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Effects of sediment removal techniques on avian communities and vegetational attributes in restored prairie pothole wetlands

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EFFECTS OF SEDIMENT REMOVAL TECHNIQUES ON AVIAN COMMUNITIES AND VEGETATIONAL ATTRIBUTES IN RESTORED PRAIRIE POTHOLE WETLANDS

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PREFACE

This thesis is written in the style of the Journal of Wildlife Management, to which a portion will be submitted for publication.

ABSTRACT

With the loss and degradation of wetlands in some areas of the Prairie Pothole Region (PPR) reaching 80-90%, it is critical that resource managers ensure that the habitat that is put back on the landscape is as high quality as possible. Resource managers have been excavating sediment and topsoil, to promote the “hemi-marsh” condition, during the wetland restoration process in the PPR for over 20 years. I refer to the commonly held perception that the hemi-marsh condition supports the most diverse avian communities in small prairie pothole wetlands as the hemi-marsh condition hypothesis. The literature currently does not address the effects of excavation on the proportion of vegetative zones (i.e., sedge meadow, emergent vegetation, and open water) or avian communities in semi-permanent wetlands that are less than 0.6 ha, yet there are thousands of these wetlands throughout the PPR. Understanding the effects of excavation and testing the hemi-marsh condition hypothesis in small prairie wetlands is important to resource managers because these small wetlands are critical for maintaining the integrity of prairie wetland complexes. I conducted vegetation surveys, avian surveys, and estimated nest success on 40 small (<0.6 ha), semi-permanent wetlands in the PPR of Minnesota to assess the influence of excavation on vegetation and avian communities. My data indicated a significant difference in the proportion of all vegetative zones between wetlands that were excavated until topsoil was exposed (topsoil excavations) and wetlands that were excavated until subsoil was exposed (subsoil excavations) ($F_{3, 148}$ = 21.533, $P < 0.001$, $\eta p^2 = 0.304$). The subsoil excavation technique increased the proportion of the open water zone (subsoil excavations: $\bar{x}$ = 20.5%, SD = 18.1 and

topsoil excavations: $\bar{x}$ = 15.7%, SD = 14.8) by inhibiting plant growth in exposed subsoil. Altering the topography within basins decreased the proportion of the sedge meadow zone when the subsoil excavation technique was used (subsoil excavations: $\bar{x}$ = 46.8%, SD = 20.7 and topsoil excavations: $\bar{x}$ = 69.9%, SD = 13.6). This technique resulted in an increase in the proportion of the emergent vegetation zone (subsoil excavations: $\bar{x}$ = 32.7%, SD = 23.4 and topsoil excavations: $\bar{x}$ = 14.6%, SD = 12.5) by replacing sedge meadow with deeper water habitat. My analyses did not show a significant difference in Shannon-Weiner Diversity Index ($F_{2,\,70}$ = 0.770, P = 0.467, ηp^2 = 0.022), Simpson's Index of Diversity ($F_{1.844}$ = 0.016, P = 0.979, ηp^2 < 0.001), or daily survival probability (F_1 = 1.334, P = 0.254, ηp^2 = 0.029) between topsoil and subsoil excavations. However, avian density ($F_{1.688}$ = 3.497, P = 0.041, ηp^2 = 0.047) and nest density (F_1 = 9.863, P = 0.003, ηp^2 = 0.180) were significantly higher in subsoil excavations. With red-winged blackbird (*Agelaius phoeniceus*) and sora (*Porzana carolina*) accounting for over 83.5% of the nests in my study, I expected to see greater avian densities and nest densities in subsoil excavations since these species required emergent vegetation for nesting substrate. My statistical models indicated that avian diversity is best predicted by a combination of the proportion of emergent vegetation spring, proportion of emergent vegetation summer, and wetland area more so than by the proportion of emergent vegetation alone which is the basis of the hemi-marsh condition hypothesis. Clearly, small, less than 0.6 ha, prairie pothole wetlands function differently than their larger counterparts. Resource managers need to recognize the limitations in small wetlands; therefore, promoting the hemi-marsh condition in small wetlands is not the most efficient use of management dollars. My recommendations are to restore small prairie wetlands to their historical topography by using the topsoil excavation technique because resource managers do not currently know the potential negative impacts that exposing subsoil could have on plant and macroinvertebrate communities.

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I cannot thank the staff at the Detroit Lakes Wetland Management District (WMD) office enough for allowing me to use their facilities and for providing me with the "laboratory" in which to conduct this research. Without the pioneering work of these resource managers, who saw the need to address restoration and management issues, this research would not have been possible. Of course, I cannot forget the conservation-minded private landowners not only for providing me access to their properties, but for recognizing the importance of putting wildlife habitat back on the landscape. I thank Shawn May, Wildlife Biologist, Detroit Lakes WMD, for working with these private landowners through the USFWS's Partners for Fish and Wildlife Program and for providing me with the maps and records for all of the properties used in this study.

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INTRODUCTION

The conversion of land for agricultural purposes has been the leading cause of wetland degradation in the Prairie Pothole Region (PPR) of the Northern Great Plains since the nineteenth century (Dahl and Johnson 1991). Prior to the Food Security Act of 1985, producers were encouraged to drain wetlands to increase agricultural production on their lands (Wenzel 1992). In the Minnesota (MN) portion of the PPR, nearly 80% of the wetlands have been lost (Wenzel 1992). The loss and degradation of wetlands in this region has had far reaching effects on vegetation, wildlife, and humans. Flood-water retention, groundwater recharge, and both consumptive and non-consumptive recreational uses are a few of the benefits and ecological services that wetlands provide. Additionally, there are many native species that depend on wetlands at some point during their life cycles. The high level of productivity of wetlands makes them critical stopover sites for many migratory bird species, which use them for resting and restoring their energy reserves. Wetlands also are required habitat for many breeding bird species. A study of the bird communities in the PPR of North Dakota and South Dakota documented 108 bird species within wetlands and 124 bird species on the adjacent uplands (Ratti et al. 2001).

By the mid-1980s, resource managers and the general public recognized that there was a need to mitigate the loss of this valuable natural resource. For over 20 years, various government agencies and non-governmental organizations have been restoring wetlands in the PPR on both public and private lands. The United States Fish and Wildlife Service (USFWS) and its partners have restored thousands of prairie wetlands throughout the region through its Partner's for Fish and Wildlife Program and Small

Wetlands Acquisition Program. The initial goal of most wetland restoration programs was to restore as much habitat as possible for the lowest monetary cost. Consequently, detailed assessments of sites have been difficult due to the large number of restored basins on the landscape. This is especially true for small, less than 0.5 ha, restored wetlands. In the past, small wetlands were often overlooked in regards to their ecological significance at both large and small spatial scales. At the landscape level, Naugle et al. (2001) found that small wetlands (<0.5 ha) are critical for maintaining the integrity of prairie wetlands complexes. According to their models, species that use multiple wetlands within a season, such as northern pintail (*Anas acuta*), are the most vulnerable to the loss of small wetlands. Despite the thousands of small basins that have been restored in the past 20 years and the thousands that currently are being managed throughout the PPR, there has been little research that addresses the habitat attributes within small wetlands and their influence on avian communities specifically. Restoration and management activities have been based on the management recommendations from research that was conducted on much larger (>50 ha) basins (Weller and Spatcher 1965). Although restoration and management decisions were made based on the best science that was available at the time, it is imperative that resource managers are provided with information on the ecology of small prairie wetlands specifically in order to help guide restoration and management decisions in the future.

By the late 1990s, resource managers across North America began to focus more attention on the potential success of their restoration efforts. The success of a wetland restoration can be assessed at multiple levels. The most basic measure of the success of a wetland restoration is restoring the hydrology to the basin. However, a fully functioning ecosystem is typically the desired goal of restoration projects. Most restored ecosystems will never achieve their historical state prior to degradation. Falk et al. (2006:1) explained that, "a more realistic goal may [*sic*] be to move a damaged system to an ecological state that is within some acceptable limits relative to a less disturbed system". Attributes of the plant and avian communities are often used to assess the success of restoration efforts and as indicators of environmental quality (Galatowitsch and van der Valk 1996, Ratti et al. 2001). Remnant plant seed and invertebrate egg banks typically are relied on for regeneration after the hydrology is restored to previously drained wetlands. Galatowitsch and van der Valk (1996) referred to the process of rapid recolonization of restored wetlands from the remnant plant seed bank as the efficient-community hypothesis. Galatowitsch and van der Valk (1996) did not find rapid recolonization in their restored wetlands. In their study, the composition of vegetation in restored wetlands is significantly different than the vegetation in natural prairie wetlands. Other studies have reported similar results, indicating that restoring these dynamic ecosystems is usually much more complex than solely restoring the hydrology (Budelsky and Galatowitsch 2000, Mulhouse and Galatowitsch 2003, Seabloom and van der Valk 2003).

Many of the wetlands in central MN have been drained through the construction of drainage ditches. The soil from the ditching process is either spread on the adjacent uplands or deposited within the basin to further prevent water from pooling. After the vegetation from upland areas is removed, cultivation and soil erosion often contribute to the process of sedimentation within the drained basins (Gleason and Euliss 1998, Gleason et al. 2003). Cultivation also can destroy remnant seed and invertebrate egg banks. Studies have documented that even a small accumulation of sediment is enough to inhibit emergence of aquatic invertebrates and vegetation by burying the remnant seed and invertebrate egg banks (Gleason and Euliss 1998, Gleason et al. 2003). Resource managers recognize that removing this accumulated sediment layer would probably be a valuable component in many wetland restorations, but developing up a sediment excavation protocol is a complex process. Sediment is distributed unevenly within basins because of variations in microtopography. This variation makes the precise removal of sediment, with conventional excavation machinery, virtually impossible. A recent study on the effects of soil removal in restored wetlands reported that the top 10 cm of soil contained the greatest number and diversity of plant seeds (Hausman et al. 2007). This makes the most valuable layer of the seed bank the most vulnerable layer to destruction by machinery during excavation.

A common technique that has been used to restore wetlands in MN is to construct dams across the drainage ditches. These dams also are referred to as earthen berms or ditch plugs. Most of these wetlands cannot be restored to their historical hydroperiod and function if the sediment and fill material are not removed. For example, if a wetland that historically flooded semi-permanently was filled in with sediment, simply plugging the drainage ditch might only be sufficient to return a temporary or seasonal hydroperiod to the basin. Therefore, restoring the historical topography of the basin is critical. Although restoring the historical topography to wetlands is critical, it is not economically feasible on basins that are much larger than 0.5 ha since the monetary cost of excavation is high.

Resource managers from the Detroit Lakes Wetland Management District (WMD) have been using two sediment excavation techniques to restore small prairie pothole wetlands for the past 20 years, thus providing an ecological laboratory in which to test the effects of multiple sediment removal techniques (Falk et al. 2006). I refer to these wetland restoration techniques as the "topsoil excavation technique" and the "subsoil excavation technique". Both techniques involve restoring hydrology to the basins with a conventional ditch plug. However, the topsoil excavation technique involves excavating sediment and fill material from within a drained basin until topsoil is exposed, while the subsoil excavation technique involves excavating sediment, fill material, and nutrient rich topsoil from within a drained basin until subsoil is exposed. I refer to wetlands restored by these two techniques as "topsoil" and "subsoil excavations" respectively. Using the topsoil excavation technique for removal of sediment and fill material is hypothesized to restore basins close to their historical topography and hydrology while uncovering remnant seed and invertebrate egg banks. Hausman et al. (2007) reported that excavation within restored wetlands has a large impact on the plant community composition. Excavation reduced the proportion of invasive species and promoted obligate wetland plant species in their study sites. In the absence of competition from invasive plant species, native plants theoretically have an increased chance of becoming established in restored wetlands. With their remnant seed and invertebrate egg banks uncovered and reduced competition, excavated wetlands could support more diverse plant and invertebrate populations (Gleason et al. 2003). Resource managers soon began to see that many of the small restored wetlands were dominated or "choked out" by dense stands of emergent vegetation (*Typha* spp.) therefore decreasing the proportion of open water habitat. This condition is not desirable because research suggests that the most diverse avian communities are found on prairie wetlands with an emergent vegetation to open water ratio of 50:50 or what is called the "hemi-marsh" condition (Weller and Spatcher 1965). The subsoil excavation technique was designed because removing the nutrient rich topsoil alters the topography and substrate within the basin, which could influence the horizontal extent of the open water zone. By increasing the proportion of open water and thus promoting the "hemi-marsh" condition, the subsoil excavation technique is hypothesized to promote higher habitat quality for wildlife in restored wetlands (Weller and Spatcher 1965). I refer to the commonly held perception that the "hemi-marsh" condition is the ideal management objective in small prairie pothole wetlands as the hemi-marsh condition hypothesis. Without empirical evidence confirming these assumptions some resource managers are hesitant to use either excavation technique until their effects on the ecosystem have been assessed.

Although plant community composition can be a useful measure of environmental quality, the number of variables affecting it makes comparative studies difficult and labor intensive. However, the horizontal extent of vegetative zones in prairie wetlands is a common and effective method for assessing habitat quality for avian communities (Weller and Spatcher 1965). Multiple studies have analyzed the effects of the horizontal arrangement of vegetation on avian diversity and density, yet its effects on nest success or nest density are largely unknown (Weller and Spatcher 1965, Weller and Frederickson 1974, Rehm and Baldassarre 2007). An analysis of vegetational attributes within wetlands, such as the proportion of the three major vegetative zones (sedge meadow, emergent vegetation, and open water), is much less labor intensive than measuring community composition and represents one of the habitat cues that is thought to directly influence the avian community (Rehm and Baldassarre 2007). Plant species diversity also is expected to be low in restored wetlands because many of the species that are sensitive to disturbance already have been eliminated from the plant seed bank (Aronson and Galatowitsch 2008, Galatowitsch and van der Valk 1996).

Avian communities commonly are analyzed to assess ecosystem health. Analyzing this taxon in restored wetlands is a powerful and efficient tool for a number of reasons. In general, avian communities can indicate the health of the ecosystem because they usually are supported by diverse plant and invertebrate communities (Smith and Smith 2006). Many avian species are affected negatively by invasive plant species and the accumulation of environmental contaminants, which are major issues in our modern landscape (Conway 2008). Migratory bird conservation also is one of the primary management objectives of many conservation agencies and organizations. The cost effectiveness of analyzing avian communities can have a role in the preference for this method of evaluation, especially compared to the cost of detailed plant community composition analyses (Ratti et al. 2001). Avian nest success commonly is used to assess habitat quality because it is an indirect measure of reproductive success. Not only could it indicate high quality plant and invertebrate communities, but it could also indicate the condition of breeding individuals both pre- and post-territory establishment. Individuals that are in the best breeding condition should establish territories in the highest quality habitat or areas with the highest potential nest success. Nest success of obligate wetland avian communities also can be a useful measure of habitat quality because many of these avian species rely exclusively on one wetland during the nesting period of the breeding season. However, some species like canvasback (*Aythya valisineria*) often use multiple small wetlands in close proximity (Mowbray 2002). Some examples of common wetland avian species in the PPR of Minnesota include the red-winged blackbird (*Agelaius phoeniceus)*, sora (*Porzana carolina*), and marsh wren (*Cistothorus palustris*). One of the difficulties with using avian communities as an indicator of habitat quality is that many avian species respond to habitat quality cues at both small and large scales (Cunningham and Johnson 2006, Quamen 2007). Multi-scale modeling techniques have allowed researchers to gain a better understanding of how avian species respond to landscape attributes (Quamen 2007). Although multi-scale modeling is a powerful tool for guiding conservation efforts, Rehm and Baldassarre (2007) found that most obligate wetland avian species, such as the American bittern (*Botaurus lentiginosus*), least bittern (*Ixobrychus exilis*), sora, and Virginia rail (*Rallus limicola*), are more sensitive to individual marsh characteristics than to surrounding habitat. Melvin and Gibbs (1996) found both the sora and Virginia rail to be area independent when selecting breeding wetlands. This suggests that some wetland avian species respond to cues at different spatial scales than many upland nesting grassland birds (Cunningham and Johnson 2006); therefore, wetland avian research should emphasize attributes at a smaller scale or within wetlands.

The objectives of my study were to compare the following between topsoil and subsoil excavations during the breeding season: (1) the proportion of vegetative zones, (2) avian diversity, (3) avian density, (4) nest success, and (5) nest density. I also determined if there was empirical evidence supporting the hemi-marsh condition hypothesis in small prairie pothole wetlands.

STUDY AREA AND WETLAND SELECTION

All wetlands included in my study were semi-permanent wetlands that were restored by the USFWS (Stewart and Kantrud 1971). They were drained for more than 20 years through drainage ditches and located in former agricultural fields. The wetlands were located on 8 properties within the Detroit Lakes WMD, which was located within the PPR of central MN. The properties included Waterfowl Production Areas and private properties. The adjacent uplands consisted of grassland habitat of either restored tallgrass prairie or tame grasses, such as smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*). The basins were classified as palustrine emergent wetlands according to Cowardin et al. (1979) and as semi-permanent wetlands according to Stewart and Kantrud (1971). All of the wetlands were 0.03-0.60 ha ($\bar{x}$ = 0.19 ha) and it had been 2-7 yr ($\bar{x}$ = 4 yr) since restoration.

Using 2008 aerial photos in a Geographic Information System (GIS) and maps provided by the Detroit Lakes WMD staff, I initially selected 50 topsoil excavations and 50 subsoil excavations that fit the above guidelines. The 2008 aerial photos were obtained from the MN Geospatial Information Office website. I randomly selected 25 wetlands in each restoration category to be included in my study. If I found that any of the first 25 wetlands did not fit the above criteria on the first site visit, I used the next closest wetland that fit the selection criteria. After visiting all of the properties on-the-ground I included 21 topsoil excavations and 19 subsoil excavations in my study; all wetlands were studied during the 2009 and 2010 breeding seasons.

METHODS

Vegetational Attributes

Since Weller and Spatcher (1965) reported that the hemi-marsh condition supports the most diverse avian communities, the emergent vegetation to open water ratio has been used extensively as an indicator of habitat quality in prairie pothole wetlands. This is a preferred method because it can be rapidly and accurately assessed in the field. I used an adapted version of the mapping technique used by Weller and Spatcher (1965). I mapped the proportion of the three major vegetative zones (sedge meadow, emergent vegetation, and open water zones), similar to those described by Stewart and Kantrud (1971), within prairie wetlands that could be delineated accurately within a single growing season. All wetlands had a similar horizontal arrangement of these vegetative zones due to the excavation associated with their restoration. The vegetative zones occurred in concentric rings with the sedge meadow zone being the most peripheral and shallow zone that is dominated by various sedges (*Carex* spp.) and grasses (*Poaceae* spp.). The next deepest zone is the emergent vegetation zone that is dominated by various cattail (*Typha* spp.) and bulrush (*Schoenoplectus* spp.) species. The open water zone has the ability to support emergent vegetation; however, the open water state is typically dominated by submerged vegetation (Stewart and Kantrud 1971).

I mapped the wetland perimeter and vegetative zones by recording Universal Transverse Mercator (UTM) coordinates along the wetland and upland interface and the interface between two vegetative zones by using a handheld geographic position system (GPS) attached to a backpack antenna. The accuracy of the GPS unit was ± 2-3 m. I mapped vegetation two times each field season in order get a measure of the spatial and temporal changes in the plant community. The spring survey was conducted in early May, which consisted of only residual vegetation from the previous growing season. The summer survey was conducted in early July, which consisted of both residual vegetation and new vegetation from that current growing season. A patch of vegetation was mapped if it was larger than approximately 4 m^2 and greater than 75% visual obstruction to the water surface. Residual vegetation was not mapped if it was completely knocked over and would not provide cover for nesting birds. I downloaded GPS coordinates into a GIS and converted those data into shapefiles to calculate the area of the wetlands and the three vegetative zones in hectares.

Avian Surveys

Call-broadcast surveys were used to sample the avian community within each wetland during the 2009 and 2010 breeding seasons. All individuals seen or heard during the survey period were recorded. My methods were adapted from the Standardized North American Marsh Bird Monitoring Protocol, which was published by the Arizona Cooperative Fish and Wildlife Research Unit in April 2008 (Conway 2008). The call-broadcast survey technique was used to elicit responses from secretive marsh birds, which are otherwise rarely seen or heard.

There was 1 survey point associated with each wetland and a complete count of all birds within the wetland was attempted since the effective range of a call-broadcast survey point is larger than 0.6 ha (Gibbs and Melvin 1993). Survey points were located on the eastern edge of the study wetlands to aid in visual identification of birds. UTM coordinates were recorded during the first survey to allow relocation on all subsequent surveys. Survey points were located on the upland-wetland vegetation interface to limit disturbance.

Surveys were conducted 30 min before sunrise to 4.5 hr after sunrise, since vocalization probability is greatest during this period (Gibbs and Melvin 1993, Conway 2008). Each point was surveyed 3 times each season based on the presumed peak in marsh bird breeding season and to ensure that at least 1 survey was conducted during the peak in each species seasonal response period (Conway 2008). As suggested by Conway (2008), survey 1 was conducted 1 May – 14 May, survey 2 the 15 May – 31 May, and survey 3 the 1 June – 15 June.

There was a 5 min passive period at each survey point prior to broadcasting focal species vocalizations. All avian species seen or heard during the passive period and during the broadcast period were recorded. All birds that were flushed from the study wetlands while the observer approached were recorded accordingly and included in the analyses. The recorded calls of species that breed in my study area were obtained from the National Marsh Bird Survey Coordinator. This ensured that the broadcast sequence coincided with the protocol and was consistent throughout the study. This broadcast sequence consisted of 30 sec of the most common vocalizations of each focal species interspersed with 30 sec of silence. The marsh birds that were included in the broadcast sequence were the least bittern, yellow rail (*Coturnicops noveboracensis*), sora, Virginia rail, American bittern, American coot (*Fulica americana*), and pied-billed grebe (*Podilymbus podiceps*). Calls were broadcast in this order because the least bittern has the least intrusive vocalization and the pied-billed grebe has the most intrusive vocalization (Conway 2008). Each survey period was 12 min, including the 5 min passive period and 7 min broadcast period. My broadcast equipment consisted of a portable MP3 player attached to an electronic predator call that was calibrated with a sound-level meter to produce 80 to 90 dB at 1 m in front of the speaker. The broadcast equipment was placed on the ground with the speaker facing the center of the wetland. The observer stood 2 m to one side of the speakers while listening for responses.

Avian diversity was calculated by using both the Shannon-Weiner Diversity Index and the Simpson's Index of Diversity since the Shannon-Weiner Diversity Index is more sensitive to differences in rare species and the Simpson's Index of Diversity is more sensitive to differences in common species (Ratti et al. 2001). Avian density is the number of individuals detected on each survey per hectare.

Avian Nesting Analyses

Nest searching began in late May during the 2009 and 2010 breeding seasons. Nests of all avian species found within the study wetlands were monitored. I was able to systematically search all wetlands entirely since they were all less than 0.6 ha. The majority of the nests were detected within the vegetation. I also located and monitored nests via incidental discovery (Kerns et al. 2010). Nest searching took place throughout daylight hours since I was not relying solely on detecting nests by flushing incubating adults. Wetlands were searched approximately every 2 weeks to locate new nests.

Nests were marked by using fluorescent flagging tied to tall vegetation placed 2-4 m from the nest in a direction that was the most visible to the approaching observer. The approach direction was recorded on each visit so that the observers could approach the nests from a different direction on subsequent visits. However, once the observers were close to the nests, they would approach from the same direction based on microhabitat characteristics to alleviate the effects of scent trails around nests and prevent excess disturbance to the vegetation at the nest site.

I estimated the age of a nest after it was located to help me estimate the expected fledging dates for altricial species and hatch dates for precocial species. These dates were used to determine the fate of the nests. In a precocial species for example, if there was no other evidence and the eggs were missing on a nest check that was well before the estimated hatch date, then I assumed that the nest was depredated. Natural history data for each species were found in Baicich and Harrison (1997) and the Birds of North America species accounts. The method for determining the age of nests varied by species. For precocial species, I determined the incubation stage by either candling or floating eggs. Waterfowl eggs were candled by using the methods of Weller (1965). This is a preferred method due to the larger size of waterfowl eggs (Klett et al. 1986). The eggs of all other precocial species were floated to determine the approximate incubation stage by using the methods of Hays and LeCroy (1971). I estimated the age of altricial nestlings based on the degree of feather development.

Nests were monitored every 3 to 5 days until the fate of the nest could be determined. Nests were recorded as successful, depredated, abandoned, disturbed, or unknown. If a nest had 1 or more individuals fledge it was recorded as successful regardless of prior disturbances. Membrane and egg shell evidence were analyzed according to Klett et al. (1986) and Mabee (1997). If a nest had fewer eggs than the previous visit, hatchlings missing early in development, or any other signs of predators, it was recorded as depredated if no individuals hatched or fledged. If adults were no longer attending nests or if eggs did not hatch, the nest was recorded as abandoned. To aid in this determination, I placed vegetation in an X-shape on the nest so that the vegetation was disturbed if an adult was still attending the nest. If a nest or eggs were damaged by the searchers, it was recorded as disturbed if no individuals hatched or fledged. If the fate of a nest could not be determined it was recorded as unknown.

Using the Mayfield Method (Mayfield 1961), I estimated nest success, which was used as a measure of habitat quality for avian communities because it is a common technique for indirectly measuring reproductive success. Although there are many techniques for analyzing nest success, Jehle et al. (2004) found that the Mayfield Method has results similar to program MARK and the Stanley Method as long as there is a short temporal interval between nest checks. It also is a preferred method because of its simplicity and the ability to make comparison across studies (Jehle et al. 2004). The measure of nest success that I reported is daily survival probability (DSP), which was the probability that a nest will survive for one day. This measure is calculated by subtracting the total number of failed nests divided by the number of exposure days (Mayfield 1961).

The number of exposure days is the number of days that a nest is exposed to the environment while under observation (Mayfield 1961). DSP was calculated separately for each wetland.

Statistical Analyses

A 3-way multivariate analysis of covariance (MANCOVA) was used to determine the influence of the factors year (2009 and 2010), survey period (spring and summer), and restoration technique (topsoil and subsoil excavation techniques) on the proportion of vegetative zones (sedge meadow, emergent vegetation, and open water zones). The Box's test of equality of covariance matrices was used to determine if the assumption of equality of covariance matrices was met. I reported the Pillai's trace test statistic which is robust to violations of the equal covariance assumption (Zar 2010).The proportion of vegetative zones was calculated by dividing the area of the vegetative zone by the total area of the wetland. I used survey period as a factor instead of a repeated measure because I was interested in the difference in the proportion of vegetated zones between survey periods or seasons. Time since restoration (yr) and wetland area (ha) were the two covariates included in my vegetation analysis. Time since restoration was included to control for the natural variation in the plant community associated with changing successional stages. Wetland area was included because it could have influenced the proportion of the basin that was excavated. Although common muskrat (*Ondatra zibethicus*) herbivory can have a major influence on the horizontal extent of the emergent vegetation zone I did not have a sufficient number of wetlands with common muskrat present to include this as a predictor variable in my analysis (2009 n = 2 and 2010 n = 12)

(Weller and Spatcher 1965). My statistical analysis was conducted by using PASW Statistics 18.0 with an alpha level of 0.05.

I used the 2-way analysis of covariance (ANCOVA) and the 2-way repeated measure ANCOVA with factors of year (2009 and 2010) and restoration technique (topsoil and subsoil excavation techniques) to analyze their influence on the avian communities. Although I studied the same wetlands in 2009 and 2010 I considered habitat selection based on site quality in any given year to be more consequential than site fidelity, which allowed me to meet the assumption of statistical independence between years (Brown and Smith 1998). The following 5 covariates were included in the 2-way ANCOVA to examine their influence on avian communities: time since restoration (yr), wetland area (ha), distance to nearest wetland (m), proportion of emergent vegetation spring, and proportion of emergent vegetation summer. Wetland area was included to account for the influence of the species area relationship. Distance to nearest wetland is the distance to the nearest semi-permanent wetland. Distances were estimated by using a GIS and 2008 aerial photography obtained from the MN Geospatial Information Office. I visited each wetland on the ground to confirm semi-permanent hydrology. I included this measure as a covariate in my analyses because of the close proximity of many of the basins in these wetland complexes. Due to their close proximity and the small spacial scale I did not consider this to be a landscape level variable. Although wetlands in the PPR typically are located in close proximity, pseudoreplication was avoided by counting only birds seen and heard within the wetland. Proportion of emergent vegetation spring and summer were calculated by dividing the area of emergent vegetation by the sum of the emergent vegetation and open water zones because this is the proportion of the wetland that is capable of supporting emergent vegetation. This is also a similar measure to the emergent vegetation to open water ratio used by Weller and Spatcher (1965). Proportion of emergent vegetation spring accounted for one of the within-wetland habitat attributes that breeding birds likely respond to initially when they arrive on the breeding grounds (Weller and Spatcher 1965). Proportion of emergent vegetation summer accounted for a within-wetland habitat attribute that breeding birds likely responded to during the nesting period. Data were arcsine transformed and log-transformed where appropriate to approximate normality (Zar 2010).

To test the hemi-marsh condition hypothesis in small prairie wetlands I used the backward elimination multiple regression to determine the relationship between the proportion of emergent vegetation and avian communities. The predictor variables time since restoration (yr), wetland area (ha), distance to nearest wetland (m), proportion of emergent vegetation spring, and proportion of emergent vegetation summer were included in the tests to control for their potential influence on avian communities. Including all of these predictor variables in the multiple regressions allowed me to identify the models that best described the functional relationship between the proportion of emergent vegetation and various measures of avian communities such as avian diversity and DSP (Zar 2010). The proportion of emergent vegetation spring and summer were calculated the same as with the ANCOVA analyses. I reported the models with the highest adjusted coefficient of determination (R^2_a) and which included the fewest predictor variables. I reported F-values based on the Wilks' lambda test statistic.

Sphericity was tested with the Mauchly's Test of Sphericity. The Greenhouse-Geisser correction was used and reported if the assumption of sphericity was violated. Partial eta-squared (ηp^2) was reported to indicate effect size.

RESULTS

Vegetational Attributes

The multivariate tests of the 3-way MANCOVA indicated that both survey period ($F_{3,\ 148} = 25.133$, $P < 0.001$, $\eta p^2 = 0.338$) and restoration technique ($F_{3,\ 148} = 21.533$, $P < 0.001$, $\eta p^2 = 0.304$) were significant predictor variables. However, year ($F_{3,\ 148} = 1.539$, $P = 0.207$, $\eta p^2 = 0.030$) was not a significant factor. Both covariates, time since restoration ($F_{3,\ 148} = 1.713$, $P = 0.167$, $\eta p^2 = 0.034$) and wetland area ($F_{3,\ 148} = 1.807$, $P = 0.148$, $\eta p^2 = 0.035$), were not significant. The tests of between-subjects effects showed that the proportions of all three vegetative zones were significantly different between topsoil and subsoil excavations: sedge meadow zone ($F_1 = 53.340$, $P < 0.001$, $\eta p^2 = 0.262$), emergent vegetation zone ($F_1 = 33.864$, $P < 0.001$, $\eta p^2 = 0.184$), and open water zone ($F_1 = 4.444$, $P = 0.037$, $\eta p^2 = 0.029$).

Avian Surveys

I detected a total of 1,156 individuals during my call-broadcast surveys during the 2009 (582 individuals) and 2010 (574 individuals) field seasons. This consisted of 40 species from 8 Orders: Anseriformes (7 species), Apodiformes (1 species), Charadriiformes (4 species), Ciconiiformes (1 species), Falconiformes (1 species), Galliformes (1 species), Gruiformes (3 species), and Passeriformes (22 species). Of the 40 species that I detected a total of 19 were detected 5 or fewer times.

I did not detect a difference in avian diversity between topsoil and subsoil excavations. The 2-way repeated measure ANCOVA on the Shannon-Weiner Diversity Index showed that year ($F_{2, 70}$ = 2.760, P = 0.070, ηp^2 = 0.073) and restoration technique ($F_{2, 70}$ = 0.770, P = 0.467, ηp^2 = 0.022) were not significant factors. This same test showed that time since restoration ($F_{2, 70}$ = 1.091, P = 0.342, ηp^2 = 0.030), wetland area ($F_{2, 70}$ = 2.868, P = 0.063, ηp^2 = 0.076), distance to nearest wetland ($F_{2, 70}$ = 0.046, P = 0.955, ηp^2 = 0.001), proportion of emergent vegetation spring ($F_{2, 70}$ = 0.715, P = 0.493, ηp^2 = 0.020), and proportion of emergent vegetation summer ($F_{2, 70}$ = 0.770, P = 0.467, ηp^2 = 0.022) were not significant covariates. The 2-way repeated measure ANCOVA on the Simpson's Index of Diversity showed that year ($F_{1.844}$ = 0.501, P = 0.592, ηp^2 = 0.007) and restoration technique ($F_{1.844}$ = 0.016, P = 0.979, ηp^2 < 0.001) were not significant factors. Furthermore, time since restoration ($F_{1.844}$ = 3.636, P = 0.032, ηp^2 = 0.049) and wetland area ($F_{1.844}$ = 3.424, P = 0.039, ηp^2 = 0.046) were significant covariates. Distance to nearest wetland ($F_{1.844}$ = 1.011, P = 0.362, ηp^2 = 0.014), proportion of emergent vegetation spring ($F_{1.844}$ = 0.697, P = 0.489, ηp^2 = 0.010), and proportion of emergent vegetation summer ($F_{1.844}$ = 0.100, P = 0.891, ηp^2 = 0.001) were not significant covariates.

Avian density was significantly different between topsoil and subsoil excavations. The 2-way repeated measure ANCOVA showed that restoration technique ($F_{1.688}$ = 3.497, P = 0.041, ηp^2 = 0.047) was a significant predictor variable, but year ($F_{1.688}$ = 2.546, P = 0.092, ηp^2 = 0.035) was not significant. This same test showed that proportion of emergent vegetation summer ($F_{1.688}$ = 3.341, P = 0.047, ηp^2 = 0.045) was a significant covariate. Time since restoration ($F_{1.688}$ = 0.100, P = 0.873, ηp^2 = 0.001), wetland area ($F_{1.688}$ = 0.416, P = 0.626, ηp^2 = 0.006), distance to nearest wetland ($F_{1.688}$ = 0.260, P = 0.734, ηp^2 = 0.004), and proportion of emergent vegetation spring ($F_{1.688}$ = 1.084, P = 0.333, ηp^2 = 0.015) were not significant.

Avian Nesting Analyses

I located and monitored a total of 170 nests of 11 species during the duration of my study, with 61 nests in 2009 and 109 nests in 2010 (Table 1). Red-winged blackbird (n = 118) was the most common breeding bird in my study wetlands, accounting for 69.4% of the nests. Sora (n = 24) was the next most common breeder followed by the marsh wren (n = 8). I located 5 or less nests of the following 8 species: American bittern, canvasback, clay-colored sparrow (*Spizella pallida*), mallard (*Anas platyrhynchos*), ring-necked duck (*Aythya collaris*), sedge wren (*Cistothorus platensis*), Virginia rail, and yellow-headed blackbird (*Xanthocephalus xanthocephalus*).

There was not a significant difference in DSP between topsoil and subsoil excavations. The 2-way ANCOVA showed that year (F_1 = 10.100, P = 0.003, ηp^2 = 0.183) was a significant factor. Restoration technique (F_1 = 1.334, P = 0.254, ηp^2 = 0.029) was not significant. None of the covariates, time since restoration (F_1 = 1.390, P = 0.245, ηp^2 = 0.030), wetland area (F_1 = 0.094, P = 0.760, ηp^2 = 0.002), distance to nearest wetland (F_1 = 0.052, P = 0.821, ηp^2 = 0.001), proportion of emergent vegetation spring (F_1 = 0.055, P = 0.816, ηp^2 = 0.001), or proportion of emergent vegetation summer (F_1 = 0.363, P = 0.550, ηp^2 = 0.008), were found to be significant.

I did detect a difference in nest density between topsoil and subsoil excavations. The 2-way ANCOVA showed that restoration technique (F_1 = 9.863, P = 0.003, ηp^2 = 0.180) was a significant factor and that year (F_1 = 0.750, P = 0.391, ηp^2 = 0.016) was not a significant factor. This same test revealed that wetland area (F_1 = 3.201, P = 0.083, ηp^2 = 0.094) was a significant covariate. However, time since restoration (F_1 = 3.064, P = 0.087, ηp^2 = 0.064), distance to nearest wetland (F_1 = 0.152, P = 0.699, $\eta p^2 < 0.003$), proportion of emergent vegetation spring (F_1 = 0.004, P = 0.952, $\eta p^2 < 0.001$), and proportion of emergent vegetation summer (F_1 = 0.037, P = 0.848, ηp^2 = 0.001) were not significant covariates.

Testing the Hemi-marsh Condition Hypothesis

The multiple regression model that best predicted the Shannon-Weiner Diversity Index included proportion of emergent vegetation spring, proportion of emergent vegetation summer, and wetland area as predictor variables. This model did explain a significant proportion (R^2_a = 0.379) of variation in the data ($F_{3, 76}$ = 17.104, $P < 0.001$).

The multiple regression model that best predicted the Simpson's Index of Diversity included all of the predictor variables: time since restoration, wetland area, distance to nearest wetland, proportion of emergent vegetation spring, and proportion of emergent vegetation summer. This model did not explain a significant proportion (R^2_a = 0.215) of variation in the data ($F_{5, 74}$ = 5.338, $P < 0.001$).

Time since restoration, wetland area, proportion of emergent vegetation spring, and proportion of emergent vegetation summer were the predictor variables included in the multiple regression model that best predicted avian density. This model did not explain a significant proportion ($R^2_a = 0.099$) of variation in the data ($F_{2, 77} = 5.333$, P = 0.007).

Wetland area, distance to nearest wetland, proportion of emergent vegetation spring, and proportion of emergent vegetation summer were the predictor variables included in the multiple regression model that best predicted DSP. This model did not explain a significant proportion ($R^2_a = 0.031$) of variation in the data ($F_{2, 51} = 1.861$, P = 0.166).

Wetland area, distance to nearest wetland, proportion of emergent vegetation spring, and proportion of emergent vegetation summer were the predictor variables included in the multiple regression model that best predicted nest density. This model did not explain a significant proportion ($R^2_a = 0.207$) of variation in the data ($F_{2, 51} = 7.898$, P = 0.001).

DISCUSSION

Vegetational Attributes

My data suggested that the subsoil excavation technique increased the proportion of the open water zone (subsoil excavations: $\bar{x}$ = 20.5%, SD = 18.1 and topsoil excavations: $\bar{x}$ = 15.7%, SD = 14.8) just as it was designed to do. The consensus among resource managers is that open water areas and interspersion in semi-permanent wetlands tend to attract certain wetland bird species such as waterfowl (Weller and Spatcher 1965), whereas wetlands with a low proportion of open water provide lower quality habitat. The open water zone is thought to provide critical pair-bonding and foraging habitat, especially when it supports diverse submerged vegetation and macroinvertebrate communities. The increase in the proportion of the open water zone in subsoil excavations is because exposed subsoil does not provide a suitable substrate for the growth of most emergent and submerged plant species. Many subsoil excavations did not support any vegetation in areas of exposed subsoil even after several years of flooding. Whereas, all topsoil excavations supported vegetation throughout the entire basin. Without emergent or submerged vegetation to support macroinverterate populations exposed subsoil cannot provide high quality foraging habitat for avian communities.

The subsoil excavation technique also decreased the proportion of the sedge meadow zone (subsoil excavations: $\bar{x}$ = 46.8%, SD = 20.7 and topsoil excavations: $\bar{x}$ = 69.9%, SD = 13.6) by altering the topography within the basins. Removing the topsoil horizon causes subsoil excavations to become substantially deeper, resulting in water consolidation within the center of the basin. Consolidating water within the center of the basins drains the peripheral sedge meadow zone. This is particularly evident not only when slopes increase due to excavation associated with topsoil removal, but also when ditch plug construction material is excavated from within or directly adjacent to wetlands. The sedge meadow zone is often the most degraded vegetative zone, since it becomes farmable during dry years and even when wetlands are drained partially. Cultivation destroys and significantly alters much of the remnant seed and invertebrate egg banks (Aronson and Galatowitsch 2008). Therefore, using a restoration technique that further degrades the sedge meadow zone could have negative ramifications on all obligate sedge meadow species.

An unanticipated outcome of the subsoil excavation technique was an increase in the proportion of the emergent vegetation zone (subsoil excavations: $\bar{x}$ = 32.7%, SD = 23.4 and topsoil excavations: $\bar{x}$ = 14.6%, SD = 12.5), since this technique originally was meant to decrease the proportion of the emergent vegetation zone by increasing the proportion of open water within restored wetlands. Based on my data and site visits I attributed this increase to the conversion of portions of the sedge meadow into emergent vegetation zone. Removing topsoil from the sedge meadow zone increased the water depth and hydroperiod, allowing the newly exposed substrate to support emergent vegetation.

Another component of my vegetation analysis was the change in the proportion of vegetative zones between the survey periods. Most resource managers would expect to see major changes in the vertical structure of wetland plant communities; however, it seems that the spatial and temporal changes that occur naturally to the proportion of vegetative zones is not as well recognized. Many small wetlands are managed to provide open water areas for waterfowl pair-bonding. My data suggested that almost all topsoil and subsoil excavations provide some open water habitat in the spring prior to the growing season. Since waterfowl pair bonding occurs during the spring, resource managers should recognize that excavating within small wetlands to provide open water habitat in July is not appropriate.

Avian Communities

My data indicated that avian diversity and nest success were not significantly different between topsoil and subsoil excavations. However, avian density (subsoil excavations: $\bar{x}$ = 32.04, SD = 29.84 and topsoil excavations: $\bar{x}$ = 23.95, SD = 18.11) and nest density (subsoil excavations: $\bar{x}$ = 18.71, SD = 11.87 and topsoil excavations: $\bar{x}$ = 12.78, SD = 7.66) were significantly higher in subsoil excavations. These seemingly contradictory outcomes were explained by the results of my multiple regressions, MANCOVA, and by applying the natural history characteristics of the common breeding bird species in the study wetlands.

The models chosen by the backward elimination multiple regressions that best predicted avian diversity included the proportion of emergent vegetation spring, proportion of emergent vegetation summer, and wetland area (ha) as predictor variables with both diversity indexes. This indicated that a combination of the proportion of emergent vegetation zone and wetland area can have an effect on avian diversity in small prairie pothole wetlands. These statistical models suggested that avian diversity tended to increase as the proportion of emergent vegetation increased. Since the results of the MANCOVA showed that the proportion of emergent vegetation was higher in subsoil excavations, I would have expected avian diversity to be higher in these wetlands. However, this was not the case because avian diversity was inherently lower in small wetlands compared to much larger wetlands (>50 ha). Given that red-winged blackbird and sora accounted for over 83.5 % of the nests in my study, it was intuitive that I saw greater avian densities and nest densities in subsoil excavations or within the wetlands with a higher proportion of the emergent vegetation zone. These species are known to have low habitat specificity and to thrive in wetlands with dense stands of emergent vegetation and few open water areas (Yasukawa and Searcy 1995, Melvin and Gibbs

1996). I attributed the greater number of nests located in 2010 (2009: n = 61 and 2010: n = 109) to a difference in the proportion of the emergent vegetation spring between years. Although there was not a statistically significant difference ($F_1 = 1.272$, $P = 0.261$, $\eta p^2 = 0.008$), the proportion of the emergent vegetation spring was greater in 2010 (2009: $\bar{x}$ = 13.1 %, SD = 16.39 and 2010: $\bar{x}$ = 19.0%, SD = 19.6). High water levels early in spring 2009 eliminated most of the residual emergent vegetation. Lower water levels in spring 2010 allow for more residual emergent vegetation to remain standing which provided more nesting substrate for red-winged blackbird and sora.

Testing the Hemi-marsh Condition Hypothesis

Although the results of my multiple regression analyses indicated that the proportion of emergent vegetation was a crucial variable for predicting avian diversity in small wetlands, my results were not consistent with the hemi-marsh condition (Weller and Spatcher 1965). There was a positive linear correlation between the proportion of emergent vegetation and avian diversity in small prairie pothole wetlands and not a peak in avian diversity at intermediate proportions of emergent vegetation. My statistical models indicated that avian diversity is best predicted by a combination of the proportion of emergent vegetation spring, the proportion of emergent vegetation summer, and wetland area more so than by the proportion of emergent vegetation alone which is the basis of the hemi-marsh condition hypothesis. Resource managers need to recognize that there are thresholds when managing prairie wetlands. There is a limit when wetlands become small enough that the hemi-marsh management strategies are no longer appropriate. There also is a limit when wetlands become large enough that the lack of open water habitat decreases avian diversity. Although my data did not identify these thresholds, they suggested that promoting the hemi-marsh condition in wetlands that are small enough to excavate, which are typically less than 1 ha, is not an efficient use of management dollars. In general, habitat quality increased as the proportion of emergent vegetation increased and open water habitat is not a vital component to the ecology of small prairie pothole wetlands. Future research should focus on identifying these thresholds and the effects of wetland restoration techniques on plant community composition and macroinvertebrate communities.

Management Implications

Although ecological restoration is not a new practice, its application to modern society is immense (Falk et al. 2006). It gives the environment a chance to recover from exploitation and degradation, while allowing resource managers to test ecological principles (Falk et al. 2006). Wetland restoration programs have provided the laboratories for assessing many ecological phenomena. The primary goal of my study was to determine the most ecologically and economically efficient techniques for restoring small prairie pothole wetlands that have been degraded through drainage and sedimentation. Due to the large number of wetland restorations that will be completed in the future, it is imperative that resource managers are provided with high quality information about the effects of various sediment removal techniques associated with wetland restorations. Because the monetary costs of excavating are high, understanding the limitations and impacts of excavating within wetland basins is crucial (Hausman et al. 2007).

My data suggested that small, less than 0.6 ha, prairie pothole wetlands function differently than larger wetlands. Resource managers need to recognize that there are limitations in these small prairie wetlands. Wetland area is likely the limiting factor associated with avian diversity since small wetlands only support a subset of the potential wetland breeding birds, i.e., those species that are not area sensitive. Resource managers can now adapt their management and restoration strategies because they know that manipulating local vegetational attributes within small wetlands will not significantly influence avian communities. Therefore, promoting the hemi-marsh condition in small wetlands is not the most efficient use of management dollars. My recommendations are to restore small prairie wetlands to their historical topography by using the topsoil excavation technique because the potential negative impacts that exposing subsoil could have on plant and macroinvertebrate communities are not fully understood. The topsoil excavation technique should restore wetland slopes similar to the adjacent topography to prevent “flashy” hydrology associated with the edges of excavated areas and borrow pits (Aronson and Galatowitsch 2008). This technique should limit the negative impacts on the sedge meadow zone that are associated with the subsoil excavation technique. With thousands of these small wetlands across the PPR, the ultimate goal of my project was to provide resource managers throughout the PPR with both valuable information and guidelines allowing them to make more well-informed decisions on-the-ground.

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Table 1. Avian species detected during call-broadcast surveys in Minnesota, USA, 2009-2010.

Species	Scientific name	Order
American goldfinch	*Spinus tristis*	Passeriformes
American redstart*	*Setophaga ruticilla*	Passeriformes
Barn swallow	*Hirundo rustica*	Passeriformes
Black tern*	*Chlidonias niger*	Charadriiformes
Blue-winged teal	*Anas discors*	Anseriformes
Bobolink	*Dolichonyx oryzivorus*	Passeriformes
Brown-headed cowbird*	*Molothrus ater*	Passeriformes
Canada goose*	*Branta canadensis*	Anseriformes
Canvasback	*Aythya valisineria*	Anseriformes
Clay-colored sparrow	*Spizella pallida*	Passeriformes
Cliff swallow	*Petrochelidon pyrrhonota*	Passeriformes
Common yellowthroat	*Geothlypis trichas*	Passeriformes
Eastern phoebe*	*Sayornis phoebe*	Passeriformes

Table 1. Continued.

Species	Scientific name	Order
Hooded merganser	*Lophodytes cucullatus*	Anseriformes
Le Conte's sparrow	*Ammodramus leconteii*	Passeriformes
Least bittern*	*Ixobrychus exilis*	Ciconiiformes
Least flycatcher*	*Empidonax minimus*	Passeriformes
Mallard	*Anas platyrhynchos*	Anseriformes
Marsh wren	*Cistothorus palustris*	Passeriformes
Palm warbler*	*Dendroica palmarum*	Passeriformes
Red-winged blackbird	*Agelaius phoeniceus*	Passeriformes
Ring-necked duck*	*Aythya collaris*	Anseriformes
Ring-necked pheasant*	*Phasianus colchicus*	Galliformes
Ruby-throated hummingbird*	*Archilochus colubris*	Apodiformes
Sandhill crane*	*Grus canadensis*	Gruiformes
Savannah sparrow	*Passerculus sandwichensis*	Passeriformes
Sedge wren	*Cistothorus platensis*	Passeriformes

Table 1. Continued.

Species	Scientific name	Order
Sharp-Shinned hawk*	*Accipiter striatus*	Falconiformes
Solitary sandpiper*	*Tringa solitaria*	Charadriiformes
Song sparrow	*Melospiza melodia*	Passeriformes
Sora	*Porzana carolina*	Gruiformes
Swamp sparrow	*Melospiza georgiana*	Passeriformes
Tree swallow	*Tachycineta bicolor*	Passeriformes
Upland sandpiper*	*Bartramia longicauda*	Charadriiformes
Virginia rail	*Rallus limicola*	Gruiformes
Wilson's snipe*	*Gallinago delicata*	Charadriiformes
Wood duck*	*Aix sponsa*	Anseriformes
Yellow warbler*	*Dendroica petechia*	Passeriformes
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	Passeriformes
Yellow-rumped warbler*	*Dendroica coronata*	Passeriformes

* Species with less than 5 detections

Table 2. Avian diversity, avian density, daily survival probability, and nest density on 40 topsoil and subsoil excavations in Minnesota, USA, 2009-2010.

	Topsoil excavations		Subsoil excavations	
Variable	Mean	SE	Mean	SE
Shannon-Weiner Diversity Index[a,b]	1.019	0.820	1.196	0.799
Simpson's Index of Diversity[a,b]	0.640	0.364	0.668	0.317
Avian Density[a,b]	23.95	18.11	32.04	29.84
Daily Survival Probability[b]	0.959	0.054	0.950	0.050
Nest Density[b]	12.78	7.55	18.71	11.87

[a] Averaged across survey periods.

[b] Means and SE are reported from untransformed data.

Figure 1. Map of the Detroit Lakes Wetland Management District in Minnesota, USA, with 8 study sites represented by gray circles.

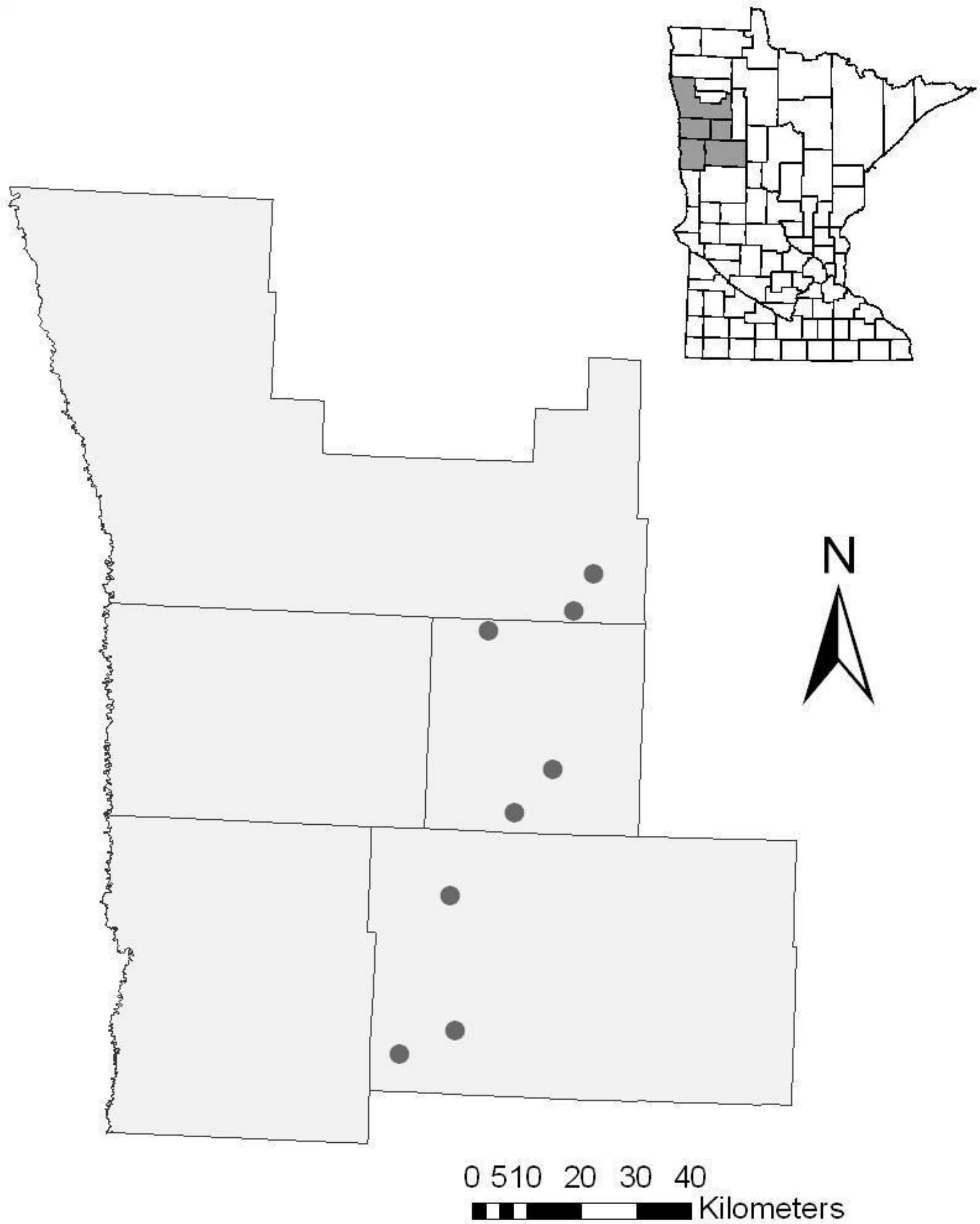

Figure 2. Map of Private Property 1 study site in Polk County, Minnesota, USA.

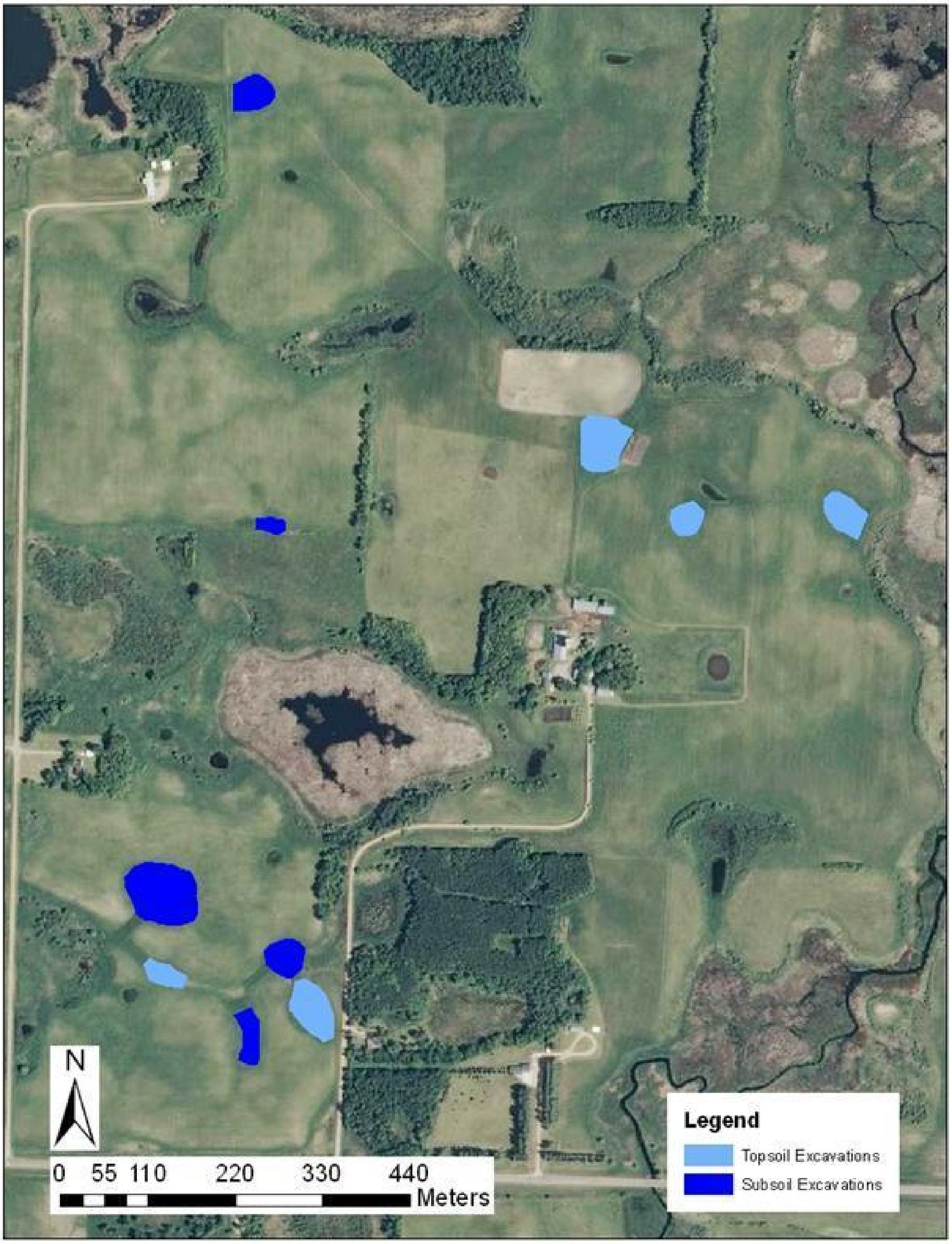

Figure 3. Map of the Sandhill Lake Waterfowl Production Area study site in Polk County, Minnesota, USA.

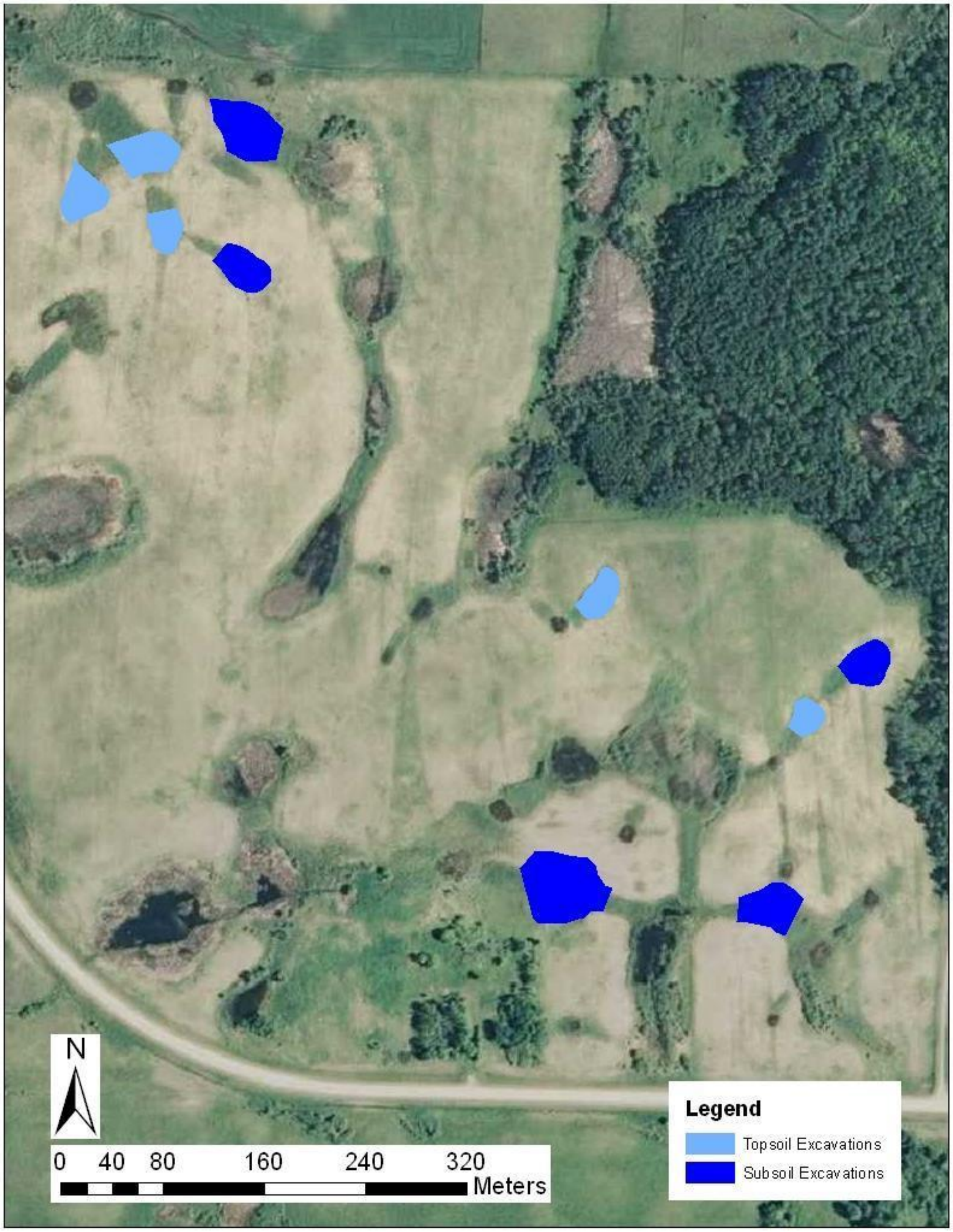

Figure 4. Map of the Nelson Praire Waterfowl Production Area study site in Mahnomen County, Minnesota, USA.

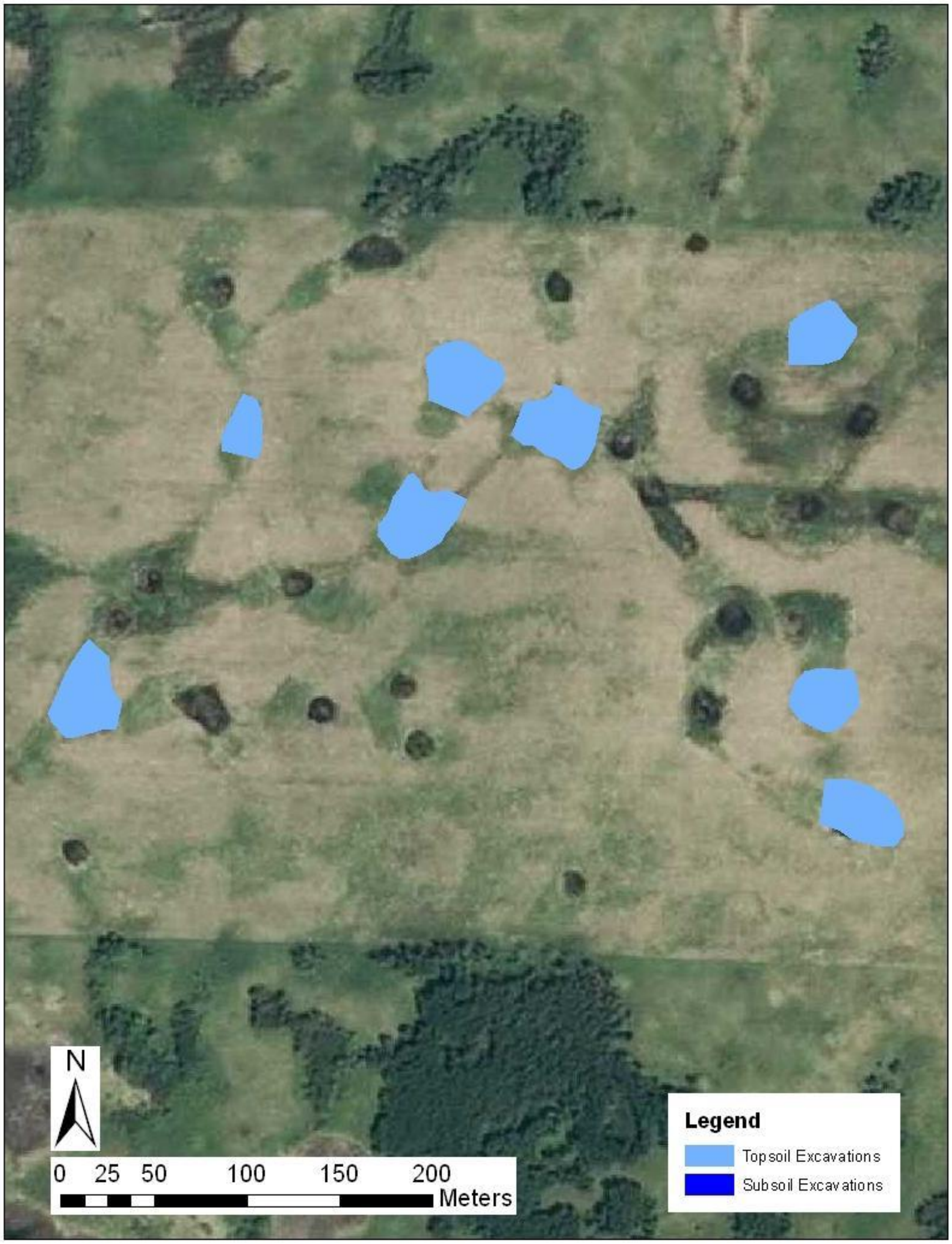

Figure 5. Map of Private Property 2 study site in Mahnomen County, Minnesota, USA.

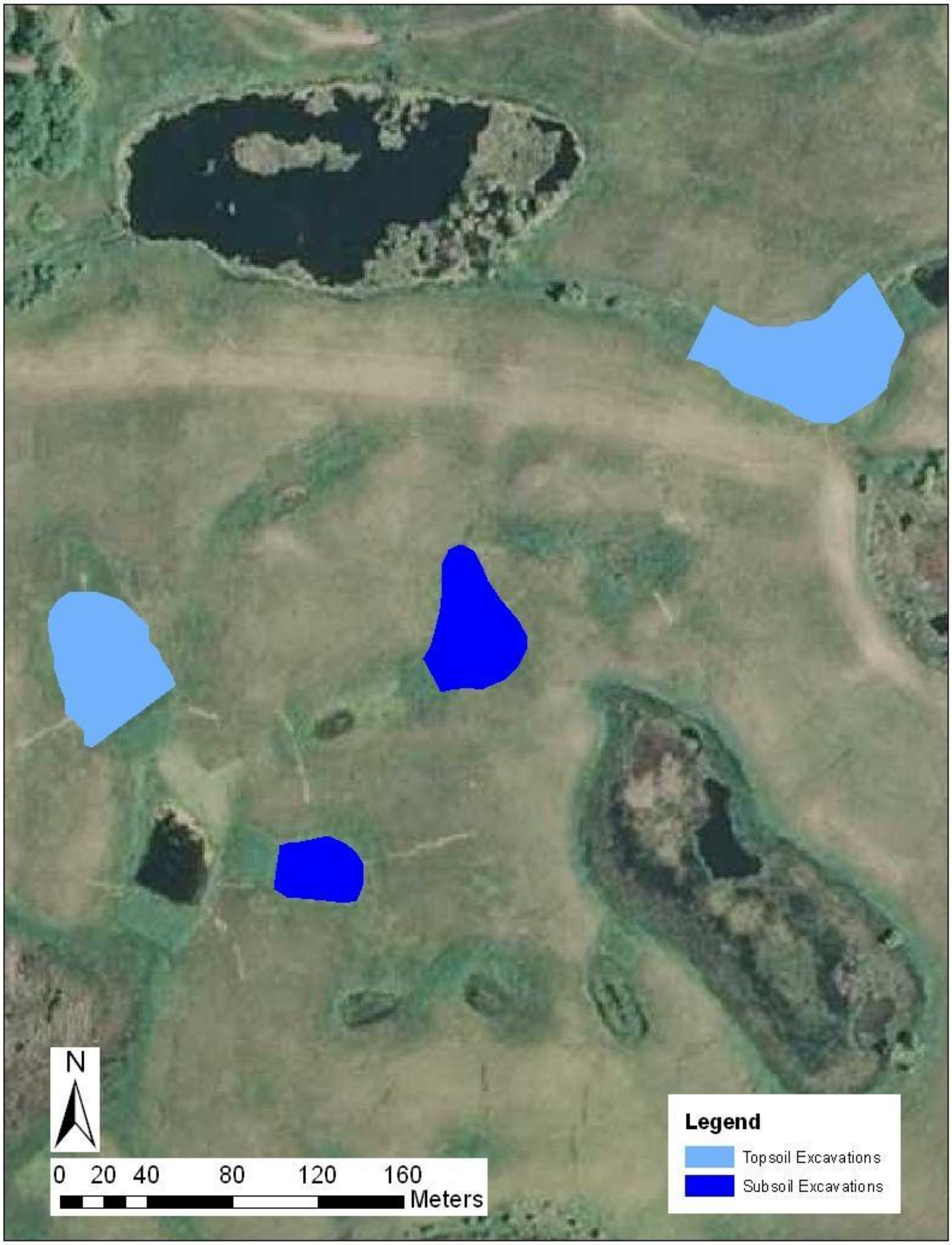

Figure 6. Map of Private Property 3 study site in Mahnomen County, Minnesota, USA.

Figure 7. Map of the Buchl Waterfowl Production Area study site in Becker County, Minnesota, USA.

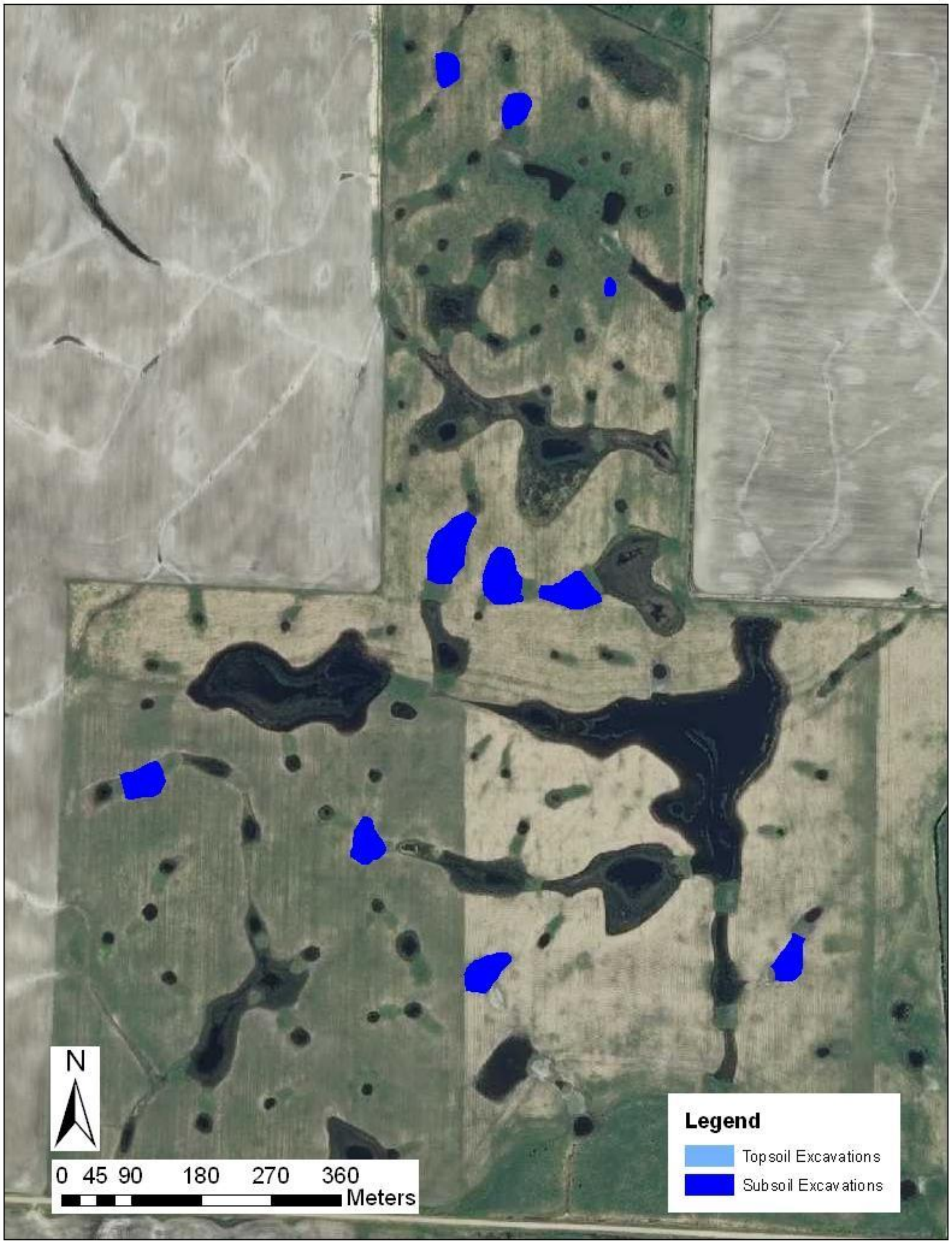

Figure 8. Map of Private Property 4 study site in Becker County, Minnesota, USA.

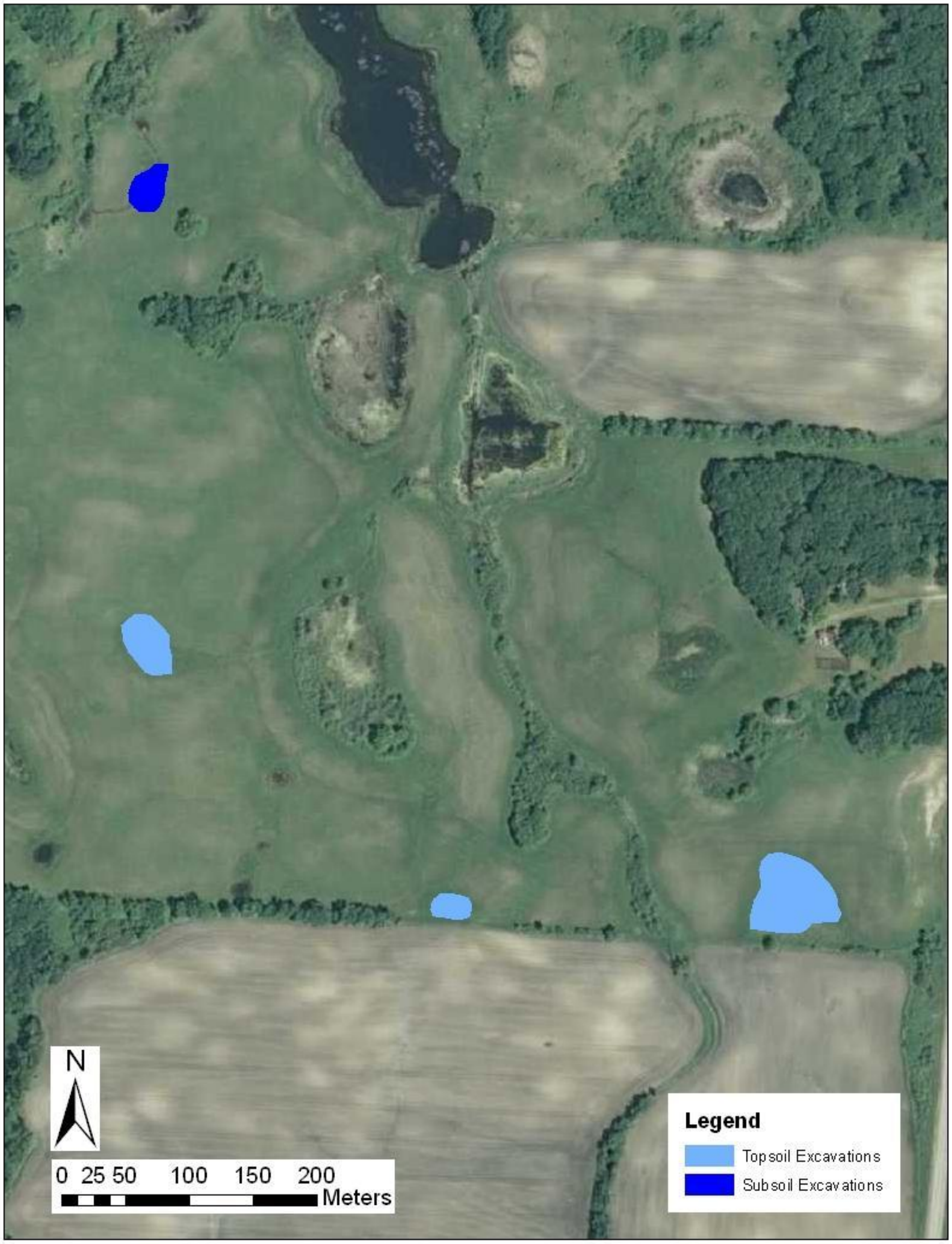

Figure 9. Map of Private Property 5 study site in Becker County, Minnesota, USA.