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Defining Western Prairie Fringed Orchid (Platanthera Praeclara) Habitat

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DEFINING WESTERN PRAIRIE FRINGED ORCHID (*PLATANTHERA PRAECLARA*) HABITAT

by

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This thesis, submitted by Michael David Knudson in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Michael D. Knudson
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ABSTRACT

Terrestrial orchids are at the forefront of the discussion about anthropogenically-driven extinction with more species threatened globally than any other plant family, mostly because of loss of habitat. The Western Prairie Fringed Orchid (*Platanthera praeclara*) is a threatened species found on the Sheyenne National Grassland in southeast North Dakota, USA. This conservation area that is a vital refuge for this species is subject to management for multiple uses including livestock grazing and recreation. Orchids are subject to continuous monitoring, but knowledge of the relationship between landscape indicators and orchid locations is limited. Research is needed to provide a greater understanding of the landscape relative to orchid habitat to develop conservation management strategies suited to dealing with threats arising from future interactions between land management and use, and climate change.

The spatial distribution of orchid habitat was defined using a suite of indicators that characterize topography, moisture, and vegetation cover and compared with orchid point-based field observations. High resolution infrared imagery, a LiDAR-derived DEM, and well observations were used to characterize landscape properties. The NDVI (a measure of vegetation cover), the Topographic Wetness Index (TWI: a measure of moisture on the landscape), the Topographic Position Index (TPI: a measure of position

on the landscape), and the depth to groundwater (a measure of the depth from the land surface to the groundwater surface) provided the best set of indicators of orchid habitat. Comparison between orchid locations and landscape indicators identified orchid metrics ($\pm 2\ \sigma$) used to classify landscape indicators which were combined to create orchid habitat maps.

This study supports that distribution of orchid habitat are influenced by the selected landscape indicators, each providing important information to the analysis. Comparison of orchid metrics with groundwater elevations showed that orchids generally occurred on average 1.01 ± 0.43 (2σ) meters above the water table. TWI and TPI demonstrated that orchids occur near margins of flow paths and near foot and toe slopes of slight elevations changes. NDVI classified vegetation cover and excluded agricultural land use. Landscape-scale analysis of orchid habitat identifies areas most in need of protection or restoration, and monitoring.

CHAPTER I

INTRODUCTION

In general, climate and more specifically temperature and precipitation, govern vegetation distribution globally and regionally. Other properties such as topography, geology, land cover, hydrology, and biology of a given species influence more local distribution patterns (Parvianinen et al., 2008). Different species flourish at different spatial and temporal scales due to variations in the above properties, life history traits, and resource availability (Vivian-Smith, 1997). In particular, spatial and temporal surface water and soil moisture dynamics can exert control over ecological systems shaping vegetation composition, diversity, and species distribution (Rodriguez-Iturbe et al., 1999; Moeslund et al., 2013). This makes spatial landscape analyses an important research tool in understanding and defining species distribution and habitat (Hof, Sieg & Bevers, 1999). However, measurement of these landscape properties may be challenging (Kopecký & Cížková, 2010).

Conservation of threatened plant species is of international concern with nearly 12.5% of global vascular flora facing extinction (Swarts & Dixon, 2009). Variations in the distribution of these species can be attributed to climate, hydrology, and topography (Parviainen et al., 2008) and therefore represents a particularly important target for landscape-scale spatial and temporal analysis. Orchidaceae are the most divers of all angiosperm families, occurring on all vegetated continents and even some Antarctic islands with an estimated 800 genera and more than 25,000 species (Swarts & Dixon, 2009; Fay & Chase, 2009). Terrestrial orchids represent one-third of orchid species and nearly half of all extinct plant species are terrestrial herbaceous perennials. Orchidaceae are at the forefront of extinction with more species under threat globally than any other plant family. Terrestrial orchids are likely to experience a greater extinction risk as a result of increasing threats such as loss of habitat and climate change (Swarts & Dixon, 2009).

Orchids have long fascinated scientists by their range of life history strategies, floral and vegetative morphology, and pollination syndromes. These complexities make orchids particularly vulnerable to climate change (Fay & Chase, 2009). Orchids may be locally abundant, but only occur in a limited number of locations, restricted by niche specificity or barriers reducing dispersal potential. Populations follow adverse sporadic or cyclical events such as flooding or drought and are often local endemics vulnerable to threatening processes. Causes of rarity in orchids can be attributed to complex life history strategies but drivers of rarity are more often linked to their unique habitats. Contributing to their high level of threat and making them ideal species for developing resources to better understand and manage habitats (Swarts & Dixon, 2009).

The Sheyenne Delta in southeast North Dakota formed as result of the Wisconsinan glaciation (Ostlie & Faust, 1996). The delta is one of three locations in North America that host large populations of the Western Prairie Fringed Orchid

(*Platanthera praeclara*) referred to herein as orchid (USDA Forest Service, 2001). The orchid was originally listed by the U.S. Fish and Wildlife Service (USFWS) as a threatened species under the Endangered Species Act of 1973 on September 28, 1989. Today the orchid is found west of the Mississippi River with approximately 90% of known orchid locations occurring in the Red River Valley of North Dakota and Minnesota, and approximately 91% of protected orchids within the valley occurring within the delta (USFWS, 2009). Here the orchid is an indicator species of graminoid wetland communities and is found within wetland basins, margins of wetlands, or near margins of flow paths. These wetland habitats are more commonly known as sedge meadows or swales (USDA Forest Service, 2001).

Orchid habitat and associated vegetation communities are crucial to orchid existence (Wolken, Sieg & Williams, 2001), and widely distributed consisting of several indistinct orchid subpopulations and isolated outliers making defining habitat difficult (Bjugstad & Fortune, 1989). Knowledge of habitat and influencing landscape properties are crucial when conservation management for a particular species is combined with other land uses (Zinko et al., 2005). Orchid habitat is surrounded by intensive agriculture and subject to impacts of grazing, fire, invasive species, pesticides, drainage, and irrigation. To sustain land use practices more needs to be understood about these unique habitats in efforts to assess and develop management strategies that are conducive to conservation (USFWS, 2009).

Remote sensing is the collection of information using instruments that are not in physical contact with the surface or phenomena of interest. Remote sensing applications provide information on the spatial and temporal heterogeneity and distribution of landscapes relative to climate, vegetation and topography (Pettorelli, 2005). Topographic and vegetation indices applied to infrared imagery and digital elevation models (DEMs) have been proven useful landscape indicators of wetland communities and properties such as soil attributes, moisture, phenology, and plant species occurrences (Gessler et al., 1995; Paruelo & Lauenroth, 1998; Zinko et al., 2005; Parviainen et al., 2008; Grabs et al., 2009; Campbell & Wynne, 2011).

Passive remote sensing includes collecting information from devices that sense the Sun's energy being reflected by Earth's surfaces (Campbell & Wynne, 2011). Vegetation is often the first surface energy encounters providing information that can be analyzed to characterize vegetation. Infrared imagery provides a measure of chlorophyll abundance and energy absorption which influence vegetation growth through photosynthesis (Myneni et al., 1995). Chlorophyll pigments reflect energy in the green spectrum (500 – 600 nm) and absorb red (600 – 700 nm) and blue (400 – 500 nm) wavelengths. High reflectance in the near infrared spectrum (700 – 1,300 nm) is due to plant mesophyll tissue. Changes in structure and function or phenology of vegetation have shown a strong relationship with climate and are the basis for many vegetation condition and land cover indicators (Paruelo & Lauenroth, 1998). Phenology is the study of relationships between vegetation and the environment, and refers to the timing of vegetative activity relative to seasonal changes influenced by climate.

Active remote sensing is when devices actively emit and record their own reflected radiation such as Light Detection and Ranging (LiDAR) (Vierling et al., 2008;

Campbell & Wynne, 2011). LiDAR instruments can measure the location of objects in *x*, *y*, *z* space when an emitted laser pulse strikes a surface and returns a portion of that radiation to the sensor (Vierling et al., 2008). A LiDAR-derived high resolution DEM and topographic indices (indicators of landscape properties) can be useful tools in identifying habitat distribution, based on what is known about a given species (Vierling et al., 2008).

Study Objective

The USFWS Western Prairie Fringed Orchid Recovery Plan identifies orchid monitoring and habitat distribution mapping important for monitoring populations and identification of habitat (USFWS, 2009; USFWS, 1996). Supplemental information that may enhance existing monitoring programs could be achieved through analyzing orchid positions in the landscape relative to indicators of landscape properties derived from remote sensing information, groundwater well observations, and orchid point-based field observations. This information may provide identification of orchid habitat within small ecological zones, change in habitat, and areas to search for orchids. Identifying the distribution of orchid habitat may be a useful tool in focusing field surveys and management efforts (Parviainen et al., 2008).

The purpose of this study was to analyze orchids spatially across the landscape to better understand the influences that landscape properties have on annual and long-term habitat conditions. Also, to determine if the spatial distribution of orchid habitat can be classified using indicators to define landscape properties relative to topography, moisture, vegetation, groundwater, and orchid positions in the landscape. Landscape distribution patterns of wetlands and species habitat can be well defined on the basis of such landscape properties (Parviainen et al., 2008). Identification of orchid habitat distribution and influencing indicators of landscape properties may contribute toward orchid monitoring and conservation efforts. Objectives of this research were to:

1. Identify indicators of landscape properties that characterize the SNG and influence orchid habitat.
2. Classify orchid habitat from 2006 to 2013 using a LiDAR-derived DEM, satellite and aerial infrared imagery, groundwater elevations, and orchid point-based field observations.
3. Compare orchid habitat distribution within grazing allotments.

CHAPTER II

LITERATURE REVIEW

Landscape Topography and Habitat Characterization

Spatial and temporal variability are common features of most plant species distributions (Hof, Sieg & Bevers, 1999). The availability of moisture can influence these distributions especially in hummocky glacial dune landscapes characterized by high groundwater elevations and a mosaic of prairie wetlands and uplands. Such landscapes exhibit spatial and temporal variations in moisture availability due to seasonal and annual shifts in moisture gradients thus influencing species distribution (Vivian-Smith, 1997; Zinko et al., 2005). These shifts in moisture gradients are primarily dependent on interactions with groundwater and atmospheric water (i.e. snowmelt, precipitation, and evapotranspiration) (Winter, 2000). These atmospheric interactions also influence spatial and temporal variations in groundwater elevations, drought and flood (Vivian-Smith, 1997).

Topography shapes vegetation composition, diversity patterns, and species distribution (Zinko et al., 2005; Andrew & Ustin, 2009). Minute changes in elevation may result in large differences in subsurface moisture and thus strong gradients in diversity and species distribution (Vivian-Smith, 1997; Zinko et al., 2005; Parvianinen et al., 2008; Moeslund et al., 2013). Topographic influences on moisture availability can be explained by the assumption that the development of the soil toposequence occurs in response to the way water moves through and over the landscape (Gessler et al., 1995). This refers to adjacent soils differing in profile characteristics influenced by local topography. The availability and movement of water is in turn controlled by topography as water moves through and over the land surface influencing flow and accumulation, groundwater flow, and soils (Gessler et al., 1995).

Other influencing properties are likely to vary throughout the landscape. These factors include redox potentials, litter accumulation, compactions levels, land use, drought and flood (Vivian-Smith, 1997). Also, biological characteristics of plant species such as symbiotic relationships, reproduction ecology and dispersal mechanisms influence species distribution. Many biotic and abiotic factors and processes have potential to drive spatial variations in species distribution patterns (Li et al., 2009). Explanations for such patterns include spatial heterogeneity of the landscape, topography, and moisture availability. Other factors include herbivore grazing, presence or absences of symbiotic fungi, variations in seed accumulation and germination, and differences in growth and mortality at different topographic positions in the landscape (Vivian-Smith, 1997; Li et al., 2009). Combinations of these factors, at multiple scales, are likely to affect variability in species distribution, from individual species to their associated vegetation to landscape patterns (Li et al., 2009).

The Sheyenne Delta: Fine-scale Topographic Variation Defines Habitats

The Sheyenne Delta lies at the southern extent of the Red River Valley of the North and is significant in many facets of geology, hydrology, biogeography, topography, and land use (Bjugstad & Fortune, 1989; Sieg & King, 1995). Numerous sand dunes and shallow blowouts impart a hummocky appearance to the landscape (Bluemle, 1979). Physical features are a direct or indirect result of glacial activity, with glacial till being the framework for the features present today. Biological features are an indirect result of glacial activity in that flora, and fauna today were largely recruited from adjacent regions. Such features contribute to the unique combinations of species that significantly enhances biodiversity in this region (Ostllie & Faust, 1996). It is essential to understand the evolutionary forces that shaped these diverse ecological systems. Physical features and biological communities developed under complex disturbance regimes that included glaciation, climatic extremes, fire, and grazing with each operating at multiple scales, frequencies, and intensities (Ostlie & Faust, 1996).

Prior to the Wisconsinan glaciation the Red River Valley likely exhibited spruce and aspen forest similar to modern day northern Canada, implying that climate conditions were considerably cooler and more moist than today (Bluemle, 2000). As the ice sheet retreated northward melt water led to the formation of Glacial Lake Agassiz inundating more than 906,500 km^2 of present-day Minnesota, North Dakota, Saskatchewan, Manitoba, and Ontario for approximately 5,000 years (Bluemle, 1974; Ostllie & Faust, 1996). Glacial Lake Agassiz left a series of beach ridges as the lake drained about 10,700 years ago, which are described by Chapman, Fischer, and Ziegenhagen (1998) as scattered low-rising ripples in the landscape extending in a north-south band along the eastern and western margins of the Red River Valley.

Rivers entering Glacial Lake Agassiz often formed extensive deltas and inlets, one of the most prominent being the Sheyenne Delta characterized today by dune formations shaped by wind prior to the establishment of vegetation (Ostlie & Faust, 1996; Chapman, Fischer & Ziegenhagen, 1998). The delta is located between the Herman and Campbell beach ridges, but geologists today believe it was not a delta but an inlet into Glacial Lake Agassiz. The sediments are believed to have been deposited in an underflow fan; deposits of sands, clays, and gravels making up the soil profile today. The layer below these deposits is nearly impervious lake sediments responsible for the relatively high groundwater elevations (Bluemle, 1974; Fritz, 2001).

Through radiocarbon-dating of sediment layers, scientists have documented post-glacial history of plant life in eastern North Dakota. Cool and moist climates supported boreal forest ~10,500 years ago (Bluemle, 2000). As climate changed to warmer conditions forest communities transitioned from boreal to more temperate species ~9,000 years ago. As climate continued to change to more arid conditions trees died off and grasslands dominated expanding to their maximum extent around 7,000 years ago, with dry conditions and wind catalyzing dune activity in areas of sparse vegetation. Then ~4,500 years ago to present day, climate conditions have been relatively moist and forests have expanded yet grasslands are still the dominant biome (Bluemle, 2000).

Today the Sheyenne Delta exhibits some of the largest (284.1 km^2) tallgrass prairie habitats, described as a mosaic of prairie wetlands and uplands including marshes, calcareous fens, sedge meadows, wet and dry prairies, and oak-aspen savannas. Rare plants, butterflies, and birds still thrive in this region (Chapman, Fischer & Ziegenhagen, 1998). Wet prairies are dominated by big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), northern reedgrass (*Calamagrostis inexpansa*) and prairie cordgrass (*Spartina pectinata*). Dry prairies occupy the beach ridges and sand dunes and are dominated by blue grama (*Bouteloua gracilis*), prairie junegrass (*Koeleria macrantha*), little bluestem (*Andropogon scoparium*), and needle and thread grass (*Stipa comate*) (Ostlie & Faust, 1996). Wetlands are dominated by sedge (*Carex*), rush (*Juncus*), or cattail (*Typha*) species.

Much of the region has been transformed from grassland into a highly fragmented system including agriculture, rural development and industry. Little grassland remains today compared to historical conditions (Ostlie & Faust, 1996). Agriculture is the predominant land use producing small grains, corn, soybeans, edible beans, sunflowers, sugar beets, and potatoes. The intensity of agriculture has resulted in higher nutrient concentrations and water quality impairments due to chemical and fertilizer use (Goldstein et al., 1996). The loss of grassland habitats and the degradation of water quality pose the greatest threat to biodiversity of this region (Ostlie & Faust, 1996).

The Sheyenne National Grassland

In the center of the Sheyenne Delta, managed by the Forest Service within the U.S. Department of Agriculture (USDA), is the Sheyenne National Grassland (SNG). The SNG is one of the largest public holdings of contiguous tallgrass prairies (284.1 km^2) characterized by a hummocky glacial dune landscape. Located in Ransom and Richland counties of southeastern North Dakota, the SNG, sometimes called “Sandhills Prairie” (Sieg & Wolken, 1999), is generally characterized by tallgrass prairie and oak savanna exhibiting a mosaic of wet and dry prairies and a variety of wetlands (Bluemle, 1979; Sieg & Wolken, 1999). Precipitation averages 530 mm per year (USDA Forest Service, 2001).

The SNG broadly exhibits four landforms: River Bottom, Sand Dune, Deltaic Plain, and Hummock and Swale (Figure 1). The River Bottom is characterized by the meandering Sheyenne River flowing through a riparian mixed deciduous forest and oak savanna (Fritz, 2001). These riparian forests are dominated by American basswood (*Tilia americana*), American elm (*Ulmus americanus*), and green ash (*Fraxinus pennsylvanica*); bur oak (*Quercus macrocarpa*) and quaking aspen (*Populus tremuloides*) occur in scattered groves within the hummocky landscape and are characterized as oak-aspen savannas (Ostlie & Faust, 1996). The Deltaic Plain landform is characterized as low flat landscape with little relief existing on the fringes of the SNG and beyond. However, due to its flat and fertile characteristics, most of the Deltaic Plain has been converted to cropland and what is not cropland is typically grazed or hayed (Bjugstad & Fortune, 1989).

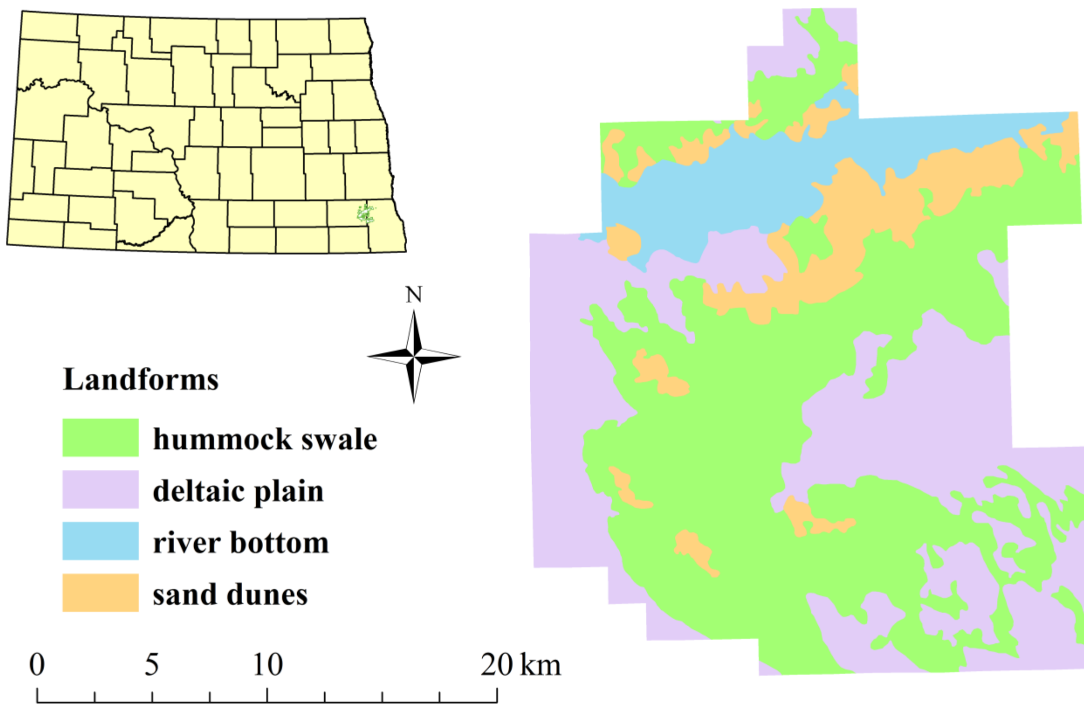

Figure 1 Landforms of the SNG located in Ransom and Richland counties of southeastern North Dakota.

The Sand Dune is characterized by sparsely vegetated dunes exhibiting blue grama, prairie junegrass, little bluestem, and needle and thread grass. According to Fritz (2001), sand dunes created by winds are a common feature on the SNG with two different varieties: parabolic and transverse ridges. Running (1996) suggests a complex mode of origin of these sand dunes where eolian activity is closely tied to fluvial response to climate change. Prevailing wind direction during dune formation appears to have been from the south, although recent blowouts indicate northwesterly winds. In general, because of topography and orientation of sand dunes, determining wind direction responsible for dune formation is inconclusive (Bluemle, 1979).

Sand dunes have been subdivided into three forms: sandsheets and high and low relief dunes (Running, 1996). High relief dunes are transverse ridges >9 meters; low relief dunes are <9 meters and parabolic in form; and sandsheets are undulating and wind scoured (Winter, 2000; Fritz, 2001). Low Relief dune formation occurred in brief pulses in the presence of sparse vegetation, migrating very little from the deflation hollow they are associated with and can be referred to as “blowout dunes” (Running, 1996). Blowout depths are usually a meter and appear to be controlled by the groundwater table. A typical blowout dune has a crescent shape ridge about 50 meters wide and 2 to 3 meters high. Sand dune sequences vary in detail from ridge to ridge (Running, 1996). Sandsheets downwind from low relief dunes are between 0.5 to 3 meters thick. Locally, small blowout dunes are present within the sandsheets (Running, 1996).

The Hummock and Swale landform is described as a glacial sand dune landscape formed during periods of sparse vegetation and blowouts. Characterized by isolated depressions with a wide variety of shapes, sizes, and elevations; exhibiting a mosaic of wetlands, uplands, and vegetative transitions. Relief is usually 1.7 to 3 meters with a slope of 2.86 to 5.71 degrees. Loamy fine sandy soils with moderate to low water holding capacity exhibit high soil moisture content because of the high groundwater elevations (Bjugstad & Fortune, 1989). In general wetlands are permeable and poorly drained compared to their neighboring uplands. Moisture gradients between can be observed through transitions in vegetation composition and diversity influenced by climate, topography, and groundwater (Vivian-Smith, 1997; Chapman, Fischer, & Ziegenhagen, 1998; Winter, 2000).

The major soil types of these landforms are Haploborolls, Calciaquolls and Udipsamments (Mollisols and Entisols) (Ostlie & Faust, 1996). Mollisols are the prevalent soils as they are most associated with grasslands and Entisols are associated with flood deposits and sand dunes (Sieg & King, 1995). Soils associated with orchid habitat are generally calcium rich cool wet prairie soils with minimum horizon development (USFWS, 1996). This includes alluvial soils, subirrigated calcareous, lacustrine soils overlaying sand, or fine-textured loess or till with low organic matter content (Sieg & King, 1995). In general these lowland soils are permeable and poorly drained and at a depth of 0 to 10 cm can be described as neutral to slightly alkaline, fertile sandy loam (Wolken, Sieg & Williams, 2001).

Orchid Biology

Orchids are terrestrial herbaceous perennials relying on established root systems that regenerate during the growing season by forming new tubers and perennating buds, giving rise to vegetative shoots the next growing season. Root systems on the SNG have multiple tubers and buds isolated from parent plants (USFWS, 1996). Vegetative shoots appear aboveground, after a period of soil warming, beginning late April into May depending on weather conditions that year (USDA Forest Service, 2001; USFWS, 2009). This life cycle indicates that annual orchid distribution and population dynamics are likely influenced by previous fall and current spring-summer conditions (Sieg & King, 1995; Sieg & Wolken, 1999). For example, fall conditions correspond with plant senescence, development of next year's perennating bud, and seed dispersal. Spring-summer conditions have a greater impact on aboveground growth (USFWS, 2009).

The orchid exhibits two distinct aboveground life states: vegetative and flowering. Vegetative plants average up to 24 cm tall, usually having one or two leaves, and remain vegetative throughout the growing season (Sieg & King, 1995). Flowering plants develop hollow flowering stalks early in the growing season, have numerous leaves (>10), and average up to 52 cm tall. The greater height and leaf area of flowering plants improve their ability to photosynthesize. Hollow flowering stalks are adaptations common in wetland vascular plants allowing oxygen to diffuse from aerial parts of the plant to the roots for respiratory demands (Sieg & King, 1995; Sieg & Wolken, 1999). Flowering typically occurs late-June to mid-July producing an indeterminate inflorescence with showy cream colored flowers arranged on a spike (Figure 2) (USFWS, 1996). Erratic flowering habits can exhibit very showy inflorescences one year and then seemingly disappear surviving only in a vegetative or dormant state for several years (Bjugstad & Fortune, 1989; USFWS, 1996). Unpredictable patterns of life state from year to year make monitoring of orchid populations and defining habitats challenging.

Figure 2 Flowering orchid; photo taken by author on SNG, July 15, 2013.

Seed Ecology

Orchids produce some of the smallest dust-like seeds known across plant species. Because of their minute size (0.07 to 0.4 mm wide and 0.11 to 1.97 mm long) there is little known about their germination ecology (Sieg & Wolken, 1999). The size and air-filled testa (seed coat) make seeds equipped for wind dispersal. Buoyancy, a rough surface, and a water-repellent lipoid layer enable water dispersal (Hof, Sieg & Bevers, 1999). Water dispersal occurs by dissemination through the soil profile and flooding, which tends to concentrate and deposit seeds along drift lines (Sieg & Wolken, 1999).

Dispersal occurs in September depending on environmental conditions inducing the release of seed capsules (USFWS, 1996). Seed distribution in sand dune grasslands vary within and among habitats in topographic position due to these dispersal mechanisms influenced by barriers such as topography, roads, and railroad tracks. Because of the biotic and abiotic processes at multiple scales influencing seed distribution orchids vary in topographic position contributing to the challenges in defining habitat (Li et al., 2009).

Symbiotic Fungi

As orchid seeds are very small, the embryo consists of only a few cells with very limited reserves and development (USDA Forest Service, 2001). For this reason orchids are dependent on mycorrhizal fungi during a portion or all of their life cycle, especially for seed germination and nutritional support before plants are capable of photosynthesis (Sharma et al., 2003; USFWS, 2009). Fungal colonization mobilizes reserves and provides nutritional support to non-photosynthetic seedlings (Sharma et al., 2003). Even with fungi present, orchids may persist in an underground state for up to or beyond two years before foliage appears aboveground (USFWS, 1996). Fungal colonization is also necessary to stimulate gluconeogenesis, which is the metabolic pathway that synthesizes glucose from non-carbohydrate carbon substrates (Sharma et al., 2003). Fungal associates of orchids likely vary among life stages and although little is known of the fungi associated with orchids, a species of *Rhizoctonia* was isolated from an orchid tuber on the SNG. Other species of fungi isolated from protocorms and adult orchids include *Ceratorhiza* and *Epulorhiza* species (Sieg & King, 1995; USFWS, 2009).

Fungal colonization and their symbiotic relationship with orchids are important to germination, seedling establishment, and recruitment of new individuals. Also, these relationships are dependent on the availability of suitable habitat, edaphic factors controlling soil mycorrhizae, and interspecific competition (USFWS, 1996; Sharma et al., 2003). There may be a stronger association between fungi and orchid habitat than there is specifically between fungi and orchids. The orchid faces certain extinction if their symbiotic fungi disappears (USFWS, 2009). Therefore the sustainability of the orchids and their fungal associates greatly depend on conservation of habitat.

Monitoring Populations

The USDA Forest Service strategy for research, management, and monitoring of orchids and their habitat is to demonstrate compliance with the Endangered Species Act and implementation of the U.S. Fish and Wildlife Service (USFWS) Western Prairie

Fringed Orchid Recovery Plan. Actions associated with this strategy are to develop and maintain appropriate disturbance and hydrologic regimes. Also, to conduct research relative to management practices, limiting factors (i.e. moisture), reproduction, and synecology of orchid habitat (USDA Forest Service, 2001). Synecology refers to the structure, development and distribution of ecological communities or habitat. Orchids have been monitored for years through population counts and point-based field observations of orchid locations using hand-held GPS devices. Application of these datasets could prove useful in defining orchid habitat through spatial identification of landscape properties that influence orchid habitat and distribution.

Across the SNG orchid populations are described as patches of larger metapopulations, isolated sub-populations, and individual outliers (USFWS, 1996; Sharma et al., 2003). Metapopulations are dynamic groupings of populations spatially shifting and subject to periodic extinctions linked by subsequent recolonization (USFWS, 1996; USDA Forest Service, 2001). Metapopulations consist of groupings of individual species likely interacting with each other through established root systems, pollination, and resource competition. Information on orchid population dynamics are limited and remain somewhat unknown (Bjugstad & Fortune, 1989; Hof, Sieg & Williams, 1999). In 1984 – 1985, a systematic mapping effort recorded approximately 2,000 orchids with densities varying from 0.01 to 6 plants m^{-2} (Bjugstad & Fotune, 1989). From 1990 – 1994 orchid densities averaged from 1.1 to 6.8 plants 100 m^{-2} (Sieg & King, 1995).

Longevity of orchids varies geographically and depends on the landscape properties and moisture conditions (USFWS, 1996). Orchids were thought to be a longlived species exhibiting periods of dormancy likely influenced by periods of drought and flood. However, a study by Sieg and King (1995) collected demographic data on the SNG (1987 – 1994) and results suggested that orchids live approximately three years or less, and once absent the odds of remaining absent were about 80%. From 1990 – 1994 orchid reappearance ranged from 73% to only 16% (Sieg & King, 1995). Reappearance rates are influenced by habitat conditions throughout the orchid's life. Stresses associated with climate such as drought and flood may affect plants into subsequent growing seasons. Moisture conditions affect orchid's ability to produce carbohydrate reserves and form perennating tissues dictating growth, survival, and reappearance (Sieg & Wolken, 1999).

A population recovery on the SNG in 1992 (a wet year) was observed after five years of very low population numbers. It is unlikely that this recovery was attributed to plants returning from dormancy. An explanation provided by Hof, Sieg and Bevers (1999), is a seed bank with viable seeds persisting through years of drought and flood. They also suggest that with a viable seed bank, land managers should be more concerned with maximizing long-term mean population levels rather than yearly population levels. Therefore it may be useful to spatially analyze orchid positions in the landscape relative to landscape properties and climate to better understand what influences orchid habitat and populations (Hof, Sieg & Bevers, 1999).

Current annual orchid monitoring efforts on the SNG are implemented by the USDA Forest Service and contracted by the North Dakota Parks and Recreation (NDPR) department. Recording orchid locations using hand-held GPS units along with orchid counts in defined study areas are two methods of field monitoring applied. The USDA

Forest Service records orchid point data in five static microplots (100 x 100 meters), although geographically distributed these areas are small and orchid point data are thus constrained. They also administer counts in six 160-acre macroplots but there is no spatial documentation of orchids in these habitats and thus only useful in studying population trends within these defined areas (USDA Forest Service, 2001).

The NDPR department through the North Dakota Natural Heritage Inventory (NDNHI) obtains funding through the Endangered Species Act of 1973, Section 7, from the USFWS for monitoring threatened and endangered species. Section 7 of the Endangered Species Act, called "Interagency Cooperation," is the mechanism by which federal agencies ensure the actions they take, funded or authorized, do not jeopardize the existence of any listed species. This monitoring effort occurs when funding is available, and private consultants are contracted by the NDPR to record orchid locations using hand-held GPS units. These datasets are eventually shared between agencies and useful in demonstrating spatial and temporal shifts in orchid distributions (USFWS, 2009). Accuracy of point data is important when applied in extracting spatial information and these monitoring efforts allow for orchid locations to be documented using high resolution hand-held GPS units with sub-meter accuracy when available.

Land Use and Environmental Influences

An estimated 100-year decline of orchid population levels throughout North America is primarily attributed to the conversion of habitat to intensive agriculture and other anthropogenic changes (Bjugstad & Fortune, 1989; Sieg & King, 1995). Additional limitations and threats to populations have been identified as herbivore grazing, invasive species, erratic flowing habits, mycotrophy, limited pollination, availability of moisture, and land use activities that influence the quantity and quality of groundwater (USFWS, 1996; USDA Forest Service, 2001). These factors can cause reductions in orchid population size and distributions (USFWS, 1996).

Knowledge is lacking on the effects of land use on orchid habitat and populations (Bjugstad & Fortune, 1989; Sieg & King, 1995; Sieg & Wolken, 1999; Wolken, Sieg & Williams, 2001). Land use plays a significant role in influencing patterns, diversity, and dynamics within and among landscapes (Ostlie & Faust, 1996).There have been studies on the impacts of grazing (Alexander et al., 2010), invasive species control (Kirby et al., 2003), and effects of fire (Willson, Page & Akyuz, 2006). Disturbances such as these may be required to remove competing vegetation and sustain orchid habitats but the effects of these disturbances need to be monitored and researched for adaptive management.

The SNG is sectioned into grazing allotments (275.3 km^2) where local producers graze their cattle (Fritz, 2001). Approximately 92% of orchid habitat identified by the USDA Forest Service is subject to grazing. The USDA Forest Service categorizes allotments relative to orchids as core, satellite, or other. Core and satellite allotments were defined by high orchid abundance, orchid persistance in wet and dry years, geographic association, and presence of geographic barriers impeding dispersal. The core and satellite allotments are then managed to promote and maintain orchid recovery after exposure to grazing, mowing, burning, noxious weed treatment, restorations, and water inundation. Allotments categorized as other may exhibit orchid presence but regardless are not managed by orchid recovery strategies (USDA Forest Service, 2001).

Historically grazing was an important process in sustaining grassland ecosystems. Grazing can be beneficial to orchid habitat when properly timed and spatially managed. However, grazing can be detrimental through trampling, reducing carbohydrate reserves, and prevention of seed dispersal (USDA Forest Service, 2001). The intensity of grazing is evident on the SNG along with invasive species, characteristic of heavily grazed grasslands (Alexander et al., 2010). Invasive species such as Kentucky bluegrass (*Poa pratensis*) and leafy spurge (*Euphorbia esula*) are dominant species on the SNG and a concern for sustaining orchid habitat and populations (Sieg & King, 1995; Wolken, Sieg & Williams, 2001). Sieg and King (1995) observed that orchid plant density was negatively correlated with Kentucky bluegrass and as it is a sod forming species it likely inhibits orchid establishment. Kirby et al. (2003), states that continuous use of chemicals to treat leafy spurge has impacted orchid habitat.

Excessive drought or flooding can cause significant reductions in orchid populations (Hof, Sieg & Bevers, 1999). Below average snowfall and rainfall accompanied by heat waves from 1987 to 1989 and orchid data justify that a decrease in flowering and increase in mortality is likely linked to changes in moisture due to drought conditions (USFWS, 1996). Below average moisture conditions decrease aboveground orchid populations and the proportion of flowering plants (USFWS, 2009). Therefore, in the absence of recruitment, mature plants with established root systems must be able to withstand duration of frequent and sometimes extended droughts. Seed dormancy and delayed germination may also enable seeds to withstand below average moisture conditions over extended periods of time. Thus established root systems and viable seeds that persist (seed bank) may be important for post-drought population recovery (Ostlie & Faust, 1996; USFWS, 2009).

Growth, flowering, reproduction and abundance of orchids in flooded habitats has been observed to vary considerably between years in areas of the SNG that show significant year-to-year variations in intensity, duration and frequency of flooding. Sieg and Wolken (1999) provide evidence that flooding differentially affects vegetative and flowering orchids with 70% of flowering plants and only 3% of vegetative plants persisting through the growing season. The low rate of persistence was attributed to the difference in physical attributes. Vegetative plants are shorter and lack hollow flowering stalks. Sieg and Wolken (1999) also documented that flooding resulted in a shift in the topographic position of orchids from low to higher positions in the landscape exhibiting suitable moisture conditions. In locations with little topographic variation, development of flowering plants may be reduced during floods. Flooding may impact orchid distribution and habitat through subsequent years depending on intensity, duration and frequency (USFWS, 2009).

Annual and seasonal groundwater fluctuations occur naturally influenced by snowmelt, rainfall, and evapotranspiration. Anthropogenic hydrological alterations that artificially draw down groundwater elevations near the root zone may have serious adverse effects on orchid habitat. Landscape properties are highly susceptible to changes in groundwater elevations and basin hydrology arising from human activities including increased use of groundwater for agricultural irrigation and municipal water supply, widening and deepening of ditches to remove water from the landscape, and chemical and fertilizer use (USFWS, 2009). Human activities pose threats to the quality and quantity of groundwater, and hydrologic regime affecting soil nutrients, availability of moisture, plant species distribution and orchid habitat (USDA Forest Service, 2001; USFWS, 2009).

Bjugstad and Fortune (1989) noted that flowering orchids were possibly responding to high levels of precipitation the year prior. Climatic processes like precipitation along climatic fronts coupled with more isolated thunderstorms play significant roles in determining availability of moisture (Ostlie & Faust, 1996). These processes such as precipitation and snowmelt influence groundwater elevations through groundwater recharge. Most recharge occurs from snowmelt and rainfall in the spring during the time that frost leaves the ground and before evapotranspiration loss from vegetation and high temperatures becomes significant. Recharge may also occur through isolated storm events (Armstrong, 1982). For example, on June 12, 2005, McLeod, ND, recorded a 114.3 mm storm event (Weather Warehouse: http://weather-warehouse.com). Precipitation influences moisture availability especially in the lateral root zone. When defining habitat parameters across the landscape, over multiple years, precipitation, snowmelt and other climatic processes that influence moisture availability may be eminent in groundwater. Especially in landscapes such as the SNG, exhibiting sandy soils with low water holding capacity and faster infiltration rates (Armstrong, 1982).

Orchid Habitat Indicators

Most species growing in heterogeneous landscapes show distinct habitat preferences and rarer species tend to prefer either hummock or swale habitats (Vivian-Smith, 1997). The orchids are associated with lowland swales, wetlands, marshes, and sedge meadow habitats. These can be primarily classified as palustrine emergent temporarily or seasonally flooded wetlands. These habitats are characterized by extreme annual and seasonal fluctuations in moisture which typically result in shifts in vegetative composition. It is likely that orchids shift in time and space in response to these fluctuations (USDA Forest Service, 2001). The orchid is most associated with wetland basins, margins of wetlands, and margins of flow paths. Preferred orchid habitats are calcareous prairies and sedge meadows subirrigated by high groundwater elevations influencing moisture gradients (USFWS, 1996; USDA Forest Service, 2001).

The Hummock and Swale landform provides the majority of orchid habitat across the SNG on wet foot and toe slopes where vegetation consists mostly of wooly sedge (*Carex lanuginosa*), northern reed grass, Baltic rush (*Juncus balticus*), and willows (*Salix* spp.). Habitats can also exist near wetter facets within big bluestem, little bluestem, Indian grass, switchgrass and prairie cordgrass communities (Bjugstad & Fortune, 1989; Sieg & King, 1995; USFWS, 1996; Sieg & Wolken, 1999). These vegetative communities cover roughly 14% of the Hummock and Swale landform (Bjugstad & Fortune, 1989).

Sieg and King (1995) observed transects supporting orchids were diverse and identified plant communities dominated by species like Kentucky bluegrass (*Poa pratensis*), Baltic rush, sedge species, willows, and northern reed grass. They also noted that other species like switchgrass, prairie cordgrass, and leafy spurge were also common. Based on their study, Sieg and King (1995), state that northern reed grass is the best indicator of orchid habitat. A study by Wolken, Sieg, and Williams (2001), indicated that percent coverage of Baltic rush was the best indicator of orchid habitat.

The primary determinants of orchid distribution in the landscape are presence of suitable habitat, dispersal routes and patterns, and moisture availability (Hof, Sieg & Bevers, 1999). It is well documented that flowering orchids are more present in wet sites than dry suggesting that flowering may be related to moisture (Sieg & King, 1995). It is also widely accepted that if water is limited it becomes the key resource impacting vegetation and ecological processes, including carbon assimilation via control of photosynthesis and stomatal closure, and nitrogen assimilation through control of the nitrogen mineralization rate (Rodriguez-Iturbe et al., 1999).

Moisture availability affects success of seed germination and seedling persistence (Ostlie & Faust, 1996), and is a critical determinant of growth, flowering, reproduction and distribution of orchids (USFWS, 2009). Sieg and King (1995) found a positive correlation between orchid density and soil moisture suggesting a relationship between moisture availability and orchid locations. Soil moisture alone affects a number of factors important for plant growth beyond water availability. For example subsurface flow is likely to transport dissolvable cations and nitrogen compounds towards wetlands potentially affecting pH and soil nitrogen content (Moeslund et al., 2013). Other factors affected include successful development of flowering plants, fruits and storage tissue. Storage tissue such as photosynthetic gains that contribute to new foliage and perennating tissue for next year's root system (Sieg & King, 1995; Sieg & Wolken, 1999). Therefore, close examination of landscape indicators of moisture conditions and observed variability in orchid positions in the landscape could provide a greater understanding of the landscape properties that influence orchid habitat from year to year.

Landscape-Scale Indicators

Based on the accumulated knowledge of orchid behavior, vegetation associations, soil wetness and inundation and drainage characteristics may provide the best landscape-scale properties indicative of orchid habitat. These properties can be represented by three well established indicators: the Normalized Difference Vegetation Index (NDVI) derived from remote sensing, and the Topographic Wetness Index (TWI) and Topographic Position Index (TPI) derived from a digital elevation model (DEM).

Normalized Difference Vegetation Index

The NDVI is one of the most widely used indices of remote sensing vegetation in monitoring condition and phenology (Myneni et al., 1995; Campbell & Wynne, 2011). NDVI is based on the fact that chlorophyll absorbs the red spectrum and mesophyll tissue reflects the near infrared spectrum (Pettorelli, 2005). Seasonal variations in NDVI values across vegetated surfaces are attributed to phenology influenced by environmental parameters like the availability of moisture. These seasonal variations have been attributed to spring warm-up, senescence, rainfall events and areas strongly influenced by climate and land use (Pettorelli, 2005; Eidenshink & Haas, 2008).

The NDVI takes the difference of near infrared and visible reflectance values normalized over total reflectance (Eidenshink & Haas, 2008). The NDVI computed values range from -1 to 1, where increasing positive values indicate increasing photosynthetic activity and green vegetation and negative values correspond to an absence of vegetation indicating other surfaces such as soil and water (Pettorelli, 2005; Eidenshink & Haas, 2008). Eidenshink and Haas (2008) used NDVI descriptive statistics of different land systems to characterize vegetation dynamics over the growing season and found that the mean NDVI was the best parameter for monitoring phenology. Paruelo and Lauenroth (1998), found that precipitation and temperature were the main climatic controls of variability between maximum and minimum NDVI and that the proportion of precipitation falling in the summer was positively associated with the date of maximum NDVI.

Descriptive statistics such as mean and standard deviation are indicators of land cover homogeneity and phenology as influenced by the environment and can therefore be used in monitoring vegetation (Eidenshink & Haas, 2008). The NDVI enables researchers to differentiate ecosystem functional types and vegetative communities but assemblages of plant species can produce similar NDVI values or temporal trends, meaning that few plant species, if any, can be identified accurately (Pettorelli, 2005). This limits the ability to define orchid habitat from imagery, but NDVI still provides useful information in defining sparse and dense vegetation, and land covers such as water, soils, and agriculture.

Topographic Wetness Index

The TWI, a steady state wetness index, is a function of both slope and the upstream contributing area per unit width orthogonal to the flow direction (Yang et al., 2005). The TWI is proportional to the potential wetness of a given location and subsurface lateral transmissivity (Grabs et al., 2009; Moeslund et al., 2013). TWI is based on the assumption that surface topography is the main controlling factor of groundwater elevations and water flow. However, TWI does not consider factors such as subsurface topography and hydrogeological characteristics. Also, the TWI is static and relies on the assumption that local slope is an adequate proxy for the effective downslope hydraulic gradient which is not necessarily true in low relief terrain. Even with these limitations the TWI has become a popular and widely used topographic index to infer information about the spatial distribution of moisture availability (i.e. the position of shallow groundwater tables and soil moisture) (Grabs et al., 2009).

TWI has been proven highly correlated to soil attributes such as horizon depth, percent silt, and organic matter (Gessler et al., 1995; Yang et al., 2005). Moeslund et al. (2013) found that the TWI was strongly correlated with local and regional gradients in species composition and soil moisture suggesting that hydrology and more specifically topographically controlled moisture gradients to be important in monitoring and management of vegetation across landscapes. This may be especially true for the SNG in that topographic moisture gradients can be strongly influenced by precipitation, groundwater, drought and flood.

Topographic Position Index

The TPI compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell. Topographic position is an inherently scale-dependent phenomenon and ecological characteristics of a site may be affected by TPI at several scales (Jenness, 2006). Most ecological and physical conditions and processes, such as plant species distribution and moisture availability, correlate closely to topographic position in the landscape.

Orchid positions in the landscape vary spatially and temporally in response to changes in moisture availability. Many physical and biological patterns and processes acting on the landscape are highly correlated to topographic position. Moisture availability and its response to local climate and groundwater elevations are recognized as determinants of vegetation distribution relative to topographic position in the landscape (Jenness, 2006; Moeslund et al., 2013). The variability in spatial distribution and topographic position among orchids across the SNG makes monitoring and documenting orchid populations and habitat parameters long-term regimes difficult.

CHAPTER III

METHODS

Study Area

The study area (52.2 km^2) was confined to the Hummock and Swale landform based on a subwatershed within the Pigeon Point – Sheyenne River watershed (hydrologic unit code (HUC) 0902020405). The subwatershed (HUC 090202040503) is defined as a closed basin and was selected based on its central location within the Hummock and Swale landform and groundwater well observations. Also, this subwatershed contained 79% (966) of orchid point data from 2006 to 2012 and all of 2013 orchid points. This allowed for all spatial point and grid data to be spatially defined by the extent of the subwatershed boundaries providing consistency in application of remote sensing indices and analyses.

Being a closed basin, this subwatershed identified a hydrologic boundary with no surface outlet. Therefore, it can be assumed that hydrological interactions and processes represented within the study area such as accumulation, evapotranspiration, and groundwater recharge act within this boundary. One noticeable issue with this boundary is the linear northeast boundary. This boundary is defined by railroad tracks that impede hydrologic flow and possibly orchid dispersal.

Watershed polygons were obtained from the North Dakota GIS Hub Data Portal (https://apps.nd.gov/hubdataportal/srv/en/main.home). The subwatershed dataset is a digital hydrologic unit boundary layer to the 6^{th} level (12-digit) consisting of geo-referenced digital data and associated attributes created in accordance with Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD) (http://pubs.usgs.gov/tm/tm11a3/). It was reasonable to define environmental parameters and habitat within boundaries of this subwatershed since topography and hydrology greatly influence orchid habitat and orchid positions in the landscape. The study area is shown in Figure 3.

Analytical Process

Landscape properties and distribution of plant species can be well defined on the basis of topography, moisture, and vegetation (Parvianinen et al., 2008). For this study, satellite and high-resolution aerial infrared imagery, a high-resolution DEM, and groundwater well observations were used to create indicators of landscape properties and compared to orchid point-based field observations to define annual orchid metrics ($\pm 2\ \sigma$) for each of the landscape indicators (NDVI, TWI, TPI, and depth to groundwater). Orchid metrics were used to classify landscape indicators and composites of landscape indicators were used to produce annual habitat maps and a 2013 validation (Figure 4).

Landscape indicators characterize properties such as topography, moisture, and vegetation cover. Landsat TM5 and Airborne Environmental Research Observational Camera (AEROCam) imagery were used to derive the NDVI, which characterized photo-

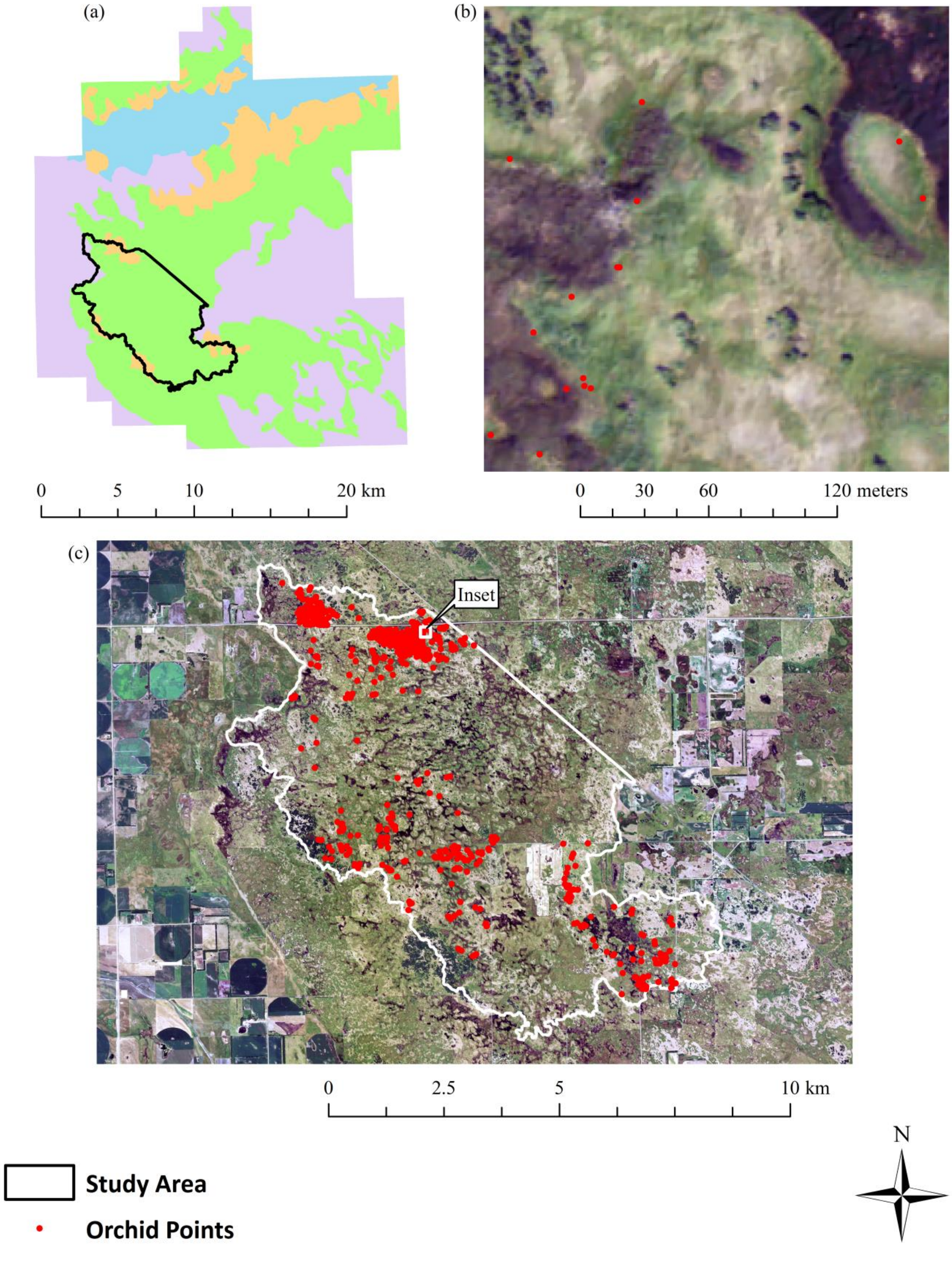

Figure 3 Study area: (a) Subwatershed boundary within landforms of the SNG (b) 2012 USDA National Agriculture Imagery Program (NAIP) imagery showing orchid locations (c) Study area map showing surrounding land cover, orchid point distribution from 2006 – 2013 and inset location.

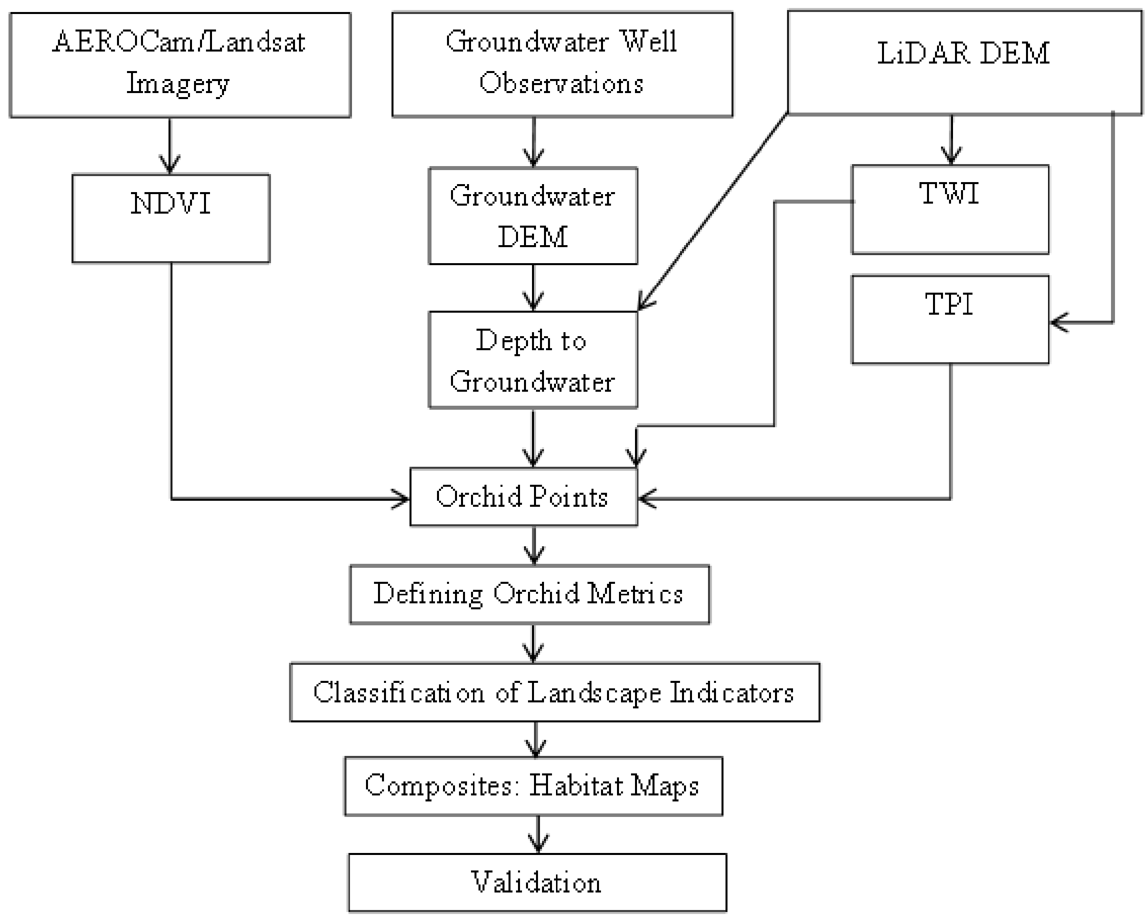

Figure 4 Flow diagram of analytical process.

synthetic activity and vegetation cover, providing information on distribution of vegetation communities and land use. Groundwater elevations were used for the creation of annual groundwater DEMs and combined with a LiDAR DEM to create annual depth to groundwater indicators representing the depth from the land surface to the groundwater surface. The LiDAR DEM was also used to generate landscape indicators TWI defining the potential wetness of a cell based on topography and slope, and TPI defining orchid positions in the landscape relative to their surrounding elevations. Landscape indicators were compared with orchid point-based field observations to define orchid metrics.

Orchid metrics are derived by using annual orchid point-based field observations to extract values from landscape indicators. Orchid metrics are therefore defined as the mean ±2 σ of landscape indicator values of orchid locations. Orchid metrics were used to classify their corresponding landscape indicators into orchid habitat, wetland and upland. Landscape indicators were also classified into single binary grids representing orchid habitat (1) and non-orchid habitat (0) and added together to analyze how landscape indicators overlap and synergize creating orchid habitat maps identifying core and fringe orchid habitat zones. Landscape indicators and the average orchid metrics (2006-2012) were then used in a validation to predict a 2013 orchid habitat map and compare to 2013 orchid point-based field observations.

Data Collection and Processing

All data (Table 1) were subset to the study area using ESRI's ArcGIS™ 10.0. All Landsat TM5 imagery was processed in ERDAS™ 2011 along with compilation of LiDAR DEM tiles and orthorectification and compilation of all AEROCam imagery. Groundwater well observations were filtered and averaged in Microsoft™ Excel and then imported into ArcGIS™ 10.0 for krigging of annual groundwater DEM's. Orchid point data and study area polygon were imported directly into ArcGIS™ 10.0. All descriptive statistics of landscape indicator values of orchid locations (orchid metrics ±2 σ) and histograms were analyzed in Microsoft™ Excel.

Table 1 Summary of data collection.

Data	Type	Origin	Spatial/ Temporal	Reference
AEROCam	Aerial Infrared Imagery	Remote Sensing	2 m/July 30, 2012	Digital Northern Great Plains (DNGP) (http://dngp.umac.org)
Landsat TM5	Multi-spectral Satellite Imagery	Remote Sensing	30 m/16 Days	U.S. Geological Survey (USGS) (http://glovis.usgs.gov)
LiDAR DEM	Digital Elevation Model	Derived from LiDAR	1 m/ Spring 2008	International Water Institute (IWI) (http://www.iwinst.org/)
Groundwater Well Observations	Point-based	Field Observations	22.5x16 km/ Monthly	North Dakota State Water Commission (http://www.swc.state.nd.us/)
Orchid Data	Point-based	Field Observations	0.1 – 5 m accuracy/ Annually (July)	USDA Forest Service Dakota Prairie Grasslands Supervisor's Office Bismarck, ND
Subwatershed /Study Area	Polygon	Geo-referenced Digital Data	52.2 km^2	North Dakota GIS Hub (https://apps.nd.gov/hubdataportal/srv/en/main.home)

Orchid Points

Orchid point data were obtained as point files from the USDA Forest Service at the Dakota Prairie Grasslands Supervisor's Office in Bismarck, ND. This dataset consisted of all known recorded orchid locations from 2006 – 2012. Because of lack of federal funding, the NDPR department was unable to fund the NDNHI recording of orchid locations in 2013. The author collected orchid point-based field observations on July 15 and 16, 2013, using a high resolution Trimble GeoXH handheld GPS unit (accuracy of 0.1 meters), and volunteers from Wisconsin Wetland Specialists recorded points using an AshTech mobile handheld unit with sub-meter accuracy; they also collected the 2012 point data for the NDNHI. Orchid point data from 2009 – 2013 collected by the USDA Forest Service, was limited to their (100 x 100 m) microplots and collected with a Trimble GeoExplorer 3 (accuracy 1 – 5 meters). Orchid point data collected for the NDNHI from 2006 – 2008 were recorded by Yellow Field Biological Surveys. The acquisition receiver for these years is unknown with an accuracy of <5 meters.

Using the Select by Attributes tool in ArcGIS™ 10.0 annual orchid points were exported creating individual point files for each year (2006 – 2013). These point files were eventually subset using the Clip tool in ArcGIS™ 10.0 to the extent of the study area. Table 2 shows the annual number of orchid points recorded within the study area. Orchid location monitoring typically occurs late June through July depending on phenology in a particular year. All orchid point data here were collected within this time annually.

Table 2 Numbers of orchid locations recorded annually within the study area.

Year	Orchids
2006	116
2007	318
2008	113
2009	20
2010	8
2011	3
2012	96
2013	292

Groundwater Well Observations

Monthly groundwater well observations were obtained from the North Dakota State Water Commission (http://www.swc.state.nd.us/). Availability of groundwater data was limited in that the number of individual well observations was reduced to below ten prior to 2006. As a result this studies time period was confined by the availability of groundwater data. Monthly groundwater well observations were delivered as two text files; one represented well observations in feet (observations were converted to meters by a multiplication factor 0.3048 for unit consistency) and the second represented site inventory including latitude and longitude. These files were spatially joined through well identification numbers.

Groundwater data were filtered in Excel to represent lagged annual conditions (i.e. spring-summer and previous fall seasons). Annual mean calculations were represented as the total mean of the previous fall (August, September, and October) and spring-summer seasons (May, June, July). April observations were used when May observations were unavailable, also annual mean calculations for an individual well had to include at least four of the six months (two fall and two spring) otherwise that well was excluded for that year. Spatial distribution of observation wells spanned an area 22.5 by 16 km with variability in the number of annual wells (Table 3; Figure 5).

Table 3 Number of annual groundwater well observations.

Year	Wells
2006	22
2007	30
2008	30
2009	30
2010	27
2011	29
2012	27
2013	24

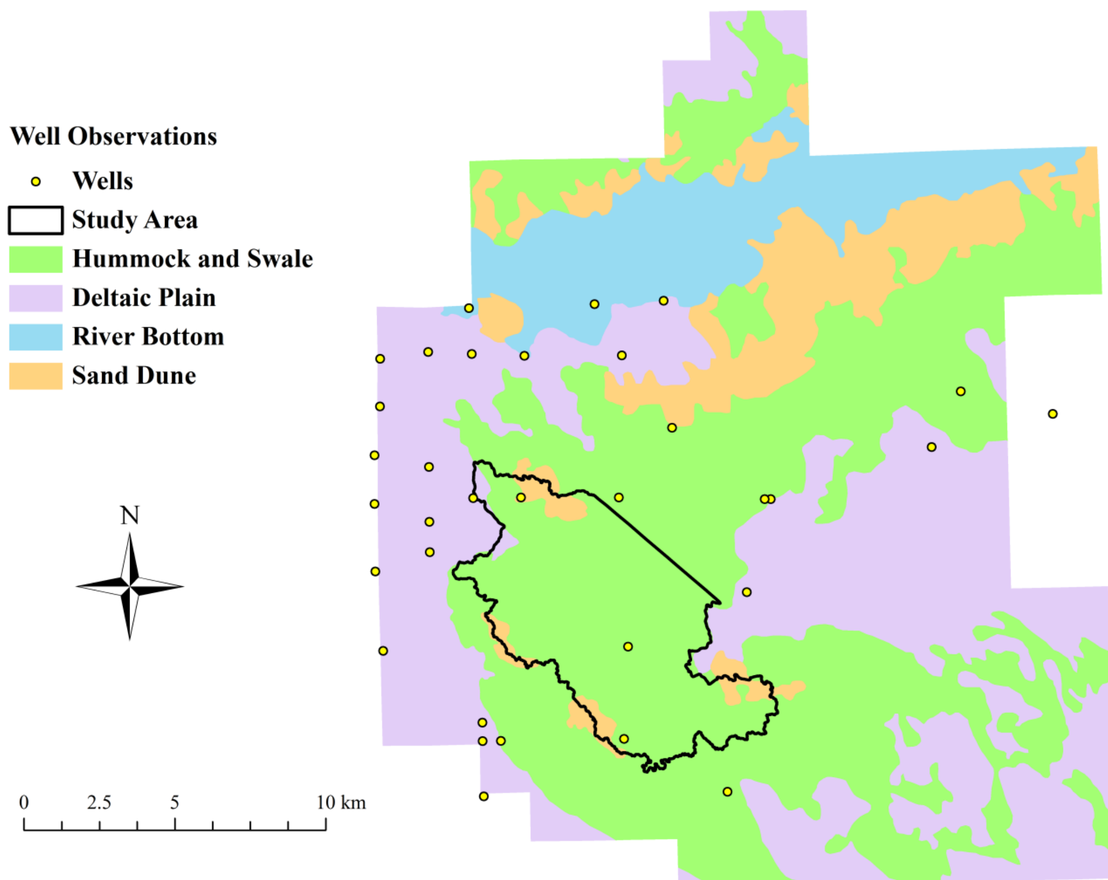

Figure 5 Groundwater well observation distribution across the SNG.

LiDAR DEM

The LiDAR DEM, obtained from International Water Institute (IWI) (http://www.iwinst.org/) and Red River Basin Decision Information Network (http://www.rrbdin.org/), is a result of private and government entities working together under the guidance of IWI regarding the Red River Basin Mapping Initiative (RRBMI). LiDAR acquisition occurred spring 2008 between April 18 and May 20. LiDAR derived DEMs were delivered as 2 x 2 km grids (.asc files) at a 1-m spatial resolution, and were obtained for the entire area of the SNG landforms and extent of groundwater well observations as seen in Figure 4. Individual tiles were mosaicked and output as a grid (.tif) using ERDAS™ 2011. This study uses the LiDAR DEM for elevation, slope and application of topographic indices. Elevation units were obtained in centimeters and converted to meters for unit consistency. Topography can influence vegetation composition, species distribution, and availability of moisture, thus the LiDAR DEM was used to generate multiple landscape indicators (TWI, TPI, and depth to groundwater).

AEROCam Imagery

AEROCam imagery was obtained from the Upper Midwest Aerospace Consortium (UMAC) at the University of North Dakota (UND) and available on the Digital Northern Great Plains (DNGP) website (http://dngp.umac.org). AEROCam is a three band (NIR, R, G) near-infrared aerial imagery source developed to provide near real-time imagery at higher spatial resolutions than currently available from satellite sources providing environmental and agricultural information to farmers and researchers.

AEROCam was flown once over the SNG on July 30, 2012, at a 2-m spatial resolution. Timing of imagery is important when studying vegetation and July is significant in that orchids are typically flowering and reaching peak phenological stages. All AEROCam images over the SNG were ortho-rectified using the Leica Photogrammetry Suite (LPS) tool in ERDAS™ 2011. Average RMSE of tie-point triangulation was <0.5 meters and imagery was compiled using the Mosaic Pro tool in ERDAS™ 2011. The NDVI was then applied using the Raster Calculator tool using the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where NIR is band 1 and RED is band 2 of AEROCam three band imagery. The NDVI grid was then subset down to the extent of the study area and resampled using the Resample tool in ArcGIS™ 10.0 to a 1-m resolution. Resampling was performed for consistency in spatial resolution with all other landscape indicators. The main limitation here is that there is only high-resolution AEROCam imagery available for 2012. NDVI values in 2012 across the study area ranged from -0.36 to 0.87 with a mean of 0.35 ±0.3 (2σ).

Landsat Imagery

The Landsat TM5 sensor has been proven useful for the characterization and assessment of vegetation condition, phenology, change detection, and spatial and temporal distribution patterns. The sensor has seven spectral bands (six visible bands with a 30-m spatial resolution and one thermal with a 120-m resolution) with an eight-bit radiometric resolution, and has a temporal resolution of 16 days. For much of the Earth's vegetative surface this temporal resolution is sufficient to capture important vegetative conditions and phenological events. However, temporal resolution is limited by cloud cover, reducing the potential of remote sensing applications and the capabilities to detect change (Cohen & Goward, 2004; Jackson et al., 2004). From 2006 – 2011 all available nearly cloud free Landsat TM5 data were downloaded from the U.S. Geological Survey (USGS) website (http://glovis.usgs.gov) for the months of April through October and were atmospherically corrected, converted to reflectance values, and subset to the SNG using ERDAS™ 2011; NDVI was processed in ENVI™ 4.8 using bands 3 (Red) and 4 (NIR).

Depth to Groundwater

The site inventory file, containing latitude and longitude and well identification numbers, was imported into ArcGIS™ 10.0 as point layers. The groundwater well observations representing lagged annual means described in the data section were joined to the site inventory file based on Site Index (well identification numbers), giving spatial reference. A point layer was created for each year (2006 – 2013) representing lagged annual mean groundwater elevations in meters. These point layers were used to create 30-m groundwater DEMs using ordinary krigging in the Geostatistical Analyst tool in ArcGIS™ 10.0. A Gaussian model (Kitanidis, 1997) was applied for this interpolation with 12 lags and lag size varied annually due to availability of well observations but was 1200 on average with an RMSE of 0.77 m on average.

The offset of the krigged groundwater grids were compared to measured groundwater elevations. This refers to the offset from the absolute groundwater elevations to the estimated elevations. Average annual groundwater estimations were 0.10 ±0.78 m (1σ). However, as this study analyzed groundwater elevations relative to the land surface and not the absolute relationship, there was no adjustment for this offset. The uncertainty (±0.78 σ) is a result of data availability and density of groundwater observation wells, and was influenced by only a few wells annually. Efforts toward continuity in well observations at higher spatial densities may improve results.

Groundwater DEMs were generated at a 30-m resolution because spatially groundwater surfaces typically change only slightly (10 cm/km) across larger spatial areas relative to direction of flow. Much of the change in groundwater surfaces is influenced by topography and vertical groundwater fluctuations because of snowmelt, rainfall, and evapotranspiration. Groundwater DEMs were used to analyze the depth from the land surface to the groundwater surface relative to orchid positions in the landscape annually. The LiDAR DEM and groundwater DEMs were used to generate depth to groundwater landscape indicators using the Raster Calculator tool in ArcGIS™ 10.0 and were output at the same 1-m resolution as the LiDAR DEM. These landscape indicators represent the depth from the land surface to the groundwater surface and were used to analyze orchid locations and their relationship to the groundwater surface.

Topographic Wetness Index

As previously described TWI is a steady state wetness index, a function of both slope and the upstream contributing area. It is proportional to the potential wetness of a given location and subsurface lateral transmissivity (Yang et al., 2005; Grabs et al., 2009; Moeslund et al., 2013). Components of TWI include a flow accumulation grid and slope grid (radians) both derived from the LiDAR DEM. To calculate the TWI, processes (described below) were applied using Model Builder in ArcGIS™ 10.0 and the output TWI grid was the same 1-m resolution as the LiDAR DEM.

To produce the flow accumulation grid the LiDAR DEM was filled using the Fill tool. This filled any sinks removing small imperfections in the data. The filled DEM was then applied to the Flow Direction tool creating a grid representing flow from each cell to its steepest downslope neighbor. The algorithm used calculates the proximity of flow in only one of eight possible directions separated by 45 degrees and is a single direction algorithm which directs flow from each cell to the adjacent cell with the steepest down slope gradient. This can result in unrealistic features producing striped features on very gentle, long and lower slopes (Yang et al., 2005; Kopecký & Cížková, 2010). The flow direction is also less suitable in flatter areas due to undefined flow paths that most likely change over time (Grabs et al., 2009). Results influenced by these limitations relative to orchid habitat would be most significant in larger flat lowlands such as sedge meadows.

The flow direction grid was then applied to the Flow Accumulation tool creating a grid of accumulated flow into each cell. This flow accumulation grid is then multiplied by the actual area of a grid cell to produce the contributing area. The area of a grid cell is then added to the flow accumulation grid to ensure that all flow accumulation cells have an area at least the same as itself. The Slope tool was applied to the LiDAR DEM to produce a slop grid, in degrees. The slope grid was then applied to the Raster Calculator tool to add 0.01 degrees to each cell. This increased the angle forcing the denominator in the wetness index to a number greater than zero. The slope grid was then multiplied by 0.0175 to convert to radians.

The TWI was then produced through the following formula using the Raster Calculator tool:

$$TWI = \ln(\frac{A_s}{tan\beta_i})$$

where A_s is the specific catchment area (cumulative upslope area draining through a cell divided by the contour width orthogonal to the flow direction) associated with i and expressed as m^2 per unit, and β_i is the slope angle of i expressed in radians. The specific catchment area is a parameter describing the tendency for a cell to receive water and local slope is a parameter describing tendency to evacuate water. The TWI can be a measure of long-term moisture availability across a landscape (Kopecký & Cížková, 2010; Yang et al., 2005; Moeslund et al., 2013), which may be useful in the identification of orchid habitat. TWI values across the study area range from 0 to 24 with low values meaning almost never saturated and high values always saturated. The mean TWI across the study area is 5.4 ±4.48 (2σ).

Topographic Position Index

The TPI compares the elevation of each cell in the LiDAR DEM to the mean elevation of a specified neighborhood. TPI's core method uses the Focal Statistics (mean) tool in ArcGIS™ 10.0. The algorithm is simply the difference between a cell elevation value and the mean elevation of that cells neighborhood. Positive TPI values represent locations that are higher than the mean of their surroundings. Negative values represent locations that are lower than their surroundings. TPI values near zero are either flat areas or areas of constant slope (Jenness, 2006).

The TPI was applied using the Land Facet Corridor Analysis tool developed at Jenness Enterprises (Jenness, 2006). This tool is an extension for ESRI's ArcGIS™ and was used to produce a TPI. To calculate the TPI, the LiDAR DEM and TPI parameters, such as neighborhood shape (circle, annulus, rectangle, and wedge) and radius of neighborhood, are used as inputs. A circle neighborhood and a radius of five cells (five DEM units) were used in this study. The TPI is then automatically generated by the Land Facet Corridor Analysis tool. Other parameters were explored such as neighborhood shape and size of radius but there was little difference observed between TPI outputs with varying parameters. Species distributions have shown relationships to TPI at multiple scales (Guisan, Weiss & Weiss, 1999). Orchid distribution and their topographic position in the landscape may also relate to TPI. Also, orchid positions in the landscape can shift with changes in habitat influenced by flooding, drought, and groundwater fluctuations. TPI values are represented as meters and across the study area values ranged from -1.04 to 1.29 with a mean TPI of 0 ±0.14 (2σ).

Defining Orchid Metrics

Annual orchid point layers were used to extract landscape indicator (NDVI, TWI, TPI, and depth to groundwater) cell values of orchid locations. Annual orchid point layers were overlaid onto each landscape indicator for their corresponding year. Extraction of cells representing orchid locations was applied using the Extract by Mask tool in ArcGIS™ 10.0; if two orchid points fell within one cell, only one record was extracted. The extracted orchid cells were converted to point coverage's and spatially joined to the original orchid point attribute data thereby associating each orchid record with an NDVI, TWI, TPI and depth to groundwater value. This process was applied to all available landscape indicators for each year 2006 – 2013.

Landscape indicator values of orchid points for each year were applied to a box plot in SPSS Inc. for removal of outliers. Outliers were removed because of the natural variability of orchid positions in the landscape resulting in spatial and temporal variability of orchid distribution. Also, orchid populations across the SNG occur as large shifting metapopulations, isolated subpopulations, and as individual outliers (USDA Forest Service, 2001; USFWS, 1996). Individual outliers include orchids that may emerge, flower, and disperse seed at lower or higher positions in the landscape as a result of below or above average moisture conditions. This is related to the orchid's ability to disperse seeds that may persist and be viable until moisture conditions and other ecological processes favor establishment and flowering. Outliers could also be a result of the varied accuracy of different hand-held GPS units.

Following removal of outliers landscape indicator values of orchid points were analyzed for descriptive statistics in Microsoft™ Excel to calculate annual orchid metrics for each landscape indicator. Annual orchid metrics were used to classify the symbolism of each landscape indicator for their corresponding year allowing the classification of landscape indicators into orchid habitat, wetland and upland. The depths to groundwater orchid metrics were applied to histogram generation in Microsoft™ Excel to analyze the distribution of orchids relative the depths to the groundwater surface. Histograms were binned every 0.1 meters ranging from 0 – 2 meters.

Classification of Landscape Indicators

Orchid metrics derived from landscape indicators (NDVI, TWI, TPI, and depth to groundwater) were used for habitat classification across the study area in two ways. First, each individual landscape indicator can be classified into three classes by defining the landscape indicators based on cells within, below or above orchid metrics. For example, depth to groundwater cell values below orchid metrics represent permanent to semi-permanent wetlands and cell values above represent uplands. For TWI, cell values below orchid metrics classify areas that are almost always dry (i.e. uplands) and cell values above classify flow paths and areas of accumulation (i.e. wetlands). TPI cell values below orchid metrics classify areas lower than their surrounding neighborhood (i.e. wetlands) and cell values above classify areas that are higher in elevation than their neighborhood (i.e. uplands). The NDVI cell values below orchid metrics classify sparse vegetation, soils, and water whereas cell values above classify dense vegetation such as trees (higher photosynthetic activity). The NDVI allows for identification of photosynthetic activity and vegetation cover, which other landscape indicators do not.

Second, orchid metrics and landscape indicators were used to classify orchid habitat from non-habitat using the Raster Calculator tool. Two binary (0 and 1) grids were produced based on orchid metrics. In the first binary grid values of 1 represent cells greater than or equal to the lowest orchid metric. In the second binary grid values of 1 represent cells less than or equal to the highest orchid metric. These two binary grids were then multiplied together producing a single binary grid where values of 1 represent cells within orchid metrics, defining the landscape relative to orchid locations. These single binary grids represent orchid habitat (1) and non-orchid habitat (0). Annual single binary grids were produced for each landscape indicator (NDVI, TWI, TPI, and depth to groundwater) based on orchid metrics for their corresponding years and then composited.

Composites: Habitat Maps

Single binary grids for their corresponding years were added together using the Raster Calculator tool. Except 2012, all years consisted of three landscape indicators (TWI, TPI, and depth to groundwater) and when added together a composite grid containing four values (0, 1, 2, and 3) is produced. Composite cell values of 3 represent areas where all landscape indicators classify orchid habitat. For 2012, the NDVI grid contributes another layer producing a five value grid (0, 1, 2, 3, and 4) where cell values of 4 are representative of where all landscape indicators classify orchid habitat. The resulting composites produce annual habitat maps showing how landscape indicators overlay and synergize. Habitat maps are unable to classify the landscape by orchid habitat, wetland, and upland however provide greater definition of orchid habitat through classification of core and fringe orchid habitat zones. Habitat maps allowed for analysis of these zones relative to percent area and how well they represent orchid point data.

Validation

A validation of habitat maps and their ability to classify orchid habitat zones based on the overall mean of orchid metrics was conducted using orchid point-based field observations from 2013. The average orchid metrics for the period of 2006 – 2012 derived from landscape indicators and orchid point data were applied to each landscape indicator creating single binary grids. Single binary grids were then added together using the Raster Calculator tool. This composite produced a habitat map identifying core and fringe orchid habitat zones and compared with 2013 orchid point data. Orchid metrics applied in this validation are based on the average orchid metrics from 2006 – 2012, excluding the NDVI.

TWI and TPI are steady state landscape indicators changing only with changes in orchid metrics. However, depth to groundwater indicators change annually and lagged 2013 mean groundwater elevations (fall 2012 August, September, October and spring-summer 2013 May, June, July) were applied in this validation. This validation was conducted to determine how well the landscape indicators and orchid metrics define the landscape relative to orchid positions in the landscape and habitat distribution.

A second validation was done to include the NDVI landscape indicator, however NDVI orchid metrics are represented for only 2012 and not an average of orchid metrics from 2006 to 2012. This validation included the 2012 NDVI as this landscape indicator has proven an important measure of vegetation cover and high-resolution infrared imagery was not available for 2013. The author acknowledges that photosynthetic activity and vegetation cover vary from year to year making this validation constrained by the 2012 NDVI.

CHAPTER IV

RESULTS

Association of Orchid Data with Landscape Indicators

Orchid populations consist of metapopulations, isolated subpopulations, and individual outliers because of reproduction ecology and dispersal mechanisms influencing orchid positions in the landscape and distribution resulting in natural outliers amongst populations. Orchid point data also result in outliers because of the varied accuracy of hand held GPS units. These factors influence this analysis and to address these influences outliers were removed. The numbers of outliers were few and varied among landscape indicators and years. Outliers were associated with higher or lower elevation and wetter or drier conditions in the landscape. After removal of the outliers, orchid metrics ($\pm 2\ \sigma$) were applied to their corresponding landscape indicators. Depth to groundwater orchid metrics were 0.59 – 1.44 m; 1.67 – 8.13 for TWI; -0.12 – 0.11 m for TPI, on average (2006 – 2013); and 0.31 – 0.61 for NDVI in 2012 (Table 4).

Orchid metrics associated with orchid point data and derived from landscape indicators (NDVI, TWI, TPI, and depth to groundwater) were used to classify the landscape indicators into orchid habitat, wetland and upland. The NDVI-based orchid metrics defined the landscape in terms of land cover types and these were aggregated to sparse vegetation, water and soils (i.e. wetland), orchid habitat, and tree cover (i.e. upland). This is a result of the information provided by infrared imagery and NDVI as an assessment of photosynthetic activity and vegetation cover. These classes represent land below, within, and above annual orchid metrics. Figure 6 demonstrates each landscape indicator and its classification of orchid habitat, wetland and upland for 2012. The individual single binary grids represent each landscape indicator and were composited into habitat maps to analyze overlaps and synergies.

Table 4 Annual and mean orchid metrics (±2 σ) for each landscape indicator from 2006 – 2013.

Landscape Indicators	Orchid Metrics	2006	2007	2008	2009	2010	2011	2012	2013	Mean
Depth to Groundwater	Low	0.19	0.44	0.79	0.53	0.88	0.86	0.43	0.56	0.59
	High	1.11	1.47	1.40	1.45	1.52	1.44	1.20	1.93	1.44
TWI	Low	1.65	1.93	1.53	1.63	0.92	2.70	1.10	1.89	1.67
	High	7.55	9.72	8.78	7.82	7.71	10.73	6.54	6.22	8.13
TPI	Low	-0.11	-0.16	-0.11	-0.07	-0.15	-0.12	-0.11	-0.13	-0.12
	High	0.10	0.11	0.09	0.06	0.15	0.10	0.16	0.12	0.11
NDVI	Low							0.31		
	High							0.61		

TWI and TPI

Both topographic indices represent their intended landscape properties such as flow path and accumulation (TWI) and cells of higher or lower elevations than the mean of their neighboring cells (TPI). The mean TWI across the study area is 5.4 ±4.48 (2σ) and orchid metrics were 1.67 – 8.13 on average and the mean TPI is 0 ±0.14 (2σ) m with orchid metrics of -0.12 – 0.11 m on average. TWI and TPI values across the landscape are less variable, relative to orchid positions in the landscape, identifying greater area of

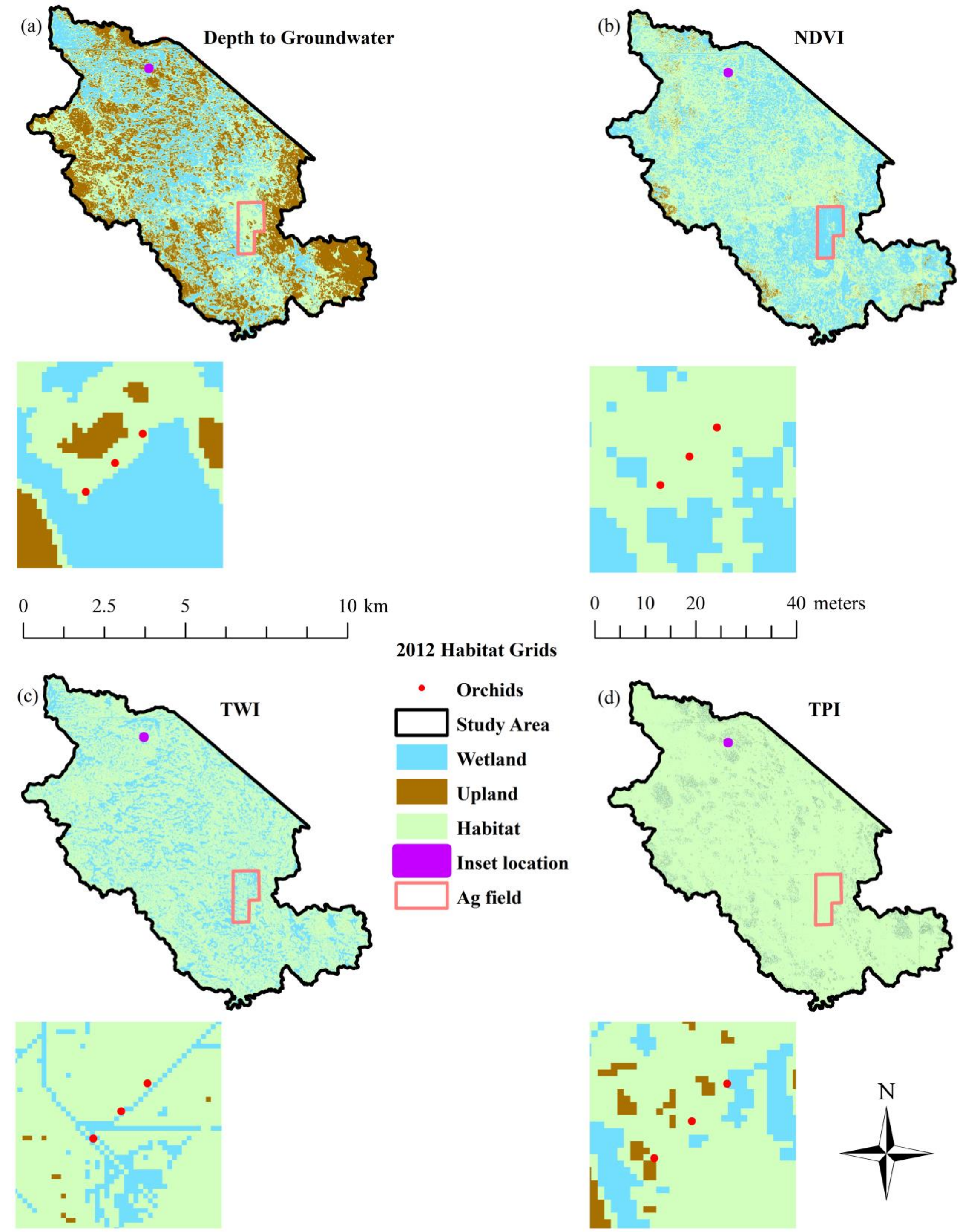

Figure 6 Classification of landscape indicators with insets demonstrating orchid metrics: (a) Depth to groundwater provided most heterogeneous classification (b) TWI demonstrates orchids occurring near or along flow paths (c) TPI demonstrates that orchids can be found at foot and toe slopes of slight elevation changes (d) NDVI classifies vegetation condition and land cover.

orchid habitat. These results represent a more homogeneous landscape with 88.9% (TPI) and 83.4% (TWI) of the landscape classified as habitat on average.

NDVI

Landsat imagery proved spatially too coarse because of the topographic variability of the landscape that results in distinct vegetative transitions between wetlands and uplands. Topographic and vegetative variations occur across the SNG at a finer scale than 30 m and thus Landsat is too coarse for this research. AEROCam imagery was available for one year limiting NDVI to July 30, 2012. Timing of the imagery is significant for analysis of vegetative productivity during orchid flowering and monitoring across the SNG. The NDVI resulted in 58.8% of the landscape classified as habitat, 38.8% as wetland, and 2.3% upland. However, wetland classification includes water, soils and sparse vegetation which may represent wetlands and uplands. NDVI orchid metrics resulted in a range of 0.31 to 0.61. Wetlands and sparsely vegetated uplands are characterized by NDVI values <0.31, and dense vegetation (i.e. trees) by values >0.61.

Depth to Groundwater

Depth to groundwater orchid metrics were 0.59 – 1.44 m on average, providing the most heterogeneous landscape classification of the SNG. Percent area of the landscape was classified as 42.0% habitat, 24.6% as wetland, and 33.4% upland on average. In years where orchid metrics classified 64.6% (2013) or 15.8% (2011) of the landscape as habitat are over- and under-representations. These results influence the overall means because of the orchid point data and groundwater well observations. For example one third of orchid points in 2013 are confined to a small area within a sedge meadow and there were only three orchid points in 2011. Also, groundwater well observations varied annually. Table 5 shows the percent area of habitat, wetland, and upland for each landscape indicator annually and on average.

Table 5 Percent area of land classified as habitat, wetland and upland for each landscape indicator annually.

	2006	2007	2008	2009	2010	2011	2012	2013	Mean
Depth to Groundwater									
Habitat	49.8%	58.4%	34.5%	54.2%	19.9%	15.8%	38.6%	64.6%	42.0%
Wetland	9.0%	2.8%	23.1%	7.0%	57.1%	65.0%	25.2%	7.6%	24.6%
Upland	41.2%	38.8%	42.4%	38.8%	23.0%	19.2%	36.2%	27.8%	33.4%
TPI									
Habitat	89.5%	92.5%	86.6%	73.3%	94.9%	90.1%	92.4%	92.0%	88.9%
Wetland	4.5%	2.1%	5.1%	12.8%	2.3%	3.8%	5.1%	3.7%	4.9%
Upland	6.0%	5.4%	8.3%	13.9%	2.8%	6.1%	2.5%	4.3%	6.2%
TWI									
Habitat	82.3%	95.5%	92.9%	85.2%	84.5%	91.0%	70.3%	65.4%	83.4%
Wetland	17.3%	3.4%	6.8%	14.4%	15.5%	1.9%	29.7%	33.6%	15.3%
Upland	0.4%	1.1%	0.3%	0.4%	0.0%	7.1%	0.0%	1.0%	1.3%
NDVI									
Habitat							58.8%		
Wetland							38.9%		
Upland							2.3%		

Composite of Landscape Indicators: Habitat Maps

Individual landscape indicators made a unique contribution to defining orchid habitat. For example, the NDVI identified an agricultural field unsuitable as orchid habitat that was included in suitable habitat zones defined by the other indicators. Orchids would likely occur in this area but land use practices would be inhibitory. The TWI identified the margins of flow paths as likely orchid habitat highlighting the importance of water flows over the land surface and through the subsurface for orchid habitat. The TPI indicator classified more of the landscape as orchid habitat than the other indicators. However, at finer scales the TPI did identifies the micro-topography that may be influencing orchid locations. Depth to groundwater grids classified the landscape relative to the relationship between orchid land surface and groundwater elevations; demonstrating moisture gradients and vegetative transitions that characterize the landscape providing orchid habitat within the mosaic of prairie wetlands and uplands.

The composite habitat maps allowed for orchid habitat to be defined by all landscape indicators (NDVI, TWI, TPI, and depth to groundwater). This provides a finer estimation of orchid habitat by defining core and fringe habitat zones, supporting that each grid provides its own unique classification significant to the landscape and orchid habitat. Yet, classification results indicated that habitat maps are mostly constrained by the depth to groundwater landscape indicators. However, the topographic indices along with NDVI are useful in defining habitat beyond that of the depth to groundwater indicators.

The 2012 habitat map is the most layered representation of orchid habitat across the landscape, as it is the only year including NDVI. These habitat maps demonstrate the landscape heterogeneity of the SNG and its vegetative communities relative to orchid locations. The 2012 habitat map demonstrates the narrow habitat corridors and rings surrounding uplands, transitioning into wetlands characterizing the spatial distribution of orchid habitat (Figure 7).

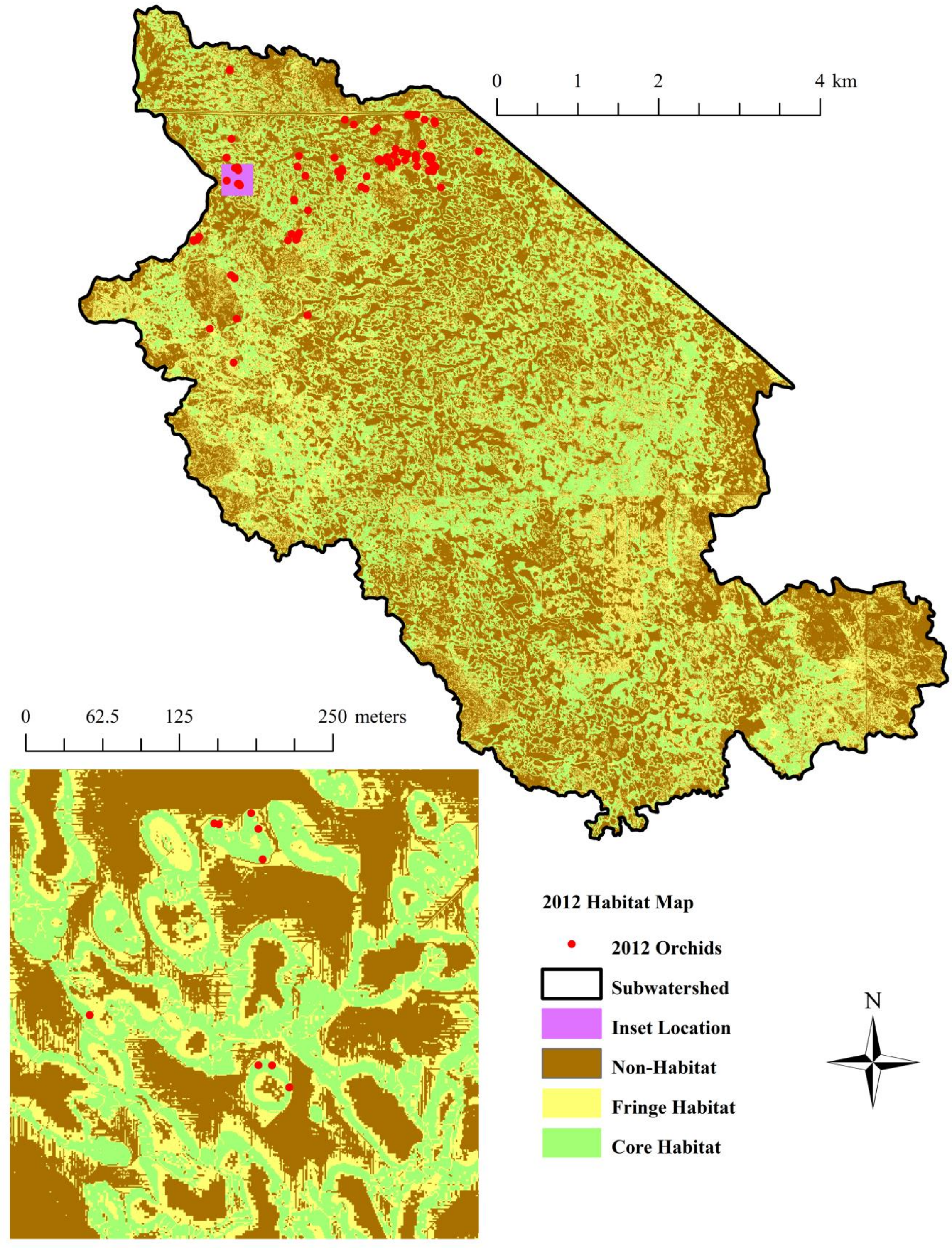

Figure 7 2012 habitat map providing spatial identification of core and fringe orchid habitat zones.

Core and Fringe Orchid Habitat Zones

Habitat maps provided identification of core and fringe habitat zones each year. Core habitat is defined by areas where all landscape indicators classified orchid habitat and is described here as having the highest probability of supporting orchids based on orchid metrics and landscape indicators; representing 30.6% of the landscape on average (Table 5). Fringe habitat zones are defined by areas where all but one grid classified orchid habitat and represents 50.3% of the landscape on average. The identification of these habitat zones represents 80.9% of the landscape on average. This suggests that a large majority of the landscape is relative to orchid metrics based on landscape indicators applied here. However, these are averages for 2006 – 2013 and NDVI was available only in 2012. The NDVI adds another indicator that describes vegetation cover relative to orchid habitat. This resulted in the 2012 habitat map producing a finer estimation of core (21.4%), fringe (30.3%), and overall (51.7%) orchid habitat (Table 6).

Table 6 Percent area of land classified as core and fringe orchid habitat zones for each habitat map.

Habitat Zones	2006	2007	2008	2009	2010	2011	2012	2013	Mean
Core Habitat	36.6%	53.9%	29.6%	35.3%	17.9%	12.7%	21.4%	37.3%	30.6%
Fringe Habitat	48.9%	38.9%	55.1%	43.2%	63.7%	73.9%	30.3%	48.2%	50.3%

Core and fringe habitat zones were also analyzed for the percentage of orchid points lying within these zones. When orchid points and core habitat zones are compared with their corresponding years 85.1% of the orchid points lay within core habitat zones on average (Table 7). When all orchid points over time (2006 – 2013) are compared to annual core habitat zones, 49.6% lay within on average. These averages are skewed because of the extreme percentages in 2010 and 2011. This is a result of limited orchid points in these years and therefore a poorer representation of the landscape and orchid habitat. If 2010 and 2011 results are excluded from the average the representation of orchid points within core habitat zones is 80.1% (annually) and 45.9% for all orchid points (2006 – 2013) on average.

Table 7 Percent of orchid points lying within core and fringe orchid habitat zones; corresponding annual orchid points and all orchid points (2006 – 2013).

Composites	2006	2007	2008	2009	2010	2011	2012	2013	Mean
Annual									
Core Orchids	78.5%	80.8%	77.9%	85.0%	100%	100%	76.0%	82.5%	85.1%
Fringe Orchids	20.7%	17.9%	21.2%	15.0%	0.0%	0.0%	21.9%	14.4%	13.9%
2006 – 2013									
Core Orchids	62.3%	77.3%	57.5%	55.3%	22.1%	5.5%	50.9%	66.2%	49.6%
Fringe Orchids	32.7%	20.5%	33.0%	36.4%	64.6%	79.2%	29.8%	29.4%	40.7%

When considering all orchid points across the entire study period we can see that core habitat zones represents 49.6% of orchid points and the majority of remaining points are represented in fringe habitat (40.7%). This analysis demonstrates that core orchid habitat zones represent ~50% of annual orchid populations; demonstrating that habitat maps producing core and fringe habitat zones derived from average orchid metrics may be well representative of long-term orchid habitat. Results also support that according to the landscape indicators applied here a large percentage of the landscape is associated with orchid habitat; indicating the importance of the entire landscape to orchid habitat conservation.

Validation

The average orchid metrics (±2 σ), from 2006 – 2012, were applied to landscape indicators and composited to create a 2013 habitat map prediction of orchid habitat. This validation included no orchid metrics derived from 2013 orchid points. The individual topographic indicators classified 90.6% (TPI) and 90.4% (TWI) of the landscape as habitat. The depth to groundwater indicator classified 45.0% of the landscape as habitat. Even though the NDVI was only available for 2012 it was applied in a second validation but orchid metrics were based only on 2012 orchid points with 58.8% habitat.

The validation habitat maps were analyzed for percent area of core and fringe habitat zones and percent of 2013 orchid points within these zones. Table 8 shows the habitat maps validation results. The habitat map validation shown in Figure 8, excluding the 2012 NDVI, defines 37.4% percent of the landscape as core habitat and 51.5% as fringe, and 52.7% of the 2013 orchid points fell within the core zones. When the 2012 NDVI is included in the validation we can see an exclusion of ~10% of the landscape from core and nearly 14% from fringe habitat zones. Yet, the representation of 2013 orchids is only slightly reduced indicating the importance of the high resolution NDVI.

Table 8 Percent area of land classified as core and fringe orchid habitat zones and the percent of orchid points lying within these zones for 2013 orchid points.

Habitat Map Validation	2013	w/2012 NDVI
Core Habitat (area)	37.4%	26.8%
Fringe Habitat (area)	51.5%	37.8%
2013		
Core Orchids	52.7%	50.7%
Fringe Orchids	41.4%	39.0%

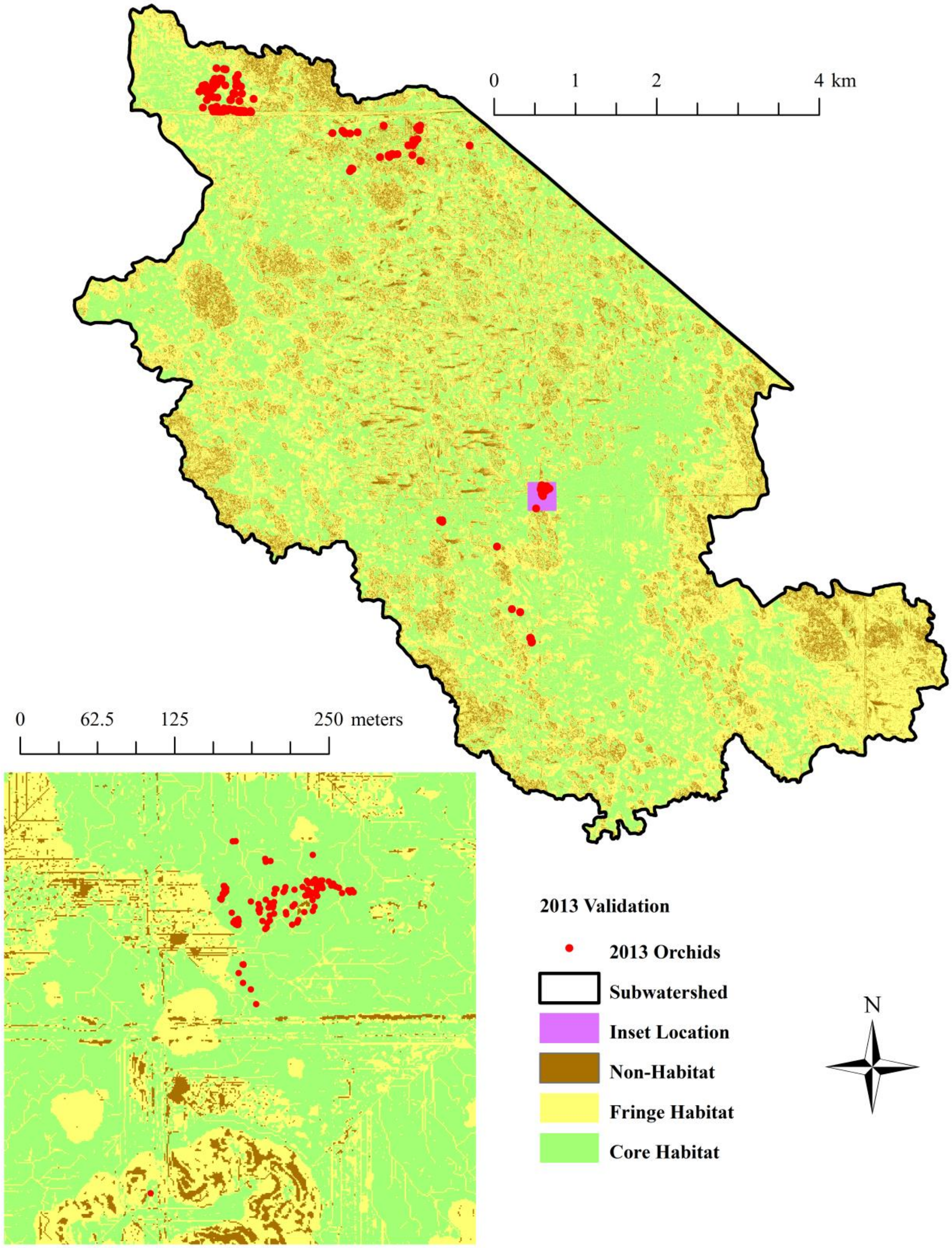

Figure 8 The 2013 habitat map validation (excluding NDVI) predicting core and fringe habitat zones based on average orchid metrics from 2006 to 2012 and 2013 groundwater elevations.

Land Surface and Groundwater Orchid Elevations

The depth to groundwater landscape indicator provided the most variable landscape classifications from year to year and significantly improved the association between orchid observations and habitat maps. This suggested that perhaps the behavior of the water table could be a major driver of orchid population dynamics from year to year. As a result, more detailed analysis was undertaken to explore this relationship between orchid positions in the landscape and the depths to the water table. Figure 9 shows annual mean land surface and groundwater elevations of orchid points derived from the LiDAR DEM and 30 meter krigged groundwater DEMs; demonstrating that orchid positions in the landscape correlate with groundwater elevations ($R^2 = 0.87$).

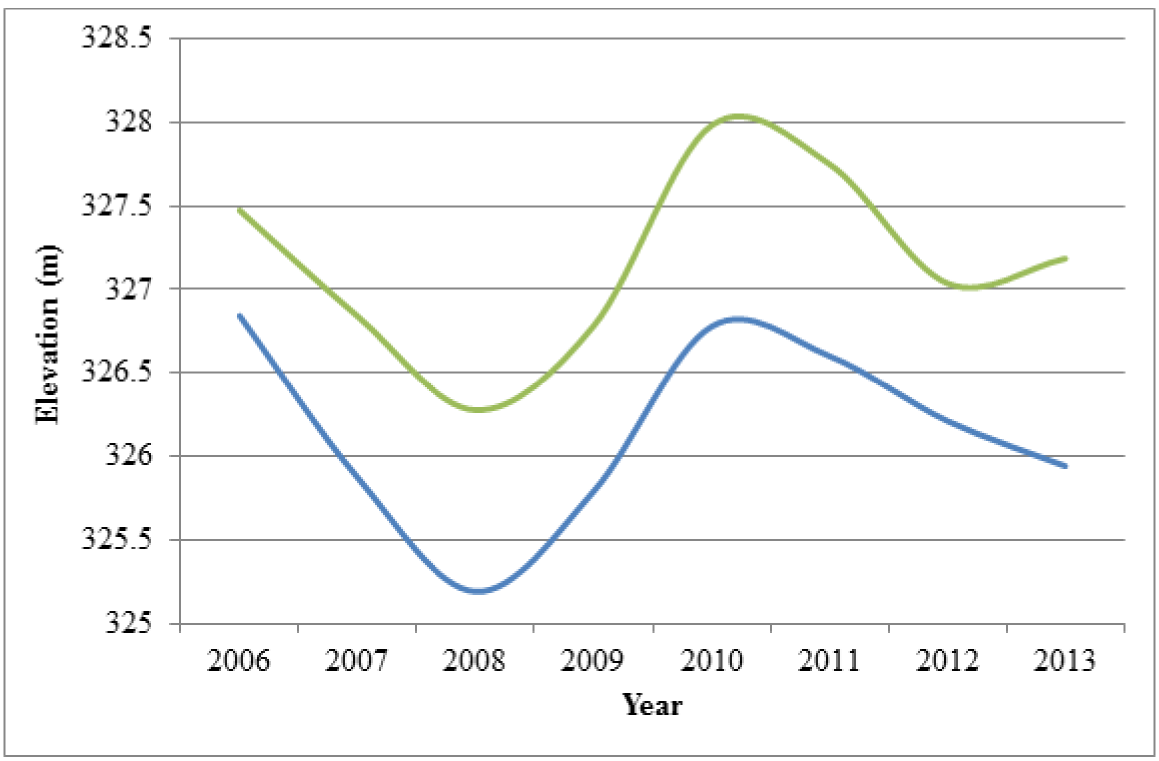

Figure 9 Mean orchid elevation at the land surface (green) and corresponding groundwater elevations (blue).

Depth to groundwater landscape indicator values of orchid locations were used to generate frequency histograms (Figure 10) to analyze the distribution of orchids showing that orchid positions in the landscape were on average 1.01 ±0.43 (2σ) m from the groundwater surface. In 2006 and 2013 orchid distribution significantly deviated from this general range of depth to groundwater. For example, in 2006 orchid distribution showed the lowest mean depth to groundwater of 0.65 ±0.46 (2σ) m. This suggests that in 2006 moisture conditions were below average and orchids were flourishing at lower position in the landscape. In 2013 orchid locations exhibit two distribution peaks with the highest mean depth to groundwater of 1.24 ±0.68 (2σ). This is likely because of the fact that 100 out of 292 orchid point observations were obtained in a large population, within a relatively small area. This specific location of orchid habitat is a lower flat sedge meadow habitat where groundwater may be slightly further from the land surface, yet because of adequate moisture conditions and other ecological processes not explored here, a population of orchids was flowering. In 2007, 2008, and 2012 histograms show more normal distribution supporting that orchids are located on average 1.01 ±0.43 (2σ) m from the groundwater table. The analysis in 2009, 2010, and 2011 was limited by insufficient orchid observations.

Frequency histograms provided detailed information on how orchid populations in the landscape may vary due to landscape properties and climate change influencing groundwater elevations. This suggests that the orchid is able to adapt to wet and dry climatic cycles by maintaining a position in the landscape with appropriate hydrologic conditions for survival and propagation.

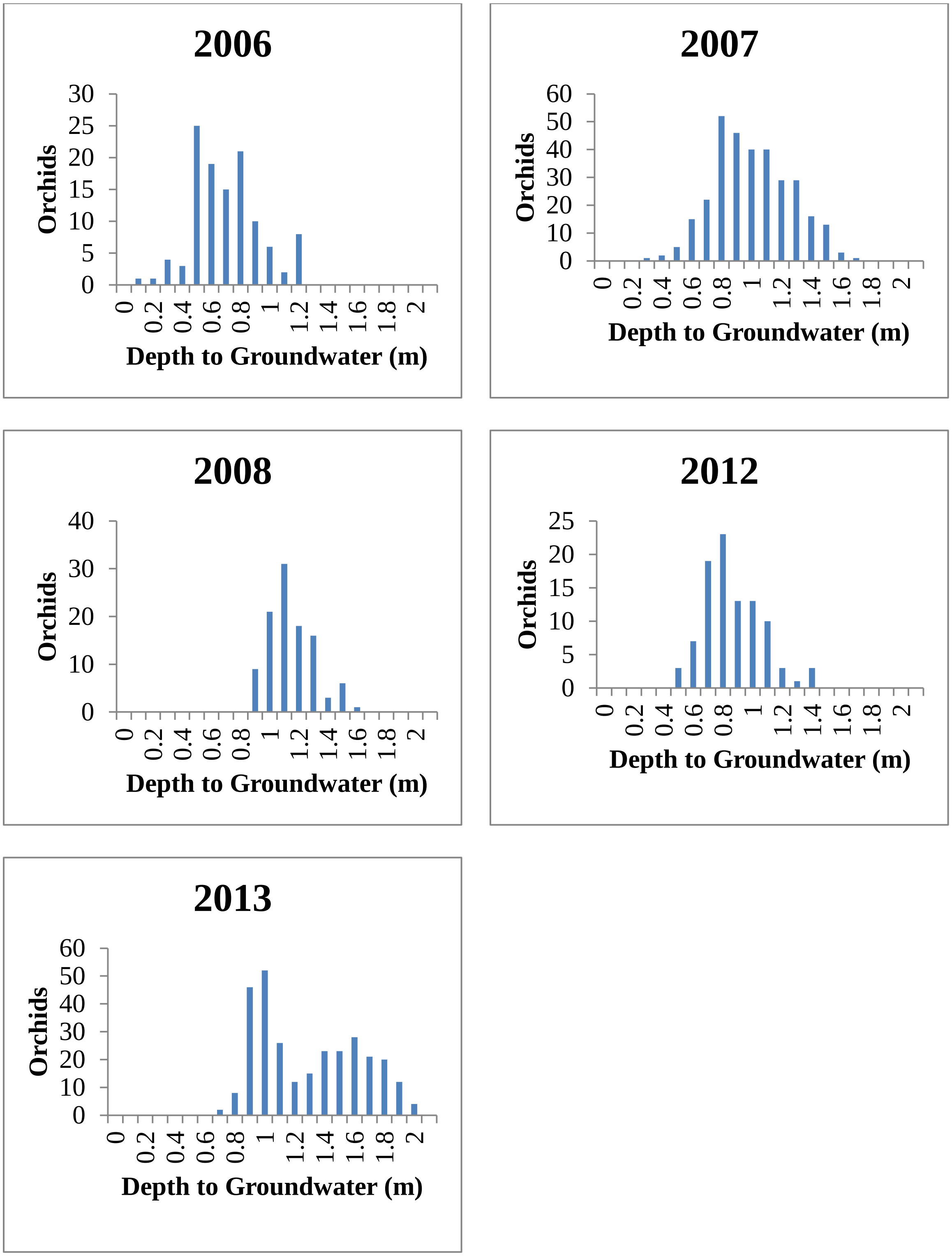

Figure 10 Depth to groundwater frequency histograms demonstrating orchid distribution.

Grazing Allotments

Allotments are categorized into core and satellite orchid allotments based on historic observations and geographic distribution (USDA Forest Service, 2001). High orchid populations occur consistently in some allotments, but orchids have been observed throughout most allotments. The variation between allotments may point to factors affecting orchid establishment other than those defined in the habitat analysis.

To examine allotment influences, relationships between habitat and orchid observations were explored for one core allotment (A Annex), five satellite allotments (Owego Annex, Berg, Milton Sr., Northrop, and Brown), and one other allotment (Griggs), as identified by the USDA Forest Service (2001) (Figure 11). The 2012 habitat map was used to analyze the difference in habitat area between allotments, showing some variation in percent area of core orchid habitat zones with 18.2% to 28.4% of the landscape within allotments classified as habitat. The percent area of core habitat zones by allotment allows identification of variations in orchid habitat among allotments identifying different orchid habitats representing different slopes (Table 9).

Table 9 Percent area and slope of core orchid habitat zones within grazing allotments derived from the 2012 habitat map.

Allotments	Core Habitat	Slope (degrees)
A Annex	20.7%	4.45
Berg	28.4%	2.94
Brown	23.7%	2.92
Griggs	18.2%	3.37
Milton Sr.	24.6%	3.56
Northrop	26.0%	3.37
Owego Annex	21.6%	4.47

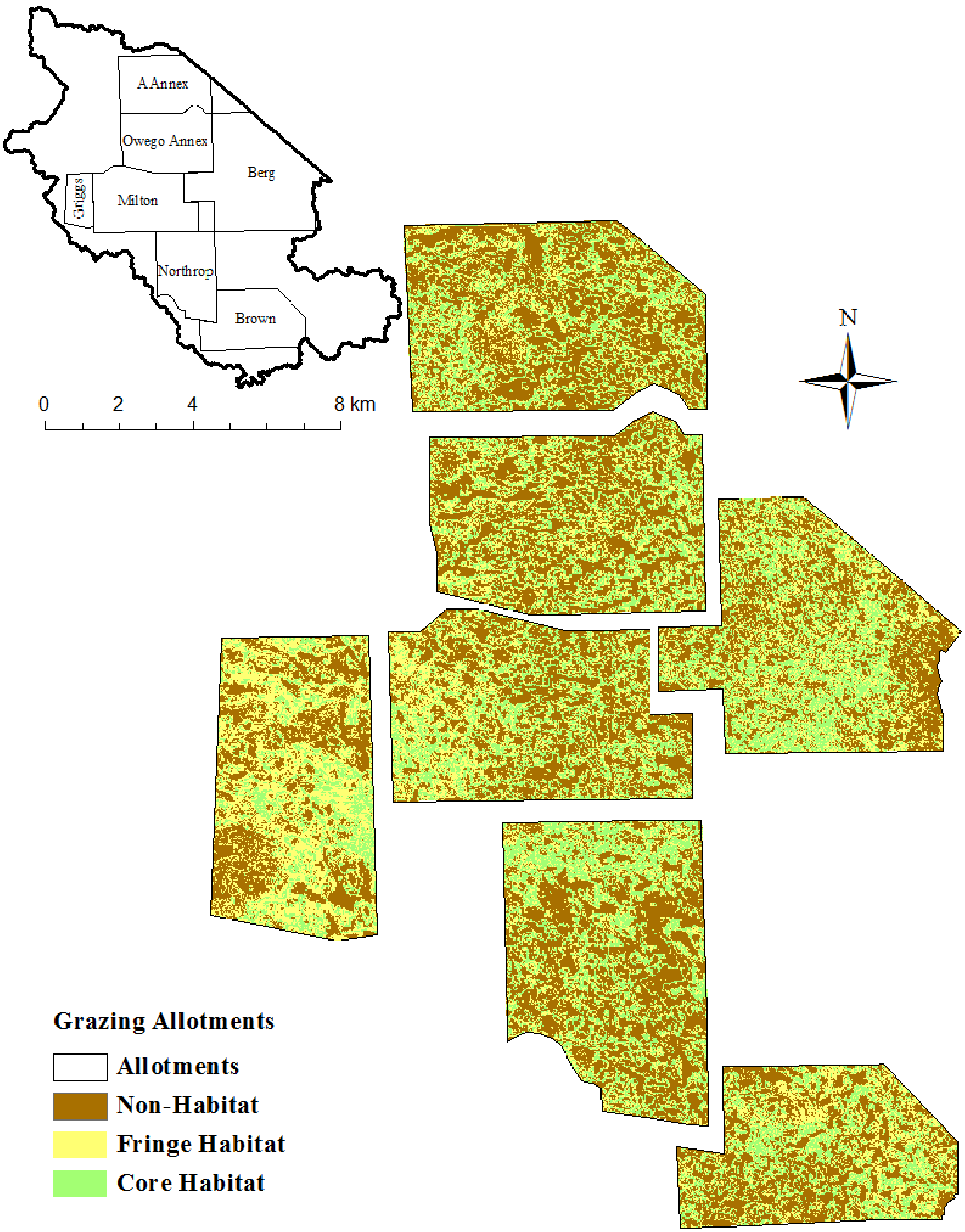

Figure 11 Habitat map (2012) of individual grazing allotments classifying core and fringe habitat zones. Allotment habitat maps are not to scale.

Some allotments (A Annex and Owego Annex) represent core habitat as narrow transition zones or corridors between wetlands and uplands exhibiting steeper slopes (4.45 and 4.47 degrees). These allotments contain orchid habitat that exists mainly in these narrow transition zones and in some cases result in ring (donut) shaped habitat zones around uplands, and long narrow corridors along margins of wetlands. Other allotments (Berg and Northrop) represent similar transition zones but exhibit shallower slopes (2.94 and 3.37 degrees) and higher percent area of core habitat due to larger flat lowlands or sedge meadows. These sedge meadows are represented by larger areas of land compared to the narrow habitat zones along wetland margins and transition zones between wetlands and uplands.

CHAPTER V

DISCUSSION

Moisture availability is recognized as the controlling resource of many ecological systems (Rodriguez-Iturbe et al., 1999). Moisture conditions present in a heterogeneous landscape are more variable at any given time and experience greater hydrologic extremes than landscapes representing more homogenous topography (Vivian-Smith, 2006). Topography controls moisture gradients and vegetation distribution through controlling precipitation accumulation and groundwater flow, assuming that groundwater elevations follow topography holds or topographic barriers (Grabs et al., 2009; Moeslund et al., 2013). Patterns of moisture availability are affected not only by site accumulation and groundwater elevations but also by evaporation and evapotranspiration, largely controlled by site exposure (Kopecký & Cížková, 2010). Topography also influences the amount of incoming solar radiation, thereby influencing these factors.

This study has shown that the positions of orchids in the landscape and orchid habitat distribution can be identified using a few landscape-scale indicators based on topography, groundwater elevations, and vegetation cover. The study found a consistent relationship between orchid point observations and depth to groundwater. Topographic indices (TWI and TPI) identified some of the fine-scale landscape relationships in demonstrating that orchids occur near margins of flow paths and can be located on foot and toe slopes of minute changes in elevation. The NDVI contributes a significant indicator in characterizing vegetation cover and land use. These landscape indicators identified core and fringe habitat zones defining orchid habitat over the SNG. This study highlighted a number of methodological and ecological issues that are discussed in the following sections.

Depth to Groundwater

The depths to groundwater landscape indicators suggest that annual fluctuations in groundwater elevations may significantly influence the availability of moisture and orchid positions in the landscape. This influence results in orchids spatially shifting horizontally, but more so vertically in the landscape. This is because of dispersal mechanisms and fluctuations in groundwater elevations influencing moisture conditions across the landscape. Groundwater elevations are influenced by both natural and anthropogenic factors such as precipitation events, drought, flood, ditching, and irrigation. Sustainably managing groundwater resources is important to the conservation of orchid habitat (USDA Forest Service, 2001; USFWS, 2009), yet challenging when managing a landscape to maintain the highest level of ecological function within the economic and social constraints imposing (Zinko et al., 2005).

The unique landscape of the SNG was well classified by the depth to groundwater landscape indicator. Permanent to semi-permanent wetlands likely exhibiting open water or cattail (*Typha*) species are defined by the depths to groundwater below orchid metrics.

Uplands or dunes likely exhibiting sparse vegetation and areas of exposed sand are defined by depths above orchid metrics. In 2012, orchid metrics ranged from 0.43 to 1.2 m above groundwater levels. This resulted in the classification of orchid habitat, wetlands and uplands in the landscape. This classification can be seen in Figure 12 and when visually compared with the 2012 NAIP (National Agriculture Imagery Program) imagery the classification is well representative of the landscape.

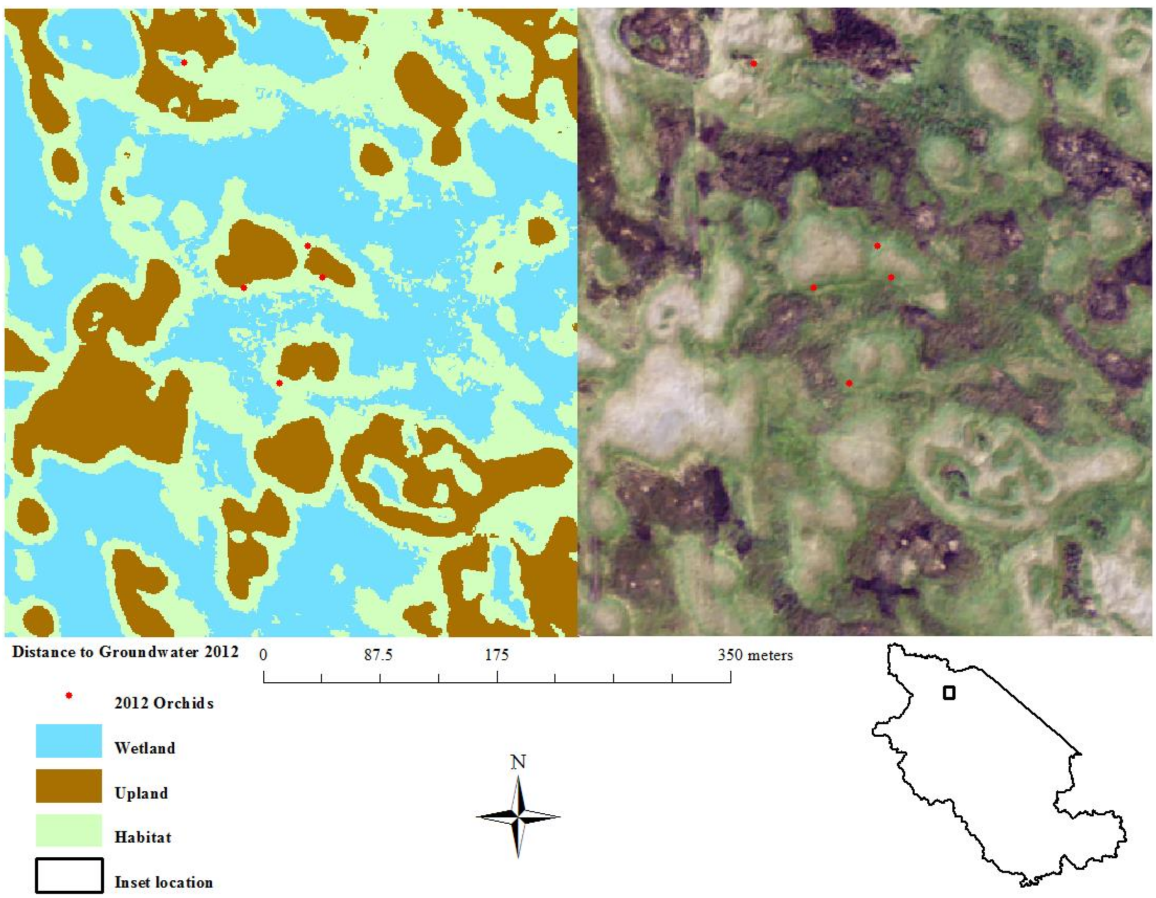

Figure 12 Depth to groundwater landscape indicator (2012) and 2012 NAIP imagery demonstrating orchid metrics and orchid locations in the landscape.

TWI and TPI

TWI and TPI were useful landscape indicators providing orchid habitat information based on the landscape properties they enhance. TWI identifies flow paths and where accumulation or flooding is most likely to occur based on topography and slope, demonstrating that orchid locations may occur near margins of these wetter facets. TPI identifies cells exhibiting higher or lower elevations than their surrounding neighborhood cells; representing areas of steeper slopes that may be more vulnerable to disturbances such as below average moisture conditions, livestock grazing, or invasive species. At a finer scale TPI identifies the micro-topography of the landscape demonstrating that orchids may be located on the foot and toe slopes of minute changes in elevation. Both indices provide information that is useful in excluding areas of very low habitat potential such as areas likely prone to flooding or disturbance. They also exhibit flow paths and slight elevation differences that could be influencing orchid locations. These indices provide an understanding of orchids spatially across the SNG relative to topographic landscape properties.

TWI and TPI are useful tools providing information on the spatial distribution of landscapes and moisture conditions. These indices have been used to infer the position of groundwater tables, soil moisture conditions, and classification of landscape features such as wetlands and uplands, ridges, slopes and valleys (Grabs et al., 2009). However, these indices are dependent on the quality and resolution of the DEM from which they were derived (Grabs et al., 2009). Fortunately a high resolution LiDAR DEM was publically available for the SNG.

TWI and TPI are steady state indices representing the landscape with limitations. To the author's knowledge there is little that can be done to improve the TPI as a landscape indicator. The TPI is likely limited by its simple methodology, characteristics of the landscape, and spatial resolution of the LiDAR DEM. The TWI is based on the assumption that surface topography is the main controlling factor of groundwater elevations and flow paths. However, other factors such as subsurface topography or hydrogeological characteristics of the aquifer may need to be considered (Grabs et al., 2009). TWI may be improved in vegetation analyses by using a multi-direction flow algorithm to improve accuracy and thus provide an enhanced representation of the landscape relative to moisture conditions (Kopecký & Cížková, 2010).

The flow routing algorithm applied here by the Flow Direction tool in ArcGIS™ 10.0 is a single flow direction. Single and multi-direction flow algorithms refer to how flow is passed from each grid cell. The single flow algorithms allow flow to only one neighboring downslope cell whereas the multi flow algorithm allows flow to more than one neighboring downslope cell depending on neighborhood size and degree of flow dispersion (Kopecký & Cížková, 2010). With that said, the TWI single flow direction algorithm used here does demonstrate that orchids can be found along or near margins of flow paths. To the author's knowledge this relationship has been suggested by the USDA Forest Service (2001) and USFWS (2009), but not spatially demonstrated over the landscape until now.

NDVI

The SNG is a mosaic of prairie wetlands and uplands with vegetative transitions that provide habitat suitable for orchids. Here the NDVI demonstrates these habitats based on vegetation cover and orchid metrics in 2012. The NDVI is useful in the classification of orchid habitat and associated vegetative communities providing a less homogenous classification of the landscape than the topographic indices. The NDVI also distinguishes land use. The identification of different land use was a noticeable contribution to the identification of habitat, excluding an agricultural field (Figure 5).

NDVI is a useful tool for terrestrial ecology in gaining a better understanding of how vegetation dynamics and distribution affect diversity, life history traits, distribution patterns and population dynamics (Pettorelli et al., 2005). Annual acquisition of high resolution infrared imagery is necessary for application of NDVI over the SNG. This would enable researchers to better understand these vegetative communities and the impacts of land use (i.e. livestock grazing) relative to orchid habitat. Availability of continuous near real-time high-resolution aerial imagery such as AEROCam or high-resolution multispectral satellite imagery such as WorldView-2 would greatly contribute to this research.

Core and Fringe Habitat Zones

The composite habitat maps provide a more layered representation of orchid habitat than did individually classified landscape indicators. Habitat maps reduce the ability to classify between wetlands and uplands yet allowed for the classification of core and fringe habitat zones. Orchids exhibit patchy distribution patterns and are spatially shifting through time, thus core habitat zones may shift and change through time relative to landscape properties such as groundwater elevations. Core habitat zones can be described as narrow transition zones between wetlands and uplands or larger flat moist lowlands known as sedge meadows. These habitat zones are spatially distributed throughout the landscape. Just because an area is classified as core habitat does not necessarily mean orchids occur there. Orchid metrics applied to landscape indicators simply demonstrate that landscape properties in these zones are likely favorable. However, these zones do identify areas to search for orchids, especially where little or no monitoring has occurred in the past.

Fringe habitat zones are described here as buffers of core habitat, where conditions may or may not favor orchids. Orchids can be found in these habitats because of dispersal mechanisms and favorable conditions promoting orchid growth. Fringe habitat is always much larger by area and can be described as the full potential extent of orchid habitat based on the orchids ability to disperse and take advantage of available resources. Fringe habitat provides areas where populations can expand and small isolated populations or individuals have established. These habitats may not support larger populations but do provide opportunity for individuals or small isolated populations to complete their life cycle and disperse seed allowing potential for orchid establishment and reproduction. In 2012, core and fringe habitat zones represented 51.7% of the landscape and the 2013 validation classified 64.6% (with 2012 NDVI) and 88.9%

(without 2012 NDVI), which is a significant indication of how important vegetation cover and conservation of orchid habitat is to orchid populations on the SNG.

Identification of habitat zones by allotment is significant in demonstrating that by percent area there is little difference between allotments. The small differences there may be are explained by landscape properties and orchid habitat within these allotments. For example, orchid habitat may vary across allotments depending mainly on topography and groundwater elevations. Orchid habitat may exist in areas defined by steeper slopes resulting in narrow orchid habitat zones within a mosaic of wetlands and uplands. Other allotments exhibit more long and narrow habitat zones along large wetland margins and large flat lowlands with moist to wet conditions defined as sedge meadows. With allotments showing fairly similar classification by percent area of core orchid habitat there are obviously other landscape properties or ecological processes that play significant roles in the presence or absence of orchids. Many of these ecological influences have been discussed such as symbiotic fungi, land use, and availability of resources.

Defining Orchid Habitat on the SNG

Observations during collection of orchid point data on July 15 and 16, 2013, indicated that orchid habitat exhibited greater diversity than non-orchid habitat across the SNG. Upland landscapes exhibited drier surfaces and composed of sparse vegetation dominated by tallgrass prairie species, Kentucky bluegrass and leafy spurge. Wetlands can be described as having a variety of shapes, sizes, and types including but not limited to open water wetlands and wetlands dominated by vegetation such as cattails, rushes, willows, sedges, and prairie cordgrass. Orchids are an indicator species of these wetlands and like all wetlands are heavily influenced by seasonal and annual variations in precipitation, groundwater elevations, and evapotranspiration rates (USDA Forest Service, 2001). Changes induced by climatic cycles influence spatial shifts in vegetation dominance and orchid positions in the landscape. Many of these changes are driven by topographic shifts in moisture gradients influenced by groundwater elevations.

Orchid habitat is characterized by moisture conditions suitable for germination, seedling establishment and reproduction. Patchy spatial distribution and variability of orchid habitats are demonstrated here and described as long narrow zones along large wetland margins, rings (donuts) around uplands transitioning into an interconnected system of wetlands, and larger areas of flat lowland sedge meadows. Observations were that these habitats were dominated by species such as rushes and sedges. Prominent associated species also included willows, cattails, redtop (*Agrostis gigantean*), northern reedgrass, and prairie cordgrass. Other observed associated species were goldenrod (*Solidago* spp.), lead plant (*Amorpha canescens*), dogbane (*Apocynum* spp.), American licorice (*Glycyrrhiza lepidota*), sweet clover (*Melilotus* spp.), and leafy spurge. These observations of habitat are consistent with other descriptions of associated vegetation composition and diversity amongst orchid habitats (Bjugstad & Fortune, 1989; Sieg & King, 1995; USFWS, 1996; Sieg & Wolken, 1999).

CHAPTER VI

CONCLUSIONS

The glacial dune landscape of the SNG is characterized by high groundwater elevations and a unique undulating topography. In such landscapes climate, topography, and groundwater are important properties influencing vegetation dynamics and landscape processes such as species distribution and moisture gradients affecting orchid habitat (Zinko et al., 2003). This unique landscape exhibits spatially distributed wetlands creating a mosaic of prairie wetlands and uplands that can have a wide variety of shapes, sizes, and elevations (Winter, 2000). These landscape properties influence vegetation transitions and diversity resulting in spatially patchy distribution patterns. Orchid habitat and their associated vegetative communities are highly influenced by their interactions with groundwater. These habitats exhibit complex flow systems resulting in a wide variety of interactions between habitats influencing not only associated vegetative communities but orchid population dynamics (Winter, 2000).

Landscape indicators derived from high-resolution infrared imagery, a high resolution LiDAR DEM, groundwater elevations, and orchid point-based field observations were useful in the classification of core and fringe orchid habitat zones. TWI and TPI are steady state indices with orchid metrics changing annually relative to the orchid's position in the landscape. These landscape indicators classified 88.9% (TPI) and 83.4% (TWI) of the landscape as orchid habitat on average providing less varied classification. Yet, it is the fine scale landscape properties that these indices enhance that contribute to the definition of orchid habitat. Enhanced properties included flow paths, accumulation, and slight elevation changes influencing orchid positions in the landscape. The NDVI, only available in 2012, classified 58.8% of the landscape as habitat. The NDVI allowed for the identification of vegetation cover and land use and demonstrated their importance. Depth to groundwater indicators classified 41.9% of the landscape as orchid habitat on average, demonstrating that annual variations in orchid distributions are likely dependent on changes in moisture availability influenced by topography and groundwater. This relationship between orchid locations and groundwater elevations was significant in allowing the identification of depth to groundwater orchid metrics of 1.01 ± 0.43 (2σ) m on average.

Compositing landscape indicators created habitat maps that classified core and fringe orchid habitat zones. Habitat maps only change relative to annual landscape indicators and orchid points but additional parameters could be investigated for their potential influence on orchid habitat such as exposure to solar radiation influencing evapotranspiration rates. Habitat maps allowed for the classification of core (30.6%) and fringe (50.3%) orchid habitat zones on average. These zones together represent approximately 80% of the landscape. Data limitations of these habitat maps are that NDVI is only available for 2012 and in 2010 and 2011 there were very few orchid point data. These limitations influence results of overall averages. What is likely more representative of orchid habitat zones is the 2012 composite characterizing 21.4% as core and 30.3% as fringe representing 51.7% of the landscape. Orchid habitat zones may provide a useful basis for focusing field surveys and allocating conservation efforts (Parvianinen et al., 2008), and may be used in identifying areas most in need of protection or restoration, design of new survey techniques, and understanding of the landscape indicator that influence spatial distribution of orchid habitat (Zinko et al., 2005).

Through validation of habitat maps it was determined that predicted core habitat zones represented 52.7% of orchid point-based field observations in 2013; representing 37.4% of the landscape. This is significant in justifying that orchid metrics and core orchid habitat zones are valid in representing orchid locations over time and useful in conservation management of the SNG, preservation of orchids, and future research.

There is no spatial identification of orchid habitat within grazing allotments. This study provides this identification and could be used to study possible relationships amongst habitat zones relative to vegetation composition, diversity, moisture availability, soil nutrients, or presence of symbiotic fungi. This could provide a greater understanding of orchid habitat within specific allotments and identify differences between allotments potentially answering why some allotments exhibit higher orchid populations and other do not. This study may also benefit or lead to adapting management of individual grazing allotments. On average 23.3% of the landscape within grazing allotments were classified as core orchid habitat providing a greater understanding of the landscape within individual grazing allotments relative to orchid locations.

This study demonstrates that orchid distribution patterns and habitat zones can be well represented on the basis of topography, groundwater elevations, vegetation cover, and orchid point-based field observations. Results support Bjugstad and Fortune (1989) in that orchid habitat distribution is widely dispersed across the SNG, and also supports Li et al. (2009) in that seed distribution in sand dune grasslands vary within and among habitats, as data and research indicate that orchid's topographic position in the landscape varies within and among habitats. The 2012 habitat map classifying 21.4% of the landscape as core orchid habitat is comparable to the estimate from Bjugstad and Fortune (1989) where they state that vegetative communities associated with orchid habitat cover roughly 14% of the Hummock and Swale landform.

This study provides a landscape assessment of the SNG and a means of mapping orchid habitat. Orchids are indicator species of wetland communities but also likely climate change, making this research important for the SNG in managing and monitoring changes on the landscape. The methodology described here could contribute to decisions about biodiversity surveys, conservation management, and identification of areas with high species rarity such as orchid habitat. Landscape indicators applied here offer comprehensive tools for further research of processes that govern orchid distribution patterns and population dynamics across the SNG. Providing knowledge that can be used to predict changes related to climate and land use, and their associated hydrologic alterations (Zinko et al., 2005).

Future Research

This study supports continued research within the SNG to monitor and explore the relationships among orchids and their habitat relative to groundwater elevations, vegetation (using near real-time high-resolution infrared imagery), topography (using a high-resolution LiDAR DEM), and other landscape indicators. Further assessment of orchid habitat and its relationship to groundwater can be further supported through higher densities of well observations and continuous monthly or bi-monthly monitoring of these wells. Orchid habitat zones identified in this study can be applied in conservation management strategies, monitoring and searching for orchids, and provides spatial information for studying various ecological communities within the SNG. Also, relationships between topography, groundwater elevations, and rare plant species likely exist elsewhere, and this methodology could be applied in other landscapes characterized by same or similar landscape properties; such as in northwest Minnesota or Manitoba where other large populations of orchids occur.

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