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Factors limiting sand dune restoration in Northwest Beach, Point Pelee National Park, Canada

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**Factors limiting sand dune restoration in Northwest Beach,
Point Pelee National Park, Canada**

By

Pritichhanda M. Nayak

Thesis

Submitted to the Department of Geography and Environmental Studies

In partial fulfilment of the requirements for

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Abstract

Known as home to rare species of flora and fauna, and their critical habitats, Northwest beach of Point Pelee National Park has undergone significant ecological and infrastructural changes in the past decades. A number of important management challenges have emerged, including conservation of endangered Five-lined Skink (*Plestiodon fasciatus*) which inhabit the extensive dune system within the park. This research investigates key factors for sand dune ecosystem restoration in Northwest beach of Point Pelee with particular attention to the conservation of Skink habitat. Random stratified sampling method was used to collect sand and vegetation samples from the disturbed and natural areas. Sand samples were also collected from the sand piles, which is a part of dune restoration process initiated by the Parks Canada.

Three aspects were considered: grain size distribution of dune sediments, vegetation assemblage and character of the dune associated species, land use and land cover change. Grain size distribution indicated that samples from most of the sand piles contained some amounts of clay/silt and pebble sized grains making it unfavourable for wind action, resulting in no significant contribution to dune formation. Most of the sand samples collected along the foredunes and water edge were appropriate for sediment transport. Shannon and Simpson's Diversity Index was calculated as 1.48 and 0.67 for natural area as compared to 0.71 and 0.35 for the disturbed area, which indicate unfavourable species diversity for dune restoration in disturbed areas.

The research also focused on the spatial and temporal changes in land use and land cover in NW beach area of Point Pelee using aerial photos for 1959, 1977, 2006 and 2015. Different time series of the aerial photos were chosen based on their availability. The Ecological land

classification system for Southern Ontario were used to classify the aerial photos for land use and land cover (LULC). LULC classes included Shoreline vegetation, Deciduous thicket, Sand Barren and Dune Type, and Infrastructures (includes Transportation and services) for the entire Northwest Beach area. Segmentation and classification tools was used to classify four different time series of aerial photos.

Grain size distribution and vegetation assemblage for dune associated species were calculated to determine the factors limiting habitat restoration process. Based on the results alternate management strategies for dune restoration in Point Pelee were recommended. The study offers key insights on the importance of timely detection, analysis and visualisation of dynamic changes for habitat restoration and maintaining ecological integrity of the Northwest beach area of Point Pelee.

Key Words: sand dune, species diversity, restoration, Five-lined skink, habitat change detection, aerial photo, segmentation, land cover and land use

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CHAPTER 1

Introduction

1.1 Background

Point Pelee National Park is a complex landscape that comprises of extensive wetlands along with beaches, dunes and forests. Wetland ecosystems are vital to the social, economic and ecological health of Canada, and constitute a prominent feature of the Canadian landscape, representing approximately 14% of Canada's total land area, and an estimated quarter of the world's wetlands (Kennedy and Mayer 2002). However, major modifications in the ecosystem structure and functions resulting from the increasing impacts of human and natural drivers. This thesis examines significant ecological disturbances that have occurred over several decades in Point Pelee National Park (PPNP), Canada. Both human (e.g., infrastructure development, promotion of tourism, landscape modification, policy changes) and ecological (e.g., lake level changes, shoreline erosion, habitat modifications) drivers have contributed to these disturbances (Trenhaile and Dumala, 1978; Trenhaile et al., 2000). The outcome of the impacts from these drivers have created many resource management challenges in Point Pelee, including conservation and protection of a number of species at risk.

Point Pelee National Park is located at the confluence of the Mississippi and Atlantic flyways (State of the Park Report, 2006). It has rare and unique characteristics in comparison to the rest of Canada that includes the Carolinian life zone. This zone in PPNP supports over 70 tree species, 27 reptile species and more than 20 species of amphibians (Parks Canada, 2015). The Park is also a critical habitat for more than 380 species of migratory birds and a wide variety of insects like the monarch butterfly (Parks Canada, 2010). PPNP protects four different ecosystem

types – wetland, Great lakes shore, savannah (non-forest) and forest (State of the Park Report, 2007). The park supports more than 750 native species of vascular plants and currently has identified 66 Species at Risk within its boundaries (Parks Canada, 2010). There are at least 18 globally rare and 42 provincially rare vegetation communities represented, many as mere remnants (Reid, 2002). The park was also recognised internationally as a Ramsar Convention site of wetland significance in 1987 (State of the Park Report, 2006).

Point Pelee National Park is located in Essex County and is about 50 km south-east of Windsor, Ontario. About 70% of the Point Pelee National Park consists of marshes and the remainder is dryland forest, swamp forest, beach, and red savanna (Smith and Bishop, 2002; Trenhaile and Dumala, 1978). Point Pelee National Park consists of approximately 420 hectares of dry land and 1070 hectares of freshwater marsh (Parks Canada 2003a; 2015). It is one of the most biodiverse Parks in Canada, lying within the Carolinian zone and extending to Lake Erie. The Carolinian life zone contains about 25% of Canada's population and consists of only 0.25% of Canada's total area (Parks Canada, 2003). The park was declared an important Bird Area by Birdlife International in 1998 and a Monarch Butterfly Reserve in a Canada-Mexico declaration in 1995 (Parks Canada, 2006).

PPNP hosts a variety of ecosystems, including savannah, marsh, forest, swamp forest, dunes, and beach. Values such as recreation, landscape beauty and conservation of biodiversity have gained prominence alongside traditional wood-production values (Store and Kangas, 2001). The two most important ecosystems, Carolinian Forest and Great Lakes Marsh are located within the Park (Parks Canada 1994). It is open year-round and receives average visitors over 300,000 annually (Parks Canada, 2010).

Since Point Pelee was declared as a National Park in 1918, there have been large scale modifications in terms of land use and land cover. Prior to establishment of the Park there were many private houses, cottages, camp grounds, and agricultural activities by the people who resided inside the Park. Even though Parks Canada removed the residences inside the park area, Point Pelee's landscape has remained subjected to significant developmental activities leading to ecosystem modifications. These include conversion of Park area into agriculture and other human usage, and an overall increase in infrastructure development such as an extensive road network and facilities for visitors. Prominent among its several impacts, ecosystem changes have posed a serious threat to the sand dune habitats that host Five-lined Skink (*Plestiodon fasciatus*).

Northwest beach (Figure 1.3) is in the sand dune ecosystem of the north end of PPNP. It is a heavily impacted beach area with largescale modifications in the structures and functions of dune ecosystem through both anthropogenic and environmental impacts. Dunes were mostly impacted when boardwalks, parking bumpers and comfort stations were installed in 1960s - 1970s (Dale and Byrne, 2010; Parks Canada 2001). The site contains compacted soil and gravels. NW beach is mostly impacted by informal paths created by visitors to get to the beach area.

It has been recognised that one of the biggest potential threats to lizard species in Canada is the loss of their habitat (Seburn and Seburn 2000; Quirt et al. 2006; COSEWIC 2007). Only one species of lizard exists in the province of Ontario, the Five-lined Skink (*Plestiodon fasciatus*) formerly *Eumeces fasciatus*. Hecknar and McCloskey (1998) noted that the five-lined skink experienced declines in their abundance in its southern Ontario populations because of conversion of suitable habitat to agriculture, urban development and commercial and recreational purposes. The species was listed in the Species at Risk Public Registry by COSEWIC as of

February 27, 2008 and it was assigned an endangered status. Habitat restoration is a top priority to conserve and protect Five-lined Skink (*Plestiodon fasciatus*). **Table 1.1** lists important features and functions of different habitats for Five-lined Skink. Due to the impact of human activity in the study area, these features have been greatly degraded. Consequently, it is important to consider the listed criteria for skink habitat restoration. This research focuses on one of the habitat types (i.e., sand dunes) which is considered as an important factor affecting their populations and rated as highly disturbed.

Table 1.1: Features, functions and disturbances status for Five-lined Skink habitats

Habitats	Features	Functions	Level of disturbance	References and Sources
Carolinian forest	Wood debris	For nesting	Medium	Hecknar, 1994
Sand Dunes	Basking	Nesting, hibernation	High	Vincer, 2009, Dale & Byrne, 2010
Boulders and logs	Large rocks and logs	Provide thermal gradient & protection from predators	Medium	Downes & Shine, 1998; Seburn, 1992
Lake Erie shore line	Wet and dry sand	Moisture	High	Howes and Loughheed, 2004
Beaches	Open sand	Moisture	Medium	Hecknar, 1994

1.2 Problem Analysis and Rationale of the Study

In the early 1960s, large areas of sand dunes were heavily impacted by the creation of parking lots near Northwest Beach. In the 1970s a boardwalk, comfort zones and parking bumpers were installed (Dale and Byrne, 2010) to accommodate, expand and attract more tourism. It was later realised that such drastic modifications in the natural landscape of Point Pelee created adverse impacts on the park ecosystem as sand dunes are important ecological habitat for five-lined skink. It was also increasingly clear the land use changes neglected the protection and conservation values held by National Parks of Canada. In particular, it led to the

destruction of sand dune habitats of the endangered five-lined-Skink (addressed as endangered species in 2007). Parking lots were removed in phases. Phase 1 was in 2007 during which one of the parking lots with comfort stations and bumpers was removed (Dale and Byrne, 2010). Other phases followed by 2014. In 2015, a new paved parking lot was installed decreasing the parking foot print. However, it has been difficult to restore the sand dune habitat due to other changes and their adverse impacts on the dune ecosystem.

Between 2007 and 2008, one of its parking lots with comfort stations and bumpers were removed to rehabilitate lost dune habitat in Northwest beach (Figure 1.3). Invasive and meadow species populated the area and did not contribute to the dune development process. Recently, in 2015, mounds of sand from an excavation at the visitor's center were placed in the NW beach as a part of the dune restoration process in the hope of providing a sand supply. Overall, large-scale modifications of the natural landscape in Northwest beach of Point Pelee National Park through continuous human interventions have created adverse impacts on the natural habitats of Carolinian fauna and flora. Conservation and protection of these species through habitat restoration has remained a key challenge for managers.



Figure 1.1: 2009 photos showing boardwalk in NW beach of Point Pelee. The site had formerly been dunes prior to the parking lot construction. The photos show the extent of damage (photo courtesy: Dr. M-L Byrne).

Following the development of infrastructures and facilities, it was realised that dune (Dale and Byrne, 2010; Nature Ontario, 2010) ecosystems in Point Pelee supported a number of species, including species at risk. Most importantly, it hosts the Five-lined Skink (*Plestiodon fasciatus*) which is an endangered species of indigenous lizard that is only found in Ontario (Dale and Byrne, 2010; Recovery strategies Report, 2010). It was also found that conservation of Five-lined Skink is directly linked to the status of sand dunes. Since the Five-lined Skink has an endangered status, urgent actions were initiated by Parks Canada for rehabilitation and re-establishment of dunes in Point Pelee as critical habitats. To address its status, the most important element is to restore its habitat. Several studies have been undertaken and many others now underway exploring possible measures for effective sand dune restoration and their sustainable management in order to address the conservation challenges (e.g., the sand dunes and their habitat dependent Five-lined Skink) in Point Pelee (Mayer et al., 1999; Dale and Byrne, 2010; BaMasoud and Byrne, 2011, 2012; Howes and Loughheed, 2004). However, no significant improvements in the restoration and rehabilitation of sand dunes have yet been achieved. There is an urgent need for comprehensive and combined analysis of key characteristics and factors for sand dune restoration in Point Pelee. Currently, Parks Canada is rehabilitating and re-establishing sand dunes in the former parking lot through planting of native species (Marram grass), bulldozing, levelling and scraping sediments to re-establish the process of sediment movement that could potentially lead to dune formation. Even though an active restoration process is in progress, the positive results are not yet obvious. This provides a rationale for undertaking a study that can help better understand the complex problems in NW beach sand dune ecosystem and offer recommendations for its future management.

Within Point Pelee National Park, this research focusses on Northwest Beach area because it has remained a focal point of management and conservation in the past decades. This particular beach area was most exposed to park development activities leading to significant modifications in its ecosystem structure and functions, and consequently remained the main target for management and conservation interventions over the past decades. **Figure 1.2** shows location of Point Pelee national park. **Figure 1.3** shows the location of Northwest beach area in which this study was conducted.

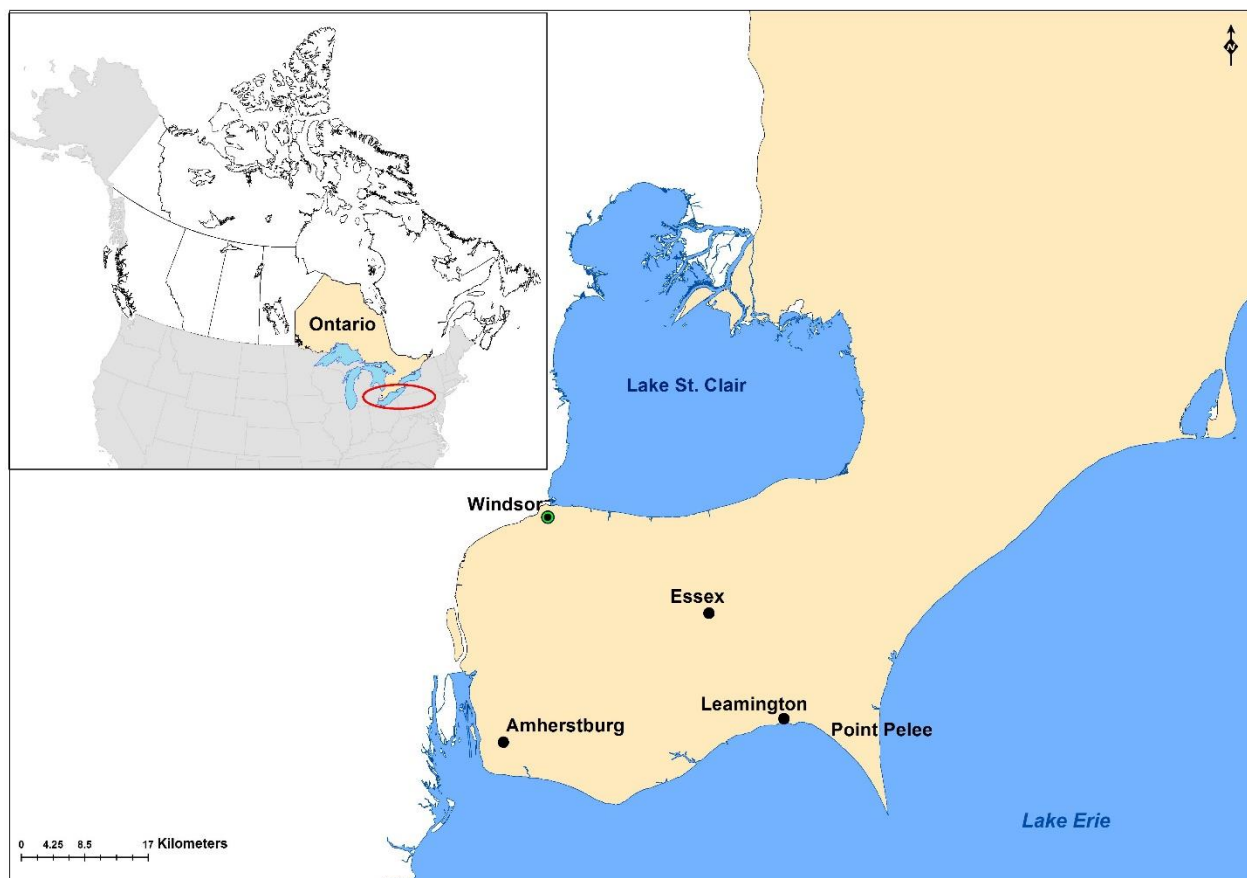


Figure 1.2: Study Site, Point Pelee National Park, Ontario (Source: ArcGIS Online)



Figure 1.3: Shows the location of Northwest beach of Point Pelee National Park, Ontario. (Source: Google Earth, 2015)

1.3 Research Goal and Objectives

The overall goal of this research is to understand the dynamic processes of sand dune formation by examining selected factors that have either limited or facilitated growth of dunes in Northwest beach of Point Pelee. To meet this goal, specific objectives are:

1. To examine the grain size suitability for dune restoration in NW beach.
2. To determine the level of variability in the vegetation assemblage and characteristics of dune-associated species for dune restoration.

3. To analyse factors responsible for land use and land cover change and its impact on dune restoration process.

Details of the research and sampling approach for meeting these objectives are described in Chapter 3 (Method Section).

1.4 Thesis Structure

The thesis is divided into five chapters. **Chapter 1** provides an introduction to the thesis through background information and problem analysis. It outlines the goal and specific objectives of the research, and places the study context into perspective. **Chapter 2** engages with review of key literature areas relevant to the objectives of the thesis. It also provides detailed description of the history of changes in Point Pelee ecosystem structure and functions, key drivers influencing those changes, and offers some reflections on the need for restoration. Sand grain size distribution, dune associated vegetation species diversity and land / land convers change analysis are discussed as three literature areas. **Chapter 3** outlines key methods used in the study. This includes methods used for data collection (e.g., sand samples, vegetation sampling) and data analysis (e.g., object oriented approach using LULC classification), and specific justifications for using such methods. **Chapter 4** provides a detailed profile of the study site. In addition, it includes visual interpretation of aerial photos of 1954 and 2015 to show the development of shoreline erosional structures and the extent of their influence on sediment transportation to Northwest beach area of Point Pelee. **Chapter 5** presents results obtained though field data collection and provides a discussion based on analysis of the results. The results and discussion are focused on critically analysing the role of sand grain size distribution, dune associated vegetation diversity, land use and land cover change in development and

restoration of Point Pelee sand dunes on its Northwest beach. **Chapter 6** draws major conclusions from the analysis done in chapter 4, and offers some recommendations for restoration and management of sand dunes, and their dependant habitats, in Point Pelee National Park.

CHAPTER 2

Literature Review

2.1 Introduction

This chapter provides a conceptual background to the research problem and sets a theoretical direction for the thesis. The research objectives are largely based on the problems in Northwest (NW) beach of Point Pelee and understanding of those problems is a key determinant for moving towards processes of restoration. Therefore, this chapter first outlines the major changes in sand dune structure and function that have taken place in NW beach over the last few decades because it is the time when the greatest human impact from trampling and beach user access occurred. In order to bring further clarity to these changes, a detailed discussion of the key drivers is undertaken, following which possible restoration strategies are discussed. Next, this chapter focusses on some of the key attributes of sand dune restoration, i.e., grain size distribution, vegetation assemblage and character of dune associated species, land use and land cover change. The final section of this chapter provides an understanding of these key areas based on the literature review. Further information on each of these three areas appears in chapter 4 (results and discussion).

2.2 Understanding key changes in NW beach of Point Pelee

Point Pelee National Park has diverse ecosystems, including savanna, marsh, forest, swamp forest, dunes and beaches (Parks Canada 2010). Sand dunes are particularly important ecosystems that support a number of species (Kotler 1984), among which are species at risk. Most importantly, sand dunes host the Five-lined Skink (*Plestiodon fasciatus*), an endangered

species and only indigenous lizard in Ontario (Dale and Byrne 2010). Sand dunes as well as sandy beaches along the shore line of Lake Erie are crucial locations for the Skink to bask in the sun for thermal regulation. In particular the female skink absorbs heat on the dunes which they use to warm their eggs (Ontario Nature, 2010). Dunes are also critical as places of hibernation for the Skink and other species. Sand dunes also provide a buffer between the waves and the Carolinian forest, thereby acting as a barrier to shore line erosion and loss of forest to the lake. However, in the past few decades, these multiple functions of sand dunes have been lost to a great extent due to large scale structural modification and, in some cases, complete destruction of sand dunes. This has resulted in a sharp decline of the Carolinian population of the Five-lined Skink which is primarily attributed to significant loss of their sand dune influenced habitat (Howes and Loughheed 2004; Hecknar and M'Closkey 1998).

The ecological changes noted above in the structure and function of sand dunes have been reported by many studies which focused on various elements contributing to sand dune formation. There are also geomorphological changes prominent among those include analysis of progressive merging of beach ridges and dunes (Coakley 1975, Trenhaile and Dumala 1977), shifts in sedimentary processes (Davidson-Arnott 1994, Byrne 1997), shoreline changes and beach erosion (BaMasoud and Byrne 2011; Hartfield 2010).

2.2.1 Historical analysis of change in structure and function of sand dunes in NW beach

Sand dune restoration activities cannot be successful without proper understanding of the formation and evolution of sand dune structure and function. Point Pelee originated as a sandy

foreland enclosing a marsh approximately 4000 years BP. Point Pelee was formed initially by the progressive merging of beach ridges and dunes formed on opposite sides of the Pelee-Lorain moraine when rising lake levels in the western basin of Lake Erie were 3-4 metres below present lake datum (Coakley 1975). However, considerable controversies exist regarding the processes and mechanisms leading to the formation of sand dunes in Point Pelee (Coakley 1976).

According to Wilson (1903), Terasmae (1969) in Coakley (1975) and Kindle (1933), deposition of longshore drift from eroding areas to the east and west is the major sand source needed in the formation of Point Pelee sand dunes.

Similar to formation and evolution of sand dunes, as discussed above, there are a wide range of views on various aspects of changes in sand dunes of Point Pelee. Trenhaile and Dumala (1977) studied the geomorphology of sand dunes by considering four distinct morphological units, i) dune units, ii) the ridge and trough, iii) the sand plains and iv) ridges in order to analyse change. Their study offers critical understanding of the processes of changes in sand dune. It also provides a baseline on the status of sand dunes against which to compare recent changes due to dune degradation. BaMasoud and Byrne (2011) examined trends in the extent of Point Pelee shoreline change for the period of 1959-2004. They extended the findings of earlier studies on mean annual rates of shoreline changes during 1918-1973 by Coakley 1977.

Major modification in the sand dunes of Point Pelee took place during 1960s when parking lots were created by replacing existing dunes. Further changes in sand dunes took place in 1970s through installation of boardwalks, parking bumpers and comfort stations (Dale and Byrne 2010). These interventions affected sand transport and have created long term impacts on the processes of sand dune formation.

2.2.2 Key drivers and their impacts on sand dunes

The changes noted in the above section have been largely influenced by both climatic and anthropogenic drivers. Several drivers of change have influenced the ongoing processes of ecological disturbance and habitat loss in Point Pelee. However, the focus in this section will be on the drivers that have directly or indirectly played a role in the modification of structure and function of sand dunes.

The role of climate in major modification of sand dunes is significant because it can cause long term or near permanent changes in dune structure and functions. Various factors have been considered to highlight the influential role of climate in relation to dunes. Variations in temperature have been observed in the Point Pelee region over the past several decades (Ricciardi, 2006). Fluctuations in temperature have significant consequences for sand deposition and erosion because temperature influences the level of sand moisture (wet and dry beaches) thereby causing excess or slow sand movement (Wiggs et al., 2004). Wind direction, velocity and condition have been noted as critical for sand dunes. Extensive work has been conducted that focuses on the role of wind in shoreline changes that has direct influence on sand dunes (Sherman, D. J. 1993). Wind-blown material provides sediments for a strong foundation upon which sand dunes are constructed (Trenhaile and Dumala 1977). Changes in the Lake Erie wind regimes have been recorded by BaMasoud and Byrne (2012). Combined with temperature fluctuations wind can influence the rate of sand movement, thereby the formation and long-term sustainability of dunes.

The Great Lakes, in general, and Lake Erie at Point Pelee in particular, experience intense storms throughout the winter. Recent studies report that most of these storms are intense

cyclonic systems (Angel 1996), that exhibit higher than normal wind speeds. High wind speed causes higher energy waves and intensifies wave action, both of in terms of strength and frequency (BaMasoud and Byrne 2012).

Lake level fluctuation is one of the principal variables of shoreline changes in Point Pelee (LaValle and Lakhan 2000). Rising lake levels influence shoreline recession where change in the shoreline is inversely correlated to lake level (BaMasoud and Byrne 2012). A rising lake level will cause the lake to move laterally inland across the shoreline, and a falling lake level will move the shoreline laterally lakeward (Crowe and Meek 2009). Such fluctuations in lake level can cause major changes in shoreline which can have direct impact on the sand dunes. BaMasoud and Byrne 2011, completed extensive research on temporal and spatial variability of shoreline changes in Point Pelee National Park over a period of five decades (1959-2004) and suggested a direct correlation with the rate of sand dune degradation. Others have suggested that the rates and patterns of beach erosion in Point Pelee have remained highly dynamic and spatially and temporally variable (Hatfield et al. 2010).

Ice cover also plays an important role in sand movement aiding or hindering sand dune formation. Shore ice coverage shields the lake shore from waves for extended periods during winter thereby offering protection to the sand shores (Assel et al. 2003), especially during storm activities which are known for their high intensity and frequency compared to other seasons. However, consistently low ice cover has been recorded in Point Pelee over the last couple of decades which exposes beach sediments deposited during other seasons to winter storm and high wind speed resulting in erosion (BaMasoud and Byrne 2012). Lack of ice cover, combined with winter storms and wind conditions, facilitates active wave actions. This causes the unconsolidated beach sediments to migrate offshore and onshore, and permanent loss of fine

sediments (e.g., fine sand, silts and clay) (BaMasoud and Byrne 2012). The fine sand would otherwise contribute to sand dune forming processes.

Intense erosion weakens and exposes the root system of the Carolinian vegetation ultimately resulting in their collapse and aggravating the process of landward erosion (Hatfield et al. 2010). Simulations of sea/lake level rise scenarios developed by the Intergovernmental Panel on Climate Change demonstrated that beach erosion constrained plants to a narrow area (closer to the coast, lower elevation, smaller than area in occurrence) resulting in high exposure to lake levels and breakdown of the successional process (Feagin et al., 2005, Garner et al., 2015).

There are a number of studies that focus on the role of ground water in influencing the hydrology of wetlands (Doss, 1993; Crowe et al 2004). It reflects on the relationship of effects of tides and waves on the ground waters and sediment transportation. There is a relationship between lake level rise, when there is a water table increase, which causes an increase in the moisture level in the beach, resulting in wet beaches (Crowe, 2009). During wet beach conditions sediment supply to the dunes is limited and dune development is slower. This has implications for how sand dunes are formed (Crowe and Meek 2009).

Global climate change, particularly sea-level rise, has added a new dimension to worldwide modification of shorelines (Jones et al 2007a; Schlacher et al., 2008b in Defeo et al., 2009). Climate change provides a larger context within which most physical processes contributing to sand dunes, as outlined above, are impacted. In other words climate change itself acts as a higher level driver that influences hydrology, geomorphology, biophysical and climatological factors associated with sand dunes. For example, there is evidence that coastal erosion is linked to global sea level rise which contributes to loss of sand dunes. Feagin et al., (2005) used a spatially explicit model of sand dune plant succession on Galveston Island, Texas

to suggest that sea-level rise is the primary mechanism causing local erosion. Northeast beach of Point Pelee suffered considerable erosional losses in the high water period of 1973, which was aggravated by a reduction in littoral drift caused by the construction of a large groyne at Marentette Beach, adjacent to the Northeast Beach (Crysler and Lathem, 1976). High lake levels with massive erosion were recorded during November 1985 and 1986, Parks Canada emplaced a series of concrete tetrapods along the northern 180m of the Northeast beach which was not effective (Lakhan and Trenhaile, 1989). Littoral drift, beach composition and sediment dynamics which are frequently impacted by climate change may affect sand dune habitats differently

Coastal erosion impacts 70% of Earth's sandy beach environment which may be caused by local (e.g., limited sediment supply) or global (e.g., sea level rise) factors (Bird 1985; Feagin et al., 2005). In particular, future climate change patterns are expected to result in western Lake Erie in the area of Point Pelee, likely resulting in a net loss to the Park's sand habitat (BaMasoud and Byrne 2011). Other direct impacts of climate change predicted for Point Pelee include; (1) change in water levels in Great Lakes leading to a drop in the water level of Lake Erie, (2) drastic reduction in winter ice cover (i.e., most of lake Erie will have 96% of winter's ice free), (3) sharp increase in temperature, (4) increase in winter and early spring storms, (5) high intensity wave action, and (6) negative accretion rates and increasing erosion – all of which can potentially impact sand dune structure and function (Scott and Suffling 2000; Lofgren et al., 2002; Mortsch et al., 2000; BaMasoud and Byrne 2011).

In addition to climatic factors a number of anthropogenic factors have contributed to the deterioration of sand dunes. A large section of the landscape surrounding Point Pelee has been used for agriculture and development. Increases in infrastructure development such as extensive road networks have been added to the park environment. This has contributed to the loss of sand

dunes. Housing and cottage development in the vicinity of the lake are found to be detrimental to dune growth (Feagin et al., 2005). Several beaches in Point Pelee are susceptible to human interference such as human made structures that were increasingly developed after Lake Erie experienced high water levels during 1972-1986. Such human interventions have led to short supply of sediments and subsequent higher rates of beach erosions (BaMasoud and Byrne 2011, 2012). Management of Point Pelee National Park has also witnessed a number of policy changes and related interventions which many scholars argue have adversely contributed to the loss of sand dunes. Significant among these, as discussed above, was the decision to create asphalt covered parking lots by removing sand dunes in the early 1950s (Parks Canada 2006).

2.3 Need for restoration

Given the processes of change in Point Pelee sand dunes there is an urgent need for restoration and management to protect the dunes from further degradation. The need for restoration is highlighted due to critical role sand dunes play in providing habitat to multiple flora and fauna species, most important among them are the five-lined Skink (*Plestiodon fasciatus*) and the Carolinian forests. Dunes are known for their significant role in maintaining ecological balance and ecosystem processes which requires that their structure and function be maintained on a continuous basis. Both the ecological and social roles and contributions of sand dunes have been highlighted in the literature. This indicates that the objective of sand dune restoration should focus on strengthening all the multiple functions played by sand dunes, which makes sand dune restoration a very complex process. In other words, achieving a balance between various ecological functions of sand dunes and between ecological and social functions complicates dune restoration and management. Consequently, different studies tend to focus on specific aspects of dune restoration, some of which are outlined below.

Vegetation plays a critical role in the building of dunes, binding of sediments, and reduction of erosion. Foredunes are formed by the continuous accumulation of wind-blown beach sand, which is trapped by burial-tolerant vegetation (Duran and Morre, 2013). Vegetation reduces wind speed, traps sand, stabilises surface sediment, provides habitat and improves aesthetic appeal (Schwendiman 1977; Hesp 1989). The dune species that are most useful in building foredunes rapidly react positively to sand burial (Maun, 1998). Moreover, these perennial species provide cover on the dunes throughout the year; if lost, erosion rates are certain to increase (Feagin et al., 2005). “The typical sand dune vegetation plays a fundamental role in dune stabilisation, consequently the loss of plant species that trap and holds sands makes the beach more vulnerable to wind and erosion” (De Lillis et al., 2004: 93).

Studies on beach erosion have a slightly different approach to restoration. As erosion is neither temporally nor spatially uniform along the parks eastern barriers, an understanding of the intensity and rate of erosion is an important prerequisite for the development of management strategies aimed at effective mitigation of this risk (Hatfield et al. 2010). Hatfield et al. (2010) suggested that some areas of the beach are under intense erosion, whereas other areas are fairly stable and are accreting (Hatfield et al. 2010). The study examined different sites to record the variation in the rate of erosion based on susceptibility. First the areas backed by open ponds and marsh and the second areas backed by ridge and swale complexes within mature Carolinian forest. It can be concluded from Hatfield et al. (2010) study that since erosion is not uniform in Point Pelee, we can learn from the experiences of areas with low intensity erosion and their contributing factors to implement restoration measures in areas witnessing high intensity erosion.

According to sedimentological studies (Hatfield et al. 2010; Ciopps et al. 2010), sands on the east beach of Point Pelee are characterized by a significant presence of quartz and calcite

along with concentrations of heavy and magnetic minerals, materials creating high susceptibility on the beach leading to long term net erosion. Hatfield et al. (2010) mapped magnetic susceptibility along the eastern beach of PPNP to identify areas under increased erosion and concluded that 2.4 km of the beach area was high in erosion.

Dale and Byrne (2010) made further recommendation on arresting sand erosion and restoring sand dunes. They identified the areas of accretion and erosion to calculate the volume and rate of sand transported. Sedimentological work was undertaken in order to study the sand movement, which included the measurement of grain size and moisture content. Additional factors influencing sand movement, such as water table position (Crowe, 2004), moisture content (Byrne and Bitton, 2001; Bauer et al. 2009; Davidson-Arnott et al., 2005), density of vegetation cover (Maun, 1989; 1994), wind condition (Sherman, D. J. 1993) and human interventions (Miyasaka et al. 2016) were considered.

2.4 Key areas for sand dune restoration

This sections briefly deals with three important factors, (i) sand grain size distribution, (ii) vegetation assemblage and character of dune species, (iii) land use and land cover change, for sand dune restoration processes in the NW beach of Point Pelee. The objectives of the research align with these three factors.

Grain size and its distribution is an important and a basic criterion for restoration of dunes in a heavily impacted beach area. If there is favourable sediment supply and wind velocity, availability of proper grain sizes tend to facilitate dune development. Therefore, examination of sand grain size distribution can answer why there might be a delay in dune development and restoration process. The literature recognises grain size distribution as an important factor in

understanding dune formation and development (Zhang and Dong, 2015; Blott and Pye, 2001; Lancaster, 2009).

Second, vegetation assemblage and character of dune associated vegetation is an essential component of dune restoration. Once it is determined if the sediment grain size in NW beach is appropriate for dune development, the next step is to assess if there is enough dune associated species available that can trap sand and hold it in place with its rhizome root system (Maun 2009). Wind helps in carrying the sand, which ultimately gets trapped in the dune vegetation. Dune associated vegetation acts as a positive barrier for sand movement and helps processes of accumulation of sand. With wind direction and velocity, the trapped sand changes shape and size. Hesp (2002) recognised that morphological development of dunes principally depends on plant density, distribution, height, cover, wind velocity, and rates of sand transport.

Third, land use and land cover change help determine the changes that have taken place in sand dunes (Gracia-Ruiz, 2010; Wijtkosum, 2012; Ales and Martin 1997). Remote sensing and GIS are effective tools to classify land use and land cover. Change in land use and land cover for different time series facilitates recognition of the changes that have impacted the dunes and disturbance in the ecosystem as a whole.

2.4.1 Grain size distributions

Intense coastal development, the inevitable consequence of economic progress, has resulted in widespread modification of sandy beach ecosystems (Defeo et al., 2009). As discussed in Chapter 1, increased shoreline control protection structures and other infrastructural development activities have restricted significant sediment inflow to the beaches or to the coast of Point Pelee. Consequently, sand dune restoration has remained a significant focus. This is

particularly important because the dunes of NW beach of Point Pelee provide critical habitat to the Five-lined Skink (*Plestiodon fasciatus*) (Dale and Byrne, 2010; Vincer, 2009).

Sediment transport rates depend on a number of factors that include the character of the sand surface, such as grain size, slope, roughness, vegetation (Zhang and Dong 2015; 2014), and moisture content (Coakley, 1975). It also depends on the attributes of the wind field, such as average wind speed (Sherman, 1993), unsteadiness, approach angle, flow compression, boundary layer development (Bauer et al. 2009). Moisture content is widely acknowledged as an important factor in controlling release of sediment from the dry surface (Bauer et al. 2009, Davidson-Arnott et al., 2005). Bauer et al. (2009) mentioned that moisture effect has two major influences in sediment transport. First, in a temporal sense, the rate of sediment transport decreases with higher precipitation and increases with dry surfaces. Secondly, in a spatio-temporal sense, shoreline excursion associated with nearshore process (e.g., wave run-up, storm surge, tidal excursions) constrains the fetch geometry of the beach, thereby narrowing the width of the beach. Under such constrained conditions the transport system begins to shut down unless wind angle becomes highly oblique thereby increasing fetch distance (Bauer et al 2009). Sediment flux at any point across a sandy surface is dependent on the wind stress, grain size, and available sand supply, as well as host of other complicating factors such as moisture content of the sand surface, grain size sorting, bed roughness, beach slope (Hardisty et al., 1988; de Vries et al., 2012), vegetation cover (Arens 1996, Bauer et al. 2009), and various surface heterogeneities that confound the general equilibrium models (Sherman and Hotta, 1990). Supply limited conditions arise when the wind driven transport capacity cannot be reached due to lack of sediment supply (Vries, S. de et al., 2014).

Presence of the above conditions significantly impacts NW beach in Point Pelee. There is a long history of sand and gravel dredging in south-east offshore from this coastline of Point Pelee. Shaw (1978) stated that sand and gravel dredging in the three kilometres area to the south of Point Pelee as well as dredging of offshore sand and gravel deposits took place at an average rate of 160,000 m³/yr. On the eastern side of Point Pelee there are no natural barriers for littoral drift at the southern limits of the park and much of the sediment moving southward is likely to get deposited offshore in deep water (Baird and Associates, 2006). Whereas on the west side of Point Pelee, mainly at Kingsville, Colchester and Leamington harbours, it is heavily armoured with hardened erosional structures which are not permeable enough, thereby restricting sediment supply to NW beach of Point Pelee.

These shoreline developments up-drift of the park have an adverse impact on the sediment supply to the park beaches. Whatever sediment flow resulting from longshore drift is being deposited in the deeper side of the central basin (Chapter 4, Figure 4.3) of the Lake Erie east of Point Pelee, there is not much left for the wind and wave action to deposit along the NW beach of Point Pelee (Braid and Associates, 2006). Vries et al. (2014) argued that in such supply limited conditions, both critical fetch length and maximum transport can be a function of supply rather than wind driven sediment transport capacity. They also stated that average sediment concentration could be determined to a great extent by the available supply rather than the wind speed. Bauer et al. (2009) argued that sand transport is related to wind speed, shear velocity and moisture content, but they did not mention about the limited sediment supply. Water level is an important consideration in sand transport because when the levels are high the beach is narrow and supply is limited and when the water levels are low the width of the beach is wider therefore

sediment supply is greater (Byrne and Bitton, 2001). However, transport capacity cannot be reached if there is insufficient supply (Vries et al. 2014).

Grain size distribution is an important factor that plays a substantial role in the sediment transport. Grain size controls creep, reptation, saltation (Hesp 2002) and suspension in dune formation and development (Zhang and Dong 2015). Elsewhere it is noted that grain size parameters can be used to determine sediment material deposition environments (Sahu, 1964, Dong et al. 2011; Zhu et al. 2014). Zhang and Dong (2015) used grain size parameters and grading standard provided by Folk and Ward (1957) to analyse sediment deposition rate. Sahu's hypothesis (1964) states that sediment grain size reflects grain mobility and energy of the deposition area.

Dale and Byrne (2010) made further recommendations on arresting sand erosion and restoring sand dunes by identifying areas of accretion and erosion to calculate the volume and rate of sand transport. Sedimentological studies focus on sand movement, which includes measurement of grain size and moisture content (Wiggs et al. 2004). Factors influencing sand movement include water table fluctuations, sand moisture content, vegetation cover density, wind condition and human interventions (Crowe 2004; Davidson-Arnott et al. 2005; Maun 1989; Sherman 1993; Miyasaka et al. 2016).

2.4.1.1 Dune development Processes

An important requisite for sand dune development includes availability of sand supply from the longshore drift, favourable onshore wind action that blows sand inland and evenly distributed dune associated species to trap sand. Dune species restrict sand from being blown away and facilitate sand accumulation. This process contributes to dunes development. Dune formation

requires that deposition of sediments is greater than erosion. Additionally, appropriate grain size is an important factor in dune formation.

Figure 2.1 shows that the waves help carry the sediments to the shore, and wind helps movement of the sediment particles. The movement of particles depends on their size. Coarser particles undergo a mechanism called reptation (Gutierrez, 2013) or creep, sliding along the ground and moving slowly, whereas the movement of medium size sediment particles is referred to as the saltation mechanism (Gutierrez, 2013). Small and very fine size or texture sediments are suspended in the air and then carried away to a greater distances. **Figure 2.1** shows the mechanisms through which wave and wind action facilitate sediment movement and deposition.

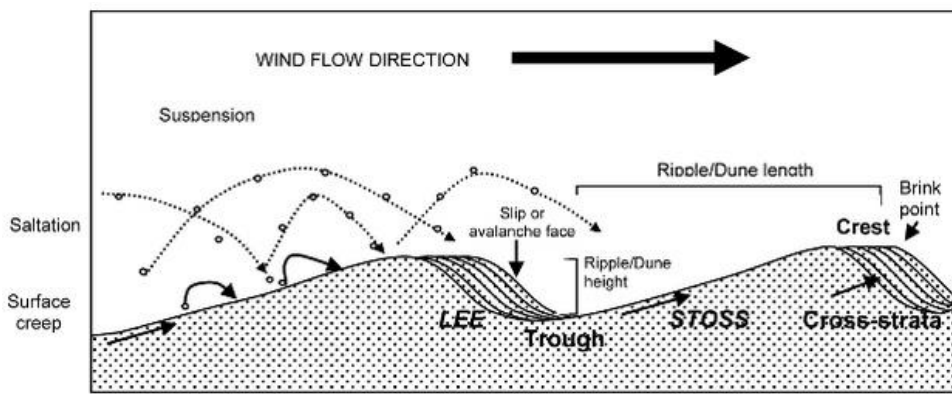


Figure 2.1: Action of wind facilitating sediment transport (Source: Sloss et al. 2012)

Sediments are carried by the wave action to the shore, carried further onshore and with wind, sediments are carried offshore resulting in sand bar or dune formation (**Figure 2.2**). Sediments are trapped by the dune associated vegetation and gradually accumulate to form dunes. Sediments of larger sizes are carried back offshore. This cycle repeats with wind direction, wind velocity, vegetation and availability of favourable sediment sizes for dune development.

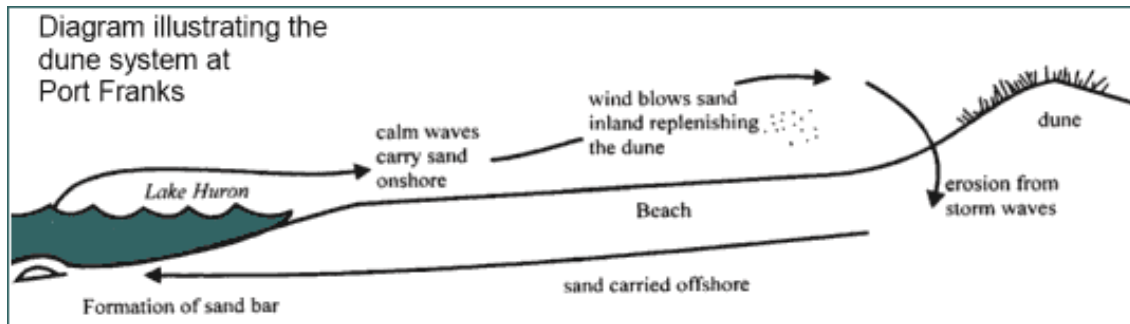


Figure 2.2: Sediment transport by wind and wave action resulting in dune development (Source: <http://lakehuron.ca/index.php?page=port-franks-sand-dune-conservation>)

2.4.2 Dune Vegetation

The typical sand dune vegetation plays a fundamental role in dune development, consequently the loss of plant species that trap and hold sand makes the beach more vulnerable to wind and erosion (De Lillis et al. 2004). Dune development and maintenance requires a sand supply, a positive sediment budget and vegetation to trap and hold the sand (Lancaster, 2009; Nordstrom and Nancy L. Jackson, 2013). The morphology of a dune is dependent on the plant species, plant architecture, density, height, sediment texture, wind velocity and the rate of sand transport (Hesp 1989). Dunes are formed when wind blows and the sediments are deposited within the vegetation. These vegetation are dune species, that trap sand and acts as an obstacle for the sediments from being blown away further. Healthy vegetation is an indicator of the health of the dunes environment. Species diversity is important to determine density and richness of the dune associated vegetation in order determine process of restoration.

Carter (1991) distinguished between sand-fixing vegetation such as *Atriplex* species and sand-building grasses such as *Ammophila* species (Marram grass) or *Elymus arenarius*. Vegetation provides a shield to sand dunes and restricts coastal erosion. Vegetation is considered

as one of the most important indicators of coastal erosion, which influences sand dunes (Miller, 2015; Peterson and Dersch, 1914).

Diversity is a composite measure that reflects richness, dominance, density, evenness. MacArthur (1955) suggested that diversity contributes to stability because increased diversity also increases the frequency and complexity of interactions in a biotic community. Au Clair and Golf (1971) indicated that change in evenness is correlated to changes in diversity. Evenness in a community is determined by the spread of the species in the area being sampled. However, to facilitate dune growth and maintain dune stability it is essential to maximise the vegetation cover of the associated species (Hesp, 1983). Density is the average number of individuals of a species on a unit area basis. Dominance is defined as the area a species occupies on a unit area basis. Evenness refers how close in numbers the species are present in a community. Richness is defined as a number different species in a community (Environment Canada, 1999).

Habitat loss is the single largest threat to biodiversity and is likely to be more significant than climate change in this century (Sala et al. 2000). Diversity is associated with variables such as evenness and richness. Importance of biodiversity for maintaining healthy, stable, and functional ecosystems has been emphasised (Chapin et al. 2000; Mustard et al. 2004). Hesp (2002) stated that high density clumps of *Ammophila breviligulata* and *Ammophila arenaria* reduce the air flow and produce dunes with a gentle seaward slope. Among the dune associated species, *A. breviligulata* is more efficient in trapping sand than other dune species (Seneca et al. 1976). Arens (1996) studied the patterns of sand transport on vegetated foredunes and observed that most of the sand is deposited in the vegetated dunefoot.

Studies on vegetation highlight that maintenance of early-succession plant species is critical, as they are usually the most important dune building species, binding sediments, and

reducing erosion (Feagin et al. 2005; Morrison and Yarranton, 1973). Early-succession perennial species provide cover on the dunes throughout the year; if they are lost, erosion rates are certain to increase (Feagin et al. 2005). “The typical sand dune vegetation plays a fundamental role in dune stabilisation, consequently the loss of plant species that trap and hold sand make the beach more vulnerable to wind and erosion” (De Lillis et al. 2004: 93).

2.4.3 Land Use and Land Cover

Land use is defined as the human use of land while land cover can be defined as the biophysical state of Earth’s surface (Turner et al. 1995). Land use is related to human use of land for agriculture, plantation, built-up. Land use and land cover is essential to evaluate the delayed results in dune restoration process in contexts such as Point Pelee. Land use being the main resource controlling primary productivity in ecosystem (Darwin et al. 1996) it was important to assess the patterns of land use and land cover change at Point Pelee through different time series. Aerial photographs of different time series were used to visualise the impacts of change from 1959, 1977, 2006 and 2015. Longitudinal studies related to land use and land cover have been effective in monitoring and evaluating the consequences of change (Adolphus and Akinbobola 2014; Wondrade et al. 2014; Rawat and Kumar, 2015; Shalaby and Tateishi, 2007; Reis, 2008). The destruction and modification of natural habitats resulting from land use change are among the most important and immediate threats to biodiversity (Newbold et al. 2015). Land use and land cover change are widespread and accelerating process, mainly driven by natural phenomena and anthropogenic activities, which in turn drives changes in the natural ecosystem (Ruiz-Luna and Berlanga-Robles, 2003; Turner and Ruscher, 2004). Such impacts have adverse results similar to what the NW beach in Point Pelee is experiencing. Attention to land use and land

cover changes will help improve planning for appropriate interventions for sustainable management, policy changes and planning. Land cover changes can impact ecosystems, environment and regional sustainable development. In specific reference to sand dunes, Gracia-Ruiz (2010) and Wijitkosum, (2012) suggested that there is a strong impact of land use and land cover change on erosion and sediment transport. Results from these type of studies provides useful information to local government for decision making, policy and planning. Similarly, land use is a fundamental parameter for measuring human impacts and for understanding human-environment interactions (Miyasaka et al. 2016).

In terms of methods to assess land use and land cover changes, Miyasaka et al., (2016) used object-based classification to generate a digital surface model using GIS and obtained high accuracy results. Monitoring of land use and land cover changes are necessary to design better management interventions and policy plans. Documenting change in land use and land cover using different time series is appropriate to manage and to help expedite the restoration process. Classifying change for different time series can provide analytical details relevant for a restoration process.

2.5 Conceptual Framework

Figure 2.3 depicts a causal diagram linking key drivers with restoration needs in NW beach ecosystem. Three key attributes of the sand dune development process, i.e., grain size distribution, vegetation assemblage, land use and land cover, are impacted by a set of climatic, geomorphic and anthropogenic drivers leading to changes in the sand dune ecosystem. The need for restoration of sand dunes results from extensive changes in the dune ecosystem over the decades. **Figure 2.3** suggests that the extent of dune degradation can be assessed by examining

the attributes facilitating dune development. Each attribute has a number of variables that need to be examined as well. The specific variables include 1) sediment supply, wet and dry beaches, beach width, position of water table for grain size distribution, 2) species richness, evenness, density for species of the dune associated vegetation, 3) lake level, development of infrastructure and facilities for land use and land cover. Further, key restoration measures can be designed based on the specific types of drivers and extent of change in NW beach of Point Pelee.

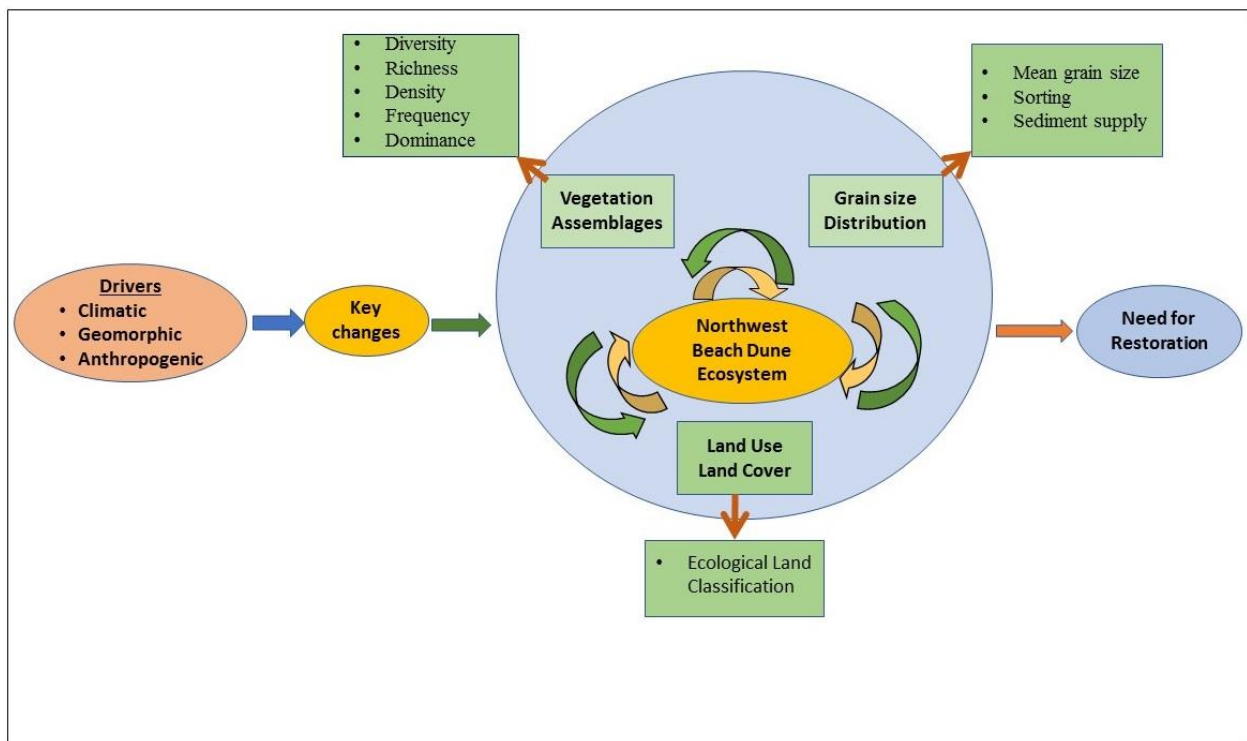


Figure 2.3: Conceptual framework for analysing sand dune restoration of NW beach of Point Pelee. Objectives of the research undertaken were the three most important fundamental aspects of dune restoration. Grain size measures the physical parameters for sediment transport, vegetation measures the parameters required to trap sand and slow down the wind velocity for dune development and LULC change directs for better management planning to restore dunes.

CHAPTER 3

Research Methods

3.1 Introduction

This chapter outlines the methods used to accomplish the outcomes of the research. It includes collection and analysis of sand samples, vegetation samples, land use and land cover (LULC) change classification. The chapter also provides details on methods used to collect the field data and data analyses. A detailed work flow for land use and land cover are explicitly mentioned along with data used and sources of the data. Restoration of skink habitat focusses on the rehabilitation of sand dunes in Northwest beach area. Three different aspects of sand dune rehabilitation were examined as part of this study and appropriate methods were used. First, this study focussed on the factors limiting and facilitating sand dune development processes. One of the important factors of sand dune development is grain size distribution. Calculation of mean grain size and sorting to determine if the sand is appropriate for dune building. Second, vegetation characteristics of the dune associated species were considered because dune associated species help trap sediments and facilitate growth of sand dunes. Third, land use and land cover change of different time series to assess the factors limiting the growth of dunes in the Northwest beach area of Point Pelee.

To examine these three objectives, a reconnaissance survey was first done to become familiar with the field context. Meetings were organised with Parks Canada staff during October -November 2015. Permission for field visits and data sharing was obtained from Parks Canada. During the field visits, sand and vegetation samples along with GPS points were collected. MS Excel was used to calculate the mean grain size and sorting of the sand samples, and to calculate

diversity indices and richness. For LULC change detection analysis, training samples for each LULC class were collected (GPS) during field visits. These training samples were used first to classify 2015 aerial photo and then proceeded with other time series using Ecological Land classification system for Southern Ontario which was available by Parks Canada. ENVI 5.2 and ArcGIS 10.2 software were used for classification of the orthophotos. Specific details about methods used to assess each objective are discussed below.

3.2 Methods for calculating grain size distribution

Sediment grain size distribution is important in aeolian research, as grain size controls creep, reptation, saltation and suspension in the dune formation and development (Zhang and Dong, 2015). Transportation of sediments depend largely on the wind velocity which is the predominant source in controlling sediment transport. Wind action helps facilitate sediment transport depending on the variability in grain sizes. Finer grains are blown away quickly as compared to the medium and coarser sizes.

Stratified random sampling method was used for collecting sand samples. Sand samples were collected both in natural as well as disturbed areas (Table: 3.3) of NW Beach. A total of 15 sand samples were collected from the fore dunes, water edge, sand piles and landward towards the water. **Figure 3.1** shows 2015 aerial photo with gps points of sand samples collected in both natural and disturbed area in the NW beach of Point Pelee. To examine grain size distribution within the samples it was necessary to separate the sediment samples into constituent particle classes using standard grain size analysis techniques. Based on the particle or grain size classes, a grain size distribution curve was generated in Excel to determine the mean grain size and the degree of sorting in the sediment samples.

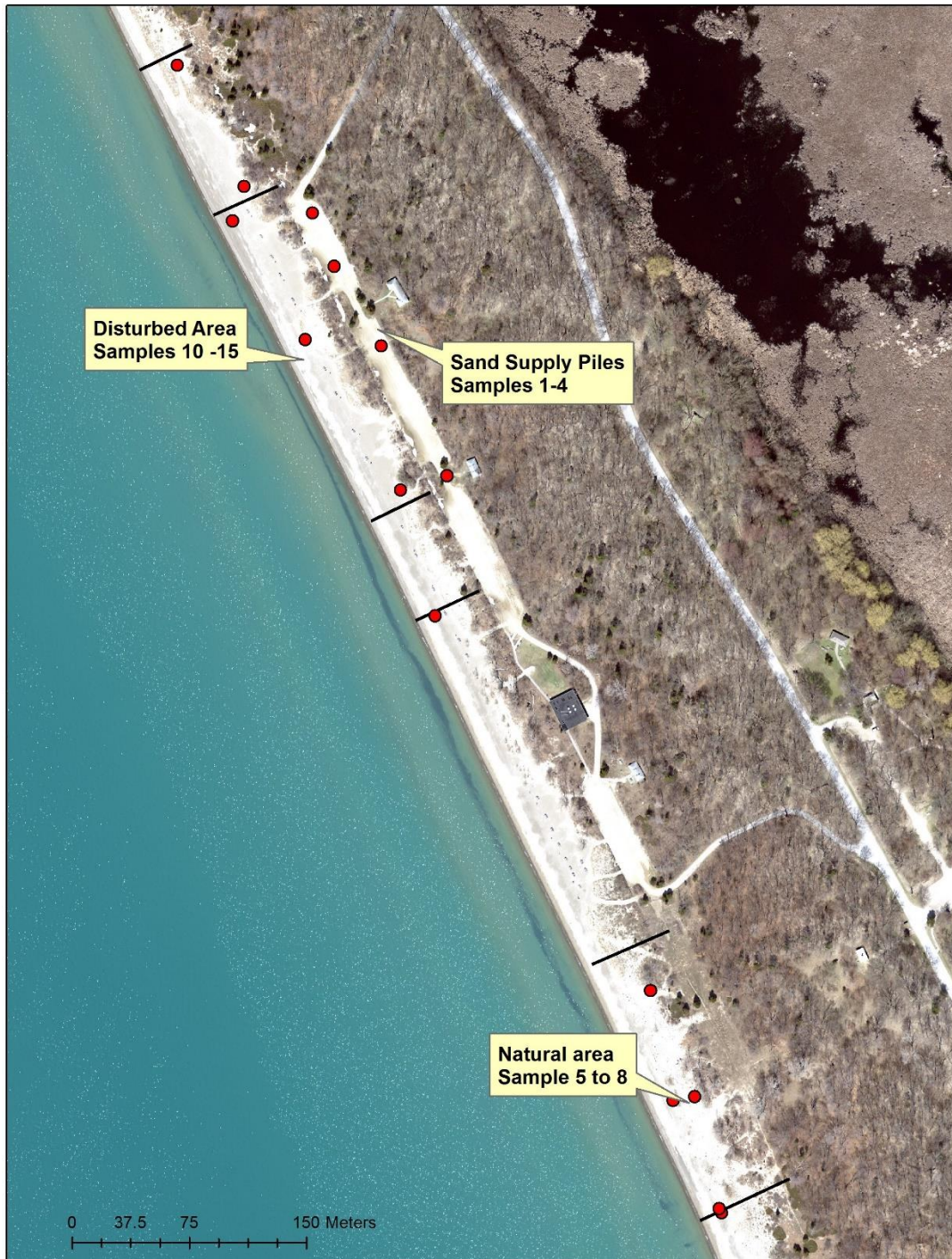


Figure 3.1: 2015 Aerial photo showing both natural and disturbed areas where sand samples were collected

Electronic balance for weighing the samples and mechanical sieving technique to separate the grain sizes into different classes were used. Grain size analysis of all sediment

samples were undertaken using standard sieve shaker, ROTAP. This sieve shaker includes eight sieves, each sieve contained a series of brass wires and a pan at the bottom. The sieves were used to separate sand particles into sizes ranging from -2 phi to >4 phi units. Each sieve with its known weight was stacked in the order of coarser to finer mesh size. The top sieve held the particles with size -2 phi units, having particles larger than granules to very fine pebbles. The last sieve (number 7 in the stack) held particle size 4 phi units i.e., about 0.0625mm. The particle size with 4 phi units represents fine sand. The finer particles that were retained in the pan was the base of the sieve, with phi units greater than 4, represents clay and silts that are found in the base of the pan.

Samples collected were placed in separate silver foil plates. The samples were allowed to dry in the oven at a temperature of about 105⁰C for 24 hours, following which they were weighed and their weights were recorded. Sieves were cleaned with the help of the barber brush and fine metal brush before their use. After sediment samples dried, each sediment sample was carefully placed on the top sieve of the stack.

The sieve stack was placed on the shaker (ROTAP) for 15 minutes. Sediments samples were allowed to pass through the series of sieves and finally reaching the pan. After 15 minutes, sieves were removed from the shaker. Sediments were collected carefully from each sieve, ensuring minimal or no loss. Sediments from each sieve were then weighed and recorded. The Wentworth classification scheme for grain size distribution (**Table 3.1**) was followed during the sieving process, sample weights and retained weight calculations. Sample weight and retained weight of the sediments were calculated using the table below.

Table 3.1: Wentworth Scheme for Grain size classification (Inman, 1952)

Grain Type	Diameter (mm)	Phi(ϕ)	Sample weight in gm	Retained weight in %
Pebble	>4.0	<-2		
Granule	2 to 4	-1 to -2		
Very Coarse Sand	1 to 2	0 to -1		
Coarse Sand	0.5 to 1	1 to 0		
Medium Sand	0.25 to 0.5	2 to 1		
Fine Sand	0.125 to 0.25	3 to 2		
Very Fine Sand	0.063 to 0.125	4 to 3		
Pan	<0.063	>4		

Mean grain size and sorting parameters were characterised based on formulae by Folk and Ward (1957) below.

$$\text{MEAN} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$\text{SORTING} = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

The graphical method is widely used and considered most appropriate to determine the mean and sorting of sediment (Blott and Pye, 2001; Zhang and Dong, 2015). Grain size was measured using phi (ϕ) units. Mean size and sorting of the samples were calculated based on the same formulae and were compared to estimate their appropriateness for sand dune development. A particle size distribution curve was produced using phi (ϕ) and retained weight to calculate the mean grain size and degree of sorting for all the sediment samples. Mean grain size determines the arithmetic average of the grains and sorting is a method of measuring the grain size variation in a sediment sample. It is a measure of how even the particle size distribution. Sorting is the uniformity of grain size (Folk and Ward, 1957). Mean grain size is an indicator of the magnitude of force that transports the grain. Sorting of the samples (**Table 3.2**) were calculated and compared to estimate their appropriateness for dune development.

Table 3.2: Folk and Ward (1957) sediment grain size classification

SORTING		
VALUES From	TO	EQUAL
0	0.35 ϕ	Very Well Sorted
0.35	0.50 ϕ	Well Sorted
0.5	0.71 ϕ	Moderately Well Sorted
0.71	1.00 ϕ	Moderately Sorted
1.00	2.00 ϕ	Poorly Sorted
2.00	4.00 ϕ	Very Poorly Sorted
>4.00	Φ	Extremely Poorly Sorted

3.3 Methods for Vegetation Samples

3.3.1 Data Collection

To determine vegetation assemblage and character, a stratified random sampling method was used to collect vegetation samples across the Northwest Beach area of Point Pelee. Using stratified random sampling, the study area was divided into a number of transects and quadrants were laid in each transect. Samples were taken along a transect across the shoreline. Aerial photo (**Figure 3.2**) shows locations of vegetation samples collected both in natural and disturbed area.



Figure 3.2: Aerial photo showing location of vegetation samples collected in both natural and disturbed area during field visits

10m x 10m quadrats (N = 10) were created with five plots of 1m x 1m size nested within (Environment Canada, 1999; USGS/NPS Vegetation Mapping Program, 1994). Four 1m x 1m plots were created on the four corners of the plot and one in the middle (**Figure 3.3**). In each of the five plots of 1m x 1m, all individuals were identified, counted and recorded. Parks Canada Ecologist, Tammy Dobbie (pers. Comm.) helped identify the species. Percentage of cover for each species in the quadrat were recorded. Percentage cover of each species was manually/visually estimated based on the ground surface area occupied by each species in that quadrat. Ground cover of a plant species is an important characteristic which determines its contribution to that community.

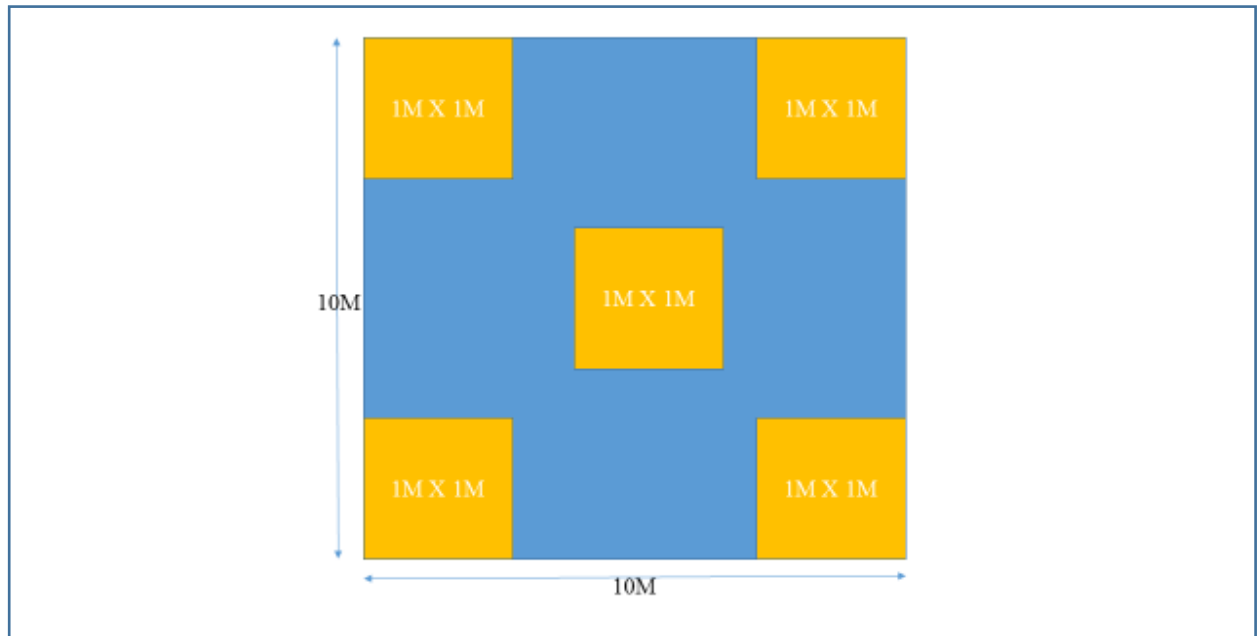


Figure 3.3: Layout of Quadrats and Sample Plots



Figure 3.4: 1m x 1m Sample plots used for vegetation sampling

Northwest beach area is heavily impacted by tourists/visitors and other development activities. There are highly disturbed areas within this beach which are in close proximity to the parking lots and facilities. Other areas are comparatively less disturbed as they are located away

from the main entrance and exit of the park, and also the parking lots. The former is referred to as ‘disturbed’ area and the latter as ‘natural’ area in this study. A number of criteria were considered to differentiate between natural and disturbed areas (**Table 3.3**). It was necessary to differentiate these two areas based on selected criteria because there was no baseline data on the vegetation diversity for this beach area. It was also important to differentiate between the two areas in order to compare species diversity and richness.

Table 3.3: Qualitative Criteria for Natural (less disturbed) Areas and Disturbed Areas

Natural (less disturbed) area	Disturbed Area
No boardwalk (less human interference)	Boardwalk
No Parking lots	Parking lots and other facilities
fewer/smaller walking trails	Main entrance to the Park and trails
Less active management	Active management
No raking activities	Heavily raked during field work

3.2.2 Vegetation data analysis

Vegetation analysis was undertaken through calculations of the following aspects:

Species Diversity was calculated using Shannon’s Diversity Index and Simpson’s Diversity Index (Morris, et al., 2014). Species diversity is a measure of diversity that incorporates both the number of species in an assemblage and some measure of their relative abundances (Gotelli and Chao, 2013). Diversity indices are mathematical functions that combine richness and evenness in a single measure (Colwell, 2012). Both richness and evenness are the most commonly used indices for measuring biodiversity. Shannon Diversity Index and Simpson’s Index are the two indices that are commonly used to measure species evenness and richness.

Shannon Diversity Index (H) = $-\sum p_i \ln p_i$ (Shannon, 1948)

Where p_i = number of individuals of particular species found divided by the total number of individuals found

\ln = natural log

Simpson's Index (D) = $1 - \sum p_i^2$ (Simpson, 1949)

Species Evenness is calculated as the ratio of diversity observed to the maximum diversity (Colwell, 2012). Evenness is not calculated independently rather derived from diversity (Morris et al., 2014).

Evenness = H/H_{max} , where H is observed diversity and H_{max} is maximum diversity

$$\text{Evenness} = \frac{\text{Shannon Diversity Index}}{\text{Total Number of species}}$$

Species Richness refers to the number of different species found in a community. Species richness of the sampled area or in a quadrat is the number of different species found.

Species richness could be low or high in a given area. The exact extent of change in species richness can only be assessed if baseline data are available. Two kinds of data were collected: i) incidence data, in which number of species found in a quadrat were sampled. ii) abundance data, in which abundance of each species was recorded. (Gotelli and Colwell, 2001; 2011).

Definitions of the following terms come from the Environment Canada, 1999.

Abundance is total number of individuals of each species in the total area sampled.

Density is the average number of individuals of a species on a unit area basis. **Relative density** is the density of one species relative to the density of all species. Density and relative density were calculated based on the following formulae (Environment Canada, 1999):

Density = number of individuals of a species in a sample/total area of the sample (m^2)

$$\text{Relative Density} = \frac{\text{Density of species}}{\text{Density of all the species}} * 100$$

Dominance is the area a species occupies on a unit area basis. It is determined by using the cover, which is calculated by the measuring the area occupied by the species when projected on the ground. **Relative Dominance** is the area a species occupies relative to the total area occupied by all species.

Dominance = area occupied by a species in a sample (m²) / total area of the sample (m²).

Relative Dominance = area occupied by a species in a sample (m²) / total cover of all species in the sample (m²) * 100

$$\text{Dominance} = \frac{\text{area occupied by a species in a sample (m}^2\text{)}}{\text{total area of the sample (m}^2\text{)}}$$

Frequency is the distribution of a species in a quadrat divided by the total number of quadrats in the sample. Frequency is the number of quadrats in which a species occurs divided by the total number of quadrats sampled.

$$\text{Frequency} = \frac{\text{Number of quadrats in which a species is found}}{\text{The total number of quadrats sampled}}$$

Relative Frequency is the distribution of one species in a sample relative to the distribution of all species. Relative Frequency = Frequency of a species in a sample divided by total frequency of all species in the sample X 100

Importance Value Index (IVI) is the sum of relative density, relative frequency and relative dominance.

IVI = Relative Density + Relative Dominance + Relative Frequency

All the above calculations were done using the Terrestrial vegetation monitoring protocols of Environment Canada (1999).

3.4 Land use and Land cover Change Detection

3.4.1 Methods

Observing changes in LULC is an important criteria to understand the cause for delays in sand dune formation and for ascertaining some of the limiting factors. Remote sensing has been extensively used for better understanding of land surface characteristics, dynamics and monitoring land use and land cover changes (Bartholome and Belwad, 2005; Gong et al., 2013). Change detection requires use of the same sensor, with the same spatial resolution with anniversary acquisition dates (Lu et al., 2004). The year 1959 was chosen to capture the status of land use and land cover classification prior to the development of infrastructure and facilities by Parks Canada. From observation of historical aerial photographs the development of infrastructure and facilities in the NW beach area started after 1959. Selection of date/year for LULC classification was also based on the availability of aerial photos.

Historical aerial photographs and Southwestern Ontario Orthophotography (SWOOP) data were used in the study. Digital orthorectified aerial photographs for the years 1959, 1977, 2006 and 2015 were collected from Parks Canada for classification. The date and time of the photographs were used based on their availability. Orthophotos 2006 and 2015 are in true colour and were acquired during spring when most vegetation was bereft of leaves. Historical photos from 1959 and 1977 were in black and white. SWOOP data for years 2006 and 2015 were also provided by Parks Canada.

A broad framework was used (**Figure 3.5**) to obtain classified maps for the 1959, 1977, 2006 and 2015. Initial field visits were conducted as part of a reconnaissance survey to get acquainted with the field context and also to make contacts with Parks Canada staff in Point Pelee. Data acquisition, including aerial photographs and other resources, was first completed prior to the start of field data collection. Ground truthing for LULC classes was undertaken. Orthoimages involved minimum pre-processing. A subset of the digital imagery was completed to isolate the study area. Segmentation approach was used to extract features based on objects. Pixels with similar spectral characteristics are grouped together into segments, represented by a set of attributes for classification. Supervised classification was used and classes for ecological land classification (Dougan and Associates 2007) were identified based on the spectral signatures collected with help of GPS. Classified maps were produced and then subjected to post-classification (see **Figure 3.4** for detailed steps used) to final resultant map.

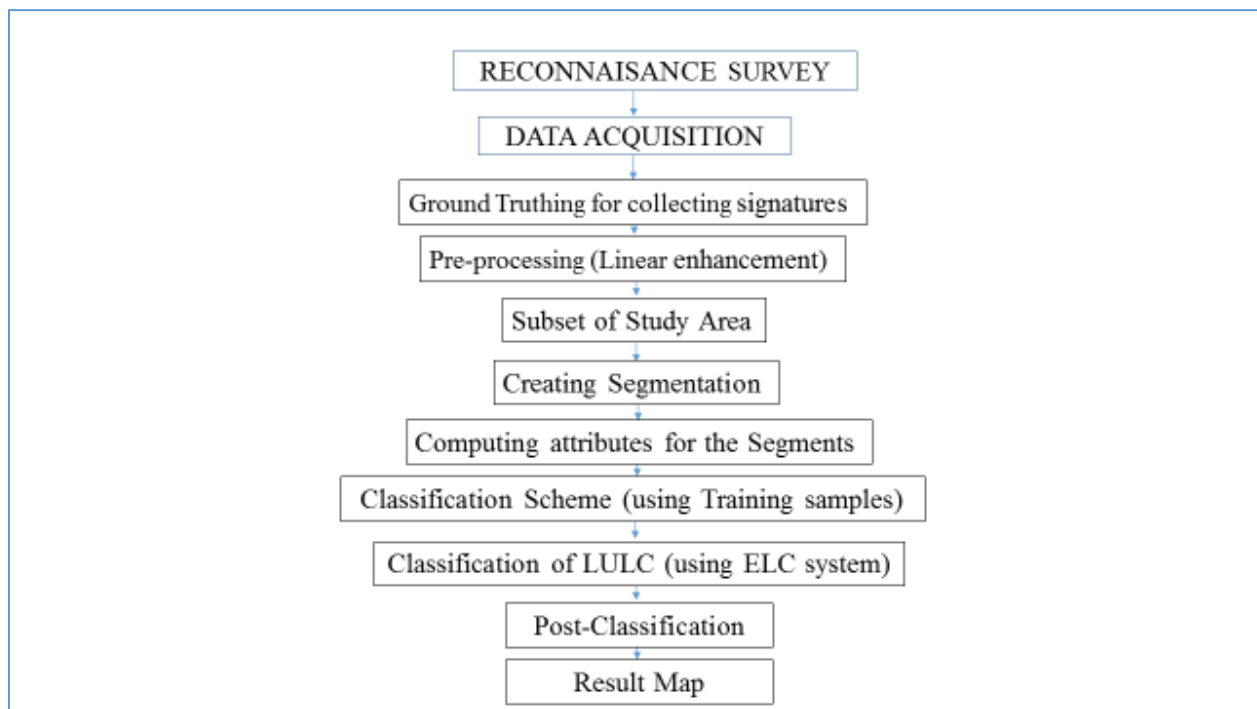


Figure 3.5: Framework of land use and land cover classification

Table 3.4: Details of Orthophoto used for classification

Year	Type	Bands	Resolution	Date of Acquisition
1959	Historical, Digital Aerial photo	Black and white, 1 band	0.25 m	1959-04-29
1977	Historical, Aerial photo	Black and white, 1 band	0.15 m	1977-11-02
2006	SWOOP(Southwestern Orthophotography Project) Digital Aerial photo	True colour, 3 bands	0.3 m	2006-03-13
2015	SWOOP, Digital Aerial photo	True colour, 4 bands	0.2 m	2015-04-17

Aerial photos for the years 2015, 2006, 1979, 1959 were smoothed and enhanced before applying supervised classification. Linear stretching of 2% was used to enhance the contrast of the image and boundaries of the objects were sharpened for better classification.

NAD_1983_UTM_Zone_17N projection was used.

Detailed vegetation types were classified based on the Ecological Land Classification (ELC) system for Southern Ontario (Dougan and Associates, 2007). ELC is the standard classification system used in the LULC classification. Due to the small size of the study area, detailed classes were included (**Table 3.6**). The main classes considered fall within the study area of about 6 hectares.

1. Shoreline Vegetation Type is classified as Sea Rocket Sand Open Shoreline Type.

Shoreline type includes open shoreline with or without vegetation and ELC classified as Sand Open shoreline type

2. Sand Barren and Dune Type

- i. Sand Barren Dune are the grasses and other species includes beach grasses, Little Bluestem - Switchgrass - Beach Open Graminoid, Dry Sand Drop seed, wormwood etc.,)
- ii. Sand Barren dune (Shrub type) which is Red Cedar Treed Sand Dune Type and also includes hop tree (*Ptelea trifoliata*), choke cherry (*Rhus aromatic*), dwarf hackberry (*Celtis tenuifolia*), red cedar (*Juniperus virginiana*).
- iii. Dry - Fresh Drummond's Dogwood Deciduous Shrub Thicket includes species like common hackberry (*Celtis occidentalis*), white mulberry, black walnut (*Juglas nigra*) and white and black oak (*Quercus alba and Q. velutinna*) other species.

The land use and land cover classes that were found in the study area are listed above.

Table 3.6 outlines land use and land cover class for Time Series. According to the Ecological Land Classification (ELC) system (for Southern Ontario, Dougan and Associates, 2007), there are three classes that fall in the study area. However, sand barren and dune type (dune associated species) in 2006 and 2015 aerial photos were able to differentiate between the sand barren dune and red cedar type. As sand barren dune were mainly the dune grasses and other species whereas, the Red cedar type were shrubs and trees. These two classes were differentiated under Shrub sand barren and dune type for 2006 and 2015. A patch of cottonwood trees were differentiated in 2015 aerial photo. In the 2006 aerial photo, cottonwood trees were not present. Interpretation of 2006 and 2015 aerial photos enabled the differentiation of new classes based on their texture, tone and colour. In 1959, there were only two broad classes namely Shoreline type and Sand Barren and Dune Types as per Point Pelee National Park, Parks Canada. Barren land, Shrub

Sand barren and dune type were under Sand Barren and dune type for 1959. In 1977, this barren land was used for building parking lots and facilities for the visitors.

Figure 3.6: Land Use Land Cover Class for Time series

LULC Class	1959	1977	2006	2015
1	Barren Land	Infrastructure & Facilities	Infrastructure & Facilities	Infrastructure & Facilities
2	Shoreline vegetation type	Shoreline vegetation type	Shoreline vegetation type	Shoreline vegetation type
3	Sand Barren & Dune (dune grasses)	Sand Barren & Dune (dune grasses)	Sand Barren & Dune (dune grasses)	Sand Barren & Dune (dune grasses)
4	Shrub Sand barren & Dune	Shrub Sand barren & Dune	Deciduous Thicket	Deciduous Thicket
			Red Cedar Treed Sand Dune	Cottonwood Trees
5	Absence of trails	Trails	Trails	Trails
6	Water	Water	Water	No water
7	Forest	Forest	Forest	Forest

3.4.1.1 Object oriented approach

An object-based image analysis approach was used to differentiate objects based on segmentation in order to classify the images. Feature extraction (example based classification) was used for segmentation of the objects. This process created objects by merging pixels, which were used as classification units instead of pixels (Miyasaka et al 2016). The object-based approach helped to quantify and classify images based on their textural, spectral, scale, and context information (Conchedda et al., 2008) along with shape and topological information (Miyasaka et al 2016). Object based image analysis has been widely used in a number of earlier studies (Blaschke et al., 2014; Hay et al., 2003; Willhauck, 2000; Walter, 2004). Petrila (2015) conducted comparative studies using object based image analysis using example based classification and rule based classification for LULC. Example based classification, proved to

show a better accuracy than rule based. Miyasaka et al. (2016) studied classification of land use on sand dunes topography using object based image analysis, digital photogrammetry, and GIS analysis with high resolution images which contributed towards relevant policies and management planning.

Digital image processing software (ENVI 5.2) was used to classify all the images. Algorithm K-nearest neighbour was used for classification. A detailed work flow (**Figure 3.7**) outlines the steps followed in the classification process. A detailed work flow for Object based analysis (**Figure 3.7**) used ENVI 5.2 and Post- Classification Smoothing and the Spatial Analyst tool in ArcGIS 10.2. Segmentation of respective images and assignment of classes were done based on the training samples (supervised classification) using K-nearest neighbour to produce classified maps. Classified maps produced for time series were then subjected to post-classification smoothing using spatial analyst (Tool box) in ArcGIS 10.2. Post-classification smoothing was necessary as there were pixels that were misclassified and were found hanging. Majority filtering was used as it replaces the misclassified pixels with neighbouring class. Other smoothing techniques such as boundary clean were used to clean the edges and boundaries before these pixels were included in the larger class. Region group includes all the cells or the pixels to the region it belongs. Set null and nibble corresponds to the values of the closest neighbours.

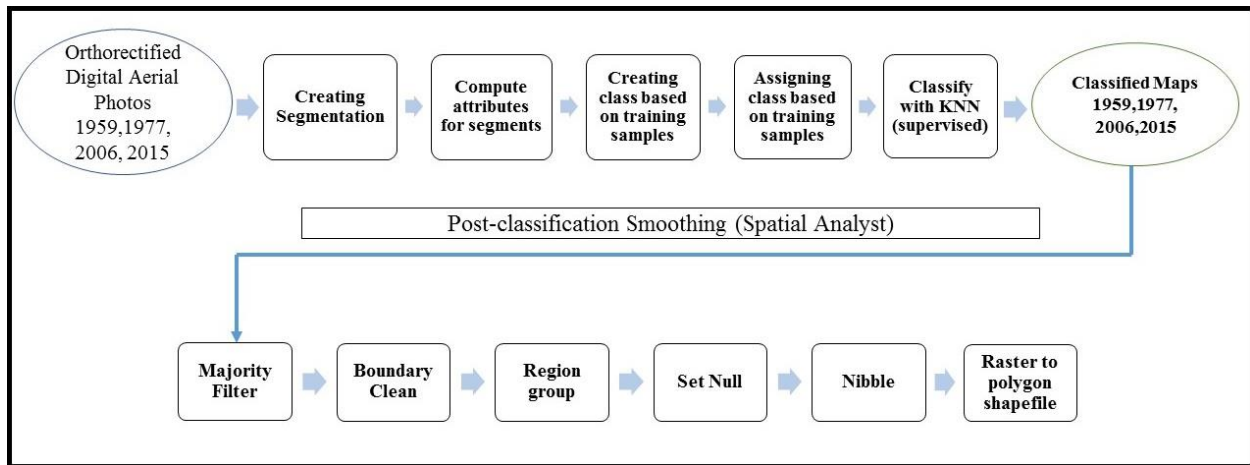


Figure 3.7: Detailed workflow used in ENVI-5.2 & ArcGIS 10.2 to achieve Classified LULC Map

Segmentation classes were identified using ENVI software and manual digitization of boundary for accurate discrimination of the classes was also undertaken. Post-classification smoothing was then applied to all four land use and land cover classified maps using the spatial analyst tool in ArcGIS 10.2 and the resultant maps were compared to evaluate change for different time series.

Chapter 3 focused on the methods used in this research for collection and analysis of data. Research methods have been carefully selected so that they can address key research questions and specific objectives. For example, collection and analysis of sand samples (Objective 1) was achieved through the use of random and stratified sampling techniques. Further, grain size analysis was undertaken using standard sieving method. Mean size and sorting were calculated based on Wentworth scheme for grain size classification, statistics and parameters provided by Folk and Ward (1957). Vegetation samples (Objective 2) were collected using random stratified sampling along the transect. Species diversity of the dune species was calculated based Shannon's Diversity Index and Simpson's Diversity. Frequency, dominance and density were calculated using the manuals of Environment Canada, 1999 and USGS/NPS

Vegetation Mapping Program, 1994. Land use and land cover classification (Objective 3) was undertaken using Object oriented approach and ecological land classification system of Southern Ontario. Clear methods outlined in Chapter 3 provides a useful direction to analyse data, present key results and offer thorough discussion pertaining to the three research objectives in Chapter 4, which follows next.

CHAPTER 4

Study Area Profile

4.1 Climate

As the southernmost tip of Canada, Point Pelee National Park is one of the warmest areas in the country. Due to its unique location, with Lake Erie on both sides, the mean daily temperature varies from -3°C in winter and 21°C in summer (Parks Canada report, spring 2005). The mean total annual precipitation in the Park is 856 mm. Due to favourable temperature and weather conditions PPNP is open around the year and receives visitors during all seasons.

4.2 Geology

Southern Ontario is dominated by Paleozoic sedimentary rocks resting on Precambrian metamorphic rocks (ELC for S. Ontario, Training material, 2011). It is comprised of Dundee Limestone that are carbonate rich and produces rich fertile soil. The bedrock consists of weak Devonian shales, which are capped by limestone from the same period and then followed by harder Silurian dolomite (Holcombe et al, 1997). Kelly (1995) noted that the Point Pelee geological structure consists of limestone overlaid with glacial till, silt, clays and sands. The thickness of the overburden ranges from zero in parts of Pelee Island to about 70m in the southern part of Kingsville (Watershed Characterisation Report, 2015).

Damery (2004) summarized that Point Pelee area was overlain by Laurentide Ice Sheet in the Late Wisconsinian and was deglaciated at Lake level fluctuation in post glacial time. With glacial retreat, the Lake Erie basin was filled with water (Stuckey and Duncan, 2010). As the water levels

rose in the lake, glacial till surrounding the area were eroded and bluffs were formed. The beaches are constantly undergoing cycles of erosion and deposition (Parks Canada, 2005).

4.3 Geomorphology

The beaches of the Great Lakes, which includes Lake Erie, are formed as a result of wave action leading to erosion and deposition of the glacial sediments along the shores of the post glacial lakes and present Great Lakes (Chapman and Putnam, 1984). Sediment deposition of longshore drift from eroding areas to the east and west was a major factor in the formation of Point Pelee (Wilson, 1903 and Kindle, 1933). Terasmae (1969) indicated littoral drift as the predominant source of sand accumulation. In the Point Pelee area there are fine glaciolacustrine sand unit and glacial till. (Coakley, 1975). Fine, well-sorted, glaciolacustrine sand overlying till was documented by Terasmae (1970) in their study based on one borehole sample near the visitor's center.

4.4 Tourism Scenario

Over 46 million people live within the 450 kilometre radius of Point Pelee National Park in both Canada and the United States (Parks Canada 2010). Point Pelee is an attractive spot for this population both from the point of acquiring property as well as tourism. By designation, Point Pelee is a day use park, open year round, with visitation averaging over 200,000 visitors annually. **Figure 4.1** shows the trend in the number of visitors to Point Pelee National Park between 1920 to 2010. Soon after national park designation, construction of roads, parking lots, picnic areas and other infrastructure significantly increased to facilitate recreation and tourism.

Since 2002 annual visitation to Point Pelee National Park has declined from 271,952 to 225,587 person day visits in 2006 (Parks Canada, 2006). This represents about a 17% decrease. Due to the bird migration phenomenon, the busiest visitation month is May, when an average of 44,575 person day visits were recorded (Parks Canada, 2006). December tends to be the slowest month with an average of 5,470 person day visits. It should be noted that regional tourism statistics have also declined (Parks Canada, 2006). Between 1999 and 2003, the Windsor, Essex County and Pelee Island Convention and Visitors Bureau reported a drop of 3.8 million visitors to the region, representing about a 26% loss (Parks Canada, 2006) (**Figure 4.1**). Point Pelee National Park generates approximately 23% of its annual operating budget of just over Canadian two million dollar (salary and goods & services) through revenues (State of the Park Report, 2006). Overall 71% of park visitors report being satisfied or very satisfied with the value they receive for their entry fee (Parks Canada, 2005).

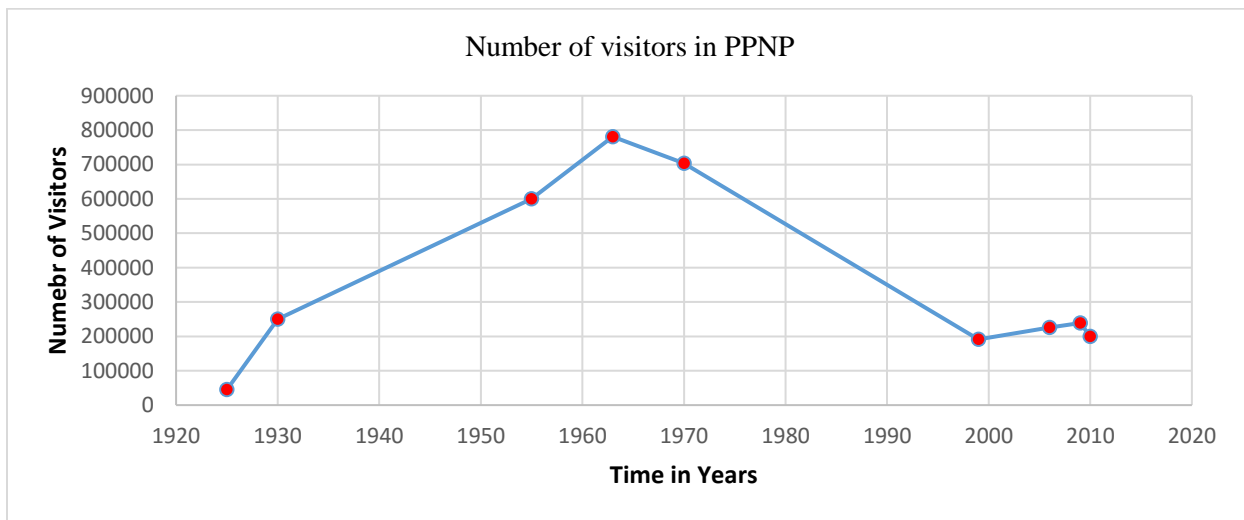


Figure 4.1: Trend in the number of visitors to Point Pelee National Park during 1920-2010

4.5 Impact of Agriculture

Point Pelee National Park is the smallest park in Canada in size. Even though it is protected, 97% of the surrounding land has been severely modified for agriculture and housing development (Parks Canada, 2006).

4.6 Sand Dredging /Gravel Mining Activity

Shaw (1978) described that offshore sand and gravel deposits were dredged at an average rate of 160,000 m³/year three kilometers to the south of Point Pelee. Sand and gravel were heavily mined on the point and shipped to the United States for construction beginning around 1870 (Battin and Nelson, 1978). In 1910, sand dredging and gravel mining started with prior permission from the Commissioner, Harkin and finally sand dredging and gravel mining came to end in 1974. This suggests that illegal dredging and mining activity started even before actual permission was granted. Baird and Associates (2007) concluded that the Wheatley Harbour has trapped or removed approximately 500,000 m³ of sand and gravel from the shoreline. Baird and Associates (2006) also stated that sediment flow by the littoral drift which was moving southward likely deposited sand offshore in deep water or in the central basin. Such removal of sand disturbs sediment budgets, possibly contributing to enhanced erosion (Masalu, 2012; Thornton et al., 2006); it may also alter particle size, changing the morphodynamic state of beaches (McLachlan 1996). Baird and Associates (2006) documented one ship could extract about 18,000 tonnes or 9,000 m³ of sand and gravel in one load. It was calculated that one ship could extract 900,000 m³ in one year.

4.7 Biodiversity

Due to the ongoing recession of the east beach of Point Pelee since 1954, the park has lost 0.6 hectares of marsh and 0.25 hectares of Carolinian Forest per year (Baird and Associates, 2006). There is an overall decline in biodiversity with respect to both fauna and flora species. Even though Point Pelee is protected under the National Parks system of Canada, a large area of its Carolinian deciduous forests and its surrounding lands have been converted to agriculture, industry and urban development in recent decades. Smith and Bishop (2002) documented historical aerial photos (1931, 1959, 1973, 1985, and 2002) to record the changes in the red cedar savanna (Carolinian forest) and found a drastic decline. Biodiversity loss in terms of forest is already documented in studies undertaken by different scholars (Smith and Bishop, 2002 and Praks Canada Report, 2005).

4.8 Shoreline Changes

Historically, there is a strong evidence that Point Pelee was experiencing shoreline erosion since 1800s (East, 1976 and Trenhaile and Dumala, 1978). Several remedies to restrict this process were attempted over the decades. Factors influencing erosion included action of wind and its direction, subaqueous slopes, shore materials, coastal currents, lake levels and isostatic changes in land levels (Kindle, 1918). Parks Canada (1976) documented the extensive nature of erosion in PPNP and recorded success and failure of various measures taken to arrest erosion by the Parks and the neighbouring areas. Wilson (1903) and Kindle (1933) documented that deposition from longshore drift was a major factor contributing to the formation of Point Pelee. Terasmae (1969) also stated that littoral drift was the predominant source of sand accumulation in Point Pelee. Within the west littoral cells, the shoreline has been intensively

impacted and armoured with hardened erosional structures such as armour stone and gabion baskets to check the sediment flow. The impact of human intervention on the active littoral zone is an imposing threat to the biodiversity of natural habitat. The shoreline is heavily protected by seawalls, groynes and stone revetments (Figure 4.4).

4.9 Sediment Movement in the Study Area

Figure 4.2 displays the direction of longshore drift in the areas adjacent to Point Pelee National Park. Longshore drift is a process in which sediments are transported along the coast with wave and prevailing wind action. Wind directs the waves to carry sediments along the coast under the influence of a current created in the surf zone. This process repeats and deposition of sediments take place along the coast. This process is called longshore drift. The sediment budget is the balance of sediment movement both by the longshore drift and through the onshore and offshore movement of sand.

The main source of sand supply to the shore of Point Pelee is being impacted due to the hardened erosional structures which limiting sediment supply. Lake Erie shoreline is heavily protected with seawalls, groynes and armour stone revetments (Baird and Associates, 2006). Several small craft harbours and marinas are located along the shoreline, namely Colchester, Kingsville and Leamington, which are protected with large, hardened stone structures that result in interruption to the supply of sediment to the beach of Point Pelee.

The presence of three major harbours, Leamington, Kingsville and Colchester, along the shoreline has led to the creation of a series of erosion protection structures to prevent erosion at these harbours (**Figure 4.2**). The erosional structures have strong impacts on the sediment flow to Point Pelee. **Figure 4.2** clarifies that with the direction of longshore drift, sediment flow has

been restricted by the hardened structures resulting in no, or an insignificant amount of sediment flow along the coast. In addition, the entire Point Pelee shoreline has been armoured with erosional control structures except the northwest beach area.



Figure 4.2: 2015 Image showing longshore drift and development of erosional structures along the shoreline (Source: Google Earth image 2015)

Figure 4.3 depicts a clear picture demonstrating sediment deposition in central basin as a result of longshore drift. Western Erie basin is 10m deep and shallower than the Central Erie basin, which is 20m deeper.

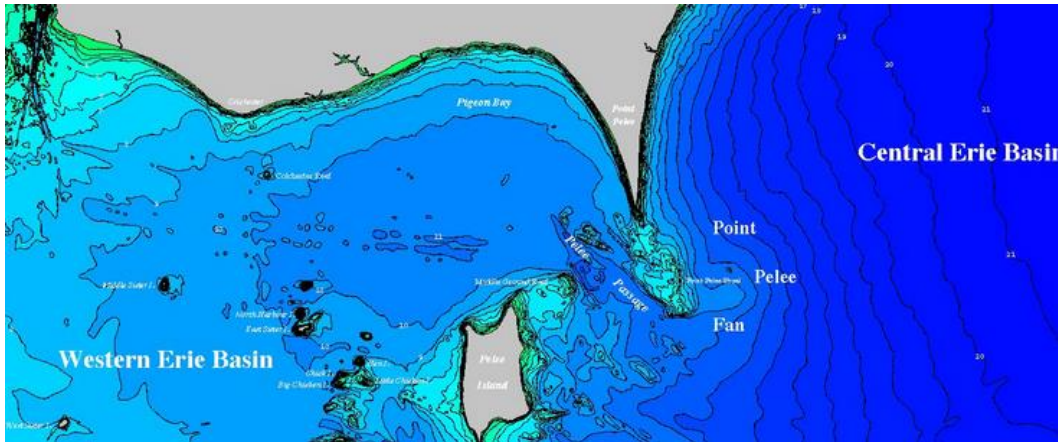


Figure 4.3: showing bathymetry of Western Point Pelee, with central and western Erie Basin (Source: <https://www.ngdc.noaa.gov/mgg/image/images/werie.jpg>)

Figure 4.4 shows a closer view of each of the harbours along the shoreline that extends to the NW beach and towards the tip of Point Pelee. There are several other erosion protection structures along the shoreline that are impermeable hard structures constantly restricting sediment deposition along the coast and creating adverse impacts along the coast. In the process of longshore drift, sediments are transported into the central basin which is deeper than that of the western basin (**Figure 4.3**). There is insignificant amount of sediment for dune development. This might be one of the strongest reasons of why the dune restoration process in NW beach of Point Pelee has been slow and have produced insignificant results. As reported elsewhere, modern coastlines are increasingly starved of sand, as dams trap sediments that would otherwise feed beaches; the sediment budget is further disrupted by activities such as quarrying, land reclamation, urbanisation, afforestation and agricultural use (Nordstrom, 2000; Sherman et al., 2002). Several studies (Sobocinski 2003; Martin et al. 2005; Dugan and Hubbard 2006) highlight the impacts of seawalls and other coastal armouring structures as a cause of significant habitat changes and ecological impacts. Similar is the case in Point Pelee where sediments are trapped by the hard erosional control structures restricting their flow to the NW beach. The history of

sand dredging and gravel mining in the south of Point Pelee adds to the scarcity of sediment supply.



Figure 4.4: 2015 Image showing development of erosional structures along the shoreline of Point Pelee (Source: Google Earth 2015)

The 1954 aerial photo visualises changes in the shoreline erosional structures for the period of 1954-2015 (**Figure 4.5**). A comparison of aerial photos of 1954 and 2015 clarifies that there is a significant difference in the erosional structures of Colchester, Kingsville and Leamington harbours based on the changes each of them have gone through. It is noteworthy that within a span of 60 years there has been a drastic increase in shoreline protection structures.



Figure 4.5: 1954 Aerial photo showing development of erosional control structures along the shoreline of Point Pelee (Hunting Survey Corporation Limited (map Library University of Toronto))

Figure 4.4 and **Figure 4.5** show a visual comparison of two time series aerial images of the development of erosional structures in 1954 and 2015. The structures in 2015 are much larger than in 1954. Over time, the shoreline protection structures have increased not only by numbers but also by their size and capacity as compared to 1954. In the case of Point Pelee, fluctuations in lake levels along with insignificant sediment supply suppresses the dune development process.

4.10 Impact of Invasive Species

Invasive species such as spotted knapweed, white sweet clover, common reed, orchard grass were generally observed during field data collection. Only one orchard grass was recorded in the sample plot. Invasive species may multiply faster than those of the native ones and result in the displacement of the later (Haber, 1998). These invasive species pose even a greater threat to the species at risk. Invasive species are also known to have significant environmental impacts on the biodiversity (Haber, 1998). Generally, invasive species make their way to a disturbed area and then establish themselves by spreading to adjacent natural areas eventually resulting in habitat loss. Northwest beach of Point Pelee has experienced a similar situation in which invasive species are abundantly spreading at the cost of native ones in the former parking lots. Important management strategies to restrict the spread of invasive species, especially in the NW beach area is important.

The present scenario in Northwest Beach of Point Pelee, from the photograph (**Figure 4.6**) help clearly identify Cottonwood trees (*Populus deltoides*) close to the shoreline. This signifies that Cottonwood trees may alter the environment making it more difficult for the marram grass to anchor sand in place. With change in specific habitats changes often resulting in conflicts. As seen in the aerial photo, Cottonwood trees were not present in 2006 or their presence was marginal, which grew into big and scattered patches in 2015. Previously, these deciduous species were found only on the woodlands and forested areas of Point Pelee. This change is a matter of concern as it seriously challenges the ecological integrity of Point Pelee and has resulted in serious habitat loss. **Figure 4.7** shows presence of Marram grass next to the shoreline and the beach area with an increasing presence of thick vegetation cover of deciduous trees in the background. It was observed during fieldwork that the Cottonwood trees were

encroaching into the Marram grass territory close to the shoreline which indicates varying lake levels along with squeeze in vegetation and beach area. **Figure 4.8** shows meadow vegetation taking over the former parking lot after it was restored as part of the dune restoration process.

Figure 4.6, Figure 4.7, Figure 4.8 provide a visual representation of ecological disturbance as meadow species are taking over the former parking lot. This parking lot was the first to be rehabilitated in this sand dune management process. This clarifies that meadow vegetation is quite competitive and dominant in nature, and capable of regeneration much faster than the native species. Meadow vegetation was unintentionally introduced as a result of agriculture activities. A meadow is an early successional stage of a forest ecosystem. The presence of meadow indicates that formation of sand dunes is ecologically untenable.



Figure 4.6: Cottonwood Trees (Deciduous species) are close to the shoreline, gradually taking over the space occupied by the native Marram grass species



Figure 4.7: Shows Marram grass in Northwest Beach of Point Pelee
(Photo courtesy M-L Byrne)



Figure 4.8: Meadow Vegetation in former parking lot

The presence of Cottonwood trees close to the shoreline suggests that they might eventually replace marram grass. On the other hand, meadow vegetation is also spreading across the area, which would result in adverse impacts on dune restoration and development process. Meadow vegetation and Cottonwood trees close to the shoreline along with fluctuating water levels indicate an active process of “Coastal Squeeze” in the dunes of Northwest Beach. Increase in water level results in narrowing of the beach area. An important consideration in the response of coastal systems to sea-level rise is the potential loss of important habitat through a phenomenon known as ‘coastal squeeze’ (Doody, 2004). The term ‘Coastal Squeeze’ has been explained by various scholars: Defra (2003) defined coastal squeeze as a process by which coastal habitats and natural features are progressively lost or drowned, caught between coastal defences and rising sea levels. Doody (2012) defined coastal squeeze as coastal narrowing leading to habitat loss. Black and Veatch (2006) defined it in relation to sea level rise and defence mechanism by which waterline moves shoreward, leading to a habitat loss. Nature et al. (2003) defined it as the process by which ‘coastal habitats are progressively reduced in area and the functionality of the area is lost while caught between sea level and fixed sea defences or high ground.

CHAPTER 5

Understanding and characterising the factors limiting sand dune development

5.1 Introduction

This chapter focuses on the factors limiting the growth of sand dunes at the highly impacted Northwest beach of Point Pelee. Northwest beach has undergone numerous changes due to recent development of infrastructure activities as well as a historic process of a series of ecological and climatological disturbances (lake level fluctuations, low ice cover).

Parks Canada is actively engaged in strengthening management strategies for efficient and productive restoration activities to address the endangered status of Five-Lined skink (*Plestiodon fasciatus*). Restoration of habitat is a top priority for Parks Canada and sand dunes are an integral part of its habitats, especially for the Five-lined skink (*Plestiodon fasciatus*) (Dale and Byrne, 2010; Ontario Recovery strategy, 2010). Restoration of sand dunes in Point Pelee is an ongoing process since 2007 when one of the parking lots was removed with an objective of restoration. Dune habitat restoration has been a key focus of research undertaken in the Park. The focus of this research is to examine the role of grain size distribution of sediments, vegetation assemblage and characteristic of dune associated vegetation, and changes in land use and land cover in the development and restoration of sand dunes. In a restoration process, it is important to understand the role of complex drivers, both anthropogenic and climatic, and their impacts on ecosystem structure and function as crucial elements for planning and implementing restoration interventions. Since restoration is a long-term process, monitoring of land use and land cover changes as well as outcomes of restoration activities is vital in order to observe progress towards ecological integrity.

This chapter includes detailed analysis of collected sand and vegetation samples and examination of land use and land cover changes to determine possible factors responsible for sand dune depletion and factors hindering the restoration process. This chapter includes three main sections. Following this introduction, the next section will analyse grain size distribution of the samples collected to find if grain size is appropriate for sediment transport contributing to dune development processes. Section 3 includes vegetation sample data and analysis of vegetation assemblage of dune associated species for facilitating dune development. Section 4 includes land use and land cover change analysis to assess in relation to dune development.

5.2 Results and Discussion

5.2.1 Grain size distribution

Sand samples were collected in and around the Northwest beach area. Sample collection included fore dunes, water edge, sand piles (to determine if these were appropriate as additional supply) and landward from the water in both natural and disturbed areas. Sand supply piles are the heaps of sand that were placed in the removed parking lots area as part of restoration process. The key question examined was ‘whether inappropriate grain size for sediment transport has severely limited dune development in NW Beach of Point Pelee?’

Why is grain size important or how is grain size contributing to dune development? Grain size is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition (Zhang and Dong, 2015; Blott and Pye, 2001). Sediment grain size distribution is also important in aeolian research, as grain size controls creep, reptation, saltation, and suspension in dune formation and development (Zhang and Dong, 2015). As a result, grain size is considered as a crucial factor of dune development processes. Dune formation happens when

there is an adequate supply of sediment, wave action and sand particles that facilitate sediment movement by the action of wind. It is important to assess grain size in determining various factors limiting the growth of sand dunes. Inversely, one of the most important aspects of the sand dune restoration process is to determine the supply of appropriate grain size for sediment transport. Objective 1 of my research, therefore, focused on determining whether there was availability of appropriate sand grain-size in NW beach area for the wind to rework.

Samples 1, 2, 3 and 4, were collected from the sand supply piles that were a part of the dune restoration activity undertaken by the Parks. Sand supply piles were placed along the NW beach area for the wind to redistribute thereby to enhance the process of dune development. Therefore, it was important to collect samples of the sand supply piles to determine the grain size suitability for dune development process. In other words, it was important to determine if the grain size in the supply piles were suitable to be carried by wind action facilitating dune formation.

The average size (mean) of the grain and sorting (standard deviation), the spread of the size of samples were calculated based on the Folk and Ward (1957) grain size statistics. This method of calculation was used for all samples 1 to 15. The mean grain size of the samples was measured using the standard sieving method. As shown in **Figure 5.1**, samples 1 to 4 were plotted using percentage of retained weight of the sample in the Y-axis and phi unit values in the X-axis. Based on the formula by Folk and Ward (1957), mean and sorting were calculated from the graph (**Figure 5.1**).

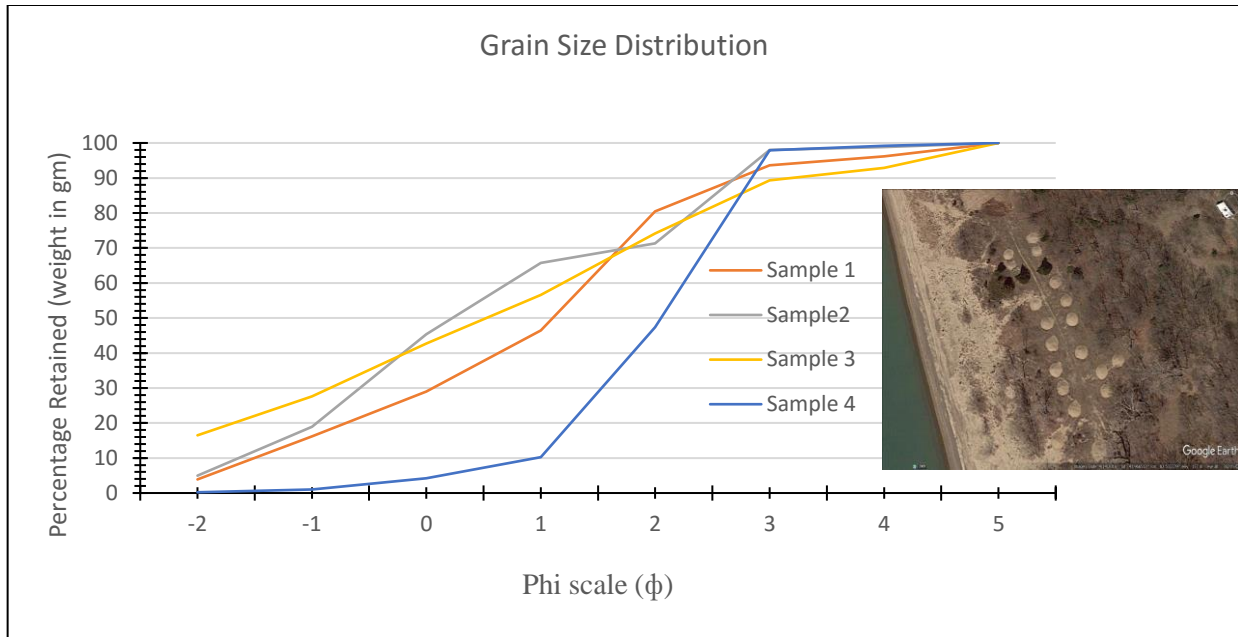


Figure 5.1: Graph showing Grain size distribution for samples 1, 2, 3, and 4

Table 5.1 shows mean and sorting of the samples calculated from the graph. The detailed formulae for the calculation of mean and sorting appear in Chapter 3. Results obtained from the calculation show variability in mean values. The mean grain size for the samples varied from 0.7ϕ to 2.0ϕ . For sample 1 the mean was 0.7ϕ whereas the sorting was 1.6ϕ . The sorting value obtained through the Folk and Ward (1957) formulae (Table 3.3, Chapter 3), confirms that the grain size of sample 1 is poorly sorted with coarse sand. The mean for sample 2 was 0.5ϕ and sorting was 1.6ϕ which indicate poorly sorted with coarse sand. Sample 3 with mean 0.4ϕ and sorting value of 2.1ϕ indicate a very poorly sorted and coarse sand. Sample 4 was found to be moderately sorted with 0.8ϕ and a mean of 2.0ϕ indicating medium sand. A higher mean size of the sample indicates the presence of a range of grain size varying between medium sand to coarse sand. The above samples are very poorly, poorly and moderately sorted.

Table 5.1: Sand Samples 1 to 4 with Mean and Sorting

Sand Samples	Mean (ϕ)	Sorting (ϕ)
Sample 1	0.7	1.6 (Poorly Sorted)
Sample 2	0.5	1.6 (Poorly Sorted)
Sample 3	0.4	2.1 (Very Poorly Sorted)
Sample 4	2.0	0.8 (Moderately Sorted)

Samples 5 to 9 (**Figure 5.2**) and samples 10 to 15 (**Figure 5.3**) were collected in around the natural and disturbed areas (See Table 3.3 Chapter 3, criteria for choosing natural and disturbed area) of NW Beach.

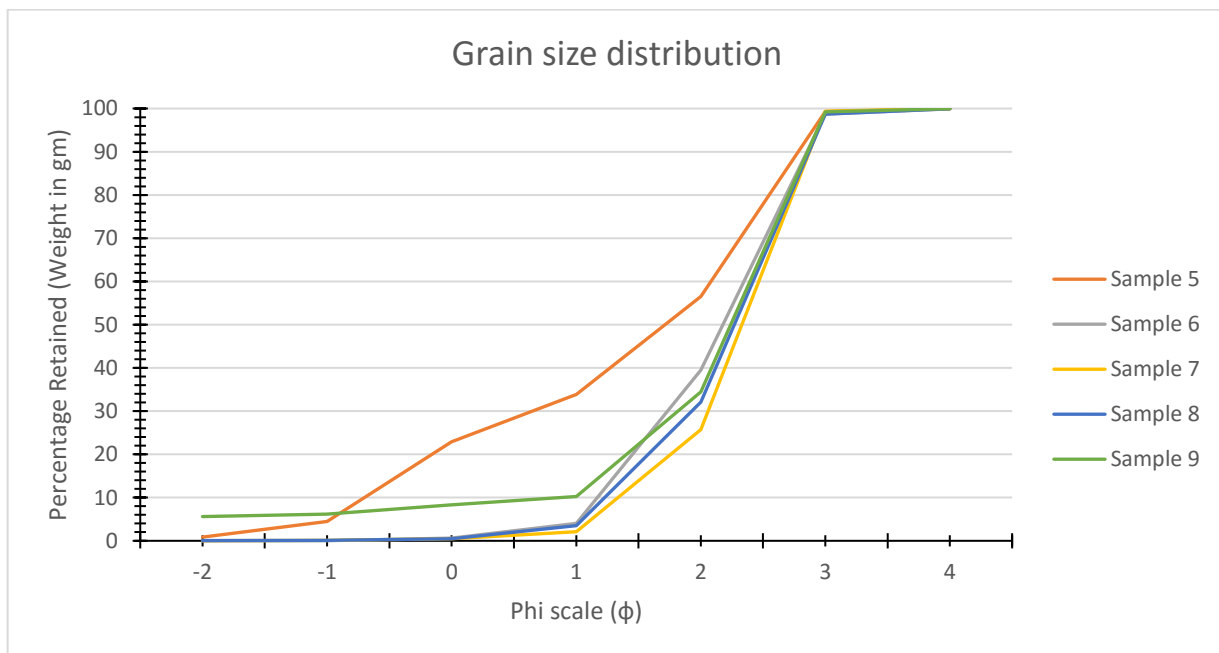


Figure 5.2: Graph showing Grain size distribution for sample 5,6,7,8 and 9

Table 5.2 shows the mean and sorting values of samples 5 to 9. The mean of the samples varied from 1.3 to 2.3 ϕ , whereas the sorting varied from poorly sorted and moderately well sorted grains size. For samples 5 and 9, the mean grain size was 1.3 ϕ and 2.1 ϕ , whereas sorting was calculated to be 1.3 ϕ and 1.1 ϕ indicating its status as poorly sorted. Mean grain size for sample 5 fell into the category of medium sand whereas sample 9 belonged to fine sand. Samples

6, 7 and 8 were moderately well sorted with values of 0.6ϕ , 0.5ϕ , and 0.6ϕ and their mean were 2.1ϕ , 2.2ϕ and 2.2ϕ . The grain size of sample 6, 7, 8 and 9 fell into the category of fine sand and were moderately well sorted (See Table 3.1 and Table 3.2, Wentworth scheme for grain size classification, Chapter 3).

Table 5.2: Sand Samples 5 to 9 with Mean and Sorting

Sand Samples	Mean (ϕ)	Sorting (ϕ)
Sample 5	1.3	1.3 (Poorly Sorted)
Sample 6	2.1	0.6 (Moderately Well Sorted)
Sample 7	2.3	0.5 (Moderately Well sorted)
Sample 8	2.2	0.6 (Moderately Well Sorted)
Sample 9	2.1	1.1 (Poorly Sorted)

Samples 10 - 15 (Figure 5.3) were collected from fore dune, landward from the water and water edge in the NW beach of Point Pelee. Samples 10 to 15 were plotted using percentage of retained weight of the sample in the Y-axis and phi unit values in the X-axis. Based on the formula by Folk and Ward (1957), mean and sorting was calculated from the graph as shown in Figure 5.3.

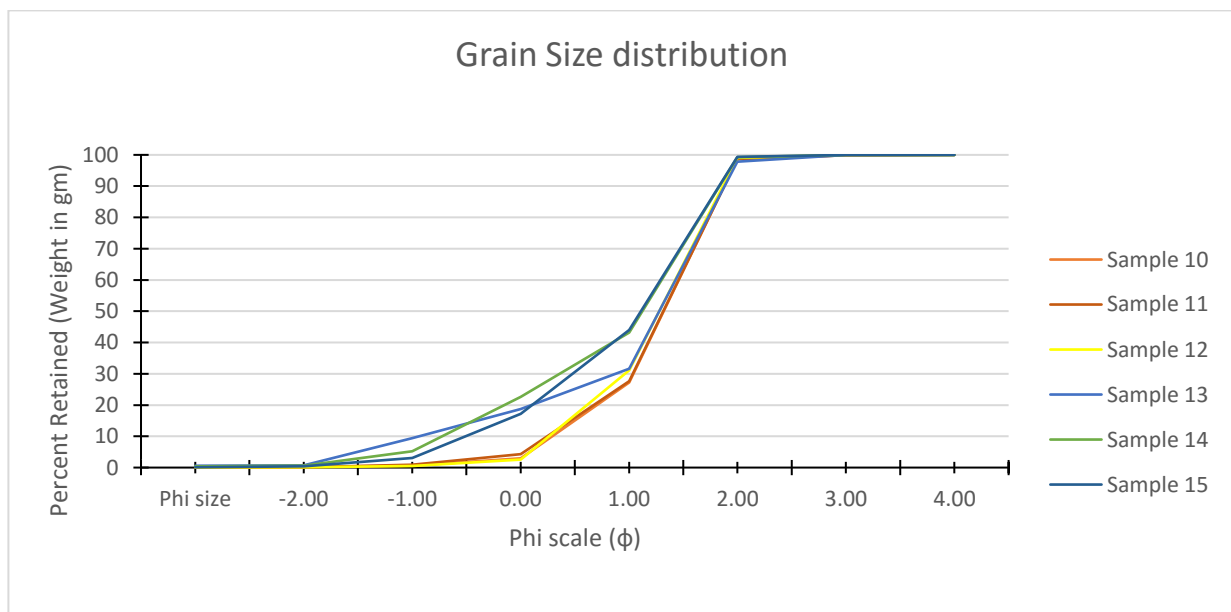


Figure 5.3: Graph showing Grain size distribution for sample 10, 11,12,13,14 and 15

Table 5.3: Sand Samples 10 to 15 with Mean and Sorting

Sand Samples	Mean (ϕ)	Sorting (ϕ)
Sample 10	2.2	0.5 (Moderately well Sorted)
Sample 11	2.2	0.6 (Moderately well Sorted)
Sample 12	2.2	0.5 (Moderately Well sorted)
Sample 13	1.9	1.0 (Poorly Sorted)
Sample 14	1.9	0.9 (Moderately Sorted)
Sample 15	2.0	0.8 (Moderately Sorted)

All samples, except sample 13, were found to have grain size of moderately to moderately well sorted. The mean value varies from 1.9ϕ to 2.2ϕ . Sample 13 was found to be poorly sorted with mean grain size of 1.9ϕ , medium sand. Unlike the other samples, 10, 11 and 12 were calculated as moderately well sorted with mean size of 2.2ϕ . Samples 14 and 15 were moderately sorted with sorting value of 0.9ϕ and 0.8ϕ and mean grain size of 1.9ϕ and 2.0ϕ with medium sand.

Samples 10, 11, and 12 show a mean grain size of 2.2ϕ and fell into the category of fine sand whereas sample 13, 14 and 15 fell into the category of medium sand (See Table 3.1 and Table 3.2 on Wentworth scale for grain size classification, Chapter 3).

5.2.1.1 Discussion

Coastal Dunes are aeolian landforms (Lancaster, 2009) that mainly develop with availability of favourable conditions such as adequate sediment supply, favourable wind velocity, wave action. Samples collected show spatial variance. According to their mean grain size, all samples from the supply piles fall in the category of medium to coarse grain sand with poorly, very poorly and sorted values for sorting. It is evident from these results that sand supply piles are inappropriate for facilitating dune development. It was observed that the samples contained some amounts of clay, silt and pebble sized grains which were not appropriate for sediment transport through wind action. Clay being cohesive in nature, resulted in hardening of

the piles rather than allowing the sediments to move freely. Supply piles (samples 1 to 4) could not contribute to the dune formation process. Well sorted with fine to medium sand is most appropriate for the wind to rework and thus will contribute to dune formation.

Sample 5 and 9 are poorly sorted with mean grain size in the category of medium sand and fine sand, whereas samples 6, 7, and 8 are moderately well sorted with mean grain size in the category of fine sand. The samples 6, 7 and 8 are fine sand with moderately well sorted and they are considered appropriate for dune development.

Samples 10, 11 and 12 are moderately well sorted with mean grain size in the category of fine sand and, therefore, are appropriate for sediment supply for dune development process. The samples 13, 14 and 15 are moderately sorted with mean grain size of medium sand. Hence, fine sand with moderately well sorted is appropriate for dune development.

Sediments with mean grain size of 2.23 phi (ϕ), fine sand, moderately to very well sorted are most appropriate for sediment transportation through the action of wind, and highly appropriate for facilitating dune formation processes (Abuodha, 2003, Byrne, Dale and BaMasoud, 2013).

Sediment transport in the beach environment is strongly dependant on the velocity of the wind. In addition, beach width (Byrne and Bitton, 2001) along with wet (Bauer, et al 2009, Byrne and Bitton, 2001) and dry (Byrne and Bitton, 2001) conditions of the beaches also play a significant role in sediment transport. For sediment transport, sand supply should also be given significant weight as wind velocity. Availability of substantial sediment supply on the beach for the reworking by the wind is the foremost requirement for sand transport. If there is enough sand for sediment transport, there should be appropriate grain size for the wind to rework. Above

results show little variability in the grain size distribution at NW beach and the samples were collected from all the areas including the foredune, landward from the water, water edge and from the sand supply piles.

5.2.2 Vegetation Assemblage

This section describes dune-associated vegetation along with its diversity and variability, in dune stability. The key question examined is ‘whether inadequate diversity of dune associated vegetation is a limiting factor for dune development in NW Beach of Point Pelee?’

Coastal management literature emphasises that diversity of dune associated vegetation can create necessary conditions and act as a key determinant of sand dune development (Maun, 1989; Hesp 2002). Dune formation is largely supported by the action of wind and waves responsible to carry the sediment particles but the presence of vegetation increases deposition and accumulation leading to dune formation. The fundamental dune shape is dictated by the life form of colonizing plant species and their inherent ability to grow vertically and horizontally in response to burial by sand (Maun, 2009). Several dune-friendly species that actively facilitate dune formation have been identified namely Marram grass (*Ammophila breviligulata*), little bluestem (*Andropogon scoparius*), wormwood (*Artemisia absinthium*), Sand dropseed (*Sporobolus cryptandrus*) (Dougan and Associates, 2007; Maun 1989; Reznicek and Catling, 1989; Hesp 2002; Davidson-Arnott, 2010). However, Marram grass is listed as one of the most efficient species in trapping sand. Specific studies undertaken by Maun (1998) found that Marram grass was more efficient in trapping sand than Little Bluestem grass. Foredunes are formed by the continuous accumulation of wind-blown beach sand, which is trapped by burial-tolerant vegetation (Durán and Moore 2013). Maun (1983), stated that Marram grass

(*Ammophila breviligulata*) is more tolerant of burial depth (100 cm) in sand than Sandreed grass (*Calamovilfa longifolia*) (60cm). The morphology of a dune is dependent on the plant species, plant architecture, density, height, sediment texture, wind velocity and the rate of sediment transport (Hesp, 1989).

Sand accumulation may occur within and around discrete or relatively discrete clumps of vegetation, individual plants, driftwood, flotsam, etc. (Hesp 2002). Morphological development of initial or the initiation of embryo dunes depends on wind velocity, rates of sediment transport and plant density, distribution, height and cover (Maun 2009). Hesp (2002), stated that the factors determining morphological evolution of foredunes are sediment supply, the degree of vegetation cover, vegetation species are equally important for dune development. Arens (1996) emphasized with high vegetation density, the foredune traps most of the incoming sand, causing dune to grow and also determined that the largest amount of sand was deposited in a zone of increasing vegetation density. Scholars have concluded that sand was mostly deposited in a sheet over wet Marram grass, then gradually covering the entire vegetation.

Species diversity was calculated using different indices. One of the most important components of dune development is dune stability in early succession. The study focused on whether there was enough dune associated vegetation for dunes in their initial formation thereby enhancing their development or growth.

To achieve the above objective vegetation samples were collected for both natural and disturbed areas. Fifty sample plots of 1m x 1m were taken. The number of individuals and the number of species were identified and calculated from each sample plot. Details on methods used in the collection of vegetation samples were discussed in Chapter 3. Shannon Diversity index and Simpson's Index were calculated and compared for both natural and disturbed areas.

The criteria for choosing natural (less disturbed) and disturbed areas within the Northwest beach area are shown in the **Table 3.3** (Chapter 3). It was necessary to compare species diversity for both areas as an indicator for developing perspectives on strengthening strategic interventions. Criteria for natural or less disturbed and disturbed areas were selected based on the human interference. These criteria were visually determined during the field work.

The extent and the level of disturbances were used to differentiate the two distinct areas. Natural areas were considered as less disturbed than the disturbed areas as they were farther from the parking lot, former boardwalk, and comparatively less numbers of walking trails than the disturbed areas. In the disturbed areas raking was actively taking place during the field visits. Management activities were more intense in the disturbed areas. The main objective is to find if the extent of disturbance through interventions is inversely correlated to the loss of diversity.

The total number of species and number of individuals were identified and counted for both natural (less disturbed) and disturbed areas (**Tables 5.4** and **Table 5.5**). Standardised number of individuals was obtained for both the areas based on their sample numbers (number of individual/total number of samples). **Table 5.4** shows the total number of species and the number of individuals found in the natural area. The total number of species recorded were 13. Species found in these sample plots were mostly identified as dune associated vegetation. A total of 471 individuals were recorded in the natural areas (**Table 5.4**). Total number of sample plots in the natural areas were 20.

Table 5.4: Total number of species and number of individuals in the Natural Area (Abundance)

NATURAL (20 samples)		
Species	Number of Individuals	Standardized number
Marram grass (<i>Ammophila breviligulata</i>)	239	11.95
Wormwood (<i>Artemisia absinthium</i>)	104	5.2
Spurge (<i>Euphorbia esula</i>)	2	0.1
Walnut (<i>Juglans regia</i>)	1	0.05
Milk weed (<i>Asclepias syriaca</i>)	9	0.45
Sand dropseed (<i>Sporobolus cryptandrus</i>)	63	3.15
Orchard grass (<i>Dactylis lomerata L.</i>)	13	0.65
River bank grape (<i>Vitis riparia</i>)	5	0.25
Poison Ivy (<i>Toxicodendron radicans</i>)	7	0.35
American germander (<i>Teucrium canadense</i>)	3	0.15
Hop tree (<i>Ptelea trifoliata</i>)	1	0.05
Blue stem (<i>Schizachyrium scoparium</i>)	22	1.1
Canada wild rye (<i>Elymus canadensis</i>)	2	0.1
Total number of species = 13	471	23.55

Table 5.5 shows the total number of species and total number of individuals found in the sample plots of disturbed areas. A total of 30 sample plots were created in the disturbed area. Total number of species found in the disturbed areas was 8, and the total number of individuals were 1216. Non-native species such as Orchard grass (*Dactylis lomerata L.*) were listed in the disturbed area. Shannon diversity Index was calculated as 1.48 and Simpson's Index as 0.67 for natural area. Within the disturbed area, Shannon diversity Index was calculated as 0.71 and Simpson's Index as 0.35.

Table 5.5: Total number of species and number of individuals in the Disturbed Area

DISTURBED (30 samples)		
Species	Number of individuals	Standardized number
Marram grass (<i>Ammophila breviligulata</i>)	960	32
Wormwood (<i>Artemisia absinthium</i>)	44	1.5
Canada wild rye (<i>Elymus canadensis</i>)	183	6.1
Milk weed (<i>Asclepias syriaca</i>)	7	0.2
Spurge (<i>Euphorbia esula</i>)	17	0.6
Switch grass (<i>Panicum virgatum</i>)	3	0.1
Poison Ivy (<i>Toxicodendron radicans</i>)	1	0.03
Sea Rocket (<i>Cakile edentula</i>)	1	0.03
Total number of species = 8	1216	40.56

Figures 5.4 and 5.5 display rank abundance for Northwest beach area based on the data collected both natural (20 samples) and disturbed (30 samples) areas. The number of individuals for each species are plotted against abundance, which are ranked according to its number of individuals. Each species is represented by the vertical bar in the figure. Rank of abundance is also called as Whittaker plot approach (Colwell, 2009), to display the relative abundance in a vegetation community in Northwest beach area.

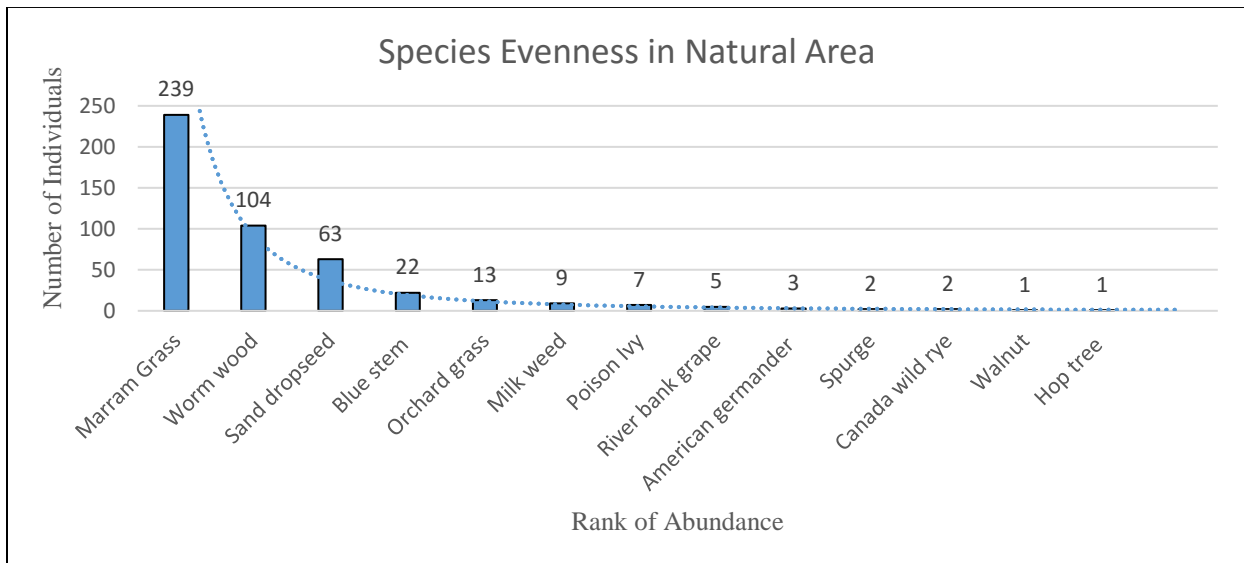


Figure 5.4: A rank-abundance curve for Natural Area of NW Beach of Point Pelee

The graph above (**Figure 5.4** and **Figure 5.5**) indicates species evenness for natural and disturbed areas. The plot displays a long tail in the histogram which indicates the skewed distribution. Both figures (5.4 and 5.5) indicate that the Northwest beach area has low evenness. There are rare species at the tail of the histogram is elongated and declining with varying abundance. Marram grass in both the areas is ranked as highest in abundance. Canada wild rye and Wormwood were ranked second and third in terms of abundance. All species in the natural and disturbed areas together are unevenly distributed. High evenness would mean relatively

equal numbers of individuals across species. Evenness for both natural and disturbed areas was calculated. Evenness in the natural area was 0.5773 and for disturbed area 0.3398.

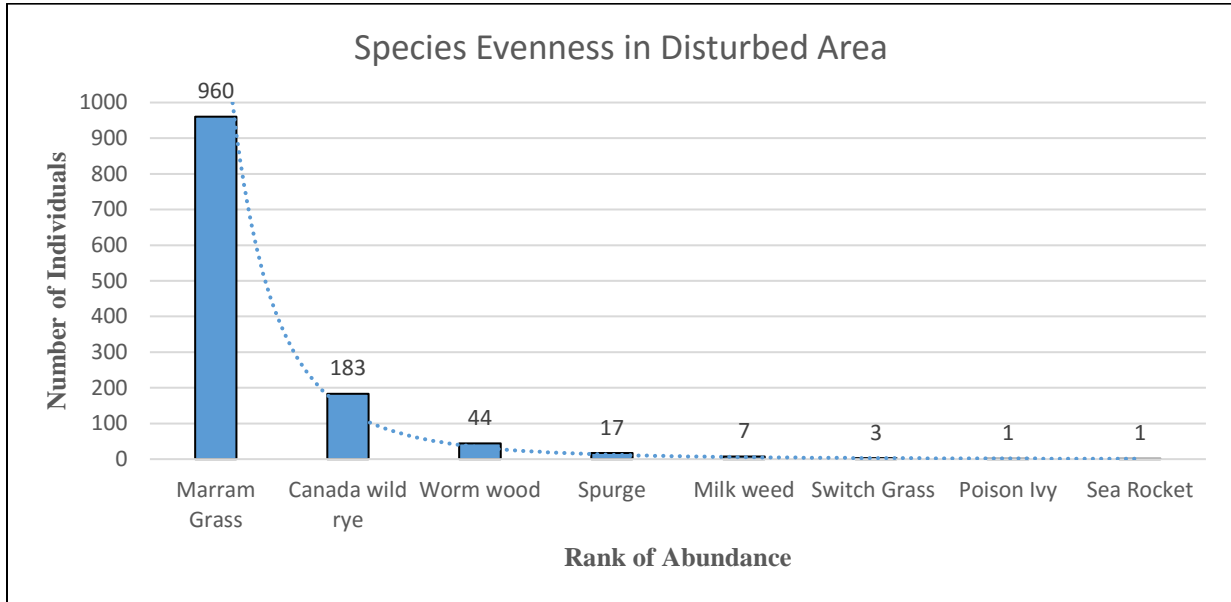


Figure 5.5: A rank-abundance curve for Disturbed Area of NW Beach of Point Pelee

In **Figure 5.6** and **5.7**, species frequency was plotted against abundance in both the natural and disturbed areas. As per **Figure 5.6** *Marram* grass, which is ranked as highest in abundance has a frequency of 45. *Wormwood* the second most abundant species, has the highest frequency of 95. *Milk weed* is ranked 6 in abundance but has the 3rd highest frequency of 30. *Sand dropseed* is ranked 3rd in abundance with a frequency of 25. *Blue stem* and *American germander* are 3rd and 9th in abundance but have the frequency of 15. *Poison Ivy*, *River bank grape* and *Orchard grass* (non-native) have a frequency of 10. *Canada wild rye* and *Spurge* have a frequency of 5 and are second least in abundance. *Hop tree* and *Walnut* are least in abundance but their frequency was 5.

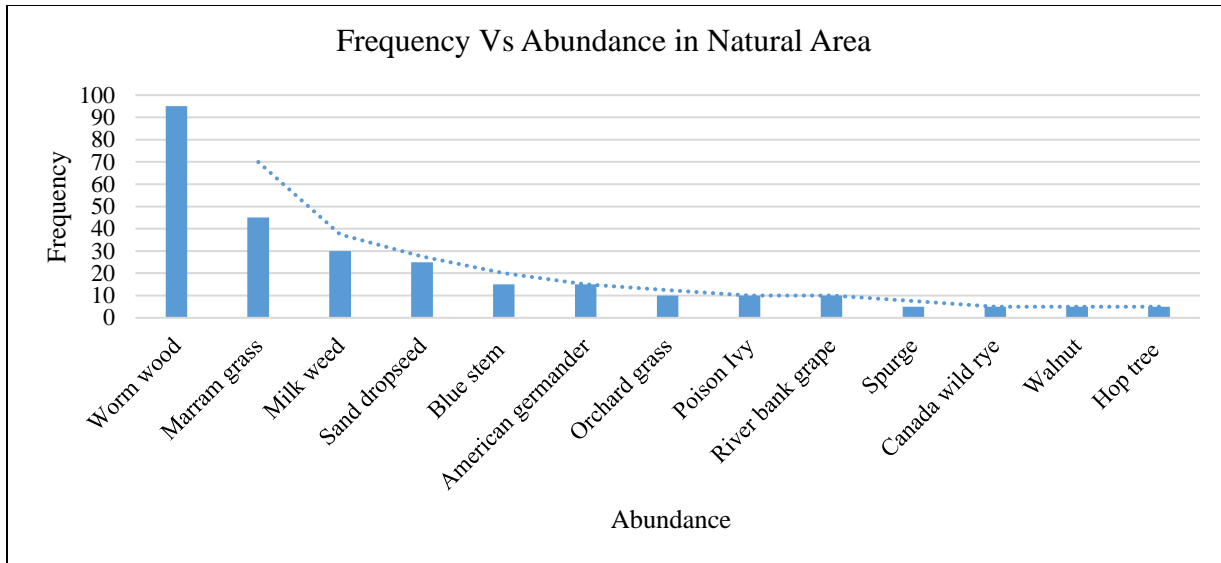


Figure 5.6: Frequency versus species abundance in the natural area of Northwest Beach of Point Pelee

Figure 5.7 shows frequency versus abundance in the disturbed areas. *Marram* grass, which ranked highest in abundance has also the highest frequency of 83.3. Canada wild rye ranked second in abundance with the second highest frequency of 33.3. Spurge has a frequency of 23.3 and ranked third in abundance. Wormwood ranked fourth in abundance but has a frequency of 13.3. Milk weed is ranked 5th in abundance and a frequency of 10. Switch grass ranked 6th in abundance with a frequency of 3.3. While the abundance of Poison Ivy and Sea Rocket ranked seventh, both have the same frequency of 3.3.

The role of vegetation density is important for dune stability. Density is the number of individuals per unit area, i.e., it is calculated based on the ratio between the number of individuals in the sample to the total area sampled (Environment Canada, 1999). Based on species densities, relative density of each species in both areas was calculated as percentage (**Table 5.6 and Table 5.7**). Relative density is the density of one species relative to the density of all other species (Environment Canada, 1999).

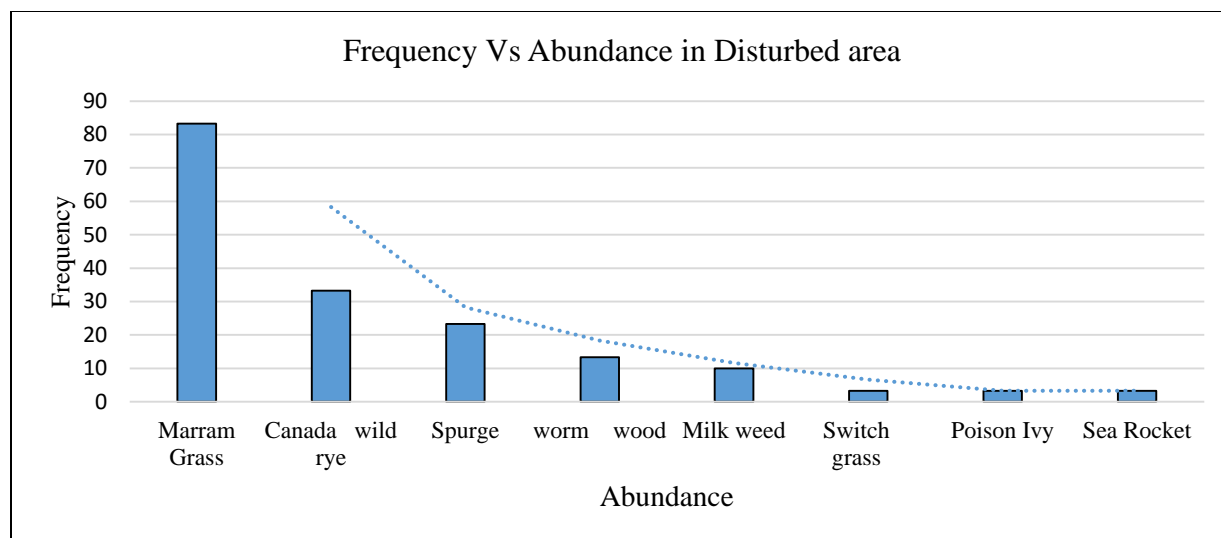


Figure 5.7: Frequency versus species abundance in the disturbed area of Northwest Beach of Point Pelee

Table 5.6 shows the relative density calculated in percent of species in the natural area. Marram grass has the highest relative density of 50.7%, Wormwood is the second highest with a relative density of 22%, Sand dropseed is the third highest with a relative density of 13.3%. Blue stem has a relative density of 4.6%, Orchard grass 2.7%, Milk weed 1.91%, Poison Ivy 1.48%, River bank grape 1.06%, Spurge and Canada wild rye 0.42%, American germander 0.63%, and Hop tree and Walnut with lowest relative density of 0.21%.

Table 5.6: Relative Density of the species in the Natural Area

Relative Density (percentage)	
Marram grass (<i>Ammophila breviligulata</i>)	50.7
Wormwood (<i>Artemisia absinthium</i>)	22.1
Spurge (<i>Euphorbia esula</i>)	0.4
Walnut (<i>Juglans regia</i>)	0.2
Milk weed (<i>Asclepias syriaca</i>)	1.9
Sand dropseed (<i>Sporobolus cryptandrus</i>)	13.3
Orchard grass (<i>Dactylis glomerata L.</i>)	2.7
Hop tree (<i>Ptelea trifoliata</i>)	0.2
River bank grape (<i>Vitis riparia</i>)	1.0
Poison Ivy (<i>Toxicodendron radicans</i>)	1.4
American germander (<i>Teucrium canadense</i>)	0.6
Blue stem (<i>Schizachyrium scoparium</i>)	4.6
Canada wild rye (<i>Elymus canadensis</i>)	0.4

Table 5.7: shows the relative density calculated in percent for the species found in the disturbed area. Marram grass has the highest relative density of 78.9%, Canada wild rye has the second highest relative density of 15.04%, and Wormwood is the third highest with relative density of 3.61%. Spurge has a relative density of 1.39%, Switch grass 0.24%, Poison Ivy and Sea Rocket have the same relative density of 0.08%.

Table 5.7: Relative Density of the species in the Disturbed Area

Relative Density (percentage)	
Marram grass (<i>Ammophila breviligulata</i>)	78.94
Worm wood (<i>Artemisia absinthium</i>)	3.61
Canada wild rye (<i>Elymus canadensis</i>)	15.04
Milk weed (<i>Asclepias syriaca</i>)	0.57
Spurge (<i>Euphorbia esula</i>)	1.39
Switch grass (<i>Panicum virgatum</i>)	0.24
Poison Ivy (<i>Toxicodendron radicans</i>)	0.08
Sea Rocket (<i>Cakile edentula</i>)	0.08

Dominance is the relative importance of a species related to degree of influence it has on ecosystem components (Environment Canada, 1999). Dominance of each species was calculated based on its area cover in a sample plot. Relative dominance is the area a species occupies with relative to the total area of all species and is described in percent.

Table 5.8 and **Table 5.9** show the dominance and relative dominance of both natural and disturbed areas. In the natural area, Wormwood has the highest dominance (3.4%) and relative dominance (44.7 %). Marram grass was the second highest with dominance of 1.14% and relative dominance of 15%. Poison Ivy with dominance 0.7 and relative dominance of 9.21%, Milk weed with dominance 0.67 and relative dominance of 8.81%, Sand dropseed with dominance of 0.57 and relative dominance of 7.5%, Orchard grass with dominance of 0.45 and

relative dominance of 5.92%, American germander with dominance of 0.27 and relative dominance 3.55% remained in the middle range. In the least dominance and relative dominance category were River bank grape with dominance of 0.12 and relative dominance of 1.57%, Canada wild rye with dominance of 0.1 and relative dominance of 1.31%, Blue stem with dominance of 0.09 and relative dominance of 1.18%, Walnut with dominance of 0.05 and relative dominance of 0.65%, Spurge and Hop tree with dominance of 0.02 and relative dominance of 0.26% (**Table 5.8**).

Table 5.8: Dominance and Relative Dominance of the species in the Natural Area

Species	Dominance	Relative Dominance
Marram grass (<i>Ammophila breviligulata</i>)	1.14	15.0
Wormwood (<i>Artemisia absinthium</i>)	3.4	44.7
Spurge (<i>Euphorbia esula</i>)	0.02	0.26
Walnut (<i>Juglans regia</i>)	0.05	0.65
Milk weed (<i>Asclepias syriaca</i>)	0.67	8.81
Sand dropseed (<i>Sporobolus cryptandrus</i>)	0.57	7.5
Orchard grass (<i>Dactylis glomerata</i> L.)	0.45	5.92
Hop tree (<i>Ptelea trifoliata</i>)	0.02	0.26
River bank grape (<i>Vitis riparia</i>)	0.12	1.57
Poison Ivy (<i>Toxicodendron radicans</i>)	0.7	9.21
American germander (<i>Teucrium canadense</i>)	0.27	3.55
Blue stem (<i>Schizachyrium scoparium</i>)	0.09	1.18
Canada wild rye (<i>Elymus canadensis</i>)	0.1	1.31

Whereas in the disturbed area, Marram grass was recorded to have highest dominance and relative dominance with 77.58 and 75.49% respectively, Wormwood with the second highest dominance and relative dominance with 0.95 and 9.46%, Canada wild rye at third highest level of dominance and relative dominance at 0.86 and 8.56%. Milk weed with dominance and relative dominance of 0.28 and 2.78%, Switch grass with dominance and relative dominance of 0.1 and

0.99%, Sea Rocket and Switch grass with dominance and relative dominance of 0.02 and 0.19% and 0.1 and 0.99 remained in the middle and lowest ranges (**Table 5.9**).

Table 5.9: Dominance and Relative Dominance of the species in the Disturbed Area

Species	Dominance	Relative Dominance
Marram grass (<i>Ammophila breviligulata</i>)	7.58	75.49
Wormwood (<i>Artemisia absinthium</i>)	0.95	9.46
Spurge (<i>Euphorbia esula</i>)	0.24	2.39
Sea Rocket (<i>Cakile edentula</i>)	0.02	0.19
Canada wild rye (<i>Elymus canadensis</i>)	0.86	8.56
Milk weed (<i>Asclepias syriaca</i>)	0.28	2.78
Poison Ivy (<i>Toxicodendron radicans</i>)	0.01	0.09
Switch grass (<i>Panicum virgatum</i>)	0.1	0.99

Table 5.10 and **Table 5.11** shows the frequency and relative frequency of both natural and disturbed areas. Frequency of a community indicates the number of times a species is occurring within the quadrats or within the total number of sample plots (Environment Canada, 1999). Frequency is expressed as a percentage. Relative frequency is described as the distribution of one species in a sample relative to the distribution of all species (Environment Canada, 1999).

In the natural area, Wormwood has the highest frequency and relative frequency of 95 and 34.54%. Marram grass was found to have frequency of 45 and relative frequency of 16.36% at second highest level, followed by Milk weed with a frequency of 30 and relative frequency of 10.90% at third highest level. Sand dropseed with a frequency of 25 and relative frequency of 9.09%, and American germander and Blue stem with similar frequency of 15 and relative frequency of 5.45 remained in the middle category. In the lowest frequency and relative frequency level were Orchard grass, River bank grape and Poison Ivy at 10 and 3.63%

respectively, and Spurge, Walnut, Hop tree and Canada wild rye 5 and 1.81% respectively (Table 5.10).

Table 5.10: Frequency and Relative Frequency of the species in the Natural Area

Species	Frequency	Relative Frequency
Marram grass (<i>Ammophila breviligulata</i>)	45	16.36
Wormwood (<i>Artemisia absinthium</i>)	95	34.54
Spurge (<i>Euphorbia esula</i>)	5	1.81
Walnut (<i>Juglans regia</i>)	5	1.81
Milk weed (<i>Asclepias syriaca</i>)	30	10.90
Sand dropseed (<i>Sporobolus cryptandrus</i>)	25	9.09
Orchard grass (<i>Dactylis glomerata L.</i>)	10	3.63
Hop tree (<i>Ptelea trifoliata</i>)	5	1.81
River bank grape (<i>Vitis riparia</i>)	10	3.63
Poison Ivy (<i>Toxicodendron radicans</i>)	10	3.63
American germander (<i>Teucrium canadense</i>)	15	5.45
Blue stem (<i>Schizachyrium scoparium</i>)	15	5.45
Canada wild rye (<i>Elymus canadensis</i>)	5	1.81

For the disturbed area, Marram grass occurred with a frequency of 83.33 and relative frequency of 48.07%. Canada wild rye has a frequency of 33.33 and relative frequency of 19.26% at level two. Spurge with a frequency of 23.33 and relative frequency of 13.45%, Worm wood with a frequency of 13.33 and relative frequency of 7.69%. Milk weed with a frequency of 10 and relative frequency of 5.76% remained in the middle level. Switch grass, Poison Ivy and Sea Rocket occupied the lowest level with exactly same frequencies of 3.33 and relative frequencies as 1.92 (Table 5.11).

Table 5.11: Frequency and Relative Frequency of the species in the Disturbed Area

Species	Frequency	Relative Frequency
Marram grass (<i>Ammophila breviligulata</i>)	83.3	48.07
Worm wood (<i>Artemisia absinthium</i>)	13.3	7.69
Canada wild rye (<i>Elymus canadensis</i>)	33.3	19.26
Milk weed (<i>Asclepias syriaca</i>)	10	5.76
Spurge (<i>Euphorbia esula</i>)	23.3	13.45
Switch grass Native (<i>Panicum virgatum</i>)	3.3	1.92
Poison Ivy (<i>Toxicodendron radicans</i>)	3.3	1.92
Sea Rocket (<i>Cakile edentula</i>)	3.3	1.92

Importance value was calculated based on the relative density, relative dominance and relative frequency to describe their role in sand dune development in the Northwest beach area. Importance value is the sum of the three measures and ranges from 0 to 300 (USDA Forest Service Climate Change, 2014). Relative density, relative dominance and relative frequency are expressed in percentages and each measure range from 0 to 100. Importance value was calculated both for natural and disturbed areas (**Table 5.12** and **Table 5.13**).

Table 5.12: Importance value Index of the species in the Natural Area

Importance Value (Natural Area)	
Marram grass (<i>Ammophila breviligulata</i>)	82.1
Wormwood (<i>Artemisia absinthium</i>)	101.2
Spurge (<i>Euphorbia esula</i>)	2.49
Walnut (<i>Juglans regia</i>)	2.67
Milk weed (<i>Asclepias syriaca</i>)	21.56
Sand dropseed (<i>Sporobolus cryptandrus</i>)	29.91
Orchard grass (<i>Dactylis glomerata</i> L.)	12.27
Hop tree (<i>Ptelea trifoliata</i>)	2.28
River bank grape (<i>Vitis riparia</i>)	6.25
Poison Ivy (<i>Toxicodendron radicans</i>)	14.26
American germander (<i>Teucrium canadense</i>)	9.6
Blue stem (<i>Schizachyrium scoparium</i>)	11.29
Canada wild rye (<i>Elymus canadensis</i>)	3.53

Table 5.13: Importance Value Index of the species in the Disturbed Area

Importance Value (Disturbed Area)	
Marram grass (<i>Ammophila breviligulata</i>)	202.5
Worm wood (<i>Artemisia absinthium</i>)	20.61
Canada wild rye (<i>Elymus canadensis</i>)	42.74
Milk weed (<i>Asclepias syriaca</i>)	8.97
Spurge (<i>Euphorbia esula</i>)	17.23
Switch grass (<i>Panicum virgatum</i>)	3.15
Poison Ivy (<i>Toxicodendron radicans</i>)	2.83
Sea Rocket (<i>Cakile edentula</i>)	2.93

For natural areas, Wormwood held the highest importance value of 102.2 compared to other species. Marram grass held the second highest importance value of 82.1. Sand dropseed has an importance value of 29.91. Walnut, Spurge, Hop tree scored the lowest importance value (**Table 5.12**).

In disturbed areas, the distribution pattern of species importance value is different than that of the natural areas. Marram grass holds the highest importance value of 202.5, Canada wild rye holds the second highest importance value of 42.74 and Wormwood holds the third highest importance value of 20.61. Poison Ivy and Sea Rocket have the lowest importance value (**Table 5.13**).

5.2.2.1 Discussion

Species diversity in the natural areas was higher compared to that of the species in the disturbed areas along the NW beach. This pattern indicates that the natural areas are less exposed to human interference. However, there is a discrepancy in the total number of sample plots studied with 20 in the natural areas compared to 30 in the disturbed areas. Vegetation sampling was also restricted to only some parts because of the strict regulations of the Parks Canada. During vegetation sampling, non-native species were observed. For example, Orchard grass, which is a non-native species, was observed in two sample plots in the natural areas. No non-native species were recorded in the disturbed areas.

In both natural and disturbed areas, the distribution of Marram grass was not even, i.e., while there was dominant presence of Marram grass in a few plots, it was absent or less present in several other sample plots. Since Marram grass is a key determinant factor facilitating sand dune formation, its uneven distribution tends to contribute to an equally uneven dune formation in the NW beach area. There was also wide variation in the species distribution and composition.

Despite fewer sample plots in the natural areas, the diversity index was found to be higher than that of the disturbed area. Species richness was higher in natural as compared to the disturbed areas which had only 8 species as compared to 13 species found in the natural areas. However, the number of individuals in the natural areas (i.e., 471) were significantly lower compared to individuals recorded in the disturbed area (i.e., 1216). This variation is partly influenced by the discrepancy in the number of sample plots in the natural (20 plots) and disturbed (30 plots) areas. Uneven patterns in vegetation cover were observed in the study area. The presence of Orchard grass, a meadow species, was observed in the natural areas. It was observed during field work that meadow plants dominated one of the parking lots that was removed for restoration of habitats in 2008. These meadow plants multiplied because of the impact of agricultural activities in the North boundaries of Point Pelee. Spotted knapweed is another invasive species that was observed during field work. Even though this species was not in the sample, it was found to be dominating in other areas including the restored parking lot. Restoration of the parking lot was undertaken to rehabilitate sand dunes and facilitate their formation process. However, the presence of these invasive species proved detrimental to dune formation process as they did not allow dune associated species to grow, and did not by themselves facilitate the dune formation process.

Species richness and abundance based on the samples observed in NW beach suggest that some species were highly abundant, while some others were present in medium abundance and the remaining had only a few individuals. There is a relationship between the level of abundance and species richness in the community. Importance value is widely used because it highlights the importance of species in terms of their contribution to the ecosystem. It defines the predominant role of the species in that ecosystem. The importance value for Hop tree was the lowest which

indicates that rare species, such as Hop tree are more susceptible to disturbance and could disappear. This warrants higher conservation priority being rendered to such species. The common Hop tree is a species at risk listed in COSEWIC 2002. Sea Rocket has also the lowest importance value and is one of the shoreline vegetation species critical for sand dune formation.

The rank-abundance curve shows a steep gradient indicating low evenness of the high ranked species. For example, Marram grass in the natural area of the NW beach has higher abundance than that of the low ranked species i.e., Walnut, Hop tree, Canada wild rye, Spurge, American germander in the natural area, and Poison Ivy, Sea Rocket and Switch grass in the disturbed area. The declining trend in the curve suggests a low species evenness in the sampled area.

Figure 5.9 shows large variation in species count in sample plots. This clearly signifies the frequency of species occurrence in the sample plots and as well as the unevenness of the species present.



Figure 5.8: Variation in species count in Sample plots

Figure 5.9 shows the sediments trapped in Marram grass whereas the in sparse vegetation the accumulation is insignificant.



Figure 5.9: Sand movement and accumulation/trapped in dune grasses.

5.2.3 Land Use and Land Cover Change

This section focusses on detecting, analysing, visualizing and estimating land use / land cover changes and its impact on sediment transport in dune restoration process.

It addresses the hypothesis ‘changes in land use and land cover have significant impact on dune development’.

Wiersma et al. (2004) studied the impact of landscape patterns and human population pressures associated with species loss in Canadian parks and proposed that the human population in the periphery of the park, visitor density and land use and land cover change do affect species loss. Wickham et al. (2000) suggested that the linkages between landscape patterns and increased human use lead to an increase in habitat fragmentation resulting in species loss within the region. Meyer and Turner (1992) stated changes in land use and land cover affect global systems (e.g., atmosphere, climate and sea level). Land use patterns and land cover analysis help define the biophysical state of Earth’s surface (Turner et al. 1995). Improved technology with reliable aerial and satellite data for monitoring land use and land cover changes have increased and this has

contributed to efficient change analysis with attention to past, present and future. Analysis of land use / land cover provides necessary tools to the policy makers and managers. Remote sensing data provide the capability to monitor a wide range of landscape biophysical properties important to management and policy, where information on these variables is needed in the past, present and future (McVicar et al. 2003).

Land use and land cover is an important measure to monitor the impact of climatic variation and human impact influencing today's pattern of change. Referring to the methods chapter, on general framework and detailed work flow, the following change maps were produced and area of different classes were calculated. **Figures 5.10, 5.11, 5.12, 5.13** provides land use and land cover classification 1959, 1977, 2006, 2015 respectively. Please refer to Tables 5.14, 5.15, 5.16, 5.17 for detailed classification.



Figure 5.10: LULC classification for 1959

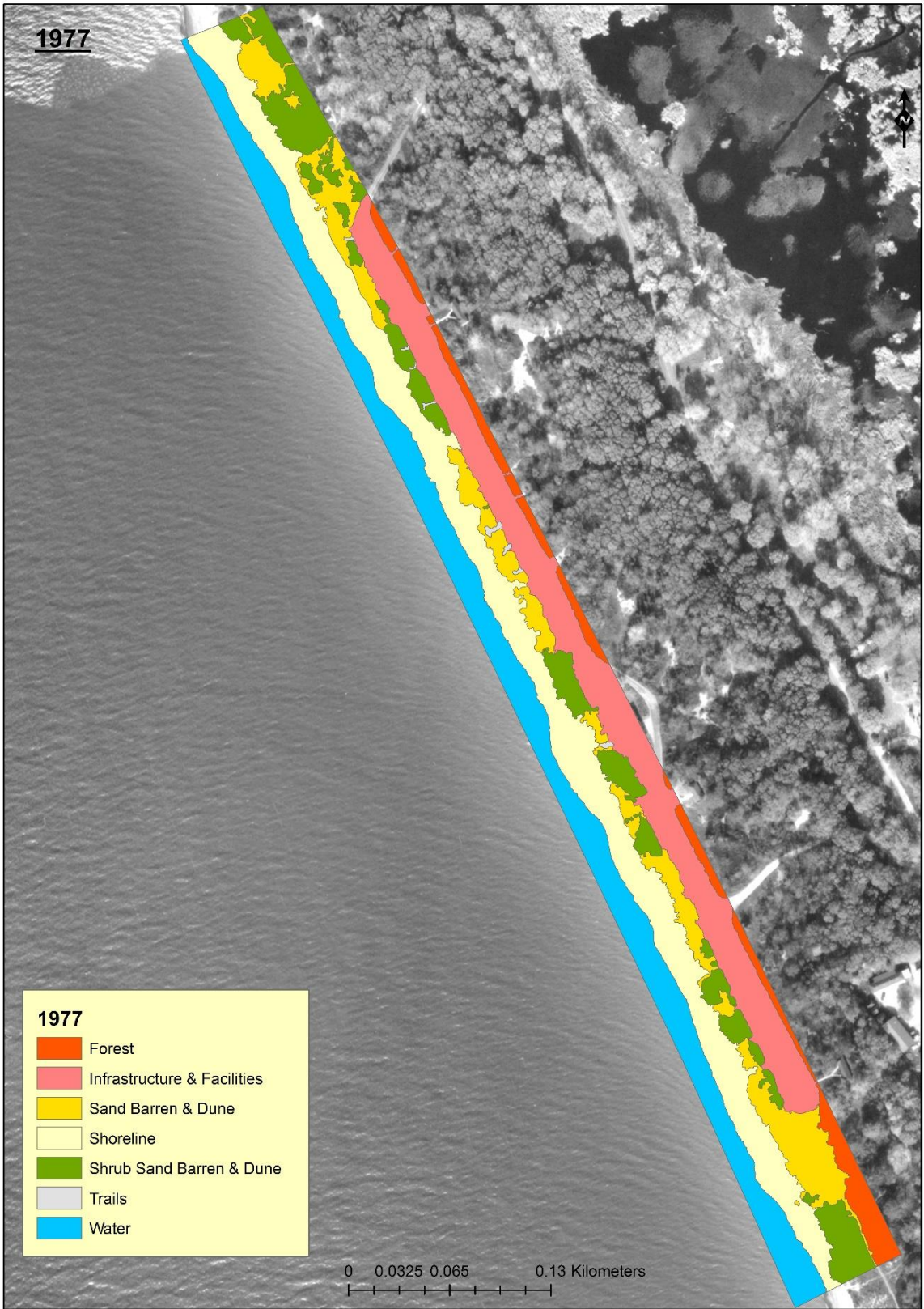


Figure 5.81: LULC classification for 1977



Figure 5.12: LULC classification for 2006



Figure 5.93: LULC classification for 2015

Table 5.14 shows land use and land cover classification for NW beach, Point Pelee in 1959. Six LULC classes were delineated according to the Ecological Land Classification System of Southern Ontario. Further details about these classes have been discussed in the Methods section of Chapter 3. Forest and water areas were delineated because they were within the study boundary but changes in these two classes were not taken into consideration. Barren land, shoreline and sand barren and dune (grasses) were dominant LULC classes followed by shrub sand barren and dune was less prominent LULC class.

Table 5.14: LULC Classification for 1959

1959	Class	Area in sq. m	Area in %
1	Barren Land	16260	26.6
2	Shoreline	17077	28.0
3	Shrub Sand Barren & Dune	609	1.0
4	Sand Barren & Dune (grasses)	16293	26.6
5	Forest	450	0.8
6	Water	10414	17.0
		61103	100

Table 5.15 shows land use and land cover classification for the year 1977. Seven LULC classes were delineated. Similar to 1959, forest and water areas were delineated because they were within the study boundary but changes in these two classes were not taken into consideration. Even then their inclusion in the study provides an idea about water level increase or decrease during that same period. Trails were significantly observed while interpreting the aerial photos. Trails are unauthorised pathways created by visitors for easy access to the beach area from the parking lots. However, trails occupied the smallest area compared to other classes. The LULC classes remained the same for the both 1959 and 1977 except for the addition of trails and infrastructure and facilities as new classes and the absence of barren land as a class. It was

observed that infrastructure and facilities were developed on the barren land. Shoreline vegetation type class occupied an area of 15904 sq. m in 1977, which suggests a decrease of 1173 sq. m of shoreline vegetation from a total of area of about 17077 sq. m. in 1959. Similarly, Shrub Sand Barren and dune type was calculated to be occupying an area of 7302 sq. m. which is a significant increase from only 609 sq. m. in 1959. Sand Barren and Dune (grasses) type recorded a significant decrease from 16293 sq. m. in 1959 to only 7880 sq. m. in 1977. When compared with 1959 classified map, the water level has increased. Trails were significantly observed in 1977 suggesting increased human interference within the park.

Table 5.15: LULC Classification for 1977

1977	Class	Area in sq. m	Area in %
1	Infrastructure & Facilities	12449	20.3
2	Shoreline	15904	26.0
3	Shrub Sand Barren & Dune	7302	12.0
4	Sand Barren & Dune (grasses)	7880	12.9
5	Trails	160	0.3
6	Forest	3855	6.3
7	Water	13557	22.2
		61107	100

Table 5.16 shows Land use and land cover classification change from 1959 to 1977. Before parking lot was installed the land was mostly barren did not have any vegetation. Change from Barren to infrastructure and facilities 26.6% to 20.3%. Change area was 3811 sq. m (6.3%). Shoreline vegetation type decreased by 1173 sq. m (2%). Increase in Shrub Sand Barren Dune by 6693 sq. m (11%). Decrease in Sand Barren & Dune (grasses) by 8413 sq. m (13.7%). Increase in lake levels from 1959 to 1977 have been experienced.

Table 5.16: Post Classification Change for 1959 to 1977

1959-1977	Class	Area in sq. m	Area in %
1	Infrastructure and facility	3811	6.3
2	Shoreline	1173	2.0
3	Shrub Sand Barren & Dune	6693	11.0
4	Sand Barren & Dune (grasses)	8413	13.7

Table 5.17 displays the LULC Classification for the year 2006. There are no major changes in the area for the infrastructure and facilities class between 1977 to 2006. According to Current and Historic LESSS (Lake Erie Sand Spit Savannah) vegetation communities and types (Dougan and Associates, 2007) Red Cedar Treed Sand dune type was classified. Shrub Sand Barren Dunes types were further classified and identified according to species such as Deciduous Thicket and Red Cedar Treed Sand Dune types. There is a small decrease in the area of Sand Barren and Dune type in 2006 compared to 1977. Deciduous Thicket occupies an area of 9302 sq. m. whereas Red Cedar Treed Sand Dune type occupies an area of 1717 sq. m. Shoreline type increased from 15904 sq. m. in 1977 to 24358 sq. m. in 2006. Area under trails increased in 2006 as compared to 1977.

Table 5.167: LULC Classification for 2006

2006	Class	Area in sq. m	Area in %
1	Infrastructure & Facilities	12420	20.4
2	Shoreline	24358	39.9
3	Deciduous Thicket	9302	15.2
4	Red Cedar Treed Sand Dune	1717	2.8
5	Sand Barren & Dune	7296	11.9
6	Trails	560	0.9
7	Forest	1237	2.0
8	Water	4217	6.9
		61107	100

Table 5.18 shows the land use and land cover classification for 2015. Eight classes were identified in 2015. Based on observations during the field work, Cottonwood Trees were classified as a new class. Cottonwood trees belong to the Deciduous type, but they were recorded close to the shoreline (i.e., about 89 sq. m. in 2015 from their insignificant presence in 2006. 2015 classified map shows a considerable increase in deciduous thicket from 9302 sq. m. in 2006 to 11,536 sq. m. Meadow vegetation was observed in the former parking lot area that was removed in 2008 to rehabilitate dunes. Red Cedar Sand dune increased from 1717sq. m in 2006 to 2522 sq. m. in 2015. Sand Barren and Dune increased from 7196 sq. m. in 2006 to 12299 sq. m. in 2015. Decrease in shoreline vegetation from 24358 sq. m in 2006 to 20611sq. m. in 2015 was observed. A higher water level was observed in 2006. The 1959 aerial photo was classified to document land use and land cover status of the study area before infrastructure development activities were undertaken. This classification provided a strong baseline for further interpretations. The area classified as barren land in 1959 (Figure 4.10) was converted into infrastructure and facilities in 1977 (Figure 4.11). In 1959, Barren land was used for transportation and other services by private residence owners inside the Park. There was no presence of deciduous thicket in 1959 and 1977 (Figure 4.10 and 4.11) which was observed in 2006 classification (Figure 4.12). A significant increase in shrub sand barren and dunes was observed between 1959 (i.e., 609 sq. m.) and 1977 (i.e., 7302 sq. m.). A significant decrease in sand barren dune type was recorded (i.e., from 16293 sq. m. in 1959 to 7880 sq. m. in 1977). Higher water levels were observed in both 1959 and 1977.

Table 5.178: LULC Classification for 2015

2015	Class	Area in sq. m	Area in %
1	Infrastructure & Facilities	8758	14.3
2	Shoreline	20611	33.7
3	Trails	603	0.9
4	Meadow Vegetation	3341	5.5
5	Deciduous Thicket	11536	18.9
6	Sand Barren & Dune (Red Cedar Treed Sand Dune)	2522	4.1
7	Sand Barren & Dune (grasses)	12299	20.2
8	Forest	1348	2.2
9	Cottonwood trees	89	0.2
		61107	100

Table 5.19 shows Land use and land cover classification change from 2006 to 2015. Decrease in Infrastructure and facilities by 6.1 % is due to the removal of one of the parking lot in 2007. This removed parking lot is covered with meadow vegetation occupying an area of about 3341 sq. m (5.5%). Increase in Red Cedar Treed Sand Dune type by 805 sq. m (1.3%). Sand Barren & Dune (grasses) were increased by 5003 sq. m (8.3%). Trails were increased by 43 sq. m (0.07%).

Table 5.19: Post Classification Change for 2006 to 2015

2006-2015	Class	Area in sq. m	Area in %
1	Infrastructure and facility	3662	6.10
2	Shoreline	3747	6.20
3	Red Cedar Treed Sand Dune	805	1.30
4	Sand Barren & Dune (grasses)	5003	8.30
5	Deciduous Thicket	2234	3.70
6	Trails	43	0.07

5.2.3.1 Discussion

A significant increase in deciduous thicket indicates increased barriers to sand movement which may have hindered the sand dune development processes. There is an increase in

deciduous thicket which clearly suggests restricted sediment supply to the parking lots. The removal of parking lots in 2008 and 2014 was a major step towards sand dune restoration. This intervention produced immediate adverse results. For example, meadow vegetation increased significantly (Table 5.18) during 2008-2014 in response to the intervention. Meadow vegetation restricts the growth of marram grass thereby restricting sediment supply for dune formation. The increase in Red Cedar Treed Sand Dune, Sand Barren & Dune (grasses) along with a decrease in Shoreline between 2006 and 2015 have an insignificant contribution to dune restoration.

Shoreline type was observed to have increased from 15904 sq. m. in 1977 to 24358 sq. m. in 2006. This major increase in shoreline is due to the fluctuation in water levels. In 1977 water level increased but recorded a decrease in 2006. An increase in lake level will narrow the beach width, and sediment supply is limited whereas, a decrease in lake level will widen the beach width increasing the sediment supply (Byrne and Bitton, 2001). The pattern of change of the multi-temporal aerial photos have opened up many avenues for park managers to effective management planning. Invasive species are a threat to biodiversity. These species are invasive as they do not belong to this particular community and have moved into a habitat and can reproduce and spread aggressively replacing the native species. Invasive species make their way into a disturbed community.

Trails that are unauthorised might help for a passage or open area for sand movement. The meadow vegetation and the Cottonwood trees close to the shoreline along with fluctuating water levels indicate an active process of “Coastal Squeeze” in the dunes of Northwest Beach, signifying the increase concern for “habitat loss” and puts forth to being challenged for the restoration process.

5.3 Conclusion

These three components i.e., 1. Grain size distribution, 2. Dune associated vegetation and 3. Land use and land cover are critical elements for sand dune restoration process (**Figure 5.14**). Each of these factors/elements can significantly contribute to the health of the sand dune. However, no one element or factor alone can lead to dune restoration.

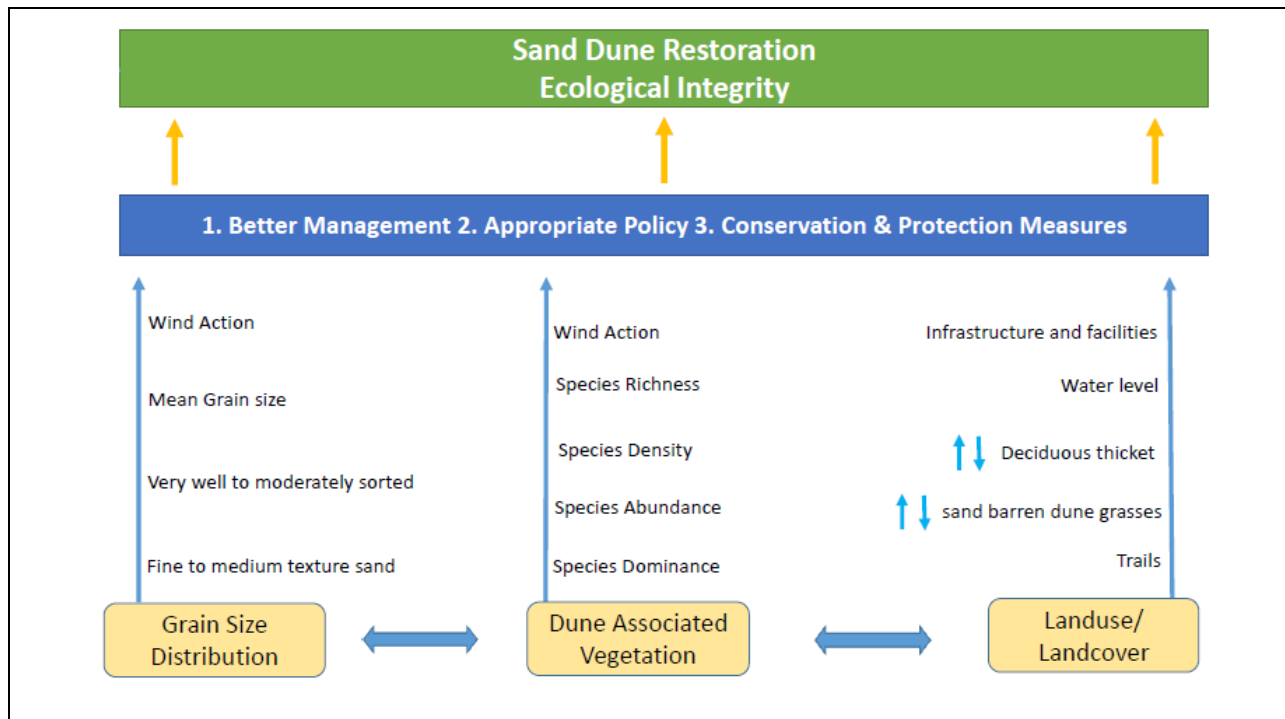


Figure 5.14: Synergistic and complementary role of key factors leading to sand dune restoration

This research found that all necessary factors such as grain size distribution, dune associated vegetation and LULC can work synergistically to produce better results in sand dune restoration process. For example, fine to medium texture sand typically leads to sand dune development, only if dune associated vegetation is present with proper density and richness in the ecosystem. The roots of these dune associated vegetation, especially Marram grass helps trap sand at the location thereby facilitating sand dune formation. Dunes are formed when wind

blows the sand which gets deposited along the vegetation that traps them. The important controlling factor is the wind velocity. As discussed in the results section, moderate to very well sorted fine to medium size grains are required for dune formation. Grain size distribution is one of the limiting factors in dune restoration process in NW beach of Point Pelee. Analysis of sand samples indicates that some of the sediments were appropriate for dune development, whereas others were not appropriate. Fine sand with moderate to moderately well sorted are appropriate for dune development (Abuodha, 2003, Byrne, Dale and BaMasoud, 2013). The role of the wind action is very critical and acts as a driving force in sand dune development. The fine grains sediments are blown away and are transported over long distances, unless there are dune associated vegetation to restrict the transportation which eventually contributes to dune development. Sand samples collected from sand piles contained silt and clay, with angular pebbly sediments, which required very strong wind to blow them. Figure 5.15 depicts that with favourable grain size (fine to medium with well to moderately well sorted) and wind action, along with better management and protection would contribute to the dune restoration process. These appropriate conditions are important to the restoration of dunes.

Determining diversity of the dune species was equally important in the dune restoration process. This is one of the important factors, which contributes to the initiation of sand dune building process. With sediment transportation dune species act as barrier in obstructing the sediments being carried away. Diversity of dune associated vegetation is essential as it contributes to the abundance and richness of the species. Health of the dunes is dependent on these vegetation. With proper planning and management species richness and density will strengthen the health of the dunes.

Time series classification of land use and land cover change streamlines better management and planning for dune restoration process. Both anthropogenic and climatic factors play an important role and have caused adverse impacts. Land use and land cover patterns suggest that changes in lake levels creates wet and dry beach and narrowing of the beach width causing imbalance in the sediment transportation. Wet beaches generally restrict sand movement while dry beaches enhance sediment transportation. In due course of time, increase in deciduous thicket restricted the sediment movement. Better management and planning intervention is required to minimise the dense thicket in order to ensure regular sediment transportation. Due to the fluctuations in lake levels and the presence of cottonwood trees close to the shoreline, an active process of coastal squeeze in the NW beach is evident. One of the parking lots was removed in 2009 and was removed for restoration within a span of six years. This, however, caused some important changes in the ecosystem as removed parking lot area was covered with meadow vegetation which were non-native invasive species.

Similarly, despite the presence of desirable grain size and associated vegetation improper land use can produce adverse impacts for dune restoration. LULC allows understanding, evaluating and quantifying effective management and monitoring strategies. These components are equally important and play a complimentary role in an ecosystem.

CHAPTER 6

Conclusions & Recommendations

6.1 Introduction

This chapter explicitly reflects on the findings based on the objectives and wraps up with recommendations on the dune restoration process. This thesis is divided into six Chapters. Chapter 1 provides an introduction. It includes brief analysis of the problem, designing study goal and objectives, description of the study area, outline of the thesis structure. Chapter 2 is based on a thorough literature review to address the three objectives leading to the development of a conceptual framework for the research. It includes discussion of the drivers of the main change in Point Pelee, main impacts of those drivers and assessment of the need for restoration. Chapter 3, offers description of the methods used for data collection and data analysis. Chapter 4, provides a description of the study site. Chapter 5, includes results and discussion based on analysis of data. This chapter is organised in line with the three objectives. Chapter 6, the current chapter, includes conclusions and recommendations.

6.2 Key conclusions of the research

The role of drivers was found to be significant, which largely impacted the structure and function of sand dunes in NW beach of Point Pelee National Park. The dunes have either lost their natural characteristics or have been completely degraded due to inappropriate grain size distribution, less or no sediment supply, sparse dune grasses and disturbance in the land use and land cover pattern. The process of dune degradation was led by both anthropogenic and climatic factors over a long period of time. The consequences of dune degradation range from

geomorphological changes to biophysical modifications resulting in serious threat to several sand dune habitat-dependent species. Important among them is the Five-lined skink which is an endangered species only found in Ontario. Sand samples for analysing grain size distribution were collected from sand piles, water edge, foredunes and landward towards the water. Mean size of the samples ranged between 0.4 and 2.3, whereas sorting ranged from very poorly to moderately well-sorted. Grain-size distribution in Northwest beach of Point Pelee varies from coarse sand to fine sand and sorting varies from very poorly sorted to moderately well-sorted.

Sediment supply has been recognised as a critical factor in dune development process, i.e., if there is no sediment supply or very little, a dissipative surfzone-beach system will operate to use all the sediment available to build the surfzone and beach and there may be no dune at all (Hesp 2012). Psuty (2004) used several models for sediment supply and suggested that sediment supply is a single factor in dune development process. Protection of the shoreline with hardened structures has disrupted the natural inflow of the sediment transport to NW beach. The study concluded inadequate sediment supply to the NW beach area. Consequently, available sediment is grossly inadequate for dune development process. Sand Dredging and gravel mining activities along with shoreline protection structures have greatly impacted sediment deficit in the NW beach of Point Pelee. Sand sample analysis using graphical method (Folk and Ward 1957) indicated that the grain size distribution was inappropriate for dune development process. Piles of sand from the visitors centre were collected and placed within the parking lots as part of the dune restoration process. These sand piles comprised of silt and clay, which are cohesive in nature and restricted sediments to be blown away by the wind. Samples were coarse sand with poorly sorted. Therefore, samples from the sand piles were inappropriate for dune development and did not contribute to dune restoration process. Samples from the foredunes and water edge

were fine to medium sand with sorting varied from poorly sorted, moderately sorted and moderately well sorted. Samples with fine sand that is moderate to moderately well sorted were appropriate for dune restoration. Even though the grain size distribution of most of the samples was appropriate it has not produced desired results.

Species diversity of dune associated vegetation was determined for both natural and disturbed areas. Diversity for both natural and disturbed areas was determined by using Shannon and Simpson's diversity Index, which showed that the natural area had higher species diversity than the disturbed area. It is important to note that the number of sample plots in natural area was twenty, whereas the total number plots sampled in disturbed area was thirty. Species richness was found to be more in natural areas as compared to the disturbed areas. Total number of species found in natural area was thirteen, whereas in disturbed area it was eight. But the total number of individuals found in disturbed area were more as compared to the natural areas, even if the total number of species found in the disturbed areas were less, i.e., number of individuals were 1216 in disturbed and 471 in natural areas.

Marram grass (*Ammophila breviligulata*) was found to be the most abundant dune species in both areas. Other species were sparse in comparison to Marram grass. This variability in number of individuals may have been linked to the number of plots being sampled. The species found in both areas were unevenly distributed.

Importance Value Index (IVI) of both natural and disturbed areas was calculated based on relative density, relative dominance and relative frequency. Species with lowest IVI indicates that they are rare. Therefore, conservation strategies should support the protection of the rare species. Species with higher IVI indicates their high relative density, relative frequency and relative dominance. Sea Rocket (*Cakile edentula*) was found to be rare in the sample plot but it is

an important shoreline vegetation type (ecological land classification). Hop tree (*Ptelea trifoliata*) was also found to be rare. Important strategies for conservation and protection of these rare species needs to be prioritised.

Land use and land cover classification provides a visual representation of the patterns of change in different time series clarifying the cause of slow or insignificant results in dune restoration process. This also provides directions for possible management strategies to be implemented. Classification of 1959 land use and land cover showed that Shrub Sand Barren Dune and Sand Barren Dune (grasses) classes occupied very insignificant area as compared to 1977. A significant decrease in Sand Barren Dune type was recorded from 1959 to 1977. Decrease from 16293 sq. m. in 1959 to 7880 sq. m. in 1977 may be due to the impact of development of infrastructure and facilities. Shoreline type decreased in 1977 in comparison with 1959, which indicates lake level rise during 1977.

Shoreline type class decreased (20611 sq. m) in 2015 as compared to 2006 (24358 sq. m) and this change in area also confirms fluctuations in lake level. Shoreline was gradually squeezed between the sand barren dune type and water level. This signifies the presence of inadequate area or narrow beach width for sediment transport. It is important to note that the number of trails increased in 2006 in comparison to 1977 with the most significant increase in 2015. This also confirms an increase in the number of footprints accessing the beach. NW beach is heavily used and is highly impacted as it remains open to visitors all year-round due to its warmer climate.

In 2007, one of the Parking lots was removed for dune restoration process. Over a span of seven years, the parking lot was dominated by meadow vegetation along with other invasive species. These species did not contribute to dune restoration process.

Invasive species were observed during the sample plots. Parks Canada is also removing the invasive species from the parking lots and planting dune species such as Marram grass. The invasive species are a threat to the native species of Point Pelee, hence Parks Canada is removing these species as a part of restoration process.

As a first step towards restoration of sand dunes it is necessary to understand the origin and evolution of Point Pelee. This will clarify key aspects of what needs to be restored based on what has been lost. In other words, an historical understanding of sand dune origin and formation in Point Pelee will provide a solid baseline to work with. Further, sand dune formation and degradation are largely influenced by a host of interconnected factors, e.g., sediment supply and transport are the key components, which again depends on the moisture content, beach width and lake level fluctuations. Sand dune restoration will not be effective unless all of those factors are addressed. It is also pertinent to evaluate the role of dominant drivers, such as climate change, in long-term management and conservation of sand dunes. Linking sand dune restoration to the conservation of other species, such as the Five-lined skink, is necessary as it clarifies the specific purpose of restoration, and could lead to clear outcomes. Sediment supply play a vital role in the restoration of dune formation process in NW beach of Point Pelee, as elaborately discussed in Chapter 4 Study Site Profile (Shoreline protection development). Inadequate sediment supply restricts the sand dune development process. Sediment supply is also complemented by grain size. As discussed in Chapter 4, shoreline has been infested with erosional protection structures which curtailed the sediment supply to the NW beach. Therefore, there is insignificant sediment supply from the longshore drift which puts NW beach in jeopardy. On the other hand history of sand dredging and gravel mining activity has turned the Southeast Shoal into a sediment deficit sink, which otherwise was known as a sediment supply sink to the beaches of Point Pelee

(Kamphuis, 1972). Therefore, sediment supply to the dunes of NW beach is insignificant. Moreover, samples that were collected from sand supply piles, which were placed as a part of the restoration process, was found as inappropriate for sediment transport and did not contribute to dune formation. Samples collected from foredunes, water edge and landward were poorly sorted, moderately to moderately well sorted with mean grain size varied from fine to medium sand. The sand samples with moderately well sorted and fine grain size was appropriate for dune development. Results show a variation in the mean grain size and sorting. Some of the samples collected from the foredunes near the landward side of the system were found to be fine sand and moderately well sorted whereas samples from the foredunes near the waterline show medium sand that is poorly sorted. This concludes that variation in the results is due to the human impact such as trampling, raking and management activities. Overall, dune restoration was found to be slow or not significant enough to be quantified.

Although diversity of the dune associated vegetation in natural area was found to be more than that of the disturbed area, no significant results in dune development was observed. Evenness was high in natural compared to the disturbed areas. Figures 5.4 and 5.5 (Chapter 5) show that species are not evenly distributed in NW beach of Point Pelee. This indicates sparse vegetation distribution along the NW beach area. This might be directly correlated with the insignificant result of dune formation.

Beach raking in NW beach was observed. Raking results in removing the top layer, disturbs the micro-organisms and opens up avenues for the sea gulls and other coastal birds to dig these organisms producing foul odor, resulting in disrupting the food chain but also disturbs the ecological integrity and dune health. Raking also affects the established dune species by uprooting and pushing them, and by disturbing the soil.

Climate change is alone one of the important component as increase or decrease in lake levels affects sediment transport. Lake level fluctuations has a direct impact on the sediment transport as it results in wet/dry conditions and change in the width of the beach. As discussed earlier (Chapter 2), low ice cover (recorded over decades in PPNP), combined with winter storms and wind conditions, facilitates active wave actions causing the unconsolidated beach sediments to migrate offshore and onshore, and permanent loss of fine sediments (BaMasoud and Byrne 2012).

To conclude, sand dune restoration is a complex process. There are no simple solutions to mitigate problems associated with it. Attempt to restore sand dunes will benefit from a more collaborative approach between scientists in a variety of fields who could design and implement interdisciplinary approaches to solving problems of sand dune restoration and management.

1. Trampling of dune species is a common activity observed during field visits in the NW beach. Studies have shown that it can take as few as 10 footsteps to destroy a marram grass colony (Parks Canada, 2016). These dune species help trap sediments for dune development process. Steps to minimise trampling to be considered as important part of the restoration process. From the vegetation density calculation it was found that Marram grass are dominant dune associated species in the NW beach. Conservation and protection of dune species are highly recommended in order to enhance the process of dune restoration. As discussed in Chapter 5 (Results and Discussion), vegetation diversity and richness are vital to maintaining the dune species. Understanding sand dune and vegetation interaction is crucial in this regard. Diversity indices calculated for natural and disturbed area indicate high diversity in natural than in disturbed areas.

2. NW beach area is being heavily raked as observed during the spring 2015. It is considered to be a beach cleaning process. Raking activities destroy not only the vegetation cover but also restricts natural regeneration of the species such as dune grasses. Raking should either be stopped or minimised.
3. Education and Stewardship for dune development planning and shoreline protection could be undertaken.
4. There should be authorised path for the visitors to avoid trampling or designated beach access should be created.
5. Interpretive signs for beach access and also along the dune area to be put in place.
6. Plantation of dune species to increase the density needs to be undertaken in order to create a balance in sand accretion so that the significant result have been achieved.
7. Removal of meadow vegetation and plantation of dune species in the former parking lot need to be considered. Results from land use and land cover classification suggests that the former parking lot was covered with meadow vegetation which is an early succession of forest ecosystem. This clearly signifies that the soil pH is more acidic and rich in organic matter which makes it impossible to hold dune species.
8. Land use and land cover classification for 1959, 1977, 2006 and 2015 shows an increase in lake level with cottonwood trees close to the shoreline that implies an active process of Coastal squeeze. This signifies loss of dune habitat. Therefore, removal of cottonwood trees from the shoreline is recommended as an effective management strategy for dune restoration.
9. Monitoring land use and land cover is necessary for better management planning. Land use and land cover classification change shows that the deciduous thicket have increased

significantly compared to the year 2006. Deciduous thicket acts as a barrier restricting the sediment transportation to the parking lot. Trimming and thinning of deciduous thicket is helpful for maintaining and creating sediment flow to the parking lots enhancing sand dune restoration.

10. Appropriate sand supply i.e., very fine sand grains are needed for dune development.

Sand supply piles to be placed with appropriate grain size to facilitate this process i.e., fine sand with moderately well sorted grains are highly recommended for dune formation in NW beach of PPNP.

Appendix 1



Figure shows raw image for 1959 with study area boundary before classification

Appendix 2



Figure shows raw image for 1977 with study area boundary before classification

Appendix 3

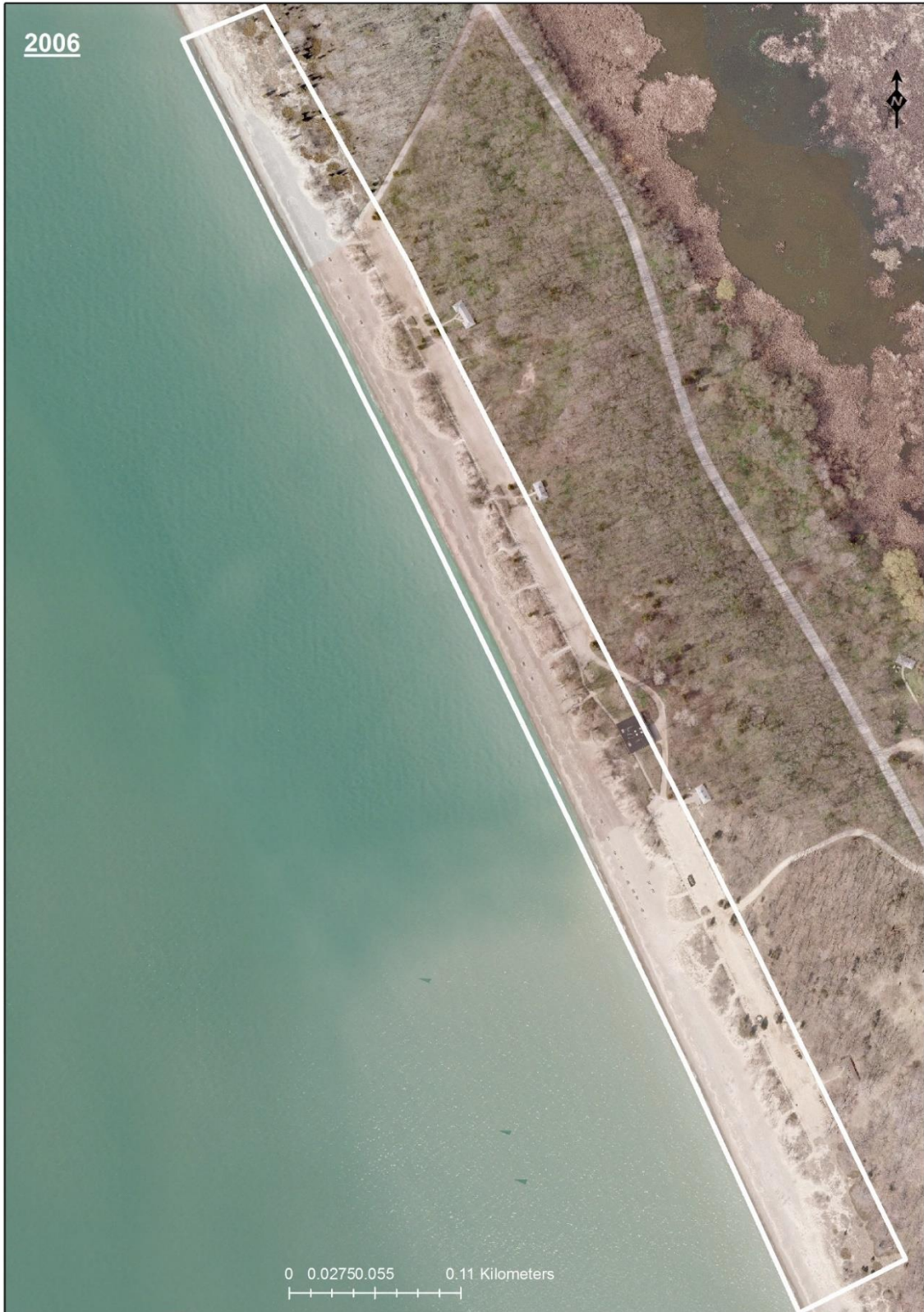


Figure shows raw image for 2006 with study area boundary before classification

Appendix 4

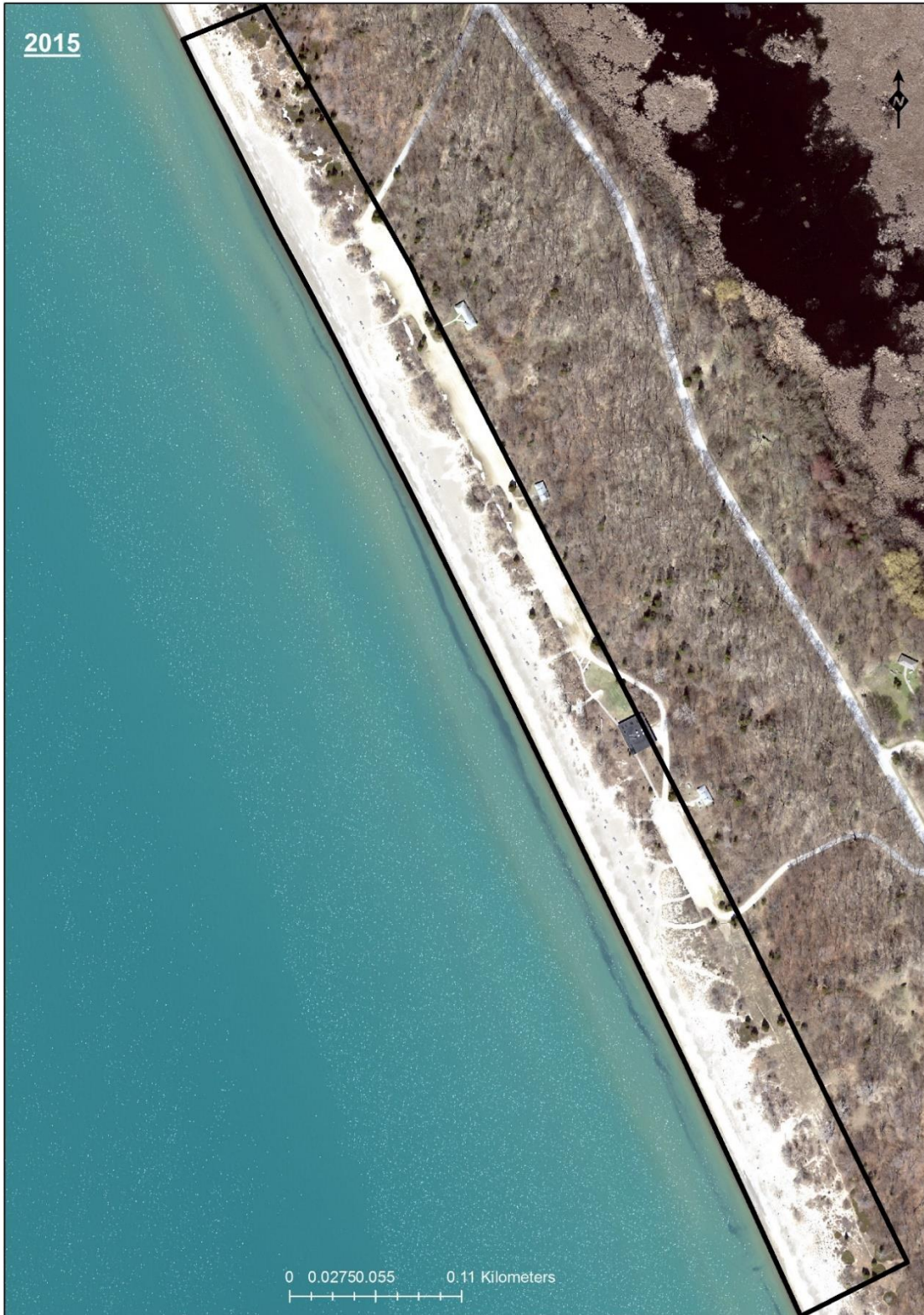


Figure shows raw image for 2015 with study area boundary before classification

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