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Impacts of Wetland Characteristics on Duck Use in the Prairie Pothole Region (PPR) 1987-2013

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IMPACTS OF WETLAND CHARACTERISTICS ON DUCK USE IN THE PRAIRIE POTHOLE REGION (PPR) 1987-2013

BY

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IMPACTS OF WETLAND CHARACTERISTICS ON DUCK USE IN THE PRAIRIE POTHOLE REGION (PPR) 1987-2013

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Finally I would like to express my love and thanks to my wife Natalie, daughter Alexis, and dog Scout for their patience, support, and motivation to work through the challenges of the past few years.

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LIST OF ABBREVIATIONS

AGL	Above ground level
AIC	Akaike's Information Criterion
AIC*c*	Second order Akaike's Information Criterion
CIR	Color-infrared
CRP	Conservation Reserve Program
cm	Centimeter
DEM	Digital Elevation Map
EROS	Earth Resources Observation and Science
FSMS	Four Square Mile Survey
GIS	Geographic Information System
GME	Geospatial Modeling Environment
ha	Hectares
HAPET	Habitat and Population Evaluation Team
km	Kilometer
m	Meter
MIPS	Map and Image Processing System
NLCD	National Land Cover Database
NPWRC	Northern Prairie Wildlife Research Center
NWI	National Wetlands Inventory
NWRS	National Wildlife Refuge System
PPR	Prairie Pothole Region
SWAP	Small Wetlands Acquisition Program
WMD	Wetland Management District
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

VRM	Vector Ruggedness Measure
WRP	Wetland Reserve Program

LIST OF DEFINITIONS

Aviatest	This variable was prepared to provide an indication as to how much of a wetland basin is available within the bounds of an FSMS plot. This variable is not necessarily correlated to WFactor. A comparison ratio was created by dividing the total basin area inside of an FSMS plot by the total basin universe size. The difference between the two areas was also calculated. These are the potential values of the Avaitest variable and the rules used to set them. "y" – These records have a within FSMS plot area that is approximately equal to the universe area. "z" – These records have a within FSMS plot area that is between 94.1% and 99.9% of the universe area and the difference between the areas is < 0.0325 acres. These are basins with slivers located outside of the FSMS boundaries and are artifacts of spatial shifts between plots and digital NWI data. "n" – These records have a within FSMS plot area that is < 94.1% and area differences > 0.0325 acres of the universe area. Most of these are large basins that extend outside of FSMS boundaries.
Basinnum	The unique identification number assigned to each basin polygon in the half-state HAPET basin data.
Prsha	Duck pairs per hectare.
Part	The half-state used in the HAPET basin data.

Sample Pond — Randomly selected wetlands stratified by wetland regime, within FSMS plots, surveyed twice annually by cooperators. Most WMDs contain 200 sample ponds consisting of a proportion of temporary, seasonal, semi-permanent and permanent wetland regimes.

Unipond — A unique site variable created by concatenating Part and Basinnum.

View-scape — A concept regarding the amount of viewable distance from wetland surface that is thought to relate to specific site security for breeding duck pairs, as greater view-scape allows for earlier predator detection and greater escape potential.

Wetland — FSMS wetland data is deeply rooted with the Cowardin et al. 1979 Classification of Wetlands and Deepwater Habitats. As such, the wetland definition provided in their document is adhered to with FSMS data sets. Cowardin et al. (1979) defines wetlands as "*lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by*

	shallow water at some time during the growing season of each year".
Wetland Area	Area within the delineated boundary of a wetland.
Wetland Perimeter	A one-dimensional linear measurement, in meters, around the outside of the sample wetland polygon.
Wetland Shape	A calculated form of perimeter-area ratio, the value of which reflects the general polygon appearance.
WFactor	The expansion factor that is applied to the duck variables. It was calculated by dividing the total basin size by the total pair pond area that was surveyed during any given year. It does not incorporate annual variation in ponded water. Wfactor can change within the group of records for the same Unipond (Part & Basinnum) when the part of a wetland that is counted changes through time.
Worldarea	Total wetland area calculated by NWI or Pywell data regardless of location relative to FSMS plot boundaries.

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ABSTRACT

IMPACTS OF WETLAND CHARACTERISTICS ON DUCK USE IN THE PRAIRIE POTHOLE REGION (PPR) 1987-2013

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Since 1987 the Waterfowl Breeding Populations and Production Estimates, also called the Four Square Mile Survey, has been conducted annually in the U.S. Prairie Pothole Region. The survey was designed to assess the influence of the Small Wetlands Acquisition Program on contributions to continental waterfowl populations (Cowardin et al. 1995). Each year cooperators visit sample wetlands during two survey periods, collecting data on observed waterfowl and pond conditions. Along with ground counts, aerial photography of sample areas is collected annually, capturing habitat conditions. My objective was to assess the influence of local and landscape factors on duck pair densities. Local factors are attributes immediately adjacent to, or within, an individual wetland that affect wetland appearance or function. Landscape factors represent wetland functions within varying compositions of upland cover types and wetland densities within Four Square Mile Survey plots. I evaluated multiple years of aerial imagery (1996, 2001, 2006, and 2011) and found few differences in feature types over the 20-year period. My technique analysis revealed that ocular (on screen) estimates of open water and trees were best at the sample pond boundary and within a 20 m buffer. Grass estimates generated from National Land Cover Data (2011) were best within the 48 m and 91 m buffers. I used an Akaike's information-theoretic approach to assess several competing models at local and landscape scales. At the local scale, the best model that reflected the

relationship between duck pairs and features showed wetland area, percentage of years dry, wetland regime, and percent open water to be the most influential factors. At the landscape scale, the best model included data pertaining to the number of wetlands present, total wetland area, and terrain ruggedness within each plot. Regardless of scale, trees were not found to be a specific deterrent to duck pairs settling.

CHAPTER 1 – COMPARISON OF THREE TECHNIQUES USED TO COLLECT ADJACENT LAND FEATURE DATA

Biologists have been reporting on duck populations as early as 1930 (Nichols et al. 1995) and wetland habitat conditions since 1955 (USFWS 2013). Numbers of duck pairs estimated each year are dependent on the number of spring wetlands present (Batt et al. 1989). Unfortunately, habitat loss has occurred due to land-use conversion, which negatively affects breeding duck pairs (Nichols 1995, Johnson et al 2008). The Prairie Pothole Region (PPR) is known for being the most productive area in North American for breeding ducks (Smith et al. 1964, Batt et al. 1989) and is ideal for agricultural crop production (Gascoigne et al. 2013). In the eastern portion of the PPR, more than 90% of historical wetlands have been drained (Tiner 2003) and nearly all of the tall grass prairie and approximately 60% of the mixed grass prairie have been converted to agriculture (Higgins et al. 2002). Of the wetlands remaining, most (58.9% to 73.2%) are surrounded by cropland (Turner et al. 1987, Austin et al. 2001). Thus, monitoring land-use changes and habitat condition become critically important for managing wildlife populations.

In the PPR, remotely sensed data are essential for quantifying and evaluating habitat conditions, gauging habitat conversion impacts, estimating population sizes, and monitoring prairie wetlands (Naugle et al 2001). Because it is impractical for most studies to measure wetland functions directly across large spatial extents, remotely sensed data are often used to regularly evaluate and assess wetland integrity as a landscape indicator (Guntenspergen et al. 2002).

There are many kinds of remotely sensed data, which are commonly used to measure a variety of environmental parameters including: surface water, land features, photosynthetically active radiation, crop yields, height and density of forest stands, and countless other applications (Estes and Loveland 1999). These data are typically acquired by active (e.g., aerial photography flight missions) and passive (e.g., satellites) aerial camera systems that collect data at various wavelengths along the electromagnetic spectrum (Estes and Loveland 1999). Many wildlife studies rely on remotely sensed data to evaluate habitat.

The ubiquitous use of geographic information systems (GIS) and the expansion of remotely sensed data capabilities have made these resources more readily available. Landscape-scale data are commonly gathered from third parties (e.g., NASA, EROS Data Center, LIDAR), then scaled down to pinpoint the area of inference. The appropriate use of such data depends on numerous variables associated with the intended project (e.g., scale, species or groups of animals, project resources, time, and accuracy) as well as the original purpose and collection method of the data. Understanding the proper use of, and most applicable sources for data, while ensuring it is complementary to a specific research question is an important step in research planning. Often this requires a comparison of data from several sources to test for potential biases. Herein, I evaluated and compared aerial photography and land-cover produced through Landsat.

The purpose of my study was to evaluate three techniques or types of remotely sensed land feature data (ocular, delineated, and land-cover), collected adjacent to sample ponds, and to determine their efficacy relative to actual conditions. This evaluation should provide guidance on which technique is most useful and efficient for assessing local feature types as they relate to duck pair settling. I also evaluated land feature change detectability at five year intervals over a twenty-year time period.

STUDY AREA

I used spatial data to evaluate candidate techniques from Four Square Mile Survey (FSMS) plots in Minnesota. In the PPR of Minnesota, 176 FSMS plots lie within six U.S. Fish and Wildlife Service (USFWS) Wetland Management Districts (WMDs): Detroit Lakes, Fergus Falls, Litchfield, Morris, Roseau, and Windom (Figure 1.1). These plots were established by USFWS personnel in the 1980s, who randomly selected 10.4-km^2 plots from a data layer stratified by ownership. They applied this stratification at the township level, and weighted it more strongly toward federal and easement ownership than private lands (Cowardin et al. 1995).

METHODS

In this study, I used data obtained from FSMS sample ponds, corresponding wetland and duck pair observations, and aerial photography collected from 1987 to 2013. In each WMD, approximately 200 sample ponds were surveyed twice annually to assess wetland condition and duck abundance. The FSMS was originally designed to estimate waterfowl production by ownership; however, this information may also be useful for understanding the effects of land features adjacent to wetlands on variables of interest, and ancillary data of this type are not collected during the FSMS.

Aerial images of FSMS plots are collected annually throughout the PPR, and are typically obtained in early May in conjunction with FSMS ground surveys. In the early study years, FSMS aerial images were taken using a Panasonic D 5000 video camera in true color. An observer in the aircraft manipulated the camera on an aluminum mount to capture video of each plot at 3,812.5 m above ground level (AGL). This method yielded photos that captured a linear path 5.2 km wide, from which a screen capture was subsequently processed through Map and Image Processing System (MIPS) software to evaluate wetland habitat conditions for each plot (Cowardin et al. 1995), using video pixel sizes of 774.5 cm^2. The USFWS changed how images of plots were captured in Minnesota in 1996, wherein they used vertical color infrared (CIR) 9x9 inch photographs. Unlike earlier images, these photos were collected from 3,200.4 m AGL at an aspect ratio of 1:15,840 to capture a plot photo an area of 13.6 km^2. Pixel sizes of these film images were 631.7 cm^2. In 2009, aerial photography for the FSMS was advanced further through the purchase and use of an Applanix 439 Digital Sensor System (DSS439). The DSS439 captured 39 mega-pixel digital images at a resolution of 5,412x7,216. This resolution was subsequently scaled back to a pixel size of 50 cm^2 to decrease processing and transfer times. Photography flights were maintained at 3,200.4 m AGL to fully capture plots, but collection became more automated through the use of a flight management system and GPS-aided inertial navigation direct georeferencing system.

I used ESRI ArcGIS 10.3.1 software to overlay FSMS spatial wetland data on aerial imagery to collect on-screen visual (ocular) percentage estimates for trees and grass adjacent to sample ponds, which I then used to assess the impact of surrounding habitat on duck pair use. This method provided estimates of percentages of open water within sample pond boundaries, trees within the 20 m, and grass within the 48 m and 91 m (Figure 1.2). Buffer lines were visually adjusted when wetland boundaries did not match the delineated edges observed in aerial images due to water level fluctuations and landscape changes that had occurred since the area was last mapped.

To determine the appropriate buffer distance to evaluate adjacent trees in high intensity agricultural landscapes, I examined a subsample of 100 random-selected wetlands in Minnesota, specifically calculating the shortest average distance from wetland and cropland edges. This distance averaged approximately 20 m. I selected grass buffers distances based on guidelines provided by McElfish et al. (2007); their study determined that grass buffers effectively captured sediment and phosphorus at a minimum distance of 9.1 m to >30.5 m, whereas nitrogen was effectively filtered within a buffer width of 30.5 m to >48.8 m, and benefits to wildlife occurred at 30.5 m to 91.4 m (McElfish et al. 2007). Therefore, I selected two buffer distances to investigate the correlation between wildlife benefits and wetland condition: 1) a buffer of 48.8 m (referred to throughout as 48 m) to assess potential chemical and sediment filtration, and; 2) a buffer of 91.4 m (91 m) for wildlife benefits.

I conducted an analysis of time periods to assess land feature variation by estimating the percentage of trees and grass present on 1,844 sample ponds in four of the available 24 years of FSMS aerial photography. I selected images for Minnesota plots at five-year intervals (1996, 2001, 2006, and 2011) over a 20-year period. Ocular estimates for 1996, 2001, and 2006 were made using scanned aerial photos acquired on CIR 9x9 inch film, whereas I used higher quality digital CIR images for 2011. I excluded images prior to 1996 due to poorer photo quality that would have increased the difficulty in identifying small spatial features, thereby affecting estimate accuracy. Poor image quality can occur because of low light conditions during capture, objects being out of focus, significant cloud cover, wispy or mostly transparent clouds over plots, alignment issues that may have caused portions of the plot to be missed, or other factors that otherwise obscure sample ponds. Images from neighboring years replaced target year imagery in eleven instances where images could not be found or quality was poor. The time period analysis was conducted using Minnesota sample ponds because aerial images of these plots were readily available for all cases.

I collected ocular estimates on 6,498 sample ponds in Iowa, Minnesota, North Dakota, South Dakota, and eastern Montana using 2011 aerial imagery to estimate the percentage of open water, trees, and grass present. In a few rare cases, aerial images from 2010 were substituted for missing or poor quality imagery in 2011. Some wetland basins were split into separate wetland polygons in the FSMS, largely due to land ownership, size, position relative to plot boundaries, or reasons dictated by protocol. In these instances, I merged sample ponds and summed or averaged their percentage estimates to represent the entire sample pond boundary.

I randomly selected a subsample of 200 Minnesota sample ponds for the technique analysis. I manually delineated each sample pond in the subsample to assess the accuracy and appropriateness of using ocular and land-cover estimates for this type of analysis. I used a random number generator in Microsoft Excel © to select 50 sample ponds from each of four wetland regimes (i.e., temporary, seasonal, semi-permanent, and permanent) for delineation. I delineated all features to a scale of approximately 0.1 ha^2. At this scale, clusters of similar land features (e.g., trees, buildings, and wetland vegetation) could be easily identified, and like feature polygons were summed to produce percentages. The largest buffer distance (91 m) was used for delineating purposes, so that smaller buffer estimates could be later clipped out and compared at similar ocular scales. I assigned land and wetland feature delineations to six groups that corresponded with National Land Cover Data (NLCD) categories: 1) Ag Field; 2) Developed/Road; 3) Grass; 4) Open Water; 5) Trees; and, 6) Wetland Vegetation (Figure 1.4). I excluded 17 wetlands due to their proximity to previously delineated wetlands and issues with clipping features of overlapped polygons in ArcMap.

I used the 2011 version of the NLCD (modified by the USFWS Habitat and Population Evaluation Team (HAPET)) to compile land-cover estimates for features adjacent to all sample ponds. I clipped NLCD data by each buffered distance to correspond with ocular estimates and extracted these data using the Geospatial Modelling Environment (GME) to assess feature areas within each clipped section. This land-cover raster layer contained 20 feature classes at approximately 30 m pixel sizes each. I merged similar classes to resemble the previously assigned; six delineated feature types (Table 1.1), summed the feature areas, and converted area to percent area for direct comparisons with ocular and delineated estimates.

STATISTICAL METHODS

I used a subsample of 200 wetlands to assess techniques used to collect feature type data (ocular, delineated, and land-cover). I restricted analyses to these wetlands because feature delineations were only conducted on this subsample of ponds and used simple linear regression analysis to compare ocular and land-cover collection techniques to estimates.

I performed a correlation analysis (R, cor, v. 3.2.3) to determine whether feature variable percentages were highly correlated in time period analysis in years 1996, 2001, 2006, and 2011. For this time period analysis, I evaluated ocular estimates collected for 1,844 sample ponds for the time period analysis. Mean values of percent open water, trees, and grass present at 48 m and 91 m scales were plotted and compared for each time period by wetland regime class (temporary, seasonal, semi-permanent, and permanent).

RESULTS

My analysis using ocular data revealed little change among variables of interest among the assessed time periods (Figure 1.3). The results from my correlation analysis indicated strong relationships between values collected for most years (Table 1.2). For example, percent trees correlated strongly with all year estimates, with *r* values ranging from 0.81 to 0.87. The weakest relationship occurred within percent open water estimates for 1996. Estimates for percent grass, within both grass buffers (48 m and 91 m), were strongly correlated in all years except for 2006 (Table 1.2).

Coefficient of determination values generated from simple linear regressions used during technique analysis indicated strong positive relationships between ocular and delineated estimates obtained at both the sample pond and 20 m buffer scales. However, estimates for the 48 m and 91 m grass buffer areas had the best fit in relation to land-cover estimates (Figure 1.6). Relationships between yearly grassland estimates collected and technique comparisons were also strong for the 48 m and 91 m grass buffers. In these yearly comparisons, estimates were strongly correlated for all years except 2006 (Table 1.3). Ocular and land-cover estimates for all sample ponds showed similar strong association (Table 1.4).

DISCUSSION

Variations observed for open water during the time period analysis may be attributed to the dynamic nature of PPR wetlands. These wetlands are known to be greatly affected by fluctuations in precipitation (Sorenson et al. 1998, Winter 2000, Johnson et al. 2005). During 1988 to 1997, for example, extreme deluge conditions were observed in the PPR, with the occurrence of second driest period (1988-1992) of the 20^{th} century followed by the wettest (1993-1997) in recorded history (Winter and Rosenberry 1998). Annual variation in precipitation is known to alter wetland vegetation cover, as well as the amount of open water within wetland basins (Kantrud 1986, Kantrud et al. 1989, Gleason et al. 2003). Seasonal wetlands are likely to be most affected by annual variations in precipitation because they are dominated by shallow-marsh zones with dynamic emergent vegetation communities. By evaluating seasonal wetlands at five-year intervals it became more likely I would encounter increased variation in cover type compared to other wetland types.

In the time period analysis, grass area for three of the four years assessed (1996, 2001, and 2011) were strongly associated with each other. Differences in 2006 likely occurred due to differences in upland phenology observed in aerial images. The capture of aerial images is timed to correspond with the first round of FSMS ground counts, which are conducted from 27 April to 15 May each year. The timing of the two FSMS counts is based on settling trends of early and late nesting duck species and on long-term duck migration patterns (Hammond 1969, Cowardin et al. 1995). Aerial imagery captured in May 2006 displayed early greening upland vegetation, which was indicative of earlier-than-average spring growing conditions. This created additional challenges in identifying grasses and non-grasses, as well as estimating grass cover percentages, which may have led to potentially biased grass estimates. Conversely, grass and tree estimates adjacent to sample ponds likely remained relatively constant throughout the past few decades as these areas are often impractical for farming use or agricultural conversion (Batt 1996).

After reviewing time period trends in Minnesota, I decided to only collect ocular estimates from the most recent year of imagery available for the remaining sample ponds. Evaluation of changes in land features over time immediately adjacent to sample wetlands did not reveal substantial variation in open water, tree, or grass estimates. It is not surprising that tree density and the amount of open water remained relatively static over the 20 years analyzed, considering the degree of past landscape alteration affecting Minnesota wetlands (Oslund et al. 2010). Similarly, I anticipated that open water and tree estimates collected for the Dakotas would vary little over this timeframe; however, I also recognize that this may not hold true for grass estimates. In the Dakotas, especially, grasslands have been at increased risk for agricultural conversion over the last decade (Wright and Wimberly 2013, Dahl 2014, Johnston 2014). Technological advancements in farm machinery, development of biogenetic drought resistance crop strains, growing demand for crops as biofuels (Searchinger et al. 2008), increased crop prices, and expiring Conservation Reserve Program (CRP) contracts have further exacerbated conversion risk (Gascoigne et al. 2013, Johnson et al. 2008, Stubbs 2007, Wright and Wimberly 2013). The expansion of agriculture and decline of grassland has also been well documented (e.g., Gascoigne et al. 2013, Higgins et al 2002, Rashford et al. 2011, Samson and Knopf 1994). Wright and Wimberly (2013) observed low grassland conversion to corn in soybean fields in Minnesota and Iowa, compared to North and South Dakota. Dahl (2014) reported, from 1997 to 2009, grassland area declined by 325,910 ha in Montana, North Dakota, and South Dakota, yet increased in Minnesota and

Iowa by 95,935 ha. Therefore, risk of conversion was less likely in the PPR of Minnesota and Iowa, because little unprotected grassland remained to be converted. Technique analysis revealed the inadequacy of ocular estimates for estimating percentage of grass out to 48 m and 91 m from the wetland edge, and indicated the time period comparison benefited from using the same technique and observer to produce comparable estimates.

After reviewing the techniques analysis, I considered delineated estimates to be the best method for estimating habitat percentage at the sample pond scale. I collected these estimates at the finest scale possible by meticulously mapping polygons and aligning delineations closely with features indicated in aerial photographs (Figure 1.5). I chose ocular estimates over delineated estimates due to the time required for delineating and the extra expense of delineating all adjacent features around all sample ponds. Considering the number of total sample pond basins, delineating each one quickly would have been impractical. Although accurate, delineating each sample pond was time consuming and would have prompted the need to hire additional technicians. Therefore, delineated estimates proved useful to gauge the accuracy of ocular and land-cover estimates.

Results of the simple linear regression revealed the strongest relationships between ocular and delineated techniques for open water and trees at the smaller buffer distances (Figure 1.6). Large land-cover pixel sizes likely omitted features smaller than 30 m^2, causing greater variability and less precision and accuracy in ocular and delineated estimates. Ocular estimates did not correspond well with delineated estimates within the 48 m and 91 m grass buffers, most likely due in part to ocular estimations being easier to evaluate at smaller scales and in more homogenous landscapes. Additionally, as buffer size increased, the ability to identify and record multiple features become more difficult and reduced the accuracy of ocular estimates. Feature type is also an important consideration in the assessment and accuracy of estimates; for example, open water and tree percentages were easier to identify and evaluate in aerial images than grass, which was more likely to be confused with similar land features, such as croplands.

From a planning perspective, scale, creation method, and original purpose should always be carefully considered when determining the best data layers to use for land feature analyses. Manually delineated estimates were best where precision and scope of the project depended on maximizing accuracy. Such delineations allow researchers to tailor the data to the project, and suggest they are more suitable for small scale projects, especially given their time consuming nature to produce. Conversely, ocular estimates are useful at small scales and depend on the skill of the person collecting the data, as well as strict adherence to collection protocols. For example, during this study, I observed that as area increased observers were required to process more information, and estimations became more variable. Land-cover estimates, using iterations of NLCD, were useful given the fact that they were originally intended to be used at large scales; however, because they were created from 30 m^2 pixel sizes, using them at fine scales may bias estimates by overlooking small features with predominate feature types. Therefore, I recommend evaluating data prior to implementing it into a research project to determine if the use of the data is practical within the scope and scale of the project, and to ensure that the data appropriately addresses the specific research questions involved.

Ultimately, I found that ocular estimates were the most practical for use at fine scales (e.g., within sample pond boundaries and the 20 m buffer), whereas land-cover data for percent grass estimates was most useful within the 91 m buffer. To assess the relationship between open water and tree values to duck pairs in the sample ponds, I retained ocular estimates for use at the wetland and 20 m buffer scales and generated land-cover estimates to calculate grassland area within the 91 m buffer. Using land-cover data to estimate grassland area provided an opportunity to gather and use additional feature type estimates; that is, land-cover data contained categories of other feature types that may have influenced duck pairs and sample ponds that were not devised *a priori* (e.g., percent crop and developed).

Studies that rely on landscape evaluations should include an in-depth review of available data (e.g., type, method collected, and practical use) during the research planning stage. Researchers should take time to review and acquire data that most accurately meets research needs depending on the scale and spatial extents of the project. The quality of aerial images available for this project was observed to greatly increase over the years, aiding in more accurate and easier manual on-screen delineating techniques. In the future, evaluating data will become even more important as better aerial images and advanced automated feature mapping techniques emerge for use.

FIGURES AND TABLES

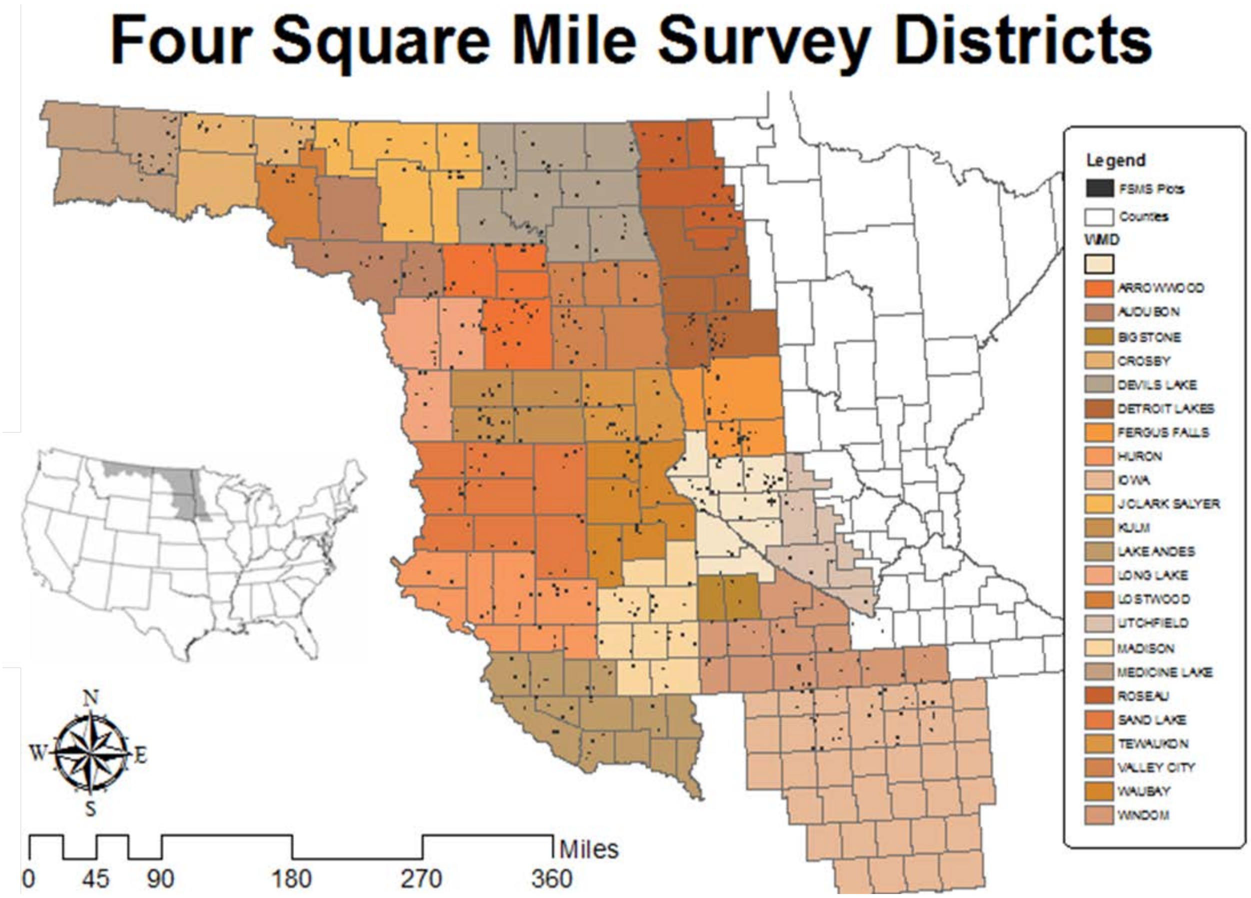


Figure 1.1. Four Square Mile Survey (FSMS) plot distribution throughout U.S. Fish and Wildlife Service Wetland Management Districts of the Prairie Pothole Region.

Figure 1.2. An example of data collection within the wetland boundary and 20 m, 48 m, and 91 m buffers. Arrows correspond by color and indicate the area for each polygon that features were estimated.

Ocular Percent Estimates

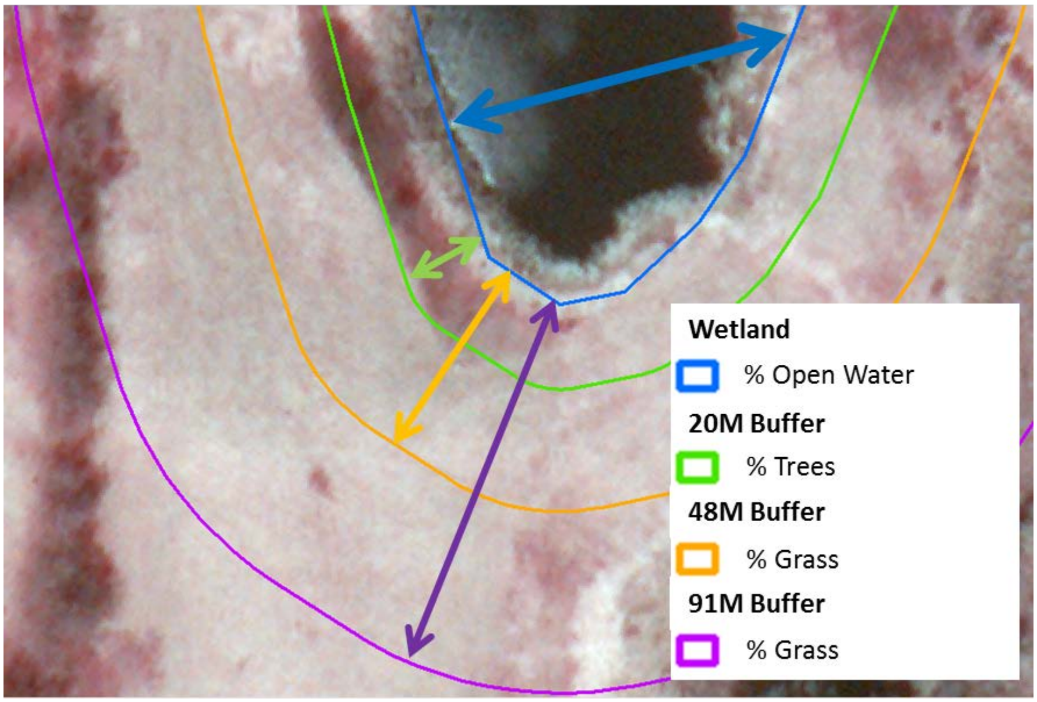


Figure 1.3. Estimates of ocular feature percentages for 1996, 2001, 2006, and 2011 by regime (temporary, seasonal, semi-permanent, and permanent). Data was collected at four scales: within the wetland boundary and 20 m, 48 m, and 91 m buffers.

Time Period Comparison of Minnesota Ocular Estimates:

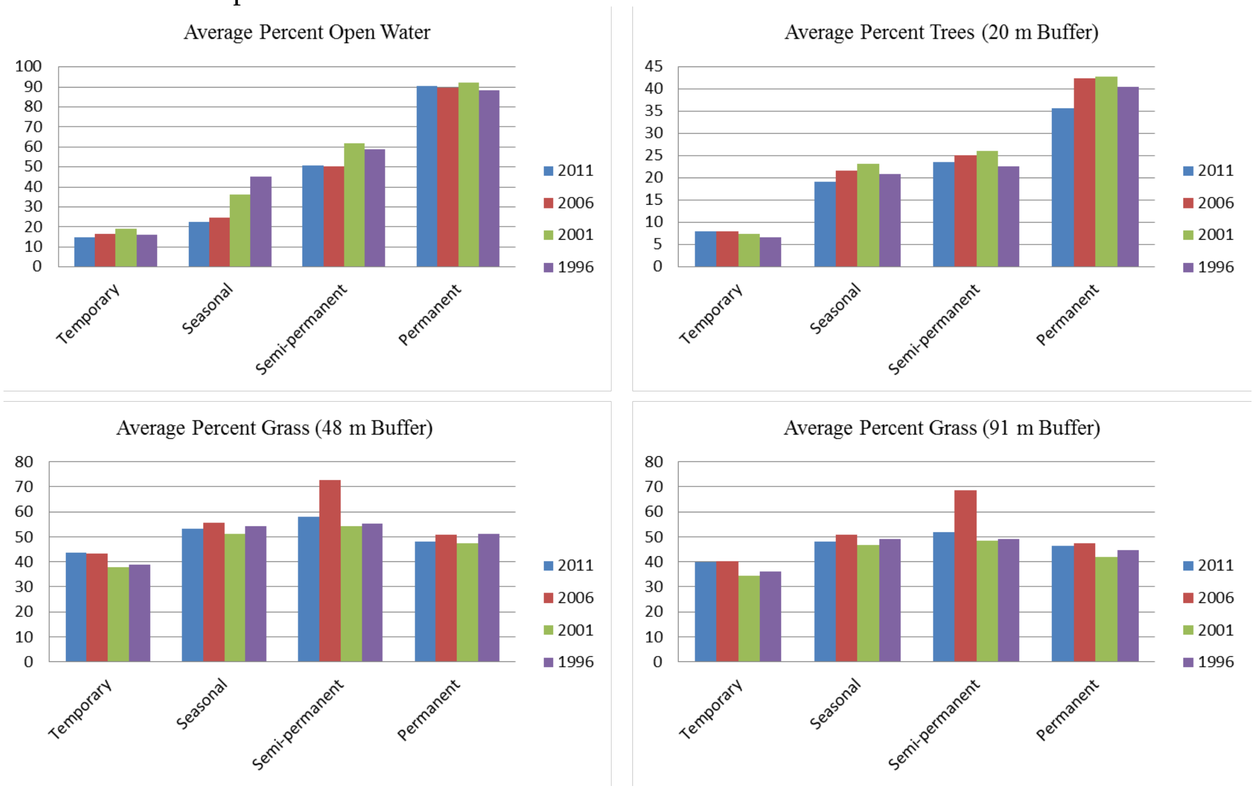


Figure 1.4. Delineated wetland example displaying feature categories: Ag Field – row crop (large and small grain crops), noticeably tilled or planted; Developed – building sites (e.g., farmsteads, cities, and waste water plants); Grass – grasslands (e.g., CRP, WRP, grassland easements, alfalfa fields, and pastureland); Open Water – wet areas within wetlands void of vegetation; Roads – state highways, county and township roads, driveways, and heavily traveled two track trails; Trees – woody hardstem vegetation (e.g., large trees and scrub shrub); and Wetland Vegetation – vegetation within the delineated wetland (e.g., *typha, scirpus, carex*).

Delineated Feature Definitions:

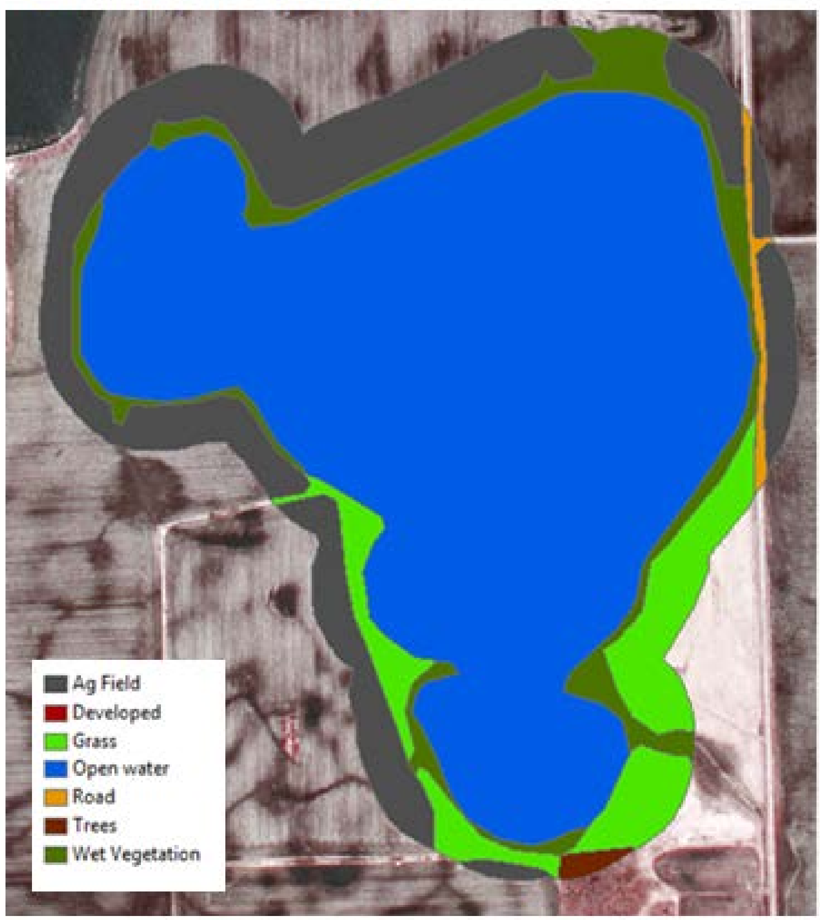
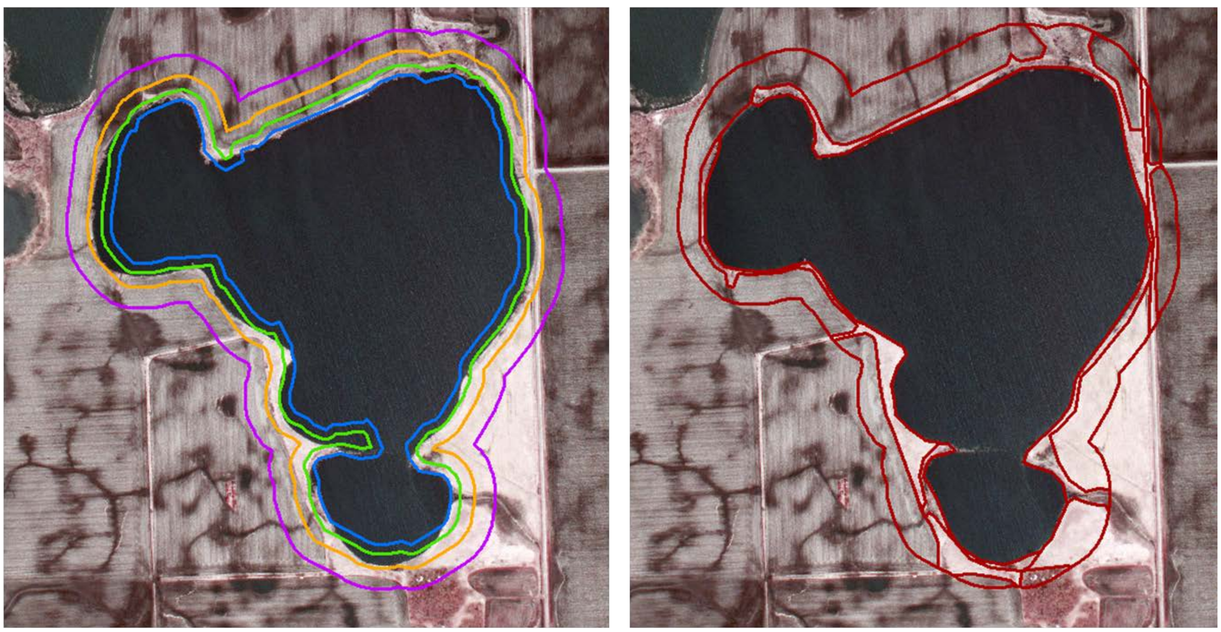


Figure 1.5. Examples comparing ocular buffers and delineated features: Example A. (left) depicts the wetland boundary (blue), 20 m buffer (green), 48 m buffer (orange), and 91 m buffer (purple) used to collect ocular percent estimates; Example B. (right) depicts a completed example of mapped features delineated within the boundary of the 91 m buffer from Example A.

MORRIS WMD
PLOT 230
SAMPLE POND 35

Methods of collecting land characteristics adjacent to sample 4 Square Mile wetlands.



A. Ocular Percentage Estimates

B. Delineated Percentage Estimates

Figure 1.6. Relationships between ocular, delineated, and land-cover estimates at the following spatial extents; open water only, 20 m (trees), 48 m (grass), and 91 m (grass).

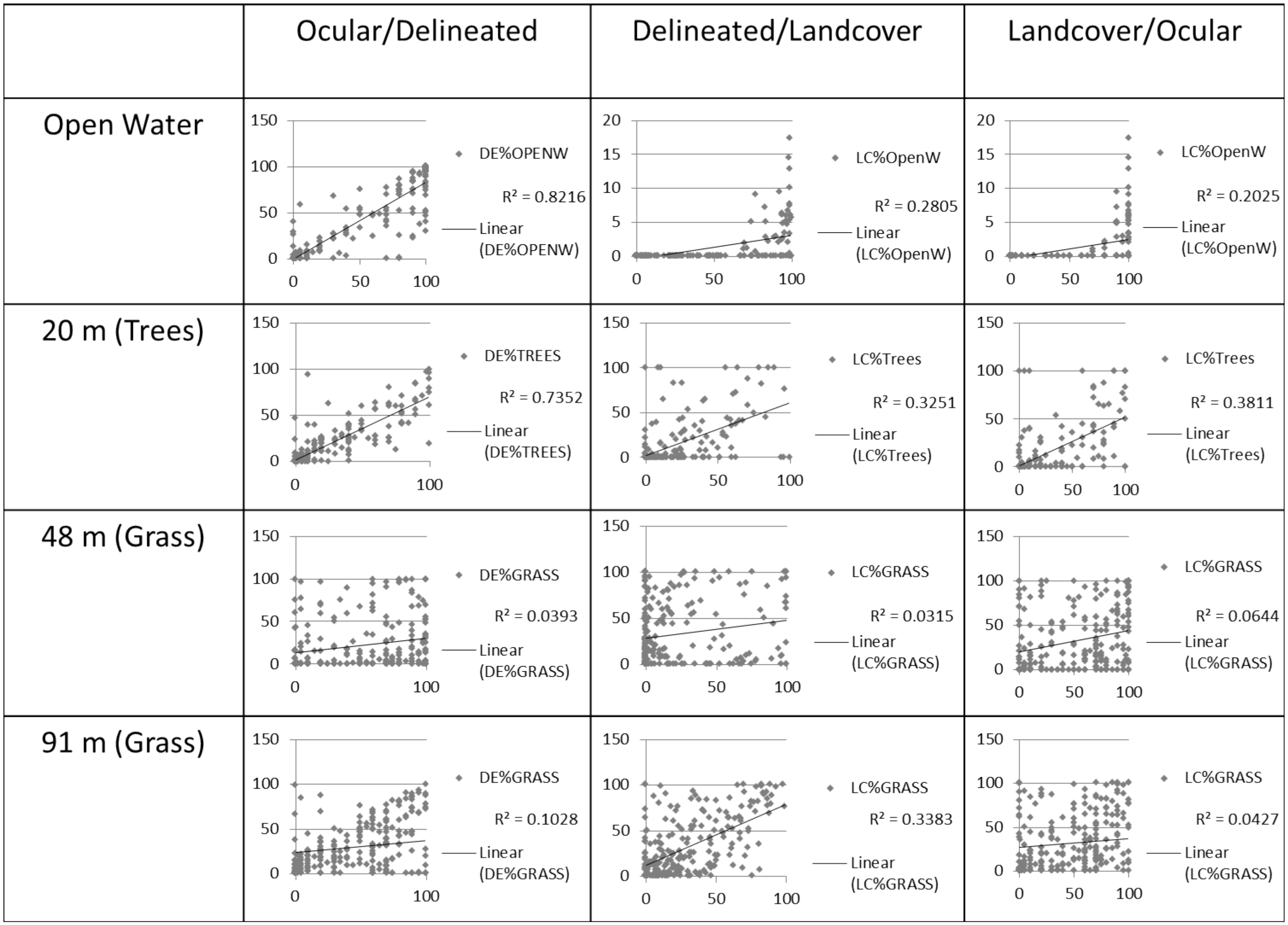


Table 1.1. Collection technique cross reference for ocular, delineated, and land-cover estimates. Techniques were matched as closely as possible to allow for feature type comparisons.

Technique Categories

Ocular Categories	Delineated Categories	2011 NLCD Categories (Appendix B)
Open Water	Open Water	10. Decision Tree Modeled Water/Wetland, 11. NDWI water from first cloud free LandSat of 2011. Open Water
N/A	Wetland Vegetation	10. Decision Tree Modeled Water/Wetland - 11. NDWI water from first cloud free LandSat of 2011. Open Water = Vegetated portion of wetland
Grass	Grass	71. Grassland/Herbaceous, 75. CRP, 76. Undisturbed Grassland, 80. Hay
Trees	Trees	40. Forest, 52. Shrub/Scrub
N/A	Ag Field	82. Crop/Cultivated Crops
N/A	Developed & Road	21. NLCD Developed (Open Space), 22. NLCD Developed (Low Intensity), 23. NLCD Developed (Medium Intensity), 24. NLCD Developed (High Intensity).

Table 1.2. Time period evaluation of Pearson's correlation coefficient values (*r*) for ocular estimates gathered from 1996, 2001, 2006, and 2011.

	2001	2006	2011
Open Water (*r*)			
1996	0.098	0.146	0.111
2001		0.692	0.698
2006			0.747
Trees (*r*)			
1996	0.87	0.821	0.806
2001		0.841	0.82
2006			0.855
48 m Grass (*r*)			
1996	0.727	0.157	0.634
2001		0.161	0.684
2006			0.146
91 m Grass (*r*)			
1996	0.742	0.153	0.641
2001		0.164	0.684
2006			0.176

Table 1.3. Pearson's correlation coefficient values for percent grass within 48 m and 91 m buffers adjacent to sample ponds.

Grass Estimates				
	91 m buffer			
48 m buffer	1996	2001	2006	2011
1996	0.971	0.726	0.141	0.632
2001		0.970	0.144	0.676
2006			0.038	0.177
2011				0.972

Table 1.4. Pearson's correlation coefficient values for ocular and land-cover estimates collected for all sample ponds.

Buffer Correlation Coefficients				
Technique	Feature	Buffer	Buffer	*r*
Ocular	Grass	48 m	91 m	0.922
Landcover	Grass	48 m	91 m	0.981
	Trees	48 m	91 m	0.981
	Crop	48 m	91 m	0.986
	Developed	48 m	91 m	0.960

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CHAPTER 2 – IMPACT OF WETLAND CHARACTERISTICS ON DUCK USE

The Prairie Pothole Region (PPR) encompasses approximately 800,000 km^2 in central North America, across five U.S. States (Iowa, Minnesota, Montana, South Dakota and North Dakota) and three Canadian Provinces (Alberta, Manitoba, and Saskatchewan). The region contains millions of small depressional wetlands and historically vast grasslands and is the most productive area for breeding waterfowl in the world (Johnson et al. 2008), and may produce 50% to 70% of North America's continental duck populations (Smith et al. 1964, Batt et al. 1989). Much of this region has been converted to agriculture, which has significantly reduced the area of quality waterfowl nesting and brood-rearing areas (Tiner 2003). In response to increased wetland drainage and declining waterfowl populations, the U.S. Fish and Wildlife Service (USFWS) began acquiring wetland, and later grassland, easements and fee purchases, using the Migratory Bird Conservation Fund through the Small Wetlands Acquisition Program ([SWAP]; U.S. Fish and Wildlife Service 2009).

The USFWS and U.S. Geological Survey (USGS), Northern Prairie Wildlife Research Center (NPWRC) began a stratified random sampling initiative for wetlands and waterfowl in 1987, to be conducted annually, in response to administrative and Congressional inquiries regarding the influences of SWAP on mid-continent waterfowl populations (Cowardin et al 1995). The survey was designed to estimate the impacts of National Wildlife Refuge System (NWRS) fee and easement lands on waterfowl breeding populations and production throughout the U.S. portion of the PPR (Reynolds et al 1996). As a result, approximately 704 Four Square Mile Survey (FSMS) plots and 5,750 wetlands in the PPR are surveyed each year to document wetland conditions and the number of breeding duck pairs by species. Additionally, aerial photography of each FSMS plot captures annual images of approximately 77,000 wetlands and the surrounding uplands. These aerial plot photos are interpreted annually to estimate area of individual wetlands. The survey spans >25 years, making it a valuable database of long-term waterfowl population parameters that are explicitly and spatially linked to habitat features (D. Hertel, USFWS HAPET).

Conservation managers in the PPR strive to target SWAP acquisitions precisely and implement management activities that will increase waterfowl production. Waterfowl population abundance objectives are, in turn, used to produce habitat objectives and develop conservation strategies (Soulliere et al. 2013). For effective conservation planning, managers need to know habitat requirements and preferences of targeted species, particularly in light of the challenges presented by inflated costs, personnel reductions, and budget restrictions (U.S. Fish and Wildlife Service 2016), as well as the development of increased cropland acreages (Rashford et al. 2011). Understanding how local factors, immediately within or adjacent to a wetland (e.g., vegetation cover type, wetland size and shape, wetland regime, soil type, and hydrology) and landscape-scale factors (e.g., dominant land use practices and topography) influence duck abundance may also assist managers in planning and implementing strategies for achieving population objectives.

Waterfowl require wetlands to meet life history needs. The three major life history events are: migration, reproduction, and molt (Swanson and Duebbert 1989), all of which take place in the PPR for many species, to varying degrees. All three of these stages require the presence of adequate food resources – primarily carbohydrates (e.g., from seeds and tubers) for use as fuel during migration, and protein (e.g., aquatic invertebrates) for feather replacement during molt, rapid follicle development, and body growth during pre- and post-breeding stages (Sugden 1973, Krapu and Swanson 1975, Swanson and Duebbert 1989). Wetlands in the PPR are seasonally available; thus, use rates typically depend on the timing of freezing and thawing before resources are either lost or become available each season (Murkin et al. 1997). In general, waterfowl use of wetlands in the PPR reflects a linear relationship between the total number of ducks and the number of wetlands in the PPR during May (Batt et al. 1989). Therefore, attractiveness of areas for waterfowl is likely dependent on both local (e.g., individual wetland quality) and landscape (e.g., abundance and quality of wetlands and grasslands) habitat factors.

To this end, landscape habitat variables have been found to be important predictors of duck abundance (Fairbairn and Dinsmore 2001). Breeding duck pairs likely evaluate landscapes based on observable general features, such as the extent and composition of nearby grassland and wetland features, threats (i.e., predators), and peripheral wetland vegetation (Cody 1985, LaGrange and Dinsmore 1989, Orians and Wittenberger 1991, Eichholz et al. 2012). Hilden (1965) identified landscape, terrain, nesting sites, other animals, and food as proximate factors that influenced habitat selection by birds.

Weller and Spatcher (1965) and Weller and Fredrickson (1974) reported that avian abundance was greatest in years when wetlands displayed a “hemi-marsh” configuration (Kaminski and Prince 1981); that is, a roughly 50:50 ratio of emergent vegetation to open water in which approximately equal areas of each are present. Hemi-marsh wetlands tend to experience greater use and host higher numbers of many avian species, particularly dabbling ducks (Murkin et al. 1982, 1997, Ringelman et al. 1982, Hemesath and Dinsmore 1993, VanRees-Siewert and Dinsmore 1996). Stafford et al. (2007) found that the number of mallard use-days during autumn in Illinois was related to the proportion of wetland area containing emergent vegetation. Avian species richness has also been found to have a positive relationship with the percentage of emergent vegetation present (VanRees-Siewert and Dinsmore 1996, Hemesath and Dinsmore 1993). VanRees-Siewert and Dinsmore (1996) observed that species richness was greatest on wetlands with wide marginal vegetation cover and centrally located areas of open water. Similarly, interspersion of vegetation to open water has been shown to support greater food abundance, isolation, and protection from predators for ducks (Kaminski and Prince 1981, Murkin et al. 1992, Sedinger 1992), whereas wetlands with little to no emergent cover provide less security and isolation for settling pairs. Rehm and Baldassarre (2007) found that edge density (e.g., the interface between vegetation and water) in wetlands, with regard to interspersion, was positively related to the number of breeding marsh birds. Greater edge density may also contribute to increased visual isolation - a factor assumed to decrease intraspecific competition and increase breeding waterfowl concentrations (Murkin et al. 1982). Wetlands with more emergent vegetation also appear to be less productive than open wetlands with less vegetation (Paquette and Ankney 1996).

Wetland vegetation cover is influenced by environmental conditions (i.e., climate and weather; Cressey 2016), agricultural disturbances (i.e., grazing and burning), vegetation dynamics, zonation patterns, and wetland type. Agricultural runoff and siltation affects wetland cover composition and invertebrate abundance (Kantrud 1986, Gleason et al. 2003). Vegetation type may be influenced by water depth, timing and duration of drawdowns, surrounding land management patches, and disturbance regimes (Kantrud et al. 1989). For example, in grazed wetlands, cattails (*Typha spp.*) are known to be replaced by sedges (*Carex spp.*), hardstem bulrush (*Scirpus acutus*), and white top (*Scolochloa festucacea*) (Evans and Black 1956, Kantrud et al. 1989). Historically, wetlands in the PPR were likely grazed by native ungulates, although muskrats (*Ondatra zibethicus*) are the principal wetland grazer today. Their populations are cyclic with wetland hydrological cycles (Meeks 1969, Kantrud et al. 1989) and they have been found to be effective at clearing large areas of emergent vegetation in high water years (Weller and Spatacher 1965, Weller and Fredrickson 1974, Walker 1959, 1965). Muskrats also affect wetland cover by creating openings in dense stands of vegetation that are then used by ducks for seclusion and resting areas.

Sizes of wetlands and edge density have been found to be important factors associated with the “hemi-marsh” concept (Weller 1978, Brown and Dinsmore 1986, Kadlec and Smith 1992). Large wetlands may have greater heterogeneity and offer additional opportunities for foraging and space for pair segregation (LaGrange and Dinsmore 1989); therefore, larger wetlands may support higher abundances and diversities of birds during spring compared to smaller wetlands. Some of these relationships are likely due to wetland shape and edge; wetlands with a greater edge to area ratio tend to support higher densities of breeding pairs (Kantrud and Stewart 1977, Mack and Flake 1980). Wetlands containing points and bays, which interrupt a natural round shape, have increased total edge and isolation, and support additional emergent vegetation in the wet-meadow and low-prairie zones (Mack and Flake 1980, Fairbairn and Dinsmore 2001).

In the PPR, climate causes both seasonal and annual changes in water depth and permanence (Kantrud et al. 1989). Ducks may use water levels as an indicator of local environmental conditions. Cowardin et al. (1998) found that total water area influenced duck abundance more than the number of wet ponds. Shallow wetland depths and mud flats may indicate declining habitat quality for many species and may cause breeding pairs to breed elsewhere despite wetland density (Austin 2002). Aquatic plants respond to variations in water levels and most emergent aquatic plants require drawdown periods to germinate. The timing of drawdown is important and influences the species of plants that are present (Meeks 1969, Bellrose and Low 1978, Fredrickson and Taylor 1982). A drawdown early in the season tends to favor smartweeds (e.g., *Polygonum lapathifolium*), mid-season favors millets (e.g., *Echinochloa walteri*), and late season favors beggarsticks (e.g., *Bidens cernua*), sprangletop (*Leptochloa dubia*), panic grass (e.g., *Panicium sp*p.), and crabgrass (*Digitaria spp.*) (Fredrickson and Taylor 1982). The rate of drawdown also influences the amount, density, and diversity of wetland vegetation that germinates. Fast drawdowns produce stands of similar vegetation, whereas slow drawdowns produce stands of more diverse vegetation (Fredrickson and Taylor 1982). In contrast, flooding stands of vegetation causes decomposition of plant material that promotes invertebrate abundance (Murkin 1989), and submerges seeds for access by foraging waterfowl. *Cladocera* and *Chironomidae* are two invertebrate orders that are common to prairie wetlands and are known to rapidly increase in abundance during high water (Swanson

1977). Mcknight and Low (1969) found that rising water levels killed emergent or upland vegetation, creating detritus that prompted production of *Chironomidae* and *Cladocera*. Straub et al (2012) reported palustrine emergent wetlands to have the greatest invertebrate biomass, whereas Joyner (1980) found that spring duck use of wetlands in Ontario was directly related to invertebrate abundance.

Dabbling ducks (*Anatinae*) tend to feed in shallow water (i.e., wet-meadow and shallow-marsh zones) of seasonal and temporary wetlands, whereas diving ducks (*Aythyini*) typically feed on benthic invertebrates and tubers located in deeper water (open-water zones) in semi-permanent and permanent wetlands (Swanson and Duebbert 1989). Kantrud and Stewart (1977) studied pair densities by wetland regime and found that seasonal wetlands were used by dabbling ducks more frequently in spring than all other regimes, whereas semi-permanent wetlands were used more frequently by diving ducks. Specifically, seasonal wetlands supported 27% more dabbling duck pairs on average than semi-permanent wetlands (Kantrud and Stewart 1977). Seasonal wetlands may be more attractive to breeding ducks due to high nutrient levels released during natural drawdowns and reflooding (Kaminski and Weller 1992). Female dabbling ducks often use temporary and seasonal wetlands during pre-nesting and egg production (Krapu et al. 1997) because these wetlands are typically rich in nutrients to replenish stores used during migration and rapid follicle development. Hens with broods may select seasonal (Talent et al. 1982, Duebbert and Frank 1984), semi-permanent, and permanent wetlands, depending on species, location, and hydrologic conditions (Stoudt 1971, Rotella and Ratti 1992).

Hydrology plays a critical role in a wetland's attractiveness to waterfowl. Hydrology dictates both the hydro-period and chemical characteristics of a wetland, which in turn affects forage, nesting cover, space for isolation, escape cover, and water quality (Swanson and Duebbert 1989). Annual fluctuations in water levels establish and maintain wetland zones. Long-term climate trends result in hydrologic cycling of semi-permanent wetlands, resulting in both extremes of flooding and drawdowns. Cyclic changes that occur in wetlands may correspond to the use of aquatic habitats during critical stages of the waterfowl reproductive cycle (Swanson and Duebbert 1989). Extended periods of high water kill off emergent vegetation, and periods of low water promote new growth (Millar 1973, van der Valk 1981, Kantrud et al. 1989). During periods of high water, submerged plants tend to dominate, as seeds of most emergent species are unable to germinate under water. During drawdowns however, emergent species re-establish from the seed bank (Kantrud et al. 1989, Weller and Spatcher 1965). When wetlands dry, nutrients bound in organic matter are released through oxidation of bottom sediments (Kantrud and Stewart 1977). Nutrient enrichment of the soil can cause increased invertebrate population responses when wetlands re-flood (Moyle 1961). Thus, the effect of water variability on wetland productivity plays a significant role in wetland selection by breeding duck pairs (Murphy et al. 1984, Parker et al. 1992, Merendino et al. 1993, Merendino and Ankney 1994, Paquette and Ankney 1996). Wetlands that experience drawdowns about every five years (Harris and Marshall 1963, Whitman 1974) tend to have greater rates of vegetation decomposition, which promotes invertebrate production (Kaminski and Prince 1981). As Merendino and Ankney (1994) found, wetlands with high productivity therefore support higher densities of ducks.

Agricultural practices can also alter how temporary and seasonal wetlands function and soil type may affect pair preference of wetlands. Wetlands can be drained to increase farmable acreage, ease the farming of a parcel (by reducing obstructions), and increase grain yields provided by enhancing soil fertility (Johnson et al. 2008). Soil type affects emergent cover, biological diversity of vegetation species, the abundance of macro-invertebrate populations present, ground water recharge rates, chemical composition, and water depth (Richardson et al. 1994). When wetlands dry, nutrients bound in organic matter are released through the oxidation of bottom soils (Kantrud and Stewart 1977). Most wetlands in the PPR are embedded in agricultural landscapes where conventional tillage increases surface water runoff (Gleason and Euliss 1998). Tilled wetlands therefore, are more likely to be affected by agricultural chemicals either through runoff or direct application. Tillage negatively affects invertebrate communities by reducing the organic content of the soil, increasing turbidity, destroying invertebrate eggs, and causing loss of organic litter, which invertebrates feed on (Euliss and Mushet 1999, Swanson and Duebbert 1989), although in some cases light tilling has been documented to have a positive effect on invertebrates (Stafford et al. 2016). Sediment loading causes reduction in water depth, clarity, and quality, which negatively impacts vegetation and invertebrate communities (Dieter 1991, Gleason and Euliss 1998). Perhaps not surprisingly, many agricultural chemicals are present in wetlands in agricultural landscapes (Baker et al. 2014, Main et al. 2014), some at levels exceeding governmental guidelines (Donald et al. 2005). These chemicals enter wetlands through precipitation after spraying and surface runoff (Liess et al. 1999). Main et al. (2014) speculated that chemicals applied during spring and summer of the prior year persisted in the soil and were subsequently deposited into wetlands following snow melt. Prolonged agricultural chemical exposure can negatively impact plant and invertebrate communities (Grue et al. 1986, Liess and Ohe 2005, Beketov and Liess 2008, Van Dijk et al. 2013, Stafford et al. 2016).

Proximal upland cover type adjacent to wetlands can also affect wetland structure and function. Buffer strips around wetlands may protect wetland functions by removing sediments and pollutants from runoff (McElfish et al. 2007). Main et al. (2014) reported fewer agricultural chemicals in wetlands that were positioned in grasslands. Sedimentation rates of wetlands with adjacent grassland may also be significantly less than those directly adjacent to agriculture (Gleason 1996, Gleason and Euliss 1996). No-till cropping practices can be beneficial as well, because flooded field stubble is likely to be more attractive to waterfowl than flooded tilled or barren soils (Swanson et al. 1974).

Landscape structure consists of both wetland and upland (e.g., grassland, cropland, and woodland) components. Areas that have ample wetlands are likely to have adjacent upland grassland components that are attractive to nesting waterfowl. Similarly, wetlands near other wetlands may be more frequently occupied, and pairs tend to settle in wetlands that have surrounding nesting cover (Clark et al. 1991). The composition of grassland and cropland in an area can affect recruitment rates and emergent vegetation characteristics as well. Many studies have identified a positive correlation between duck nesting success and increasing grassland cover (Greenwood et al. 1995, Reynolds et al. 2001, Stephens 2003, Stephens et al. 2005). Thompson et al. (2012) found that nesting success was highest when ducks nested >100 m from the nearest wetland. Landscapes containing wetland complexes within grasslands likely offer habitat for a greater diversity and density of species as opposed to monotypes (Naugle et al. 2001, Webb et al. 2010). Fairbairn and Dinsmore (2001) reported that the amount of wetland habitat in an area predicted species richness in complexes of wetlands in Iowa. Conversely, isolated wetlands rarely meet all the needs of breeding ducks (Brown and Dinsmore 1986, Kaminski and Weller 1992).

The “Wetland Complex” concept is used to refer to general areas with clusters or groups of both wetlands and grass stands of different types. However, the size or number of wetlands required to meet concept criteria is rarely defined. Johnson et al. (1994) provided one definition of size requirements, recommending that wetland complexes should be 32 ha to 400 ha in size with a ratio of 4 ha of upland to 1 ha of wetland and contain multiple wetland types. Wetland complexes are assumed to experience greater use by waterfowl, most likely due to the availability and abundance of essential habitats.

In contrast, trees may act as visual and physical obstructions that may deter birds from using habitats and hindering escape from predators (Slagsvold et al. 2014). As European settlers moved into the prairies, they reduced natural disturbances (i.e., fire) and added trees to the grassland landscape (Samson and Knopf 1994). Trees likely provide habitat for predators that might not otherwise be present (Sargeant et al 1993). Bakker (2003) summarized numerous studies that reported grassland nesting birds declined in abundance as woody vegetation increased. Encroachment of woody vegetation near wetlands may reduce duck use (Kantrud 1986). Rumble and Flake (1983) found that duck brood use decreased on stock ponds as woody vegetation increased. However, few published studies have investigated the potential effects of trees on duck abundance or pair density at large breeding scales.

Combinations of factors (e.g., cover, regime, water permanence, size, adjacent habitat, predation risk) likely contribute to wetland use by duck pairs. Many studies have linked duck use with invertebrate abundance (Murkin et al. 1982, Murkin and Kadlec 1986), and wetland selection by breeding waterfowl appears to be influenced by cover type and abundance of invertebrates (Voigts 1976, Ringelman et al. 1982, Dwyer 1992). Invertebrate abundance may, in fact, be the best indicator of wetland quality for breeding ducks (Joyner 1980).

Waterfowl management practices in the PPR have traditionally focused on factors such as managing for large blocks of grass, wetland complexes, water level manipulation, wetland restorations, disturbance manipulations, and provision of quality upland cover. Limited information is available on local site-scale factors within and around individual wetlands that could affect settling propensity of duck pairs. The objective of my study was to assess the influence of landscape and local factors on waterfowl pair density by evaluating the following working hypotheses:

1. Wetlands absent of trees will be selected more frequently by settling duck pairs than wetlands with trees. Density of duck pairs will decrease with increased presence of woody vegetation within the periphery of wetland basins.
2. Diverse wetlands will attract greater densities of breeding duck pairs. Diverse wetlands have greater variation in shape and have variable water permanence (percent full), which also increases productivity.
3. Changes to emergent vegetation in wetlands may shift cover patterns (types; Stewart and Kantrud 1971) and make wetlands more or less attractive to

settling duck pairs; thus, pair use will change correspondingly. Duck abundance should be observed at its highest during “hemi-marsh” conditions. Use of wetlands will fluctuate as changes occur in wetland vegetation structure.

4. Proximal upland vegetation will influence wetland cover type and in turn duck abundance. Wetlands with adjacent grassland buffers more evenly capture and distribute nutrient and sediment loads from runoff which prevents overloading and results in better productivity and attractiveness to duck pairs.

STUDY AREA

I evaluated 583 plots within a portion of the PPR covering 33.5 million hectares and containing six level 3 ecoregions: 42) Northwestern Glaciated Plains; 43) Northwestern Great Plains; 46) Northern Glaciated Plains; 47) Western Corn Belt Plains; 48) Lake Agassiz Plain; and 51) North Central Hardwood Forests (Figure 2.6; Wiken et al. 2011). There are 105 level 3 ecoregions in the U.S. that consist of further subdivided regions of level 2 and level 1 ecoregions (USEPA 2016). Level 3 ecoregions are considered appropriate for use in regional decision making (Wiken et al. 2011). The PPR is characterized by generally drier, heavily glaciated grasslands and wetlands to the west, flat to gently rolling glaciated tallgrass and short grass prairies centrally; extremely flat and highly productive soils of the historic Lake Agassiz lake bed to the northeast; a mosaic of forests, wetlands, lakes, croplands, pastures, and dairy operations in the far east; and nearly level to gently rolling glaciated till plains that have been extensively converted for corn and soybean production in the southeast (Wiken et al. 2011).

The USFWS and its partners have conducted annual FSMS in the PPR of Iowa, Minnesota, Montana, North Dakota, and South Dakota since 1987. The area is known for its abundant pothole wetlands, left by the retreating Wisconsin glacier. The Northern Great Plains of the Dakotas and Montana make up the south and west boundaries of the region, the international border with Canada serves as the north boundary, and the eastern boundary lies at the prairie-hardwoods transition zone in Minnesota (Figure 2.1).

The FSMS is divided by Wetland Management District (WMD, Figure 2.2) and plots are randomly selected based on a stratified sample of USFWS ownership interests: 1) Federal—the plot contained at least 65 ha of USFWS Waterfowl Production Area; 2) Easement—the plot contained at least 65 ha of USFWS wetland easements; 3) Refuge—the plot contained any amount of land in a National Wildlife Refuge, or; 4) Private—the plot contained at least 94% private land and contained no National Wildlife Refuge lands (Oslund et al 2010). Approximately 200 randomly selected wetlands, stratified by regime, in each of the 22 WMDs are surveyed annually for each district, and are representative of four of the seven major wetland classes (temporary, seasonal, semi-permanent, and permanent). Although wetlands from the other three classes (ephemeral, alkali, and fen) were not specifically included in the sample data set, some field observations are recorded incidentally for these classes.

Other studies have found that duck pairs are not equally distributed across the breeding grounds (e.g., Stewart and Kantrud 1973, Reynolds et al. 2006). To account for the large spatial extent, variability of features, and unequal distributions of duck pairs across the PPR, I divided the PPR into 10 blocks using a combination of level 3 ecoregions and WMD boundaries. I kept block sizes and sample sizes within each block as even as possible by assessing distributions within each of the areas. Block codes were assigned alphabetically based on general location (W-western, C-central, and E-eastern) and numerically, in ascending order from North to South. The western blocks (W1, W2, and W3) were almost completely located in the Northwestern Glaciated Plains, the central blocks (C1, C2, C3, and C4) were almost entirely composed of features of the Northern Glaciated Plains, and the eastern blocks contained more variable features with areas predominately in the Lake Agassiz Plain (E1), North Central Hardwood Forests (E2), and the Western Corn Belt Plains (E3; Figure 2.6).

METHODS

Cooperators from each WMD conduct surveys on sample ponds twice each year. The first survey occurs between April 27 and May 15 and second from May 20 to June 6. Data collected includes: observed waterfowl numbers by social groups and species (Dzubin 1969), wetland type (Cowardin et al 1979), vegetation interspersion class as defined by Stewart and Kantrud (1971), and an ocular estimate of the percentage of water inundating the wetland basin. The sample pond dataset included: sample pond identifier, number of years sampled, sample number, basin area, basin perimeter, wetland class, and location.

During the creation of the FSMS in the mid-to late 1980s, the USFWS National Wetlands Inventory (NWI) office in St. Petersburg, FL delineated and created wetland and upland habitat features using color-infrared aerial photography collected from the late 1970s and early 1980s. These data were prepared as both digital Geographic Information Systems (GIS) layers and hard-copy paper maps and are commonly referred to as “Pywell” data (Pywell and Niedzwiadek 1980, Cowardin et al, 1995). In

Minnesota, the majority of the sample ponds are still from Pywell delineated wetlands. In the mid-1990s, digital NWI wetland data became available for North and South Dakota, and from 2000 to 2009, the sample ponds have been converted to basins derived from the NWI delineated wetlands. The Iowa FSMS plots and sample ponds were recreated in 2006 using 2002 NWI data in an effort to better evaluate state programs.

Digital Pywell and NWI data were processed to create wetland basin data. The process collapsed adjacent polygons that share a common boundary by using a series of rules, and then retained the deepest water regime as the label for the resulting polygon (Johnson and Higgins, 1997). Wetland basins were then overlaid with ownership data, and basins were clipped into polygons to create a pool of potential sample ponds. As a result, sample ponds with differing ownership assignments now allow for the survey to quantify the potential effect of ownership on duck breeding populations and production estimates. Sample ponds were selected using a stratified random sample that treated the wetland basin classes as strata; this method was used to obtain a sample throughout the range of wetland basin sizes and to avoid oversampling of small basins that are often dry (Cowardin et al. 1995).

Approximately 5,750 sample ponds are currently surveyed each year throughout 22 WMDs on 704 plots. The FSMS dataset from 1987 to 2013 contained 99,673 records for 6,320 sample ponds, accounting for changes made to the survey over time. Wetlands that originated from the same parent basin were treated within the annual FSMS as individual sample ponds. There are instances when all parts of the parent wetland basin may be counted during the survey, but recorded as multiple ponds; this may cause some wetlands to be split and possibly surveyed and counted twice. In order to combine all available pair data for a wetland basin, I processed these pair data by summing values based on a “unipond” variable, which is a combination of “part” and “basinnum”.

Sample pond areas were selected within plot boundaries. For example, the area surveyed is often only a portion of the entire wetland, whether the wetland basin was located completely within the bounds of a FSMS plot or extended beyond the plot perimeter. Larger (e.g., >40.5 ha) sample ponds typically extended beyond the plot boundary. Since the entire wetland is not completely surveyed, these wetlands caused additional difficulties when developing models to predict duck pair density. To address this, an expansion factor variable was created and named “WFactor”, which was calculated by dividing the total wetland basin area (ha) by the total area surveyed (ha) in counts for a given year. Duck pair data from a wetland basin were then extrapolated for the entire wetland using the summed values multiplied by WFactor.

To assess local and landscape features near sample ponds, I removed wetlands with large uncounted areas outside of plot boundaries, as those areas were not included in the buffers. I used a variety of techniques to identify and mark these wetlands for exclusion. First, I calculated the percentage of the wetland that was counted by dividing the area counted (prsha) by total wetland area (worldarea). I used avaitest, a FSMS attribute, for indicating the amount of wetland area within the bounds of a FSMS plot as follows: y) wetland records have a within plot area that is approximately equal to the universe area; z) wetland records have within plot areas between 94.1% to 99.9% of the universe area; and n) wetland records have within plot area <94.1% and area differences are >0.0325 acres of the universe area (i.e., most are large wetlands that extend outside FSMS plot boundaries). I marked wetlands where <80% of the area was counted for exclusion, and I further evaluated those that were between 80% to 99% counted in ArcGIS to ensure buffers fully captured the appropriate features. I used aviatest y and z values to identify wetlands within plots that had low count percentages.

Of the 6,320 sample ponds, 5,148 had 80% to 100% of their area counted. The excluded 1,172 wetlands had aviatest values of 535 n, 581 y, and 56 z values. I excluded 58 y wetlands due to buffer issues. The inclusion of all other y and z wetlands yielded a total sample ponds total for analysis of 5,727 ponds. The majority of the 593 excluded wetlands were semi-permanent (n = 219) and permanent (n = 227) wetlands. I anticipated that the effect of removing seasonal, semi-permanent, and temporary wetlands would be minimal, due to the large number of these wetland types that remained in the dataset. In contrast, the effect on permanent wetlands was much greater considering these wetlands represented 51.6% of the permanent wetlands in the sample pond dataset (Table 2.1).

The number of years a sample pond had been counted during the FSMS varied primarily by the ability to obtain landowner permission to conduct surveys. Sample ponds were also replaced for other reasons, such as alteration due to filling, development, farming, and observer concerns about access to wetlands. Because comparing duck pair data among sample ponds counted over short (e.g., 1 to 2 year) and long (e.g., 15 to 25 year) durations may not be reasonable, I evaluated the 6,320 sample ponds to determine the distribution of years that wetlands had been counted (Figure 2.3).

A large proportion of sample ponds had been surveyed the entire 25 years, meaning that these ponds were selected for study during the first year of the survey. Some changes occurred in the early years of the survey and ponds were dropped and replaced for sampling as necessary. For a number of years thereafter (9 to 18 years surveyed), the number of ponds surveyed remained relatively stable with only minor changes occurring to the sample pond dataset.

I eliminated sample ponds from further analyses that had been counted <9 years after evaluating the natural breaks in the number of years that ponds were counted. This decreased the number of sample ponds by 1,852, yielding a total of 4,468 ponds, and reduced potential bias between short and long term sample pond means. Temporary wetlands were most affected by this exclusion process because they had a greater risk of conversion to agriculture (Oslund et al. 2010) and may no longer function as wetlands. Small, converted wetlands were difficult to detect when temporary wetlands were drawn into the FSMS sample and were subsequently replaced after one year of counts (Table 2.3).

In summary, excluding sample ponds with WFactors >1.25 and <9 years of counts reduced wetland sample size for my analyses to 5,156 and 4,468 ponds, respectively. When exclusion practices were combined the resulting number of remaining wetlands for inclusion was reduced by 43.2%, from 6,320 to 3,950. Seasonal wetlands were least affected (38.0% excluded), followed by semi-permanent wetlands (41.2% excluded). Permanent wetlands were excluded the most (63.9% excluded), followed by temporary wetlands (48.0% excluded; Table 2.4). The remaining 3,950 sample ponds were used to analyze the effect of local features on duck settling patterns.

The sample pond universe in the FSMS was composed of NWI wetlands in Iowa, North Dakota, and South Dakota, along with Pywell wetlands in Minnesota. I exported wetland basins from Iowa and Minnesota plot vector data and merged them with wetland basins in North and South Dakota, acquired from B. Wangler (HAPET Bismarck, ND), into a single shapefile for processing. I calculated perimeter and area for all wetlands using ArcMAP 10.1 XTools Pro. Perimeter is a one-dimensional linear measurement (m), around the outside of two-dimensional sample pond polygons. Area included everything within the delineated sample pond in m².

Baker and Cai (1992) described three indices to account for patch, or in my case wetland shape. The second index they described appeared to best correspond to the variation associated with wetland shape. This shape index is calculated from a ratio of area and perimeter using the equation:

$$\text{Shape Index} = \frac{0.282 * \text{Perimeter}}{\sqrt{\text{Area}}}$$

The index is an estimation of general polygon appearance, the proportion of edge to user defined habitat, and may explain variation in duck pair density estimates on similarly-sized wetlands. Small, round wetlands have a shape index close to 0.0 (circle), whereas wetlands with complex shapes would have values >1.1 (square; Baker and Cai 1992; Figure 2.4).

I evaluated plot context for the FSMS to investigate the influence of landscape composition on breeding duck densities. I used 2011 land-cover data from the National Land Cover Database (NLCD, acquired through satellite imagery, from the USGS Earth Resources Observation and Science (EROS) Data Center to assess upland cover in plots. Land-cover data included land use classifications based on agricultural practices (small or large grain row crop), trees (deciduous or coniferous), grassland (conservation, pasture, or hay land), and development. I used total number of wetlands, wetland area, and duck density to evaluate plot context. Riffell et al. (2003) evaluated patch use of birds within a landscape context on the North Shore of Lake Huron and found that annual fluctuations of patch-level characteristics (e.g., water depth, flood duration) changed patch use for some species among years.

I used NLCD rasters created by USGS EROS Data Center, subsequently modified by HAPET that were available within the Prairie Pothole Joint Venture boundary, to analyze upland features within each FSMS plot. I used the 2011 iteration of the NLCD that was updated with HAPET spatial wetland basins and undisturbed grassland layers. This land-cover raster data distinguished land-cover types across nine classes (Appendix A) within pixel sizes of approximately 30 m (HAPET Land-cover metadata). I evaluated FSMS plot contexts to determine local and landscape extent (matrix) effects on duck populations. I calculated percentages for each cover class, total number of wetlands, wetland area, and duck abundance values to evaluate plot context at both local and landscape extents.

I used the Geospatial Modeling Environment (GME) technique in conjunction with ArcMap 10.1 to calculate percentages of land-cover types within plots and adjacent to sample ponds. The GME technique relies on the R environment to compute ranges and percentages from raster files. To evaluate landscape context of FSMS plots, I ran the polygon intersect function in GME to count the number of pixels for each land-cover type and summed the total number of pixels. I exported these data to Microsoft Excel © and generated percentages of each land-cover type for 583 plots, and for the 48 m and 91 m buffers, for all sample ponds.

Terrain ruggedness likely affects the number of wetlands in a landscape, which may influence the number of duck pairs that settle into an area (Batt 1996). Ducks may be attracted to a range of rugged landscapes due to the amount of grassland habitat present, increased surface area for nesting, or the ability to hide from predators (Horn et al. 2005). Alternatively, too much terrain variation may affect lines of sight and prevent ducks from detecting predators, limit their escape routes, and possibly increase the risk of predation. I used a Vector Ruggedness Measure (VRM) to assess FSMS plots and areas adjacent to sample ponds for topographic roughness. The VRM estimates heterogeneity of terrain and is less correlated with slope than other ruggedness modeling techniques. Lack of significant correlation with slope also allows VRM to estimate a component of terrain separate from slope (Sappington et al. 2007).

Terrain ruggedness is a measure of landscape topographic variability or complexity of an area and is typically based on the standard deviation of elevation (Ascione et al. 2008). I used Digital Elevation Models (DEM) acquired from USGS for the entire PPR to compute VRM values. These DEMs were created in 2009 and were available at 1/3 arc-second (~10 m) in most areas and at 1/9 arc-second (~3 m) in some areas. To reduce file size and decrease processing time, I clipped DEMs in ArcGIS to align with FSMS plot boundaries buffered to 400 m.

I used the Benthic Terrain Modeler (BTM) for ArcGIS 10.1 to calculate VRM values from DEMs. This tool was developed collaboratively by the National Ocean and Atmospheric Administration Coastal Services Center, Oregon State University, and the Massachusetts Office of Coastal Zone Management, and consists of a series of custom scripts in R designed to allow researchers to examine and classify benthic environments. Although developed for oceanic research, the tool employed general principles that made it flexible to use in upland analyses (Wright et al. 2005). The package included a script add-on for VRM to identify terrain rugosity, and did so by measuring the dispersion of vector orthogonal relative to terrain surface. Flat, smooth, steep areas received low VRM values, whereas irregular, steep, and rugged areas had high values (Sappington et al. 2005). Output values ranged from 0 (no terrain variation) to 1 (most terrain variation), with typical values for general terrains ranging between 0 to about 0.4 (Wright et al. 2005). After I created the VRM raster for all FSMS plots, I used Zonal Statistics to summarize averaged VRM values for each plot and buffered sample pond polygons. I also created new polygons for my buffered sample pond polygons that included the area from the edge of sample pond polygons to the 91 m buffer polygon. These polygons excluded wetland areas, thereby preventing the flat, non-rugged wetland surface area from causing a smoothing effect that would reduce VRM averages (Figure 2.5).

Terrain slope can affect wetland condition and its attractiveness to duck pairs by influencing factors such as the amount of concealment cover, nesting habitat, predator detection, water permanence and depth, and tree presence (Swanson et al. 1988, Sun et al. 2002). Slope represented the rate or gradient of change of elevation and the inclination of the slope is measured in degrees and ranged from 0-90. I created a slope raster from the plot DEM raster to analyze this effect on duck pair density, and calculated means and standard deviations from the buffered sample ponds and plot layers using ArcGIS Zonal Statistics (Figure 2.5).

I assessed water level variability within wetlands based on their estimated percent full values from multiple years. I calculated the standard deviation of percent full observations for the years sample ponds were surveyed to estimate this variability. I used standard deviations to evaluate whether sample ponds had stable, variable, or highly variable water levels. Wetlands with high standard deviation values had greater variation in percent full values over the number of years they were surveyed. Lower standard deviation values meant that sample wetlands were observed with similar water levels over the years surveyed, and therefore indicated little or no variation in water permanence.

I grouped duck species with similar life histories into guilds based on species use of wetland type (Kantrud and Stewart 1977) and settling affinity (Johnson and Grier 1988). Johnson and Grier (1988) studied settling patterns of 10 common duck species in North America and assigned species to three patterns: homing (returning to habitat used the previous year); opportunistic (settling in the first encountered site that likely contains all requisites for breeding and survival); and flexible (a mixture of portions of homing and opportunistic settling). Homing species tend to be more predictable with respect to wetland use, whereas opportunists are less predictable (Johnson and Grier 1988). Therefore, I defined guilds as: 1) dabbling ducks (mallard [*Anas platyrhynchos]*, gadwall [*Anas strepera]*, and northern shoveler [*Anas clypeata]*, northern pintail [*Anas acuta]*, blue-winged teal [*Anas discors]*, American green-winged teal [*Anas crecca*], American wigeon [*Anas Americana]*, and wood duck [*Aix sponsa])*; 2) diving ducks (canvasback [*Aythya valisineria]*, redhead [*Aythya Americana]*, lesser scaup [*Aythya affinis]*, ring-necked duck [*Aythya collaris]*, and ruddy duck [*Oxyura jamaicensis])*; 3) homing dabblers (mallard, gadwall, and northern shoveler); 4) homing divers (canvasback, redhead, and lesser scaup), and, 5) opportunistic (northern pintail and blue-winged teal).

ANALYTICAL APPROACH

I used an information-theoretic approach to evaluate variation in duck pair use with respect to wetland quality and manageable local and landscape features (Anderson et al. 2000). Herein, I describe potential ecologically important covariates that I used to build a set of candidate models:

1) Landscape context likely influences duck use of various habitats. Few studies have assessed landscape context in relation to breeding duck use (Brown and Dinsmore 1986, Naugle et al. 1999, Fairbairn and Dinsmore 2001, and Riffell et al. 2003). I evaluated the following landscape variables at the FSMS plot scale.

a. Number of wetlands within FSMS plots [WETNUM]. The number of ducks in an area has been found to have a linear relationship with the number of May wetlands (Batt et al 1989). Areas that have ample wetlands are likely to have adjacent upland grassland components that are conducive to nesting (Clark et al. 1991) and attract more species than isolated wetlands (Brown and Dinsmore 1986).

b. Total wetland perimeter [PERIMETER]. High perimeter-to-area ratios decrease competition by increasing useable space and have been found to be important to many wetland species (Weller and Spatcher 1965, Fairbairn and Dinsmore 2001). This value incorporates total perimeter and area of all wetlands within FSMS plots. Perimeter-to-area values increase with shoreline variability and as the number of wetlands within plots increases.

c. Wetland area [WETAREA]. Fairbairn and Dinsmore (2001) found that the amount of wetland habitat in the landscape acts as a predictor of species richness. Smaller wetlands situated within complexes attracted greater abundances and diversity of species than isolated, larger wetlands (Brown and Dinsmore 1986).

d. Grassland area [GRASSLAND]. Nest success has been found to be positively related to the amount of perennial grass cover surrounding a 10.4-km^2 landscape (Reynolds et al 2001). The degree of nest success in an area is thought to influence duck use and abundance (Howerter et al. 2008). Ducks nesting in areas with little grassland tend to cluster, whereas in grassland dominated areas they tend to disperse (Devries and Armstrong 2011, Shaffer et al. 2006). Ducks prefer idle or infrequently disturbed grasslands and avoid pasture and other heavily disturbed grass patches (Hoekman et al. 2006). Krapu et al. (1997) reported that wetlands embedded within intact grasslands have higher invertebrate productivity, an important food source for nesting females and ducklings, which could also increase attractiveness.

e. Woodland area [WOODLAND]. Wood-shrub areas are frequently used for nesting by mallards in the prairie-parklands of Canada. These areas may reduce visual contact between nesting mallards, possibly reducing home range sizes and allowing for more nesting pairs in an area (Mack et al. 2003). In the PPR, trees are thought to reduce the number of settling pairs since they provide perches for avian predators. A 2003 study attributed 25% of gadwall brood mortality to avian predators (Pietz et al. 2003), which may have benefited from trees. Bloom et al. (2013) found in the Canadian PPR that female mallards had the greatest duckling survival when they avoided woody cover.

f. Cropland area [CROPLAND]. Most wetlands in the PPR are embedded in agricultural landscapes, where conventional tillage increases surface water runoff (Gleason and Euliss 1998). In landscapes dominated by cropland, ducks have been found to nest in higher densities in the remaining grassland patches (Devries and Armstrong 2011). This is likely caused by their tendency to avoid agriculture fields for nesting habitat (Shaffer et al. 1999), as well as negative agricultural effects on wetland quality (Dieter 1991, Gleason and Euliss 1998).

g. Developed area [DEVELOPED]. Developed areas have been altered by anthropogenic encroachment, such as housing, industrial, or other buildings, which typically destroys wildlife habitat. The greater the amount of developed area (e.g., cities) within a plot, the greater displacement of habitat for wildlife. The amount that development affects wildlife likely depends on the ratio of habitat to developed area.

h. Open water area [PLOTWATER]. Increased total open water area within plots should provide more wetland habitat and affect landscape duck pair abundance. Areas that have ample open water are likely to have increased grassland habitat due to less farming pressure on the area. Areas with greater wetland habitat would also have greater usable space for ducks (Guthery et al. 2005).

i. Terrain Ruggedness [RUGGEDNESS]. Plots with low values of terrain ruggedness are flatter than areas with high values where the terrain is more rolling and uneven. High variability or complexity of terrain ruggedness in a FSMS plot may be unfavorable to some waterfowl species due to the creation of physical obstacles blocking view or escape. Terrain ruggedness may also create wetland types that are unfavorable to waterfowl. The proximal factors causing this effect is unknown, but could be related to wetland productivity and depth.

2) Local wetland related variables have long been known to affect duck use (e.g., Weller and Spatcher 1965, Weller and Fredrickson 1974, Murkin et al 1982, Murkin and Kadlec 1986, Kantrud et al. 1989). These variables are site specific and encompass adjacent features that directly influence duck pair use.

j. Wetland size [AREA]. Large wetlands may attract more birds than smaller wetlands. Leschisin et al. (1992) found that wetlands with larger surface areas and shoreline lengths had greater duck use. Brown and Dinsmore (1986) found a significant relationship between the number of nesting waterfowl species and wetland size. Species richness was greatest on larger wetlands, but 20-30 ha wetlands were identified as more productive for bird species than larger wetlands (up to 180 ha; Brown and Dinsmore 1986).

k. Wetland shape [SHAPE]. Wetlands with higher edge-to-area ratios can influence duck distribution by providing more areas for foraging, loafing, brood rearing, and escape cover opportunities (Mack and Flake 1980, Fairbairn and Dinsmore 2001, Stevens et al. 2003).

l. Wetland vegetation cover type [COVER]. The influence of cover type on duck use is likely associated with "hemi-marsh" concepts (Weller and Spatcher 1965, Weller and Fredrickson 1974, Murkin et al. 1997). Hemi-marsh wetlands with increased edge densities have been found to attract more birds, a factor attributed to greater visual isolation (Murkin et al. 1982, Rehm and Baldassarre 2007). Cover types that favor even ratios of cover to open water should correlate positively with duck use.

m. Water permanence [PERM]. Wetlands that have fluctuations in percent-full from year to year may contain higher densities of aquatic invertebrates and rejuvenated plant growth (Van der Valk 1981). Fluctuations in percent-full likely cause periods of exposure of wetland soils followed by periods of inundation that encourage plant and invertebrate responses (Weller and Spatcher 1965, Kaminski and Prince 1981, Kantrud et al. 1989). Wetland productivity is assumed to be higher in wetlands that have variable water levels from year to year.

n. Percent years dry [DRY]. Duration of intermittent wetland drying can affect vegetation and invertebrate communities, wetland productivity, and attractiveness to duck pairs. Wetlands that dry periodically may have greater invertebrate productivity and may be more attractive to duck pairs than wetlands that remain constantly flooded (Van der Valk 1981).

o. Wetland regime [REGIME]. During the breeding season, dabbling ducks often select temporary and seasonal wetlands during pre-nesting and egg production (Krapu et al. 1997). These wetlands are typically rich in nutrients essential for replenishing stores burned during migration, molt, and egg production. Breeding pair densities are likely to be higher in areas comprised of multiple wetlands with different water regimes.

p. Open water area [OPENWATER]. Open water and vegetation cover on wetlands can influence settling of waterfowl breeding pairs (Weller and Fredrickson 1974). Duck pairs have been found to select wetlands that exhibit "hemi marsh" (50% cover to 50% open water) characteristics (Weller and Spatcher 1965, Weller and Fredrickson 1974, Kaminski and Prince 1981). An equal ratio of vegetation to open water creates habitat conducive for duck foraging, security, and pair spacing.

q. Adjacent upland grass [GRASS]. Duck pairs often settle in wetlands that have surrounding nesting cover (Clark et al. 1991). Grass buffer strips around wetlands provide nesting areas for breeding ducks, and protect and maintain wetland functions by removing sediments and pollutants from runoff (McElfish et al. 2007). Sedimentation rates for wetlands with adjacent grassland are significantly less than those adjacent to agricultural areas (Gleason 1996, Gleason and Euliss 1996).

r. Adjacent trees [TREES]. Trees act as visual and physical obstacles that make habitats appear inimical by limiting available grassland nesting cover, creating corridors that limit escape, and promoting advantageous conditions for predators (Naugle et al. 1999, Bakker 2003).

s. Adjacent crop [CROP]. Wetlands with higher adjacent farmed areas are affected more by nutrient and sediment loading than those surrounded by grass. Sediment loading causes reduction in water depth, clarity, and quality, which negatively impacts vegetation and invertebrate communities (Dieter 1991, Gleason and Euliss 1998). Nutrient loading also negatively affects vegetation and invertebrate communities, which are two important factors for breeding ducks.

t. Adjacent developed [ALTERED]. Adjacent developed areas likely affect wildlife through disturbance and habitat displacement. At the local scale, wetland sizes to shoreline developed area ratios likely have greater disturbance levels and thus, negatively affects isolation and security to wild duck pairs. Large permanent, wetlands (lakes) are most likely to have developed areas (e.g., cabins, resorts).

u. Adjacent terrain [SLOPE]. Terrain slope adjacent to wetlands can influence habitat and land-use types, sediment and nutrient loading, nesting, view-scape, and duck pair abundance. Ducks likely select wetlands with moderate slope, where grass persists due to difficulty to farm (Batt 1996), offering unimpaired escape routes and predator detection. Local topographic variation increases the range of water depths, foraging habitats, and vegetation communities (Ma et al. 2010).

SELECTION OF CANDIDATE MODELS

I separated candidate models of duck pair density into two groups: landscape and local. Covariates in local models included wetland productivity (WP), wetland attractiveness (WA), diverse wetlands (DW), view-scape (local; VS1), and wetland status (WS), whereas covariates in landscape models included plot habitat (PH), wetland density (WD), and view-scape (landscape; VS2) to represent ecologically plausible explanations that may be used, alone or in combination, to evaluate working hypotheses.

Local models were focused on individual sample wetlands and proximal features. Wetland productivity is the ability of a wetland to rejuvenate itself and avoid becoming unproductive (Brinson et al. 1981, Grace 1999). These wetlands in the PPR are typically characterized by diverse vegetation communities and abundant invertebrates. Because I was unable to evaluate invertebrate and vegetation dynamics for each sample pond, I attempted to account for productivity processes that create these conditions. Wetland attractiveness is the likelihood a wetland will appeal to and be used by a duck pair based on habitat features at local and landscape scales. Diverse wetlands often have complex or irregular shapes, sizes, and cover types that may result from being located in areas of increased terrain ruggedness. These wetlands may have higher percentages of dry years, which may influence wetland vegetation cover communities and invertebrate productivity in more dynamic ways (Anteau and Afton 2009). View-scape (local) was intended to account for features that may negatively influence a duck's sense of security. Areas with high view-scape scores were hypothesized to cause duck pairs to avoid areas and result in the lowest use. My wetland status model evaluated wetland area, the number of years the wetland was dry, regime, and average percent open-water. This model was intended to evaluate the entire wetland, including factors that may have influenced productivity and, ultimately, use by ducks.

Landscape models focused on features present within FSMS plots. Plot habitat evaluated the quantity of wetlands, grasslands, and open water available to ducks within each plot. Wetland density included the number of wetlands, wet area, and terrain ruggedness in each plot; the amount of ruggedness in a plot may influence the number and size of wetlands. View-scape (landscape) was similar to view-scape (local), but considered tree abundance and ruggedness of the plot, instead of at the sample pond scale.

Statistical Analyses

I used Pearson's correlation tests to evaluate collinearity among covariates. I considered covariates to be strongly related if values were ≤-0.60 or ≥0.60. In cases where collinearity was detected, I selected the covariate that I deemed most ecologically plausible based on a review of the scientific literature. I used generalized linear mixed models (package lmer) in R (The R Foundation for Statistical Computing 2015) version 3.2.3 to evaluate relationships between numbers of observed duck pairs, by guild, with respect to landscape and local wetland contexts. For dependent variables (guild 1 and guild 2), I considered eleven local covariates proximal to sample ponds and six landscape covariates within each FSMS plot, as mentioned in my model descriptions. I performed log transformations on my dependent variables (guild) to reduce skewness, improve relationships between input and output variables, and approximate normal distributions of error terms within models. I standardized my covariates by centering the data around their means to improve model performance and facilitate direct comparisons between covariate effects (Schielzeth 2010). I evaluated best-approximating and competing models using second order Akaike's Information Criterion (AIC_c; Anderson and Burnham 2002). Models were considered competitive within candidate sets if they were within 3.0 AIC units of the best approximating model. I evaluated parameter estimates and their confidence intervals for best and competing models to evaluate the effect sizes of covariates. I calculated 95% confidence intervals for parameter estimates to interpret covariate effect sizes. I back-transformed regression coefficients to interpret percent change on the original scale (average counts) following Guthery and Bingham (2007).

RESULTS

Pearson's correlation tests revealed several cases of collinearity among proposed covariates. Within landscape and local covariate groups, areas of grass and crop had correlation values of -0.84 and -0.81, respectively, indicating strong inverse relationships. Ultimately, I retained grass and dropped crop because duck pairs are more likely to have a positive relationship with the amount of grass present for use as nesting cover. When comparing landscape and local covariates, I detected strong correlation values for similar land features for areas of grass (0.60), crop (0.60), trees (0.66), and terrain relief (0.63). These values indicated that little variation existed between landscape and local scales, and might suggest that landscape size was inadequate to detect true landscape effects. I retained grass, trees, and terrain measurements at both scales because candidate models used these covariates and I used a different metric (e.g., local: average guild count, landscape: plot estimated guild values) for guilds at both scales.

I compared guilds to determine if it was statistically appropriate to evaluate all guilds and found strong positive correlations between guilds that contained similar species. Guild 1 was consisted of eight dabbler species (American green-winged teal, American wigeon, blue-winged teal, gadwall, mallard, northern pintail, northern shoveler, and wood duck), three of which were used to create guild 3 (mallard, gadwall, and northern shoveler), and another two for guild 5 (blue-winged teal and northern pintail). Guild 2 was comprised of five diver species (canvasback, lesser scaup, redhead, ring-necked duck, and ruddy duck), and guild 4 was created by using three of these species (canvasback, redhead, and lesser scaup). I removed Guilds 3, 4, and 5 from further analyses because they were highly correlated with the guilds they were derived from (i.e., $r > 0.95$).

To account for disparity in wetland sizes that were excluded due to WFactor values, I grouped sample ponds into categories based on size: [VS] very small (<0.4 ha), [SM] small (0.4 to 2.0 ha), [M] medium (2.0 to 8.1 ha), [LG] large (8.1 to 40.5 ha), and [XL] extra-large (>40.5 ha). As predicted, a higher proportion of XL wetlands (83.8%) were excluded due to their size. The very small, small, medium, and large size categories were well represented in the data, with inclusion rates of 99%, 95.4%, 88.4%, and 66.7%, respectively (Table 2.2).

Local Models

My local analyses included 26 years of data from 3,950 sample ponds which were counted ≥9 years and averaged over time from the FSMS. The majority of sample ponds were seasonal (42.2%) and semi-permanent wetlands (31.7%; Table 2.5). Of all sample ponds, 3,103 (78.6%) were small wetlands, ranging from 0.4 to 20 ha in size (Table 2.6). Sample ponds exhibited varying degrees of adjacent grass, with many (21.2%) having very little grass and a few (6%) being completely surrounded by grass. Most sample ponds (84.2%) had few or no trees within their margins. Additionally, many of these wetlands frequently held water the majority of time (27%), whereas 24.2% held water the entire time (Table 2.7).

Five local candidate models, formulated to explain wetland and proximal features, for guilds 1 revealed that the WETLAND STATUS was the best approximating model (AIC_c = 8675.0) and guild 2 (AIC_c = 4222.3). The model-averaged parameter estimates for AREA (AREA = 0.63; 95% CI: 0.61, 0.65), YRSDRY (YRSDRY = -0.16; 95% CI: -0.18, -0.14), REGIME (REGIME = 0.06; 95% CI: 0.04, 0.09), and OPENWATER (OPENWATER = 0.18; 95% CI: 0.16, 0.20) indicated important relationships with duck pair abundance in guild 1. Guild 2 model-averaged parameter estimates for AREA (AREA = 0.27; 95% CI: 0.26, 0.29), YRSDRY (YRSDRY = -0.03; 95% CI: -0.04, -0.01), REGIME (REGIME = 0.05; 95% CI: 0.03, 0.06), and OPENWATER (OPENWATER = 0.04; 95% CI: 0.02, 0.05) also indicated interpretable relationships. The best local models for guilds 1 and 2 were separated from the next best model by 232.1 and 85.7 AIC_c units, respectively (Table 2.11).

Landscape Models

My landscape analyses evaluated features for 583 FSMS plots. The dominant land feature within most plots was agriculture. Most plots contained small percentages of grassland (68.8% from 0.4% to 40%), wetland (83.9% from 0.01% to 20%), and woodland (98.1% from 0 to 20%) areas. Most plots (41.0%) contained ≥100 wetland basins (Table 2.8).

Three landscape candidate models, formulated to represent variation in duck pair abundance at the plot level for guilds 1 and 2, revealed WETLAND DENSITY to be the best approximating model. The model-averaged parameter estimates for guild 1 RUGGEDNESS (RUGGEDNESS = 0.07; 95% CI: 0.06, 0.10), WETNUM (WETNUM = 0.38; 95% CI: 0.36, 0.40), and WETAREA (WETAREA = 0.35; 95% CI: 0.33, 0.37) indicated positive relationships, but all lower CI boundaries included zero, suggesting high variability and weak relationships. Guild 2 model-averaged parameter estimates for RUGGEDNESS (RUGGEDNESS = 0.09; 95% CI: 0.07, 0.11), WETNUM (WETNUM = 0.32; 95% CI: 0.30, 0.34), and WETAREA (WETAREA = 0.37; 95% CI: 0.35, 0.38) also indicated weak relationships. The best approximating landscape model for guilds 1 and 2 were separated from the next best model by 551.8 and 351.9 AIC_c units, respectively (Table 2.12).

I modeled breeding duck pair abundance, by guild, on sample ponds to identify variables possibly explaining settling patterns and use of specific (local) wetlands. The best approximating model at the local level for guilds 1 and 2 included covariates for AREA, OPENWATER, REGIME, and YRSDRY, and at the landscape level included RUGGEDNESS, WETAREA, and WETNUM. Because my covariates were z-standardized, I treated them as separate univariate models and evaluated changes at increments of one standard deviation (Schielzeth 2010). AREA had the strongest positive associations with guilds 1 and 2 at the local scale, followed by weaker, but still positive impacts of OPENWATER and REGIME, and a negative association with YRSDRY (Table 2.13). At the landscape scale, WETNUM had the strongest positive association with guild 1, followed by slightly weaker positive impacts of WETAREA, and very low but positive association with RUGGEDNESS. WETAREA had the strongest positive association with guild 2, followed by slightly weaker positive impacts of WETNUM, and a low but positive association with RUGGEDNESS (Table 2.14).

At the local scale for guild 1, model-predicted duck pair abundance increased by 33.6% for every additional standard deviation increase (0.79 ha) in AREA (95% CI: 32.9%, 34.3%). Effect sizes were not estimated for REGIME since it was a categorical variable. For guild 2, the model-predicted pair abundance would increase by 20.8% for every additional increase (0.79 ha) in AREA (95% CI: 20.5%, 21.1%). At the landscape scale for guild 1, the model yielded that for every one standard deviation increase in WETNUM (39.3 %), predicted duck pair abundance would increase by 6.5% (95% CI: 6.4%, 6.6%). For guild 2, one standard deviation increases to WETAREA (89.1 ha) predicted a corresponding 6.7% (95% CI: 6.5%, 6.8%) increase in guild 2 abundance.

DISSCUSSION

My results suggested that wetland area had a fairly strong positive relationship with duck pair abundance for guilds 1 and 2 at the local scale. Cowardin et al. (1988) reported similar findings, where their best-fit models included both wetland area and the square root of area, which served as an index to shoreline length. Colwell and Taft (2000) detected a strong positive relationship with wetland size and the number and species of breeding waterbirds. Reynolds et al. (2006) found that predicted duck pairs increased nonlinearly with wetland size, with higher predicted pair densities on smaller wetlands. Webb et al. (2010) found wetland area to have a significant positive relationship with both dabbler and diving breeding duck pairs migrating through the Rainwater Basin of Nebraska. The relationship between breeding duck pairs and wetland area is intuitive, as area likely dictates the number of duck pairs a pond can support.

However, there are other ecological reasons why this relationship makes sense. Wetlands that are larger may have more room for pair spacing, more foraging opportunities, or more heterogeneity (Lagrange and Dinsmore 1989). Larger wetlands likely have more shoreline due to having greater edge, and perhaps more complex shapes, factors that provide additional seclusion from other ducks, invertebrate forage (Murkin et al. 1992), and escape cover. Finally, larger wetlands may have more abundant wet-meadow and low-prairie zones (Kantrud and Stewart 1977, Mack and Flake 1980, Fairbairn and Dinsmore 2001) where ducks often concentrate to feed (Stewart and Kantrud 1977, Leschisin et al 1992). Conversely, smaller wetlands have been found to be more attractive for breeding birds (Brown and Dinsmore 1986), and typically have higher edge-to-area ratios (Stevens et al. 2003). Small, seasonal wetlands were reported to support an average of 15% more breeding dabbling duck pairs than larger semi-permanent wetlands, and have been found to increase the duck pair suitability of larger wetlands (Naugle et al. 2001).

As predicted, my models suggest that the number and area of wetlands in a landscape was important to attracting duck pairs at the landscape scale. Research conducted by Brown and Dinsmore (1986), Kadlec and Smith (1992), Kaminski and Weller (1992), Johnson et al. (1994), Cowardin et al. (1998), and Fairbairn and Dinsmore (2001) all indicated that areas containing high wetland densities had the strongest relationships with duck abundance in general. Greater wetland area within a complex of wetlands also supported higher species richness (Fairbairn and Dinsmore 2001, Webb et al. 2010). Greater numbers of small wetlands can increase the total area-to-edge ratio for a plot, which has been found to relate significantly with species richness (Fairbairn and

Dinsmore 2001). I found that, at the landscape scale, FSMS plots that contained greater numbers of wetlands attracted more breeding dabbling duck pairs (guild 1), and plots with greater wetland areas attracted more breeding diving duck pairs (guild 2). These relationships are relatively intuitive because the foraging habits and nesting requirements for dabblers and diving ducks are quite different. Dabbling ducks are more prone to use temporary and seasonal wetlands during the breeding season, whereas diving ducks seek deeper semi-permanent and permanent wetlands (Stewart and Kantrud 1977).

The amount of open water within a sample pond also had a strong positive relationship with duck pair abundance. My results indicated that the relationship between breeding duck pairs and open water habitat was greater than with vegetation cover composition. Similarly, many studies have found that duck abundance was greater on wetlands in a “hemi-marsh” state (e.g., Weller and Spatcher 1965, Weller and Fredrickson 1974, Murkin et al. 1982, 1997, Ringelman and Longcore 1982, Hemesath and Dinsmore 1993, and VanRees-Siewert and Dinsmore 1996). My results varied, likely due to the contents of my models, and the timing and focus of the FSMS. COVER and OPENWATER had a correlation score of 0.1 and were not included together in any of my candidate models. FSMS protocols were created based on recommendations by Hammond (1969), who suggested the use of multiple methods to meet the goal of obtaining a “complete count”. On expansive hemi-marsh wetlands, FSMS observers use several techniques (e.g., walk/wade, zig-zag in heavy cover, boat/canoe, making loud noises) to flush reclusive breeding pairs from cover while managing their time effectively to count all wetlands within the plot. Some of this variation may be due to the ease with which open wetlands containing emergent vegetation are surveyed, as well as the corresponding difficulty in surveying small open pockets of water surrounded by tall, dense emergent vegetation. Furthermore, depending on cover conditions, some ducks may simply hide or evade observers to avoid detection.

At local scales, it is probable that ducks compare one wetland to another within a suitable landscape (Hilden 1965, Talent et al. 1982, Mulhern et al. 1985, Orians and Wittenberger 1991). At this scale, wetland variables that influence productivity and security may be better predictors of duck pair use. Wetland water levels that vary annually, as found by Murphy et al. (1984), Kantrud et al. (1989), Swanson and Duebbert (1989), Parker et al. (1992), Merendino et al. (1993), Merendino and Ankney (1994), and Paquette and Ankney (1996) are generally most productive, and wetlands in a hemi-marsh state (Weller and Spatcher 1965, Weller and Fredrickson 1974, Kaminski and Prince 1981, Murkin et al. 1982, 1997, Ringelman and Longcore 1982, Hemesath and Dinsmore 1993, VanRees-Siewert and Dinsmore 1996) often provide characteristics most attractive to breeding duck pairs. Visual isolation, as outlined by Murkin et al. (1982) and Rehm and Baldassarre (2007), is also important to the hemi-marsh concept because it allows territorial duck species to occupy space in greater abundance at close proximity. My wetland productivity model was the closest to incorporating these favorable wetland traits for ducks. This model ranked in the middle of the five local models I evaluated and was 1266.1 AIC_c units from the best model.

At the landscape scale, trees are often assumed to have a negative impact on duck pair use, primarily because they are considered to be “unnatural” in the traditional duck breeding areas of the PPR. Stewart and Kantrud (1973), however, reported that duck distributions were unequal throughout different biotic regions in North Dakota. In the

PPR, there are typically higher pair estimates in the western and central areas, where there are fewer trees, but lower in the east, where more trees persist (HAPET 2016). Reynolds et al. (2006) reported that the number of duck pairs per wet area generally increased from south to north and from east to west in the PPR. It has been further suggested that the presence of trees deter duck pair use (Sargeant et al. 1993, Kantrud 1986, Rumble and Flake 1983). At local scales, trees may provide habitat for predators that depredate hens, nests, and broods. Shutler et al. (2000) found a negative relationship between blue-winged teal abundance and trees within a 10-m margin of wetlands, but failed to detect such a relationship for nine other duck species. My research evaluated trees and terrain features at both the local and landscape scales, but the models that included trees and terrain were found to be the least competitive models evaluated, suggesting little foundational support for the deterrent effects of trees (Table 2.9-2.12).

My results also indicated that grass at the local (Table 2.9 and 2.11) and landscape (Table 2.10 and 2.12) scales were not as important as other features. The proportion of grass in the landscape is important for nesting cover, but may not be as important during the initial site selection process. Clark et al. (1991) and Naugle et al. (2001) found that areas with higher grassland concentrations supported higher numbers of ducks. Similarly, HAPET models use research recommendations about the maximum travel distances between wetlands to appropriate grassland nesting sites based on bi-annual FSMS counts of breeding duck pairs. In fact, highly productive wetlands with little surrounding grassland may attract more breeding duck pairs than adjacent grasslands can support (D. Hertel, USFWS HAPET, Fergus Falls, MN, personal communication, March 2015). Pairs might be counted by FSMS as they use these wetlands for feeding and replenishing fat reserves, but may disperse to other areas with higher quality nest habitat, or they may remain and choose to use poorer quality nesting cover.

I assumed that variable topographic roughness within a FSMS plot would be an important predictor of wetland density and, therefore, duck pair abundance. My results suggested that topographic variability was indeed at least a modest predictor of duck pair abundance (Table 2.9 and 2.10). The degree of topographic variability within a landscape is likely more synchronous with the ratio of wetlands to uplands (Cedfeldt et al. 2000). Here, more variability, characterized by rolling topography, leads to higher wetland densities due to increased numbers of low areas that hold water. A balance between high and low VRM scores would likely be preferential because too much variability, along with steep banks, may result in increased drainage and runoff along with fewer wetland basins. Less topographic variation would produce more homogeneous terrain that contain few wetland basins and incurs a greater risk of conversion to cropland.

Large, permanent wetlands were most affected by the WFactor exclusion and their removal affected the conclusions of my project. Large and extra-large sample ponds comprised a relatively small proportion of all sample ponds investigated during my analyses (Table 2.2), however their presence and influence within FSMS plots was still evaluated by including the percentage of wetland area present within the plots. These large wetlands may contribute to attracting settling ducks to nearby smaller wetlands, which in turn may provide better quality nesting and brood habitat.

Factors found to promote higher pair densities on small or moderately sized sample ponds could also be applied to large wetlands. Management activities are also typically easier to conduct and manipulate in and around small to moderate sized wetlands. Larger wetlands often present more challenges associated with habitat management and decision-making, such as greater numbers of involved stakeholders who must sign off on proposed actions, previously established restrictions on certain types of management activities, and limited areas in which to perform wildlife enhancement actions (e.g., presence of fish and inability to regulate hydrology).

Species-specific models are likely more informative than grouping species by guilds, especially when evaluating large spatial scales. In the PPR, duck species tend to concentrate in areas based on life history and nesting preferences. For example, wood ducks are more abundant in the eastern portion of the PPR where hardwood trees and forested wetlands are more prevalent. Gadwall, northern pintail, and redheads are typically found in greater numbers in the western portion of the PPR (HAPET and NPWRC unpublished data). Even when guild sizes were reduced to only include two to three species, the results were strongly correlated with the more inclusive dabbler and diver guilds. Dzubin (1969) advised against grouping similar duck species and instead recommended the use of individual species analyses when evaluating relationships between wetland numbers and breeding duck pairs. As such, specific species models would be more informative for making management decisions related to individual species.

Finally, I focused on two spatial extents based on aerial images and available FSMS data at both plot and wetland scales. My landscape analysis was limited to features contained within 10.4-km² areas and likely missed effective detection of very large continuous wetlands and uplands (e.g., areas >10.4-km²) not fully contained within plots. Evaluating a larger area outside of plot boundaries would likely reveal additional information about the role of landscape features on settling breeding duck pairs. Future research should be conducted over various time series and at multiple spatial extents around FSMS sample areas, and should focus on individual species. Such research could provide additional, valuable information about the effects of landscape context on breeding duck pair use, duck species population changes over time, land feature effects over time, and could even help predict the influence of climate change on individual species use, distributions, and production in the PPR.

MANAGEMENT IMPLICATIONS

The results of my research suggested that breeding ducks appear to cue in on certain areas according to the number of wetlands present and the type and size of the wetland area primarily, whereas the amount of wetland habitat and likely nesting habitat available were less influential. Conservation managers should first evaluate their territories based on general landscape features, and then secondly by local attributes of individual habitats. By doing this, they can first identify priority areas (e.g., wetland complexes) to which ducks are already likely to respond based on this information, and then identify and assign priorities to individual wetlands for enhancement projects. In turn, each enhancement project at the local scale then contributes to a composite view of the overall landscape effect.

In general, by working in areas where wetland densities and area are larger at the landscape scale, managers have the best opportunity to influence duck pair settling in their respective territories through management actions. Clark et al. (1991) hypothesized that areas that have abundant wetlands were more likely to have wetlands that meet the specific requirements of breeding ducks. Managing for the number of wetlands through protection, restoration, and enhancement activities should increase the attractiveness, productive potential, and density of breeding duck pairs in the area. Upland habitat protection and management can also be an effective way of sustaining or increasing the duck production potential of an area (Reynolds et al. 2001, Reynolds et al. 2005, Reynolds et al. 2006).

Terrain ruggedness likely influences the number and size of wetlands present due to the amount of variation in the landscape and the slope of an area. Terrain effects are unmanageable; however, they could be used as an important indicator of remaining habitat based on the relative ease of farming specific sites. My research results did not provide evidence that terrain ruggedness at the landscape scale or slope at the local scale were also significant deterrents to breeding duck pairs.

My research results did not support the hypothesis that trees were a significant deterrent to settling duck pairs in the PPR, although my results should be validated, perhaps experimentally (e.g., through tree removal and planting). Similarly, my results did not appear to suggest that tree removal as a management strategy would be useful for increasing breeding duck pair use at the scales I studied. Wetland attractiveness to settling duck pairs may not be diminished by trees; however, patches of trees take up space that could otherwise provide grassland nesting cover, and can offer perches for avian predators, thereby negatively impacting nesting success and duckling mortality.

FIGURES, TABLES, and APPENDICES

Figure 2.1. The location and extent of the Prairie Pothole Region.

Figure 2.2. Location of Four Square Mile Survey plots within USFWS Wetland Management Districts.

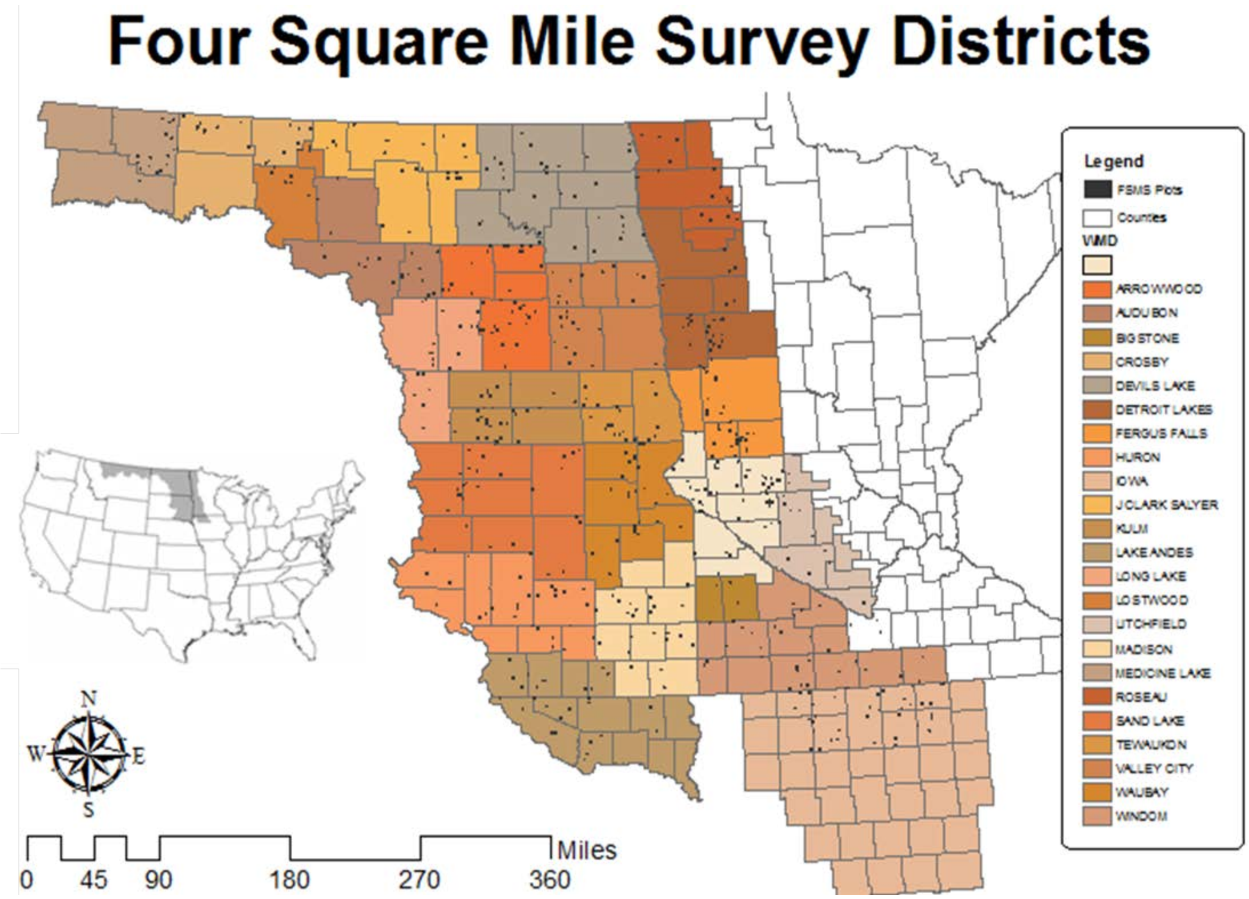

Figure 2.3. Distribution of 6,320 sample ponds in the Four Square Mile Survey by year's survey.

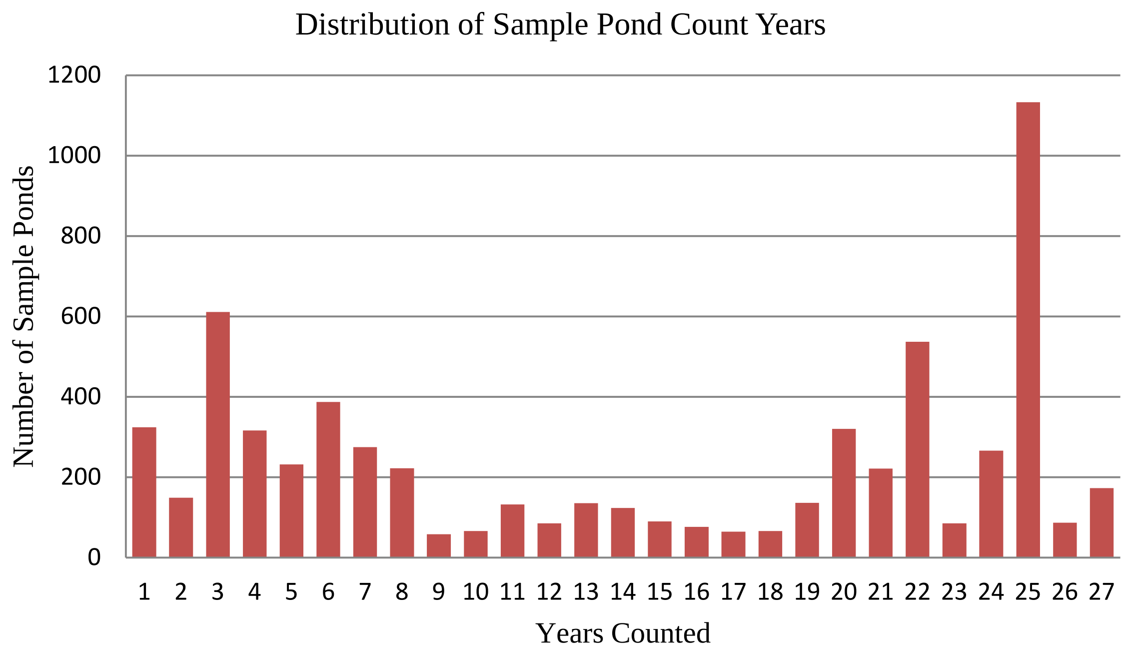

Figure 2.4. Examples of calculated shape values for sample wetlands in various Wetland Management Districts using corrected perimeter-to-area calculations, as described by Baker and Cai (1992). Left to right shape calculations expand showing increased variation in wetland shape. Plot represents a 10.4 km² Four Square Mile Survey sample block.

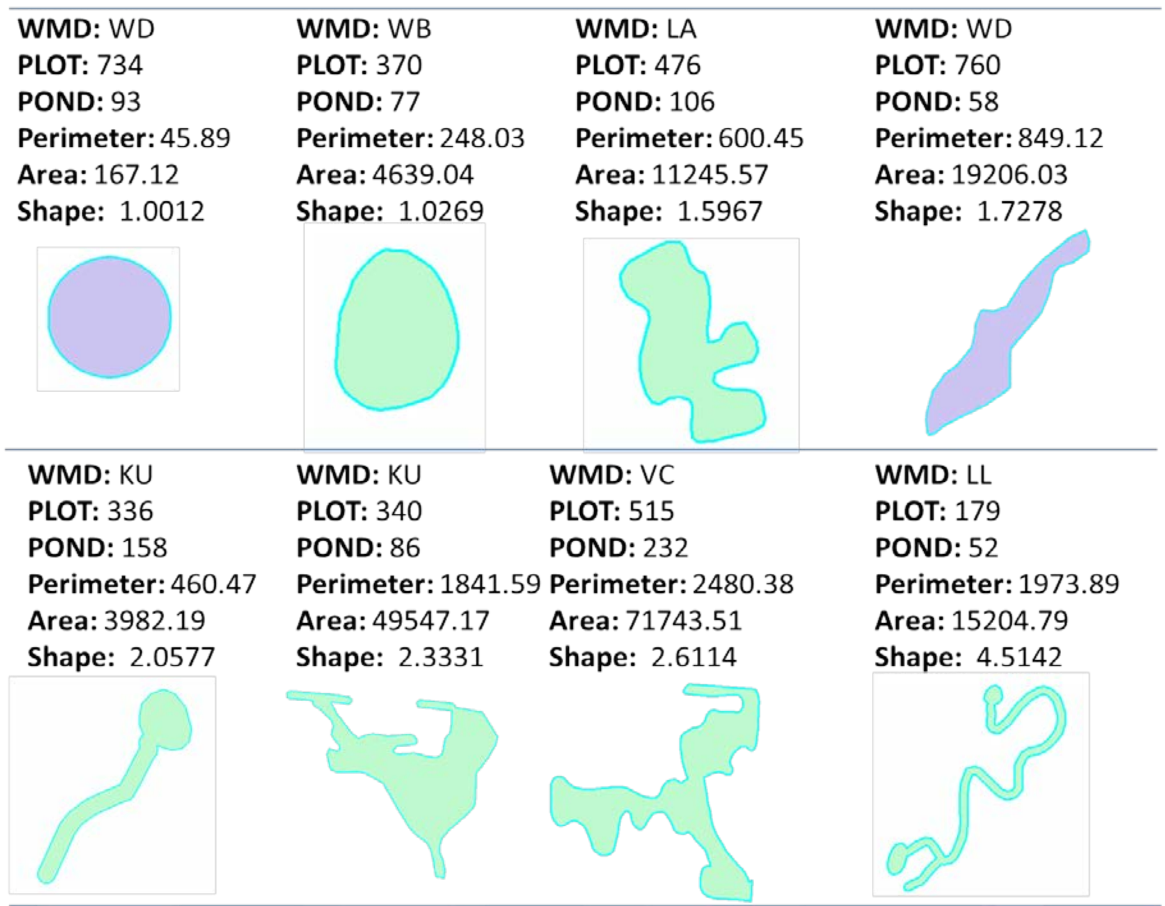

Figure 2.5. An example of the Vector Ruggedness Measure (VRM; left) and slope (right) raster for Detroit Lakes Wetland Management District Four Square Mile Survey plot 315. Means and standard deviations were calculated for VRM and slope within 6,454 buffered sample ponds and 583 plot areas.

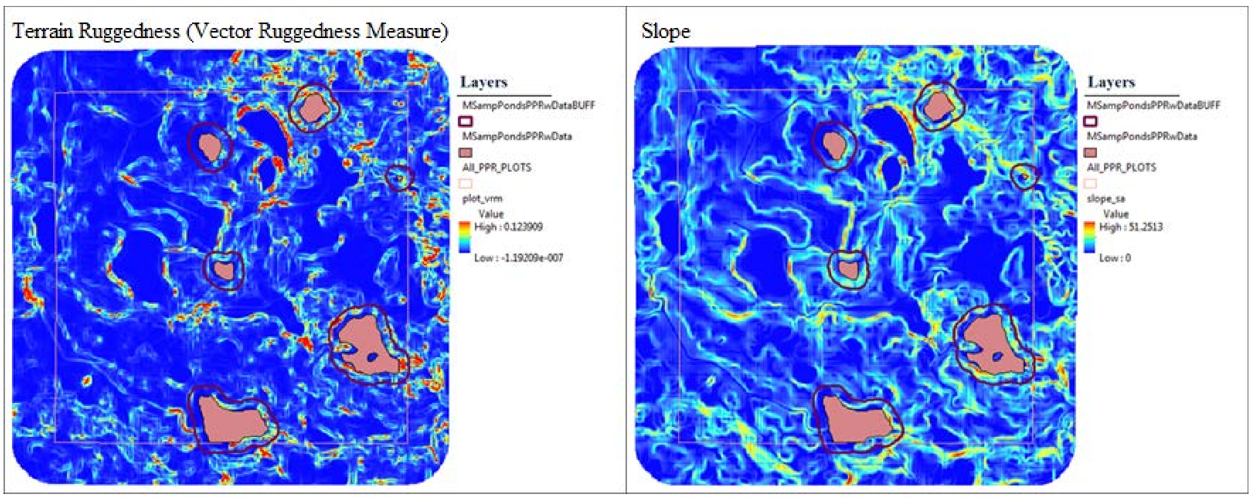

Figure 2.6. Ecological Regions and Wetland Management District boundaries used to create ten blocks across the Prairie Pothole Region. Zone names were assigned based on general position (western, central, or eastern) and numbers were selected in ascending order from North to South.

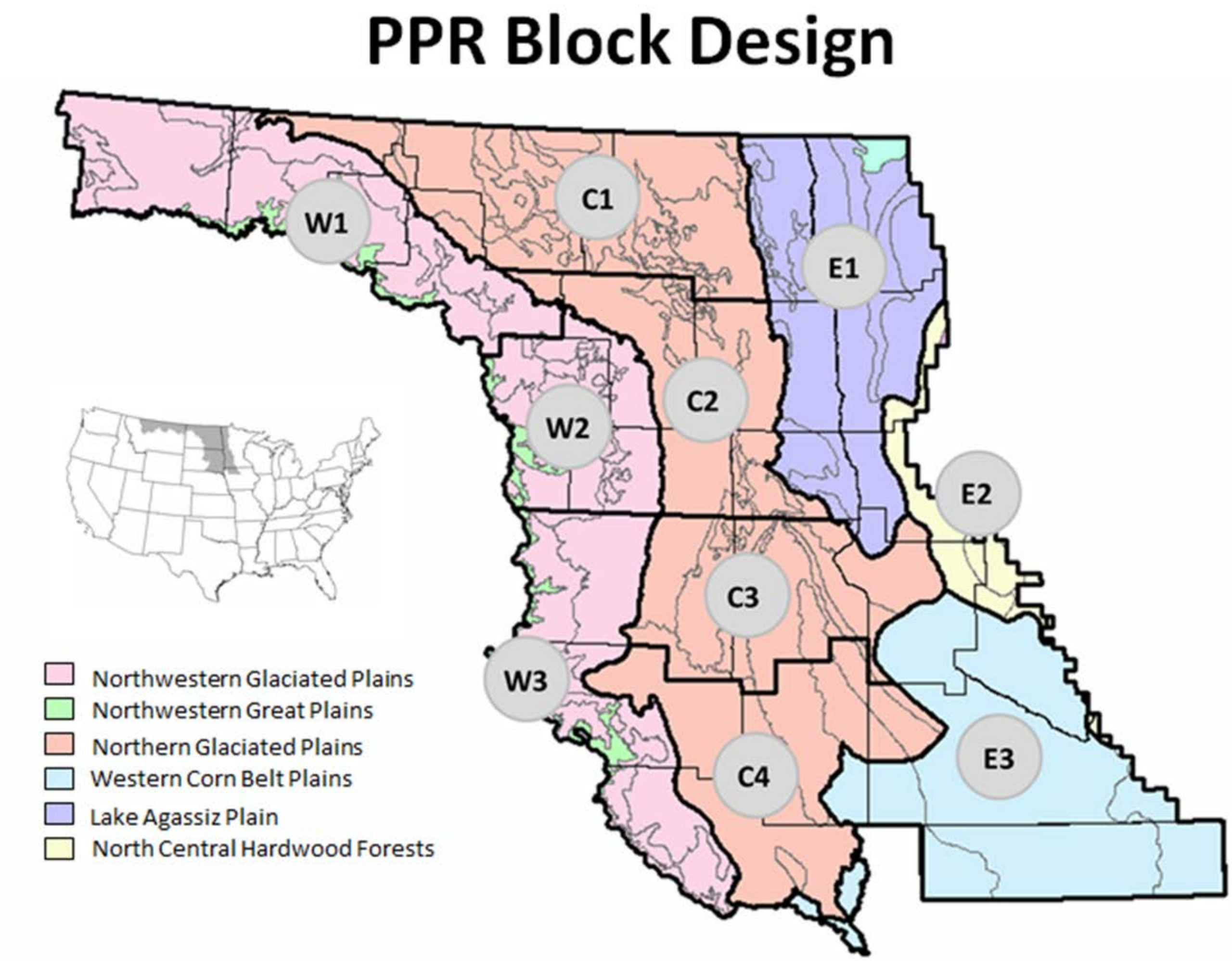

Table 2.1. The distribution of sample wetlands, by regime, that were included or excluded based on percentage of wetland area counted, percentage of basin sampled, and feature types collected using buffers.

Regime	Wetlands	Included	% Included	Excluded	% Excluded
Temporary	1,543	1,505	97.5	38	2.5
Seasonal	2,476	2,367	95.6	109	4.4
Semi-permanent	1,861	1,642	88.2	219	11.8
Permanent	440	213	48.4	227	51.6
Grand Total	6,320	5,727	90.6	593	9.4

Table 2.2. Proportion of sample wetlands, by size categories, that were included or excluded for analysis.

Size Category	Range	Wetlands	Included	% Included	Excluded	% Excluded
VS - Very Small	< 0.4 ha	2,986	2,957	99.0	29	1.0
SM - Small	0.4 – 2.0 ha	1,620	1,545	95.4	75	4.6
M - Medium	2.0 – 8.1 ha	965	853	88.4	112	11.6
LG - Large	8.1 – 40.5 ha	496	331	66.7	165	33.3
XL - Extra Large	> 40.5 ha	253	41	16.2	212	83.8
Total		6,320	5,727	90.6	593	9.4

Table 2.3. Distribution of sample wetlands, by regime, counted in the survey for more or less than nine years.

Regime	Wetlands	≥9 Yrs Counted	% ≥9 Yrs Counted	<9 Yrs Counted	% <9 Yrs Counted
Temporary	1,543	904	58.6	639	41.4
Seasonal	2,476	1,764	71.2	712	28.8
Semi-permanent	1,861	1,442	77.5	419	22.5
Permanent	440	358	81.4	82	18.6
Grand Total	6,320	4,468		1,852	

Table 2.4. Distribution of sample wetland associated WFactors (the expansion factor that is applied to the duck variables for sample ponds divided by plot boundaries and receive only a partial count of the total basin area) within four value ranges.

WFactor Range	# of Sample Wetlands	%
1	4,733	74.9
1.01-1.25	423	6.7
1.26-3.00	613	9.7
3.01-5000	551	8.7

Table 2.5. Distribution and area of 3,950 Four Square Mile Survey sample ponds by wetland regime class.

Regime	Count	Percent	Mean Area (ha)
1	873	22.1	9.2
2	1,668	42.2	11.7
3	1,252	31.7	40.7
4	157	4.0	161.9

Table 2.6. Distribution of 3,950 Four Square Mile Survey sample ponds by shape value generated using Baker and Cai’s (1992) shape equation.

Shape		
Range	Frequency	Percent
≥1.00 - <1.03	355	9.0
≥1.03 - <1.08	737	18.7
≥1.08 - <1.25	1,298	32.9
≥1.25 - <2.0	1,181	29.9
≥2.0 - <15	379	9.6

Table 2.7. Distribution of 3,950 Four Square Mile Survey sample ponds (local) by feature types within and immediately adjacent to wetlands.

	Grass		Trees		Water Permanence		Area (ha)		Yrsdry	
Range	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
0	616	15.6	3,327	84.2	43	1.09	0	0.0	954	24.2
>0 - <20	836	21.2	437	11.1	570	14.43	3,103	78.6	1,067	27.0
≥20 - <40	554	14.0	81	2.1	1,733	43.87	329	8.3	790	20.0
≥40 - <60	502	12.7	43	1.1	1,498	37.92	163	4.1	600	15.2
≥60 - <80	534	13.5	26	0.7	59	1.49	81	2.1	330	8.4
≥80 - <100	645	16.3	31	0.8	12	0.30	44	1.1	175	4.4
100	263	6.7	5	0.1	35	0.89	230	5.8	34	0.9

Table 2.8. Distribution of feature types within 583 Four Square Mile Survey plots (landscape).

Range	Grassland	Percent	Woodland	Percent	Plot Wet Area	Percent	Wetland Count	Percent
0	0	0.0	151	25.9	0	0.0	0	0.0
>0 - <20	224	38.4	421	72.2	489	83.9	77	13.2
≥20 - <40	177	30.4	9	1.5	79	13.6	83	14.2
≥40 - <60	96	16.5	1	0.2	10	1.7	69	11.8
≥60 - <80	64	11.0	1	0.2	1	0.2	59	10.1
≥80 - <100	22	3.8	0	0.0	4	0.7	56	9.6
100	0	0.0	0	0.0	0	0.0	239	41.0

Table 2.9. Local candidate models (WS -wetland status, DW – diverse wetlands, WP – wetland productivity, WA – wetland attractiveness, and VS1 – view-scape local) used to predict within sample pond and adjacent feature effects on guild 1, based on number of parameters (*K*), -2 log-likelihood score (-2 log), Second-order Akaike's Information Criterion (AIC_c), and model weight (w_i).

Model ID	Model	*K*	-2 Log	AIC_c	ΔAIC_c	w_i
WS	AREA+YRSDRY+REGIME+OPENWATER	7	8,511.1	8,675.0	0.0	1
DW	AREA+SHAPE+COVER+YRSDRY+SLOPE	8	8,717.9	8,907.1	232.1	<0.001
WP	COVER+PERM+YRSDRY+GRASS	7	9,755.3	9,941.1	1,266.1	<0.001
WA	GRASS+OCTREES+COVER+WETNUM	7	10,860.8	11,066.0	2,391.0	0
VS1	TREES+SLOPE	5	10,869.4	11,022.2	2,347.2	0

Table 2.10. Landscape candidate models (WD – wetland density, PH – plot habitat, and VS2 – view-scape landscape) used to predict plot feature effects on guild 1, based on number of parameters (*K*), Second-order Akaike's Information Criterion (AIC_c), and model weight (w_i).

Model ID	Model	*K*	-2 Log	AIC_c	ΔAIC_c	w_i
WD	WETNUM+WETAREA+RUGGEDNESS	6	5,842.0	5,943.8	0.0	1
PH	WETNUM+GRASSLAND+PLOTWATER	7	6,369.3	6,495.6	551.8	<0.001
VS2	WOODLAND+RUGGEDNESS	5	8,236.1	8,354.4	2,410.5	0

Table 2.11. Local candidate models (WS -wetland status, DW – diverse wetlands, WP – wetland productivity, WA – wetland attractiveness, and VS1 – view-scape local) used to predict within sample pond and adjacent feature effects on guild 2, based on number of parameters (K), -2 log-likelihood score (-2 log), Akaike's Information Criterion (AIC), and model weight (w_i).

Model ID	Model	K	-2 Log	AIC$_c$	ΔAIC$_c$	w_i
WS	AREA+YRSDRY+REGIME+OPENWATER	7	4,135.4	4,222.3	0.0	1
DW	AREA+SHAPE+COVER+YRSDRY+SLOPE	8	4,208.3	4,308.1	85.7	<0.001
WP	COVER+PERM+YRSDRY+GRASS	7	5,264.2	5,371.0	1,148.7	<0.001
WA	GRASS+OCTREES+COVER+WETNUM	7	5,776.6	5,892.4	1,670.1	0
VS1	TREES+SLOPE	5	5,792.6	5,878.8	1,656.4	0

Table 2.12. Landscape candidate models (WD – wetland density, PH – plot habitat, and VS2 – view-scape landscape) used to predict plot feature effects on guild 2, based on number of parameters (K), -2 log-likelihood score (-2 log), Akaike's Information Criterion (AIC), and model weight (w_i).

Model ID	Model	K	-2 Log	AIC$_c$	ΔAIC$_c$	w_i
WD	WETNUM+WETAREA+RUGGEDNESS	6	6,011.3	6,115.8	0.0	1
PH	WETNUM+GRASSLAND+PLOTWATER	7	6,342.0	6,467.7	351.9	<0.001
VS2	WOODLAND+RUGGEDNESS	5	8,144.4	8,261.5	2,145.7	0

Table 2.13. The best approximating local candidate model explaining variation in guild 1 and 2 values for Four Square Mile Survey (FSMS) sample ponds. Includes mean, standard deviation, effect estimate, standard error, regression coefficient lower and upper confidence intervals, and predicted change based on an increase of one standard deviation.

Local: Wetland Status

Guild 1			Regression Coefficient				Predicted change per 1 SD		
Effect	Mean	Standard Deviation	Estimate	SE	LCL	UCL	Mean	LCL	UCL
INTERCEPT			1.000	0.092	0.821	1.180			
AREA	3.657	0.792	0.633	0.011	0.612	0.653	1.882	1.844	1.922
OPENWATER	55.483	39.314	0.179	0.010	0.159	0.199	1.196	1.172	1.221
REGIME	2.175	0.816	0.062	0.012	0.040	0.085			
YRSDRY	26.315	26.550	-0.159	0.012	-0.183	-0.136	0.853	0.833	0.873

Guild 2			Regression Coefficient				Predicted change per 1 SD		
Effect	Mean	Standard Deviation	Estimate	SE	LCL	UCL	Mean	LCL	UCL
INTERCEPT			0.189	0.043	0.104	0.274			
AREA	3.657	0.792	0.273	0.007	0.258	0.287	1.313	1.295	1.332
OPENWATER	55.483	39.314	0.038	0.007	0.024	0.053	1.039	1.025	1.054
REGIME	2.175	0.816	0.049	0.008	0.033	0.064			
YRSDRY	26.315	26.550	-0.025	0.008	-0.042	-0.009	0.975	0.959	0.991

Table 2.14. The best approximating landscape candidate model explaining variation in values for guild 1 and 2 values for Four Square Mile Survey (FSMS) plots. Includes mean, standard deviation, effect estimate, standard error, regression coefficient lower and upper confidence intervals, and predicted change based on an increase of one standard deviation.

Landscape: Wetland Density Model

Guild 1			Regression Coefficient				Predicted change per 1 SD		
Effect	Mean	Standard Deviation	Estimate	SE	LCL	UCL	Mean	LCL	UCL
INTERCEPT			5.009	0.215	4.587	5.431			
RUGGEDNESS	0.000	0.000	0.078	0.009	0.060	0.096	1.081	1.062	1.101
WETAREA	1377.723	890491.436	0.349	0.009	0.332	0.366	1.417	1.393	1.442
WETNUM	149.418	104.102	0.384	0.010	0.364	0.404	1.468	1.440	1.497

Guild 2			Regression Coefficient				Predicted change per 1 SD		
Effect	Mean	Standard Deviation	Estimate	SE	LCL	UCL	Mean	LCL	UCL
INTERCEPT			2.867	0.294	2.290	3.444			
RUGGEDNESS	0.000	0.000	0.092	0.009	0.073	0.110	1.096	1.076	1.116
WETAREA	1377.723	890491.436	0.366	0.009	0.349	0.384	1.442	1.417	1.468
WETNUM	149.418	104.102	0.318	0.010	0.298	0.338	1.374	1.347	1.402

(Appendix A)

Wetland Management District Abbreviations Used in the Four Square Mile Survey

Code – Wetland Management District

AR – Arrowwood (Region 6)

AU – Audubon (Region 6)

CL – Crosby & Lostwood (combined) (Region 6)

DE – Detroit Lakes (Region 3)

DL – Devils Lake (Region 6)

FF – Fergus Falls (Region 3)

HU – Huron (Region 6)

IA – Iowa (Region 3)

JC – J. Clark Sayler (Region 6)

KU – Kulm (Region 6)

LA – Lake Andes (Region 6)

LF – Litchfield (Region 3)

LL – Long Lake (Region 6)

MA – Madison (Region 6)

MO – Morris (Region 3)

ML – Medicine Lake (Region 6)

RO – Roseau (Region 3)

SL – Sand Lake (Region 6)

TE – Tewaukon (Region 6)

VC – Valley City (Region 6)

WB – Waubay (Region 6)

WD – Windom (Region 3)

(Appendix B)

Detailed National Land-cover Class Definitions for the PPJV Extent for Raster "PPJV_2011_Land-cover"

- The extent includes only the area within the PPJV boundary. The raster data is taken from the EROS Data Center's work for the 2011 HAPET land-cover project.
- Note: Linear road features were minimized prior to use in compilation for NLCD classes 21 and 22.

(Definitions based on NLCD 2001 Land-cover Class Definitions)

10. Decision Tree Modeled Water/Wetland – all areas of open water and/or wetland vegetation. Includes: Temporary, Seasonal, Semipermanent, Lake, and Riverine wetlands.

11. NDWI water from first cloud-free LandSat of 2011. Open Water - All areas of open water, generally with less than 25 percent cover of vegetation or soil.

21. NLCD Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for <20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes

22. NLCD Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover.

These areas most commonly include single-family housing units.

23. NLCD Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. NLCD Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial properties. Impervious surfaces account for 80 to100 percent of the total cover.

31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for <15 percent of total cover.

40. Forest - Areas dominated by trees generally >5 meters tall, and >20 percent of total vegetation cover.

52. Shrub/Scrub - Areas dominated by shrubs; <5 meters tall with shrub canopy typically >20 percent of total vegetation. This class includes true shrubs, young trees in early successional stages, or trees stunted from environmental conditions or influences.

71. Grassland/Herbaceous - Areas dominated by grammanoid or herbaceous vegetation, generally >80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

75. CRP – Areas enrolled in the USDA Conservation Reserve Program and the Conservation Practice that have resulted in the planting of perennial non woody vegetation.

76. Undisturbed Grassland - Areas dominated by grammanoid or herbaceous vegetation, generally >80 percent of total vegetation. These areas are not subject to grazing or intensive management such as tilling. These areas commonly include Conservation Reserve Program and Waterfowl Production Area lands.

80. Hay - Areas of grasses, legumes, or grass-legume mixtures planted for hay crops, or areas of grammanoid or herbaceous vegetation typically hayed on a perennial cycle. NOTE: This definition may be changed to include only tame hay with specific alfalfa thresholds, depending on how the classification process distinguishes this class

82. Crop / Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton. Also includes areas of perennial woody crops, such as orchards and vineyards. Crop vegetation accounts for >20 percent of total vegetation. This class also includes all land being actively tilled.

111. FWS Temporary Wetland

112. FWS Seasonal Wetland

113. FWS Semipermanent Wetland

114. FWS Lake Wetland

115. FWS Riverine Wetland

116. FWS Intermittent Riverine Wetland

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