

FACTORS INFLUENCING THE DENSITY AND DISTRIBUTION OF BREEDING
WATERFOWL IN NORTH-CENTRAL MONTANA

by

Sean Patrick Fields

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Biological Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

January, 2011

©COPYRIGHT

by

Sean Patrick Fields

2011

All Rights Reserved

APPROVAL

of a thesis submitted by

Sean Patrick Fields

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to the Division of Graduate Education.

Dr. Jay J. Rotella

Approved for the Department of Ecology

Dr. David W. Roberts

Approved for the Division of Graduate Education

Dr. Carl A. Fox

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Sean Patrick Fields

January, 2011

ACKNOWLEDGEMENTS

This research was funded by the U. S. Fish and Wildlife Service, Region 6 National Wildlife Refuge System. My colleagues in the Habitat and Population Evaluation Team Office provided valuable discussion, insight and support throughout the study, for which I am grateful. I am very fortunate to work with a professional group of devoted wildlife biologists.

I am extremely grateful to my mentor and supervisor, Ron Reynolds, whose vision and dedication to waterfowl management made this research possible. His ability to push me to achieve my career goals as a biologist is inspirational. I am honored to have worked with him.

I sincerely thank my committee members Dr. Jay J. Rotella, Dr. Scott Creel and Terry Shaffer. Their patience, guidance, and support were invaluable throughout the study.

For assistance in the field, I thank all of the FWS biologists, managers, and technicians at the Benton Lake, Bowdoin and Charles M Russell National Wildlife Refuge complexes. I especially thank Ryan Stutzman, for his diligence, positive attitude and good humor during the two field seasons of this study.

Finally, I am indebted to my wife and colleague, Vanessa, for her contributions, understanding and lasting patience throughout this study.

TABLE OF CONTENTS

1. INTRODUCTION TO THESIS	1
Thesis Organization	2
Literature Cited	4
2. WETLAND RESOURCES OF NORTH-CENTRAL MONTANA.....	5
Introduction.....	5
Methods.....	10
Study Area	10
Wetland Basin Development	12
Results.....	14
Discussion	21
Literature Cited	27
3. FACTORS INFLUENCING THE DENSITY AND DISTRIBUTION OF BREEDING WATERFOWL IN NORTH-CENTRAL MONTANA	29
Introduction.....	29
Methods.....	34
Study Area	34
Sample Wetland Basin Selection	35
Breeding Duck Survey.....	37
Wetland Habitat Measurements	40
Landscape Habitat Measurements	42
Data Analysis	45
Results.....	51
Wetland Habitat Measurements	51
Landscape Habitat Measurements	52
Model Assessment	53
Cross Validation.....	54
Spatial Autocorrelation	54
Individual Species Analysis.....	56
Mallard.....	56
Northern Pintail.....	62
Gadwall	67
Northern Shoveler	72
Blue-winged Teal.....	77
Prediction Map.....	82
Discussion	84
Management Implications.....	90

TABLE OF CONTENTS – CONTINUED

Literature Cited	92
APPENDICES	97
APPENDIX A: Histograms, Pearson Absolute Correlation Coefficients, and X-Y Scatter Plots	98
APPENDIX B: Model Coefficient Tables	104

LIST OF TABLES

Table	Page
2.1. Number and area of basins in north-central Montana summed by water regime	15
2.2. Number and area of basins in north-central Montana summed by size category	16
2.3. Mean, range and standard deviation of basin area in north-central Montana by water regime.....	17
2.4. Number and area of north-central Montana basins summed by ecoregion	19
2.5. Number and area of north-central Montana of basins summed by ecoregion and water regime	20
2.6. Number and area of basins in the geographic regions of the PPR summed by water regime.....	25
3.1. Covariates and definitions used in breeding pair models.....	44
3.2. Breeding duck home range sizes and respective buffer distance from wetland centers used to approximate the home ranges	45
3.3 Biological hypotheses for the response of breeding duck pairs to local and landscape scale habitat characteristics	49
3.4 Landscape habitat characteristics within a home range buffer of sample basins (n) during 2008 and 2009 surveys	52
3.5. Repeated 10-fold cross validation results for top overall models.	54
3.6. Competing <i>a priori</i> and exploratory models for analysis of mallard breeding pair abundance	57
3.7. Competing <i>a priori</i> and exploratory models for analysis of northern pintail breeding pair abundance	64
3.8. Competing <i>a priori</i> and exploratory models for analysis of gadwall breeding pair abundance	69

LIST OF TABLES - CONTINUED

Table	Page
3.9. Competing <i>a priori</i> and exploratory models for analysis of northern shoveler breeding pair abundance	74
3.10. Competing <i>a priori</i> and exploratory models for analysis of blue-winged teal breeding pair abundance.	79
3.11. Observed zero counts versus expected zeros from each species full models.....	89

LIST OF FIGURES

Figure	Page
2.1. The Prairie Pothole Region of North America	6
2.2. Elements of the Cowardin et al. (1979) classification and the corresponding NWI codes (from Johnson and Higgins 1997)	8
2.3. Conversion process of NWI-delineated wetlands to basins	9
2.4. The western portion of the Northwest Glaciated Plains ecoregion of Montana ...	11
2.5. Sub-ecoregions of the western portion of the Northwest Glaciated Plains ecoregion.....	12
2.6. Date (mm/yy) of photography used in delineating the wetlands of north-central Montana.....	14
2.7. Frequency distribution of the size categories for the basins of north-central Montana	16
2.8. Geographic Regions of the U.S. PPR.....	24
3.1. The Prairie Pothole Region of North America	30
3.2. The U. S. Fish and Wildlife Service Region 6, Mountain-Prairie Region	33
3.3. Location of the study area.	35
3.4. The location of the 61 survey plots.	37
3.5. Inverse distance weighted (IDW) interpolated wetness model for seasonal basins in survey area for 2008 (top) and 2009 (bottom).....	53
3.6. Correlograms of raw observation data (squares) and model residuals (triangle) for each species.	55
3.7. Estimated mallard breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations. Dotted lines represent the 95% confidence limits.....	59

LIST OF FIGURES - CONTINUED

Figure	Page
3.8. Estimated mallard breeding pairs on (A) riverine, (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations. Dotted lines represent the 95% confidence limits.....	60
3.9. Estimated mallard breeding pairs on (A) permanent and (B) temporary basins in relation to the proportion of cropland in the home range landscape and on (C) permanent and (D) temporary basins in relation to the length of the full pool perimeter. Data points represent the observations. Dotted lines represent the 95% confidence limits.	61
3.10. Estimated northern pintail breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.....	65
3.11. Estimated northern pintail breeding pairs on (A) riverine, (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.....	66
3.12. Estimated northern pintail breeding pairs on a temporary 0.4 ha (1 acre) basin in relation to the study area location in terms of easting (MTX) and northing (MTY).	67
3.13. Estimated gadwall breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.....	70
3.14. Estimated gadwall breeding pairs on (A) riverine, (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.....	71
3.15. Estimated gadwall breeding pairs on a temporary 0.4 ha (1 acre) basin in relation to the study area location in terms of easting (MTX) and northing (MTY).	72
3.16. Estimated northern shoveler breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.....	75

LIST OF FIGURES - CONTINUED

Figure	Page
3.17. Estimated northern shoveler breeding pairs on (A) riverine, (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.....	76
3.18. Estimated blue-winged teal breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.....	80
3.19. Estimated blue-winged teal breeding pairs on (A) riverine, (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations	81
3.20. Estimated blue-winged teal breeding pairs on a temporary 0.4 ha (1 acre) basin in relation to the study area location in terms of easting (MTX) and northing (MTY)	82
3.21. The estimated density and distribution of mallard breeding pairs across north-central Montana in 2009 by public land survey section.....	83

ABSTRACT

Continental waterfowl population declines in the early 1980s led to the development and implementation of the North American Waterfowl Management Plan. The plan identified wetland and grassland losses in the Prairie Pothole Region (PPR) of Canada and the United States as the major causes of low continental duck populations. North-central Montana is the only remaining PPR area in the United States without a ground-based annual survey to monitor breeding duck populations and quantify breeding duck habitat. The purpose of this study was to establish an annual breeding duck survey in north-central Montana to 1) develop species-specific breeding pair predictive models, and 2) apply the models to estimate the density and distribution of breeding ducks and identify priority areas for conservation actions. 1969 indicated breeding duck pairs were observed on approximately 700 wetland basins in 2008 and 2009. A competing model analysis was used to identify local- and landscape-scale habitat characteristics to predict breeding duck pairs on wetland basins. The five most commonly observed species were modeled separately; those species were mallard (*Anas platyrhynchos*), northern pintails (*A. acuta*), gadwall (*A. strepera*), northern shoveler (*A. clypeata*) and blue-winged teal (*A. discors*). At the local scale, wetland basin area, the square root transformation of wetland basin area and wetland basin class were important predictors for all species. Northern pintail, gadwall and blue-winged teal exhibited a strong location effect, occurring more in the northern and eastern portions of the study area. At the landscape scale, the proportion of agricultural lands surrounding a sample basin was associated with the greater abundance of all species. Northern pintail and blue-winged teal breeding pair abundance increased when the proportion of seasonal and semipermanent basin wetland surface area in the landscape around sample basin decreased. Results from this study provide land managers with initial information on where breeding waterfowl are settling across the PPR landscape of north-central Montana. The continuation of this research for several more breeding seasons will enable conservation partners to efficiently target important breeding waterfowl habitat for conservation actions.

CHAPTER 1.

INTRODUCTION TO THESIS

The importance of Prairie Pothole Region (PPR) grassland and wetland habitats to North American breeding waterfowl has been the focus of considerable attention in recent decades. Many studies have directed attention to the degradation of these mid-continental northern prairie habitats as a result of agriculture land use practices. In addition to the > 50% of grassland habitats converted to cropland in the U.S. PPR (USDA 1994), > 50% of the total wetland area of the U.S. PPR has been lost to agricultural drainage (Tiner 1984, Dahl 1990, Dahl and Johnson 1991). The resulting waterfowl population declines of the 1980s led to extensive breeding duck research in the PPR, guided by the North American Waterfowl Management Plan. Most of that research in the U.S. has been conducted in North Dakota and South Dakota where the majority of the remaining U.S. PPR wetlands occur (Stewart and Kantrud 1971, Johnson and Higgins 1997).

The quality and quantity of breeding duck habitat in the Montana portion of the PPR has yet to be quantified. Breeding duck studies conducted in the Montana PPR indicate the area differs considerably in habitat composition compared to eastern areas of the U.S. PPR (Orthmeyer and Ball 1990, Bayless 1992, Ball et. al 1995). The investigators associated these habitat differences, including lower wetland densities and higher frequency of large grassland tracts used for nesting, with higher nest success. Additionally, Krapu et al. (1983) reported higher nest success as pond numbers decreased

in eastern areas of the PPR. Higher nest success in the western U.S. PPR increases the value of this region for continental population recruitment. However, these site-level studies do not encompass the variable landscape of the Montana PPR. Understanding the abundance and distribution of wetland basins across the PPR of Montana will help estimate the value of north-central Montana, and consequently the entire U.S PPR, to continental duck populations.

The study goals were to assess how several breeding duck species used wetland basins with different habitat characteristics at local- and landscape-scales with data gathered through an annual breeding duck survey. This research will be part of the of the long-term adaptive conservation process for waterfowl management in PPR that is outlined in the NAWMP and executed by the partners of Prairie Pothole Joint Venture.

Thesis Organization

Chapter 2 focuses on the wetland resources in the PPR of north-central Montana. Wetland basins have yet to be mapped and quantified for the PPR of north-central Montana. These data are valuable for understanding how Montana contributes to the overall composition and distribution of wetland basins and waterfowl habitat in the U.S. PPR. Additionally, wetland basins are the primary sampling unit for the breeding duck survey we developed in the next chapter.

Chapter 3 focuses on influences on breeding duck settling patterns in north-central Montana. Specifically, differences in breeding duck densities and spatial distribution across the landscape were examined in relation to local- and landscape-scale

habitat characteristics. An annual breeding duck survey was designed for monitoring populations as part of the of the long-term adaptive conservation process for waterfowl management in PPR.

Literature Cited

- Ball, I. J., R. L. Eng, and S. K. Ball. 1995. Population Density and Productivity of Ducks on Large Grassland Tracts in North Central Montana. *Wildlife Society Bulletin* 23:767-773.
- Bayless, S.R. 1992. Duck Population Responses to Water Development in North Central Montana. M.S. Thesis, Montana State University, Bozeman. 76pp.
- Dahl T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online.
- Dahl, T., and C. E. Johnson. 1991. Status and Trends of Wetlands in the Conterminous United States, Mid-1970's to Mid-1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C . 28 pages.
- Johnson R.R., and Higgins K.F. 1997. Wetland Resources of Eastern South Dakota. Brookings: South Dakota State University. 102pp.
- Krapu, G.L., A.T. Klett, and D.G. Jorde. 1983. The effect of variable spring water conditions on mallard reproduction. *Auk* 100(3): 689-698.
- Orthmeyer, D. L., and I. J. Ball. 1990. Survival of Mallard Broods on Benton Lake National Wildlife Refuge in North Central Montana USA. *Journal of Wildlife Management* 54:62-66.
- Stewart, R.E., and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Resource Publication 92. Washington, DC: US Fish and Wildlife Service.
- Tiner, R. W., Jr. 1984. Wetlands of the United States: Current Status and Trends, U. S. Fish and Wildlife Service, Washington
- U.S. Department of Agriculture. 1994. Summary report: 1992 National Resources Inventory. U.S. Department of Agriculture, Natural Resources Conservation Service, Iowa State University, Ames, IA.

CHAPTER 2.

WETLAND RESOURCES OF NORTH-CENTRAL MONTANA

Introduction

The Prairie Pothole Region (PPR) of North America is characterized by small northern prairie wetlands left in the wake of retreating Wisconsin Pleistocene glaciers. These small shallow wetlands, commonly called potholes, historically covered >20% of many PPR landscapes (Johnson and Higgins 1997). The PPR encompasses 777,000 km² of mixed prairie and aspen parkland habitats that extends from the southern edge of the boreal forests of Canada southeast into north-central United States (Figure 2.1). Prairie potholes are the most important breeding habitat for North American waterfowl, with production estimates ranging from 50% to 80% of the continent's most abundant species (Batt et al. 1989). In addition to supporting a variety of fish and wildlife species, prairie potholes are valuable, both socially and economically, to the rural agricultural communities in the PPR (Leitch and Fridgen 1998, Hubbard 1988).

Information about the abundance and distribution of wetlands is critical to understanding the functions and values potholes have in the prairie landscape. Furthermore, these data provide a foundation for wetland-dependant wildlife research. The National Wetland Inventory (NWI) was established in 1974 to develop information on the location, extent, and types of wetlands (USFWS 2002). The NWI uses information on hydrology, hydrophytes, and hydric soils to delineate wetlands and deepwater habitats in accordance with national photographic, cartographic, and digitizing

standards (USFWS 1995). Dahl et al. (2009) provided a detailed description of the NWI wetland delineation techniques.

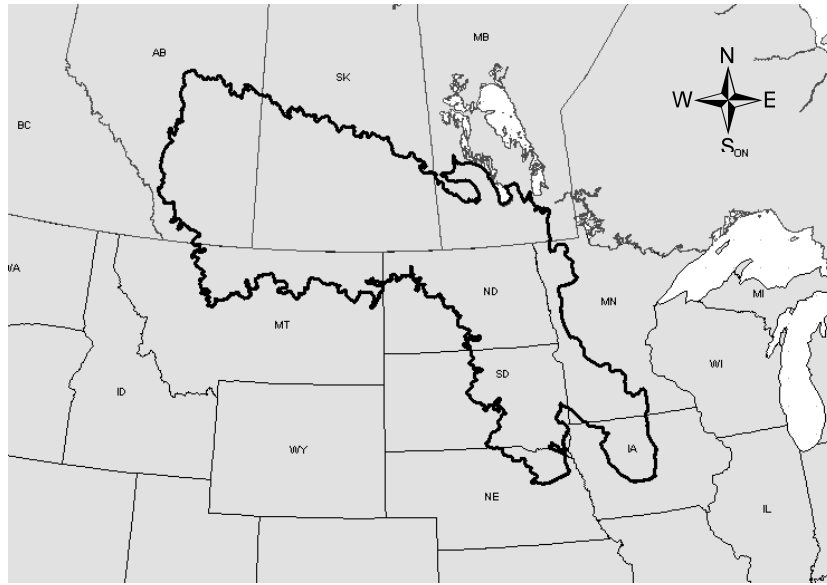


Figure 2.1. The Prairie Pothole Region of North America (black outline).

Cowardin et al. (1979) developed a hierarchical wetland classification with several levels based on amount of vegetation cover and relative length of flooding (i.e. hydroperiod) during the year. The classification categorizes wetlands and deep water habitats with similar hydrologic, geomorphic, biotic, and chemical characteristics (Figure 2.2). The USFWS adopted the Cowardin et al. (1979) classification for wetlands and deepwater habitats in the NWI wetland mapping protocol. Cowardin et al. (1979) used the following definitions for wetlands, deepwater habitats and rivers:

- Wetlands:

“Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface of the land or the land is covered by shallow water. [...] 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”.

- Deepwater Habitats:

“Deepwater Habitats are permanently flooded lands lying below the deepwater boundary of wetlands. “(6.6 ft or 2.0 m).

- River:

“The Riverine System [...] includes all wetlands and deepwater habitats contained within a channel, [...] is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens.”

Traditionally, the definition of wetlands has not included rivers, streams, and deep permanent water. Although rivers and streams function differently than shallow pothole

basins, the Cowardin et al. (1979) classification system addresses these issues and includes these related wetland habitats. Cowardin (1982) defined a basin as “a land feature capable of holding water because of topography or soil type”. Basins comprise one or more wetland polygons and are classified on the basis of wetland zones as described by Stewart and Kantrud (1971). The zone having the most permanent water regime (i.e. hydroperiod; duration of surface water) determines the water regime of the basin (Figure 2.3).

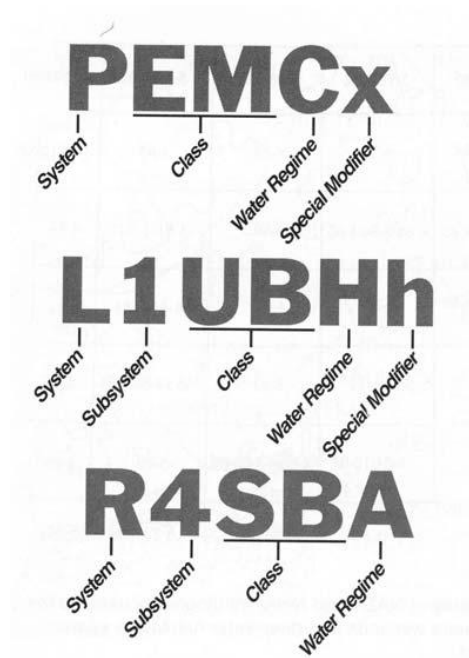


Figure 2.2. Elements of the Cowardin et al. (1979) classification and the corresponding NWI codes (from Johnson and Higgins 1997)

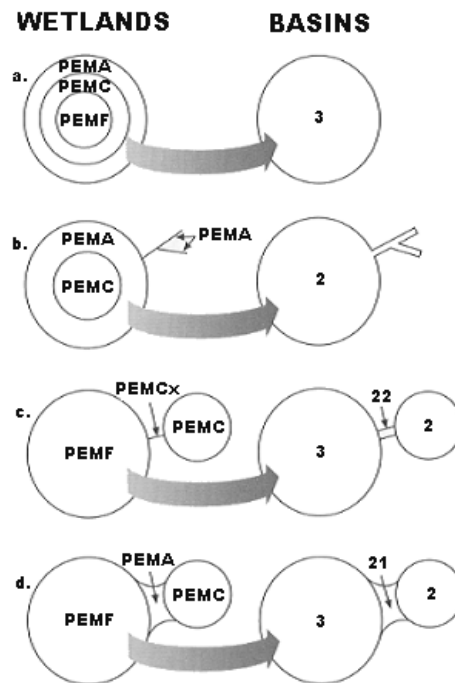


Figure 2.3. Conversion process of NWI-delineated wetlands to basins. Wetlands delineated by the NWI were converted to basins by dissolving arcs and classifying the basin's water regime by the most permanent wetland within it. Basins codes: 3 = Semipermanent, 2 = Seasonal, 21 = Temporary connector, 22 = Seasonal ditch (from Johnson and Higgins 1997.)

The abundance, general distribution, and characteristics of PPR wetlands and basins have been quantified for all areas of the region except north-central Montana. These data are a foundation for wetland-dependent wildlife research in the U.S. PPR. Without this spatial and demographic information on wetlands, landscape-level waterfowl habitat and population research would be very difficult in north-central Montana. Therefore, the purpose of this study is to map and summarize basins in the PPR of north-central Montana to allow for spatially explicit analysis of waterfowl habitat.

Methods

Study Area

The western portion of the Northwest Glaciated Plains ecoregion of Montana (Woods, Omernik et al. 2002; hereafter north-central Montana) was the study area for the project. The area encompasses 75,517 km² of interspersed cropland, mixed grassland, and shrubland containing a gradient of wetland communities ranging from dense to sparse with rivers and streams distributed throughout the landscape. Land use is predominantly livestock grazing and dry land farming. Mean annual precipitation ranges from 25 to 38 centimeters, with about 20 to 30 percent falling as snow. The study area is bounded on the north by the Canada border, west by the Rocky Mountain Front, south by the Missouri River and Northwest Great Plains ecoregion, and to the east by the Valley county eastern boundary (Figure 2.4).



Figure 2.4. The western portion of the Northwest Glaciated Plains ecoregion of Montana (shown in grey).

The western portion of the Northwest Glaciated Plains ecoregion comprises 8 sub-ecoregions (Figure 2.5). Each is unique in the type, quality, and quantity of environmental resources including different compositions of wetland basins. The Cherry Patch Moraines, Sweetgrass Uplands, Rocky Mountain Front Foothills Potholes, and Milk River Pothole Upland regions are characterized by prairie pothole wetlands and rolling hills comprising the quintessential ‘knob-and-kettle’ landscape of the Prairie Pothole Region. The North Central Brown Glaciated Plains and Glaciated Dark Brown Prairie contain large expanses of small grain agriculture supported by fertile soils. The Glaciated Northern Grasslands are characterized by large expanses of intact grasslands primarily used for livestock grazing. The Foothills grasslands are transition areas

between the glaciated prairies and the mountains characterized by rolling hills and streams.

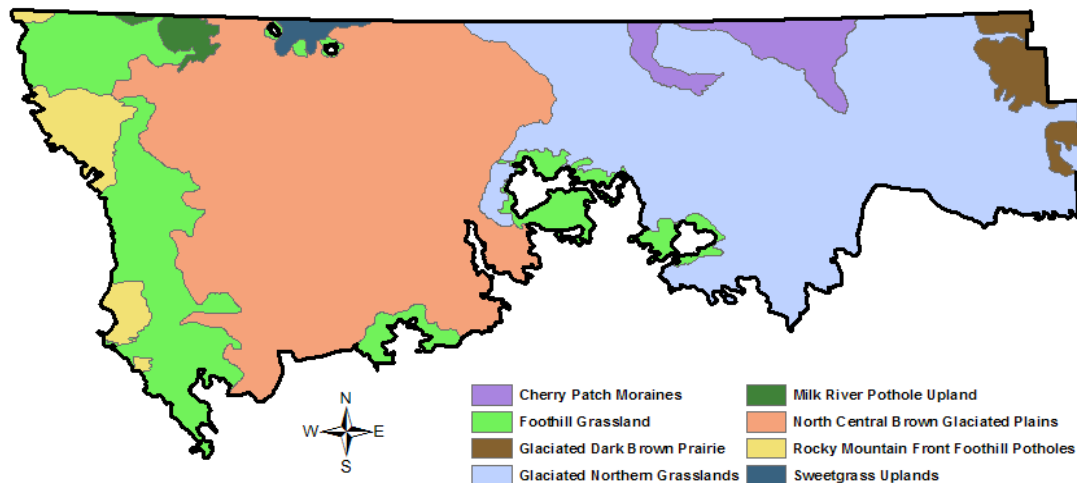


Figure 2.5. Sub-ecoregions of the western portion of the Northwest Glaciated Plains ecoregion (Woods et al. 2002)

Wetland Basin Development

The protocol for converting digital NWI wetland polygon data to basins and for classifying basin water regime (i.e. hydroperiod) was developed by USFWS personnel to support modeling the potential duck breeding-pair distribution in South Dakota, North Dakota, and northeastern Montana (Cowardin *et al.* 1995). Cowardin *et al.* (1995) described five basin classes based on water regime; temporary, seasonal, semipermanent, lake, riverine. Currently, little is known how breeding waterfowl use riverine habitats in north-central Montana. However, the riverine wetlands are potentially important habitats for breeding waterfowl during drought years when shallow prairie wetlands are generally drier in the spring compared to riverine systems. Therefore, I split the riverine class to

include an intermittent riverine class to assess the importance of both seasonal streams and perennial rivers to breeding waterfowl settling patterns in the study area.

Photography from October 1980 through July 1989 was used as the base imagery to delineate and classify north-central Montana wetlands and deep water habitats (Figure 2.6). Although the image acquisition dates and resulting NWI delineated wetland polygons are 21-30 years old, extensive wetland drainage has not occurred in the study area in that time period. Dahl (1990) estimated the historic loss of wetlands at about 27% in Montana, most of which occurred during early 1900s.

Prior to this study, final NWI wetland maps were digitized in an area encompassing 6,118,846 ha (400 7.5' NWI final maps), completing the digital wetland layer for the study area. I adapted spatial analysis techniques originally developed for the U.S. PPR digital basin conversion process for the basin conversion in the glaciated plains of north-central Montana. Seamless NWI digital data for the study area were delivered from the NWI as polygon and line geodatabase feature classes. These wetland data were then converted to basin GIS layers with a series of Arc Macro Language programs (AMLs) and INFO programs in ArcInfo Workstation 9.2 (Environmental Systems Research Institute, 1996). Linear wetlands were buffered by a distance of 7.32 m to convert them to polygons. Buffer distances were selected to maintain consistency with basin spatial layers created for North Dakota (Cowardin *et al.* 1995) and South Dakota (Johnson and Higgins 1997) and verified during preliminary analysis of aerial imagery. Arcs separating wetlands were deleted to produce composite, contiguous basin features classified by water regime (Figure 2.3). The basins were uniquely numbered and labeled

as temporary, seasonal, semipermanent, permanent, riverine or riverine-intermittent.

Once all of the basins were inventoried, I adapted descriptive summaries used by Rieger (2004) to describe the abundance, general distribution, and characteristics of basins in north-central Montana.

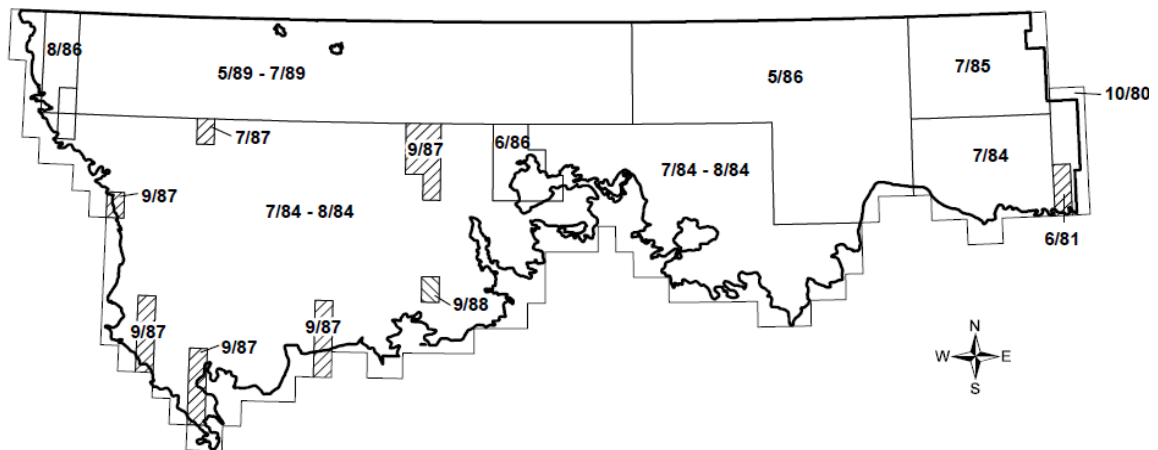


Figure 2.6. Date (mm/yy) of photography used in delineating the wetlands of north-central Montana

Results

187,494 basins existed in the glaciated plains of north-central Montana. Surface water covered approximately 246,333 ha or 3.3% of the 7,551,715 ha of the study area. Of the 187,494 basins, 862 (0.5%) were classified as permanent basins, 383 (0.2%) were classified as riverine basins, 2,103 (1.1%) were classified as intermittent riverine basins, 52,087 (27.8%) were classified as seasonal basins, 23,462 (12.5%) were classified as semipermanent basins, and 108,597 (57.9%) were classified as temporary basins (Table

2.1). Of the total number of basins, 107,545 or 57.4% were < 0.2 ha (0.5 acres), 134,144 or 71.5% were < 0.4 ha (1 acre), 154,965 or 82.7% were < 0.8 ha (2 acres), 172,833 or 92.2% were < 2.0 ha (5 acres), and 180,010 or 96.0% of all basins were < 4.0 ha (10 acres) in area (Table 2.2, Figure 2.7).

Mean size of all basins in north-central Montana was 1.3 ha (3.2 acres). The size range was from 0.0 ha to 6442.4 ha (15,919.5 acres), with Tiber Reservoir (Lat: -111.192, Lon: 48.355) being the largest basin in the study area. The mean size of temporary basins was 0.5 ha (1.2 acres). The mean size of seasonal basins was 0.9 ha (2.2 acres). Mean size of semipermanent basins was 2.8 ha (6.9 acres). Mean size of permanent basins was 59.2 ha (146.3 acres). Mean size of riverine basins was 41.6 ha (102.8 acres) and of intermittent riverine basins was 6.7 (16.6 acres) respectively (Table 2.3).

Table 2.1. Number and area of basins in north-central Montana summed by water regime.

Water Regime	Number	% Number	Area (ha)	% Area
Permanent	862	0.5%	51,051.9	20.7%
Semipermanent	23,462	12.5%	66,760.8	27.1%
Seasonal	52,087	27.8%	47,900.0	19.4%
Temporary	108,597	57.9%	50,506.5	20.5%
Riverine	383	0.2%	15,922.9	6.5%
Riverine-intermittent	2,103	1.1%	14,191.6	5.8%
	187,494	100%	246,333.7	100.0%

Table 2.2. Number and area of basins in north-central Montana summed by size category.

Size Category	Number	% Number	Hectares	Acres	% Area
<0.2	107,545	57.4%	8,928.0	22,061.4	3.6%
0.2 - <0.4	26,599	14.2%	7,572.2	18,711.2	3.1%
0.4 - <0.8	20,821	11.1%	11,786.0	29,123.7	4.8%
0.8 - <2.0	17,868	9.5%	22,312.0	55,134.0	9.1%
2.0 - 4.0	7,177	3.8%	20,060.0	49,569.2	8.1%
+4.0	7,484	4.0%	175,675.6	434,102.0	71.3%
	187,494	100.0%	246,333.7	608,701.5	100.0%

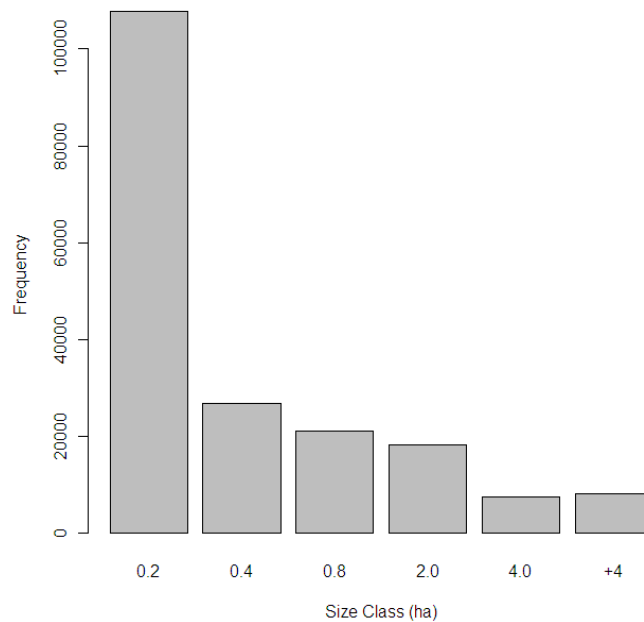


Figure 2.7. Frequency distribution of the size categories for the basins of north-central Montana. Size Category key: 0.2 represents basins < 0.2 ha, 0.4 represents basins > 0.2 ha and < 0.4 ha, 0.8 represents basins > 0.4 ha and < 0.8 ha, 2.0 represents basins > 0.8 ha and < 2.0 ha, 4.0 represents basins > 2.0 ha and < 4.0 ha, + 4.0 represents basins > 4.0 ha.

Table 2.3. Mean, range, standard deviation and first (Q1) and third (Q3) quartiles of basin area in north-central Montana by water regime.

Water Regime	Number	Area (ha)	Min (ha)	Q1 (ha)	Max (ha)	Q3 (ha)	Mean (ha)	sd (ha)
Permanent	862	51,051.9	0.0+	0.3	6,442.4	24.3	59.2	298.9
Semipermanent	23,462	66,760.8	0.0+	0.1	4,392.2	1.3	2.8	35.6
Seasonal	52,087	47,900.0	0.0+	0.1	691.7	0.6	0.9	6.1
Temporary	108,597	50,506.5	0.0+	0.1	300.4	0.3	0.5	2.2
Riverine	383	159,22.9	0.0+	0.6	3,135.0	8.2	41.6	246.6
Riverine - intermittent	2103	141,91.6	0.0+	0.5	982.4	4.9	6.7	27.8
All Regimes	187,494	246,333.7	0.0+	0.1	6,442.4	0.5	1.3	27.1

The Glaciated Northern Grasslands ecoregion contained 44.2% of all basins in north-central Montana that covered 3.2% of the ecoregion total area. The North Central Brown Glaciated Plains contained 22.9% of all basins that covered 2.8% of the ecoregion total area. 15.7% of all basins are located in the Cherry Patch Moraines ecoregion, and the basins covered 6.2% of the ecoregion. The Foothill Grassland ecoregion contained 8.2% of all basins that covered 3.2%, the Rocky Mountain Front Foothill Potholes contained 4.4% of all basins that covered 6.8%, the Milk River Pothole Upland contained 1.8% of all basins that covered 3.0%, the Sweetgrass Uplands contained 1.6% of all basins that covered 3.6%, and the Glaciated Dark Brown Prairie contained 1.2% of all basins in the study area that covered 1.0% of the total ecoregion area (Table 2.4).

The Glaciated Northern Grasslands ecoregion contained 15,048.1 ha or 36.4% of the total basin area. The North Central Brown Glaciated Plains contained 81,960.8 ha or 33.6% of the total basin area. The Foothill Grassland ecoregion contained 35,831.9 ha or

14.7% of the total basin area. The Rocky Mountain Front Foothill Potholes contained 16,807.9 ha or 6.9%, The Cherry Patch Moraines contained 15,048.1 ha or 6.2%, the Milk River Pothole Upland contained 1,948.9 ha or 0.8%, the Glaciated Dark Brown Prairie contained 1,757.0 or 0.7%, and the Sweetgrass Uplands contained 1,686.5 ha or 0.7% of the total basin area (Table 2.4).

In 5 of the 8 ecoregions, the surface area of semipermanent basins was greater than all other water regimes (Table 2.5). The Milk River Pothole Upland and Cherry Patch Moraines ecoregions contained more seasonal basins surface area compared to the other water regimes. The North Central Brown Glaciated Plains contained more permanent basin surface area compared to the other water regimes. The largest basin in the study area, Tiber Reservoir with a permanent water regime, occurred in the North Central Brown Glaciated Plains ecoregion. Temporary basins were the most numerous of all basin classes in 5 of the 8 ecoregions with seasonal basins the most numerous in the reminding ecoregions.

Table 2.4. Number and area of north-central Montana basins summed by ecoregion. The difference in summary totals (471 basins, 2734.5 ha) between the overall study area and the ecoregions is because the study area is slightly larger than the ecoregion boundaries to accommodate the breeding waterfowl study design.

Ecoregion (ha)	Ecoregion Area (ha)	% of eco-region	Number	% Number	Area (ha)	% Area (ha)
Cherry Patch Moraines	241,939.7	6.2%	29,288	15.7%	15,048.1	6.2%
Foothill Grassland	1,112,694.8	3.2%	15,387	8.2%	35,831.9	14.7%
Glaciated Dark Brown Prairie	169,792.8	1.0%	2,287	1.2%	1,757.0	0.7%
Glaciated Northern Grasslands	2,732,521.7	3.2%	82,571	44.2%	88,558.1	36.4%
Milk River Pothole Upland	65,054.5	3.0%	3,418	1.8%	1,948.9	0.8%
North Central Brown Glaciated Plains	2,934,655.4	2.8%	42,862	22.9%	81,960.8	33.6%
Rocky Mountain Front Foothill Potholes	248,488.9	6.8%	8,188	4.4%	16,807.9	6.9%
Sweetgrass Uplands	46,567.0	3.6%	3,022	1.6%	1,686.5	0.7%
			187,023	100%	243,599.2	100%

Table 2.5. Number and area of north-central Montana basins summed by ecoregion and water regime.

Ecoregion	Water Regime	Number	% Number	Area (ha)	% Area
Cherry Patch Moraines	Permanent	28	0.10%	1,201.10	8.00%
	Semipermanent	907	3.10%	2,092.10	13.90%
	Seasonal	9,423	32.20%	6,808.30	45.20%
	Temporary	18,875	64.40%	4,583.50	30.50%
	Riverine-intermittent	55	0.20%	363.2	2.40%
		29,288	100.00%	15,048.10	100.00%
Foothill Grassland	Permanent	187	1.20%	7,180.20	20.00%
	Semipermanent	3,535	23.00%	12,970.00	36.20%
	Seasonal	4,949	32.20%	5,970.10	16.70%
	Temporary	6,136	39.90%	5,100.30	14.20%
	Riverine	161	1.00%	2,189.50	6.10%
	Riverine-intermittent	419	2.70%	2,421.90	6.80%
		15,387	100.00%	35,831.90	100.00%
Glaciated Dark Brown Prairie	Permanent	4	0.20%	59.8	3.40%
	Semipermanent	331	14.50%	757.1	43.10%
	Seasonal	437	19.10%	342.8	19.50%
	Temporary	1,456	63.70%	578.5	32.90%
	Riverine-intermittent	59	2.60%	18.7	1.10%
		2,287	100.00%	1,757.00	100.00%
Glaciated Northern Grasslands	Permanent	217	0.30%	15,297.30	17.30%
	Semipermanent	9,643	11.70%	23,156.40	26.10%
	Seasonal	19,297	23.40%	18,721.70	21.10%
	Temporary	52,248	63.30%	19,253.90	21.70%
	Riverine	98	0.10%	3,620.10	4.10%
	Riverine-intermittent	1,068	1.30%	8,508.70	9.60%
		82,571	100.00%	88,558.10	100.00%
Milk River Pothole Upland	Permanent	22	0.60%	252.4	13.00%
	Semipermanent	276	8.10%	374.5	19.20%
	Seasonal	1,941	56.80%	956.8	49.10%
	Temporary	1,175	34.40%	334.5	17.20%
	Riverine	1	0.00%	26.9	1.40%
	Riverine-intermittent	3	0.10%	3.9	0.20%
		3,418	100.00%	1,948.90	100.00%

Table 2.5. continued

North Central Brown Glaciated Plains	Permanent	305	0.70%	21,462.00	26.20%
	Semipermanent	6,982	16.30%	20,835.60	25.40%
	Seasonal	10,150	23.70%	11,217.20	13.70%
	Temporary	24,952	58.20%	17,640.50	21.50%
	Riverine	78	0.20%	8,591.40	10.50%
	Riverine-intermittent	395	0.90%	2,214.30	2.70%
		42,862	100.00%	81,960.80	100.00%
Rocky Mountain Front Foothill Potholes	Permanent	112	1.40%	4,018.60	23.90%
	Semipermanent	1,385	16.90%	5,421.10	32.30%
	Seasonal	3,740	45.70%	3,055.80	18.20%
	Temporary	2,759	33.70%	2,551.30	15.20%
	Riverine	67	0.80%	1,292.60	7.70%
	Riverine-intermittent	125	1.50%	468.5	2.80%
		8,188	100.00%	16,807.90	100.00%
Sweetgrass Uplands	Permanent	5	0.20%	345.6	20.50%
	Semipermanent	335	11.10%	581.4	34.50%
	Seasonal	1,949	64.50%	534.6	31.70%
	Temporary	728	24.10%	186	11.00%
	Riverine-intermittent	5	0.20%	39	2.30%
		3022	100.00%	1,686.50	100.00%

Discussion

The basins of north-central Montana are diverse in size, composition, and distribution across the landscape. The ecoregions within the Northwest Glaciated Plains provide a good mechanism to spatially separate and quantify the basins on the landscape. The heavy agriculture areas of the Glaciated Dark Brown Prairie and North Central Brown Glaciated Plains contain the lowest density of wetland basins on the landscape.

These two ecoregions are dominated by small temporary basins (Table 2.5). In contrast, the smaller ecoregions with lower densities of agricultural lands contain the highest density of basins across the landscape; those ecoregions are the Cherry Patch Moraines, Rocky Mountain Front Foothill Potholes, Sweetgrass Uplands, and Milk River Pothole Upland (Table 2.4). These areas are composed of a higher percentage of seasonal wetlands compared to the agricultural landscapes of the Glaciated Dark Brown Prairie and North Central Brown Glaciated Plains. The Glaciated Northern Grasslands ecoregion, covering approximately 36% of the entire study area, contains 44.2% of all basins in the landscape. This area is characterized by relatively low grassland fragmentation due to agriculture compared to the Glaciated Dark Brown Prairie and North Central Brown Glaciated Plains.

A comparison of wetland basins in three geographic regions of the U.S. PPR elucidates how the basin composition is variable across the region. To compare the basin composition of north-central Montana to the other geographic areas of the U.S. PPR, North Dakota, South Dakota and northeast Montana were combined as the central geographic region (Figure 2.8). Minnesota and Iowa were combined as the eastern geographic region of the U.S. PPR. Each of these geographic partitions is similar in terms of historic wetland drainage. Bishop (1981) estimated that Iowa had lost up to 95% of the natural wetlands by the 1980's. Johnson et al. (2008) estimated that 85% of the Minnesota potholes have been drained. In contrast, Dahl (1990) estimated the historic loss of wetlands at about 35% in South Dakota, 50% in North Dakota, and 27% in Montana. I combined the two basin riverine classes in north-central Montana for

comparison with the other geographic areas of the U.S. PPR where only one riverine class was mapped. I also labeled the lake basins in the other geographic areas as permanent for comparison purposes.

The density of north-central Montana basins was similar to the eastern region densities compared to basin density in the central region of the U.S. PPR. Including rivers, the wetland density of north-central Montana was 0.03 basins/ha compared to 0.11 basins/ha in the central region and 0.03 basins/ha in the eastern region. These basins comprised 3.3% of the total landscape of north-central Montana, 9.6% of the central region and 5.3% of the eastern region. Depressional basins, which exclude rivers, comprised 2.9 % of the total area of north-central Montana, 9.0% in the central region and 4.8% in the eastern region. The composition of north-central Montana basin classes was similar to the central region basin class composition compared to the eastern region where permanent basins comprised 46% of the total basin surface area (Tables 2.6). In north-central Montana, the riverine classes comprised approximately 12.2% of all surface water compared to 6.3% and 8.9% in the central and eastern region, respectively (Table 2.6).

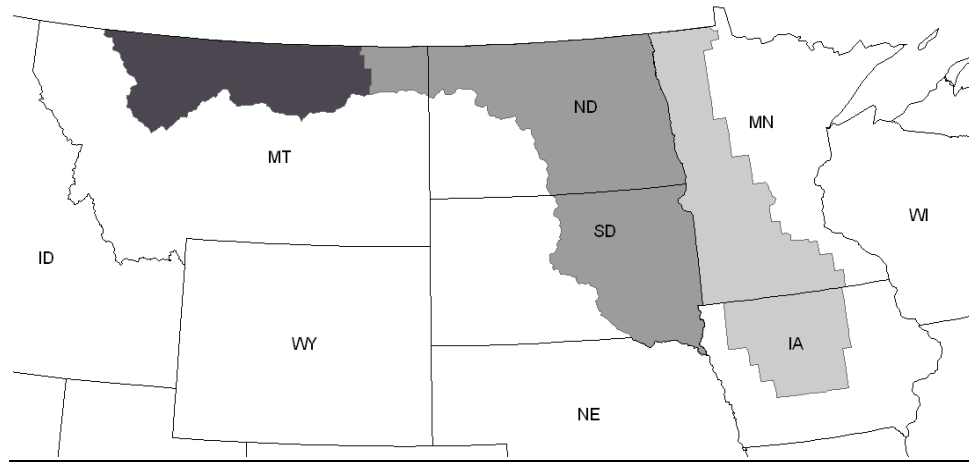


Figure 2.8. Geographic regions of the U.S. PPR. Western (black), Central (dark grey) and Eastern (light grey)

Table 2.6. Number and area of basins in the geographic regions of the U.S. PPR summed by water regime. The two riverine classes are combined.

Geographic Zone	Water Regime	Number	% Number	Area (ha)	% Area (ha)
Western (North-central MT)	Permanent	862	0.50%	51,051.90	20.70%
	Semipermanent	23,462	12.50%	66,760.80	27.10%
	Seasonal	52,087	27.80%	47,900.00	19.40%
	Temporary	108,597	57.90%	50,506.50	20.50%
	Riverine	2486	1.30%	30,114.50	12.20%
		187,494	100.00%	246,333.70	100.00%
Central (ND, SD, NE MT)	Permanent	6,832	0.30%	554,282.10	24.30%
	Semipermanent	195,923	7.30%	635,161.30	27.80%
	Seasonal	1,151,458	42.90%	632,082.90	27.70%
	Temporary	1,325,370	49.40%	319,021.70	14.00%
	Riverine	3,698	0.10%	143,623.80	6.30%
		2,683,281	100.00%	2,284,171.90	100.00%
Eastern (MN & IA)	Permanent	25,394	5.90%	378,063.60	46.10%
	Semipermanent	45,394	10.60%	134,755.10	16.40%
	Seasonal	170,953	40.00%	122,412.70	14.90%
	Temporary	176,574	41.30%	111,953.40	13.60%
	Riverine	9,142	2.10%	73,232.60	8.90%
		427,457	100.00%	820,417.30	100.00%

Although wetland densities are lower in the PPR of Montana compared to the other geographic regions, past breeding duck studies have investigated the value of the region in terms of waterfowl density and productivity. Several studies have reported the average productivity of breeding ducks was several times higher than in many parts of the PPR (Orthmeyer and Ball 1990, Bayless 1992, Ball et. al 1995). The authors suggested the availability of large tracts of nesting habitat supporting relatively low predator populations was the primary reasons for the high waterfowl productivity. Furthermore, Krapu et al. (1983) reported higher nest success in the PPR as pond numbers decreased.

Additionally, several studies in north-central Montana found that the number of breeding pairs per hectare of water was high in relation to the eastern areas of the PPR (Gjersing 1970, Mundinger 1975, Hudson 1983). Consequently, higher nest success in the western U.S. PPR potentially leads to a disproportionate contribution to continental population recruitment compared to the eastern areas of the U.S. PPR.

Although the wetland basin composition of north-central Montana is lower in frequency and density compared to other areas of the U.S. PPR, the region contains highly productive areas that benefit the mid-continental breeding duck population. Further landscape-scale studies to estimate the overall contributions of Montana PPR wetlands basins to breeding duck populations would be beneficial. This study provides a means for future research studies to assess the landscape as a whole in terms of wetland basin composition and investigate the value of those basins to wetland-dependent wildlife. By protecting the existing wetland basins on the landscape, and restoring drained wetland basins, land managers will maintain quality habitat, not only for the mid-continental breeding duck populations, but for many of the region's wetland-dependent wildlife species.

Literature Cited

- Ball, I. J., R. L. Eng, and S. K. Ball. 1995. Population density and productivity of ducks on large grassland tracts in northcentral Montana. *Wildlife Society Bulletin* 23:767-773.
- Bayless, S.R. 1992. Duck Population Responses to Water Development in North Central Montana. M.S. Thesis, Montana State University, Bozeman. 76pp.
- Batt B.D.J., Anderson M.G., Anderson C.D., Caswell F.D. 1989. The Use of Prairie Potholes By North American Ducks. Pages 204-227 in A. Van Der Valk, editor. *Northern Prairie Wetlands*. Iowa State University Press, Ames, USA.
- Gjersing, F.M. 1970. A study of waterfowl production on two rest-rotation grazing units in northcentral Montana. M.S. Thesis, Montana State University, Bozeman. 42pp.
- Bishop, R. 1981. Iowa's wetlands. *Proceedings of the Iowa Academy of Science* 88:11-16.
- Cowardin L.M., Carter V, Goblet F.C., LaRoe ET. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. Washington, DC, USA: FWS/OBS - 79/31.
- Cowardin, L. M. 1982. Some conceptual and semantic problems in wetland classification and inventory. *Wildlife Society Bulletin* 10:57-60.
- Cowardin, L. M., T. L. Shaffer, and P. M. Arnold. 1995. Evaluation of duck habitat and estimation of duck population sizes with a remote-sensing-based system. National Biological Service, Biological Science Report 2, Washington, D.C. U.S. Fish and Wildlife Service.
- Dahl T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online.
- Dahl, T.E., J. Dick, J. Swords and B.O. Wilen. 2009. Data Collection Requirements and Procedures for Mapping Wetland, Deepwater and Related Habitats of the United States. Division of Habitat and Resource Conservation, National Standards and Support Team, Madison, WI. 85 p.
- Hubbard, D. E. 1988. Glaciated prairie wetland functions and values: a synthesis of the literature. U.S. Fish Wildl Serv Biol Rep 88(43), Washington, D.C.

- Hudson, M.S. 1983. Waterfowl production on three age-classes of stockponds in northcentral Montana. M.S. Thesis, Mont. State Univ., Bozeman. 45pp.
- Johnson R.R., and Higgins K.F. 1997. Wetland Resources of Eastern South Dakota. Brookings:South Dakota State University. 102pp.
- Johnson R.R., Oslund FT, Hertel DR. 2008. The past, present, and future of prairie potholes in the United States. *Journal of Soil and Water Conservation*. 63:84-87.
- Krapu, G.L., Klett, A.T., and D.G. Jorde. 1983. The effect of variable spring water conditions on mallard reproduction. *Auk* 100(3): 689-698.
- Leitch J.A., Fridgen P. 1998. Functions and values of prairie wetlands: Economic realities. *Great Plains Research*. 8:157–168.
- Mundinger, J.G. 1975. The influence of rest-rotation grazing management on waterfowl production on stock water reservoirs in Phillips County, Montana. M.S. Thesis, Montana State University., Bozeman. 100pp.
- Orthmeyer, D. L., and I. J. Ball. 1990. Survival of Mallard Broods on Benton Lake National Wildlife Refuge in Northcentral Montana USA. *Journal of Wildlife Management* **54**:62-66.
- Stewart, R.E., and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Resource Publication 92. Washington, DC: US Fish and Wildlife Service.
- U.S. Fish and Wildlife Service National Wetlands Inventory. 2002. A Strategy for the 21st Century. U.S. Fish and Wildlife Service. Washington, DC, USA.

CHAPTER 3.

FACTORS INFLUENCING THE DENSITY AND DISTRIBUTION OF
BREEDING DUCKS IN NORTH CENTRAL MONTANAIntroduction

The Prairie Pothole Region (PPR), known for supporting the highest density of breeding ducks in North America, encompasses 777,000 km² of mixed prairie and aspen parkland habitats that extends from the southern edge of the boreal forests of Canada southeast into north-central United States (Figure 3.1). The region is characterized by a millions of shallow glaciated wetlands that undergo a dynamic wet-dry cycle, supporting an abundance of waterfowl and other water birds (Murkin et al. 2000). The PPR is the primary breeding area for upland nesting ducks (Batt et al. 1989) with breeding pairs exceeding 39 pairs/km² in areas of North and South Dakota (Reynolds et al. 2006).

North American waterfowl population declines in the early 1980s lead to the development and implementation of the North American Waterfowl Management Plan (NAWMP) by the United States and Canada, and subsequently by Mexico. The plan identified wetland and grassland losses in the PPR as the major causes of low continental duck populations. Since European settlement, > 50% of the total wetland area of the PPR has been lost to drainage, mostly due to agriculture (Tiner 1984, Dahl 1990, Dahl and Johnson 1991). The U.S. Department of Agriculture's (USDA) National Resources Inventory determined the nation's privately owned grassland decreased by approximately 10 million hectares between 1982 and 2003, and in some states, such as Iowa, almost all

native grasslands have been destroyed since settlement. In Montana 50%, North Dakota 67%, and South Dakota 53% of grasslands have been converted, mostly to cropland, since settlement (USDA 1994).

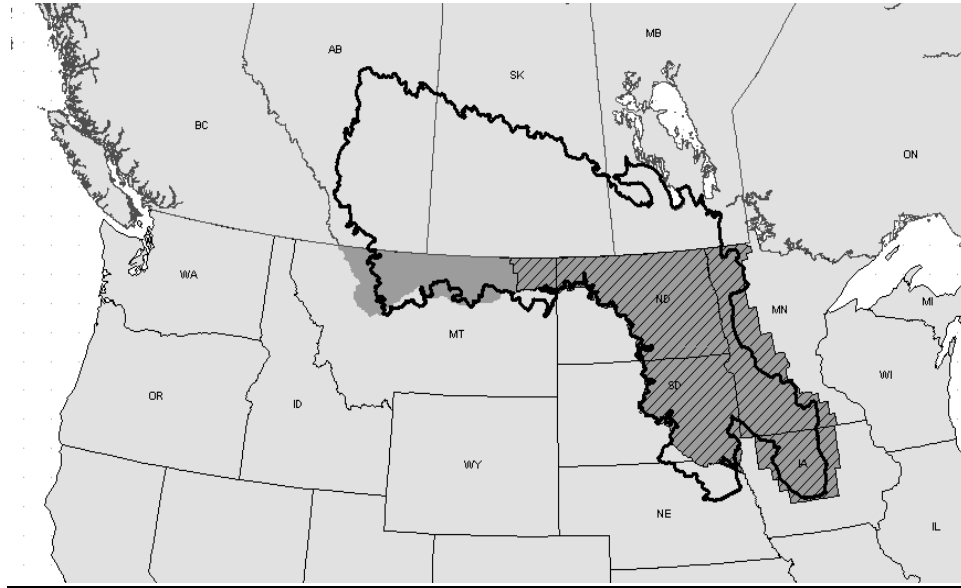


Figure 3.1. The Prairie Pothole Region of North America (black outline). The U.S. Prairie Pothole Joint Venture is shown in dark gray; cross-hatching identifies the primary working area within the PPJV

The NAWMP outlined a strategy to restore continental waterfowl populations and established regional partnerships, known as Joint Ventures, to prioritize wetland and grassland conservation efforts and implement the plan. Joint ventures are composed of Federal, State and local government agencies, non-governmental conservation organizations, Tribes, and other entities. The Prairie Pothole Joint Venture (PPJV) was formed to focus on waterfowl conservation efforts in the United States portion of the

PPR, which includes areas of Montana, North Dakota, South Dakota, Minnesota and Iowa (Figure 3.1).

The United States Fish and Wildlife Service (Service) is the principal federal waterfowl management and regulatory agency in the United States and coordinates the activities of the PPJV. The Service has long been involved in monitoring wetland conditions and duck populations, conducting the waterfowl breeding population and habitat survey in cooperation with Canada since 1955. Although this survey provides important data used for setting annual waterfowl hunting regulations, it does not provide spatially explicit data for local- and regional-level management. In 1985, the Service issued a directive to the National Wildlife Refuge System Program to establish improved, standardized methods for estimating waterfowl breeding populations and production from National Wildlife Refuge System lands. Survey methods developed at the USGS Northern Prairie Wildlife Research Center (Cowardin et al. 1995) have been used by National Wildlife Refuges in the U.S. PPR since 1987 to annually estimate duck breeding population size and productivity from Service owned, privately owned protected, and privately owned non-protected habitats. In 1989, the PPJV adopted the survey, known as the “Four Square Mile Survey” (FSM survey), as its official survey for monitoring duck populations and prioritizing conservation activities in the PPJV area.

Since then, the FSM survey has been part of the biological foundation of an iterative, adaptive planning and conservation process for breeding waterfowl in the PPR of the Dakotas and northeastern Montana. Data from the FSM survey were used to develop spatially explicit models to relate waterfowl breeding populations and

recruitment responses to landscape characteristics. These models were then applied to the landscape using geographic information system (GIS) techniques to prioritize conservation treatments and target land units for conservation actions. Model predictions are provided to land managers as maps and are valuable tools for making waterfowl habitat management decisions. This is a long-term adaptive process that includes updating models with annually collected survey data and conducting new studies to update and improve model performance.

The Service's Region 6 (Figure 3.2) receives approximately \$10-\$12 million annually from the Migratory Bird Conservation Fund for the acquisition of breeding waterfowl habitat. Most of these funds originate from the Migratory Bird Hunting Stamp Act, as amended in 1958, and are used to purchase conservation easement interests in wetland and upland habitats important to breeding waterfowl. The Region focuses these funds on geographic areas previously approved by U.S. Congress and designated as wetland management districts. The Benton Lake and Bowdoin wetland management districts, in Montana, remain as the only two districts of 24 in the PPJV without an annual ground-based breeding waterfowl survey. These districts, two of the largest in the PPJV, encompass over 10.4 million hectares and comprise 21% of the PPJV geographic area. The quality of breeding duck habitat in the Benton Lake and Bowdoin districts has yet to be quantified.



Figure 3.2. The U.S. Fish and Wildlife Service Region 6, Mountain-Prairie Region (shown in dark gray).

The primary land use, outside of agricultural areas of north-central Montana, is livestock grazing with large tracts ($> 20 \text{ km}^2$) of continuous grassland with relatively low populations of nest predators (Ball et al. 1995). Population growth rates for upland-nesting duck species in the PPR are sensitive to variation in nesting success (Johnson et al. 1992, Hoekman et al. 2002). Nest success for several duck species was below population maintenance levels in the 1980s and predation was implicated as the primary cause of duck nest loss in the PPR (Klett et al. 1988). In north central Montana, the average productivity of dabbling ducks on large grassland tracts with relatively low predator populations was several times higher than in many parts of the PPR where the effects of habitat fragmentation and high predator populations are severe (Ball et al 1995). Furthermore, predator populations appear to be relatively low even in the highly fragmented areas of north-central Montana compared to other agricultural areas of the

U.S. PPR (Orthmeyer and Ball 1990). These potential waterfowl habitat ‘hot spots’ are conservation priorities for PPJV partners. A breeding waterfowl survey, acting as the biological foundation of an iterative, adaptive planning conservation process, will allow the Service and the PPJV to quantify the importance of north central Montana for breeding duck habitat and its contribution to continental waterfowl populations.

The purpose of this study was to (1) use breeding duck survey data to develop species specific breeding duck (*Anatinae*) predictive models, and (2) apply the models to estimate the density and distribution of breeding ducks across the area and identify priority areas for conservation treatments in the Bowdoin and Benton Lake wetland management districts of north-central Montana. This study will be part of the long-term adaptive conservation process described above to support the conservation efforts of the PPJV.

Methods

Study Area

The Northwest Glaciated Plains ecoregion (Woods et al. 2002) within Benton Lake and Bowdoin districts was the study area for the project (Figure 3.3). The area encompasses 75,517 km² of interspersed cropland, mixed grassland, and shrubland containing a gradient of wetland communities ranging from dense to sparse with rivers and streams distributed throughout the landscape. Land use is predominantly livestock grazing and dry land farming. Mean annual precipitation ranges from 25 to 38

centimeters, with about 20 to 30 percent falling as snow. The study area is bounded on the north by the Canada border, west by the Rocky Mountain Front, south by the Missouri River and Northwest Great Plains ecoregion, and to the east by Northeast Montana WMD.

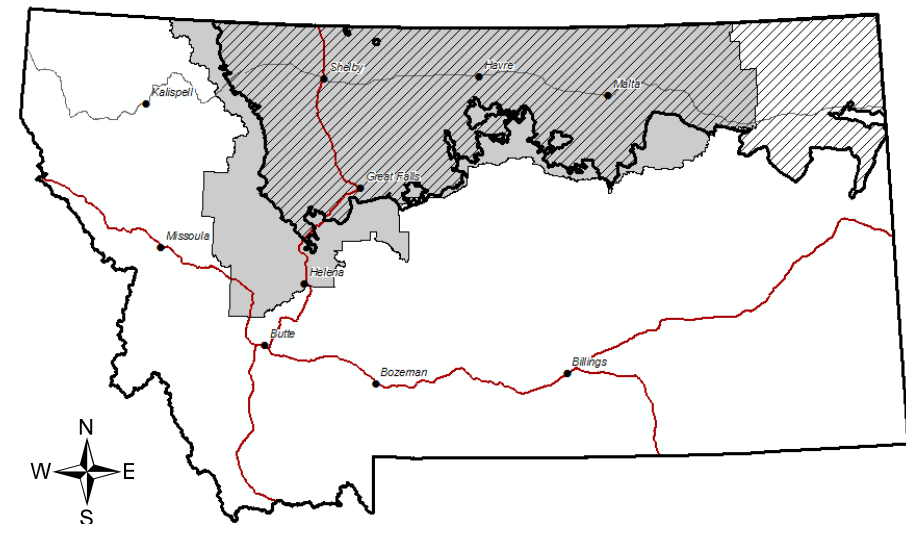


Figure 3.3. The location of the study area. The location of the Benton Lake and Bowdoin wetland management districts in Montana is shown in grey. The Northwest Glaciated Plains ecoregion is shown in cross-hatching. The study area is identified where the cross-hatching and grey background overlap.

Sample Wetland Basin Selection

Breeding duck surveys were conducted on a sample of wetland basins. A two-stage stratified random sampling design (Cochran 1977) was used to account for the variation in basin densities across the landscape and the variation in the composition of the 6 basin classes. The study area was divided into 10.4-km^2 (4-mi^2) primary sampling units (hereafter plots) using aggregated 1-mi^2 public land survey sections. Plot size was

chosen to approximate the home range size of a breeding mallard hen (Cowardin et al. 1988). Individual wetland basins within a plot served as secondary sampling units in the 2-stage sampling design. Clustering sample wetland basins within survey plots increased the number of sampled basins by reducing travel time for a limited number of field observers.

The survey plots were divided into four strata to minimize the variance in the breeding duck counts. Ideally, each survey plot would have been assigned to a stratum based on the expected number of breeding duck pairs occupying the plot. Since these data were not available, the plots were categorized based on the best surrogate of breeding duck pairs from previous modeling efforts in the U.S. PPR. Reynolds et al (2006) found the square root of wetland basin surface area to be the most significant predictor of breeding pairs. I calculated the square root of wetland basin surface area for each basin within a survey plot and then summed that for all basins within a plot to estimate the potential number of breeding ducks within each survey plot. Plots with no basins were removed from the study.

Sample size was based on budgetary constraints rather than trying to achieve a specific statistical power. I estimated that the available field observers would be able to survey approximately 700 basins dispersed among 61 plots based on previous breeding waterfowl survey efforts in the U.S. PPR. The 61 plots were allocated among strata using Neyman optimum allocation methods (Neyman 1934) (Figure 3.4). Sample basins were stratified on basin class then randomly selected from all available basins within the sample plots. The optimal allocation of wetland basin class strata avoided oversampling

classes with smaller variances, such as temporary basins, that are more numerous and may be dry more frequently than other classes (Reynolds et al. 2006). I included approximately 750 wetlands in the sample in anticipation of being denied access to some basins.

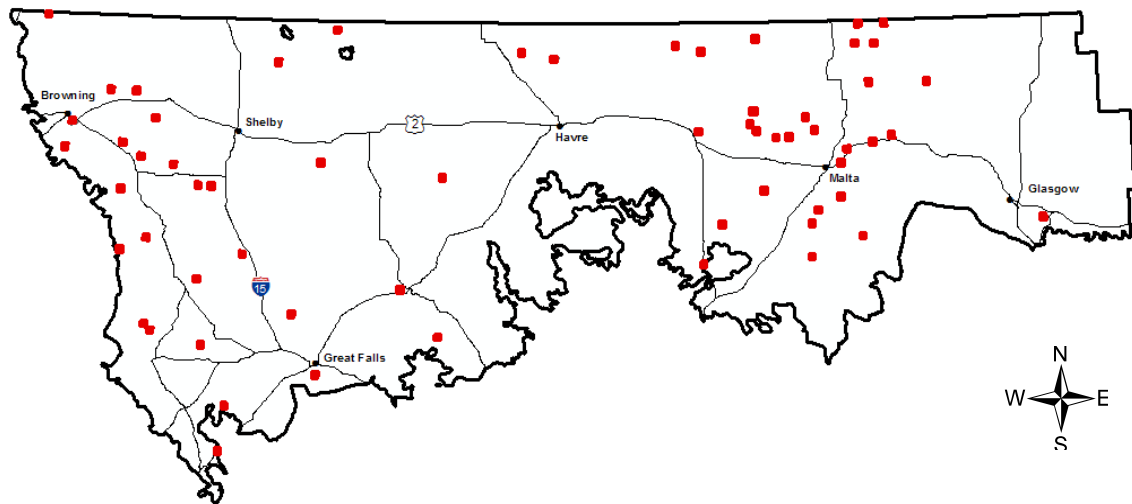


Figure 3.4. The location of the 61 survey plots (shown in red).

Breeding Duck Survey

I used methods described by Cowardin et al. (1995) to conduct the breeding waterfowl surveys. Each sample basin was surveyed twice to encompass the breeding phenologies of the different waterfowl species in the study area. Field observers visited each sample wetland once during the period May 1 – May 15 and again during the period May 20 – June 4. The first survey period is for species that initiate nesting early in the breeding season, such as mallard (*Anas platyrhynchos*) and northern pintail (*A. acuta*). The second survey period is for species that initiate nesting later in the breeding season,

such as gadwall (*A. strepera*), and blue-winged teal (*A. discors*). Private land access was requested if a landowner, lessee, or tenant could be identified and contacted.

Approximately 160 landowners were contacted via letters and phone calls each year prior to the survey to request access permission. Field observers also sampled wetland basins where access permission was denied via observations from public roads and adjacent land where permission had been obtained. In these situations, ducks were counted and recorded on any basin that was entirely visible from the viewing location. Changes in access permission and wetland conditions due to rain and snow resulted in some basins being surveyed during only one of the survey periods.

Survey plots were assigned to field observers and all sample basins within a given 4 mi² plot were surveyed in a single day when conditions allowed. Permission, weather, accessibility, wetness, numbers of birds, numbers of sample basins, and size of wetlands affected the rate at which plots could be surveyed. If the survey of basins within a plot could not be completed in one day, the remaining basins were surveyed the following day. Surveys began mid-morning and continued until mid-late afternoon and were discontinued during steady rainfall or winds exceeding 32 kilometers per hour (20 mph). Hardcopy, plot-based maps were provided to crew members depicting the perimeter and unique numerical identifier of the sample basins. Color aerial photography (National Agricultural Imagery Program [NAIP] 2005) was overlaid on the maps to assist observer orientation and navigation to survey wetlands. Field observers were also provided with hand-held GPS receivers for navigation purposes. Landowner contact information was included on the hardcopy maps.

I used methods described by Dzubin (1969) and Hammond (1969) to record duck population data. Sample basins were accessed on foot or at a distance by all-terrain vehicles (ATV) to reduce disturbance. The entire wetland basin was scanned instantaneously and unique duck social groups of all species were separately tallied. Social groups were determined by behavior and spatial arrangements of different waterfowl species. A social group was defined as > 1 duck of the same species associating with each other in close proximity and not exhibiting territorial or aggressive behavior towards one another. Social groups were recorded on data cards using fractional notation with the number of males / number of females for each social group present (e.g., 1 male gadwall and 1 female gadwall = 1/1) (Dzubin 1969). Data were recorded for all wetland basins that contained surface water regardless of whether birds were present. Observers disturbed dense vegetation in sample basins to count all ducks present. Only waterfowl that were settled on the water during observation were counted. If observer disturbance caused ducks to leave the sample basin, the birds were counted and the direction and likely destination of birds leaving the wetland was noted to reduce the possibility of recounting birds on sample basins that had not yet been surveyed.

Field observers collected information on basin characteristics once the waterfowl survey was completed. The extent of the wetland area of the sample basin was estimated as percent full by comparing the current surface water with the NWI wetland basin polygon on the field map. A basin with no surface water was recorded as dry and was not surveyed for waterfowl. Additionally, the vegetative cover class was determined by patterns of vegetation and open water interspersions (Stewart and Kantrud 1971).

Appendix B contains examples of plots maps and survey cards used to count breeding duck pairs on sample wetlands.

Although all waterfowl on survey basins were recorded, survey data were later interpreted to estimate indicated breeding pairs. Distinctive pairs (1 male and 1 female) and male ducks in groups of 1-5 were interpreted as indicated breeding pairs, except American wigeon (*Anas americana*) and northern shoveler (*Anas clypeata*), for which only distinctive pairs were interpreted as breeding pairs (Dzubin 1969). All other groupings were considered as migrants or non-breeders and were not included in the analysis.

Wetland Basin Measurements

I measured 7 local wetland covariates at each sample basin (Table 3.1). The amount of temporal and spatial variation in surface water has been shown to be important variable in the regression models developed for predicting breeding duck pairs in the PPR (Reynolds et al. 2006 & 2007, Cowardin et al. 1988 & 1995). I used a covariate that measures the amount of surface water (WAREA) that individual basins contain during the breeding season. During each survey, field observers recorded a percent full estimate to quantify the amount of surface water on each sample pond, using the maximum wetland extent as mapped by NWI as a reference. The percent full estimate was then used to derive WAREA for each sample basin.

Similar to Reynolds et al. (2006) and Cowardin et al. (1988 & 1995), I included a covariate for wetland class (WCLASS) comprised of six wetland categories as described in the wetland resources chapter. Stewart and Kantrud (1971) observed that

ducks did not occupy the various basin classes equally in the PPR of North Dakota.

On large wetlands, dabbling ducks tend to occur more frequently along the shallow water shoreline zone than in the deepwater zone (Kantrud and Stewart 1977). Also, some dabbling duck species use shoreline emergent vegetation zones for hiding cover. Reynolds et al (2006) used the square root of wet area as a proxy for shoreline length in their best fitting models. Assuming that most pothole wetlands are generally round, the circumference of the basin is proportional to the wetland radius, which is proportional to the square root of the wetland area. I applied two measures of shoreline length as explanatory variables; the square root of wet area (SQRTWA) and the wetland perimeter length as mapped by NWI (PERIM). PERIM represents the shoreline of a wetland basin that is 100% full of water. SQRTWA is a proxy for the shoreline length for the specific surface water conditions of a survey year.

Stewart and Kantrud (1973 & 1974) found that ducks were not distributed equally throughout the biotic regions of North Dakota. Reynolds et al (2006 & (2007) used UTM easting and UTM northing as covariates in their best fitting models. I measured the spatial position in meters (Montana State Plane coordinates) of each sample wetland centroid, using northing (MTY) and easting (MTX) as covariates.

Upland characteristics immediately adjacent to wetlands also may affect the use of that wetland by breeding duck pairs. Krapu et al. (1997) and Reynolds et al. (2007) reported that temporary and seasonal wetlands located in cropland attracted fewer pairs of breeding ducks compared to wetlands not in cropland. I used a categorical variable (UCLASS) that identifies the adjacent upland land use as cropland, perennial nesting

cover or other. If any portion of the sample basin was adjacent to agricultural cropland, UCLASS = cropland. If the basin was not adjacent to cropland and was adjacent to upland nesting cover, UCLASS = nesting. All other basins were categorized as UCLASS = other. I used the Northwest Region GAP Analysis Land Cover (US Geological Survey 2010) data layer to measure this covariate.

Landscape Habitat Measurements.

Landscape characteristics within various distances surrounding wetland basins may also influence the wetland's attractiveness to breeding ducks. Identifying the scale at which to measure landscape-level variables may be as important as determining which variables to measure (Levin 1992). To investigate how landscape characteristics influence the number of breeding pairs using a wetland basin, I measured 3 different landscape characteristics within a species-specific breeding home range size (i.e. radius) of sampled basin centers (Table 3.1 & 3.2)

Extensive research has focused on how ducks settle on the breeding grounds. A correlation between the number of wetlands and number of breeding ducks at different scales is well known (Crissey 1969, Dzubin 1969, Stewart and Kantrud 1974, Johnson and Grier 1988, Batt et al. 1989, Cowardin and Blohm 1992). Johnson and Grier (1988) estimated a positive correlation between landscape pair densities and pond densities across the PPR. Lokemoen (1973) found wetlands that were more isolated from others received less use by breeding ducks. I used the total number of seasonal and semi-permanent wetland basins containing surface water (i.e. ponds) (WCOUNT) and the proportion of the ponded surface water within a specified radius of a wetland basin

(PWAREA) as explanatory variables in the modeling process. I predicted that landscapes around individual wetland basins with more ponds and ponded surface water will attract more duck pairs compared to landscapes with fewer basins.

Krapu et al. (1997) estimated a negative effect of cropland on number of breeding pairs when temporary and seasonal pond area increased in 50.8 km² plots. Reynolds et al. (2007) estimated that duck pairs selected wetlands differently when embedded in cropland, grazed land, and undisturbed grass cover. I used the percent of cropland within a specified home range radius of a wetland center as an explanatory variable (PCROP). The Northwest Region GAP Analysis Landcover (US Geological Survey 2010) was the data layer used to measure this covariate. I predicted that less fragmented landscapes around individual wetland basins would attract more duck pairs compared to more fragmented landscapes.

All landscape covariates were measured using spatial analysis techniques in ArcMap 9.2 (ESRI 2006). Wetland basin centroids were calculated and buffered to represent the species-specific home range areas. The Northwest Regional GAP land cover data were processed to measure the proportion of cropland within each buffer. Aerial imagery was collected each year with fixed-wing aircraft to measure the wetland conditions on all sample plots. Surface water on all plots was mapped using remote sensing image processing techniques with SPRING software (Camara 1996). For each year, percent full of individual basins in the study area was estimated using inverse distance weighted interpolated surface modeling techniques. The count of all seasonal

and semi-permanent wetlands containing water (i.e. percent full > 0) and corresponding surface water within a home range buffer were then quantified for each sample wetland.

Table 3.1. Covariates and definitions used in breeding pair models

Covariate	Definition
WCLASS	Wetland basin classification (temporary, seasonal, semi-permanent, permanent, riverine, riverine-intermittent)
WAREA	Area of wetland basin covered by surface water measured in square meters
SQRTWA	Square root of area of wetland basin covered by water. A proxy for wetland perimeter for a sample basin during a specific survey year.
PERIM	Wetland perimeter in meters as mapped by NWI, representative of full pool.
MTX	The easting spatial location in Montana state plane coordinate system measured in meters
MTY	The northing spatial location in Montana state plane coordinate system measured in meters
UCLASS	The adjacent upland land use classification (cropland, nesting cover, other) to wetland
WCOUNT	Total count of seasonal and semi-permanent wetland basins containing water within a species-specific home range area from wetland center
PWAREA	Proportion seasonal and semi-permanent wetland basin surface area within a species-specific home range area from wetland center
PCROP	Proportion cropland within a species-specific home range area from wetland center

Table 3.2. Breeding duck home range sizes and respective buffer distance from wetland centers used to approximate the home ranges. Adapted from Reynolds et al. 2006.

Species	Home Range	Buffer	Source
	Area (km ²)	Distance (m)	
Mallard	10.4	1810	Cowardin et al (1985)
Northern Pintail	12.8	2015	Derrickson (1978)
Northern Shoveler	1.15	605	Poston (1974)
Gadwall	2.04	805	Gates (1962), Duebbert (1966)
Blue-winged Teal	2.04	805	Dzubin (1955)

Data Analysis

Three suites of competing models were developed for each of 5 different species of ducks to estimate the factors influencing the abundance and distribution across the study area during the breeding season. Species-specific models were developed because of potential differences in the way that the various duck species settle on wetlands with different characteristics. I analyzed separate models for the five most common species in the U.S. PPR: blue-winged teal (*Anas discors*), mallard (*A. platyrhynchos*), gadwall (*A. strepera*), northern shoveler (*A. clypeata*), and northern pintail (*A. acuta*). Factors measured at the local wetland scale were assessed in the *a priori* Wetland Suite while factors measured at a species-specific home range landscape scale were assessed in the Landscape Suite. The Landscape Suite was considered exploratory because all combinations of covariates were used in the models. A third exploratory Combined Model Suite was created using the most-supported models in the Wetland and Landscape suites (0-2 ΔAIC_c , for non-nested models, Burnham and Anderson, 2002). I included the full model in the exploratory Combined Suite to ensure I was not overlooking significant covariates. The exploratory models have two purposes; they can confirm the validity of

variables included in the *a priori* models as well as suggest future variables and hypotheses of research interest in this long-term adaptive study.

Biologically defensible *a priori* models hypothesizing the effects of the covariates on breeding pair abundance were constructed based upon previous studies of duck/wetland relationships (Table 3.3). The *a priori* and exploratory models were evaluated through Akaike's Information Criterion (Akaike 1973) corrected for small sample size (AIC_c) (Hurvich 1989). Ranking ΔAIC_c and models weights facilitated detection of the model or models best suited for making predictions (Burnham and Anderson 2002). Model weights were used to average model predictions to account for model selection uncertainty.

I modeled the total number of breeding duck pairs observed on wetlands using generalized linear mixed models, a Poisson distribution, and log-link function in the glmmML library (Broström 2009) in software R (R Development Core Team 2009). The Poisson distribution is commonly used when analyzing discrete count data when large counts are rare events (Neter et al. 1996, Agresti 2007). Mixed models are useful for modeling the dependence among observations inherent in repeated measures studies and for accommodating overdispersion among Poisson responses (Breslow and Clayton 1993). Mixed models are well suited to repeated measures studies where not all subjects were surveyed at each time period, resulting in missing data (Bolker 2008). Dry wetlands, changes in access permission, seasonal inaccessibility (e.g. flooded access roads), and replacement wetlands in the second year resulted in missing data in the study. I accounted for the lack of independence in the repeated measures using a compound

symmetrical correlation structure. The correlation structure treats the multiple measures as independent in time, but possibly correlated because of uniqueness of the subjects.

Generalized linear mixed models are also useful for accounting for spatial autocorrelation in the count data (Zuur et al. 2009). Positive spatial autocorrelation indicates the clustering of similar values across geographic space, while negative spatial autocorrelation indicates that neighboring values are more dissimilar than expected by chance. Positive spatial autocorrelation leads to the underestimation of standard errors, and elevated type I errors, if not accounted for in the modeling process (Legendre 1993). Correlograms are one way to assess the extent of spatial auto-correlation in the data (Cliff and Ord 1981). I created correlograms in program PASSaGE (Rosenberg 2001) to assess spatial autocorrelation in the observed counts for each species.

Currently, goodness-of-fit methods for generalized linear mixed models are not well defined (Pan and Lin 2005). Repeated (n=10) 10-fold cross validation (Rodrigues et. a. 2010) was used as a form of goodness-of-fit to 1) assess the predictive ability of the best fitting models and 2) calculate a squared correlation coefficient value that summarizes the discrepancy between observed values and predicted values (R^2). The cross-validation procedure consisted of estimating the coefficients of the model from 9 of the randomly selected subsets (i.e. folds) of observations and applying the model to the remaining 1 subset of observations to assess the predictive capabilities. This is completed 10 times until all folds have been used to both estimate the model coefficients and test the model in separate validation routines. The 10-fold cross validation process was repeated 10 times resulting in 100 estimates that were averaged to produce final error

estimates and prediction R^2 estimates for each model. Although the root mean square error (RMSE) is a frequently-used measure of the differences between values predicted by a model and the values actually observed, mean absolute error (MAE) is a measure that is more robust to outliers in the data that can result in large RMSE estimates (Willmott and Matsuura 2005). Both RMSE and MAE were calculated and reported in the cross validation results.

Potential correlations between covariates (i.e. multicollinearity) were inspected using Pearson correlation coefficients. Appendix A contains the Pearson correlation coefficients, histograms and x-y scatterplots of wetland and landscape variables used in each of the five species breeding pair models.

Table 3.3. Biological hypotheses for the response of breeding duck pairs to local and landscape scale habitat characteristics. The Wetland suite was developed *a priori* to data analysis. The Landscape suite was considered exploratory because all covariate combinations were used. I used the top models in the two suites with exploratory techniques to expand on the Combined suite. All models include WAREA and SQRTWA terms. Model notation is for Mallard.

Hypothesis	Model	Model Structure
<u>Wetland Suite</u>		
1) Null Model – positive sqrt (wet area) effect with a negative wet area effect	$MALL_{WAREA+SQRTWA}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA)$
2) Positive full wetland perimeter effect	$MALL_{WAREA+SQRTWA+PERIM}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(PERIM)$
3) Separate intercepts for upland classes	$MALL_{WAREA+SQRTWA+UCLASS}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(UCLASS)$
4) Positive wet area to sqrt(wet area) interaction effect	$MALL_{WAREA+SQRTWA+(WAREA*SQRTWA)}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_2(WAREA*SQRTWA)$
5) Separate intercepts for wetland class	$MALL_{WAREA+SQRTWA+WCLASS}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(WCLASS)$
6) Location effect, separate intercepts for wetland classes	$MALL_{WAREA+SQRTWA+WCLASS+LOCATION}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(WCLASS) + \beta_4(MTX) + \beta_5(MTY) + \beta_6(MTX * MTY)$
7) Location effect	$MALL_{WAREA+SQRTWA+LOCATION}$	$\beta_0 + \beta_1(WAREA) + \beta_2(MTX) + \beta_3(MTY) + \beta_4(MTX * MTY)$
<u>Landscape Suite</u>		
1) Positive seasonal and semi-permanent wetland count effect – species home range area	$MALL_{WAREA+SQRTWA+WCOUNT}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(WCOUNT)$
2) Positive seasonal and semi-permanent proportion wetland area effect - species home range area	$MALL_{WAREA+SQRTWA+PWAREA}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(PWAREA)$

Table 3.3. continued

Hypothesis	Model	Model Structure
3) Negative proportion crop effect - species home range area	$MALL_{WAREA+SQRTWA+PCROP}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(PCROP)$
4) Positive seasonal and semi-permanent wetland count effect and negative percent crop effect - species home range area	$MALL_{WAREA+SQRTWA+WCOUNT-PCROP}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(WCOUNT) + \beta_4(PCROP)$
5) Positive percent seasonal and semi-permanent wetland surface area and wetland count effect - species home range area	$MALL_{WAREA+SQRTWA+PWAREA+WCOUNT}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(PWAREA) + \beta_4(WCOUNT)$
6) Positive proportion seasonal and semi-permanent wetland surface area and negative percent crop effect - species home range area	$MALL_{WAREA+SQRTWA+PWAREA+PCROP}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(PWAREA) + \beta_4(PCROP)$
7) Positive percent seasonal and semi-permanent wetland surface area and count and negative percent crop effect - species home range area	$MALL_{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}$	$\beta_0 + \beta_1(WAREA) + \beta_2(SQRTWA) + \beta_3(PWAREA) + \beta_4(WCOUNT) + \beta_5(PCROP)$

Results

Wetland Basin Habitat Measurements

Field observers surveyed breeding ducks on 657 basins in 2008 and 704 basins in 2009. Of the original sample of 746 basins, 25 were removed because they were drained, included steep gradients (e.g. seeps, coulees), or due to mapping misclassification (i.e. not wetlands). The basins removed from the sample were replaced for the 2009 survey. In 2008, 80 basins were not sampled because landowners denied access or could not be contacted and 19 basins were missed by field observers. In 2009, 42 of the original 746 basins were not surveyed because of denied access permission and no sample basins were missed by field observers. No wetland basin was permanently removed from the sample because it was dry or because permission to access the pond was denied by the private landowner. Permission will be requested again in subsequent survey years for basins without access for a given survey year.

North-central Montana was in a moderate to severe drought cycle in May 2008 compared to slightly dry to normal conditions in May 2009 (MT DNRC, 2009). In 2008, 336 sample basins (51%) were dry during both count periods compared to 206 (29%) in 2009. 1969 indicated breeding pairs of the 5 principal species occurred on 142 basins in 2008 and 232 basins in 2009. Mallard accounted for 41% of the indicated breeding pairs, northern pintail 19%, gadwall 19%, blue-winged teal 13%, and northern shoveler 8% of the indicated breeding pairs.

Landscape Habitat Measurements

Agricultural land use around individual sample basins varied widely across the study area. Although PCROP ranged from approximately 0-1 for all species, most of the sample basins were situated in landscapes where agricultural use was lower than 30% of the total area (Table 3.4; Appendix A). Seasonal and semipermanent wetland basin densities around sample basins also varied widely, ranging from 0 for each species up to 208 for northern pintail. Seasonal and semipermanent wetland surface area ranged from 9% of the NOPI home range area to 30% of the NSHO home range area around a sample basin. Interpolated surface models for each basin class showed that geographic trends were consistent between years but that there was striking difference in water levels between 2008 and 2009 (Figure 3.5).

Table 3.4. Landscape habitat characteristics within a home range buffer of sample basins (n) during 2008 and 2009 surveys

species	variable	$\bar{x}$	sd	min	max
NOPI (n=690, buffer =2015m)	WCOUNT	29.65	40.99	0.00	208.00
	PWAREA	0.01	0.02	0.00	0.09
	PCROP	0.27	0.26	0.00	0.95
MALL (n=690, buffer =1810m)	WCOUNT	24.26	33.88	0.00	181.00
	PWAREA	0.01	0.02	0.00	0.10
	PCROP	0.27	0.27	0.00	0.98
GADW (n=660, buffer =805m)	WCOUNT	5.35	7.67	0.00	51.00
	PWAREA	0.02	0.05	0.00	0.49
	PCROP	0.26	0.30	0.00	0.99
BWTE (n=660, buffer =805m)	WCOUNT	5.35	7.67	0.00	51.00
	PWAREA	0.19	0.05	0.00	0.49
	PCROP	0.26	0.30	0.00	0.99
NSHO (n= 737, buffer =605m)	WCOUNT	3.44	4.79	0.00	30.00
	PWAREA	0.03	0.09	0.00	0.87
	PCROP	0.24	0.30	0.00	1.00

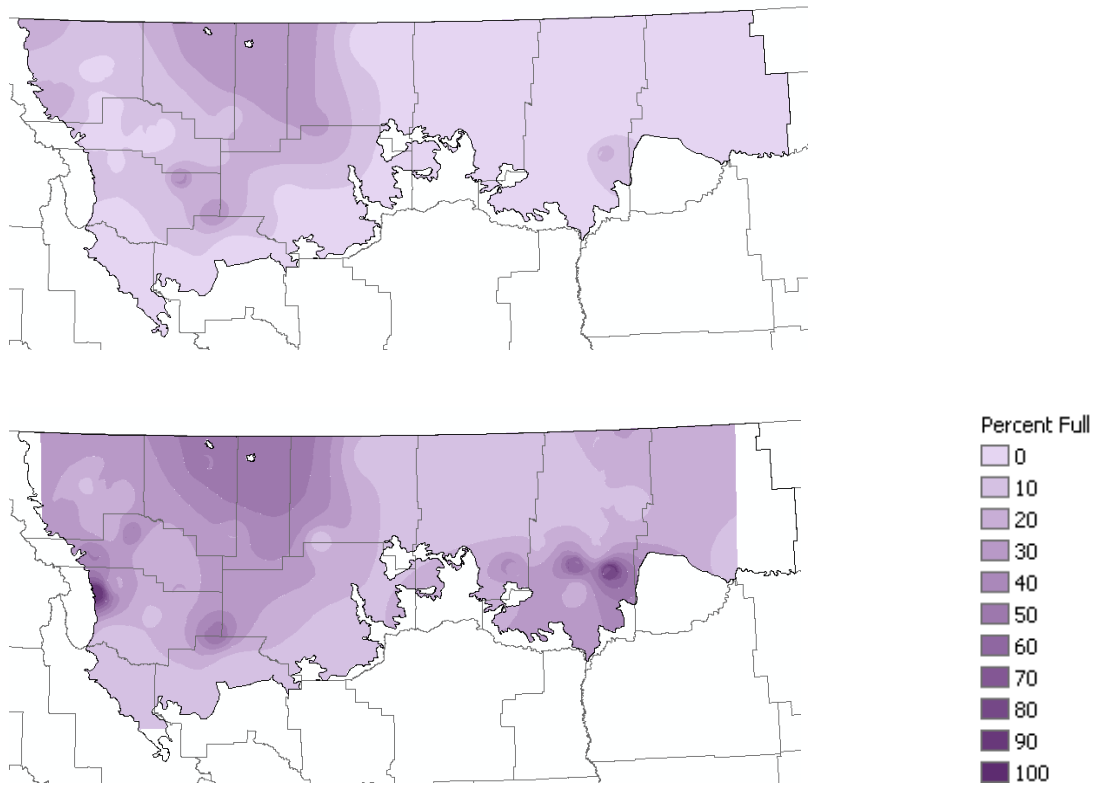


Figure 3.5. Inverse distance weighted (IDW) interpolated wetness model for seasonal basins in survey area for 2008 (top) and 2009 (bottom).

Model Assessment

Model cross validation results and correlograms are presented prior to the competing model results to provide information on the quality of the top models. Although some of the habitat associations were weakly supported in some species' models, the information is provided to elucidate potentially important associations for future analysis. This two-year study provides the foundation for long-term breeding duck research that will continue indefinitely in Montana.

Cross Validation. The calculations of RMSE and MAE indicate that all top models predict breeding pairs adequately, with Mallard predicting within approximately 1 breeding pair (MAE) of the observed values and the remaining species predicting within approximately 0.5 breeding pairs (MAE) of the observed values (Table 1). The R^2 values range from 0.41 for northern pintail to 0.20 for northern shoveler.

Table 3.5. Repeated 10-fold cross validation results for top overall models. Root mean square error (RMSE), mean absolute error (MAE) and the prediction squared correlation coefficient (R^2) are reported for each species top model.

Species	RMSE	MAE	R^2
MALL	2.56	1.08	0.27
NOPI	1.57	0.54	0.41
GADW	1.76	0.57	0.32
NSHO	0.67	0.27	0.20
BWTE	1.04	0.39	0.30

Spatial Autocorrelation. Correlograms indicated positive and negative spatial autocorrelation existed at different distances between sample basins in the observed pair counts for all species (Figure 3.6). The correlograms of model residuals indicated the models accounted for all positive spatial auto-correlation in the data. However, model residuals for mallard, northern pintail, and gadwall indicated negative spatial auto-correlation (i.e. more variation than expected) in neighboring sample basins within 2000 m proximity.

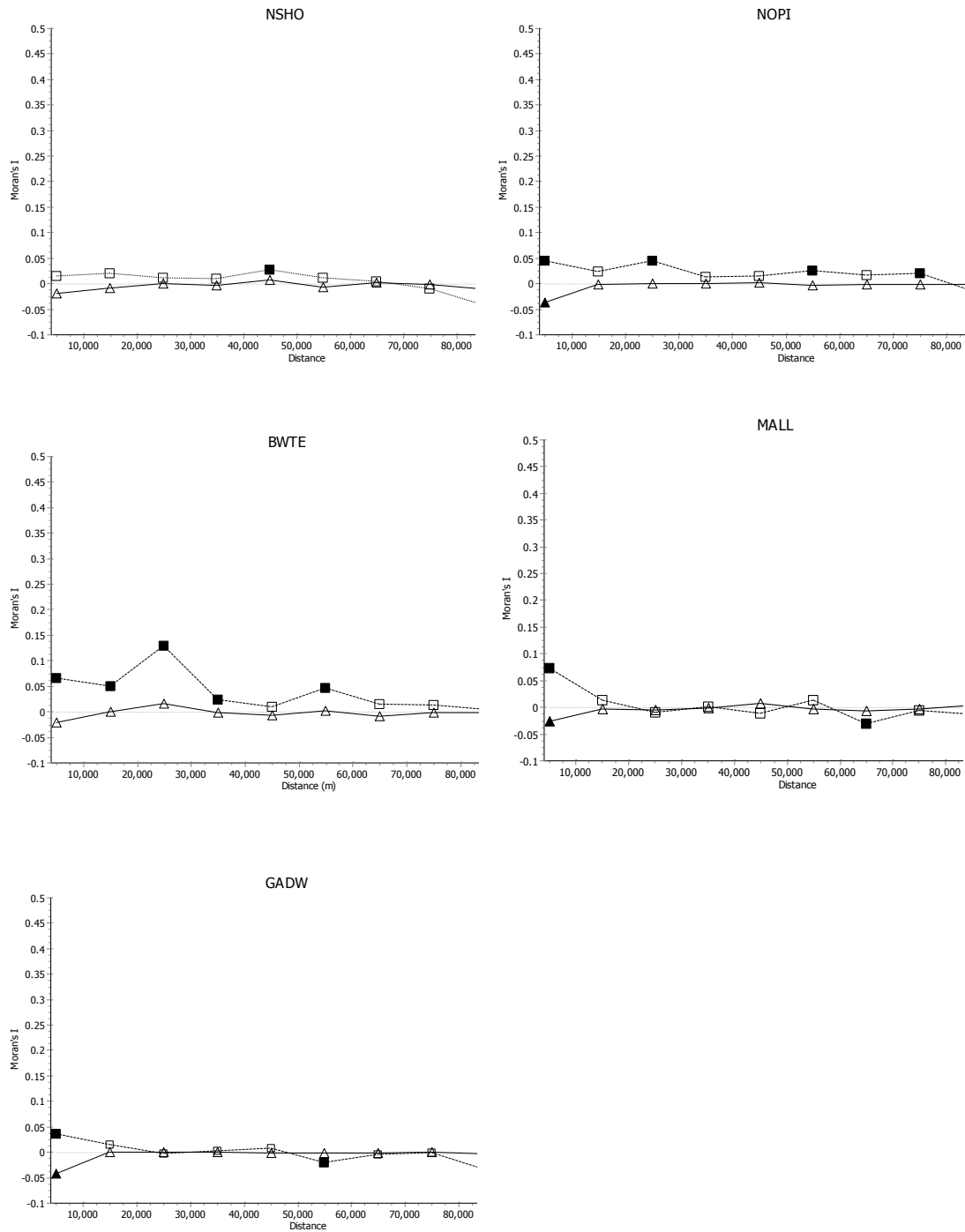


Figure 3.6. Correlograms of raw observation data (squares) and model residuals (triangle) for each species. Solid squares and triangles indicate significant spatial autocorrelation. Distance is measured in meters

Individual Species Analysis

Mallard. The mallard *a priori* Wetland Suite competing model analysis provided support for two models. The most parsimonious models, $MALL_{WAREA+SQRTWA+WCLASS}$ and $MALL_{WAREA+SQRTWA+PERIM}$, received the majority of support ($\Sigma\omega_i = 0.936$) and had AIC_c values within 1.714 units of each other (Table 3.6). Coefficient estimates for WAREA were negative in both models and estimated coefficients for SQRTWA were positive for both models ($B_{WAREA} = -0.000019$, 85% CI -0.000023- -0.000015; $B_{SQRTWA} = 0.014230$, 85% CI 0.012115- 0.016345; Appendix B). These estimates were consistent with my hypothesis based on previous studies in the U.S. PPR. The estimated coefficients for wetland basin class in the most parsimonious Wetland Suite model, $MALL_{WAREA+SQRTWA+WCLASS}$, provided strong support (i.e. 85% confidence interval does not include 0; Arnold 2010) that breeding pair abundance is correlated with wetland class. Breeding mallard pairs abundance increased as the full pool perimeter length increased in the second-best Wetland Suite model, $MALL_{WAREA+SQRTWA+PERIM}$ ($B_{PERIM} = 0.000204$, 85% CI 0.000144 - 0.000264; Appendix B)

Models in the exploratory Landscape Suite consistently received less support than did top models in the Wetland Suite. Two models, $MALL_{WAREA+SQRTWA+PCROP}$ and $MALL_{WAREA+SQRTWA+WCOUNT+PCROP}$, had ΔAIC_c values ≤ 2 . However, the maximized log-likelihood of the second-best model ($MALL_{WAREA+SQRTWA+WCOUNT+PCROP}$; $\log[\mathcal{L}] = -484.1300$) is essentially the same as the top model with one less parameter ($\log[\mathcal{L}] = -484.6175$). Consequently, the second-best model is not really supported. The two models are close

in AIC_c values only because $MALL_{WAREA+SQRTWA+WCOuNT+PCROP}$ adds 1 parameter and therefore will be within 2 ΔAIC_c units, even though the fit, as measured by the log-likelihood value, is not improved (Burnham and Anderson 2002, Arnold 2010). In the top Landscape Suite model, the mallard breeding pair abundance was positively associated with the proportion of cropland within a home range area of the basin. This was contradictory to my hypothesis of a negative effect of cropland on breeding mallard pairs

Table 3.6. Competing *a priori* and exploratory models for analysis of mallard breeding pair abundance

Model	k	AIC_c	Within Suite		All Suites	
			ΔAIC_c	w_i	ΔAIC_c	w_i
Wetland Suite						
$MALL_{WAREA+SQRTWA+WCLASS}$	8	972.144	0.000	0.657	20.251	< 0.01
$MALL_{WAREA+SQRTWA+PERIM}$	4	973.857	1.714	0.279	21.965	< 0.01
$MALL_{WAREA+SQRTWA+WCLASS+LOCATION}$	11	976.953	4.809	0.059	25.060	< 0.01
$MALL_{WAREA+SQRTWA+UCLASS}$	5	981.987	9.844	0.005	30.095	< 0.01
$MALL_{WAREA+SQRTWA+(WAREA*SQRTWA)}$	4	988.596	16.453	0.000	36.704	< 0.01
$MALL_{WAREA+SQRTWA}$	3	995.802	23.659	0.000	43.910	< 0.01
$MALL_{WAREA+SQRTWA+LOCATION}$	6	997.732	25.588	0.000	45.840	< 0.01
Landscape Suite						
$MALL_{WAREA+SQRTWA+PCROP}$	4	979.293	0.000	0.459	27.401	< 0.01
$MALL_{WAREA+SQRTWA+WCOuNT+PCROP}$	5	980.348	1.054	0.271	28.455	< 0.01
$MALL_{WAREA+SQRTWA+PWAREA+PCROP}$	5	981.310	2.016	0.167	29.418	< 0.01
$MALL_{WAREA+SQRTWA+PWAREA+WCOuNT+PCROP}$	6	982.291	2.998	0.103	30.399	< 0.01
$MALL_{WAREA+SQRTWA+WCOuNT}$	4	997.695	18.402	0.000	45.803	< 0.01
$MALL_{WAREA+SQRTWA+PWAREA}$	4	997.809	18.515	0.000	45.916	< 0.01
$MALL_{WAREA+SQRTWA+PWAREA+WCOuNT}$	5	999.629	20.336	0.000	47.737	< 0.01
Combined Suite						
$MALL_{WAREA+SQRTW+WCLASS+PERIM+PCROP}$	10	951.892	0.000	0.940	0.000	0.670
$MALL_{WAREA+SQRTW+WCLASS+PCROP}$	9	958.278	6.386	0.038	6.386	0.277
$MALL_{FULL}$	17	959.551	7.658	0.020	7.658	0.015
$MALL_{WAREA+SQRTW+PERIM+PCROP}$	10	965.107	13.215	0.001	8.289	0.010

The Combined Model suite contained 3 models created by combining the two best Wetland Suite models with the best Landscape Suite model. I also included the full model in the Combined Model suite, yielding a total of 4 models. The most parsimonious model was $MALL_{WAREA+SQRTW+WCLASS+PERIM+PCROP}$ with the majority of support ($w_i = 0.940$), and the next best model had a ΔAIC_c value > 6 . Mallard breeding pair abundance was positively associated with the square root of wetland area, the full pool perimeter length and the proportion of cropland within a home range area of a sample basin. Mallard breeding pair abundance was negatively associated with wetland area ($B_{WAREA} = -0.000017$, 85% CI -0.000021 - -0.000013 ; Appendix B). Breeding mallard pair abundance was strongly associated with wetland basin class (Figures 3.7 & 3.8). Approximately 2.5 times the number of breeding mallard pairs are estimated to occur on permanent and temporary basins in landscapes of high agricultural use compared to permanent and temporary basins in landscapes with low agricultural use (Figure 3.9)

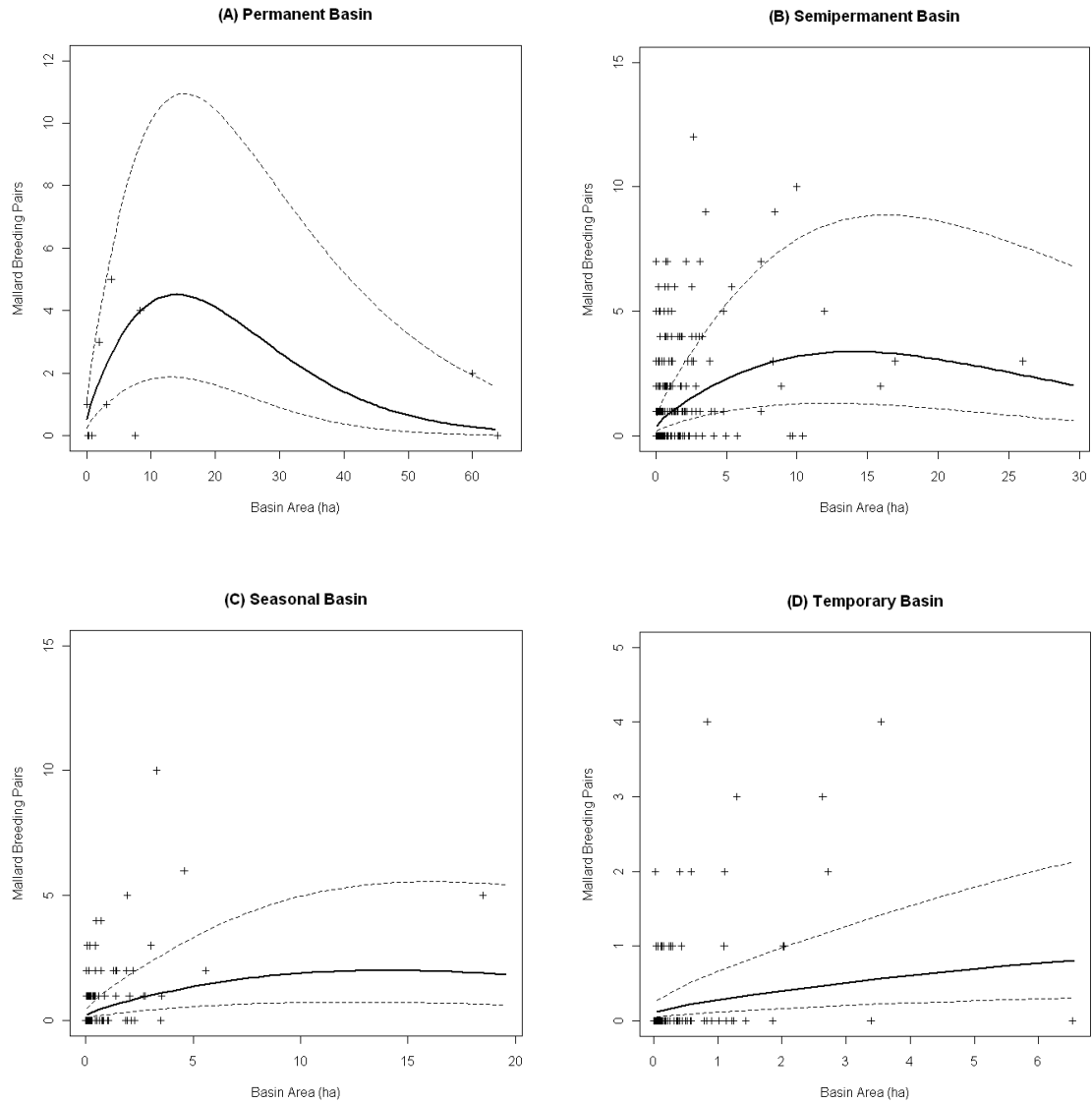


Figure 3.7. Estimated mallard breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations. Dotted lines represent the 95% confidence limits.

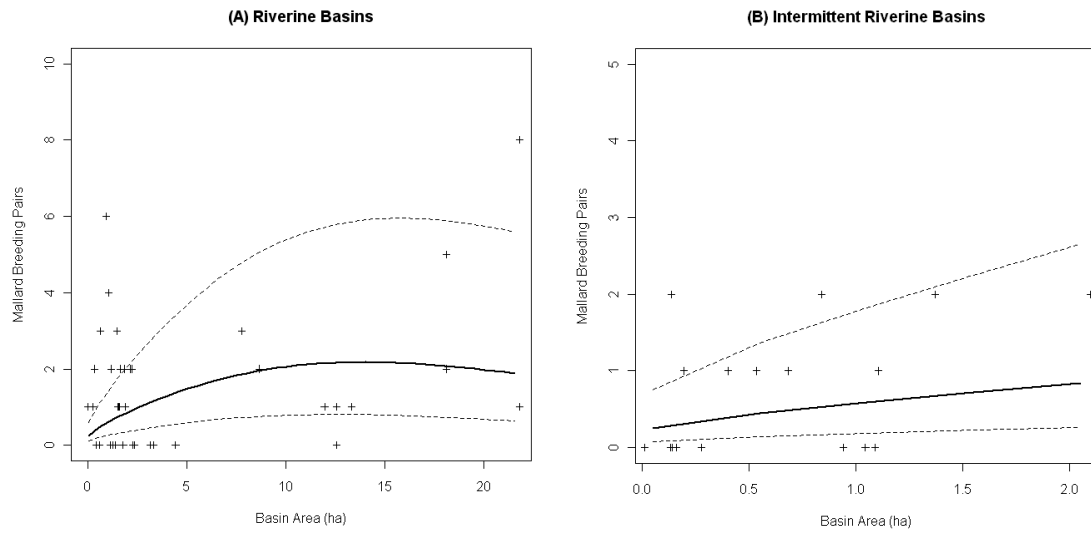


Figure 3.8. Estimated mallard breeding pairs on (A) riverine and (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations. Dotted lines represent the 95% confidence limits.

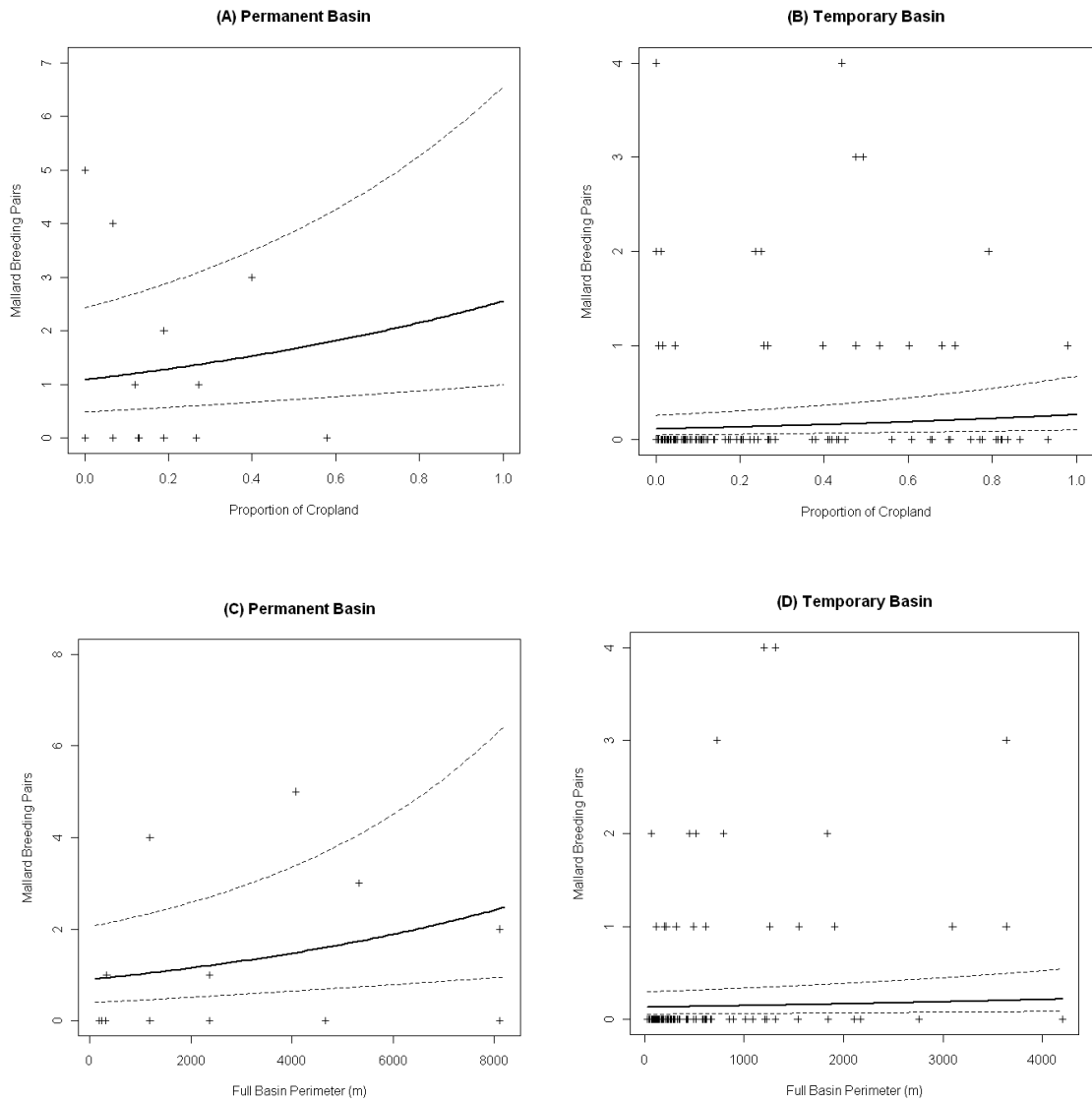


Figure 3.9. Estimated mallard breeding pairs on (A) permanent and (B) temporary basins in relation to the proportion of cropland in the home range landscape and on (C) permanent and (D) temporary basins in relation to the length of the full pool perimeter. Data points represent the observations. Dotted lines represent the 95% confidence limits.

Northern Pintail. The northern pintail *a priori* Wetland Suite competing model analysis ranked $NOPI_{WAREA+SQRTWA+WCLASS+LOCATION}$ as the most parsimonious model with all of the support (Table 3.7). Coefficient estimates for WAREA was negative and estimates for SQRTWA were positive ($B_{WAREA} = -0.000030$, 85% CI -0.000039- -0.000021; $B_{SQRTWA} = 0.01893$, 85% CI 0.015331- 0.022529; Appendix B). The estimated coefficients for WCLASS provided strong support (i.e. 85% confidence interval does not include 0; Arnold 2010) that breeding northern pintail abundance was associated with wetland basin class. The top *a priori* model provided strong evidence for a location effect for breeding northern pintail pairs.

Models in the exploratory Landscape Suite were consistently less supported than the top model in the Wetland Suite. Model selection uncertainty resulted in four landscape models within 2 AIC_c units of the most supported model. However, the maximized log-likelihood of the second-best ($NOPI_{WAREA+SQRTWA+PWAREA+WCOUNT}$; $\log[\mathcal{L}] = -364.1047$) and third-best ($NOPI_{WAREA+SQRTWA+PWAREA+PCROP}$; $\log[\mathcal{L}] = -364.1368$) models are essentially the same as the top model with one less parameter ($NOPI_{WAREA+SQRTWA+PWAREA}$; $\log[\mathcal{L}] = -364.6388$). Consequently, these two models are not really supported. The two models are close to the top model in AIC_c values only because they add 1 parameter and therefore will be within 2 ΔAIC_c units, even though the fit, as measured by the log-likelihood value, is not improved (Burnham and Anderson 2002, Arnold 2010). The resulting top two Landscape Suite models provide strong evidence that northern pintail breeding pair numbers are negatively associated with the proportion of surface water within a breeding home range of a basin ($B_{PWAREA} = -18.28$,

85% CI -30.839 - -5.72; $B_{PWAREA} = -23.39$, 85% CI -38.1788 - -8.6012; Appendix B).

This is contrary to my hypothesis of a positive effect.

$NOPI_{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}$ provided weak evidence that the proportion of cropland positively influenced breeding northern pintail pair abundance. The model also provided weak evidence that the frequency of seasonal and semipermanent wetlands within a breeding home range of a basin positively influenced breeding northern pintail pair abundance.

The Combined Model suite contained 2 models created by combining the best Wetland Suite model with the two top Landscape Suite models. The full model was included in the Combined Suite which yielded a total of three models. Model selection uncertainty resulted in two models within 2 AIC_c units (Table 3.7). The two top models comprise the 95% confidence set of all models ($\Sigma\omega_i = 0.973$). Northern pintail breeding pair abundance was negatively associated with wetland area and positively associated with the square root of wetland area (Appendix B). The proportion of seasonal and semi-permanent wetland surface water in the breeding home range landscape was negatively associated with breeding pair abundance, contrary to my hypothesis. The supported models indicated that breeding northern pintails pair abundance was strongly associated with wetland basin class (Figures 3.10 & 3.11). The top model for breeding pair abundance of northern pintails also included a location effect with higher breeding pair abundance estimated in the northern and eastern portions of the study area (Figure 3.12).

Table 3.7. Competing *a priori* and exploratory models for analysis of northern pintail breeding pair abundance.

Model	k	AIC _c	Within Suite		All Suites	
			ΔAIC _c	w _i	ΔAIC _c	w _i
Wetland Suite						
						<
NOPI _{WAREA+SQRTWA+WCLASS+LOCATION}	11	663.065	0.000	1.000	9.868	0.01
						<
NOPI _{WAREA+SQRTWA+LOCATION}	6	684.536	21.471	0.000	31.339	0.01
						<
NOPI _{WAREA+SQRTWA+WCLASS}	8	720.818	57.753	0.000	67.620	0.01
						<
NOPI _{WAREA+SQRTWA}	3	742.056	78.991	0.000	88.858	0.01
						<
NOPI _{WAREA+WCLASS}	5	742.344	79.279	0.000	89.146	0.01
						<
NOPI _{WAREA+SQRTWA+(WAREA*SQRTWA)}	4	743.534	80.469	0.000	90.336	0.01
						<
NOPI _{WAREA+SQRTWA+PERIM}	4	743.615	80.550	0.000	90.417	0.01
Landscape Suite						
						<
NOPI _{WAREA+SQRTWA+PWAREA}	4	739.336	0.000	0.336	86.138	0.01
						<
NOPI _{WAREA+SQRTWA+PWAREA+WCOUNT}	5	740.297	0.961	0.208	87.099	0.01
						<
NOPI _{WAREA+SQRTWA+PWAREA+PCROP}	5	740.361	1.025	0.201	87.164	0.01
						<
NOPI _{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}	6	741.093	1.757	0.140	87.895	0.01
						<
NOPI _{WAREA+SQRTWA+PCROP}	4	742.745	3.409	0.061	89.547	0.01
						<
NOPI _{WAREA+SQRTWA+WCOUNT}	4	744.046	4.710	0.032	90.848	0.01
						<
NOPI _{WAREA+SQRTWA+WCOUNT+PCROP}	5	744.774	5.438	0.022	91.576	0.01
Combined Suite						
NOPI _{WAREA+SQRTWA+WCLASS+LOCATION+PWAREA}	12	653.198	0.000	0.487	0.000	0.487
NOPI _{WAREA+SQRTWA+WCLASS+LOCATION+PWAREA+WCOUNT+PCROP}	14	653.202	0.004	0.486	0.004	0.486
NOPI _{FULL}	17	658.942	5.744	0.027	5.744	0.027

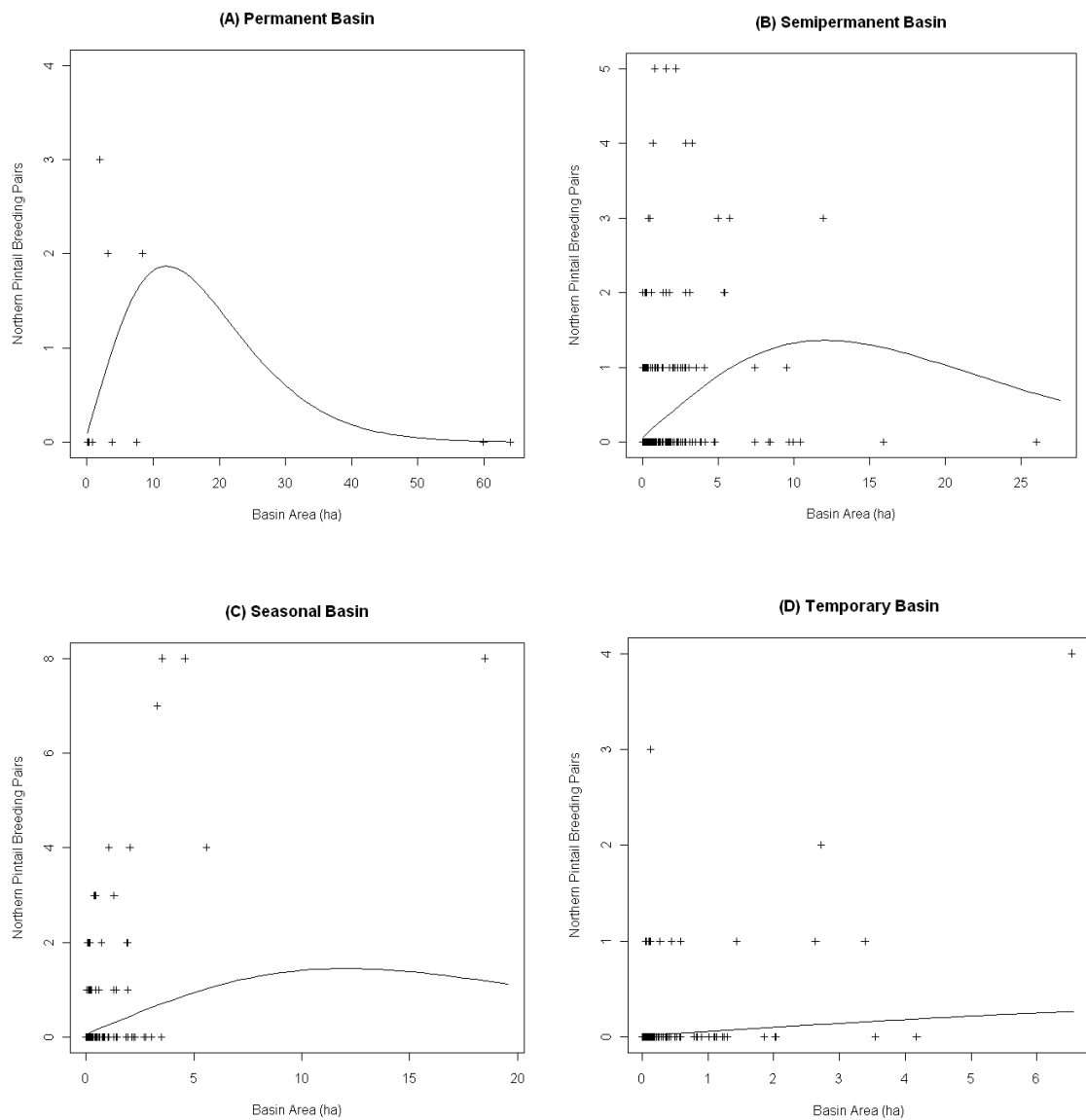


Figure 3.10. Estimated northern pintail breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.

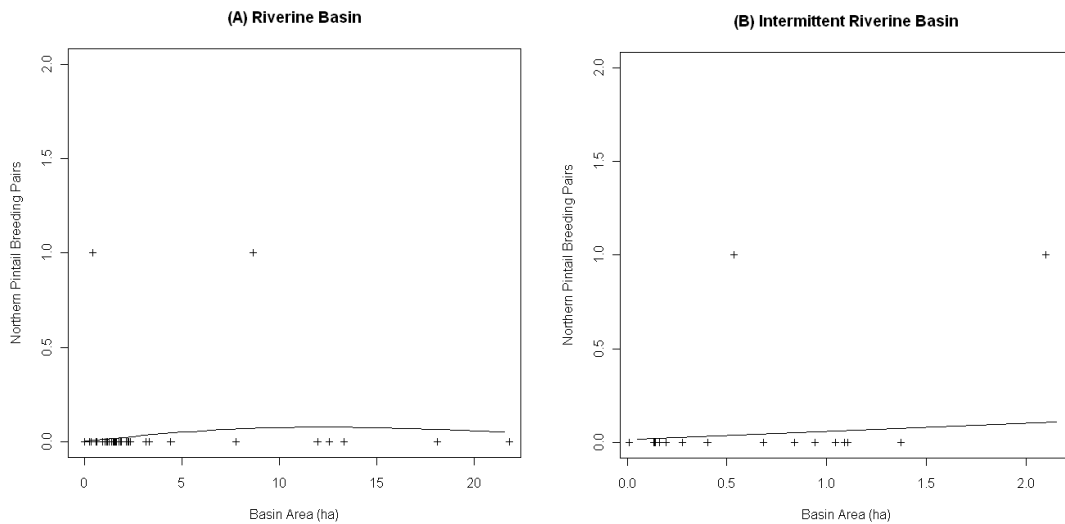


Figure 3.11. Estimated northern pintail breeding pairs on (A) riverine and (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.

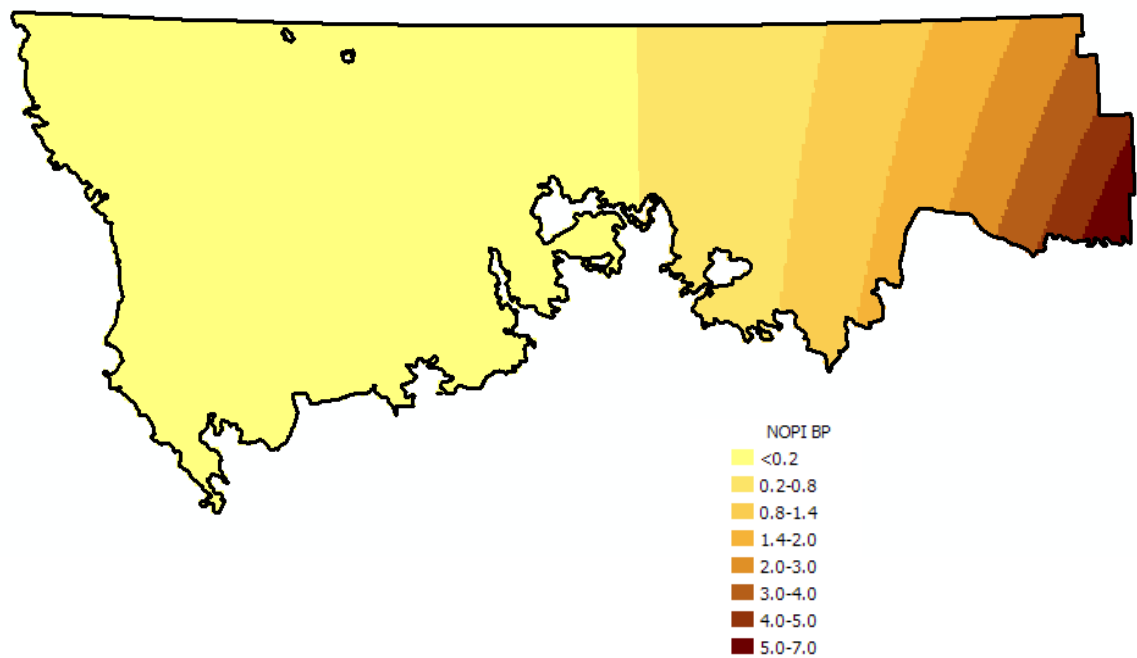


Figure 3.12. Estimated northern pintail breeding pairs on a temporary 0.4 ha (1 acre) basin in relation to the study area location in terms of easting (MTX) and northing (MTY).

Gadwall. The gadwall *a priori* Wetland Suite competing model analysis ranked $GADW_{WAREA+SQRTWA+WCLASS+LOCATION}$ as the most parsimonious model with all of the support ($w_i = 1.0$). The next best supported model had a ΔAIC_c value > 8 (Table 3.8). Coefficient estimates for WAREA was negative and estimates for SQRTWA were positive, consistent

with my hypothesis ($B_{\text{WAREA}} = -0.000023$, 85% CI -0.000030 - -0.000016 ; $B_{\text{SQRTWA}} = 0.01801$, 85% CI 0.014655 - 0.021365 ; Appendix B). The estimated coefficients for wetland class provided strong support for breeding gadwall pairs on all wetland classes except the semipermanent basin classes. The top *a priori* model provided evidence for a location effect for breeding gadwall pairs.

Models in the exploratory Landscape Suite were consistently less supported, based on AIC_c values, then the top model in the Wetland Suite. Model selection uncertainty resulted in two landscape models within 2 AIC_c units of the most supported model. However, the maximized log-likelihood of the second-best

($GADW_{\text{WAREA}+\text{SQRTWA}+\text{WCOUNT}+\text{PCROP}}$; $\log[\mathcal{L}] = -352.604$) and third-best

($GADW_{\text{WAREA}+\text{SQRTWA}+\text{PWAREA}+\text{PCROP}}$; $\log[\mathcal{L}] = -352.605$) models are essentially the same as

the top model with one less parameter ($GADW_{\text{WAREA}+\text{SQRTWA}+\text{PCROP}}$; $\log[\mathcal{L}] = -352.634$).

Consequently, these two models are not really supported. The two models are close to the top model in AIC_c values only because they add 1 parameter and therefore will be within 2 ΔAIC_c units, even though the fit, as measured by the log-likelihood value, is not improved (Burnham and Anderson 2002, Arnold 2010). The top Landscape Model provided strong evidence for the proportion of cropland around a basin positively influencing gadwall breeding pair abundance ($B_{\text{PCROP}} = 0.652$, 85% CI 0.071248 - 1.232752 ; Appendix B).

The Combined Model suite contained a model that combined the best Wetland Suite model with the best Landscape Suite model. The full model was included in the Combined Suite for a total of two models. The top model (

$GADW_{WAREA+SQRTWA+WCLASS+LOCATION+PCROP}$) received the majority of support ($\Sigma\omega_i = 0.918$),

with the full model $> 4 AIC_c$ away. However, the top Wetland Suite model,

$GADW_{WAREA+SQRTWA+WCLASS+LOCATION}$, was within 2 AIC_c units of the top Combined Suite

model. Similar to the top Wetland Suite model, the overall top model provided strong support for wetland basin class as a predictor for breeding gadwall pair abundance

(Figures 3.13 & 3.14). The top model provided some evidence of a location effect, with higher breeding pair abundance estimated in the northern and eastern portions of the study area (Figure 3.15).

The top overall model provided strong support for proportion of cropland in the breeding home range landscape positively influencing gadwall breeding pair abundance ($B_{PCROP} = 0.7818$, 85% CI 0.22884 - 1.33476; Appendix B).

Table 3.8. Competing *a priori* and exploratory models for analysis of gadwall breeding pair abundance.

Model	k	AIC_c	Within Suite		All Suites	
			ΔAIC_c	w_i	ΔAIC_c	w_i
Wetland Suite						
$GADW_{WAREA+SQRTWA+WCLASS+LOCATION}$	11	664.366	0.000	1.000	1.967	0.134
$GADW_{WAREA+SQRTWA+LOCATION}$	6	683.185	18.820	0.000	20.787	< 0.01
$GADW_{WAREA+SQRTWA+WCLASS}$	8	693.866	29.500	0.000	31.468	< 0.01
$GADW_{WAREA+SQRTWA+(WAREA*SQRTWA)}$	4	697.221	32.855	0.000	34.822	< 0.01
$GADW_{WAREA+UCLASS}$	5	709.672	45.306	0.000	47.274	< 0.01
$GADW_{WAREA+SQRTWA}$	3	715.888	51.522	0.000	53.490	< 0.01
$GADW_{WAREA+SQRTWA+PERIM}$	4	716.956	52.590	0.000	54.557	< 0.01
Landscape Suite						
$GADW_{WAREA+SQRTWA+PCROP}$	4	715.329	0.000	0.389	52.930	< 0.01
$GADW_{WAREA+SQRTWA+WCOUNT+PCROP}$	5	717.301	1.972	0.145	54.902	< 0.01
$GADW_{WAREA+SQRTWA+PWAREA+PCROP}$	5	717.303	1.975	0.145	54.905	< 0.01
$GADW_{WAREA+SQRTWA+WCOUNT}$	4	717.755	2.426	0.116	55.356	< 0.01

$GADW_{WAREA+SQRTWA+PWAREA}$	4	717.852	2.524	0.110	55.454	< 0.01
$GADW_{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}$	6	719.300	3.972	0.053	56.902	< 0.01
$GADW_{WAREA+SQRTWA+PWAREA+WCOUNT}$	5	719.756	4.428	0.042	57.358	< 0.01
Combined Suite						
$GADW_{WAREA+SQRTWA+WCLASS+LOCATION+PCROP}$	12	662.398	0.000	0.918	0.000	0.359
$GADW_{FULL}$	17	667.226	4.828	0.082	4.828	0.032

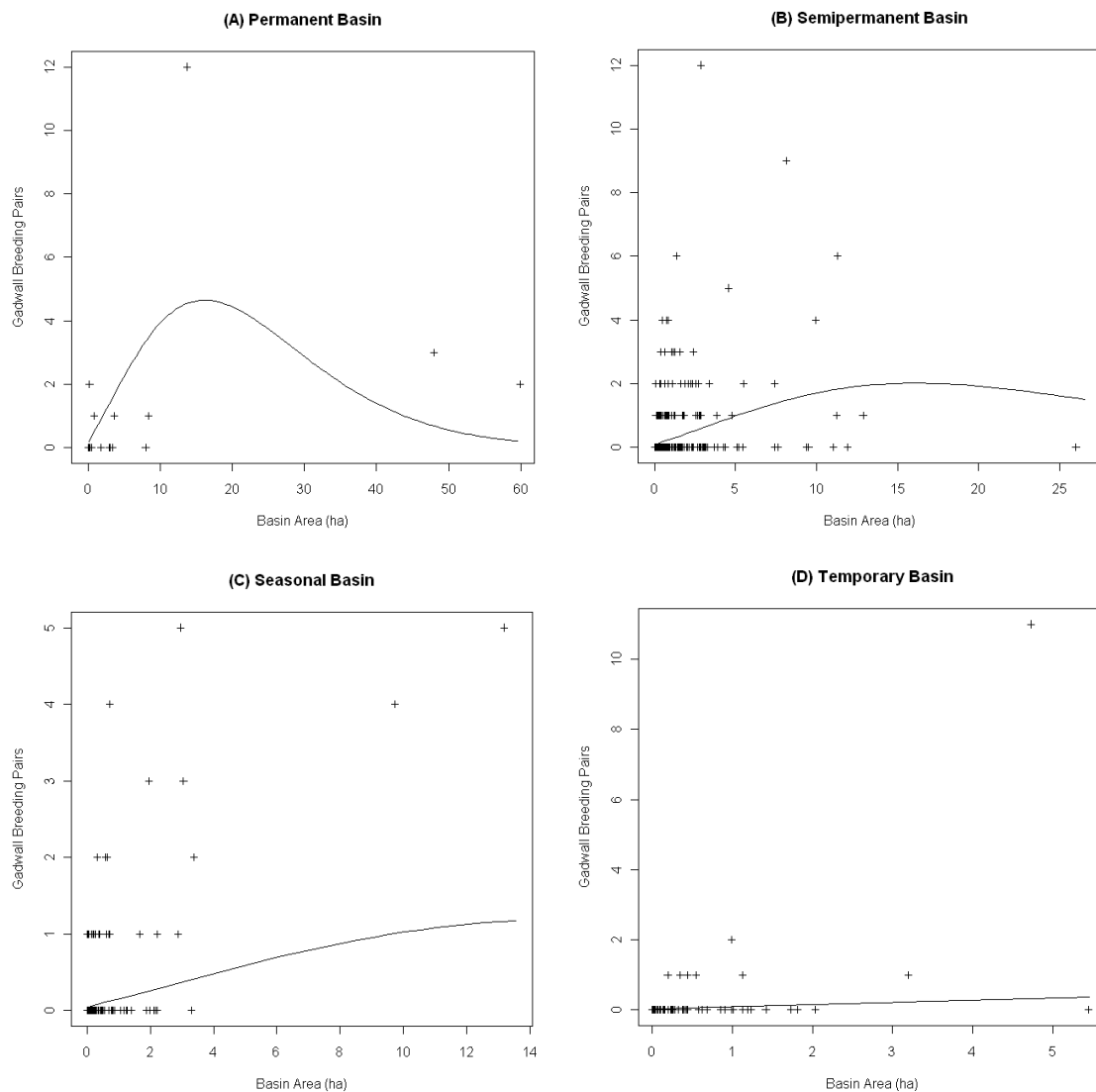


Figure 3.13. Estimated gadwall breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.

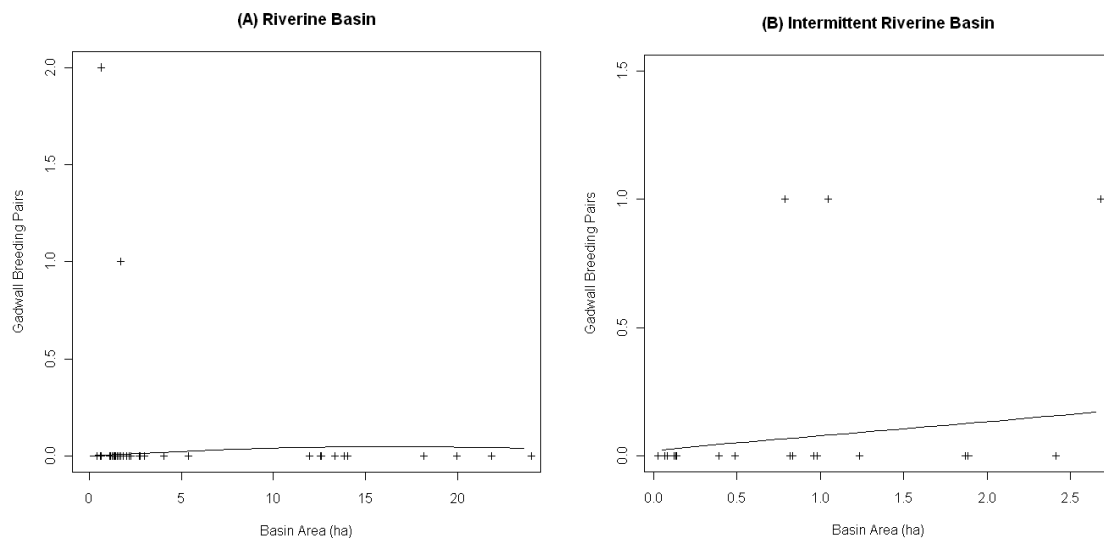


Figure 3.14. Estimated gadwall breeding pairs on (A) riverine and (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.

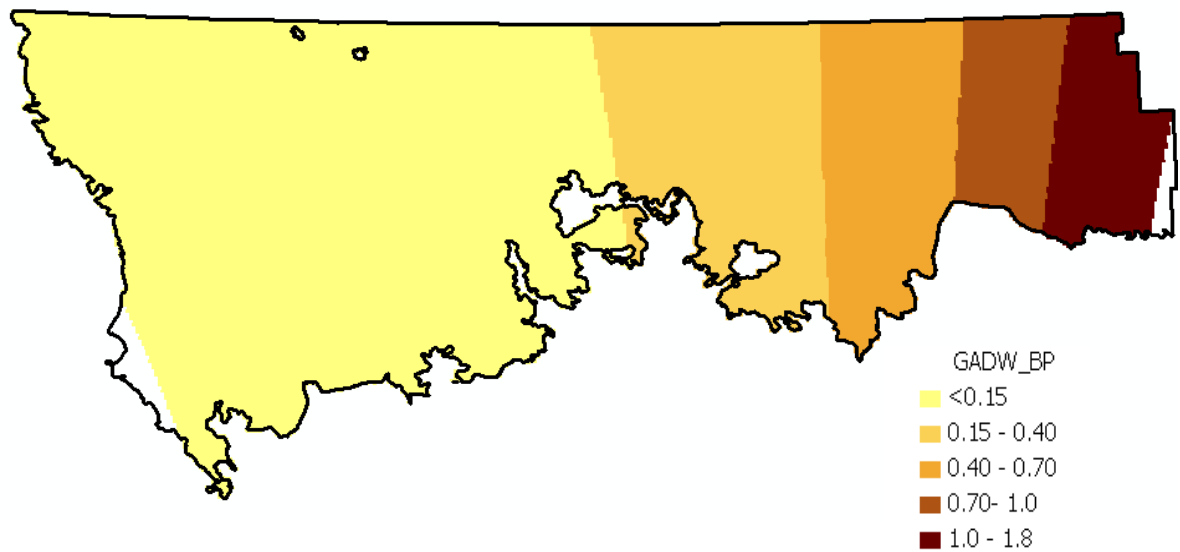


Figure 3.15. Estimated gadwall breeding pairs on a temporary 0.4 ha (1 acre) basin in relation to the study area location in terms of easting (MTX) and northing (MTY).

Northern Shoveler. The northern shoveler *a priori* Wetland Suite competing model analysis ranked $NSHO_{WAREA+SQRTWA+WCLASS+LOCATION}$ as the most parsimonious model with most of the support ($w_i = 0.899$). The next best supported model had a ΔAIC_c value > 4 (Table 3.9). Coefficient estimates for WAREA was negative and estimates for SQRTWA were positive ($B_{WAREA} = -0.000047$, 85% CI -0.000060 - -0.000034; $B_{SQRTWA} = 0.026730$, 85% CI 0.021517- 0.031943; Appendix B). The estimated coefficients for

wetland class provided some support for a wetland basin class as an important predictor of breeding northern shoveler abundance. The top a priori model provided weak evidence of a location affect.

Models in the exploratory Landscape Suite were consistently less supported than the top model in the Wetland Suite. Model selection uncertainty resulted in two Landscape Suite models within 2 AIC_c units. However, the maximized log-likelihood of the second-best ($NSHO_{WAREA+SQRTWA+WCOUNT-PCROP}$; $\log[\mathcal{L}] = -245.331$) models was essentially the same as the top model with one less parameter ($NSHO_{WAREA+SQRTWA+PCROP}$; $\log[\mathcal{L}] = -245.609$). Consequently, the larger model is not really supported. The models is close to the top model in AIC_c value only because it adds 1 parameter and therefore will be within 2 ΔAIC_c units, even though the fit, as measured by the log-likelihood value, is not improved (Burnham and Anderson 2002, Arnold 2010). The top Landscape Suite model provided strong evidence that the proportion of cropland in the breeding home range landscape was positively associated with gadwall breeding pair abundance ($B_{PCROP} = 0.6549$, 85% CI 0.082644 - 1.227156; Appendix B).

The Combined Model suite contained a model created by combining the best Wetland Suite model with the best Landscape Suite models. The full model was also included in the Combined Suite. The top Combined Suite model,

$NSHO_{WAREA+SQRTW+WCLASS+LOCATION+PCROP}$, was also the overall top model and was 7.6 times more likely to be the best explanation for breeding northern shoveler pair settling patterns on the basins in north-central Montana than the full model. Northern shoveler breeding pair abundance was negatively associated with wetland area and positively associated

with the square root of wetland area (Table 3.9). The proportion of cropland in the breeding home range landscape was positively associated with breeding northern shoveler abundance (Figure 3.10). Although the top model contained the location covariates, it provided weak evidence for a location effect (i.e. 85% CI overlaps 0). Wetland class was an important predictor of breeding northern shoveler abundance (Figures 3.16 & 3.17).

Table 3.9. Competing *a priori* and exploratory models for analysis of northern shoveler breeding pair abundance

Model	k	AIC_c	Within Suite		All Suites	
			ΔAIC_c	w_i	ΔAIC_c	w_i
Wetland Suite						
$NSHO_{WAREA+SQRTWA+WCLASS+LOCATION}$	11	481.441	0.000	0.899	5.059	0.065
$NSHO_{WAREA+SQRTWA+LOCATION}$	6	485.824	4.383	0.101	9.442	< 0.01
$NSHO_{WAREA+SQRTWA+WCLASS}$	8	501.645	20.204	0.000	25.262	< 0.01
$NSHO_{WAREA+SQRTWA}$	3	501.913	20.472	0.000	25.531	< 0.01
$NSHO_{WAREA+SQRTWA+PERIM}$	4	502.253	20.812	0.000	25.871	< 0.01
$NSHO_{WAREA+SQRTWA+(WAREA*SQRTWA)}$	4	502.578	21.137	0.000	26.196	< 0.01
$NSHO_{WAREA+SQRTWA+UCLASS}$	5	503.371	21.930	0.000	26.989	< 0.01
Landscape Suite						
$NSHO_{WAREA+SQRTWA+PCROP}$	4	501.274	0.000	0.367	24.892	< 0.01
$NSHO_{WAREA+SQRTWA+WCOUNT+PCROP}$	5	502.744	1.470	0.176	26.362	< 0.01
$NSHO_{WAREA+SQRTWA+PWAREA+PCROP}$	5	503.299	2.025	0.133	26.917	< 0.01
$NSHO_{WAREA+SQRTWA+WCOUNT}$	4	503.565	2.291	0.117	27.182	< 0.01
$NSHO_{WAREA+SQRTWA+PWAREA}$	4	503.917	2.643	0.098	27.535	< 0.01
$NSHO_{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}$	6	504.726	3.452	0.065	28.343	< 0.01
$NSHO_{WAREA+SQRTWA+PWAREA+WCOUNT}$	5	505.509	4.235	0.044	29.127	< 0.01
Combined Suite						
$NSHO_{WAREA+SQRTW+WCLASS+LOCATION+PCROP}$	12	476.382	0.000	0.821	0.000	0.821
$NSHO_{FULL}$	17	480.459	4.078	0.107	4.078	0.107

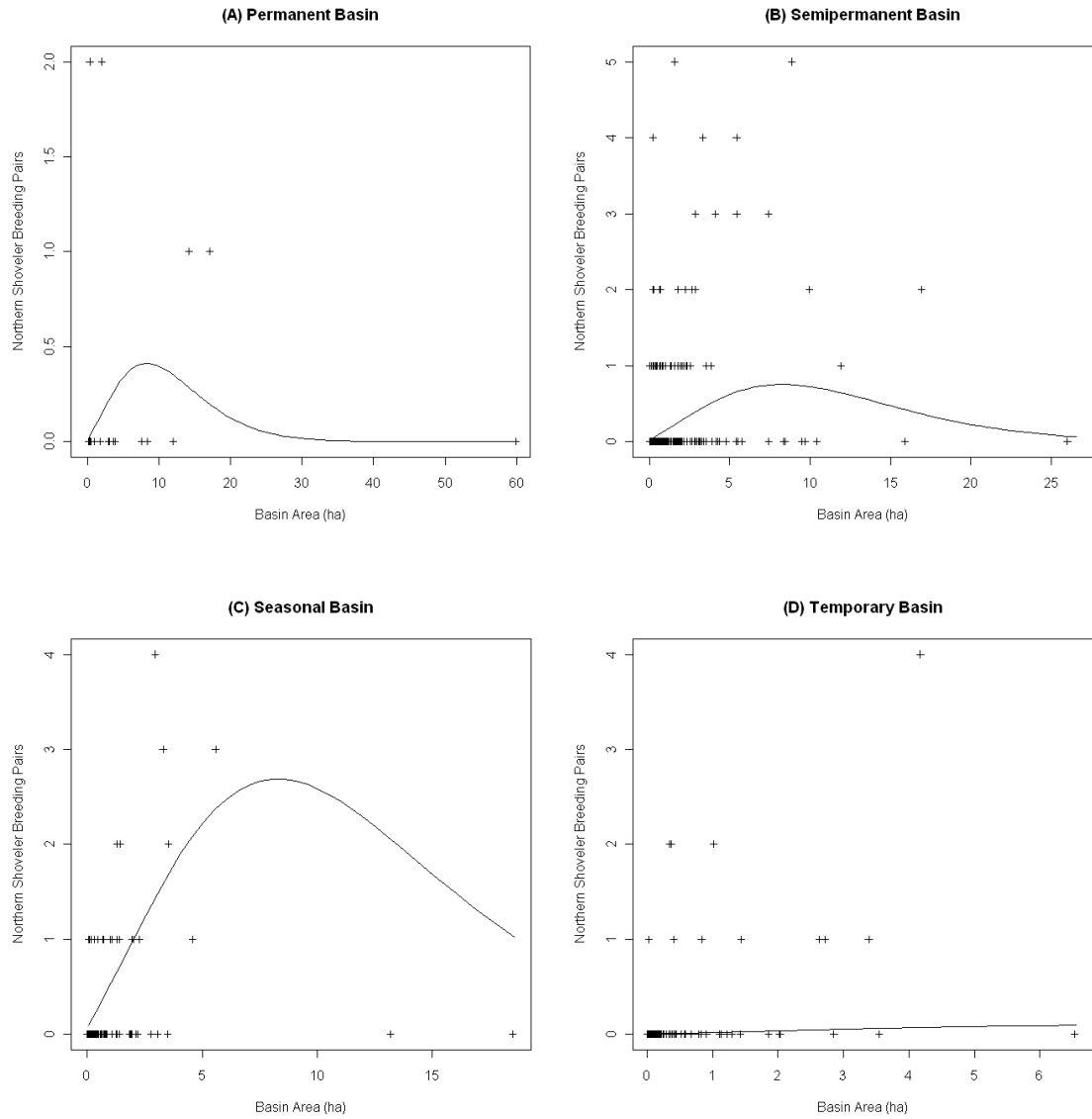


Figure 3.16. Estimated northern shoveler breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.

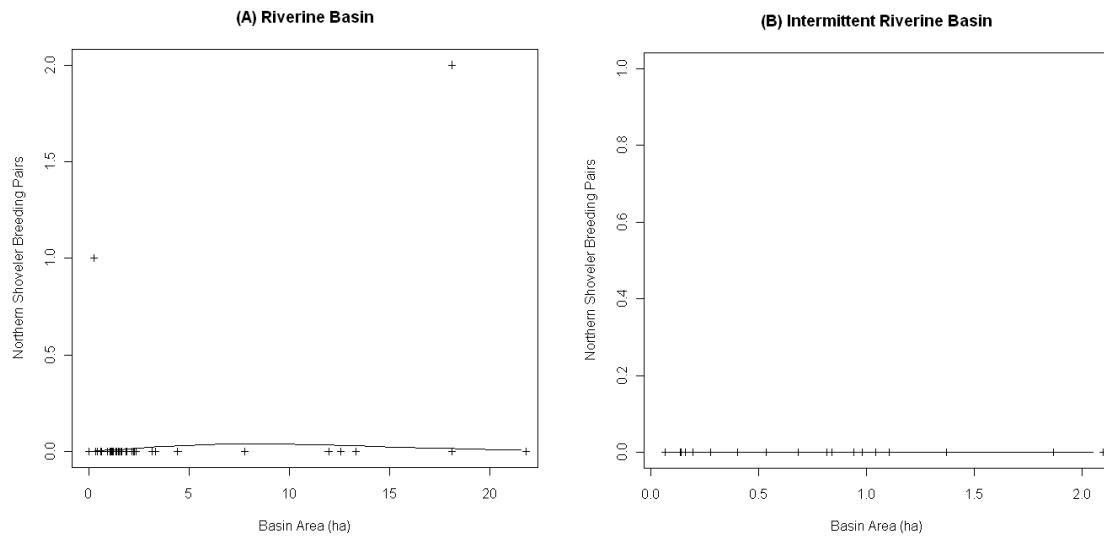


Figure 3.17. Estimated northern shoveler breeding pairs on (A) riverine and (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.

Blue-winged Teal. The blue-winged teal *a priori* Wetland Suite competing model analysis ranked $BWTE_{WAREA+SQRTWA+WCLASS+LOCATION}$ as the most parsimonious model with most of the support ($w_i = 0.997$). The next best supported model has a ΔAIC_c value > 11 (Table 3.10). Blue-winged teal breeding pairs were positively associated with the square root of wetland area and negatively associated with wetland area ($B_{WAREA} = -0.000037$, 85% CI $-0.000030 - -0.000024$; $B_{SQRTWA} = 0.024740$, 85% CI $0.019471 - 0.030009$; Appendix B). The estimated coefficients for WCLASS provided strong support for wetland basin class as a predictor of breeding blue-winged teal abundance. The top *a priori* model provided strong evidence for a location effect for blue-winged teal, with more estimated breeding pairs in the northern and eastern portions of the study area (Figure 3.12).

Models in the exploratory Landscape Suite were consistently less supported than the top model in the Wetland Suite. Model selection uncertainty resulted in two Landscape Suite models within 2 AIC_c units (Table 3.10). However, the maximized log-likelihood of the second-best model ($BWTE_{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}$; $\log[\mathcal{L}] = -297.024$) was essentially the same as the top model with one less parameter ($BWTE_{WAREA+SQRTWA+PWAREA+WCOUNT}$; $\log[\mathcal{L}] = -296.696$). Consequently, the larger second-best model is not supported. The model is close to the top model in AIC_c value only because it adds 1 parameter and therefore will be within 2 ΔAIC_c units, even though the fit, as measured by the log-likelihood value, is not improved (Burnham and Anderson 2002, Arnold 2010). The top Landscape Suite model provided strong evidence that the frequency and total surface area of seasonal and semipermanent basins within a breeding

home range area of a sample basin was positively associated with breeding blue-winged teal pair abundance.

The Combined Model suite contained two models; one developed by combining the best Wetland Suite model with the best Landscape Suite models, and the full model. The full model was the most overall supported model comprising the 95% confidence set of all models ($w_i = 0.996$). In the top model, blue-winged teal breeding pair abundance was negatively associated with wetland area, full pool perimeter, and the proportion of seasonal and semi-permanent surface water in the breeding home range landscape. Pairs were positively associated with the square root of wetland area and the number of seasonal and semi-permanent wetlands in the breeding home range area of a basin. The top overall model provided support for wetland basin class as an important predictor of breeding blue-winged teal abundance (Figures 3.18 & 3.19). The best model also provided strong evidence of a location effect, with higher breeding pair abundance estimated in the northern and eastern portions of the study area (Figure 3.20). Although the top models contained covariates for adjacent upland class, and the proportion of cropland in the breeding home range landscape, neither was estimated to be significant.

Table 3.10. Competing *a priori* and exploratory models for analysis of blue-winged teal breeding pair abundance

Model	k	AIC_c	Within Suite		All Suites	
			ΔAIC_c	w_i	ΔAIC_c	w_i
Wetland Suite						
$BWTE_{WAREA+SQRTWA+WCLASS+LOCATION}$	11	557.649	0.000	0.997	15.470	< 0.01
$BWTE_{WAREA+SQRTWA+LOCATION}$	6	569.061	11.412	0.003	26.882	< 0.01
$BWTE_{WAREA+SQRTWA+(WAREA*SQRTWA)}$	4	587.128	29.478	0.000	44.949	< 0.01
$BWTE_{WAREA+SQRTWA+WCLASS}$	8	603.395	45.745	0.000	61.216	< 0.01
$BWTE_{WAREA+SQRTWA+UCLASS}$	5	606.605	48.955	0.000	64.426	< 0.01
$BWTE_{WAREA+SQRTWA+PERIM}$	4	610.919	53.270	0.000	68.740	< 0.01
$BWTE_{WAREA+SQRTWA}$	3	612.767	55.117	0.000	70.588	< 0.01
Landscape Suite						
$BWTE_{WAREA+SQRTWA+PWAREA+WCOUNT}$	5	606.140	0.000	0.511	63.961	< 0.01
$BWTE_{WAREA+SQRTWA+PWAREA+WCOUNT+PCROP}$	6	607.520	1.380	0.256	65.341	< 0.01
$BWTE_{WAREA+SQRTWA+WCOUNT}$	4	608.981	2.841	0.123	66.802	< 0.01
$BWTE_{WAREA+SQRTWA+WCOUNT+PCROP}$	5	610.484	4.344	0.058	68.305	< 0.01
$BWTE_{WAREA+SQRTWA+PWAREA}$	4	611.778	5.638	0.031	69.599	< 0.01
$BWTE_{WAREA+SQRTWA+PWAREA+PCROP}$	5	613.536	7.396	0.013	71.357	< 0.01
$BWTE_{WAREA+SQRTWA+PCROP}$	4	614.558	8.418	0.008	72.379	< 0.01
Combined Suite						
$BWTE_{FULL}$	17	542.179	0.000	0.997	0.000	0.996
$BWTE_{WAREA+SQRTW+WCLASS+LOCATION+WCOUNT}$	12	554.581	12.402	0.002	12.402	0.002

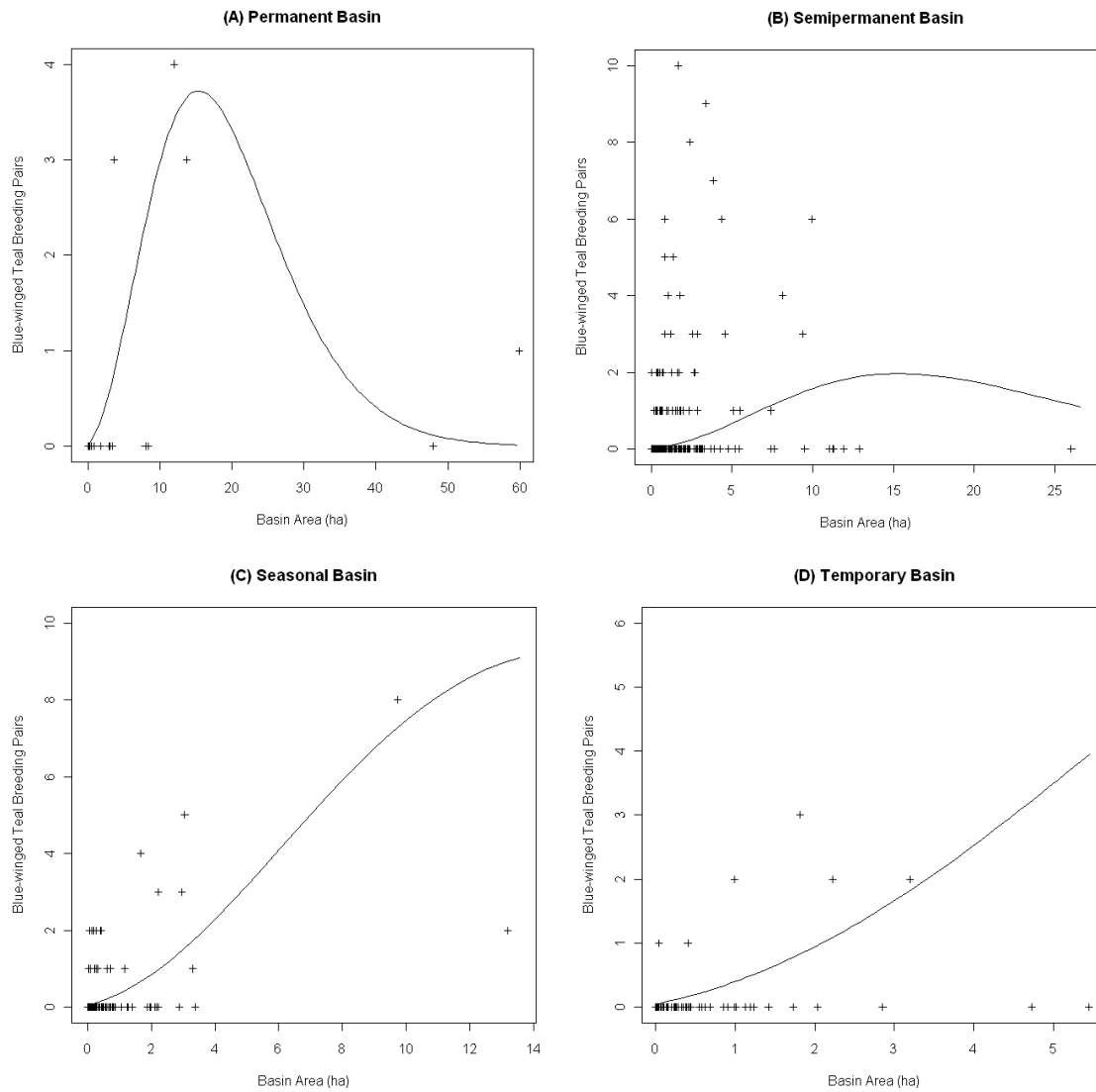


Figure 3.18. Estimated blue-winged teal breeding pairs on (A) permanent, (B) semipermanent, (C) seasonal, and (D) temporary basins in relation to wetland basin area (ha). Data points represent observations.

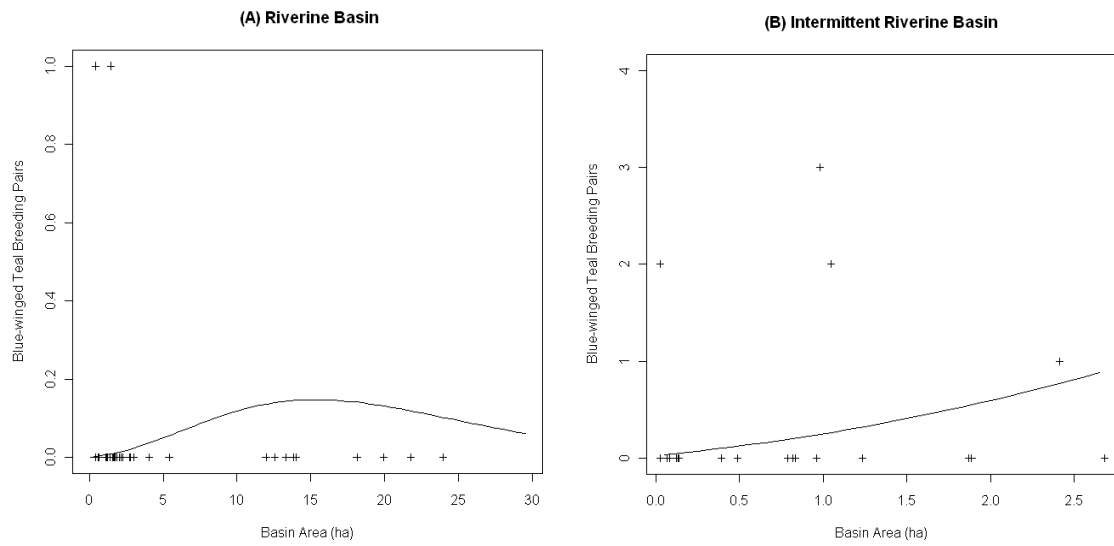


Figure 3.19. Estimated blue-winged teal breeding pairs on (A) riverine and (B) intermittent riverine basins in relation to wetland basin area (ha). Data points represent observations.

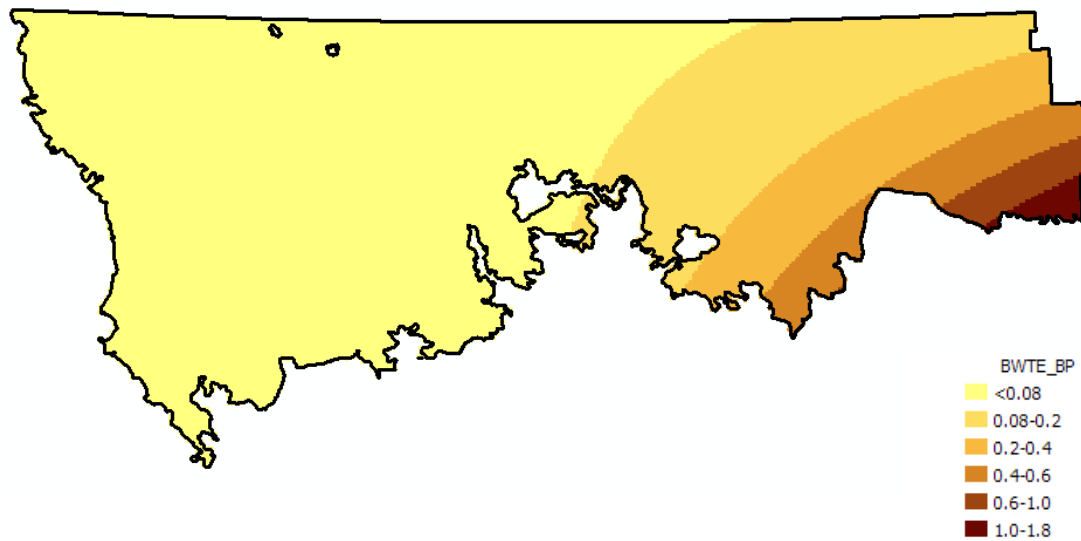


Figure 3.20. Estimated blue-winged teal breeding pairs on a temporary 0.4 ha (1 acre) basin in relation to the study area location in terms of easting (MTX) and northing (MTY).

Prediction Map

A mallard density and distribution map was created by applying all models to wetland basins and half-mile river sections in the study area. The model predictions were weighted by AIC_c weights (w_i) and summed for final estimates. To avoid extrapolation, predictions were limited for wetland basins that were larger than the maximum sampled basin sizes for each basin class. The estimated breeding mallard pairs were then aggregated to 1-mi² public land survey sections and displayed in arbitrary categories (Figure 3.21). The map is based on 2009 wetland conditions since 2008 was a drought year. Future maps will be based on average wetland conditions. Other species prediction maps will be created after subsequent survey years when more data is available.

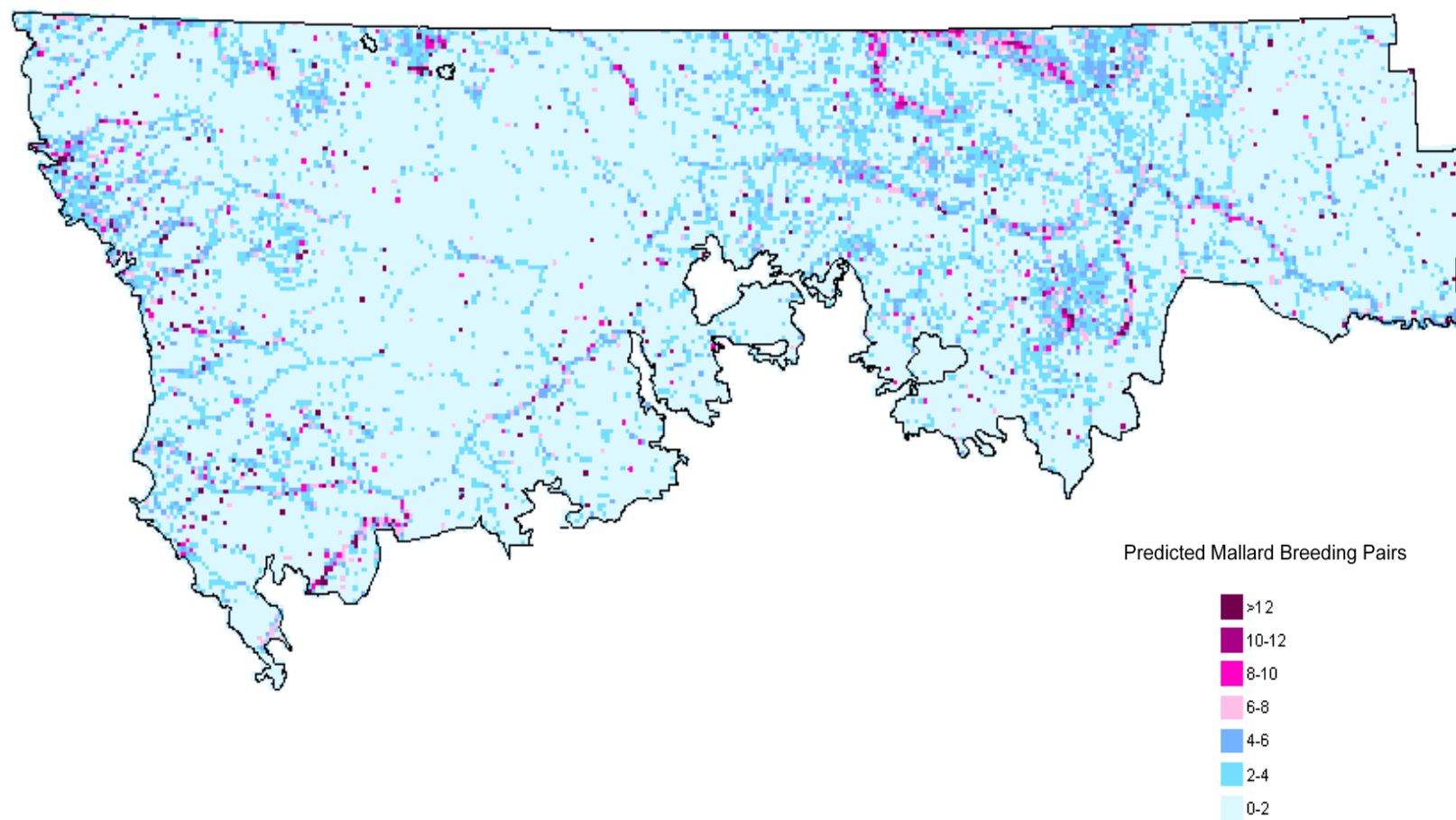


Figure 3.21. The estimated density and distribution of mallard breeding pairs across north-central Montana in 2009 by 1 mi² public land survey section.

Discussion

Results from this study are in agreement with results of earlier studies that demonstrated positive relationships between local basin conditions and breeding duck numbers in the U. S. portion of the Prairie Pothole Region. All five modeled species used breeding habitats at both the wetland basin scale and the home range landscape scale. In general, habitat characteristics at the local scale had a stronger influence on breeding duck pair abundance than did habitat characteristics at the home range landscape scale.

As hypothesized, the wetland area and square root of wetland area were important predictors for all species. This is consistent with the previous modeling results from Reynolds et al. (2006 & 2007). The estimated negative influence of increasing basin size and the positive influence of increasing shoreline length (i.e. SQRTWA) on breeding pair densities are supported by tens of thousands of wetland observations from 1985 through 2010 in the PPR of North Dakota, South Dakota and northeast Montana (T. L. Shaffer, USGS, personal communication). The quadratic relationship between the breeding pairs and wetland surface area indicates that breeding pair densities do not increase linearly with wetland size, but are a function of both increasing wetland area and wetland perimeter (i.e. SQRTWA).

Basin class was a strongly supported predictor variable for all species. Modeling results indicated that each basin class was not used equally for an individual species. However, caution must be applied when interpreting this result considering the most of the study area was in a drought in 2008 and parts of the study area in 2009. Overall low

basin availability may play a role in the relatively high breeding pair abundance on permanent and riverine basins. Contrary to these results, several studies on wetland use by breeding waterfowl indicate seasonal and semipermanent basins are used extensively during different stages of the breeding season (Stewart and Kantrud 1973, Kantrud and Stewart 1977, Dwyer et. al 1979, Ruwaldt et. al 1979, Johnson and Grier 1988, Krapu et al. 1997)

I hypothesized that all species would be associated with a location effect. However, northern pintails, gadwall and blue-winged teal were the only species strongly associated with a location effect. Breeding pairs for the three species are positively associated with basins in the northern and eastern areas of north-central Montana. Additional data may provide insight to the other species. Previous studies in the other areas of the PPR indicate all 5 species have a strong location effect, using different areas of their breeding range disproportionately (Reynolds et al, 2006 & 2007, Stewart and Kantrud 1973).

I found varying degrees of landscape scale-dependence in breeding habitat use by breeding ducks. All 5 principal species were positively associated by the proportion of agricultural lands within a home range area around a sample basin contrary to my hypothesis of a negative effect. This positive association may be explained by the premise that agricultural lands are generally located in the most productive areas in the landscape. The wetlands situated in these productive landscapes may also have abundant aquatic food sources waterfowl exploit during the breeding period. Additionally, greater availability of cereal grains in the agricultural landscape provides some dabbling duck

species with an important diet component of during the breeding period (Krapu 1992). Furthermore, wetland densities on the breeding ground may be a more important determinant of breeding duck distribution than upland landscape composition.

The proportion of seasonal and semipermanent basin wetland area in the landscape around sample basins was negatively associated with northern pintail and blue-winged teal breeding pair densities. This was contrary to my hypothesis of a positive association. The majority of breeding waterfowl research in the literature (e.g. Johnson and Grier 1988) found that breeding dabbling ducks preferred to settle in areas containing a robust complex of wetlands compared to areas with only isolated wetlands. These studies focused more on wetland frequency versus total wetland surface area. However, caution must be applied when interpreting this result until additional data can be collected resulting in more precise estimates.

Blue-winged teal breeding pair numbers were positively affected by the total number of seasonal and semipermanent basins, but negatively associated by the proportion of surface area from those basins. This supports past research in North Dakota and South Dakota where breeding dabbling duck pair numbers were greater in areas of many small basins compared to areas with few large basins (USWFS HAPET Office, unpublished data). Contrary to my hypothesis, no other species were positively associated with a high frequency of seasonal and semipermanent basins in the home range area around a sampled basin. Again, additional data are required to refine the models and make sound inference on how breeding ducks in north-central Montana settle on the breeding grounds.

Several assumptions were made throughout the study. In the breeding waterfowl survey, I assumed field observers correctly located each sample basin and instantaneously scanned, correctly identified, and counted all waterfowl on the basin (i.e. census, 100% detection). Counting breeding waterfowl on incorrect basins, missing birds on sample basins, and incorrect waterfowl identification can greatly reduce model precision and accuracy. Pagano and Arnold (2009) used an independent double observer sampling approach to demonstrate the assumption of 100% detection probabilities for ground-based waterfowl counts was false and surveys based on this erroneous assumption underestimated population size by 10–29%. However, Rotella et al. (1995) suggested the discrepancy between mark-recapture methods and the *ad-hoc* approach used in this study may be inconsequential for long term monitoring efforts. To minimize these errors, training for the survey protocol and waterfowl identification was provided each year to all field observers. Hand-held GPS receivers were provided for locating sample basins. Future analysis should include a method for estimating an observer effect. Additionally, a double-observer sampling approach should be evaluated for reducing detection bias in future surveys.

The competing model analysis also incorporated several assumptions. Repeated measures GLMM assume 1) within-subject (i.e. sample basin) variation lower than among subjects 2) adjacent observations are likely to be more correlated than more distant observations 3) heterogeneous variances 4) normally distributed random effects 5) fixed X. The glmmML R library used to fit the models implicitly uses a compound symmetrical correlation structure for within-subject variation. Although a compound

symmetrical correlation structure is appropriate for this analysis using two years of data, a different correlation structure (e.g. first order autoregressive, Toeplitz) may be required in subsequent analysis when counts closer together in time will be more related than counts over longer time periods.

Generalized linear mixed models are useful for accommodating the overdispersion often observed among outcomes that have a Poisson distribution (Breslow 1984). Dispersion estimates in the observed breeding pair count data indicate that a Poisson distribution may not be appropriate for modeling the breeding pair data since the mean and variance differ in most of the five modeled species (Table 3.11). However, estimated dispersion parameters ($\hat{\phi}$) from the most parsimonious model for each species indicated that the best fitting model accounted for the overdispersion in the dataset. Overdispersion can be caused by a lack of independence in the data and GLMMs account for the dependent subject structure in repeated measures studies. The resulting dispersion estimates indicated the data can be adequately modeled with GLMM using the Poisson distribution.

In addition to overdispersion, count data often exhibit more zero observations than would be allowed for by a Poisson distribution (Heilbron 1994). Ignoring zero inflation can have two consequences; 1) the estimated parameters and their standard errors may be biased (Lambert 1992), and 2) the excessive number of zeros can cause overdispersion (Martin et al. 2005). I compared the expected number of zeros from the full model fitted values for each species to the observed number of zeros in the breeding pair counts. All full models accounted for the observed zeros adequately (Table 3.11).

Table 3.11. Observed zero counts versus expected zeros from each species full models. The mean ($\hat{\mu}$) and variance ($\hat{\sigma}^2$) from the breeding pair counts and dispersion estimates ($\hat{\phi}$) from the full models

Species	Observed Zeros	Expected Zeros	$\hat{\mu}$	$\hat{\sigma}^2$	$\hat{\phi}$
Mallard	408	403	1.16	9.38	0.84
Northern Pintail	556	555	0.55	4.65	1.18
Northern Shoveler	558	553	0.57	6.65	1.57
Gadwall	514	525	0.23	0.56	1.41
Blue-winged Teal	642	645	0.38	1.65	1.15

The model predictions for mallards indicate that many areas in the Montana PPR are of high interest to conservation partners (Figure 3.13). The predictions are based on 2009 wetland basin conditions, when the majority of the wetland basins in the study area were <50% full (Figure 3.5). In years when the basins are full across the landscape, north central Montana could potentially produce substantially more ducks than predicted with 2009 water conditions.

Although the R^2 values are relatively low, ranging from 0.20 (NSHO) to 0.41 (NOPI), the cross validation results indicate the predictive ability of the top models is adequate, ranging from within 0.27 (NSHO) to 1.08 (MALL) breeding pairs. The relatively high prediction error (MAE) for mallards is most likely due to a few outliers in the data. Those outliers result from basins that had many breeding pairs (>40) during each of the survey years.

The exploratory analysis leads to hypotheses that may be of interest for future research. As the proportion of cropland in the landscape around a wetland basin

increased, the breeding pair abundance also increased for all five principal species. Additionally, the blue-winged teal breeding pair abundance increased with the greater pond density in the surrounding landscape. This study investigated a single landscape scale that approximates a breeding home range for each species. Future research investigating habitat characteristics, such as pond numbers and pond surface area, at multiple scales may further elucidate what landscape components are associated with breeding pair abundance.

Management Implications

Understanding the distribution of breeding waterfowl and the factors that affect those distributions will improve effective management of duck populations (Johnson and Grier 1988). This observational study initiated the process to gain a better understanding of the breeding waterfowl populations in the PPR of north-central Montana. A major challenge in conducting observational studies is to draw unbiased causal inferences when unknown confounding covariates are present in the observed processes. Although the associations discussed in this study provide insight to land managers on local- and landscape-scale habitat characteristics important to breeding ducks, sound inference can only be achieved through long-term data encompassing the variation in landscape resources over time.

For land managers, protecting and restoring the existing wetland basins across the landscape, especially those on private land that are under the greatest threats, will help ensure that habitat for breeding ducks remains in north central Montana. The long-term

continuation of this study for several more breeding seasons will enable partners of the PPJV to more efficiently target important breeding waterfowl habitat for conservation actions.

Literature Cited

- Agresti, A. 2007. An Introduction to Categorical Data Analysis, Second edition. John Wiley & Sons, Inc., Hoboken, New Jersey.
- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 *in* International symposium on information theory, Akademiai Kiado, Budapest, Hungary.
- Ball, I. J., R. L. Eng, and S. K. Ball. 1995. Population density and productivity of ducks on large grassland tracts in northcentral Montana. *Wildlife Society Bulletin* **23**:767-773.
- Batt, B. D. J., M. G. Anderson, C. D. Anderson, and F. D. Caswell. 1989. The use of prairie potholes by North American ducks. Pages 204-227 *in* A. v. d. Valk, editor. Northern Prairie Wetlands. Iowa State University Press, Ames.
- Bolker, B. 2008. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology and Evolution* **24**:127-135.
- Breslow, N. E., and D. G. Clayton. 1993. Approximate inference in generalized linear mixed models. *Journal American Statistical Association* **88**:9-25.
- Broström, G. 2009. glmmML: Generalized linear models with clustering. R package version 0.81-6. <http://CRAN.R-project.org/package=glmmML>.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.
- Camara, G., R. C. M. Souza, U. M. Freitas, J. Garrido, and F. Mitsuo II. 1996. SPRING: Integrating remote sensing and GIS by object oriented data modeling. *Computers and Graphics* **20**:395-403.
- Cliff, A. D., and J. K. Ord. 1981. Spatial processes: models and applications. Taylor & Francis.
- Cowardin, L. M., and R. Blohm, J. 1992. Breeding population inventories and measures of recruitment. Pages 423-445 *in* B. D. J. B. e. al., editor. Ecology and management of breeding waterfowl. University of Minnesota, Minneapolis.
- Cowardin, L. M., D. H. Johnson, T. L. Shaffer, and D. W. Sparling. 1988. Applications of a simulation model to decisions in mallard management. U.S. Fish and Wildlife Service Technical Report 17. 28 pp.

- Cowardin, L. M., T. L. Shaffer, and P. M. Arnold. 1995. Evaluations of duck habitat and estimation of duck population sizes with a remote-sensing-based system. National Biological Service Biological Science Report 2., Wasington, D. C.
- Crissey, W. F. 1969. Prairie potholes from a continental viewpoint. Saskatoon Wetlands Seminar. Canadian Wildlife Service Report Series 6:161-171.
- Dahl, T., and C. E. Johnson. 1991. Status and Trends of Wetlands in the Conterminous United States, Mid-1970's to Mid-1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C . 28 pages.
- Dahl, T. E. 1990. Wetlands Losses in the United States 1780's to 1980's. U.S . Department of the Interior, Fish and Wildlife Service, Washington, D.C . 13 pp.
- Dwyer, T. J., G. L. Krapu, and D. M. Janke. 1979. Use of Prairie Pothole Habitat by Breeding Mallards. *Journal of Wildlife Management* **43**:526-531.
- Dzubin, A. 1969a. Assessing breeding populations of ducks by ground counts. Pages 178–230 *in* Saskatoon Wetlands Seminar. Canadian Wildlife Service Report Series 6, Ottawa, Ontario, Canada.
- Dzubin, A. 1969b. Comments in carrying capacity of small ponds for ducks and possible effects of density on mallard production. Pages 138-160 *in* Saskatoon Wetlands Seminar. Canadian Wildlife Service Report Series 6, Ottawa, Ontario, Canada.
- Environmental Sciences Research Institute. 2006. ArcGIS Version 9.2. Redlands, California, USA.
- Hammond, M. C. 1969. Notes on conducting waterfowl breeding population surveys. Pages 238–258 *in*. Saskatoon Wetlands Seminar. Canadian Wildlife Service Report Series 6, Ottawa, Ontario, Canada.
- Heilbron, D. C. 1994. Zero-altered and other regression models for count data with added zeros. *Biometrical Journal* **36**:531-547.
- Hoekman, S. T., L. S. Mills, D. W. Howerter, J. H. Devries, and I. J. Ball. 2002. Sensitivity analyses of the life cycle of midcontinent mallards. *Journal of Wildlife Management* **66**:883-900.
- Hurvich, C. M., and C. L. Tsai. 1989. Regression and Time-Series Model Selection in Small Samples. *Biometrika* **76**:297-307.

- Johnson, D. H., and J. W. Grier. 1988. Determinants of Breeding Distributions of Ducks. *Wildlife Monographs*:1-37.
- Johnson, D. H., J. D. Nichols, and M. D. Schwartz. 1992. Population dynamics of breeding waterfowl. Pages 446-485 *in* B. Batt, editor. *Ecology and Management of Breeding Waterfowl*. The University of Minnesota Press, Minneapolis, MN.
- Kantrud, H. A., and R. E. Stewart. 1977. Use of Natural Basin Wetlands by Breeding Waterfowl in North-Dakota. *Journal of Wildlife Management* **41**:243-253.
- Klett, A. T., T. L. Shaffer, and D. H. Johnson. 1988. Duck nest success in the Prairie Pothole Region. *Journal of Wildlife Management* **52**:431-440.
- Krapu, G. L., and Kenneth J. Reinecke. 1992. Foraging ecology and nutrition. Pages 1-29 *in* *Ecology and Management of Breeding Waterfowl*. University of Minnesota Press, Minneapolis, MN.
- Krapu, G. L., R. J. Greenwood, C. P. Dwyer, K. M. Kraft, and L. M. Cowardin. 1997. Wetland use, settling patterns, and recruitment in mallards. *Journal of Wildlife Management* **61**:736-746.
- Legendre, P. 1993. Spatial autocorrelation: Trouble or new paradigm? *Ecology* (Washington D C) **74**:1659-1673.
- Levin, S. A. 1992. The problem of pattern and scale in ecology. *Ecology* **73**:1943-1967.
- Lokemoen, J. T. 1973. Waterfowl Production on Stock-Watering Ponds in Northern Plains. *Journal of Range Management* **26**:179-184.
- Murkin, H. R., A. G. van der Valk, and W. R. Clark. 2000. *Prairie wetland ecology: the contribution of the Marsh Ecology Research Program*. Iowa State University Press, Ames, Iowa, USA.
- Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. *Applied linear statistical models*. McGraw-Hill, Boston, MA.
- Neyman, J. 1934. On the Two Different Aspects of the Representative Method: The Method of Stratified Sampling and the Method of Purposive Selection. *Journal of the Royal Statistical Society* **97**: 558-606.

- Orthmeyer, D. L., and I. J. Ball. 1990. Survival of Mallard Broods on Benton Lake National Wildlife Refuge in Northcentral Montana USA. *Journal of Wildlife Management* **54**:62-66.
- Pagano, A. M., and T. W. Arnold. 2009. Detection Probabilities for Ground-Based Breeding Waterfowl Surveys. *Journal of Wildlife Management* **73**:392-398.
- Pan, Z., and D. Y. Lin. 2005. Goodness-of-fit methods for generalized linear mixed models. *Biometrics* **61**:1000-1009.
- R Development Core Team 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org>.
- Reynolds, R. E., C. R. Loesch, B. Wangler, T. L. Shaffer. 2007. Waterfowl Response to the Conservation Reserve Program and Swampbuster Provision in the Prairie Pothole Region, 1992-2004. U.S. Fish and Wildlife Service Biological Report 90 pp.
- Reynolds, R. E., T. L. Shaffer, C. R. Loesch, and R. R. Cox. 2006. The Farm Bill and duck production in the Prairie Pothole Region: Increasing the benefits. *Wildlife Society Bulletin* **34**:963-974.
- Rodríguez, J. D., A. Pérez, J. A. Lozano, (2010) "Sensitivity Analysis of k-Fold Cross Validation in Prediction Error Estimation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 32, no. 3, pp. 569-575
- Rosenberg, M. S. 2001. PASSAGE. Pattern Analysis, Spatial Statistics, and Geographic Exegesis. Version 1.0. Department of Biology, Arizona State University, Tempe, AZ.
- Rotella, J. J., J. H. Devries, and D. W. Howerter. 1995. Evaluation Of Methods For Estimating Density Of Breeding Female Mallards. *Journal of Field Ornithology* **66**:391-399.
- Ruwaldt, J. J. J., L. D. Flake, and J. M. Gates. 1979. Waterfowl Pair Use of Natural and Man Made Wetlands in South-Dakota. *Journal of Wildlife Management* **43**:375-383.
- Stewart, R. E., and H. A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. Resource Publication 92, Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, Washington, D.C. 57pp.

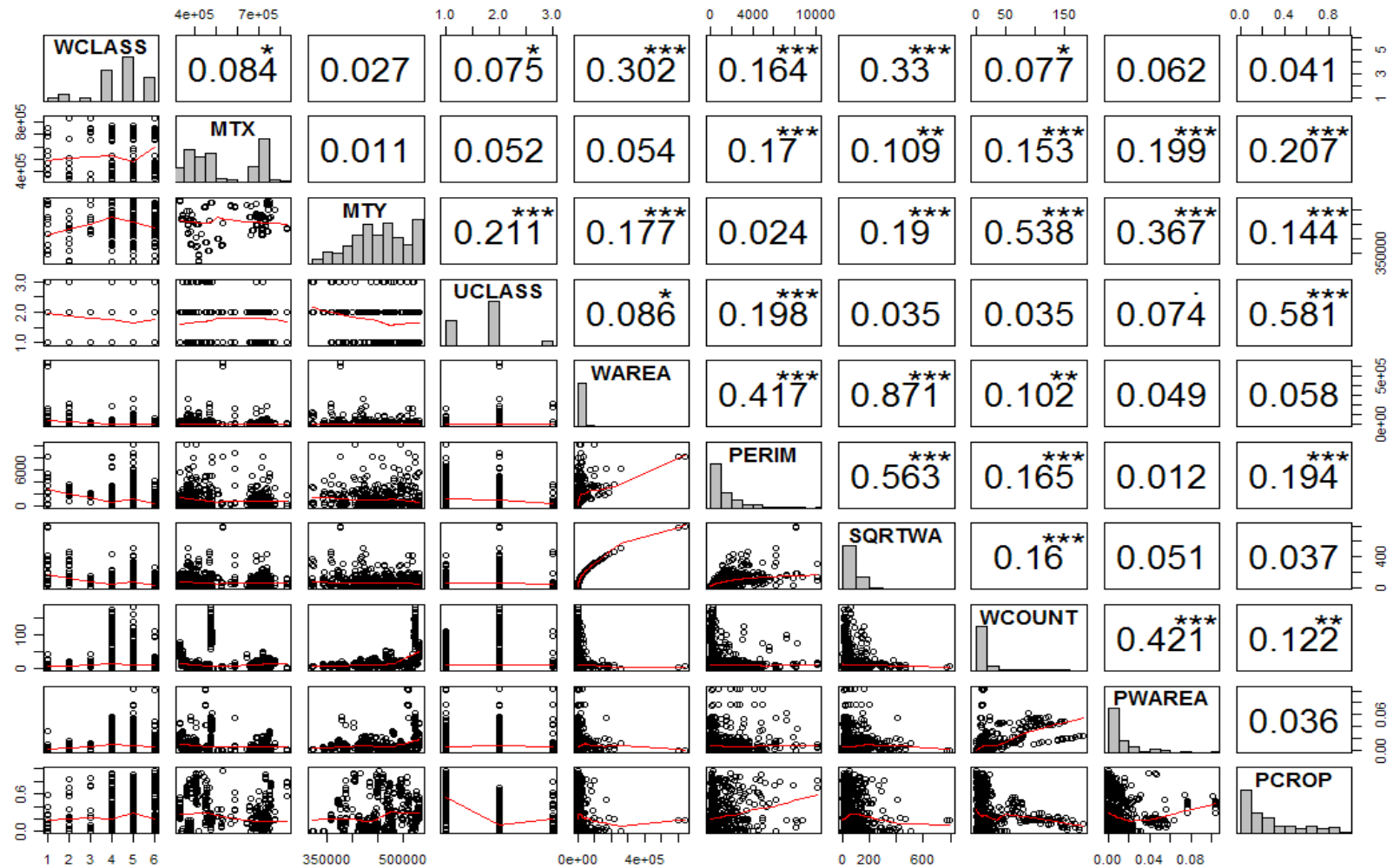
- Stewart, R. E., and H. A. Kantrud. 1973. Ecological Distribution of Breeding Waterfowl Populations in North-Dakota. *Journal of Wildlife Management* **37**:39-50.
- Stewart, R. E., and H. A. Kantrud. 1974. Breeding Waterfowl Populations in Prairie Pothole Region of North-Dakota. *Condor* **76**:70-79.
- Tiner, R. W., Jr. 1984. Wetlands of the United States: Current Status and Trends, U. S. Fish and Wildlife Service, Washington, D.C.: U.S. Government Printing Office.
- U.S. Geological Survey, National Biological Information Infrastructure, Gap Analysis Program (GAP). 2010. National Landcover Version 1.
- U.S. Department of Agriculture. 1994. Summary report: 1992 National Resources Inventory. U.S. Department of Agriculture, Natural Resources Conservation Service, Iowa State University, Ames, IA.
- Willmott, C. J., and K. Matsuura. 2005. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Research* **30**:79-82.
- Woods, A. J., J. Omernik, M. , J. A. Nesser, J. Sheldon, J. A. Comstock, and S. H. Azevedo. 2002. Ecoregions of Montana, 2nd edition (color poster with map, descriptive text, summary tables, and photographs). Map scale 1:1,500,000.
- Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. Smith. 2009. *Mixed Effects Models and Extensions in Ecology with R*. Springer, New York, NY.

APPENDICIES

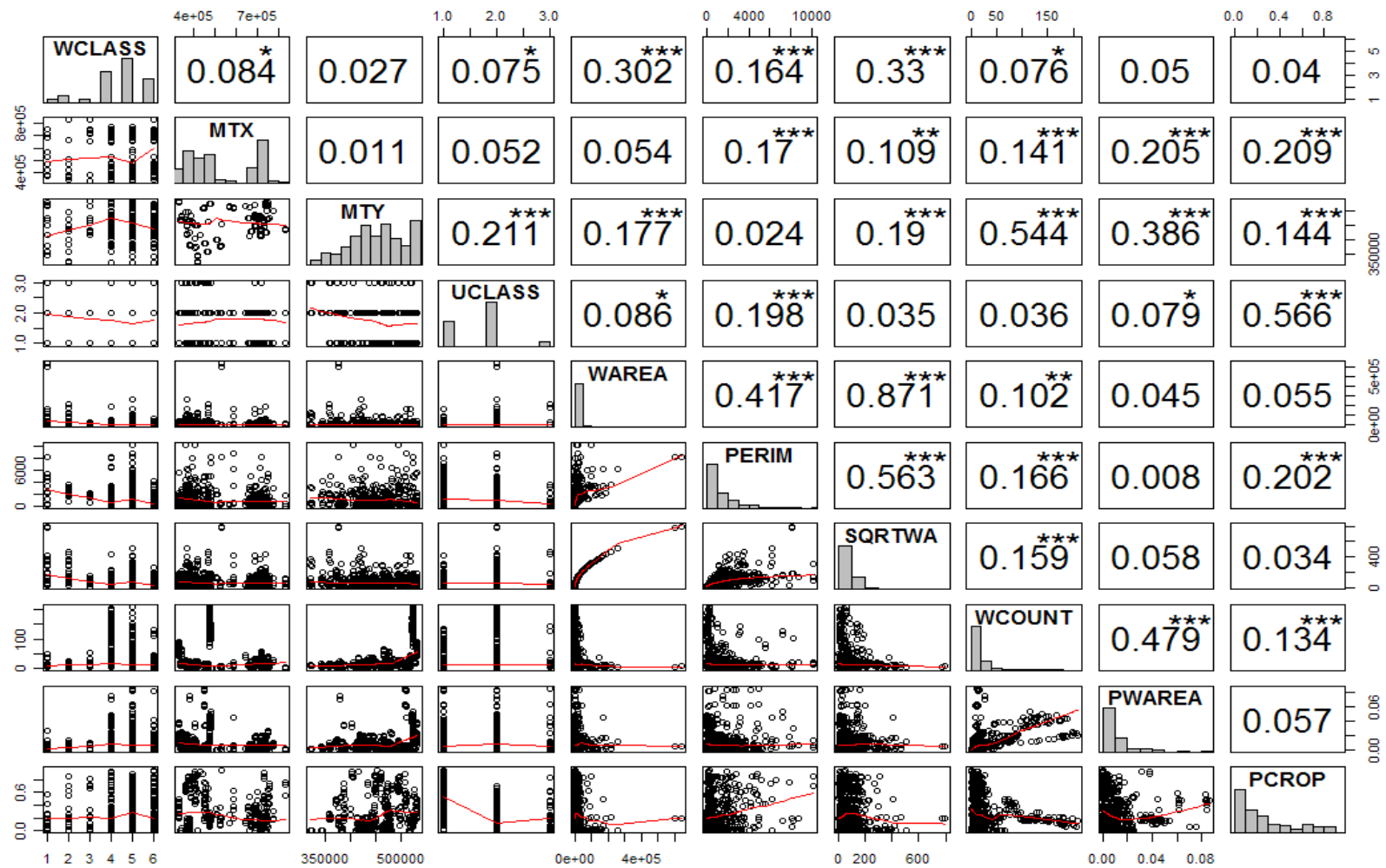
APPENDIX A

HISTOGRAMS, PEARSON ABSOLUTE CORRELATION COEFFICIENTS
AND X-Y SCATTER PLOTS

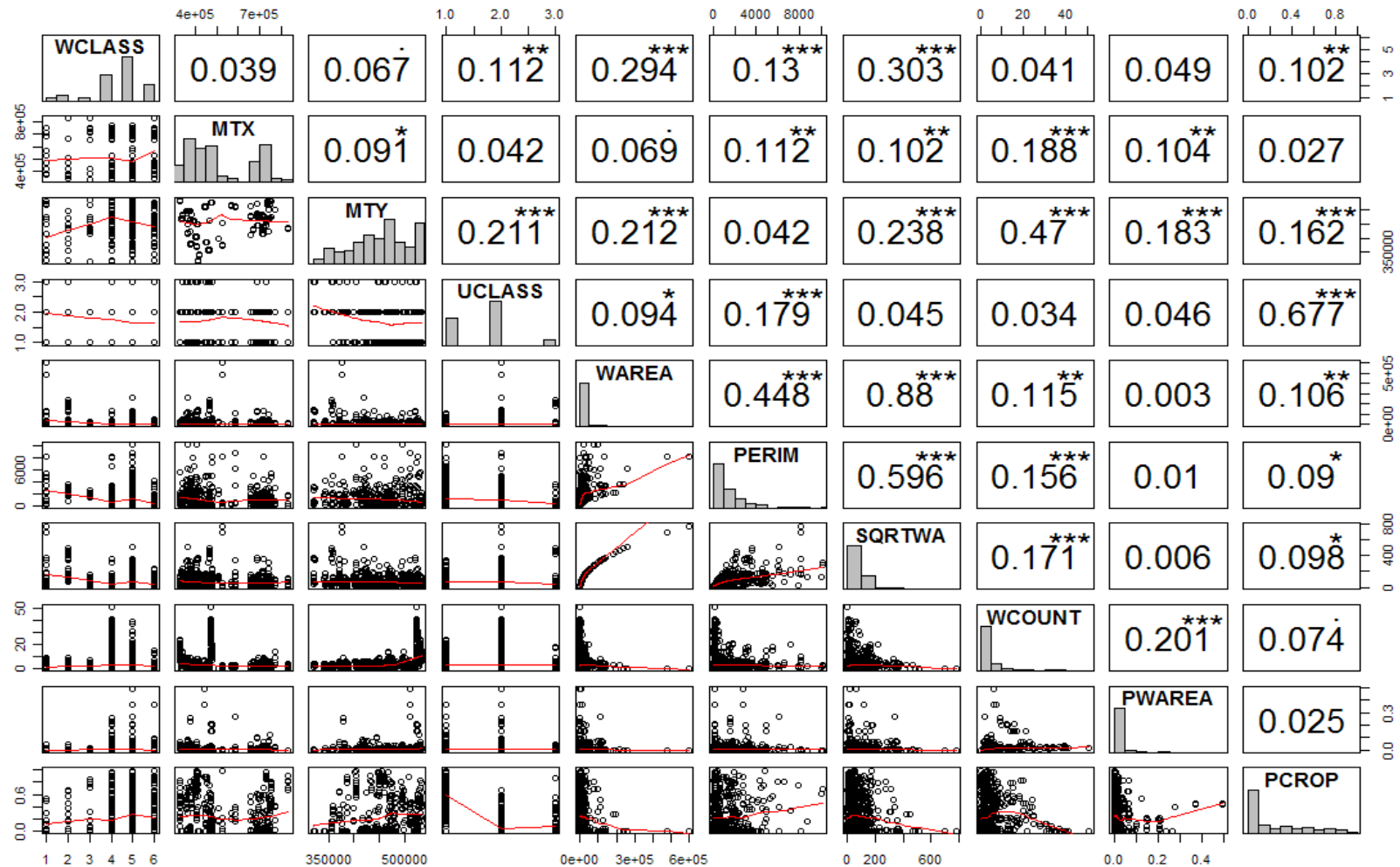
Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of wetland habitat and landscape variables used in mallard breeding pair models



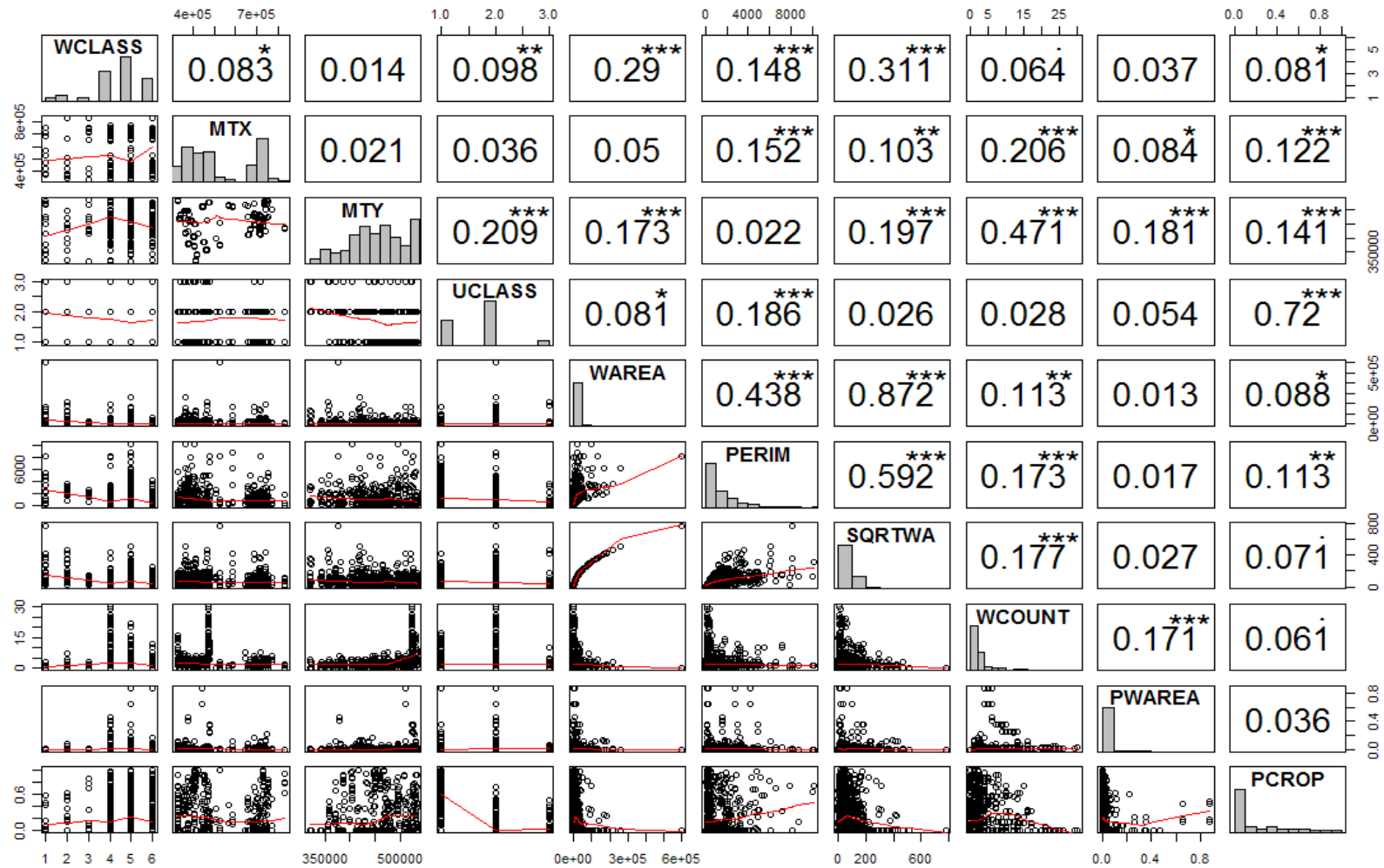
Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of wetland habitat and landscape variables used in northern pintail breeding pair models



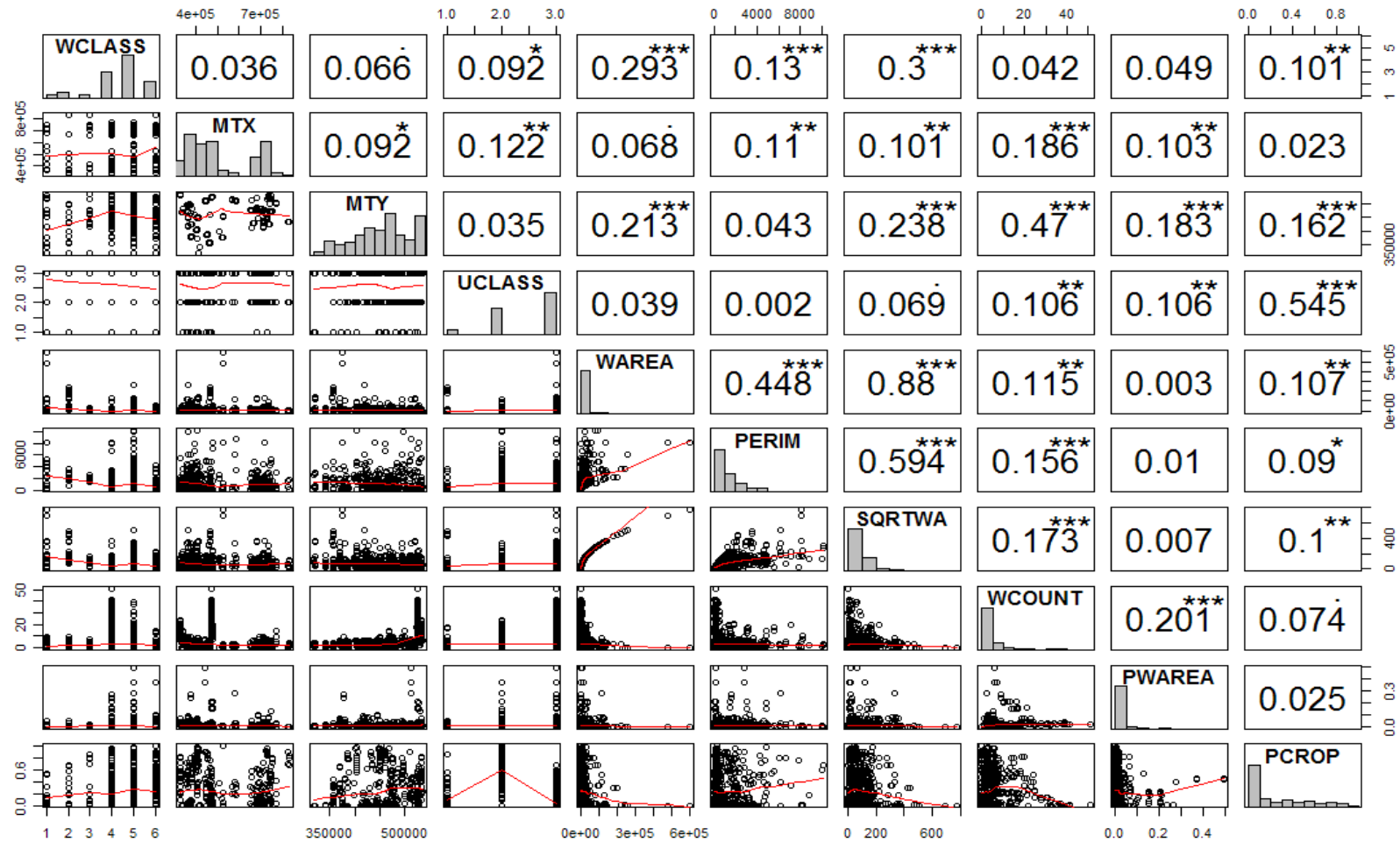
Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of wetland habitat and landscape variables used in gadwall breeding pair models



Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of wetland habitat and landscape variables used in northern shoveler breeding pair models



Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of wetland habitat and landscape variables used in blue-winged teal breeding pair models



APPENDIX B

MODEL COEFFICIENT TABLES

MALLARD

Top Wetland Suite mallard model coefficient estimates, standard errors, and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85%LCI	85%UCI
(Intercept) - WCLASS PERMANENT	-1.097000	0.385600	-1.652264	-0.541736
WAREA	-0.000019	0.000003	-0.000023	-0.000015
SQRTWA	0.014230	0.001469	0.012115	0.016345
WCLASS RIVERINE	-0.581600	0.445300	-1.222832	0.059632
WCLASS RIVERINE-INTERMITTENT	-0.663800	0.569800	-1.484312	0.156712
WCLASS SEASONAL	-0.650900	0.392500	-1.216100	-0.085700
WCLASS SEMIPERMANENT	-0.195900	0.377400	-0.739356	0.347556
WCLASS TEMPORARY	-1.394000	0.421100	-2.000384	-0.787616

Second-best Wetland Suite mallard model coefficient estimates, standard errors, and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85%LCI	85%UCI
(Intercept)	-1.907000	0.134900	-2.101256	-1.712744
WAREA	-0.000018	0.000003	-0.000022	-0.000014
SQRTWA	0.013250	0.001492	0.011102	0.015398
PERIM	0.000204	0.000042	0.000144	0.000264

Top overall mallard model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) – WCLASS PERMANENT	-1.390000	0.384000	-1.942960	-0.837040
WAREA	-0.000017	0.000003	-0.000021	-0.000013
SQRTWA	0.012990	0.001520	0.010801	0.015179
WCLASS RIVERINE	-0.584000	0.438000	-1.214720	0.046720
WCLASS RIVERINE-INTERMITTENT	-0.837000	0.568000	-1.654920	-0.019080
WCLASS SEASONAL	-0.664000	0.386000	-1.219840	-0.108160
WCLASS SEMIPERMANENT	-0.330000	0.372000	-0.865680	0.205680
WCLASS TEMPORARY	-1.330000	0.417000	-1.930480	-0.729520
PERIM	0.000123	0.000043	0.000061	0.000185
PCROP	0.854000	0.258000	0.482480	1.225520

NORTHERN PINTAIL

Top Wetland Suite northern pintail model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-12.170000	3.793000	-17.631920	-6.708080
WAREA	-0.000030	0.000006	-0.000039	-0.000021
SQRTWA	0.018930	0.002499	0.015331	0.022529
WCLASS RIVERINE	-2.617000	0.934100	-3.962104	-1.271896
WCLASS RIVERINE-INTERMITTENT	-2.466000	0.992700	-3.895488	-1.036512
WCLASS SEASONAL	-0.580200	0.529800	-1.343112	0.182712
WCLASS SEMIPERMANENT	-0.312100	0.513700	-1.051828	0.427628
WCLASS TEMPORARY	-1.609000	0.586700	-2.453848	-0.764152
MTX	0.000012	0.000007	0.000002	0.000022
MTY	0.000015	0.000008	0.000003	0.000027
MTX:MTY	0.000000	0.000000	0.000000	0.000000

Top Landscape Suite northern pintail model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept)	-3.122000	0.242400	-3.471056	-2.772944
WAREA	-0.000029	0.000006	-0.000038	-0.000020
SQRTWA	0.018560	0.002602	0.014813	0.022307
PWAREA	-18.280000	8.722000	-30.839680	-5.720320

Second-best Landscape Suite northern pintail model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept)	-3.342000	0.295300	-3.767232	-2.916768
WAREA	-0.000029	0.000006	-0.000038	-0.000020
SQRTWA	0.018720	0.002611	0.014960	0.022480
PWAREA	-23.390000	10.270000	-38.178800	-8.601200
WCOUNT	0.004254	0.003678	-0.001042	0.009550
PCROP	0.500400	0.450200	-0.147888	1.148688

Top overall northern pintail model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-15.800000	3.989000	-21.544160	-10.055840
WAREA	-0.000028	0.000006	-0.000037	-0.000019
SQRTWA	0.019520	0.002456	0.015983	0.023057
WCLASS RIVERINE	-2.620000	0.933700	-3.964528	-1.275472
WCLASS RIVERINE-INTERMITTENT	-2.382000	0.995400	-3.815376	-0.948624
WCLASS SEASONAL	-0.306900	0.538900	-1.082916	0.469116
WCLASS SEMIPERMANENT	-0.059810	0.523200	-0.813218	0.693598
WCLASS TEMPORARY	-1.338000	0.594400	-2.193936	-0.482064
MTX	0.000016	0.000007	0.000006	0.000026
MTY	0.000024	0.000009	0.000011	0.000037
PWAREA	-28.620000	8.778000	-41.260320	-15.979680
MTX:MTY	+0.000000	+0.000000	+0.000000	+0.000000

Second-best overall northern pintail model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-17.340000	4.142000	-23.304480	-11.375520
WAREA	-0.000028	0.000006	-0.000037	-0.000019
SQRTWA	0.019390	0.002456	0.015853	0.022927
WCLASSRIVERINE	-2.769000	0.943100	-4.127064	-1.410936
WCLASSRIVERINE-INTERMITTENT	-2.754000	1.022000	-4.225680	-1.282320
WCLASSEASONAL	-0.441700	0.541600	-1.221604	0.338204
WCLASSEMPERMANENT	-0.220400	0.527400	-0.979856	0.539056
WCLASSTEMPORARY	-1.510000	0.599400	-2.373136	-0.646864
MTX	0.000020	0.000007	0.000010	0.000030
MTY	0.000026	0.000009	0.000013	0.000039
PWAREA	-24.540000	9.304000	-37.937760	-11.142240
WCOUNT	-0.000493	0.003609	-0.005690	0.004704
PCROP	0.869400	0.449200	0.222552	1.516248
MTX:MTY	+0.000000	+0.000000	+0.000000	+0.000000

GADWALL

Top Wetland Suite gadwall model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-9.991000	3.980000	-15.722200	-4.259800
WAREA	-0.000023	0.000005	-0.000030	-0.000016
SQRTWA	0.018010	0.002330	0.014655	0.021365
WCLASSRIVERINE	-2.981000	0.847500	-4.201400	-1.760600
WCLASSRIVERINE-INTERMITTENT	-2.173000	0.912500	-3.487000	-0.859000
WCLASSEASONAL	-1.183000	0.545400	-1.968376	-0.397624
WCLASSEMIPERMANENT	-0.606100	0.511700	-1.342948	0.130748
WCLASSTEMPORARY	-1.671000	0.611300	-2.551272	-0.790728
MTX	0.000007	0.000008	-0.000005	0.000019
MTY	0.000014	0.000009	0.000001	0.000027
MTX:MTY	0.000000	0.000000	0.000000	0.000000

Top Landscape Suite gadwall model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept)	-3.397000	0.283000	-3.804520	-2.989480
WAREA	-0.000023	0.000005	-0.000030	-0.000016
SQRTWA	0.017100	0.002430	0.013601	0.020599
PCROP	0.652000	0.403300	0.071248	1.232752

Top Combined Suite gadwall model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-10.590000	3.963000	-16.296720	-4.883280
WAREA	-0.000023	0.000004	-0.000029	-0.000017
SQRTWA	0.018150	0.002305	0.014831	0.021469
WCLASS-RIVERINE	-3.037000	0.842800	-4.250632	-1.823368
WCLASS-RIVERINE-INTERMITTENT	-2.460000	0.922600	-3.788544	-1.131456
WCLASS-SEASONAL	-1.210000	0.538100	-1.984864	-0.435136
WCLASS-SEMIPERMANENT	-0.696600	0.507000	-1.426680	0.033480
WCLASS-TEMPORARY	-1.765000	0.608600	-2.641384	-0.888616
MTX	0.000009	0.000008	-0.000003	0.000021
MTY	0.000014	0.000008	0.000002	0.000026
PCROP	0.781800	0.384000	0.228840	1.334760
MTX:MTY	0.000000	0.000000	0.000000	0.000000

NORTHERN SHOVELER

Top Wetland Suite northern shoveler model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	se(coef)	85% LCI	85% UCI
(Intercept) WCLASS-PERMANENT	-6.313000	4.195000	-12.353800	-0.272200
WAREA	-0.000047	0.000009	-0.000060	-0.000034
SQRTWA	0.026730	0.003620	0.021517	0.031943
WCLASS-RIVERINE	-0.263100	0.834500	-1.464780	0.938580
WCLASS-RIVERINE-INTERMITTENT	-11.030000	118.400000	-181.526000	159.466000
WCLASS-SEASONAL	0.235200	0.678200	-0.741408	1.211808
WCLASS-SEMIPERMANENT	0.679300	0.651300	-0.258572	1.617172
WCLASS-TEMPORARY	-0.063570	0.722700	-1.104258	0.977118
MTX	0.000003	0.000009	-0.000010	0.000016
MTY	-0.000001	0.000009	-0.000014	0.000012
MTX:MTY	0.000000	0.000000	0.000000	0.000000

Top Landscape Suite northern shoveler model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept)	-4.466000	0.350200	-4.970288	-3.961712
WAREA	-0.000049	0.000009	-0.000062	-0.000036
SQRTWA	0.027000	0.003610	0.021802	0.032198
PCROP	0.654900	0.397400	0.082644	1.227156

Overall top northern shoveler model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-7.110000	4.181000	-13.130640	-1.089360
WAREA	-0.000047	0.000009	-0.000060	-0.000034
SQRTWA	0.026940	0.003622	0.021724	0.032156
WCLASSRIVERINE	-0.275300	0.828900	-1.468916	0.918316
WCLASSRIVERINE-INTERMITTENT	-11.360000	111.500000	-171.920000	149.200000
WCLASSEASONAL	0.188200	0.674100	-0.782504	1.158904
WCLASSEMIPERMANENT	0.611800	0.649000	-0.322760	1.546360
WCLASSTEMPORARY	-0.184100	0.723100	-1.225364	0.857164
MTX	0.000004	0.000009	-0.000009	0.000017
MTY	-0.000000	0.000009	-0.000013	0.000013
PCROP	1.081000	0.399600	0.505576	1.656424
MTX:MTY	0.000000	0.000000	0.000000	0.000000

BLUE-WINGED TEAL

Top *a priori* Wetland Suite blue-winged teal model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face.

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-25.210000	4.796000	-32.116240	-18.303760
WAREA	-0.000037	0.000009	-0.000050	-0.000024
SQRTWA	0.024740	0.003659	0.019471	0.030009
WCLASSRIVERINE	-2.060000	1.105000	-3.651200	-0.468800
WCLASSRIVERINE-INTERMITTENT	0.027490	0.944000	-1.331870	1.386850
WCLASSEASONAL	0.152100	0.759000	-0.940860	1.245060
WCLASSEMIPERMANENT	0.632600	0.725400	-0.411976	1.677176
WCLASSTEMPORARY	-0.832500	0.837400	-2.038356	0.373356
MTX	0.000036	0.000009	0.000023	0.000049
MTY	0.000040	0.000010	0.000026	0.000054
MTX:MTY	0.000000	0.000000	0.000000	0.000000

Top Landscape Suite blue-winged teal model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face

	coefficient	standard error	85% LCI	85% UCI
(Intercept)	-4.928000	0.457300	-5.586512	-4.269488
WAREA	-0.000044	0.000009	-0.000057	-0.000031
SQRTWA	0.028330	0.004010	0.022556	0.034104
PWAREA	-5.314000	2.514000	-8.934160	-1.693840
WCOUNT	0.054290	0.019290	0.026512	0.082068

Top blue-winged teal model coefficient estimates, standard errors and respective 85% confidence intervals. Those covariates whose estimated coefficients had 85% confidence intervals that did *not* include zero are indicated with bold type face

	coefficient	standard error	85% LCI	85% UCI
(Intercept) WCLASS PERMANENT	-31.890000	23.260000	-65.384400	1.604400
WAREA	-0.000038	0.000009	-0.000051	-0.000025
SQRTWA	0.029850	0.003955	0.024155	0.035545
WCLASSRIVERINE	-2.160000	1.113000	-3.762720	-0.557280
WCLASSRIVERINE-INTERMITTENT	0.095920	0.961600	-1.288784	1.480624
WCLASSEASONAL	0.082640	0.772400	-1.029616	1.194896
WCLASSEMIPERMANENT	0.735100	0.737100	-0.326324	1.796524
WCLASSTEMPORARY	-1.010000	0.857900	-2.245376	0.225376
PERIM	-0.000286	0.000089	-0.000414	-0.000158
MTX	0.000035	0.000009	0.000022	0.000048
MTY	0.000037	0.000010	0.000023	0.000051
UCLASSag	7.374000	22.760000	-25.400400	40.148400
UCLASSnest	7.450000	22.760000	-25.324400	40.224400
WCOUNT	0.043390	0.018920	0.016145	0.070635
PWAREA	-6.541000	2.500000	-10.141000	-2.941000
PCROP	0.624000	0.699300	-0.382992	1.630992
MTX:MTY	+0.000000	+0.000000	+0.000000	+0.000000