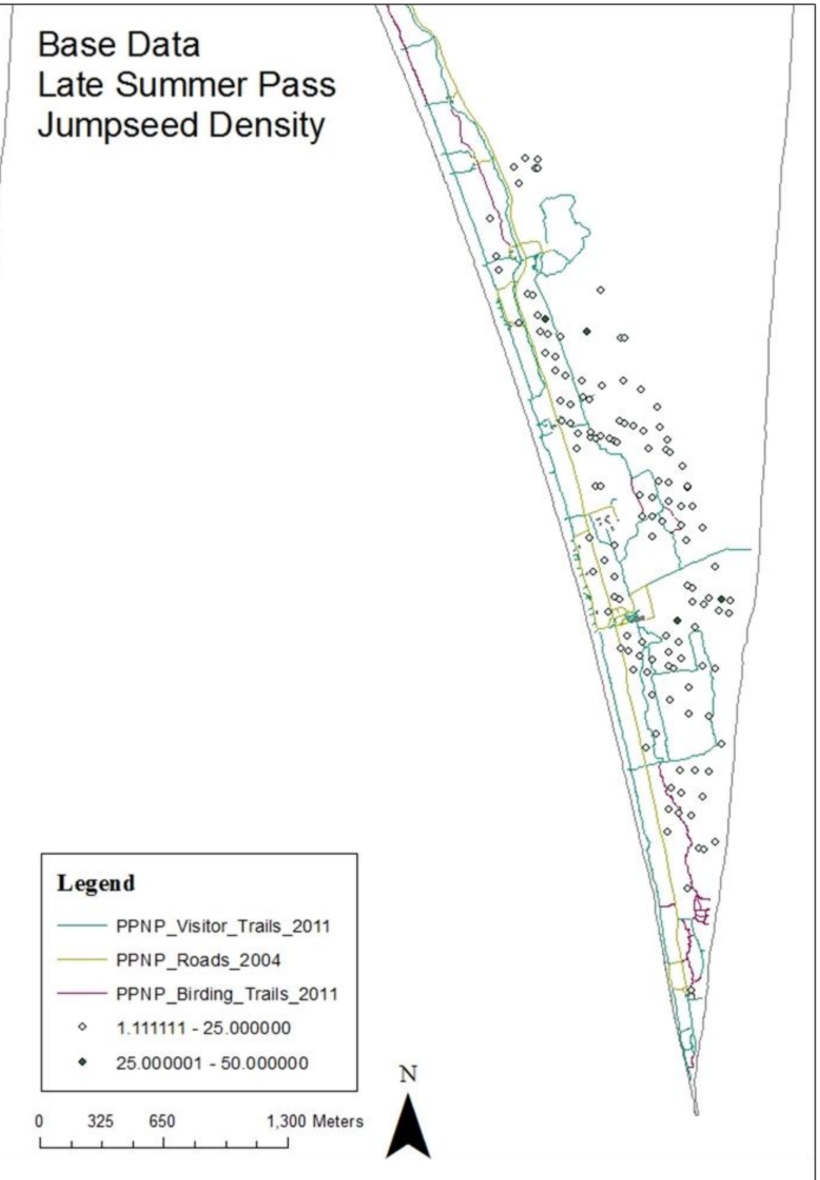


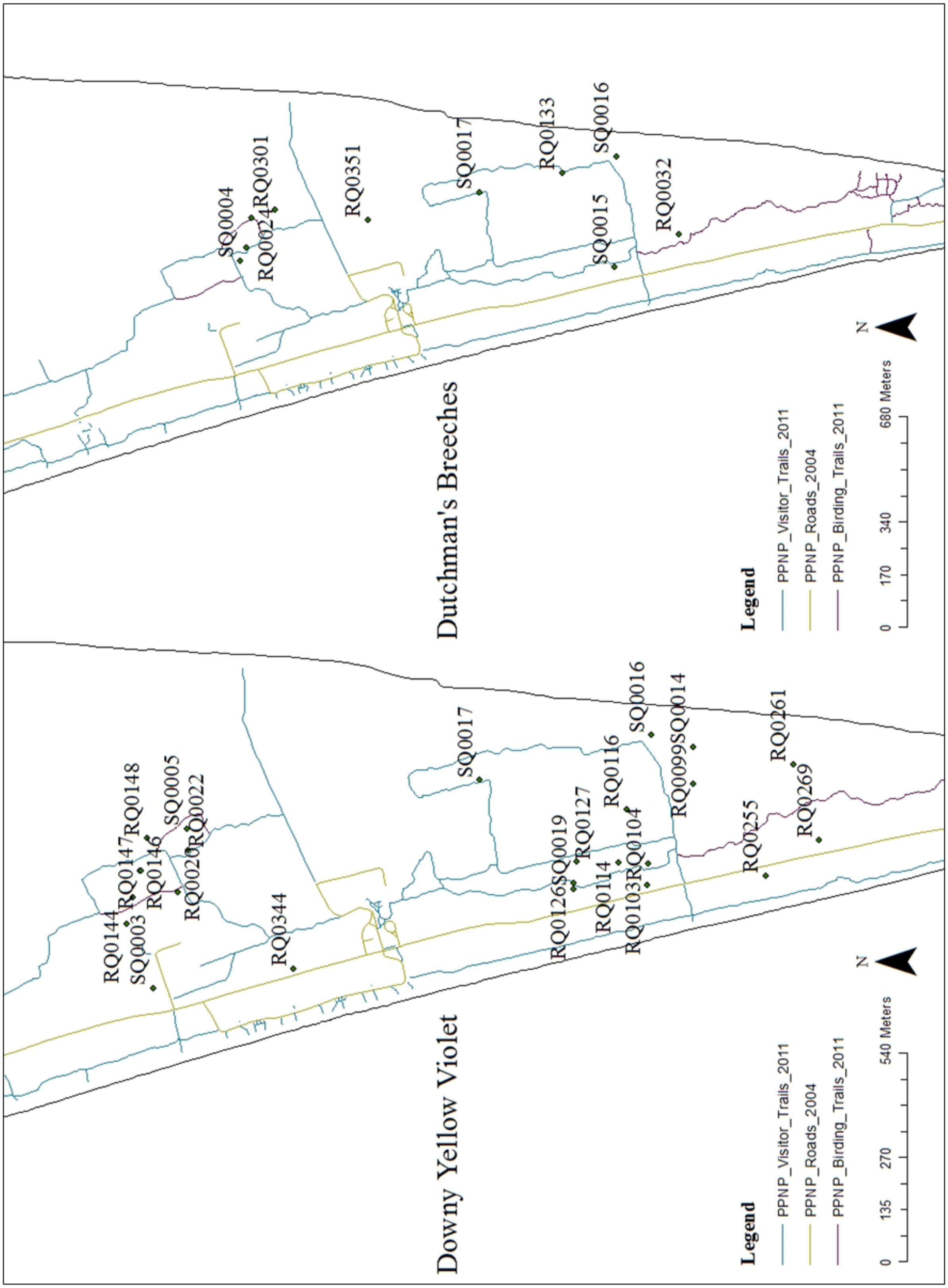
Base Data
Spring Pass
Prickly Gooseberry
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.862690 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
75.000001 - 100.000000
0
325
650
1,300 Meters
N

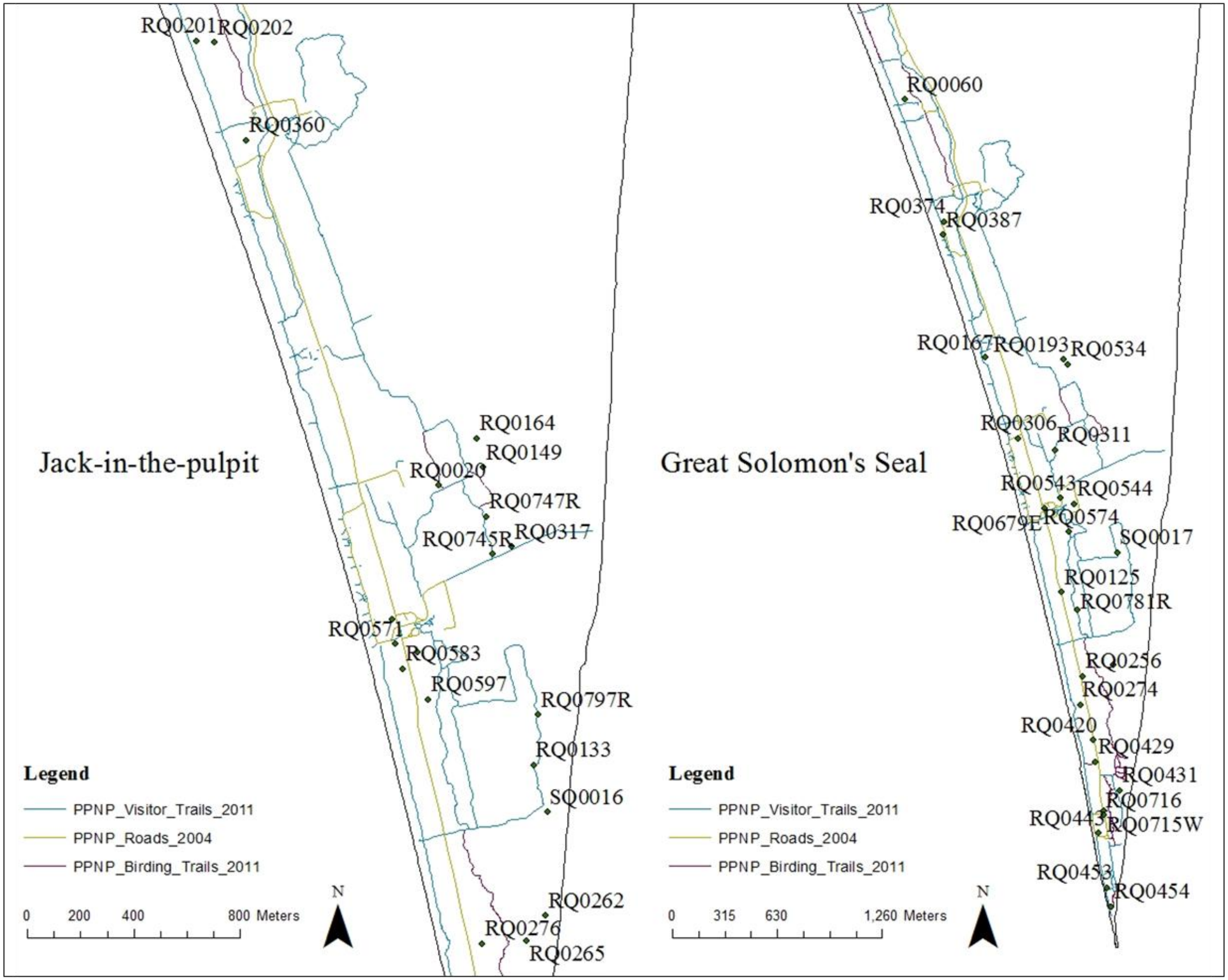

Base Data
Spring Pass
Tall Goldenrod Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.793658 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
75.000001 - 100.000000
0
325
650
1,300 Meters
N
Base Data
Late Summer Pass
Tall Goldenrod
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.000000 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
0
325
650
1,300 Meters
N

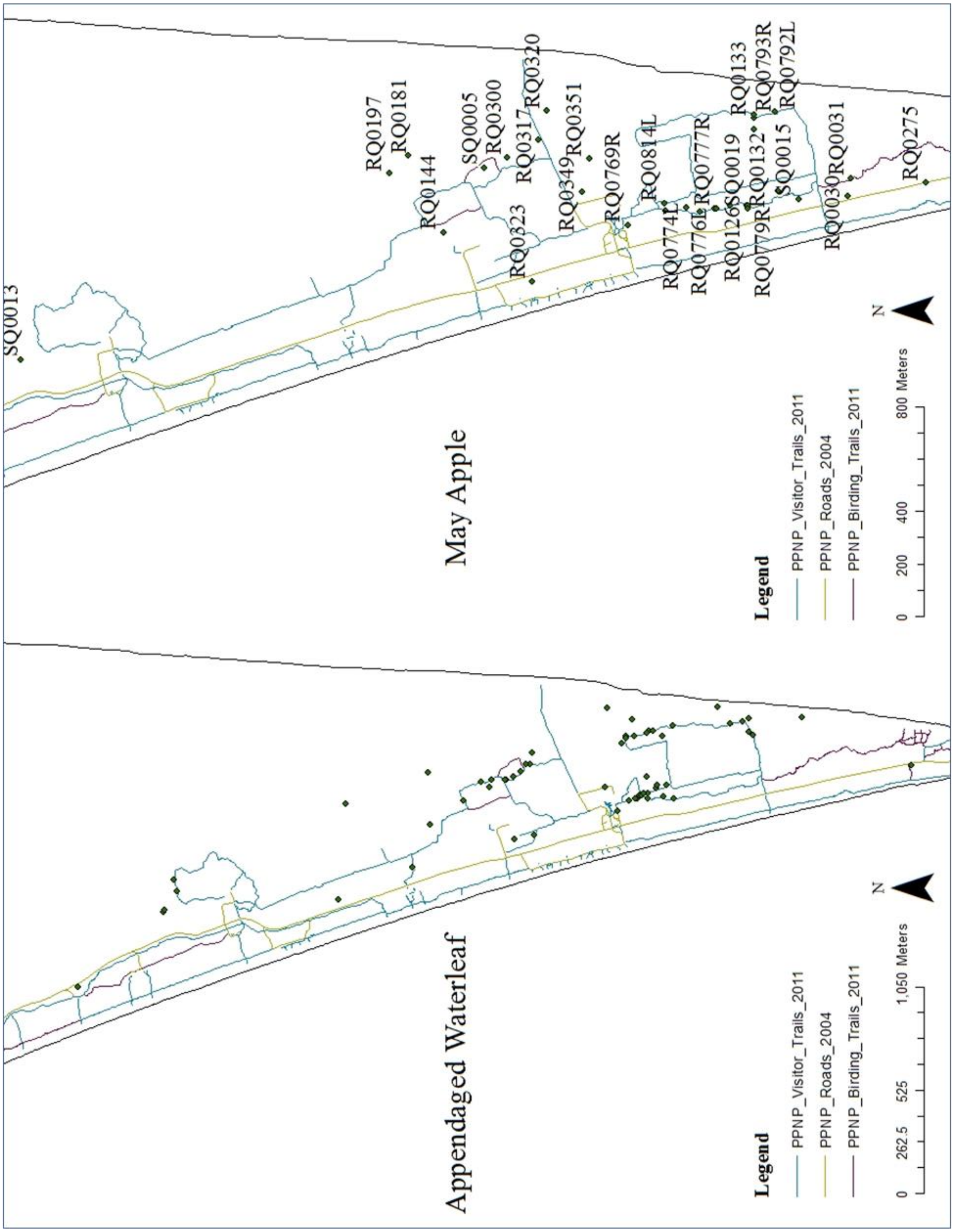

Base Data
Spring Pass
Wavy-leaved Aster
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.000000 - 10.000000
10.000001 - 20.000000
0
325
650
1,300 Meters
N
Base Data
Late Summer Pass
Wavy-leaved
Aster Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.000000 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N


Base Data
Late Summer Pass
White Avens Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.775194 - 10.000000
10.000001 - 25.000000
0
325
650
1,300 Meters
N

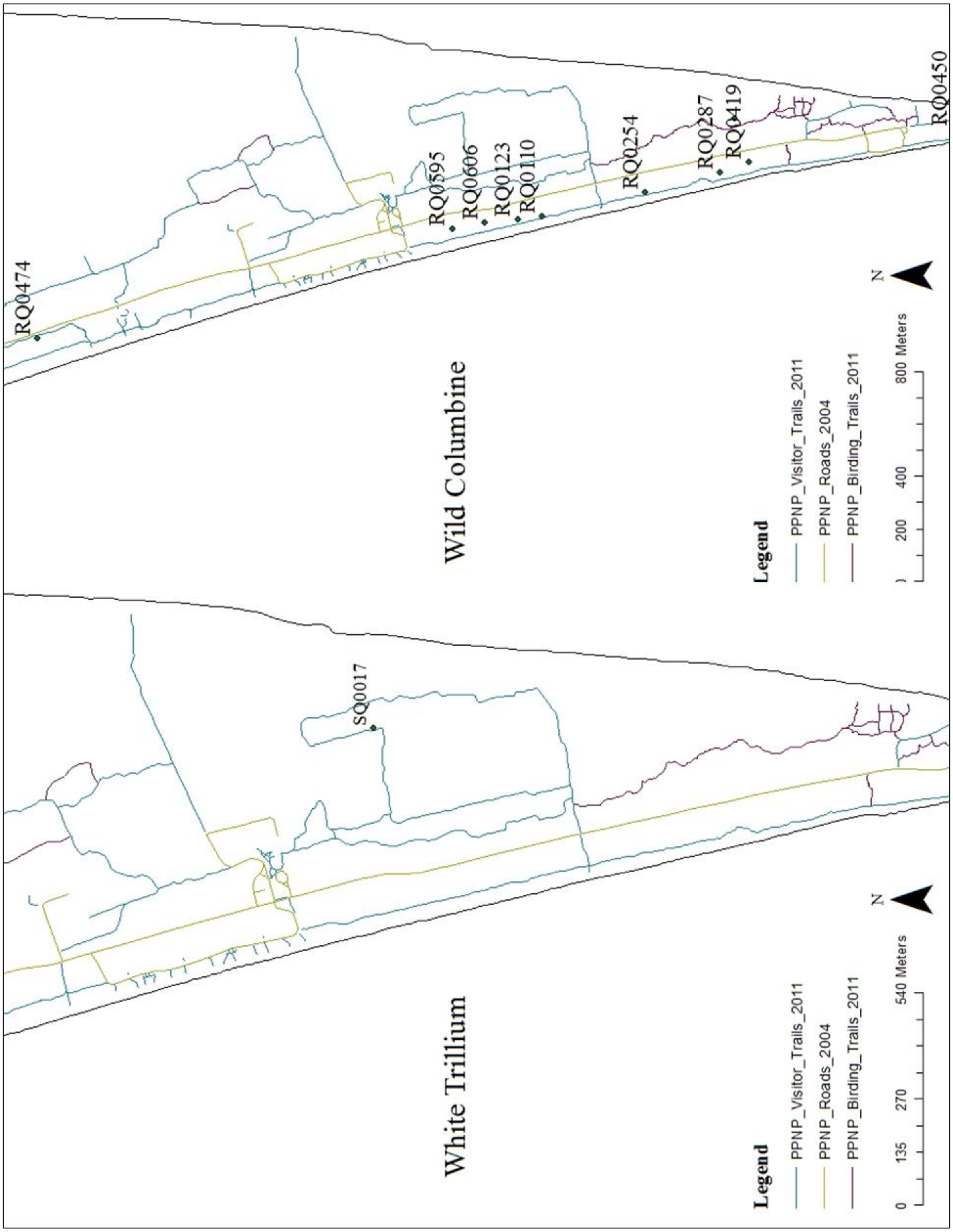

Base Data
Late Summer Pass
Jumpseed Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.111111 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N

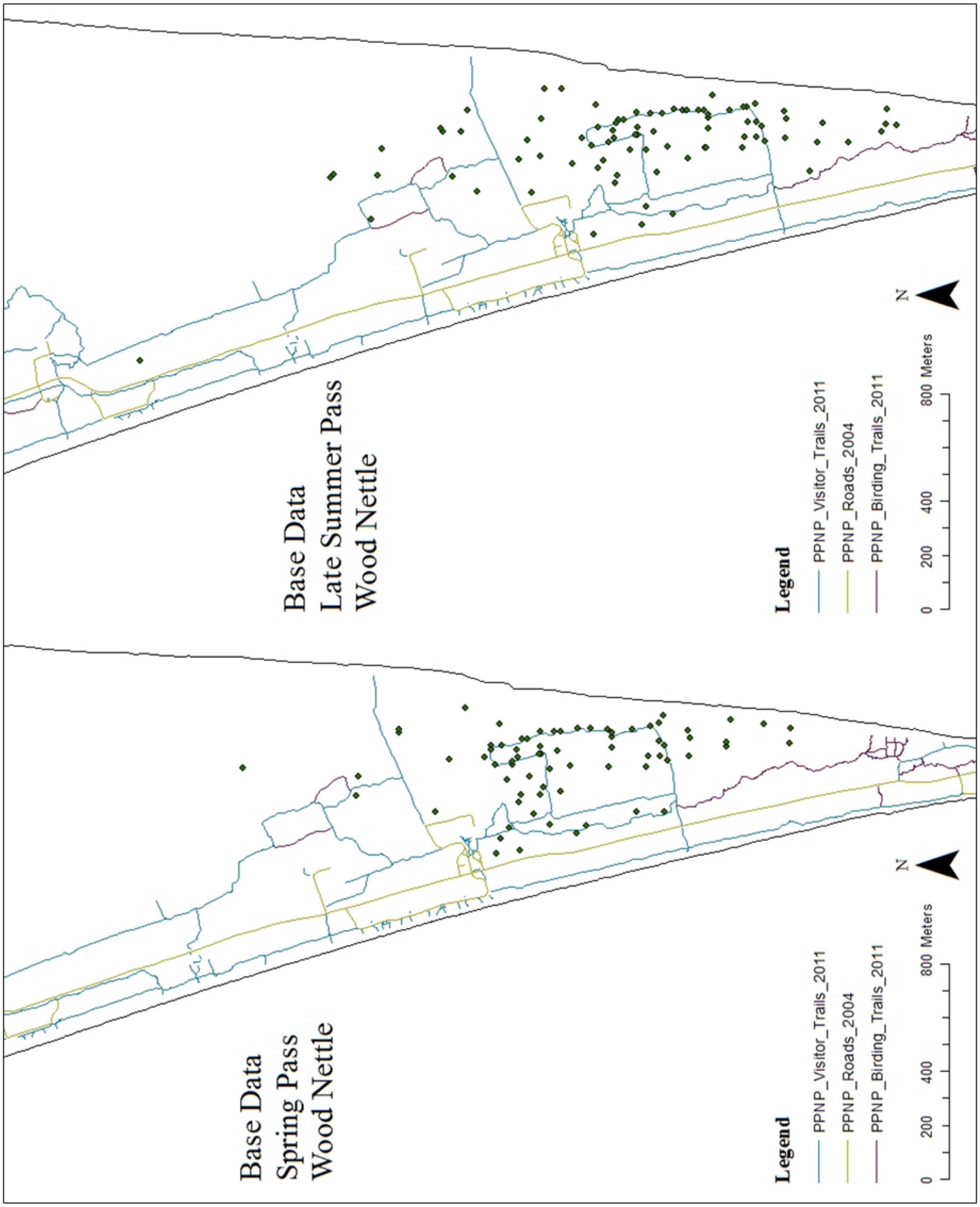

Downy Yellow Violet
Dutchman's Breeches
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 135 270 540 Meters
0 170 340 680 Meters
N
RQ0144
SQ0003
RQ0147
RQ0146
RQ0148
SQ0005
RQ0022
RQ0344
SQ0017
RQ0126
SQ0019
RQ0127
RQ0114
RQ0103
RQ0104
RQ0116
SQ0016
RQ0099
SQ0014
RQ0255
RQ0269
RQ0261
SQ0004
RQ0024
RQ0301
RQ0351
RQ0133
SQ0015
RQ0032

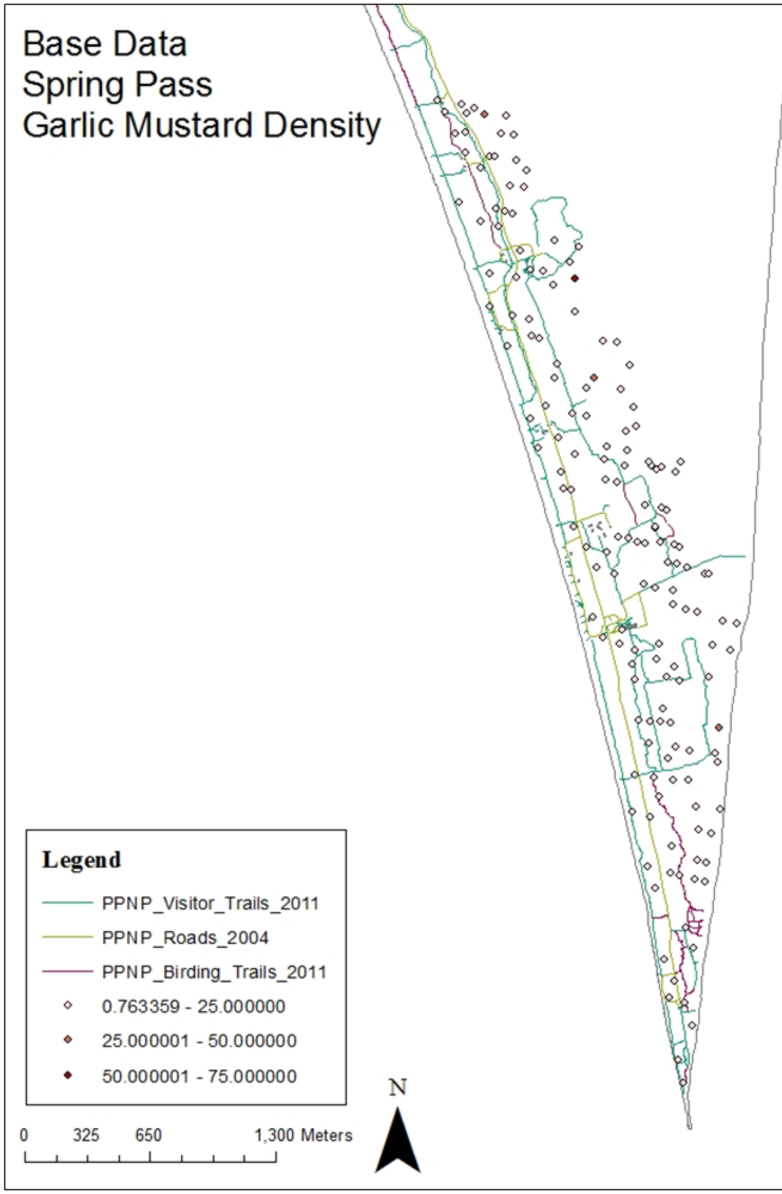

Jack-in-the-pulpit
RQ0201
RQ0202
RQ0360
RQ0164
RQ0149
RQ0020
RQ0747R
RQ0745R
RQ0317
RQ0571
RQ0583
RQ0597
RQ0797R
RQ0133
SQ0016
RQ0262
RQ0276
RQ0265
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters
N
Great Solomon's Seal
RQ0060
RQ0374
RQ0387
RQ0167
RQ0193
RQ0534
RQ0306
RQ0311
RQ0543
RQ0544
RQ0679E
RQ0574
SQ0017
RQ0125
RQ0781R
RQ0256
RQ0274
RQ0420
RQ0429
RQ0431
RQ0716
RQ0443
RQ0715W
RQ0453
RQ0454
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 315 630 1,260 Meters
N

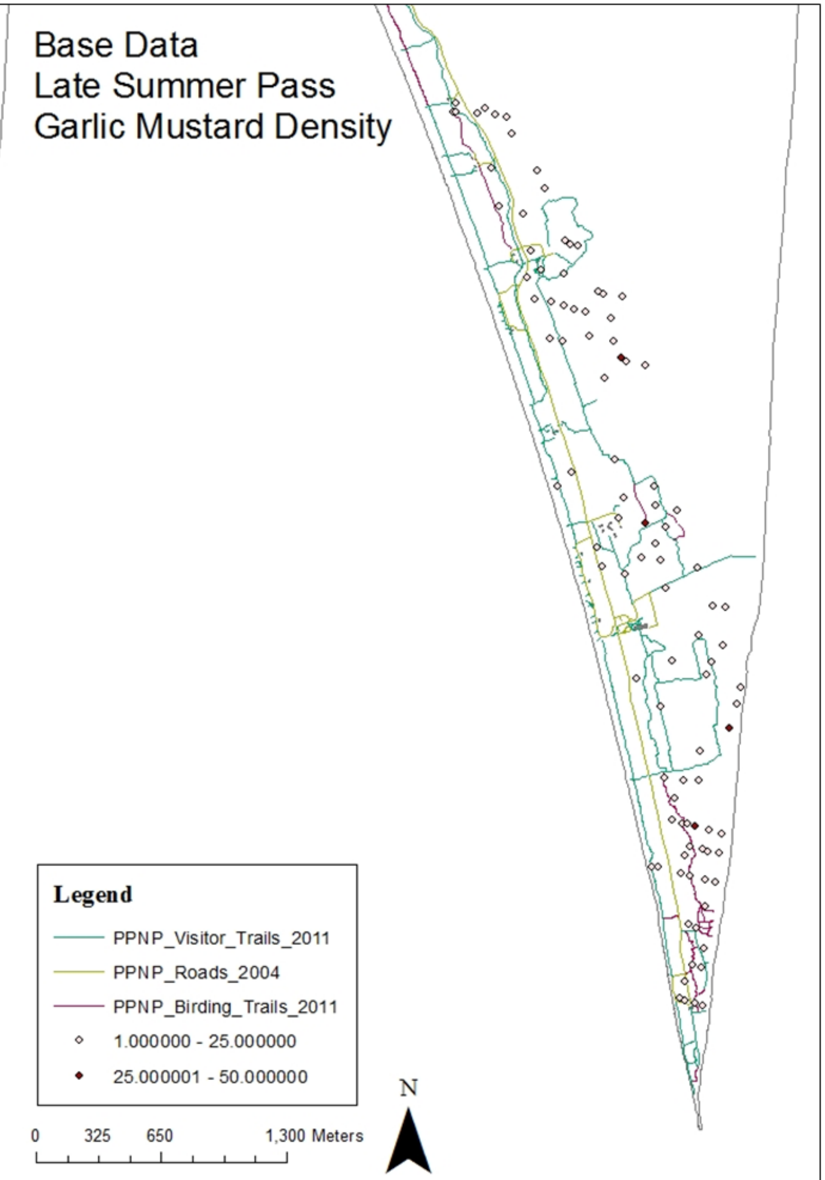


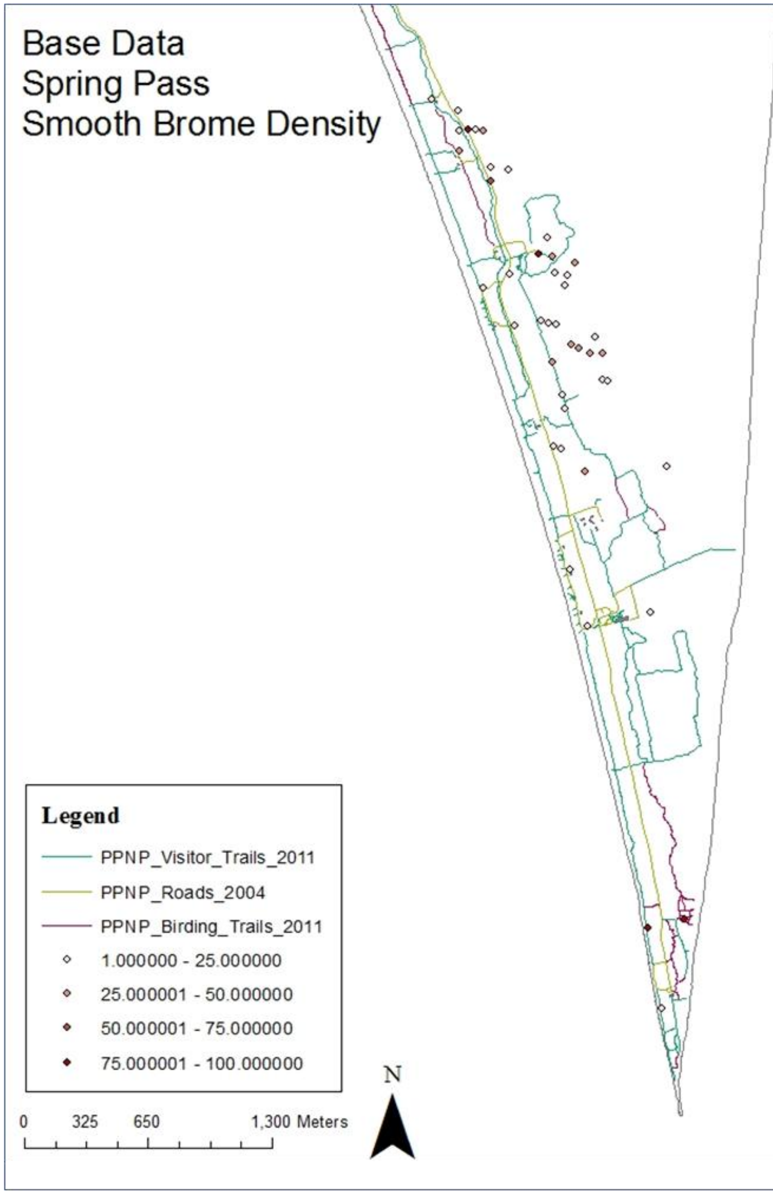
May Apple
SQ0013
RQ0197
RQ0181
RQ0144
SQ0005
RQ0300
RQ0317
RQ0320
RQ0351
RQ0323
RQ0349
RQ0769R
RQ0814L
RQ0774L
RQ0776L
RQ0777R
RQ0126
SQ0019
RQ0133
RQ0779R
RQ0132
RQ0793R
SQ0015
RQ0792L
RQ0030
RQ0031
RQ0275
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0
200
400
800 Meters
N
Appendaged Waterleaf
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0
262.5
525
1,050 Meters
N

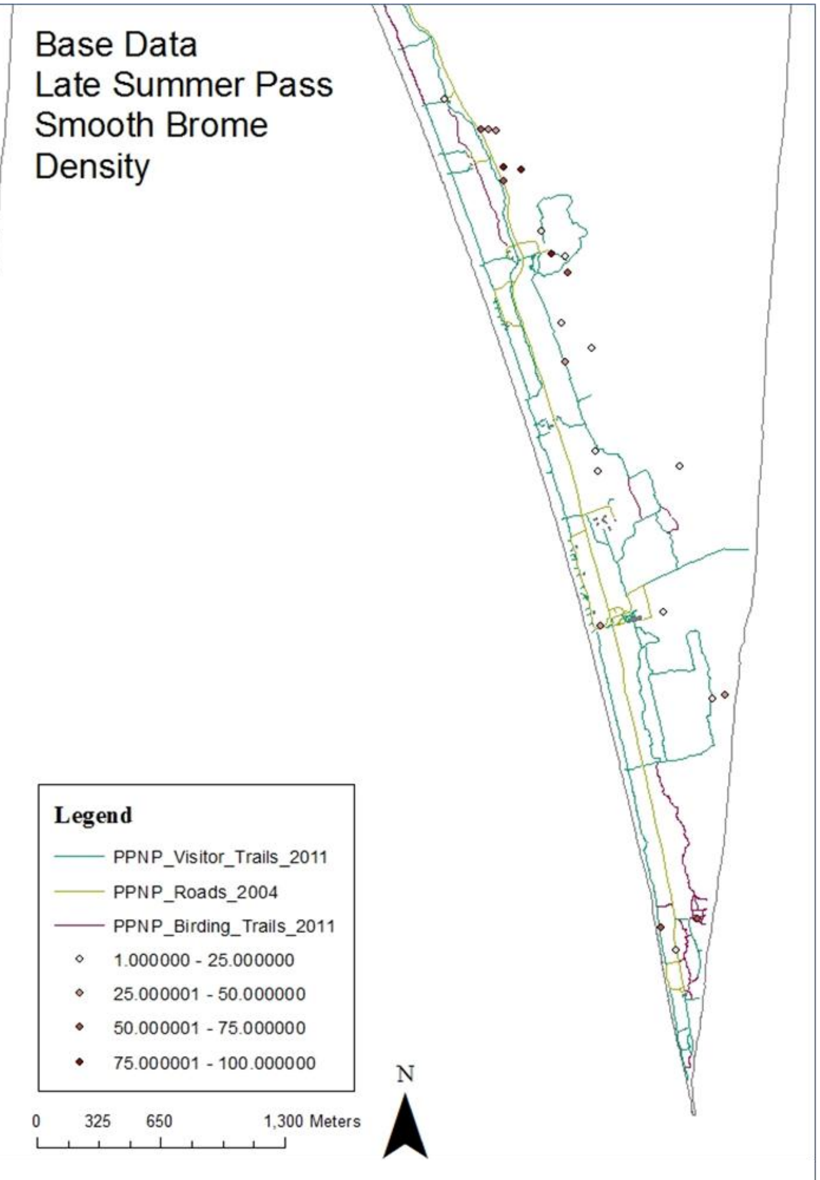

Wild Columbine
RQ0474
RQ0595
RQ0606
RQ0123
RQ0110
RQ0254
RQ0287
RQ0419
RQ0450
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters
N
White Trillium
SQ0017
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 135 270 540 Meters
N

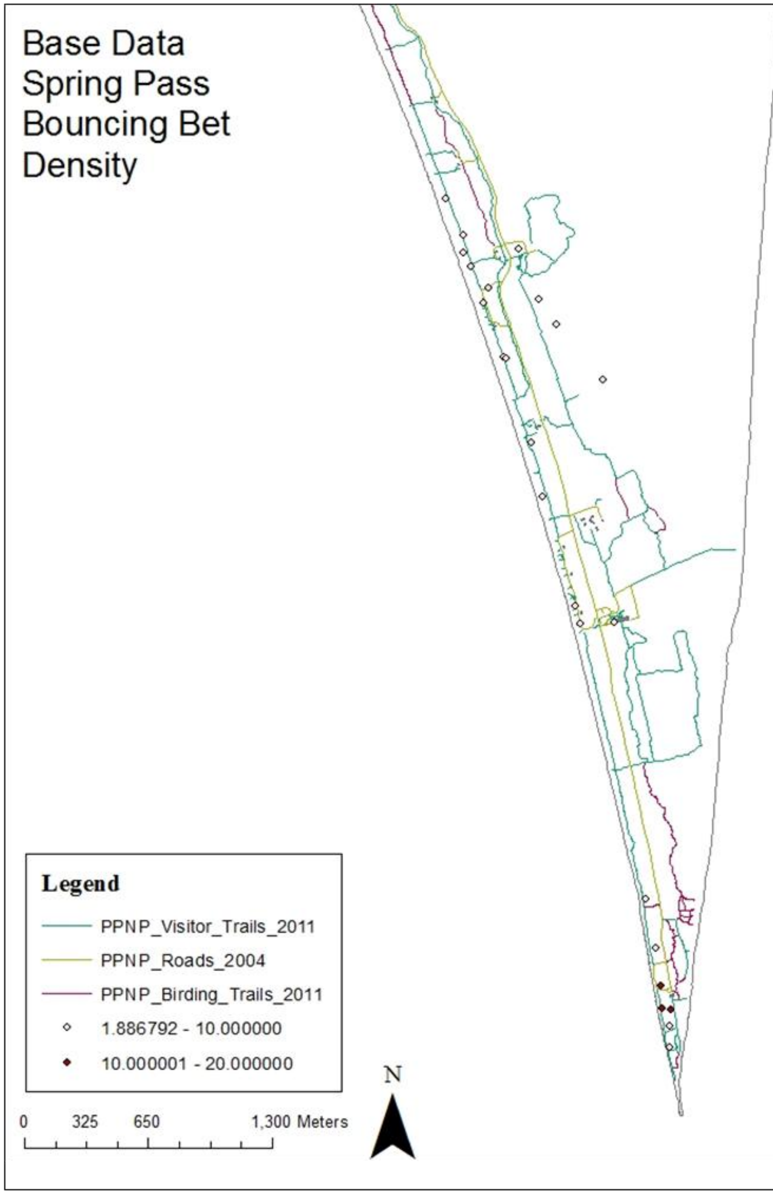

Base Data
Spring Pass
Wood Nettle
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0
200
400
800 Meters
N
Base Data
Late Summer Pass
Wood Nettle
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0
200
400
800 Meters
N

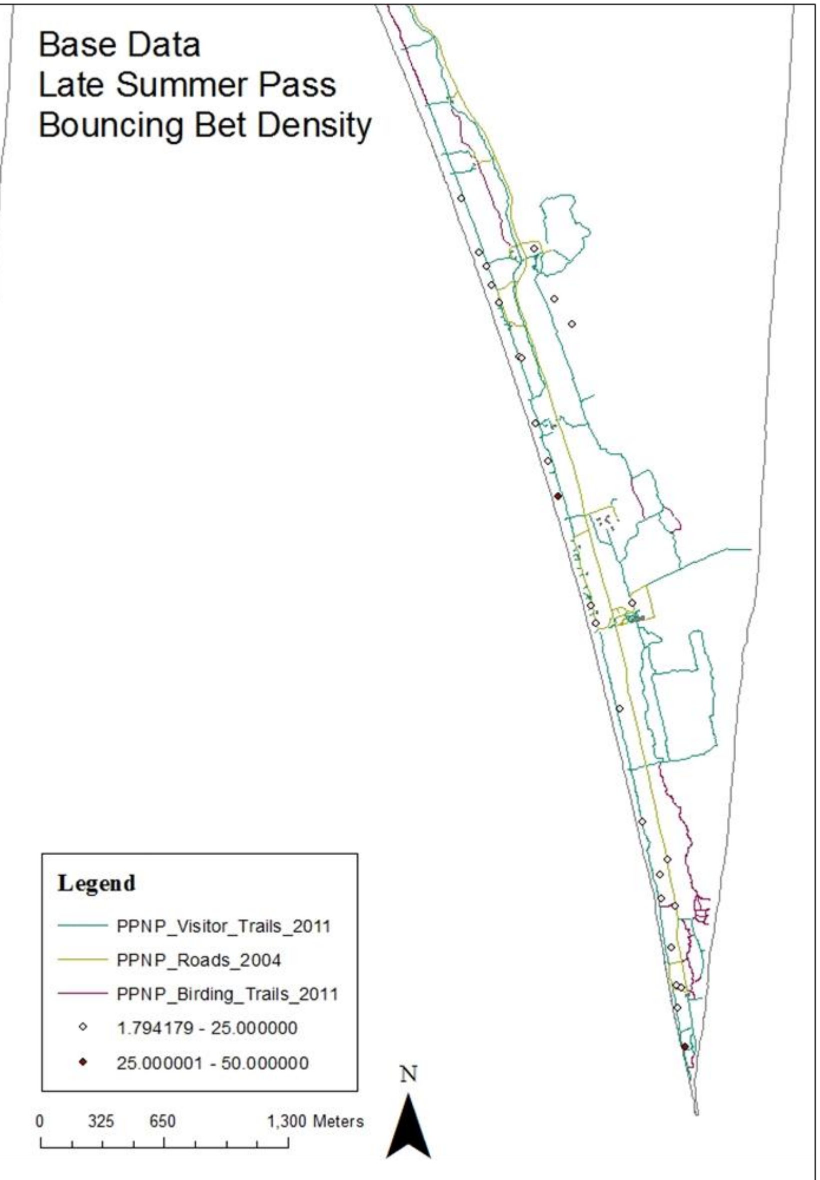

Base Data
Spring Pass
Garlic Mustard Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.763359 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
0 325 650 1,300 Meters
N

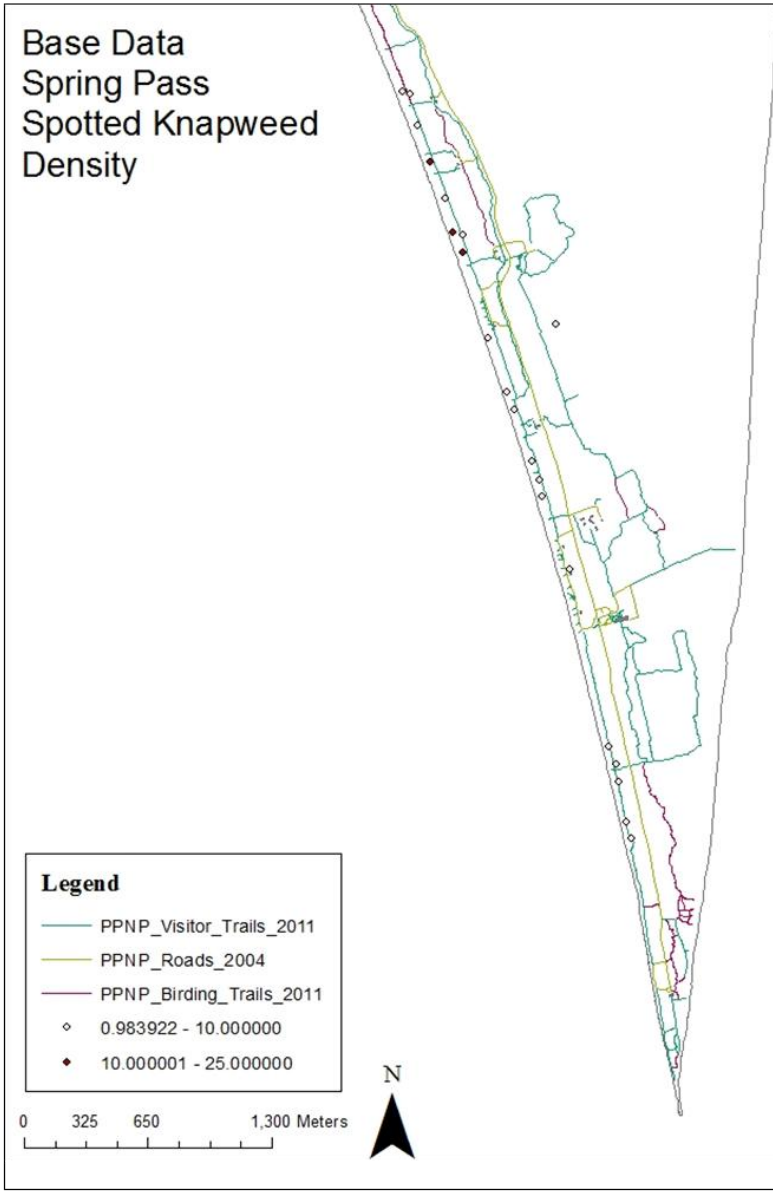

Base Data
Late Summer Pass
Garlic Mustard Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.000000 - 25.000000
25.000001 - 50.000000
0 325 650 1,300 Meters
N


Base Data
Spring Pass
Smooth Brome Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.000000 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
75.000001 - 100.000000
0 325 650 1,300 Meters
N

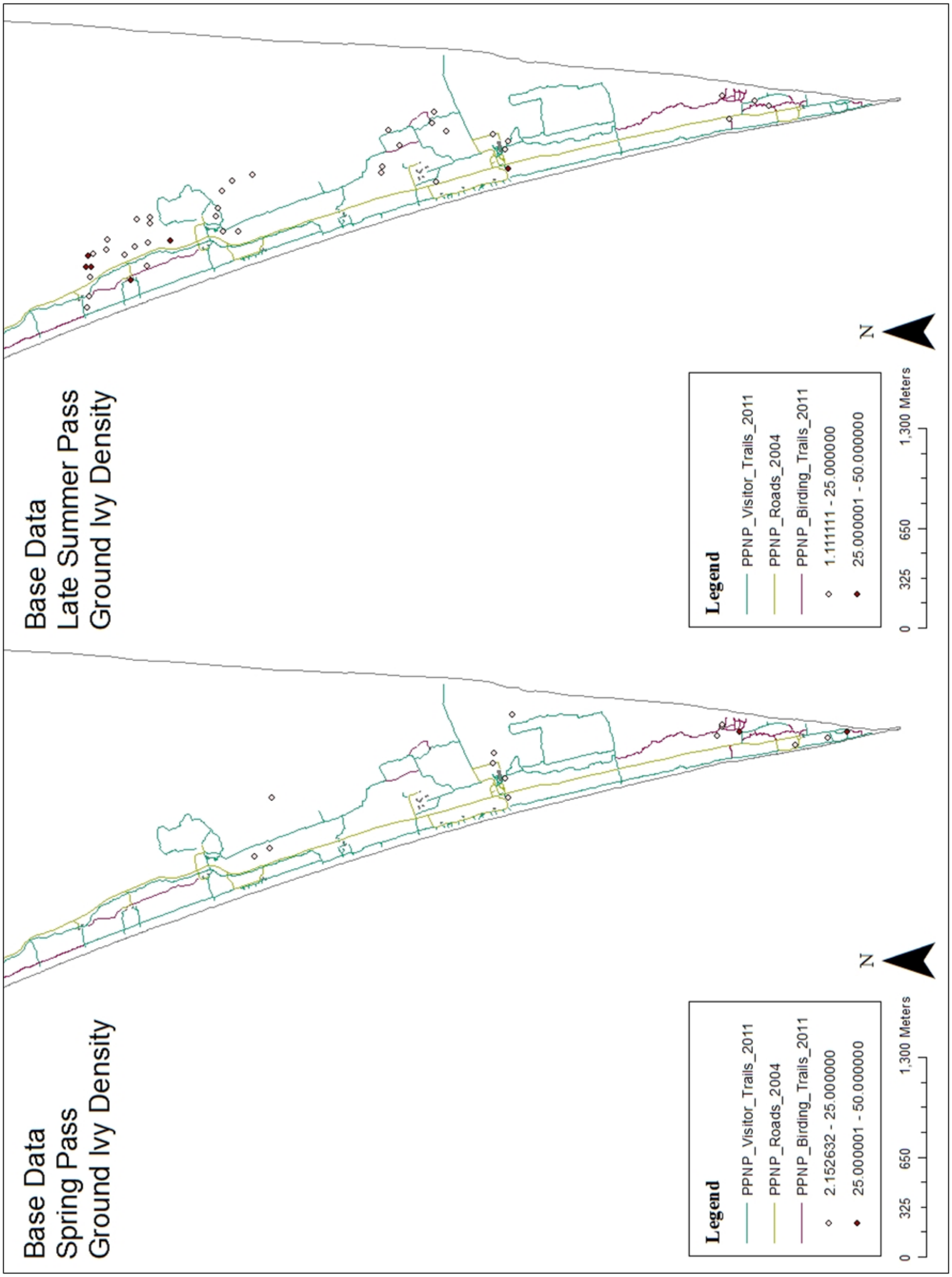

Base Data
Late Summer Pass
Smooth Brome
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.000000 - 25.000000
25.000001 - 50.000000
50.000001 - 75.000000
75.000001 - 100.000000
0 325 650 1,300 Meters
N

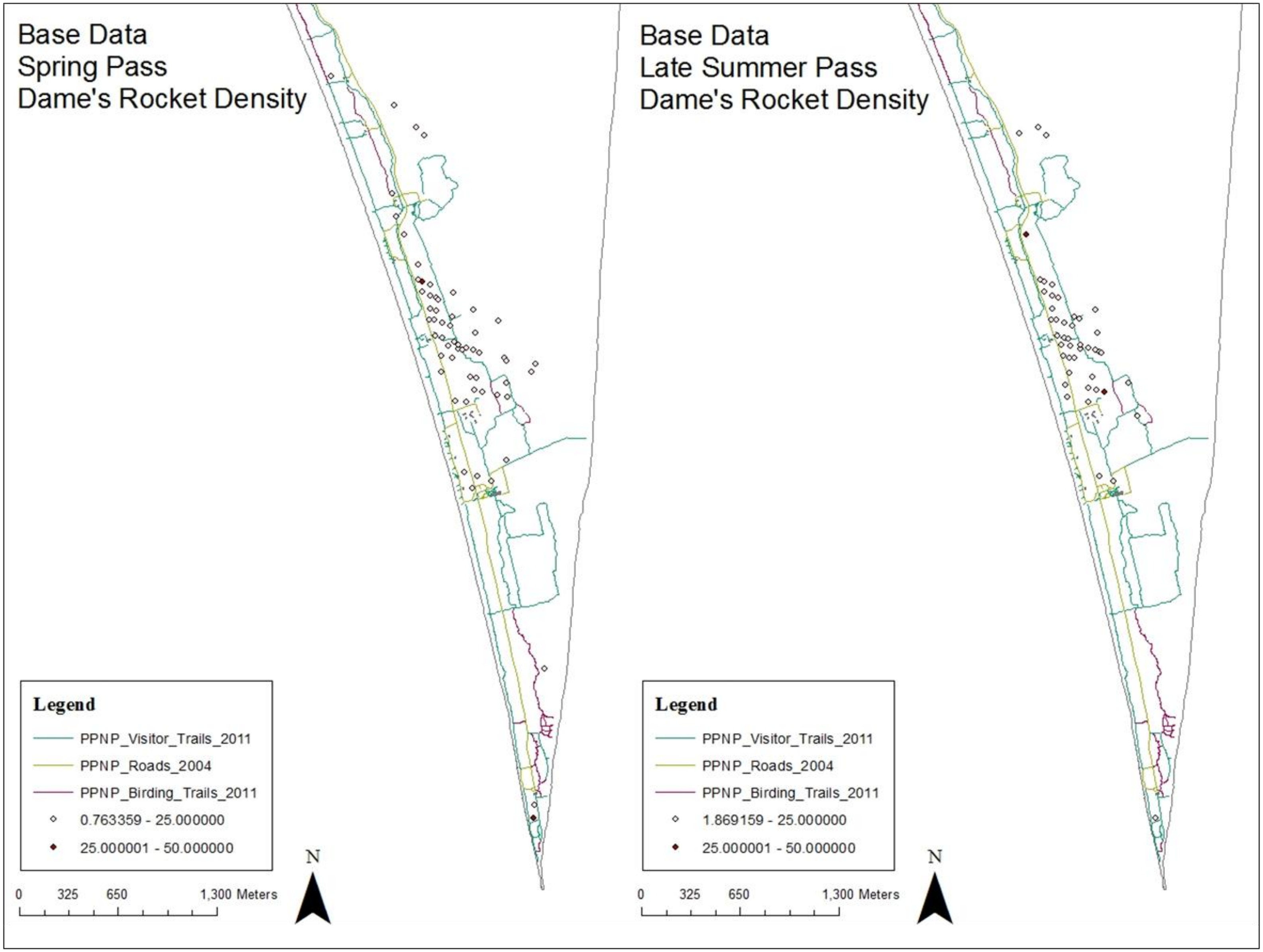

Base Data
Spring Pass
Bouncing Bet
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.886792 - 10.000000
10.000001 - 20.000000
0
325
650
1,300 Meters
N


Base Data
Late Summer Pass
Bouncing Bet Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.794179 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N

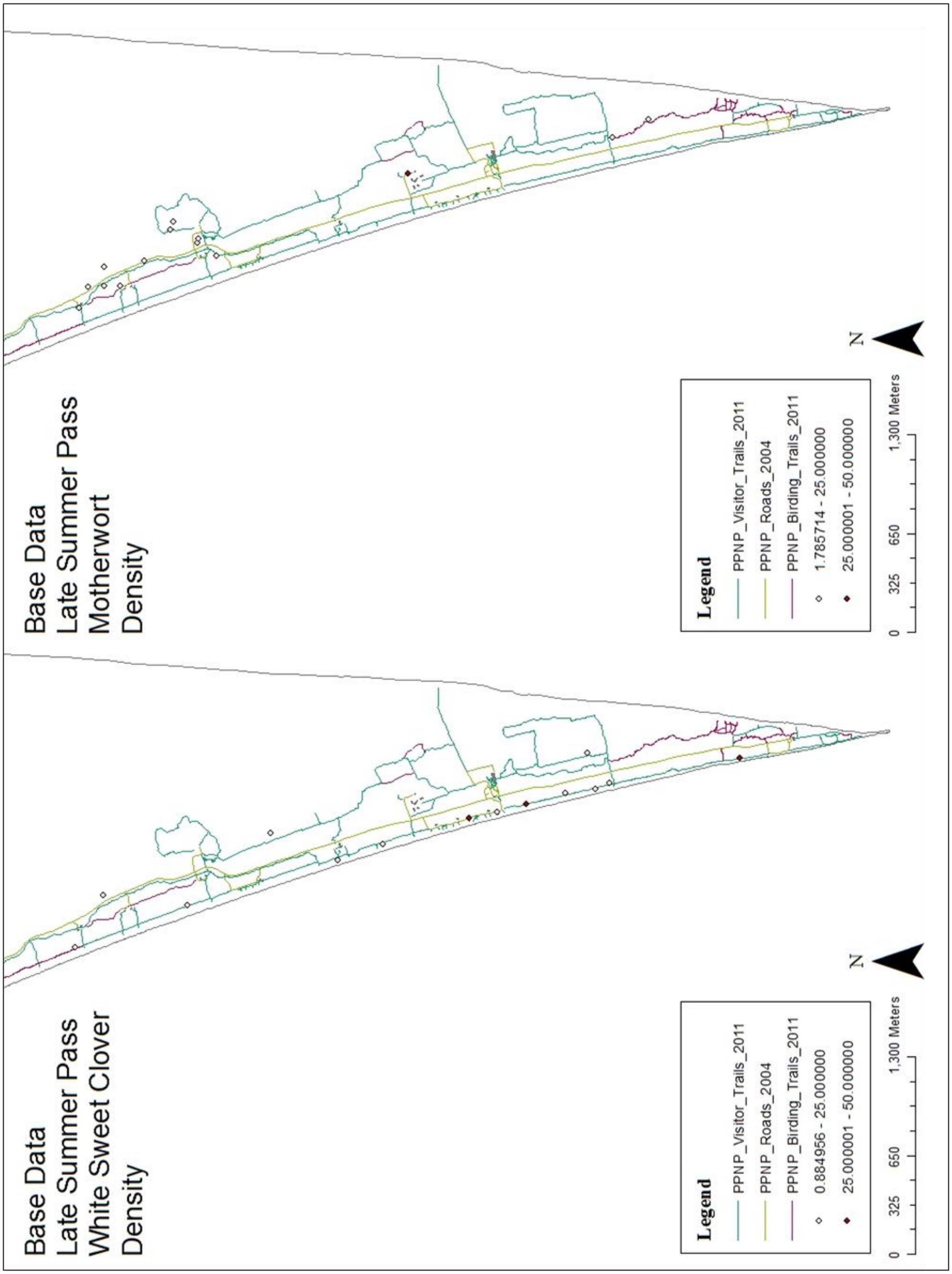

Base Data
Spring Pass
Spotted Knapweed
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.983922 - 10.000000
10.000001 - 25.000000
N
0 325 650 1,300 Meters

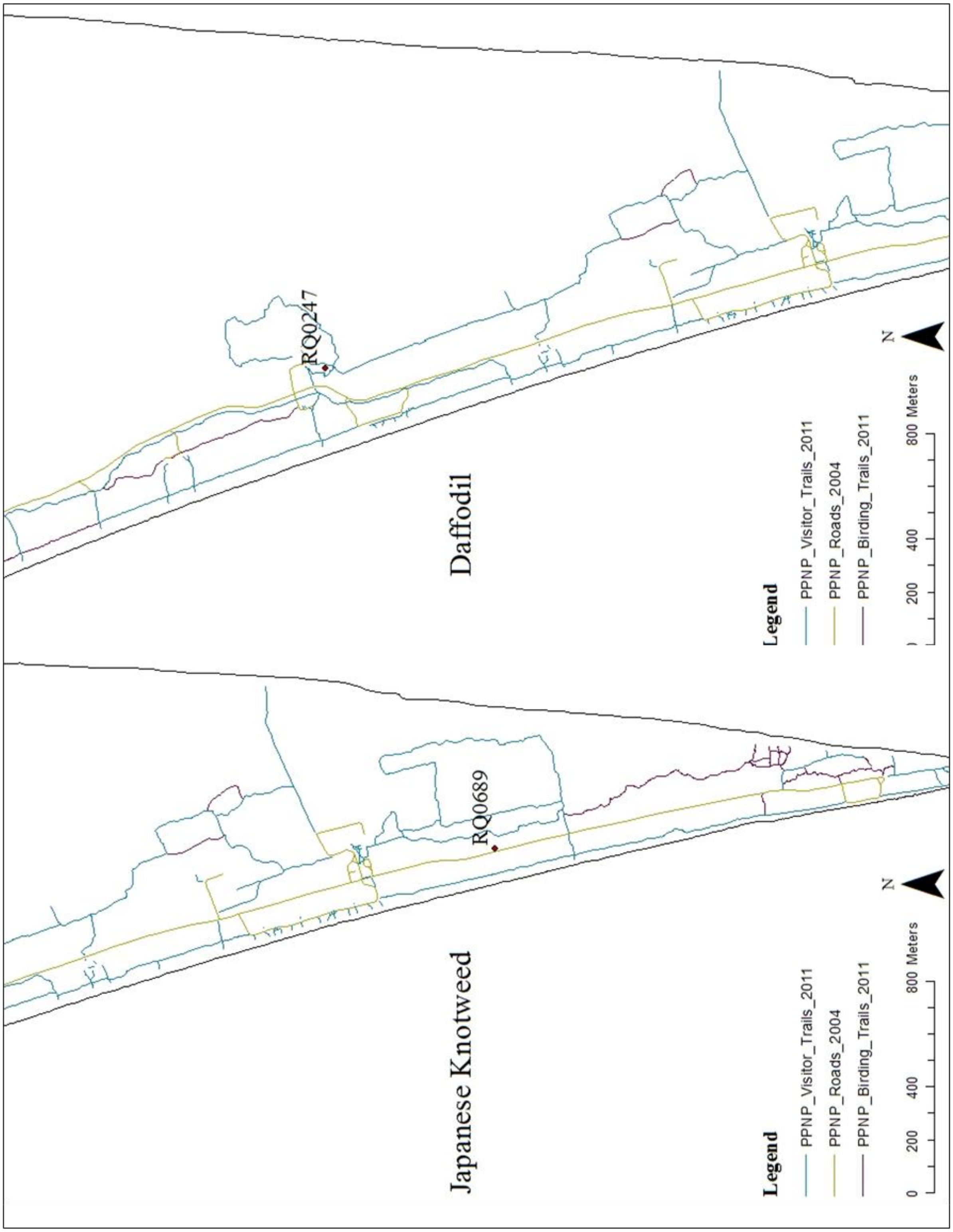

Base Data
Late Summer Pass
Spotted Knapweed
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.925926 - 25.000000
25.000001 - 50.000000
N
0 325 650 1,300 Meters

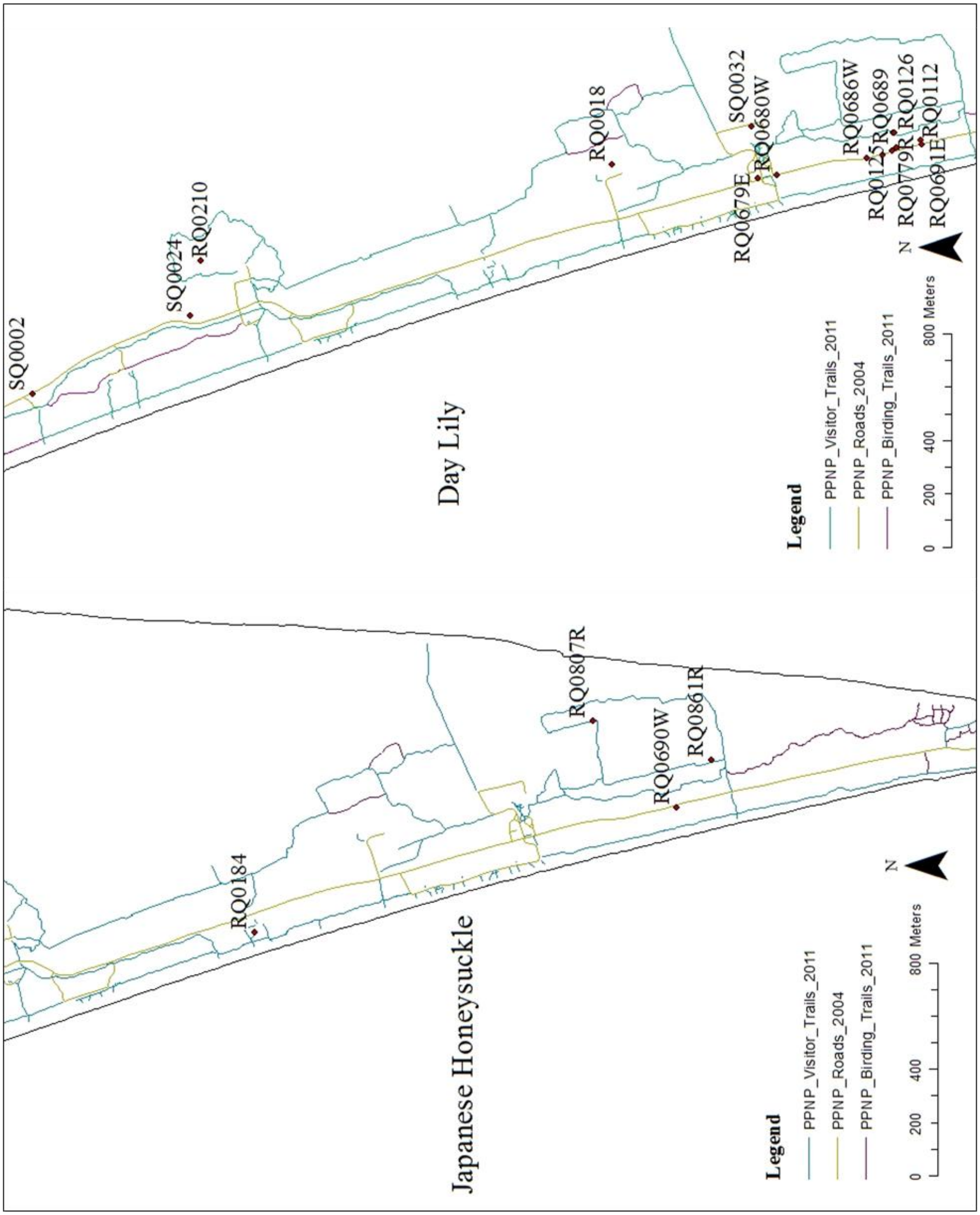

Base Data
Spring Pass
Ground Ivy Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
2.152632 - 25.000000
25.000001 - 50.000000
0 325 650 1,300 Meters
N
Base Data
Late Summer Pass
Ground Ivy Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.111111 - 25.000000
25.000001 - 50.000000
0 325 650 1,300 Meters
N

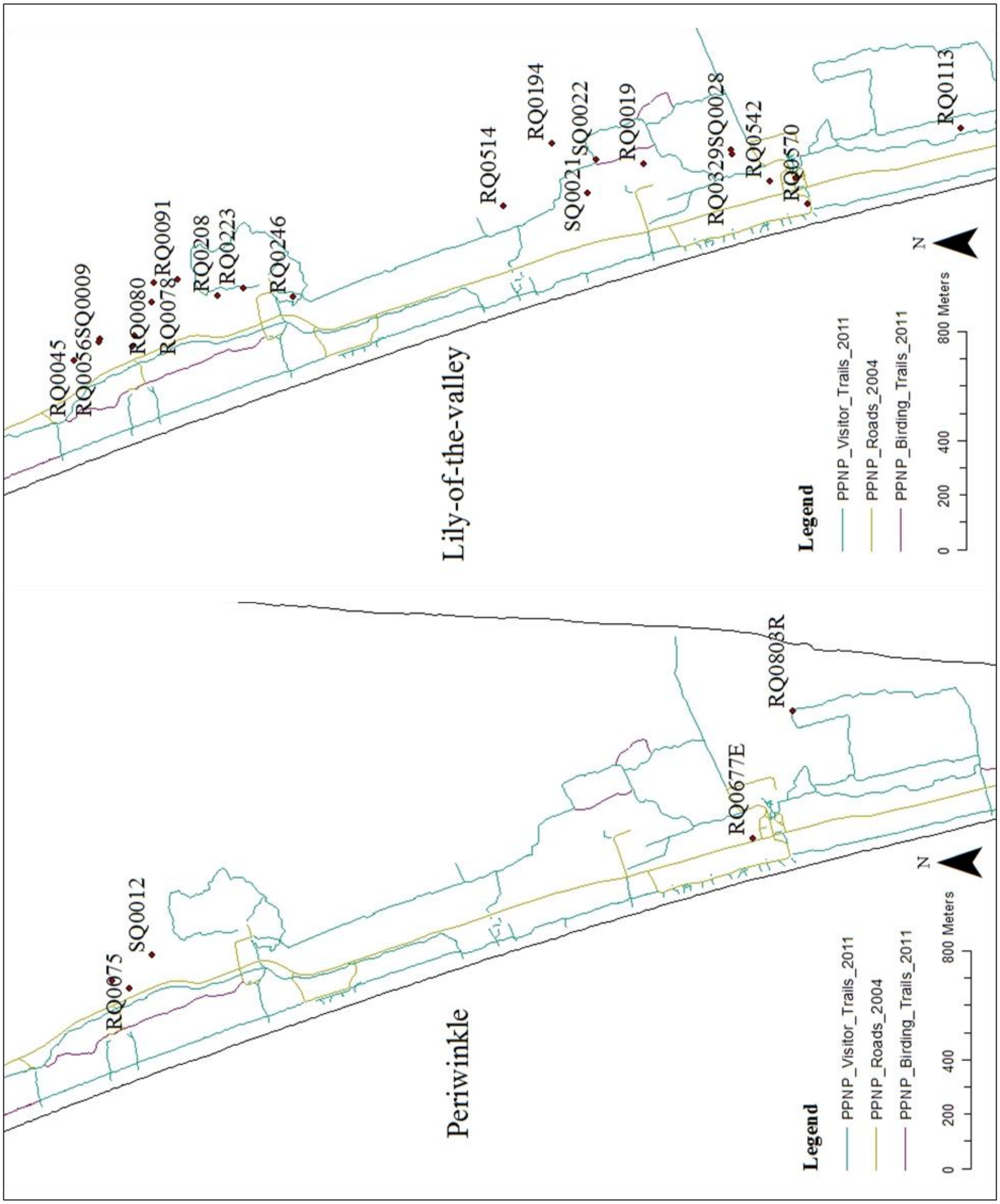


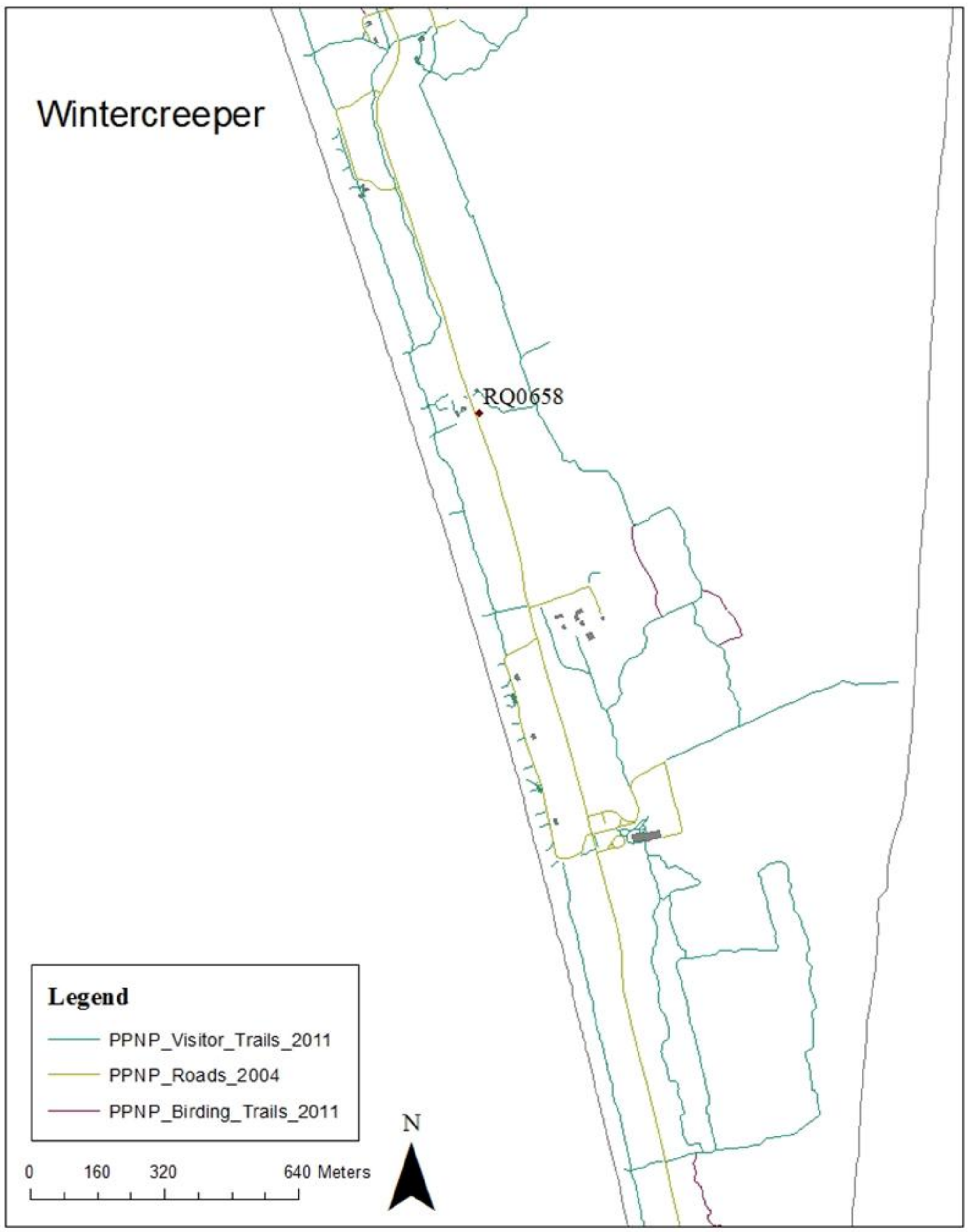
Base Data
Spring Pass
Dame's Rocket Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.763359 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N
Base Data
Late Summer Pass
Dame's Rocket Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.869159 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N

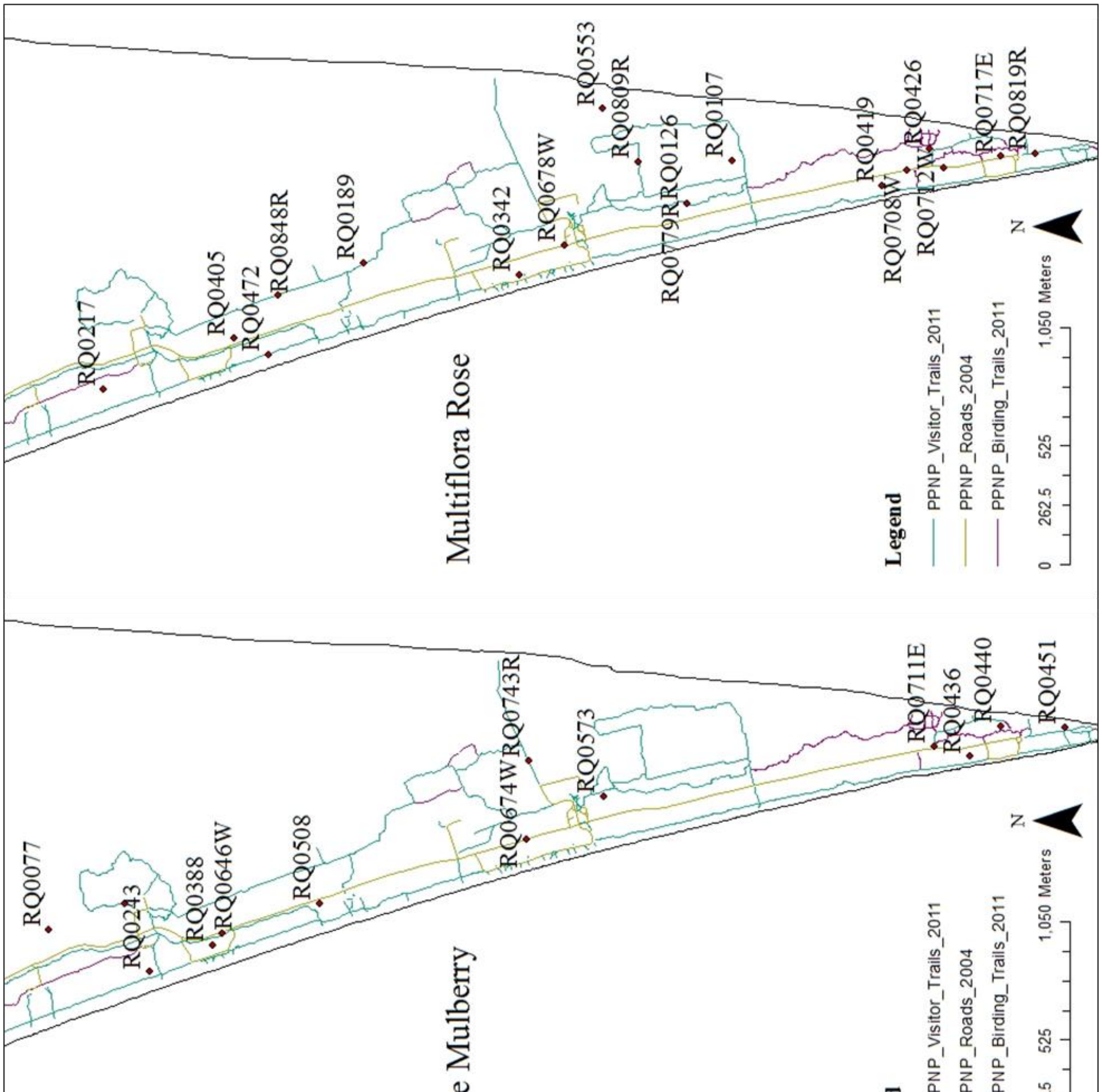

Base Data
Late Summer Pass
White Sweet Clover
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0.884956 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N
Base Data
Late Summer Pass
Motherwort
Density
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
1.785714 - 25.000000
25.000001 - 50.000000
0
325
650
1,300 Meters
N

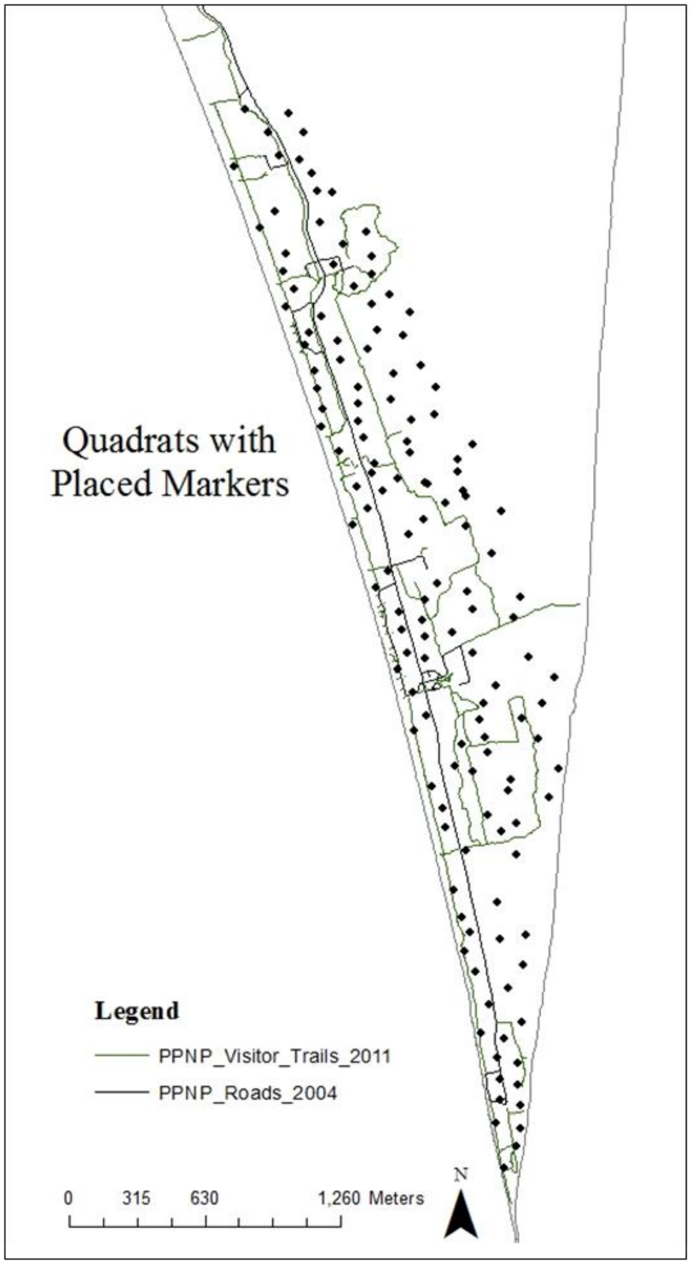

Japanese Knotweed
RQ0689
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters
N
Daffodil
RQ0247
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
200 400 800 Meters
N


Day Lily
SQ0002
SQ0024
RQ0210
RQ0018
SQ0032
RQ0680W
RQ0679E
RQ0686W
RQ0689
RQ0126
RQ0112
RQ0125
RQ0779R
RQ0691E
N
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters
Japanese Honeysuckle
RQ0184
RQ0807R
RQ0690W
RQ0861R
N
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters

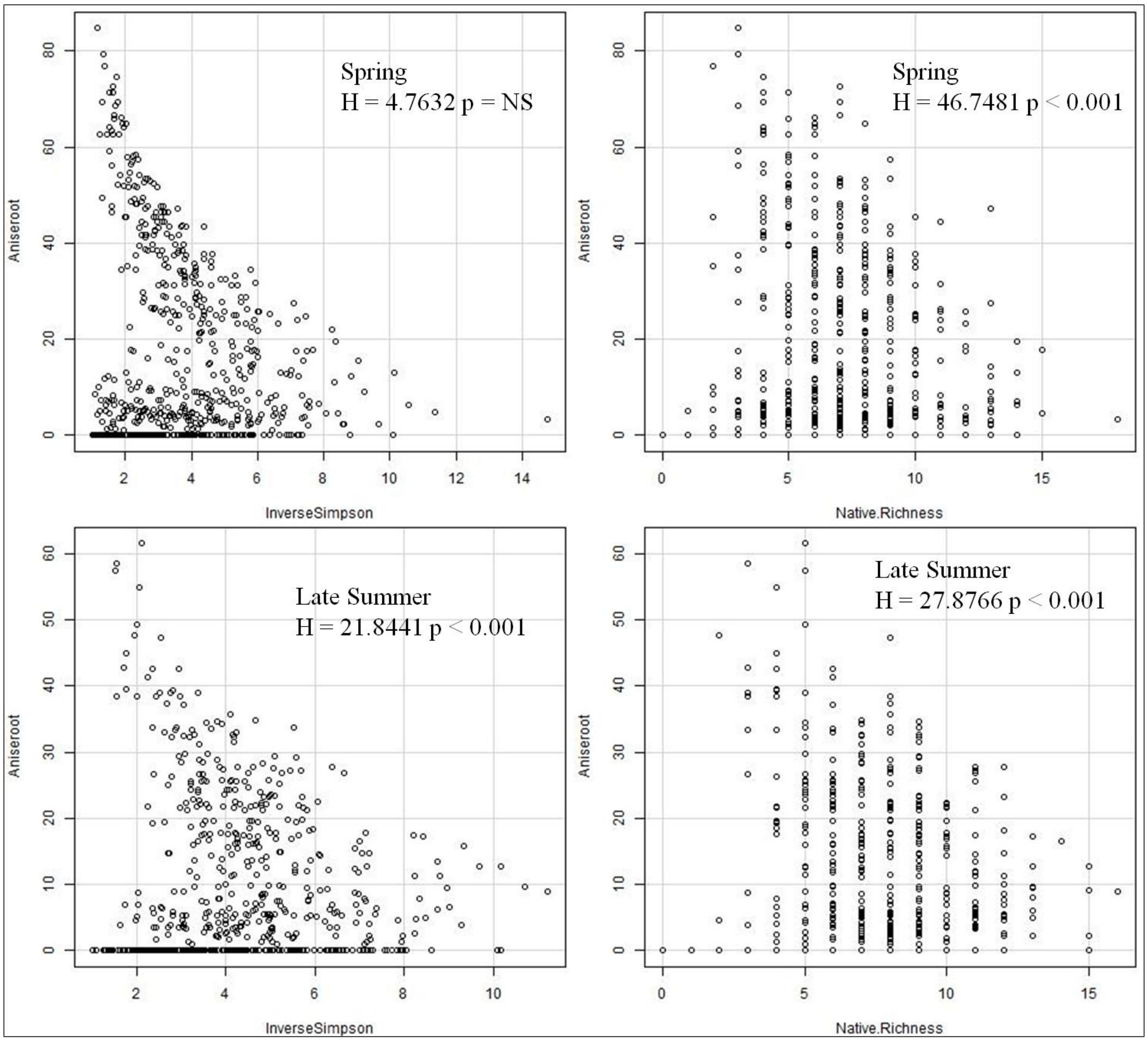

Lily-of-the-valley
RQ0045
RQ0056
SQ0009
RQ0080
RQ0078
RQ0091
RQ0208
RQ0223
RQ0246
RQ0514
RQ0194
SQ0021
SQ0022
RQ0019
RQ0329
SQ0028
RQ0542
RQ0570
RQ0113
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters
N
Periwinkle
RQ0075
SQ0012
RQ0677E
RQ0803R
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 200 400 800 Meters
N

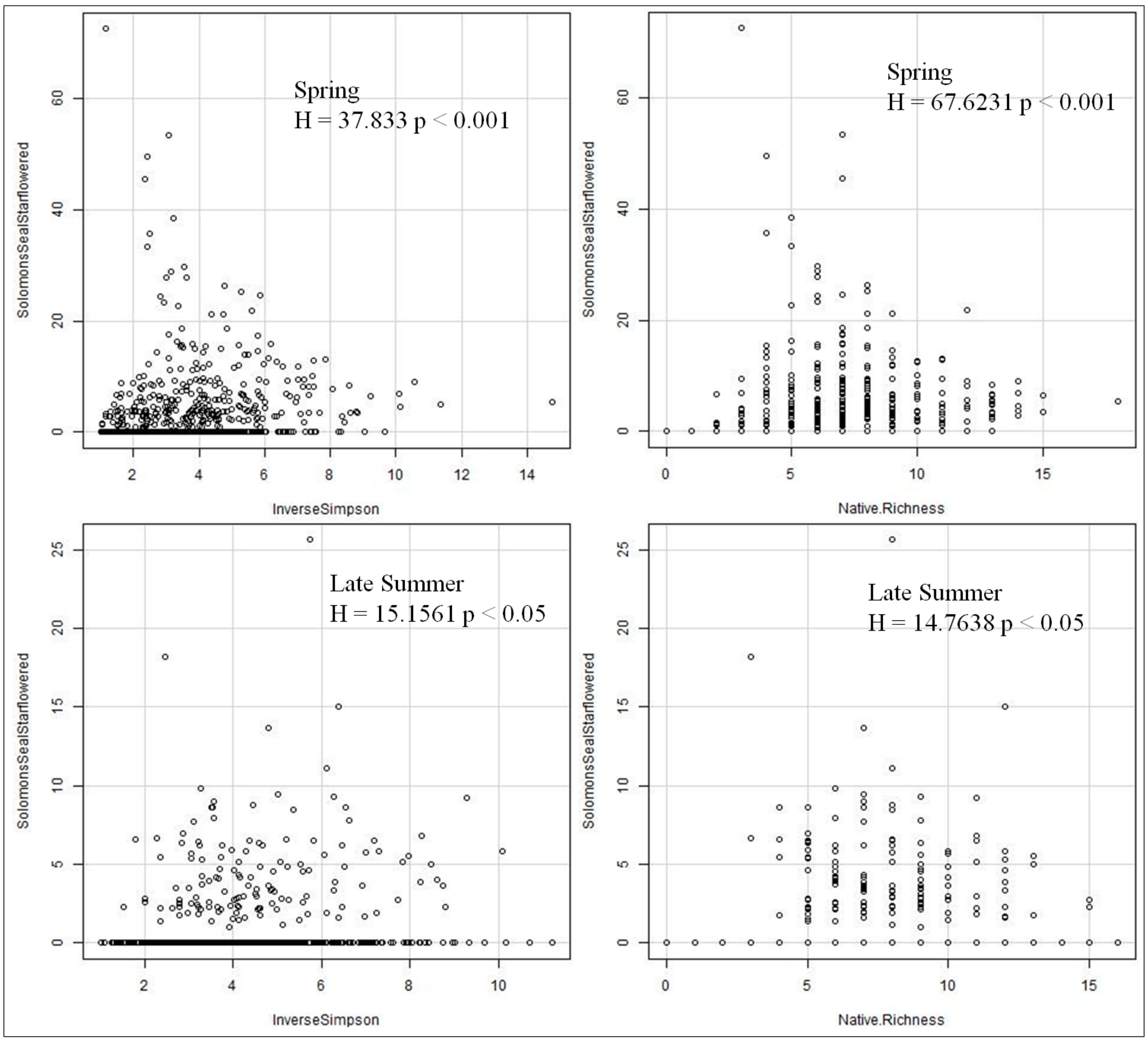

Wintercreeper
RQ0658
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
N
0 160 320 640 Meters

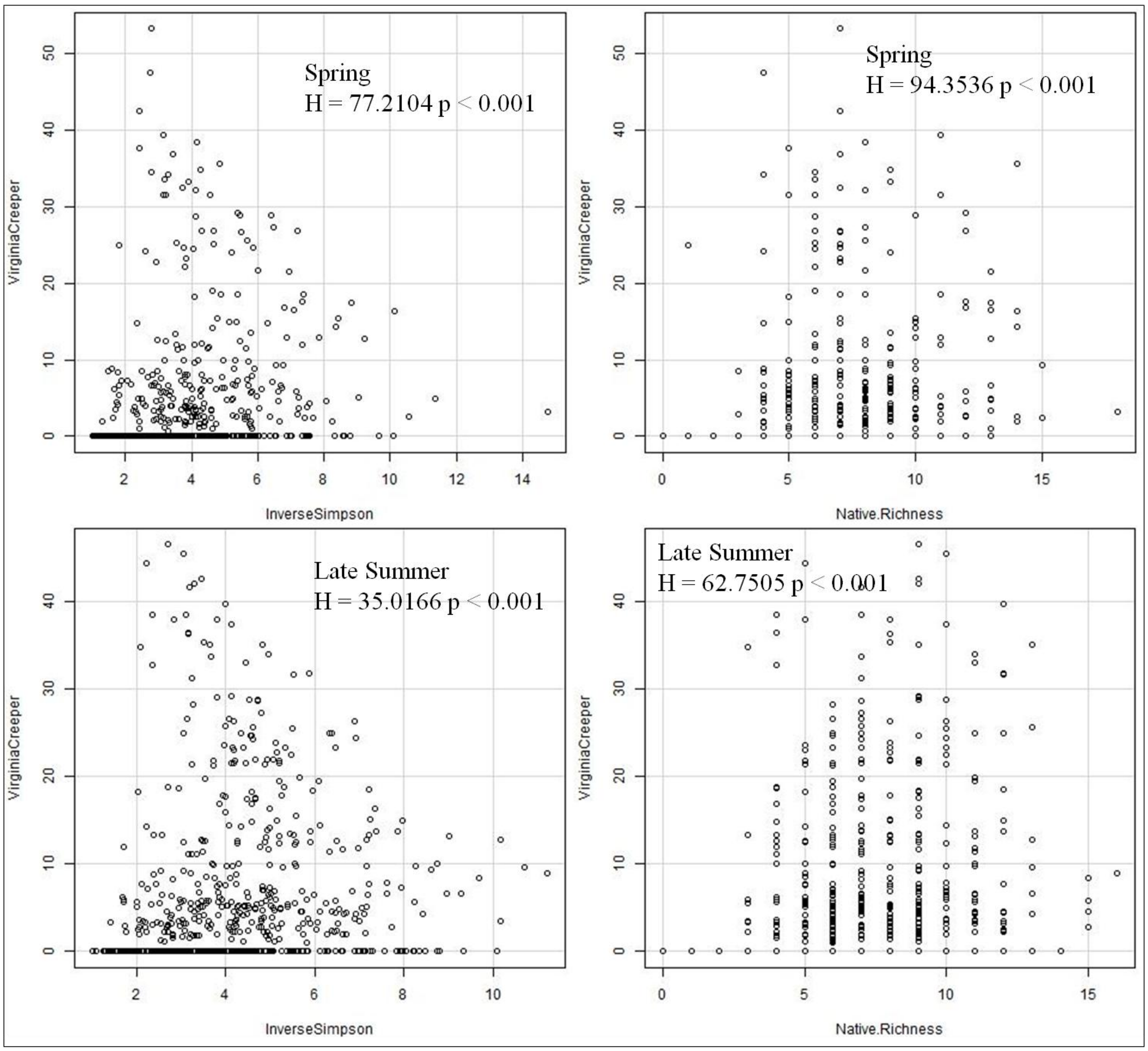

White Mulberry
RQ0077
RQ0243
RQ0388
RQ0646W
RQ0508
RQ0674W
RQ0743R
RQ0573
RQ0711E
RQ0436
RQ0440
RQ0451
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 262.5 525 1,050 Meters
N
Multiflora Rose
RQ0217
RQ0405
RQ0472
RQ0848R
RQ0189
RQ0342
RQ0678W
RQ0553
RQ0809R
RQ0779R
RQ0126
RQ0107
RQ0419
RQ0708W
RQ0426
RQ0712W
RQ0717E
RQ0819R
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
PPNP_Birding_Trails_2011
0 262.5 525 1,050 Meters
N

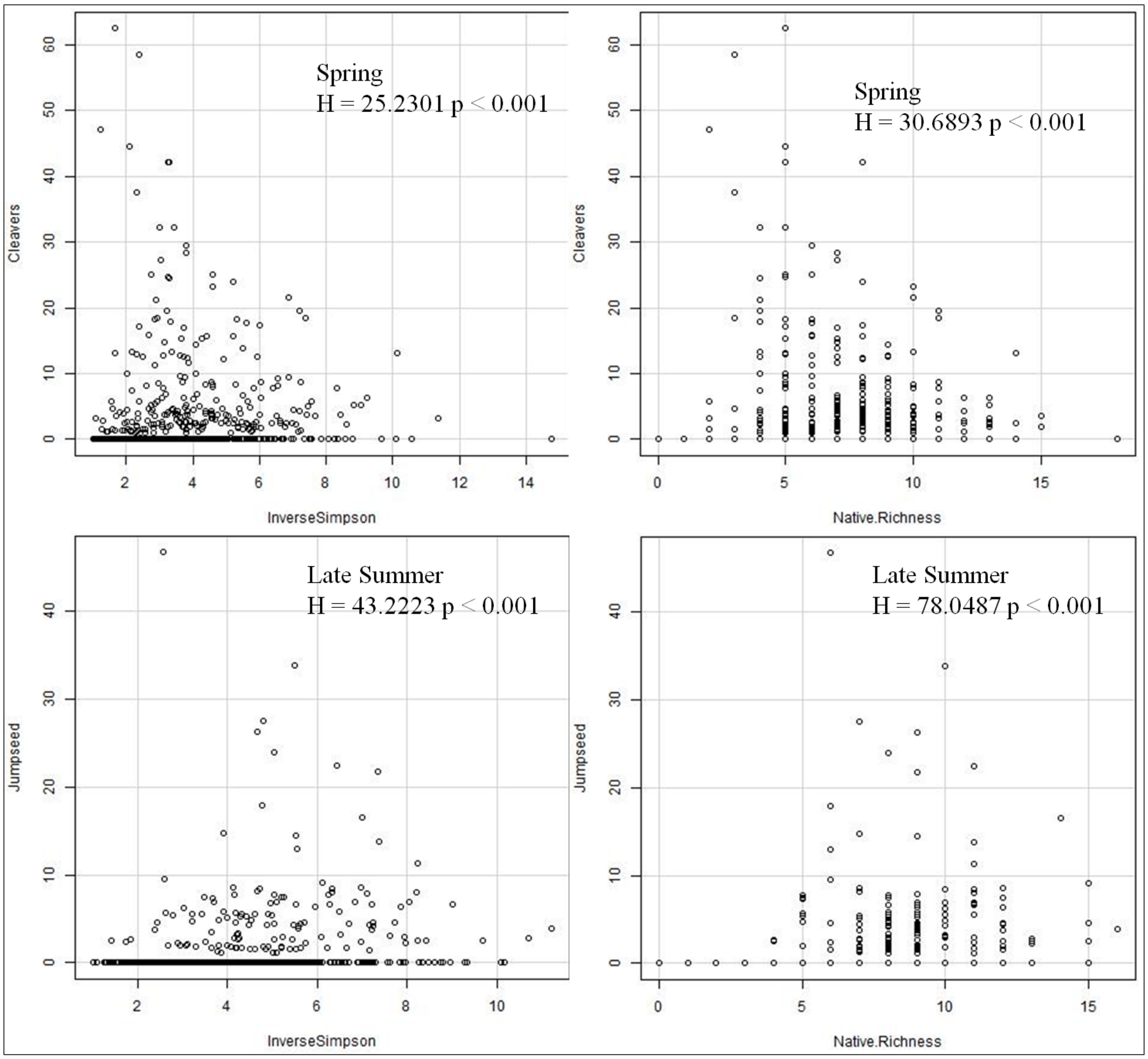

Quadrats with
Placed Markers
Legend
PPNP_Visitor_Trails_2011
PPNP_Roads_2004
0
315
630
1,260 Meters
N

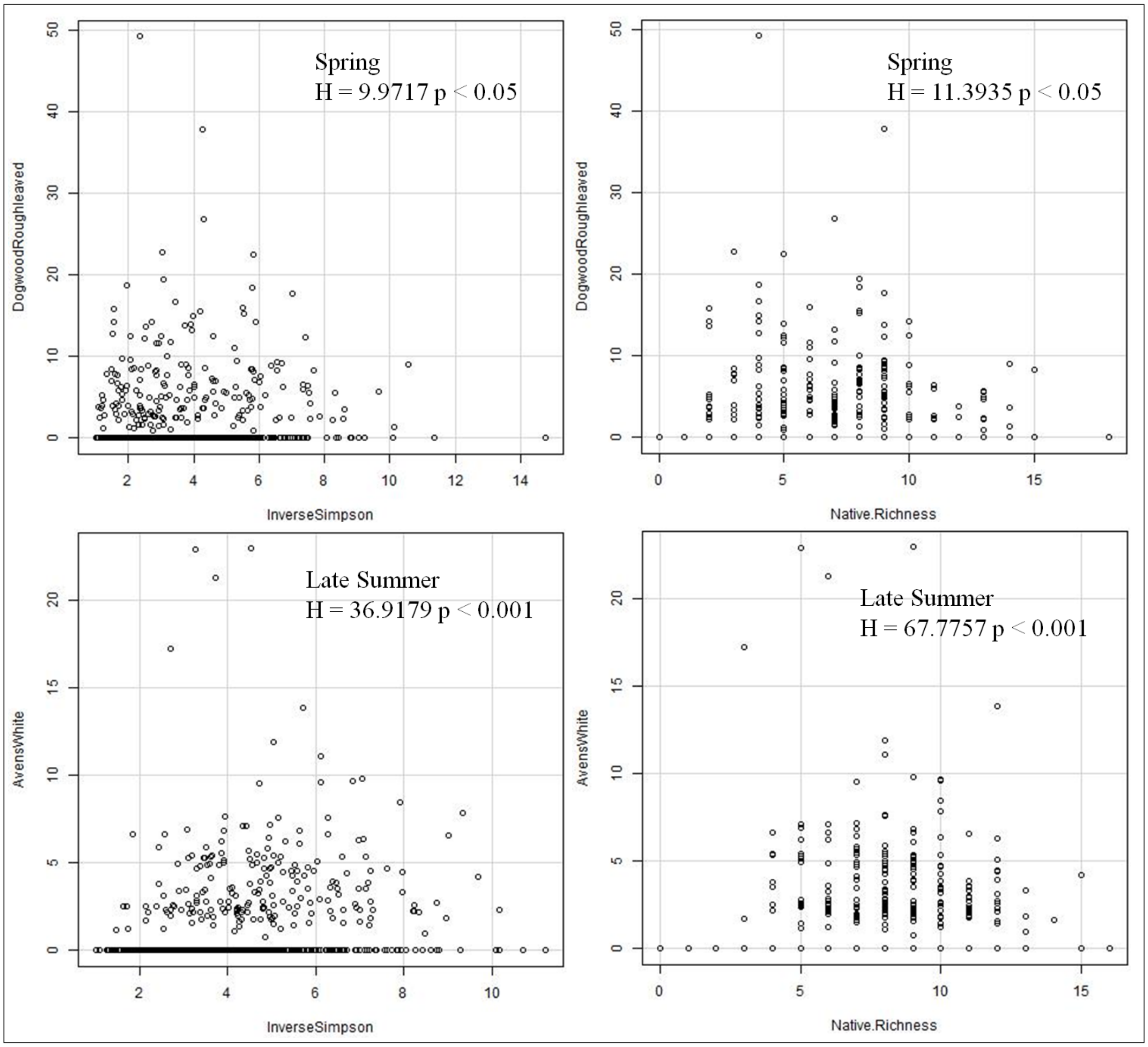
Appendix B Scatter Plots

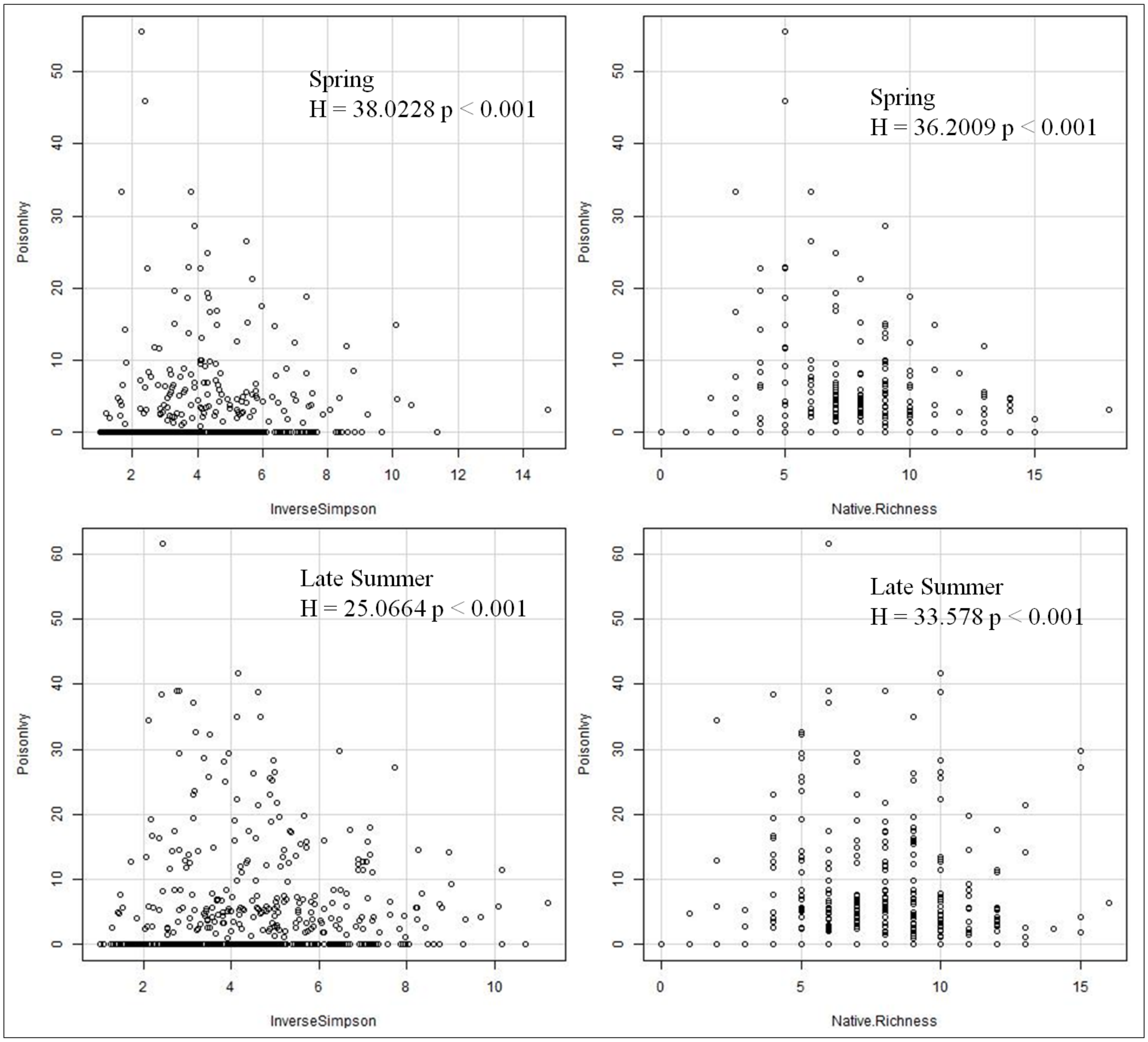

Spring
H = 4.7632 p = NS
Aniseroot
InverseSimpson
Spring
H = 46.7481 p < 0.001
Aniseroot
Native.Richness
Late Summer
H = 21.8441 p < 0.001
Aniseroot
InverseSimpson
Late Summer
H = 27.8766 p < 0.001
Aniseroot
Native.Richness

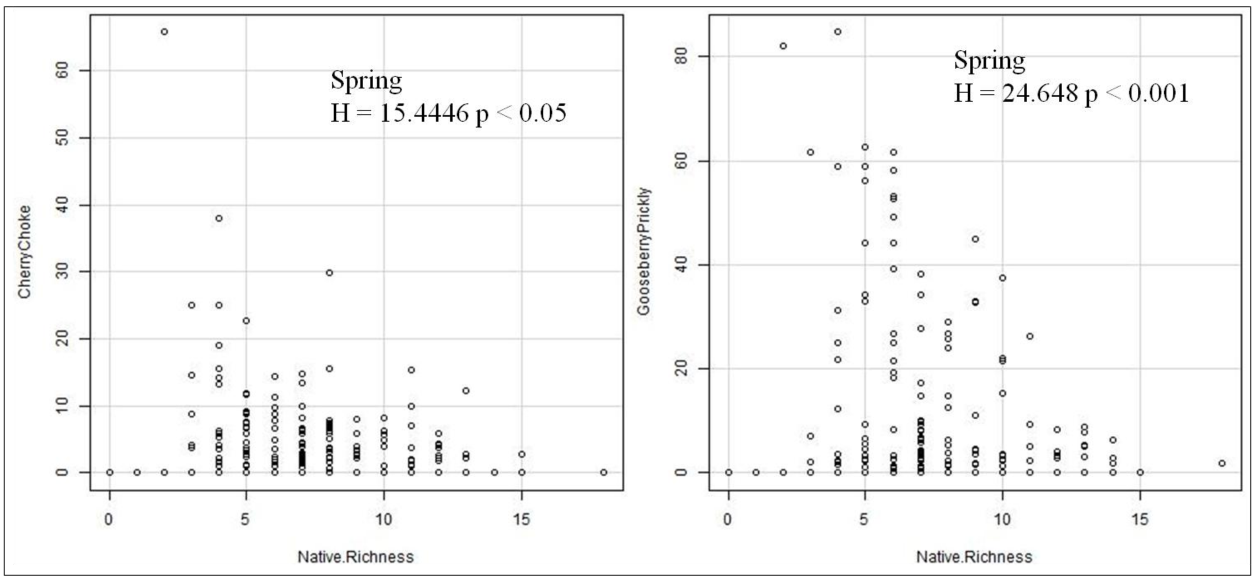

Spring
H = 37.833 p < 0.001
Spring
H = 67.6231 p < 0.001
Late Summer
H = 15.1561 p < 0.05
Late Summer
H = 14.7638 p < 0.05
SolomonsSealStarflowered
InverseSimpson
Native.Richness


Spring
H = 77.2104 p < 0.001
Spring
H = 94.3536 p < 0.001
Late Summer
H = 35.0166 p < 0.001
Late Summer
H = 62.7505 p < 0.001
VirginiaCreeper
InverseSimpson
Native.Richness

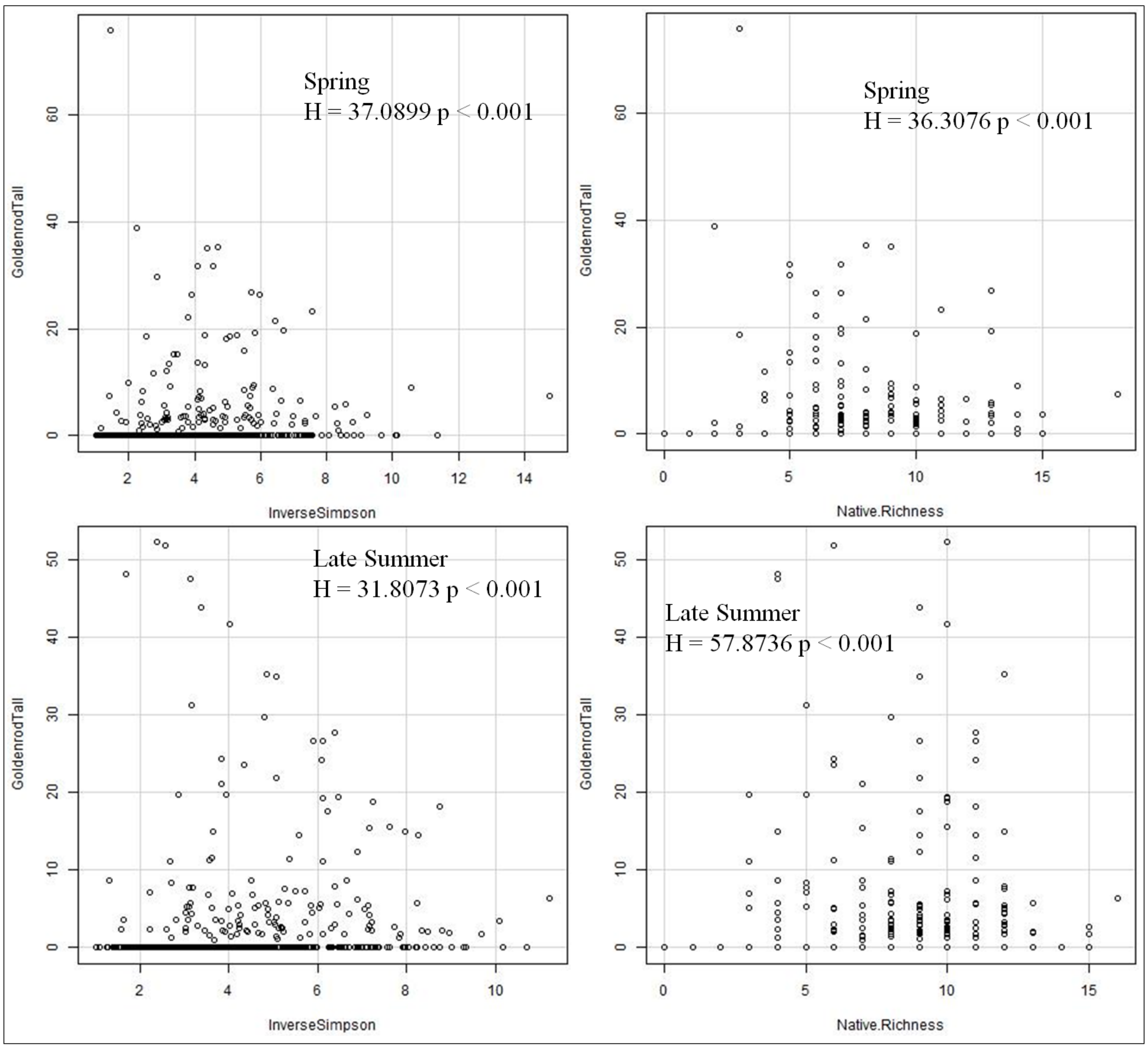

Spring
H = 25.2301 p < 0.001
Cleavers
InverseSimpson
Spring
H = 30.6893 p < 0.001
Cleavers
Native.Richness
Late Summer
H = 43.2223 p < 0.001
Jumpseed
InverseSimpson
Late Summer
H = 78.0487 p < 0.001
Jumpseed
Native.Richness

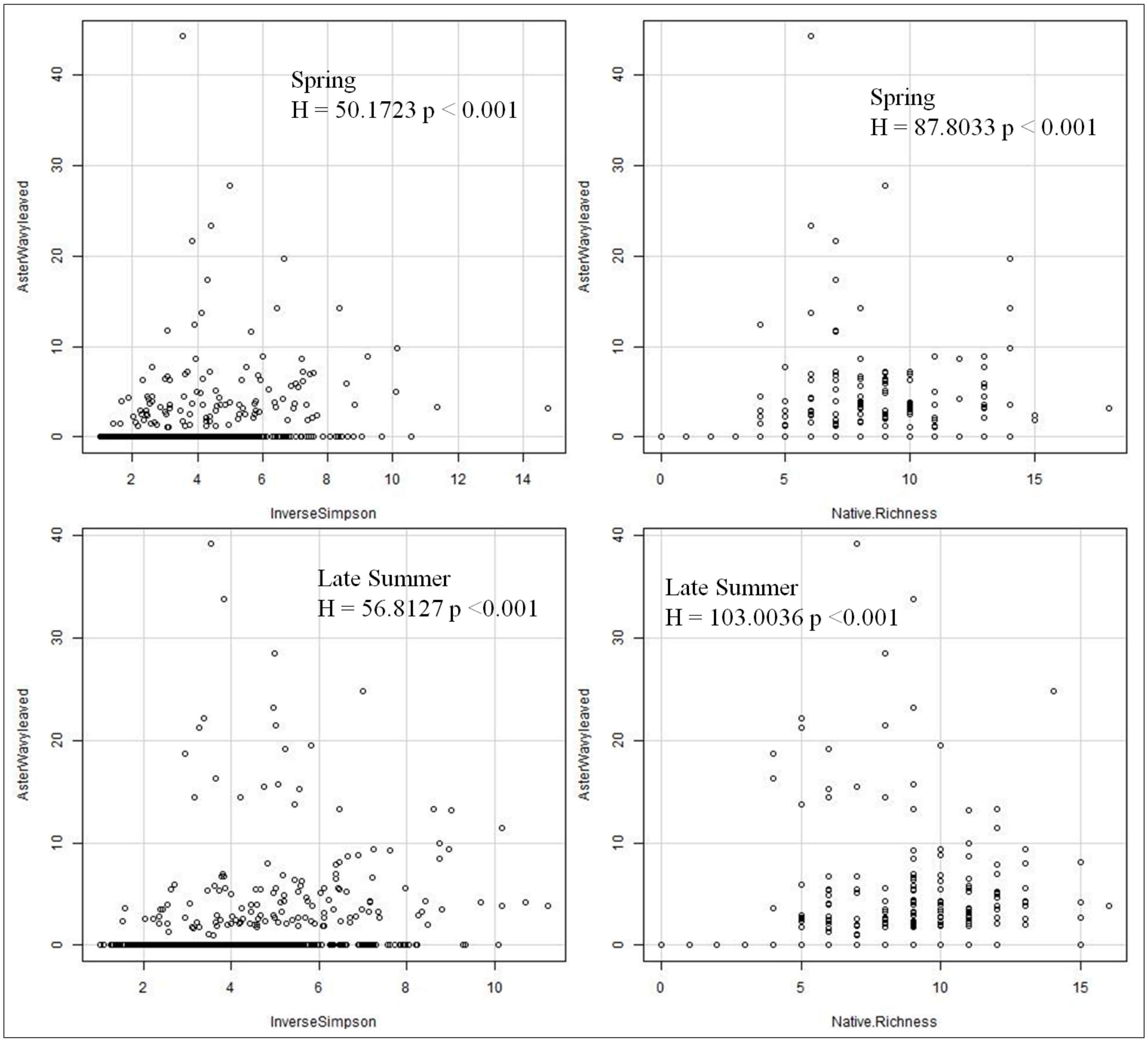

Spring
H = 9.9717 p < 0.05
DogwoodRoughleaved
InverseSimpson
Spring
H = 11.3935 p < 0.05
DogwoodRoughleaved
Native.Richness
Late Summer
H = 36.9179 p < 0.001
AvensWhite
InverseSimpson
Late Summer
H = 67.7757 p < 0.001
AvensWhite
Native.Richness

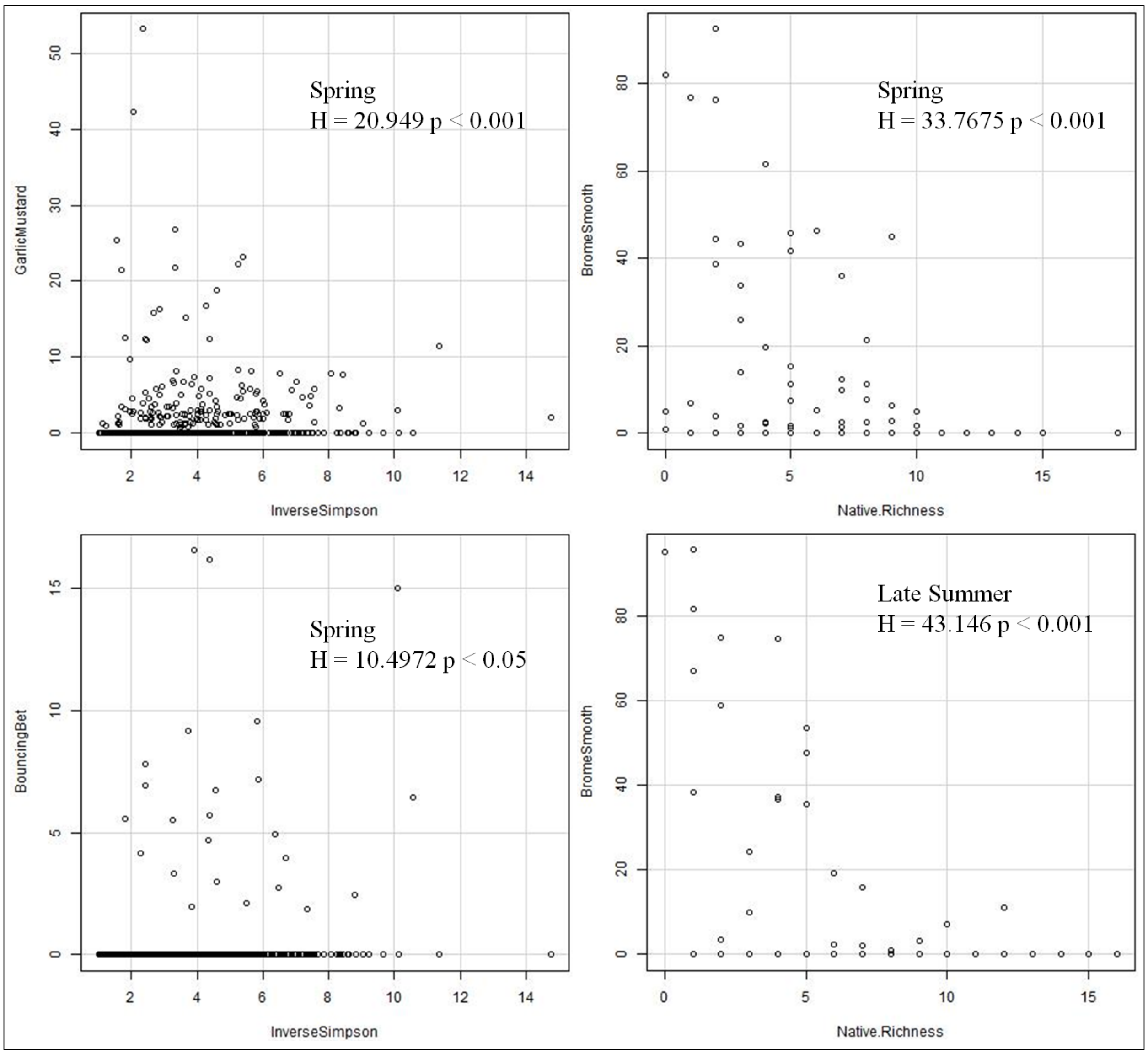

Spring
H = 38.0228 p < 0.001
Spring
H = 36.2009 p < 0.001
Late Summer
H = 25.0664 p < 0.001
Late Summer
H = 33.578 p < 0.001
PoisonIvy
InverseSimpson
Native.Richness

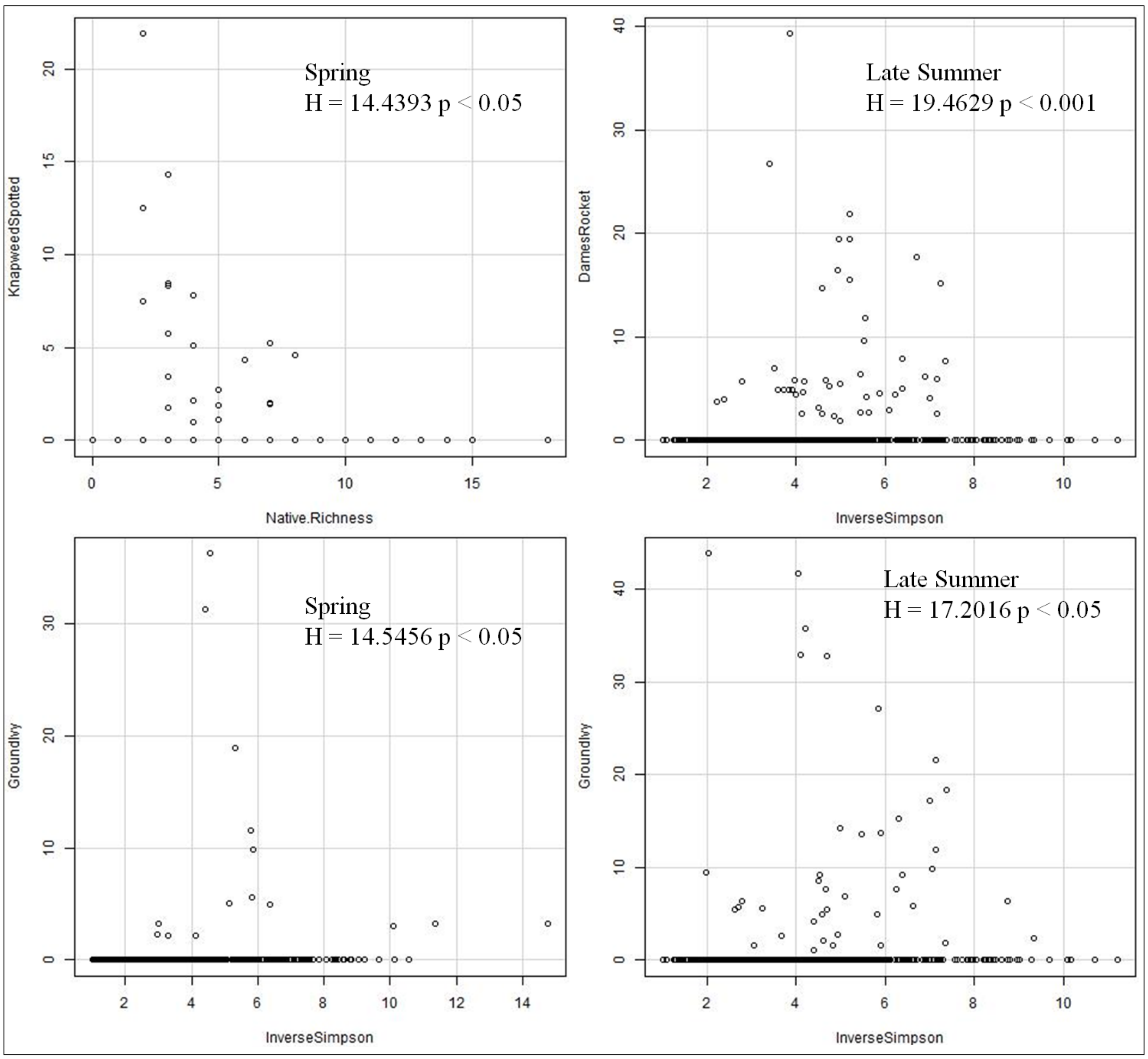


Spring
H = 15.4446 p < 0.05
CherryChoke
Native.Richness
Spring
H = 24.648 p < 0.001
GooseberryPrickly
Native.Richness

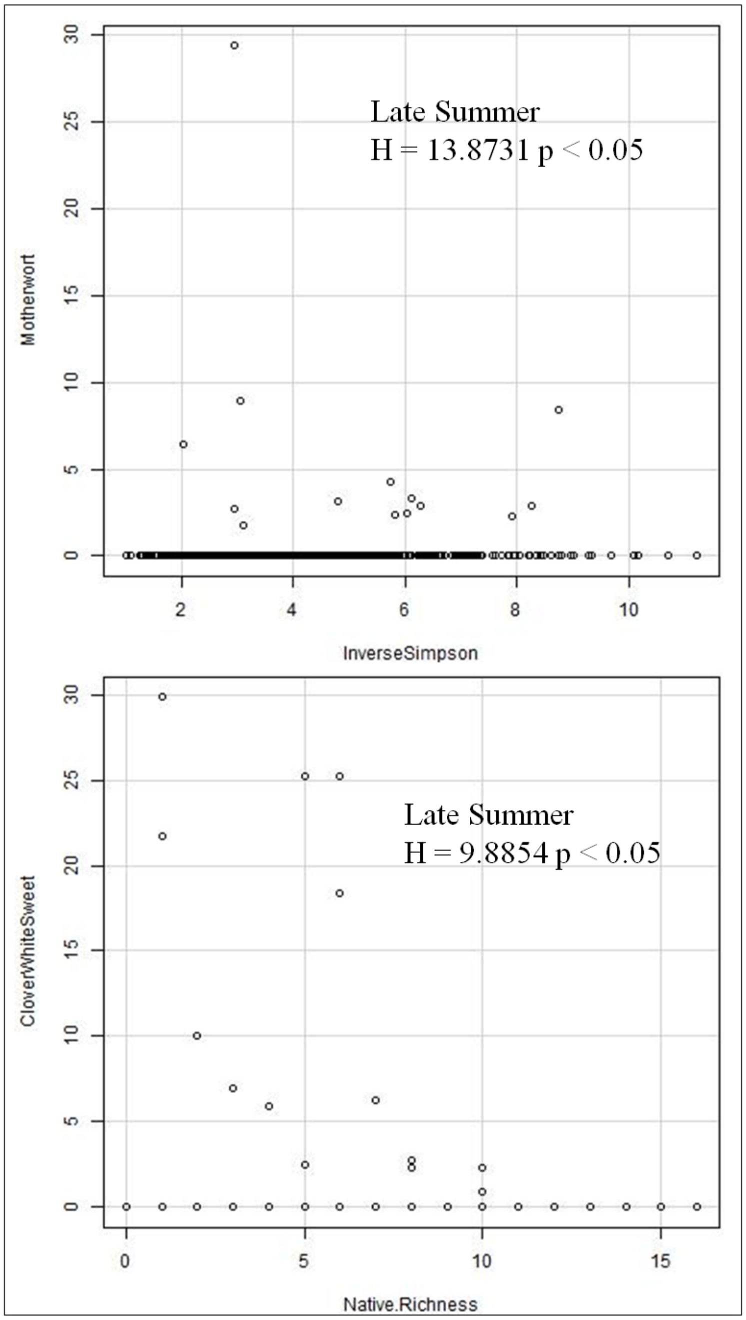

Spring
H = 37.0899 p < 0.001
GoldenrodTall
InverseSimpson
Spring
H = 36.3076 p < 0.001
GoldenrodTall
Native.Richness
Late Summer
H = 31.8073 p < 0.001
GoldenrodTall
InverseSimpson
Late Summer
H = 57.8736 p < 0.001
GoldenrodTall
Native.Richness


Spring
H = 50.1723 p < 0.001
Spring
H = 87.8033 p < 0.001
Late Summer
H = 56.8127 p <0.001
Late Summer
H = 103.0036 p <0.001
AsterWayleaved
InverseSimpson
Native.Richness


Spring
H = 20.949 p < 0.001
GarlicMustard
InverseSimpson
Spring
H = 33.7675 p < 0.001
BromeSmooth
Native.Richness
Spring
H = 10.4972 p < 0.05
BouncingBet
InverseSimpson
Late Summer
H = 43.146 p < 0.001
BromeSmooth
Native.Richness



Spring
H = 14.4393 p < 0.05
KnapweedSpotted
Native.Richness
Late Summer
H = 19.4629 p < 0.001
DamesRocket
InverseSimpson
Spring
H = 14.5456 p < 0.05
GroundIvy
InverseSimpson
Late Summer
H = 17.2016 p < 0.05
GroundIvy
InverseSimpson


Late Summer
H = 13.8731 p < 0.05
Motherwort
InverseSimpson
Late Summer
H = 9.8854 p < 0.05
CloverWhiteSweet
Native.Richness