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Brood Abundance and Invertebrate Availability in Crop-Dominated Landscapes in the Prairie Pothole Region

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BROOD ABUNDANCE AND INVERTEBRATE AVAILABILITY IN CROP-DOMINATED LANDSCAPES IN THE PRAIRIE POTHOLE REGION

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
Catrina Victoria Terry
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ABSTRACT

The Prairie Pothole Region (PPR) is the most important region for ducks in North America, producing over half the ducks on the continent, and it is a priority landscape for wetland and grassland conservation. Agricultural expansion has changed the PPR, and the majority of grasslands and potholes have been converted into row-crops. The loss of nesting habitat has directly caused nest success to decline. Most of the remaining wetlands are surrounded by row-crops, and are considered lower quality because they receive runoff of sediment and chemicals, which may decrease primary forage for young ducklings as well as inhibit wetland vegetation. Wetland quality and the availability of forage may influence brood abundance in wetlands in crop-dominated landscapes.

I surveyed wetlands in row-crop dominated landscapes of the eastern PPR in the United States. Over two summers, I surveyed wetlands for broods and sampled wetlands to quantify the aquatic invertebrates available for ducklings. I detected 345 broods and sampled 230 unique wetlands. I used N-mixture models to evaluate factors that influence brood abundance with, based on biologically relevant covariates measured at the wetland level. Brood abundance was positively associated with the abundance of aquatic invertebrates and the amount of grassland surrounding the wetland. I then examined the factors within the wetland that may influence the aquatic invertebrates available for ducklings. I used linear mixed effects models to determine which variables influenced forage abundance, while controlling for effects of year and sampling round by assigning them as random effects. The strongest and most consistent effect I uncovered was that invertebrate abundance decreased as DO concentration and wetland depth increased. Row-crop expansion in the PPR is a concern for waterfowl production, with most conservation efforts

going to wetlands surrounded by grasslands. I consistently found broods using wetland embedded in agriculture. Brood abundance was influenced by grassland and aquatic invertebrates and aquatic invertebrates were most influenced by DO concentrations and wetland depth. The wetlands in my study are most at-risk but my study indicates that they provide valuable habitat for broods through the summer months and should be conserved.

CHAPTER 1. GENERAL INTRODUCTION

The Prairie Pothole Region (PPR) is expansive, covering over 700,000 km², ranging from central Iowa to central Alberta. Pothole wetlands of the PPR were created 12,000 years ago when glaciers receded from the area leaving millions of depressions in the landscapes. These potholes are characterized by drought-driven variation in wetland abundance, size, depth, and duration of inundation (Eullis et al. 1999), and are surrounded by shortgrass and tall grass prairies. The PPR exhibits wet/dry cycle which increases productivity and impacts vegetation and available aquatic invertebrates within the wetland. These wetlands provide ample habitat and forage for migratory birds and are responsible for producing the majority of North America's ducks (Austin et al. 2001).

Today, over half of these wetlands have been drained and replaced with agriculture. Remaining wetlands are now subject to runoff and sedimentation and the native prairies that once surrounded these wetlands have been transformed to row crops and nonnative grasses (Dahl 2014). Potholes surrounded by row-crops are less likely to be conserved because the surrounding nesting habitat has been reduced and quality of wetlands is potentially low due to increased sedimentation, changes in vegetation, and addition of pesticide and fertilizer (Grue et al. 1989, Euliss and Mushet 1996). These wetlands have higher chances of vanishing from the landscape than wetlands surrounded by prairie grasses (Brice et al. 2017), and need to be studied to understand their value in duck production. Wetlands embedded in row-crops have not been targeted for conservation, but recent research in South Dakota found that agricultural wetlands in the spring had a higher abundance of blue-winged teal (*Spatula discors*) and higher abundance of invertebrates (Janke et al. 2019). These wetlands may also provide important food resources for

ducklings, but it is not known whether these wetlands retain their high invertebrate abundance throughout the summer.

The biggest driver of recruitment for dabbling ducks is nest success (Hoekman et al. 2002) but in North Dakota the most influential factor for recruitment is duckling survival (Amundson et al. 2013). Ducklings are most susceptible to mortality their first two weeks of life, concurrently during this time their diet is almost entirely invertebrates (Chura 1962). Wetlands that support high availability of invertebrates are the wetlands that will benefit ducklings the most and in turn are important to conserve for duck production (Cox et al. 1998). Understanding the mechanisms involved in brood abundance of wetlands can gear management decisions to conserve productive wetlands.

The Waterfowl Breeding Population and Habitat Survey estimates breeding pair densities but does not account for waterfowl successfully fledging their young (USFWS 2018). Brood surveys are conceptually valuable for assessing duck production at local scales and can be extrapolated across larger landscapes. However, because brood detectability is so poor (Ringelman and Flake 1980), traditional survey methods have been unable to provide useful estimates of duck production (Pagano and Arnold 2009). Unmanned aerial vehicles (UAVs) provide a way to increase accuracy and efficiency of brood counts (Bushaw et al. 2021). Brood surveys, when paired with wetland metrics can help determine which wetlands are most important for duck production in highly altered agricultural systems.

My thesis focuses on evaluating brood abundance at the wetland level. In the second chapter, I conducted brood surveys with a UAV equipped with a thermal imaging camera, and sampled wetlands to assess how abundance is influenced at the wetland level. In the third chapter, I

investigated wetland factors that influence the available forage for ducklings, aquatic invertebrates.

CHAPTER 2. BROOD ABUNDANCE IN CROP-DOMINATED LANDSCAPES IN THE PRAIRIE POTHOLE REGION

2.1. INTRODUCTION

The Prairie Pothole Region (PPR) is the most important region for ducks in North America, producing over half the ducks on the continent (Batt et al. 1989). The PPR provides migrating ducks, breeding hens, and ducklings a place to refuel, nest, and fledge and thus it is a priority landscape for wetland and grassland conservation (Batt et al. 1989). The PPR is expansive, covering over 770,000 km², ranging from central Iowa to central Alberta, and is so productive for ducks because it is filled with millions of small wetland basins historically surrounded by shortgrass and tallgrass prairie (Kantrud et al. 1989, Eullis and Mushet 1996). Abundant wetlands attract pairs, intact grasslands offer nesting cover, and healthy wetlands provide habitat for broods to fledge.

Agricultural expansion has changed the PPR, and by the late 1990s, only 1% of native tall grass and less than 30% of native mixed grass prairie remained, while the rest had been converted to cropland (Sugden and Beyersbergen 1984, Wright and Wimberly 2013). As an example, over the course of forty years, soybeans in North Dakota have expanded over 2000% (Doherty et al. 2013). More recently, from 2008 to 2012, 3.6 million acres of grassland were converted to corn for ethanol production (Wright et al. 2017). The loss and fragmentation of grasslands has lowered nest success of ducks (Sovada et al. 2000, Phillips et al. 2003, Stephens et al. 2008). Much attention has been given to the loss of grasslands; however, also important are the loss and degradation of wetlands on which pairs and broods rely.

Half of the wetlands in the PPR have been drained for agriculture, and in the southeastern portion of the PPR nearly 90% of wetlands have been drained (Dahl 2014). Row-crop conversion has eliminated the numerous small seasonal and temporary wetlands that support duck pairs (Kantrud and Stewart 1977). In some cases, conversion has caused consolidation of many small wetlands to form large permanent wetlands (Krapu et al. 2018), although even these larger wetlands continue to decrease in size (Johnston and McIntyre 2019). Wetland loss has slowed, wetlands in the Dakotas are still being lost at a rate of 3% per year (Johnston 2013). More than 60% of the remaining wetlands are now surrounded by row-crop agriculture and have been highly altered, which may negatively impact waterfowl populations and reduce carrying capacity and productivity (Dahl 2014).

Wetlands embedded in row-crop agriculture are considered lower quality because they receive runoff of sediment and chemicals (Castelle et al. 1994). Wetlands surrounded by cropland may hold 8.5 times more sediment than wetlands surrounded by grassland (Luo et al. 1997).

Increased sedimentation can degrade the function of the wetland by reducing seed germination (Hartleb et al. 1993), which alters the food web (Murkin 1989), and sediment can accumulate to the point where the basin no longer acts as a functional wetland (Gleason and Euliss 1998).

Wetlands embedded in row crops have little or no upland buffer, which would otherwise reduce runoff of sediment and chemicals into the wetland (Castelle et al. 1994). Castelle et al. (1994) determined that a buffer of at least 15 m was necessary to protect wetlands from runoff of agricultural chemicals and provide habitat for wildlife. Buffers are critical for duck pairs and broods because chemical and sediment runoff can decrease the abundance of invertebrates (Doren et al. 1997) that they forage on (Swanson and Meyer 1973, Cox et al. 1998).

Invertebrates are the primary diet of ducklings during their fastest growth period (Reinecke 1979), and ducklings spend over 60% of their day in wetlands actively foraging for food (Sedinger 1992). Greater duckling growth has been observed in wetlands with a higher abundance of aquatic invertebrates (Hunter et al. 1984, Cox et al. 1998). Cooper and Anderson (1996) investigated how nekton invertebrates and zooplankton influenced brood densities and found that total invertebrate density was associated with increased brood use. Cox et al. (1998) noted that total invertebrate abundance was more significant than invertebrate biomass, suggesting that ducklings forage on invertebrates that are readily available. Dessborn et al. (2009) observed a positive correlation between brood use of lakes and abundance of emerging chironomids. Wetlands that support high availability of invertebrates are wetlands that should benefit ducklings the most and in turn are important to conserve for duck production (Cox et al. 1998).

Brood abundance on individual wetlands is also highly dependent on the landscape context. Rotella and Ratti (1992) found that landscapes with a higher density of wetlands had higher brood abundance, but broods used the same number of wetlands and traveled similar distances in low and high density areas. Higher brood abundance was also observed in landscapes with higher perennial grasses (Walker et al. 2013, Carrlson et al. 2018), which is presumably related to higher levels of nest density and/or success. Landscape-level characteristics affect duckling occupancy and abundance, and the wetland itself provides foraging opportunities and cover that are vital for duckling growth and survival (Krapu 1979, Stafford et al. 2002).

Most broods use either seasonal or, more commonly, semi-permanent wetlands (Duebbert and Frank 1984, Dzus and Clark 1997, Raven et al. 2007), and occupancy is positively related to the amount of wet area (Walker et al. 2013). Brood abundance is positively influenced by moderate

amounts of vegetation throughout the wetland (Walker et al. 2013, Carrlson et al. 2018). Raven et al. (2007) observed higher brood use on wetlands dominated by bulrush, and wetlands with more vegetation at the edge of the wetland. Nummi and Pöysä (1995) observed higher dabbling duck use in wetlands with more emergent vegetation. Stafford et al. (2002) linked high survival of mallard ducklings to their use of wetlands that had both emergent vegetation and submerged aquatic vegetation.

Wetlands embedded in row crops have a higher chance of being drained than wetlands surrounded by prairie grasses (Brice et al. 2017), and so there is a critical need to study these wetlands to understand their value to duck production. Recent research in South Dakota found that wetlands embedded in crops had a higher abundance of spring-migrating blue-winged teal (*Spatula discors*) and a higher abundance of invertebrates (Janke et al. 2019). It is not known whether these wetlands retain their high invertebrate abundance throughout the summer to provide food resources for ducklings, and if so, whether broods take advantage of these resources.

My objectives are to quantify brood abundance on wetlands in crop-dominated landscapes and identify wetland characteristics that affect brood abundance. To address these objectives, I conducted repeat-observer brood surveys with an unmanned aerial vehicle and thermal camera, and simultaneously sampled the aquatic invertebrate community, classified emergent and submerged aquatic vegetation in wetlands, and measured prairie buffer around wetlands.

2.2. METHODS

Study Area

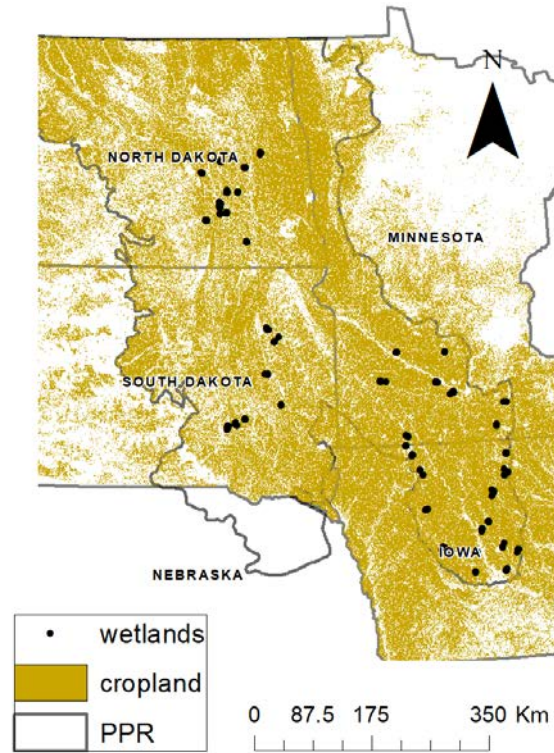


Figure 2.1. Wetlands sampled in 2019 and 2020 in relation to the Prairie Pothole Region and crop-dominated landscapes. Crop data was generated from USDA cropland data layer in ArcMap 10.6.

My study was conducted in the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota (Figure 2.1.). This portion of the PPR is characterized by a high prevalence of row-crop agriculture, primarily corn (*Zea mays*), soybeans (*Glycine max*), and wheat (*Triticum sp.*). Most wetlands have been drained, and the remaining temporary, seasonal, and semi-permanent wetlands are typically embedded in row-crops. The breeding duck community is dominated by dabbling ducks such as blue-winged teal, mallard (*Anas platyrhynchos*), northern

pintail (*Anas acuta*), gadwall (*Mareca strepera*), northern shoveler (*Spatula clypeata*), and wood ducks (*Aix sponsa*), but also supports canvasbacks (*Aythya valisineria*), redheads (*Aythya americana*), ruddy ducks (*Oxyura jamaicensis*), and hooded mergansers (*Lophodytes cucullatus*).

My study sites were primarily on private lands, except in Iowa, where the majority of remaining wetlands were on public lands. In 2019, study sites were within a 96 km radius of Jamestown, ND, Huron, SD, Medelia, MN and Humboldt, IA. In 2020 the sampling range was reduced due to limitations associated with the COVID-19 pandemic, and study sites were within a 96 km radius of Glenfield, ND and Ames, IA.

My study sites were selected collaboratively with Ducks Unlimited (DU). To obtain study sites that would enable me to sample wetlands in crop-dominated landscapes, DU and I used the national wetland index (NWI), cropland data layer (CDL) and national land cover database (NLCD). Based on our spatial layers we created a 9.66 x 9.66 km² grids with >60 % crops covering the area. Within these grids I classified high and low brood water availability, 40-518 ha and 5-40 ha, respectively within 10 km², while requiring a 5 ha wetland minimum and a 518 ha maximum to target wetlands preferred by broods. I then created 50 points per state with half of all points classified as low brood water and half classified as high brood water. These points represented my potential sites and from these, 10 sites were randomly selected per state, half in low brood water areas and half in high brood water areas. Additional requirements for sites were five wetlands (<10.12 ha in size) within 20.72 km² of a randomized point. If more than five wetlands were within 20.72 km² of randomized point, five wetlands were randomly selected.

Equipment

I conducted brood surveys with an unmanned aerial vehicle (UAV) because brood detectability is so poor (Ringelman and Flake 1980) that traditional survey methods have been unable to provide useful estimates of duck production (Pagano and Arnold 2009). UAVs increase accuracy and efficiency of brood counts (Bushaw et al. 2021). In North Dakota and South Dakota, I flew a battery powered DJI Matrice 210 quadcopter UAV, (6.1-kg weight, 716 x 220 x 236 mm dimensions). In Iowa and Minnesota, a battery powered DJI Matrice 200 quadcopter UAV (6.1-kg weight, 716 x 220 x 236 mm dimensions) was used. Both UAVs were powered by 22.8 V lithium pro ion batteries that permitted surveys of ~20 minutes, and batteries were changed if needed during a survey. A generator was used to charge batteries in the field to allow us to fly surveys until completed. The DJI Matrice 210 was equipped with two cameras that I could toggle between during flight. The first was a DJI Zenmuse XT thermal imaging camera (640 x 512 resolution; 19 mm lens; 30 Hz; white-hot filter). The second was a Zenmuse X4S optical camera (5472 x 3648 resolution, 8.8 mm lens). The DJI Matrice 200 was equipped with one camera: the Zenmuse XT2 that supported two lenses, thermal (640 x 512 resolution; 19 mm lens; 30 Hz; white-hot filter) and optical (4000 x 3000 resolution, 8 mm lens). The thermal lens enabled us to detect thermal signature of duck broods and the optical lens allowed us to capture images of the duck broods to identify them to species and age class.

Brood Surveys

My study took place June 1–August 15 during 2019–2020. Iowa and South Dakota were surveyed first because they are at lower latitudes with earlier springs, followed by North Dakota and Minnesota. I conducted two rounds of repeat brood surveys each season to account for early- and late-nesting species (Pagano and Arnold 2009). I followed brood survey guidelines from

Pagano and Arnold (2009) and Carrlson et al. (2018); I surveyed each wetland twice within a 24 hr period once between sunrise and noon and again 1600–sunset. Due to logistical constraints, the same observer performed both surveys, which has the potential to bias detectability, but previous research has shown that prior detections of broods does not influence the probability of resighting broods during the second survey (Pagano and Arnold 2009). Following guidelines set forth by Vas et al. (2015), the UAV was launched at least 100 m from wetlands to limit disturbance to duck broods. I flew the UAV at a height of 43 m to search the wetland for broods; this height allowed me to locate broods in cover and avoid heat signatures from red-winged blackbirds (*Agelaius phoeniceus*) in emergent vegetation. I flew the UAV in transects across the wetland to ensure the entire wetland and emergent vegetation were surveyed. At the time, software restricted us to flying transects manually: after flying a transect I moved the UAV to ensure partial overlap of the previous transect and flew parallel to my previous route. Flight speed during surveys varied because flights were manual. I started all flights with the thermal camera, and once a brood was detected I switched to the optical camera and descended to 10 m, where broods were able to be identified to species and age class. To ensure accurate speciation and limit disturbance to broods, I captured pictures of all broods, which were processed for brood identification and enumeration on a computer after completion of the survey. Broods were considered resights if they were located on the same wetland, were the same species, and brood size was within three ducklings and one age sub-class (Pagano and Arnold 2009). Start and end time of each wetland survey was recorded, and prior to each survey I recorded temperature, humidity, wind speed and cloud coverage. With the UAV, I estimated the percentage of wetland inundation and estimated percent emergent vegetation that covered the wetland.

Invertebrate Sampling

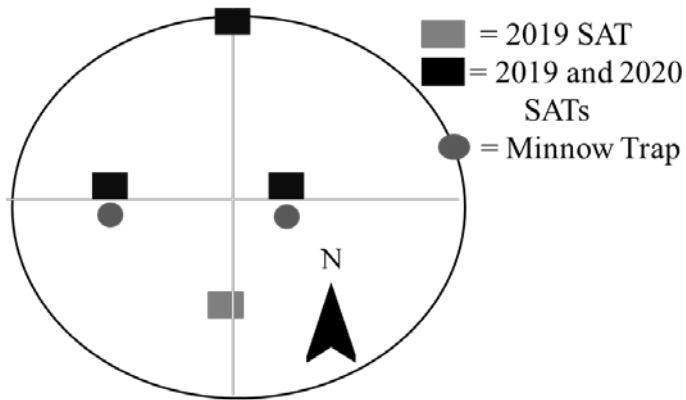


Figure 2.1. Diagram of the surface activity traps I placed in each wetland in in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota in 2019 and 2020. In 2019 I used four SATs and in 2020 I used three SATs.

I collected potential forage for ducklings with surface activity traps (SATs) based on the design by Hanson et al. (2000). The SAT was a 25 cm x 15 cm clear acrylic box with a funnel on the front to trap aquatic invertebrates inside. Traps were designed to be positioned 5 cm above the water column with the rest of the trap below the surface. Unlike traditional activity traps (Murkin et al. 1983) the SAT enabled me to capture aquatic invertebrates found on or just below the surface of the water column that are most likely to be consumed by ducklings (Hanson et al. 2000). I also used SATs because they provided clean samples and allowed for quicker processing time in the lab and provide information on the relative abundance of forage for ducklings in the wetland (Murkin et al. 1983).

Each trap was fitted with a fish exclusion device (2.5 cm in x 2.5 cm mesh wire) on the funnel of the trap to prevent fish and large predator invertebrates from entering and biasing the

composition of samples (Elmberg et al. 1992). Traps were placed in the wetland on a T-post, at a minimum depth of 20 cm to ensure a significant amount of the SAT was inundated with water, and a minimum of 5 cm of the trap above water to ensure capture of surface aquatic invertebrates. Traps were placed to face the edge of the wetland. Traps were left in the wetland for 24 hours (\pm 2 hours) to capture invertebrates at different diel emergence times (Murkin et al. 1983). After 24 hours I collected all invertebrates into a whirl-pak with 70% ethanol, dyed with rose-bengal to process later in the lab (Figure 2.1.).

In 2019, I placed 4 SATs in the wetland, at a randomly selected distance (0%, 30%, 60%, 90%) from the wetland edge towards the center along each of the 4 cardinal directions (Fig. 2.2). A leave-one-out analysis of 2019 data (R package *vegan*) showed that both 3 and 4 traps provided similar information on composition and abundance of aquatic invertebrates in the wetland (Oksanen et al. 2008), so in 2020 I deployed three traps to save collecting time in the field and processing time in the lab.

To evaluate the effect of wetland characteristics on invertebrates and brood abundance, I collected conductivity and temperature using a YSI Sonde Pro 50 at each SAT location. I also recorded water depth at each SAT location and estimated distance to nearest vegetation. I used minnow traps to assess presence and absence of fish, because fish can fundamentally alter the food web of wetland ecosystems (Zimmer et al. 2000, Hanson et al. 2005). I placed two minnow traps at the two traps closest to the middle as they represented my deepest locations. I checked minnow traps and enumerated and identified all fish and amphibians to species level before returning them to the wetland.

In the lab, each sample was emptied out into a 100 x 15 mm petri dish with 36 squares etched into the dish. This allowed us to quantify aquatic invertebrate abundance and composition of

each SAT with a stereo microscope. All individuals were enumerated and classified to the family level except for Amphipoda which was classified to the species level, and zooplankton which was classified to order (Cladocera, Ostracoda, Copepoda). If zooplankton were numerous (>500/sample) they were subsampled: 25% of the sample was counted and then extrapolated to represent the entire sample. Nine squares in my 36 square petri dish represented the 25% of the sample and these squares were randomly assigned prior to sampling. All nine squares were counted to subsample zooplankton. Subsampling 25% of the sample resulted in a more accurate count than a lower percentage subsampled, best represented the entire sample, and decreased processing time (King and Richardson 2002).

Vegetation Composition

At each SAT, I calculated the frequency of submerged aquatic vegetation (SAV) and coarse particulate organic matter (CPOM) with a 15-tine garden rake (Nyman and Chabreck 1996). I dragged the rake along the substrate of the wetland for 0.5 m and then pulled straight up, three times at each SAT. After each drag, I counted how many of the tines had SAV and/or CPOM on them. Additionally, I counted how many species of SAV were present at each SAT.

I qualitatively classified inundated emergent aquatic plants within the wetland boundary. I recorded percentage of the following emergent vegetation: cattail (*Typha sp.*), river bulrush (*Scirpus fluviatilis*), round-stem rush (*Scirpus validus*), reed canary (*Phalaris arundinacea*), other rush (*Scirpus sp.*), sedge (*Carex sp.*), phragmites (*Phragmites australis*), smartweed (*Persicaria amphibian*), other forbs, water plantain (*Alisma sp.*), sagittaria (*Sagittaria sp.*) until this percentage reached 100. I used this percentage paired with the overall percentage of emergent vegetation covering the wetland to calculate coverage of each type of vegetation, i.e., if

a wetland was 20% emergent vegetation and 100% cattail then I calculated 20% coverage of cattail in the wetland.

I extended the cardinal transects used for invertebrate samples into the upland area surrounding the wetland, and measured buffer width from the wetland edge inland to 50 m or until I reached crops. Within the 50 m buffer, I recorded the vegetation type of the buffer and buffer width at each vegetation shift. Vegetation was classified as warm season grasses, cool season grasses, annual weeds, reed canary grass, shrubs/cottonwoods/willows, forests, corn/soybeans, or other. Wetlands were considered to have crops within 50 m of the wetland edge if one cardinal transects encroached on crops within the 50 m.

Wetlands were all sampled twice, unless they held <20 cm of water necessary to sample invertebrates with a SAT, or time constraints precluded a second sample.

Statistical Analyses

I first evaluated all my variables and screened them based on biological relevance and collinearity (Dormann et al. 2013). I used Program R 4.1.0 (R Core Team 2021) with the package *unmarked* to implement hierarchical Poisson abundance models (Royle 2004) to evaluate brood count data while accounting for detection probability. Using N-mixture models I was able to diagnose how brood abundance (corrected for detection probability) was related to wetland-level covariates. Brood count data were based on the number of unique broods detected between surveys one and two for each round. Each wetland sampled per round was considered unique because wetland covariates, (i.e., invertebrate communities, wetland depth) can fundamentally change over the 30 days that elapse between rounds and I wanted to know what factors influenced abundance at the time of the surveys. To evaluate model fit I used Akaike's

Information Criterion corrected for small sample size (AICc) and compared competing models by their AICc values (Burnham and Anderson 2002).

I used N-mixture models to estimate abundance of duck broods in wetlands, and to determine whether brood abundance was influenced by invertebrate abundance, wetland vegetation, or the buffer around wetlands. I included all broods from all guilds of ducks. Invertebrate abundance data were highly variable, and I used a log+1 transformation to improve assumptions of normality. Total abundance of invertebrates was used for this analysis because previous research has shown that ducklings generally forage on readily available food (Cox et al. 1998).

Broods were assumed to have equal detection probability across all wetlands. Each brood could be detected twice, once during the first survey and again during the second survey. I first tested a global model of variables that could influence brood detectability, which included time, relative humidity, wind speed and temperature at surveys. I used backwards stepwise elimination of variables based on AICc scores with the *drop1()* function, which sequentially removed non-significant effects and improved AICc score. After I reached a reduced detection model, I created a global model of all my wetland covariates that could influence brood abundance. My global model included total invertebrates, percent grass within a 50m buffer of the wetland, average wetland depth, percent of cattail covering the wetland, and percent of emergent vegetation (excluding cattail) that covered the wetland (Table 2.1.). I again used backwards step-wise elimination based on AIC scores to arrive at a reduced model; to ensure I had selected the best-fitting model, as a final check I added back covariates to the fully reduced model and examined model fit.

The best fitting model was selected based on AICc score (Burnham and Anderson 2004) and models within 2 AICc that had additional parameters were considered uninformative (Arnold

2010). Models are reported here with their AICc scores and weight, and I reported my best fit model with 85% confidence intervals commensurate with AIC-based model selection (Arnold 2010). Additionally, I calculated model-averaged coefficients for models within 2 AICc of my top model, to account for model uncertainty (Cade 2015).

Table 2.1. Covariates used to evaluate wetland effect on brood abundance and their mean and standard deviation (SD) across all wetland sampling occasions (n = 412).

Covariates		Description	Mean	SD
Total invertebrates		Average invertebrates captured across traps per wetland	886.43	1283.55
Wetland depth		Average depth of a wetland	60.02	21.66
Cattail		Percentage of wetland covered by cattail	34.86	25.85
Emergent vegetation		Percentage of wetland covered by emergent vegetation (excluding cattail)	15.70	18.21
Grass within 50 m		Percentage of crops along 4 transects, 50m from the wetland edge	50.87	33.32

2.3. RESULTS

During the summer of 2019 and 2020, I sampled 230 unique wetlands at 45 sites across 4 states.

In 2019, I sampled 148 distinct wetlands in round 1; in round 2, I resampled 94 of these wetlands. In 2020, I sampled 95 distinct wetlands in round 1, (23 of which were also sampled in 2019) and in round 2, I resampled 75 of these wetlands. From these 412 sampling occasions over the course of two summers and two rounds I detected 345 broods (Table 2.2.). I detected broods of 7 dabbling duck species: blue-winged teal, northern shoveler, mallard, wood duck, gadwall, northern pintail, and American green-winged teal (*Anas crecca*). I also detected broods of 4 other

duck species: canvasback, redhead, ruddy duck, and hooded merganser. I located 345 unique broods, 305 dabbling broods and 40 other broods (Table 2.3.).

Of the 412 sampling occasions, 40% had ≥ 1 brood and 20% had ≥ 2 broods. Blue-winged teal were my most commonly detected brood, followed by wood ducks and then mallards. Cattail dominated wetlands in my study but river bulrush, round stem rush, reed canary, smartweed and other forbs were also present in my sampled wetlands. Of the wetlands sampled, 60% of them had crops within 50 m of the wetland edge. On average wetlands were surrounded by 51% grassland cover within the 50 m buffer.

Table 2.2. Wetlands sampled and surveyed in 2019 and 2020 within crop-dominated landscapes of the Prairie Pothole Region of North Dakota (ND), South Dakota (SD), Iowa (IA), and Minnesota (MN).

State	Sampling occasions	Invertebrate samples	Broods detected	Wetland with crops within 50m
IA	143	495	111	40
MN	60	240	55	31
ND	156	531	138	130
SD	53	212	41	47
TOTAL	412	1478	345	248

Table 2.3. Broods detected during 2019 and 2020 field seasons in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota. (BWTE=blue-winged teal, UNKDAB = unknown dabbler, WODU = wood duck, MALL= mallard, RUDU = ruddy duck, NSHO = northern shoveler, GADW = gadwall, NOPI = northern pintail, HOME = hooded merganser, REDH = redhead, CANV = canvasback, AGWT = American green-winged teal, UNKDIV = unknown diver, TOT = total)

STATE	BWTE	UNK DAB	WODU	MALL	RUDU	NSHO	GADW	NOPI	HOME	REDH	CANV	AGWT	UNK DIV	TOT
IA	18	19	44	22	0	0	0	0	8	0	0	0	0	111
MN	22	18	2	6	4	2	0	0	0	0	0	0	1	55
ND	53	13	2	10	20	18	9	7	0	4	1	1	0	138
SD	24	7	0	3	2	3	1	1	0	0	0	0	0	41
TOT	117	57	48	41	26	23	10	8	8	4	1	1	1	345

There were seven competitive models for brood detection (<2 AICc, Table 2.5.), indicating multiple weak effects. My top model included humidity and wind speed of survey 1 and temperature and wind speed of survey 2. However, wind speed at survey 1, and temperature of survey 2 were not significant in the top-ranked model ($p > 0.05$) and were deemed to be uninformative parameters. Model-averaged coefficients indicate that detection was positively associated with humidity at survey 1 (0.016 ± 0.007 , $p = 0.01$) and wind speed at survey 2 (0.086 ± 0.039 , $p = 0.03$). There was a weak negative association between wind speed at survey 1 and detection probability at (-0.062 ± 0.036 , $p = 0.08$). There were no significant effects of temperatures at survey 1 (0.034 ± 0.025 , $p = 0.17$) or 2, (-0.034 ± 0.022 , $p = 0.12$), nor the timing of survey 1 (-1.439 ± 0.898 , $p = 0.11$) or 2 (-1.535 ± 0.983 , $p = 0.12$). Using the principle of parsimony, I selected the detection model that contained only percent humidity of survey 1 (Figure 2.3.) as my best model, because it was within 2 Δ AICc of the top model and had fewest parameters.

There were 4 competitive models of brood abundance (<2 AICc, Table 2.7.). My top model included two covariates: brood abundance was positively associated with abundance of aquatic invertebrates (0.159 ± 0.053 , $p < 0.01$; Figure 2.4.) and the percent of grass within the 50 m buffer (0.004 ± 0.002 , $p = 0.03$; Figure 2.5.). All competing models included grass within 50 m buffer and abundance of invertebrates, but additional covariates were not significant and deemed uninformative.

A constant model for detection and abundance yielded a detection probability of 0.61 (85% CI: 0.42–0.80) and my abundance estimate was 0.97 broods (85% CI: 0.87–1.07) per wetland or 400 broods over the 412 sampling occasions. My top model included one detection covariate

(humidity of survey 1) and two site covariates (invertebrate abundance and grass buffer), and I had a detection probability of 0.50 (85% CI: 0.50–0.51) and my estimated abundance was 1.35 broods (85% CI: 1.35–1.19) per wetland or 556 broods over all sampling occasions.

Table 2.5. N-mixture models of brood detection in crop-dominated landscape of the United States PPR in June–August 2019 and May–July 2020. Models included the percent humidity of the first survey (Humid1), the temperature of the first survey (temp1) and the second survey (temp2), wind speed of the first survey (wind1) and the second survey (wind2), the time of the first survey (time1) and the second survey (time2).

Detection			
Covariates	AICc	ΔAICc	Weight
Humid1+temp2+wind1+wind2	1654.67	0.00	0.19
Humid1+temp2+wind2	1654.74	0.07	0.19
Humid1+wind2	1654.83	0.16	0.18
Humid1+time2+temp1+temp2+wind1+wind2	1655.43	0.76	0.13
Humid1+time1+time2+temp1+temp2+wind1+wind2	1655.53	0.86	0.13
Humid1+temp1+temp2+wind1+wind2	1655.73	1.06	0.11
Humid1	1656.52	1.86	0.08

Table 2.6. Model averaged coefficient values with 85% confidence intervals for the top ranked model for detection of repeat brood surveys in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota. Models included the percent humidity of the first survey (Humid1), the temperature of the first survey (temp1) and the second survey (temp2), wind speed of the first survey (wind1) and the second survey (wind2), the time of the first survey (time1) and the second survey (time2).

Detection			
Covariate	Coefficient	Lower CI	Upper CI
Humid1	0.016	0.006	0.026
Wind1	-0.062	-0.114	-0.010
Wind2	0.086	0.030	0.142
Temp1	0.034	-0.002	0.070
Temp2	-0.034	-0.066	-0.002
Time1	-1.439	-2.732	-0.146
Time2	-1.535	-2.951	-0.119

Table 2.7. N-mixture models of brood abundance in crop-dominated landscape of the United States PPR in June–August 2019 and May–July 2020. Models included the abundance of invertebrates found in wetlands (invert ab), the percent of grass that covered a 50 m buffer around the wetland (% grass), the percent of cattail covering a wetland (cattail), the percent of all other emergent vegetation covering a wetland (emergent veg) and the average depth of a wetland (wetland depth).

Covariates	Abundance		
	AICc	ΔAICc	Weight
Invert ab + % grass	1649.3	0.00	0.32
Invert ab + % grass + cattail	1650.7	1.40	0.16
Invert ab + % grass + emergent veg	1650.9	1.62	0.14
Invert ab + % grass + wetland depth	1651.2	1.90	0.12
Invert ab + % grass + cattail + emergent veg	1651.3	2.06	0.11
Invert ab	1652.2	2.95	0.07
Invert ab + % grass + cattail + emergent veg + wetland depth	1652.6	3.31	0.06
% grass	1656.0	6.76	0.10
Null	1656.5	7.25	0.10

Table 2.8. Model averaged coefficient values with 85% confidence intervals for the top ranked model for abundance of repeat brood surveys in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota. Coefficients included the abundance of invertebrates found in wetlands (invert ab), the percent of grass that covered a 50 m buffer around the wetland (% grass), the percent of cattail covering a wetland (cattail), the percent of all other emergent vegetation covering a wetland (emergent veg) and the average depth of a wetland (wetland depth).

Covariate	Abundance		
	Coefficient	Lower CI	Upper CI
Invertebrate abundance (ln+1)	0.159	0.082	0.236
% grass	0.004	0.001	0.006
Cattail	-0.002	-0.005	0.001
Emergent veg	-0.002	-0.006	0.002
Depth	-0.001	-0.005	0.003

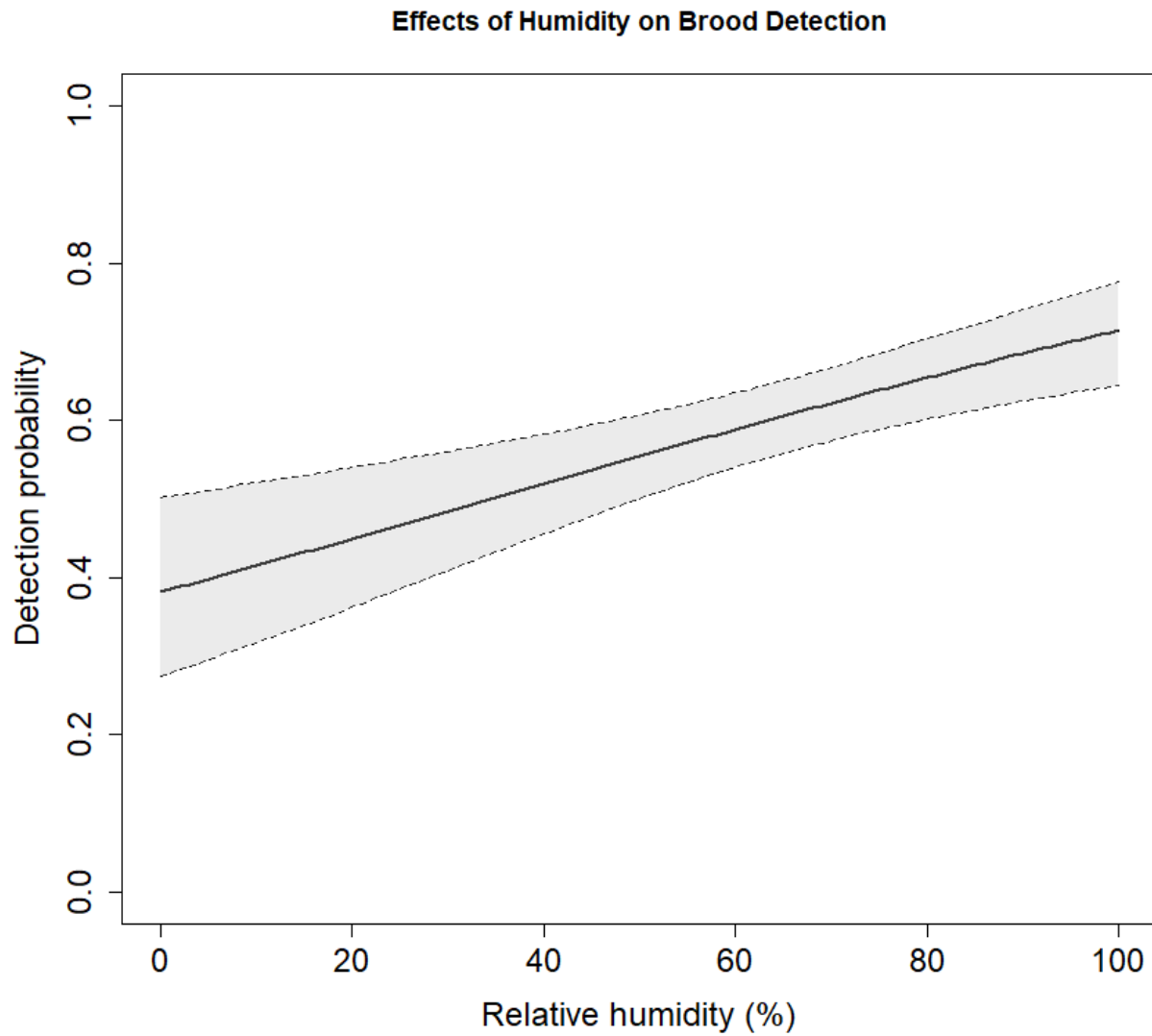


Figure 2.3. Predicted detection rate of broods in relation to percent humidity of the first survey in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota, with 85% confidence intervals.

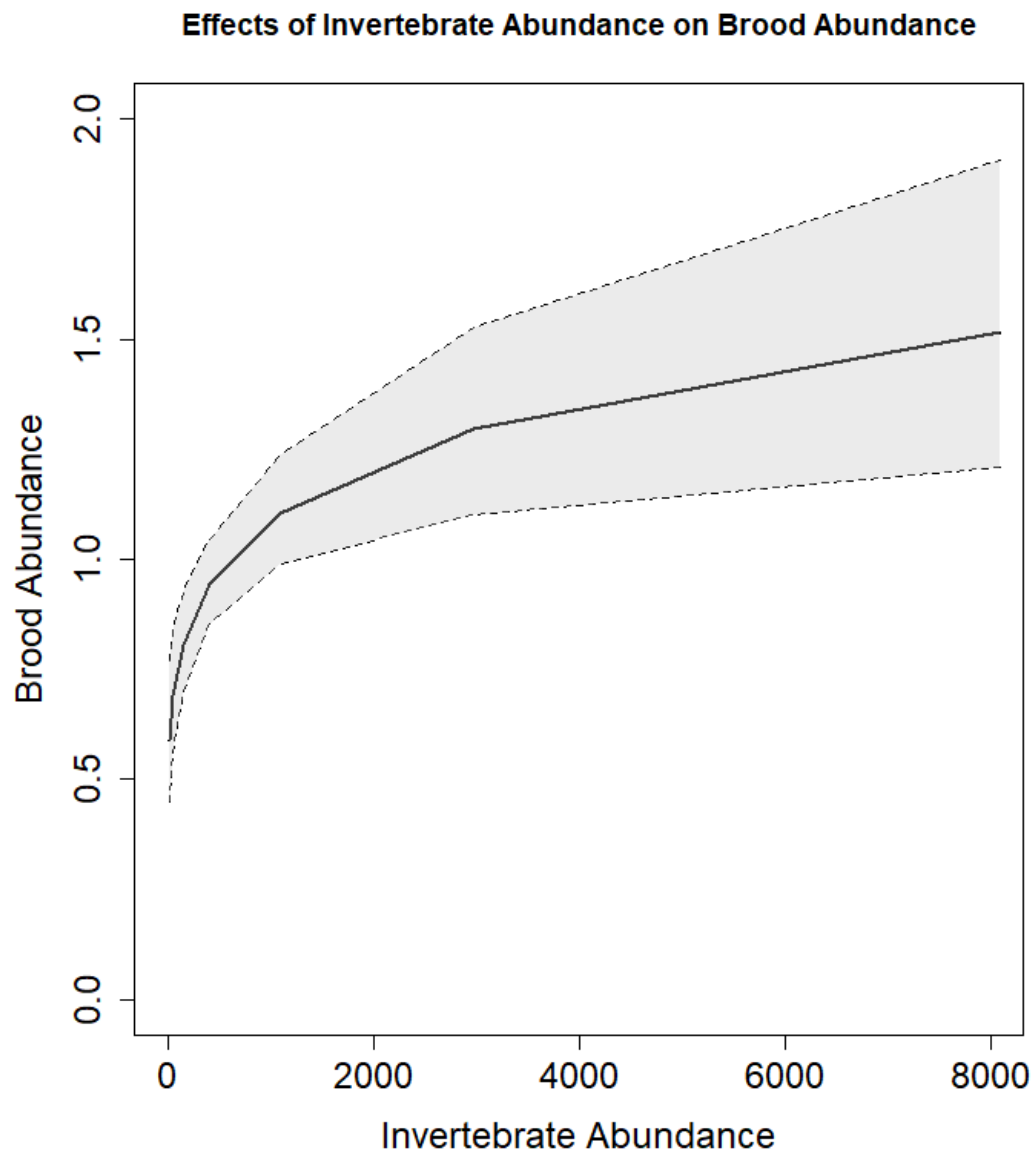


Figure 2.4. Predicted brood abundance in relation to total abundance of aquatic invertebrates ($\ln+1$) in wetlands sampled in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota, with 85% confidence intervals.

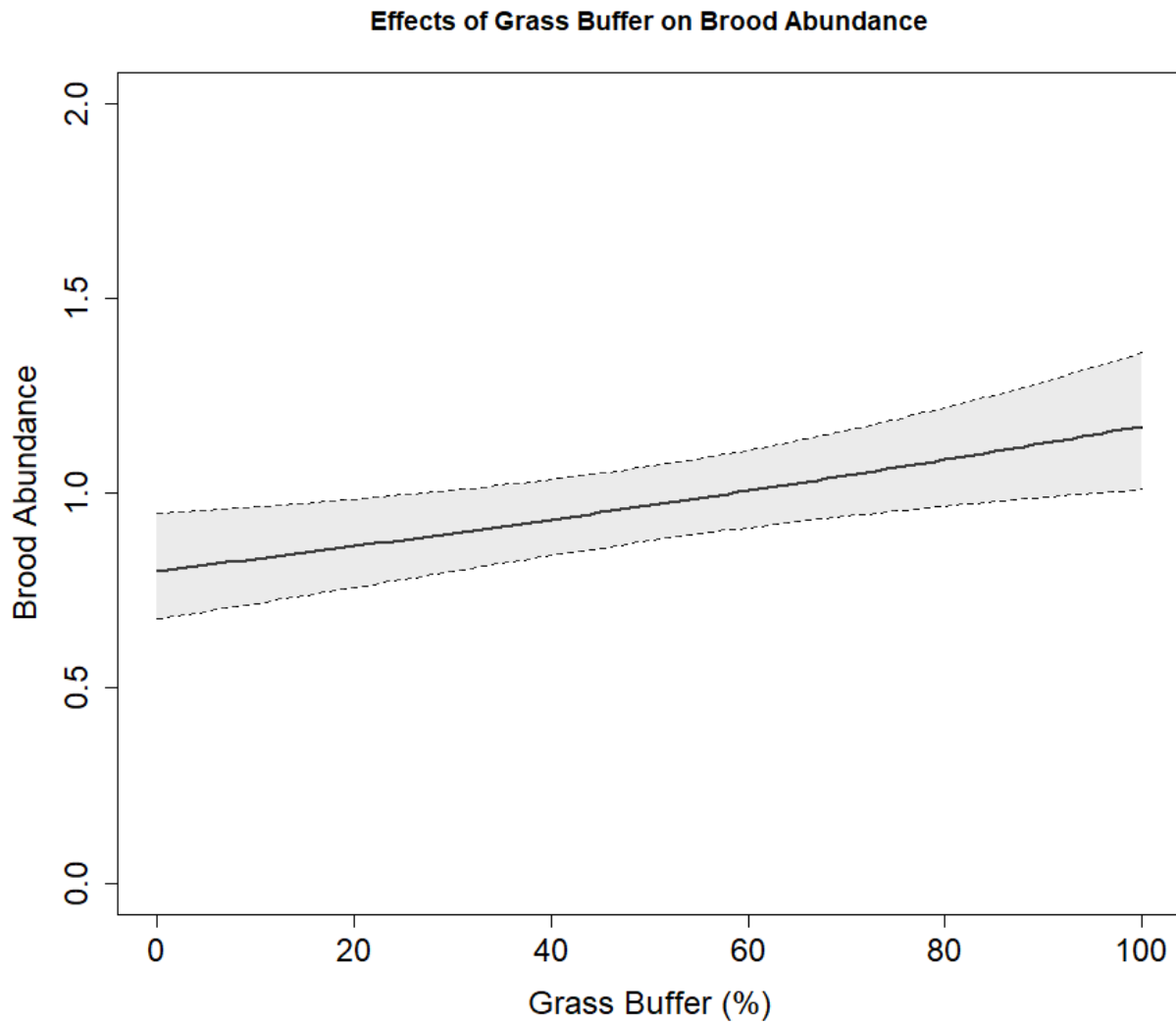


Figure 2.5. Predicted brood abundance in relation to the percent of grass within a 50m buffer of the wetland, sampled in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota, South Dakota, Iowa, and Minnesota, with 85% confidence intervals.

2.4. DISCUSSION

In my study, I surveyed wetlands for broods and sampled wetlands in crop-dominated landscapes to examine characteristics that may influence brood abundance. Most wetland conservation in the Prairie Pothole Region focuses on those surrounded by prairie grasses, despite the fact that the majority of wetlands in the PPR are surrounded by row-crop agriculture. In my study, I found

that ducks used wetlands in this heavily modified landscape, and brood abundance was positively associated with the abundance of aquatic invertebrates and the amount of grassland surrounding the wetland.

Brood abundance was higher on wetlands with more aquatic invertebrates. Brood abundance may have increased with aquatic invertebrate abundance because they are a vital resource for foraging ducklings. Cooper and Anderson (1996) also observed higher brood abundance in wetlands with higher invertebrate abundance, which is more important than the species of invertebrates present (Cooper and Anderson 1996, Cox et al. 1998). While my methods for invertebrate collection were different, I still was able to achieve similar results by just sampling for invertebrates that would be available forage for ducklings. Ducklings spend most of their time foraging for food (Sedinger 1992) and wetlands with higher abundance of invertebrates make foraging more efficient resulting in faster duckling growth, higher brood occupancy, and higher brood abundance (Hunter Jr. et al. 1984, Cox et al. 1998). It remains unclear whether hens may have sampled multiple wetlands and selected to lead their broods to those with higher invertebrate abundance, and/or whether those high-quality wetlands result in higher brood survival, but recent research suggests that hens bring their broods first to wetlands they have recently visited and not necessarily to the nearest wetland from their nest (Casazza et al. 2020).

Brood abundance increased as the amount of grass within a 50 m buffer surrounding the wetland increased. Grassland likely offered local nesting habitat for hens, and buffers with more grassland habitat help prevent chemicals and sediment from reaching the wetlands, which may increase the abundance of invertebrates (Castelle et al. 1994, Sovada et al. 2000, Phillips et al. 2003, Walker et al. 2013, Carrlson et al. 2018). This is in accordance with previous studies that

have shown that brood abundance is positively influenced by grassland buffer surrounding wetlands (Carrlson et al. 2018, Kemink et al. 2019).

I was surprised to find that multiple variables had no effect on brood abundance at the wetland level. Many studies reported brood abundance, occupancy, and survival to be influenced by the amount of emergent vegetation that covers the wetland (Nummi and Poysa 1995, Stafford et al. 2002, Raven et al. 2007, Walker et al. 2013, Carrlson et al. 2018) with higher brood use in wetlands half-covered in emergent vegetation. In my study, overall emergent vegetation and types of emergent vegetation did not affect brood abundance. Emergent vegetation offers escape cover for ducklings, but it also influences the abundance and composition of aquatic invertebrates (Voigts 1976, Murkin and Ross 2000). So, while emergent vegetation did not directly influence brood abundance in my study, it could indirectly affect community structure by altering the availability of aquatic invertebrates for ducklings. The depth of the wetland was also not significant in my analysis; since the majority of my broods were dabbling ducks that feed at the surface, I expected deeper wetlands to hold fewer broods because food may be harder to access (Baschuk et al. 2012). This was not the case in my study, and in fact, deeper wetlands may be more likely to retain water for the duration of the brood rearing season compared to shallower wetlands.

Overall, my study showed that in a crop-dominated landscape brood abundance at the wetland level is most influenced by availability of forage and presence of adjacent grassland buffers. This landscape is heavily altered, and most grasslands have been converted to row-crop agriculture. Nevertheless, we consistently found broods using wetlands embedded in agriculture. My results suggest that wetlands with higher abundances of aquatic invertebrates and more available grassland around the wetland will support more broods. Most of my wetlands were less than 10

ha, and these small wetlands are most at risk of drainage in crop dominated landscapes. My results indicate that these at-risk wetlands provide valuable habitat for broods through the summer months and should be conserved.

CHAPTER 3. FACTORS AFFECTING AVAILABLE FORAGE FOR DUCKLINGS

3.1. INTRODUCTION

The Prairie Pothole Region (PPR) is the most important breeding area for waterfowl in North America (Batt et al. 1989). This dynamic grassland-wetland mosaic is characterized by drought-driven variation in wetland abundance, size, depth, and duration of inundation. The wet/dry cycle increases productivity, because in years when potholes dry out macrophyte biomass production is maximized (Murkin et al. 2000, Johnson et al. 2005). The wet/dry cycle thereby impacts vegetation composition, which in turn influences aquatic invertebrates when the potholes fill with water in subsequent years (Weller 1994, van der Valk 2005).

The aquatic invertebrates found in potholes make up the majority of waterfowl diet during nesting and brood rearing (Krapu and Reinecke 1992) and are necessary for ducklings to survive and grow (Swanson and Meyer 1973, Reinecke 1979, Cox et al. 1998). However, many factors can influence the availability of aquatic invertebrates to waterfowl. The wet/dry cycle has caused aquatic invertebrates found in the PPR to be highly tolerant to a variety of conditions, including wide ranges of salinity (Euliss and Mushet 1999). Voigts (1976) surmised that wetlands interspersed with emergent vegetation produced the highest abundance and diversity of aquatic invertebrates. These hemi-marsh wetlands also held a higher abundance and diversity of birds during the breeding season (Weller and Spatcher 1965, Murkin et al. 1982). Stewart and Downing (2008) concluded that macroinvertebrates were more abundant in wetlands characterized by a higher abundance of coarse particulate organic matter (CPOM). The availability of dissolved oxygen in wetlands can have differential effects on invertebrate abundance by taxa (Nebeker 1972, Nebeker et al. 1992). Additionally, fish negatively influence

diversity and abundance of aquatic invertebrates, while shallow water depths positively influenced invertebrate abundance (Zimmer et al. 2000).

The potholes and the aquatic invertebrates they produce have been decreasing across the PPR. Half of the original potholes in North and South Dakota have been drained to create more land for crops, and to make it easier to maneuver farm equipment (Dahl 2014). Drainage of potholes may keep those depressions dry in all but the wettest years, and although invertebrates have adapted to wet/dry cycles, sustained dry conditions cause the community of invertebrates to die out (Murkin and Ross 2000, Wrubleski and Ross 2011). Farming has also reduced quality of remaining wetlands by altering the hydrology of the potholes, and by increasing sedimentation and chemical runoff (Castelle et al. 1994, Dahl 2014). Diminished wetland quality can negatively affect aquatic invertebrates and the waterfowl that rely on them as a food source. Increased sedimentation directly impacts invertebrate egg banks in the soil and insect emergence due to burial by the sediments (Gleason et al. 2003). Sedimentation indirectly impacts invertebrates because it changes plant communities due to burial of seeds and decreased plant germination leading to loss of habitat and available forage (Galinato and van der Valk 1986). Sedimentation is predicted to cause most shallow wetlands to fill up resulting in a complete loss of function (Burris and Skagen 2012). Runoff from row-crops, especially insecticide runoff can lower abundance of invertebrates (Doren et al. 1997, Van Dijk et al. 2013). Castelle et al. (1994) determined that a grassland buffer of at least 15 m was necessary to protect wetlands from the adverse effects of croplands, but in intensive agricultural areas it is common for wetlands to have little to no buffer. Indeed, Euliss and Mushett (1999) found significantly higher abundances of Ostracods and Cladocerans in wetlands surrounded by grasslands than in wetlands surrounded by crops. On the other hand, Janke et al. (2019) found important prey items for ducks were actually

higher in wetlands surrounded by crops than wetlands surrounded by grasslands, and wetlands surrounded by crops also had higher abundance of blue-winged teal. Although Ostracods and Cladocerans are generally not considered important prey items for migrating ducks, the literature is conflicted about the extent to which wetlands surrounded by crops support healthy aquatic invertebrate communities that benefit foraging waterfowl, and there have been no late-summer studies that evaluate aquatic invertebrates that are available to ducklings.

Compared to diets of adult ducks, little research has evaluated the diets of ducklings or the aquatic invertebrate forage available during the brood-rearing season. Ducklings have been known to consume Chironomidae, Cladocera, Gastropoda, Corixidae, Coleoptera, and Amphipoda (Sugden 1973). Cox et al. (1998) observed higher growth rates in ducklings when wetland invertebrate abundance was higher and noted that the abundance of invertebrates was more important to duckling growth and survival than the biomass and diversity of invertebrates. In chapter 2, I focused on brood abundance in crop dominated landscapes and found that the total abundance of aquatic invertebrates was positively related to brood abundance. In chapter 3, I focus on factors that may influence aquatic invertebrate abundance and determine which characteristics of cropped landscapes influence invertebrate abundance. From the available literature I hypothesize that buffer, wetland cover type, SAV, and CPOM are important factors influencing invertebrate abundance (Weller and Spatcher 1965, Voigts 1976, Murkin et al. 1982, Castelle et al. 1994, Euliss and Mushet 1999, Stewart and Downing 2008).

3.2. METHODS

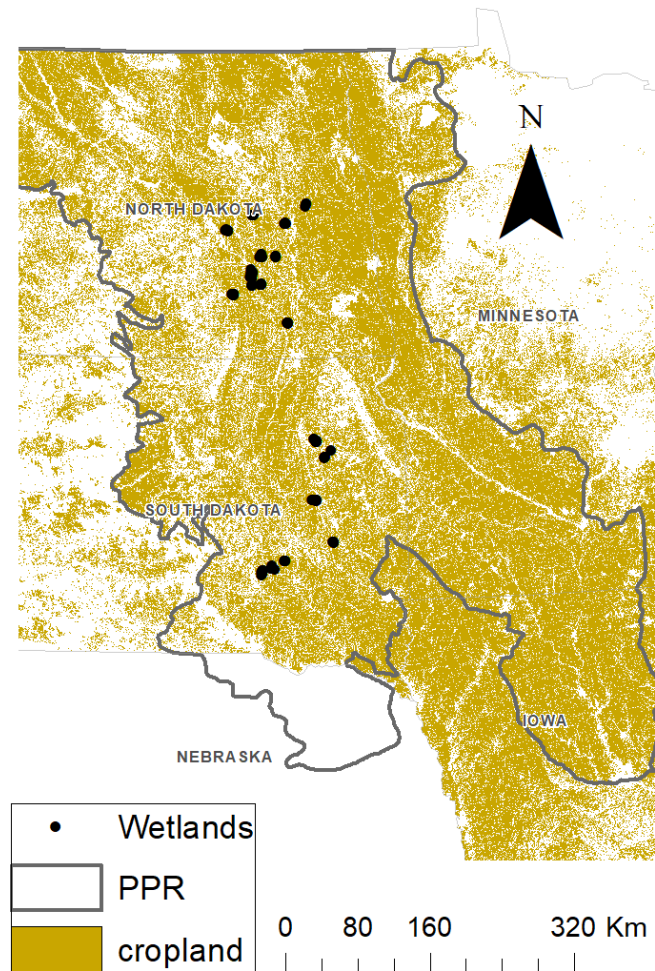


Figure 3.1. Wetlands sampled in 2019 and 2020 in relation to the Prairie Pothole Region and crop-dominated landscapes. Crop data generated from USDA cropland data layer in ArcMap 10.6.

Sampling protocol and study sites were identical to chapter 1, except only North and South Dakota were included in this analysis (Figure 3.1.).

Wetland sampling occurred between June 10 and August 15. I collected potential forage for ducklings with surface activity traps that were immersed for 24 hours. I put out 4 SATs in 2019

and 3 SATs in 2020 at cardinal direction transects in each wetland at a randomized distance from the wetland edge. At each SAT, I measured water depth, conductivity, dissolved oxygen, and temperature with a YSI sonde pro 50. Invertebrate samples were collected the following day and stored in ethanol for later processing in the lab. I quantified aquatic invertebrate abundance and composition, classified to the family level except for Amphipoda which was classified to the species level, and zooplankton which was classified to order. At each SAT I calculated the frequency of SAV and CPOM with a 15-tine garden rake. I recorded percentage of the following emergent vegetation within the wetland boundary: cattail (*Typha sp.*), sedge (*Carex sp.*), reed canary (*Phalaris arundinacea*), water plantain (*Alisma sp.*), and burreed (*Sparganium sp.*), until this percentage reached 100. I used this percentage paired with the overall percentage of emergent vegetation covering the wetland to calculate coverage of each type of vegetation, i.e., if a wetland was 20% emergent vegetation and 100% cattail then I calculated 20% coverage of cattail in the wetland.

I measured buffer width from the wetland edge inland to 50 m. I classified vegetation within the 50 m buffer as warm season grasses, cool season grasses, annual weeds, reed canary grass, shrubs/cottonwoods/willows, forests, corn/soybeans, or other. Wetlands were all sampled twice, approximately 30 days apart, unless they held less than 20 cm of water necessary to sample invertebrates with a SAT, or time constraints precluded a second sample.

Statistical Analysis

I first evaluated all my variables and screened them based on biological relevance and collinearity (Dormann et al. 2012). I conducted three separate analyses to determine how wetland characteristics impacted available forage for ducklings. Because ducklings have been shown to respond to the total abundance of food (Cox et al. 1998), I grouped my response variables into

three categories: total aquatic invertebrates, zooplankton, and nekton invertebrates. I separated zooplankton and nekton invertebrates to determine how wetland variables impacted passive versus active invertebrates that are both available as forage for ducklings. Invertebrate abundance data were highly variable, and I used a log+1 transformation to improve assumptions of normality. I summed invertebrate abundance for each sample collected and analyzed each sample as unique because factors in the wetland (i.e., depth, SAV, CPOM) can impact invertebrates in traps. I first tested a global model of variables that could influence forage for ducklings that included wet area of a wetland, wetland depth, emergent vegetation, SAV, CPOM, temperature of the wetland, conductivity, dissolved oxygen concentration, and grass buffer. I used linear mixed effects models in the *lme4* package (Bates et al. 2005) to determine which variables influenced forage abundance, while controlling for effects of year and sampling round by assigning them as random effects. I used restricted maximum likelihood estimation (Gurka 2006) for my analysis because when using maximum likelihood, the top models were overinflated with multiple parameters that were not significant and considered uninformative (Arnold 2010). Additionally, I used model-averaged coefficients on models within 2 AICc of my top model, to account for model uncertainty (Cade 2015). All analyses were conducted in R (version 4.1.0; R Core Team). I present means \pm SD of the covariates of my global model (Table 3.1.)

Table 3.1. Variables used to evaluate wetland effects on available forage for ducklings with their mean and standard deviation (SD) across all wetland sampling occasions (n=209).

Covariates	Description	MEAN	SD
Total invertebrates	invertebrates captured per trap	1148.25	2282.2
Nekton invertebrates	nekton invertebrates captured per trap	165.97	200.8
Zooplankton	zooplankton captured per trap	982.28	2249.44
Total wet area (ha)	size of wetland multiplied by percent wetland inundation	1.73	1.51
Cattail	Percentage of wetland covered by cattail	53.52	21.42
Emergent vegetation	Percentage of wetland covered by emergent vegetation (excluding cattail)	38.46	24.25
% of grass within 50m	percentage of grass along 4 transects, 50m from the wetland edge	29.18	27.28
Average conductivity (μS)	conductivity at each SAT per wetland	801.55	545.43
Wetland depth	depth at each SAT	57.99	22.15
Average SAV across wetland	% of SAV across wetland	31.44	39.49
Average CPOM across wetland	% of CPOM across wetland	62.01	52.76
Dissolved oxygen concentration	dissolved oxygen concentration at each SAT	17.86	21.07
Wetland temperature (C)	water temperature at each SAT	20.41	2.51

I constructed three separate model sets for each of the three response variables (total invertebrates, total zooplankton, and total nekton). I used the *drop1()* function for backwards

stepwise elimination of variables based on AICc scores, which sequentially removed non-significant effects and improved model fit. To ensure I had selected the best-fitting model, as a final check I sequentially added back previously eliminated covariates to the fully reduced model. The best fitting model was selected based on AICc score (Burnham and Anderson 2004) and models within 2 AICc that had additional parameters were considered uninformative (Arnold 2010). Models are reported here with their AICc scores and weight, and parameter estimates are presented with 85% confidence intervals.

3.3. RESULTS

In summers of 2019 and 2020, I sampled 105 unique wetlands at 20 sites across 2 states. In 2019, I sampled 76 distinct wetlands in round 1 and in round 2, I resampled 40 of these wetlands. In 2020, I sampled 48 distinct wetlands in round 1 (19 of which were also sampled in 2019) and in round 2, I resampled 45 of these wetlands. From these 209 wetland sampling occasions I collected 743 invertebrate samples. In North Dakota there were 526 invertebrate samples and in South Dakota there were 210 invertebrate samples.

Invertebrate abundance varied by year and sampling round, with more invertebrates collected in the second round and in 2020 (Figures 3.2., 3.3., 3.4.). Across years and sampling rounds, I counted an average of 1,148 (SD=2,282) aquatic invertebrates in each sample. The majority of my invertebrate abundance was composed of zooplankton, accounting for 79.8% (2019) and 84.1% (2020) of my samples collected in round 1, and 89.3% (2019) and 89.8% of my samples collected in round 2 (Figures 3.2., 3.4.). Cladocera, Ostracoda, and Copepoda were most abundant in my study and were found in 99.5%, 99.5% and 99.1% of all samples, respectively.

Cladocera were the most abundant zooplankton collected in my samples (Figure 3.4.) while Hemiptera and Diptera were my most common order of nekton invertebrates collected. Corixidae was my most common family of Hemiptera and averaged 28 individuals per trap and was encountered in 99% of all samples, while Chironomidae was my most common family of Diptera and averaged 17 individuals per trap and was encountered in 97% of all samples (Figure 3.3.). Odonata was my least common order of nekton invertebrate; within Odonata, Coenagrionidae was the most common family and averaged 1 individual per wetland and was encountered in 49% of all samples. I also collected two species of amphipods, *Hyaella azteca* and *Gammarus lacustris*, and encountered them in 55% and 10% of all my samples, respectively.

The majority of my wetlands (64.5%) had crops within 10 m of the wetland edge with 86.7% of wetlands being defined as cover type 2 or 3. My wetlands ranged in size from 0.084–7.642 ha with an average size of 1.73 ha. I only had three types of emergent vegetation that averaged more than 5% of a wetland's vegetation: cattail (*Typha sp.*) averaged 72.7% of the emergent vegetation, sedge (*Cerex sp.*) averaged 6.6% of the wetland, and burreed (*Sparganium sp.*) averaged 5.3% of the emergent vegetation. SAV and CPOM were abundant across wetlands and averaged 49.6 % and 55.2%, respectively.

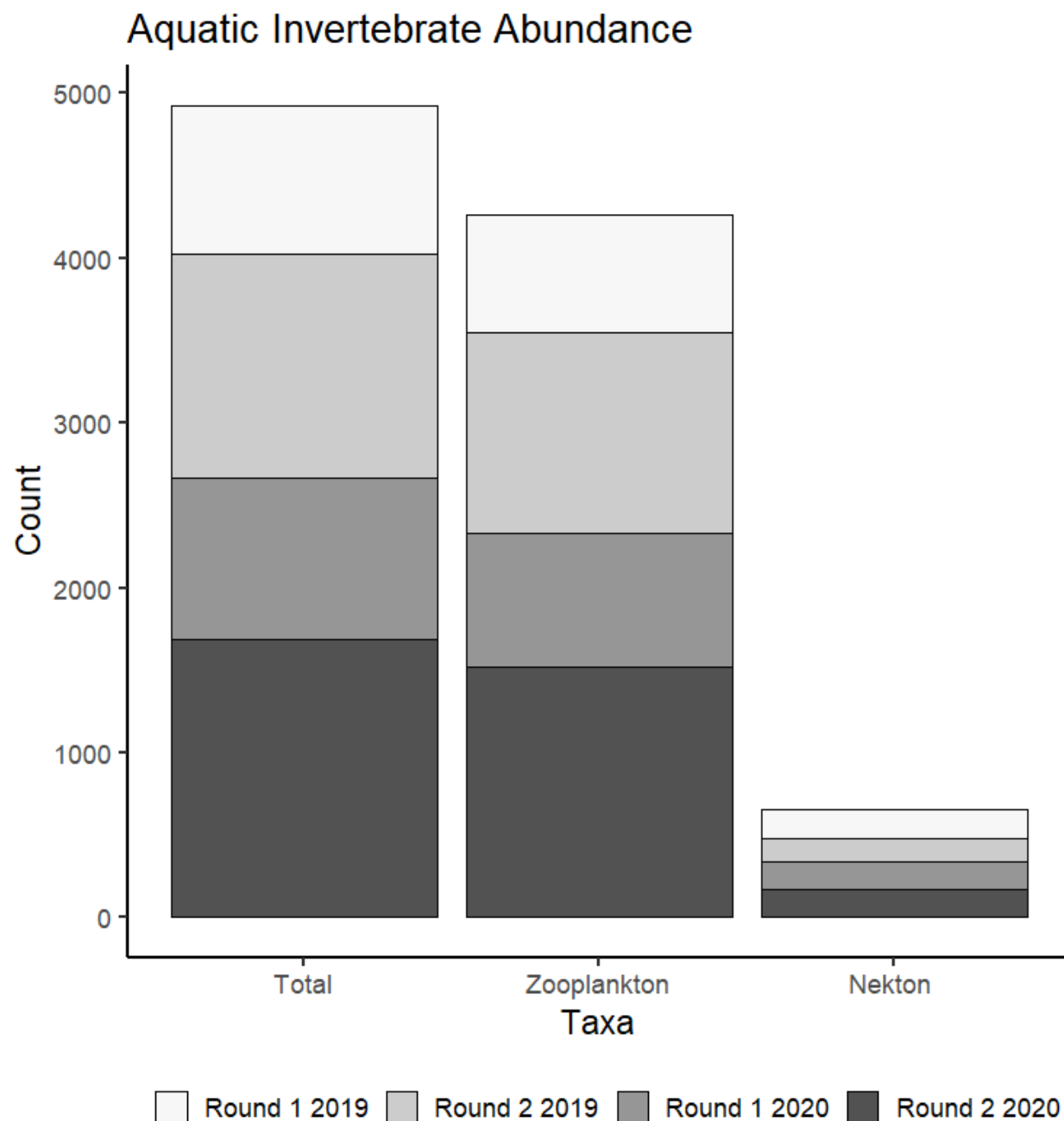


Figure 3.2. Invertebrate samples collected in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota and South Dakota. Shown are total invertebrate abundance, zooplankton abundance, and nekton abundance averaged per trap to represent invertebrates collected from each trap.

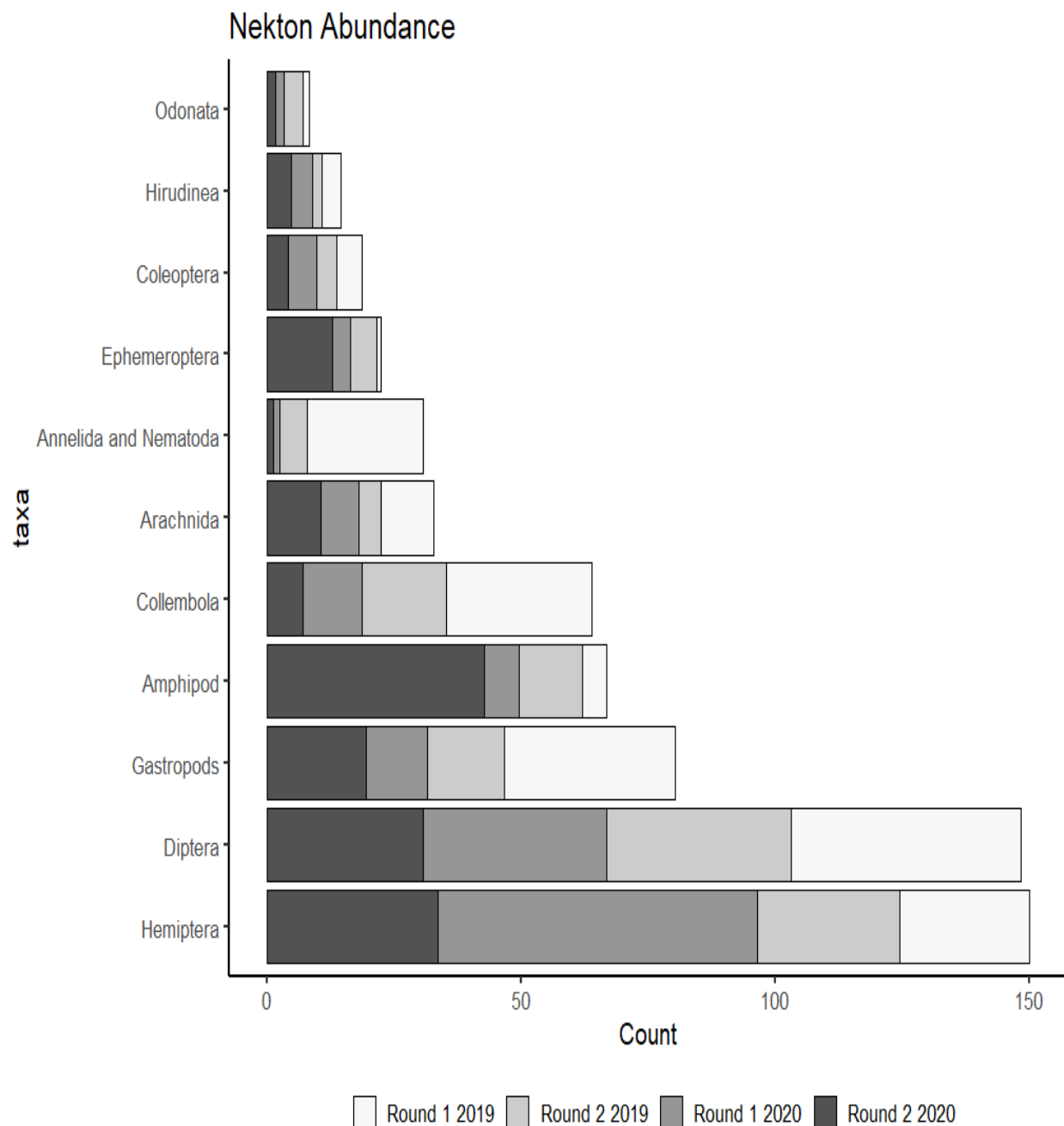


Figure 3.3. Nekton invertebrate abundance sampled in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota and South Dakota. Nekton abundance is averaged by trap. Hemiptera is the total of Pleidae, Corixidae, Notonectidae, Belostomatidae, Gerridae, Hebridae, Mesoveliidae, Nepidae, Reduviidae, Saldidae, Veliidae, and unknown Hemiptera. Diptera is the total larval Chaoboridae, Chironomidae, Athericidae, Ceratopogoniidae, Culcidae, Dixidae, Dolichopodidae, Empididae, Ephydriidae, Psychodidae, Sciomyzidae, Stratiomyidae, Tabanidae, Tipulidae, and Diptera pupa. Gastropoda is the total Planorbidae, Bithyniidae, Hydrobiidae, Physidae, Lymnaeidae, Sphaeriidae, and unknown

Gastropoda. Amphipoda is the total *Gammarus lacustris* and *Hyaella azteca*. Collembola is the total Entomobryidae, Smithuridae and unknown Collembola. Arachnida is the total of Hydrachnidae and Aranea. Annelida and Nematoda are the total of Oligochaeta and Nematoda. Ephemeroptera are the total of Baetidae, Caenidae, and unknown Ephemeroptera. Coleoptera are the total larval and adult Carabidae, Chrysomelidae, Curculionidae, Dryopidae, Dytiscidae, Elmidae, Gyrinidae, Haliplidae, Hydrachnidae, Hydrochidae, Hydrophilidae, Scirtidae, Staphylinidae, and unknown Coleoptera. Hirudinea are the total Glossiphoniidae and Erpobdellidae. Odonata are the total larval of Aeshnidae, Coenagrionidae, Lestidae, Libellulidae, and Zygoptera.

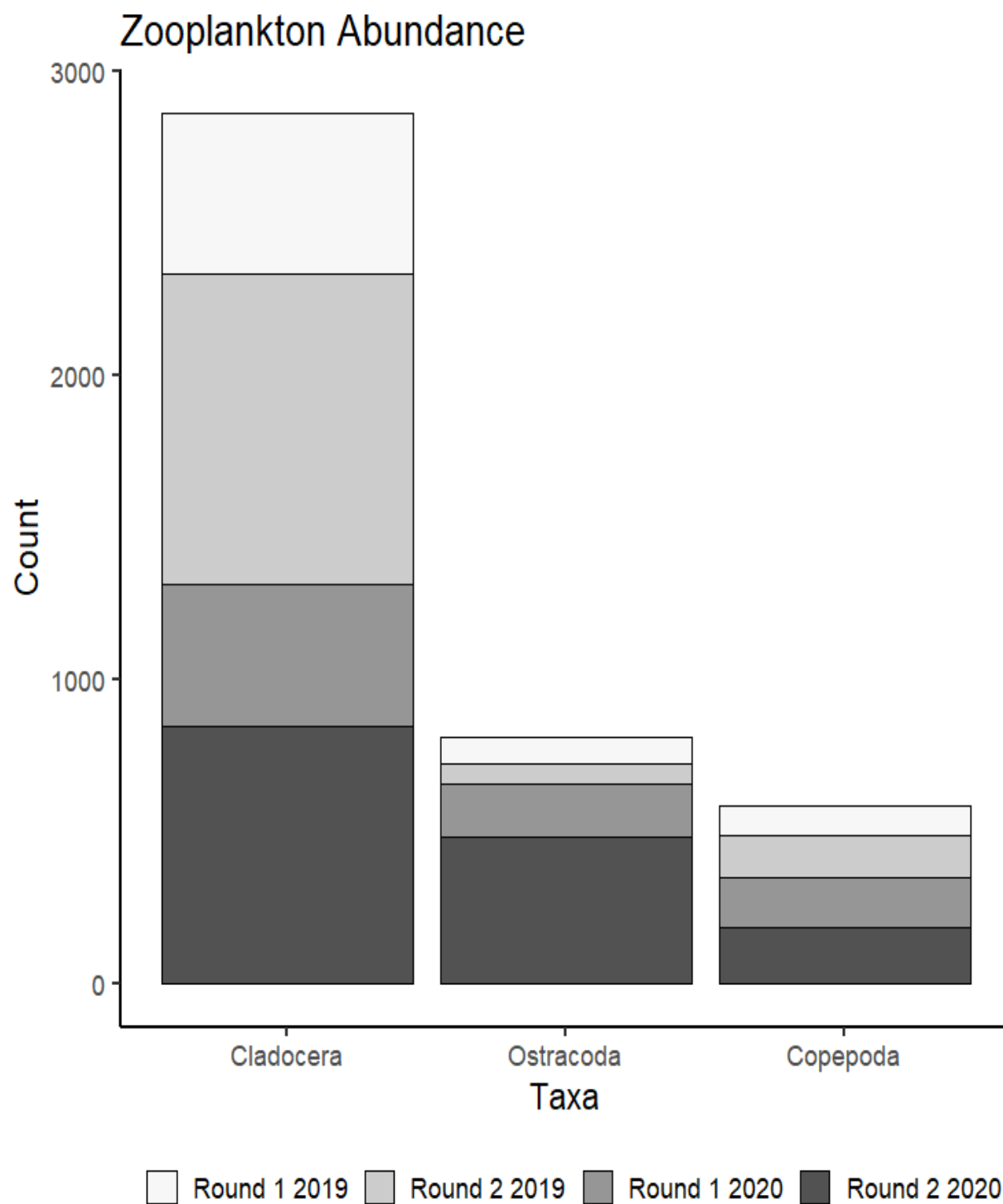


Figure 3.4. Zooplankton collected in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota and South Dakota. Zooplankton abundance were averaged by trap.

The best-fitting model for total abundance of invertebrates included only two covariates: total invertebrate abundance decreased with wetland depth (-0.008 ± 0.003) and DO concentration (-0.009 ± 0.004) (Table 3.2., 3.3., and Figure 3.5.). Surprisingly, I found that variables in the literature which often influence invertebrate abundance, including grassland buffer, emergent vegetation, cover type, and SAV had no significant effect on total invertebrate abundance in my study.

Table 3.2. Linear mixed effect models of duckling forage abundance in crop-dominated landscape of the United States PPR in June-August 2019 and May-July 2020. Models included depth of the surface activity trap (depth) and dissolved oxygen concentration (DOc).

Covariates	AICc	Δ AICc	Weight
Depth+DOc	2281.03	0	0.97
Depth	2288.16	7.12	0.03
DOc	2301.19	20.15	0
Null	2303.68	22.64	0

Table 3.3. Coefficient values at 85% confidence intervals of duckling forage abundance for the top ranked model. Coefficients include depth of the surface activity trap in the wetland (depth) and dissolved oxygen concentration (DOc)

Covariate	Coefficient	Lower CI	Upper CI
Depth	-0.0081	-0.0007	-0.0061
DO	-0.0091	-0.0130	-0.0059

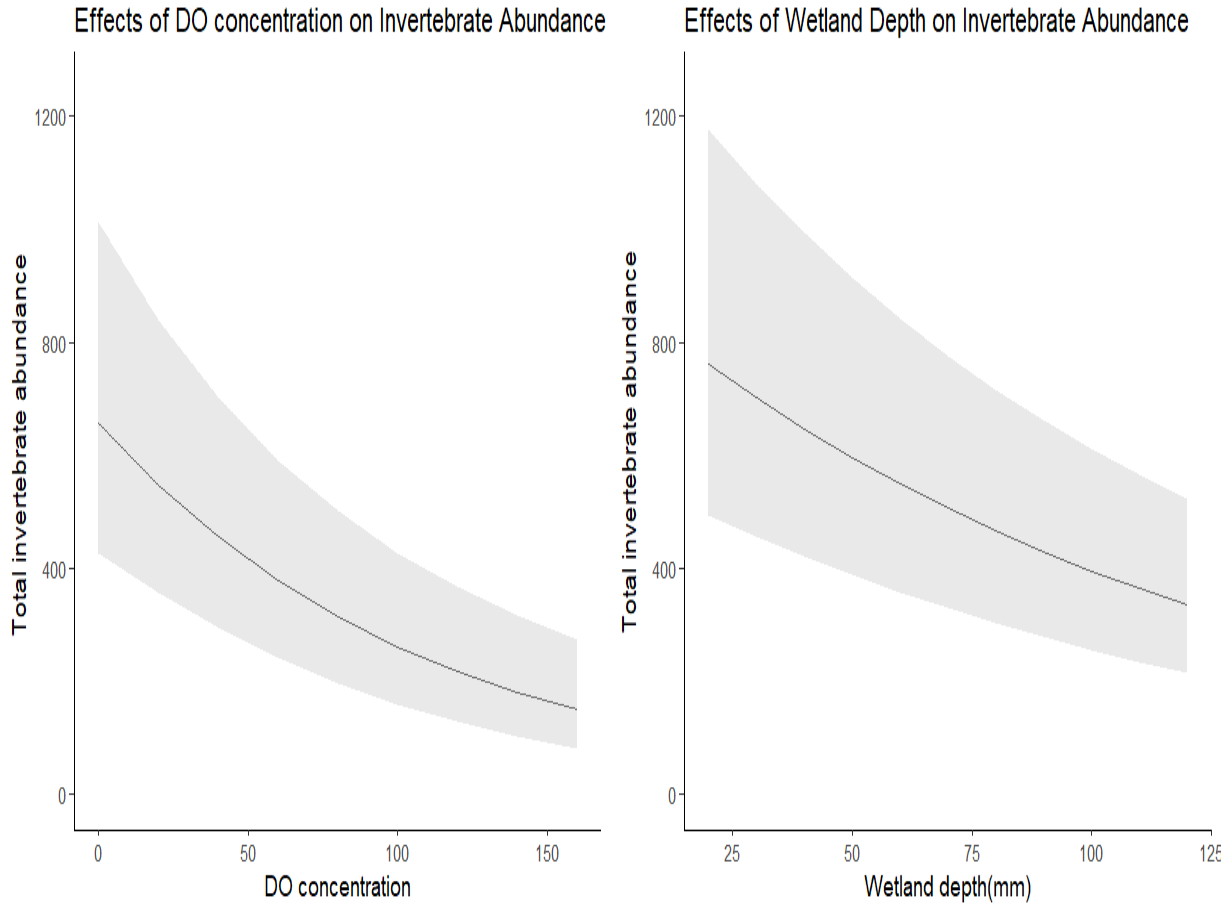


Figure 3.5. Predicted invertebrate abundance in relation to dissolved oxygen concentration and wetland depth, in wetlands sampled in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota and South Dakota, with 85% confidence intervals.

The best-fitting model for nekton abundance was similar to that of total invertebrate abundance.

The top model included significant effects of dissolved oxygen and water depth. Nekton abundance decreased as DO concentration (-0.006 ± 0.002) and wetland depth (-0.008 ± 0.001) increased (Table 3.4., 3.5., and Figure 3.6.). Surprisingly, cover type, buffer, CPOM, and SAV had no significant effect on total nekton invertebrate abundance.

Table 3.4. Linear mixed effect models of duckling forage abundance for nekton invertebrates in crop-dominated landscape of the United States PPR in June-August 2019 and May-July 2020. Models included depth of the surface activity trap (depth) and dissolved oxygen concentration (DO).

Covariates	AICc	Δ AICc	Weight
Depth + DO	1690.27	0.00	0.90
Depth	1694.60	4.33	0.10
Null	1739.10	48.84	0.00
DO	1741.31	51.04	0.00

Table 3.5. Coefficient values at 85% confidence intervals of duckling forage abundance of nekton invertebrates for the top ranked model. Coefficients include depth of the surface activity trap in the wetland (depth) and dissolved oxygen concentration (DO).

Covariate	Coefficient	Lower CI	Upper CI
DO	-0.0058	-0.0077	-0.0039
Depth	-0.0077	-0.0090	-0.0064

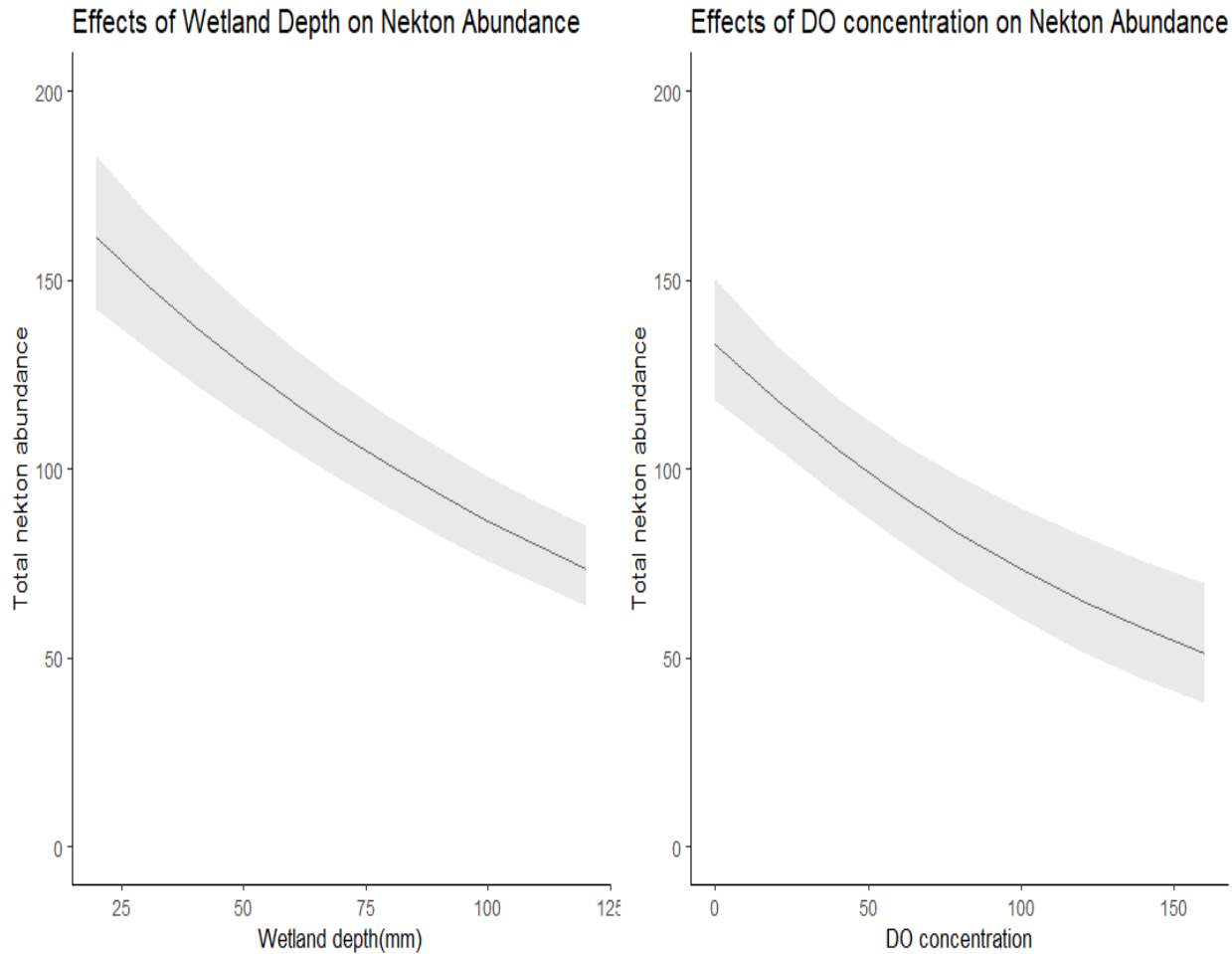


Figure 3.6. Predicted nekton abundance in relation to dissolved oxygen concentration and wetland depth, in wetlands sampled in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota and South Dakota, with 85% confidence intervals.

The top-ranked models for zooplankton abundance included negative effects of dissolved oxygen concentrations in wetlands and depth of a wetland on zooplankton. The most parsimonious model only included depth of the wetland (-0.0092 ± 0.0026) and was less than 2 AICc from the top model. Emergent vegetation, temperature of the wetland, and buffer had no significant effect on zooplankton abundance. AICc model selection indicated that there were two competing

models (<2 AICc, Table 3.6.) and model-averaged coefficients (Table 3.7., Figure 3.7.) were similar to those from the top model.

Table 3.6. Linear mixed effect models of duckling forage abundance for zooplankton in crop-dominated landscape of the United States PPR in June-August 2019 and May-July 2020. Models included depth of the surface activity trap (depth) and dissolved oxygen concentration (DO), ranked by AIC value.

Covariates	AICc	Δ AICc	Weight
Depth + DO	2658.35	0.00	0.56
Depth	2658.85	0.50	0.44
Null	2669.59	11.24	0.00
DO	2672.25	13.90	0.00

Table 3.7. Model averaged coefficient values at 85% confidence intervals of zooplankton abundance for the top ranked models within 2 Δ AICc. Coefficients include depth of the surface activity trap in the wetland (depth) and dissolved oxygen concentration (DO).

Covariate	Coefficient	Lower CI	Upper CI
Depth	-0.0092	-0.0118	-0.0066
DO	-0.0053	-0.0090	-0.0016

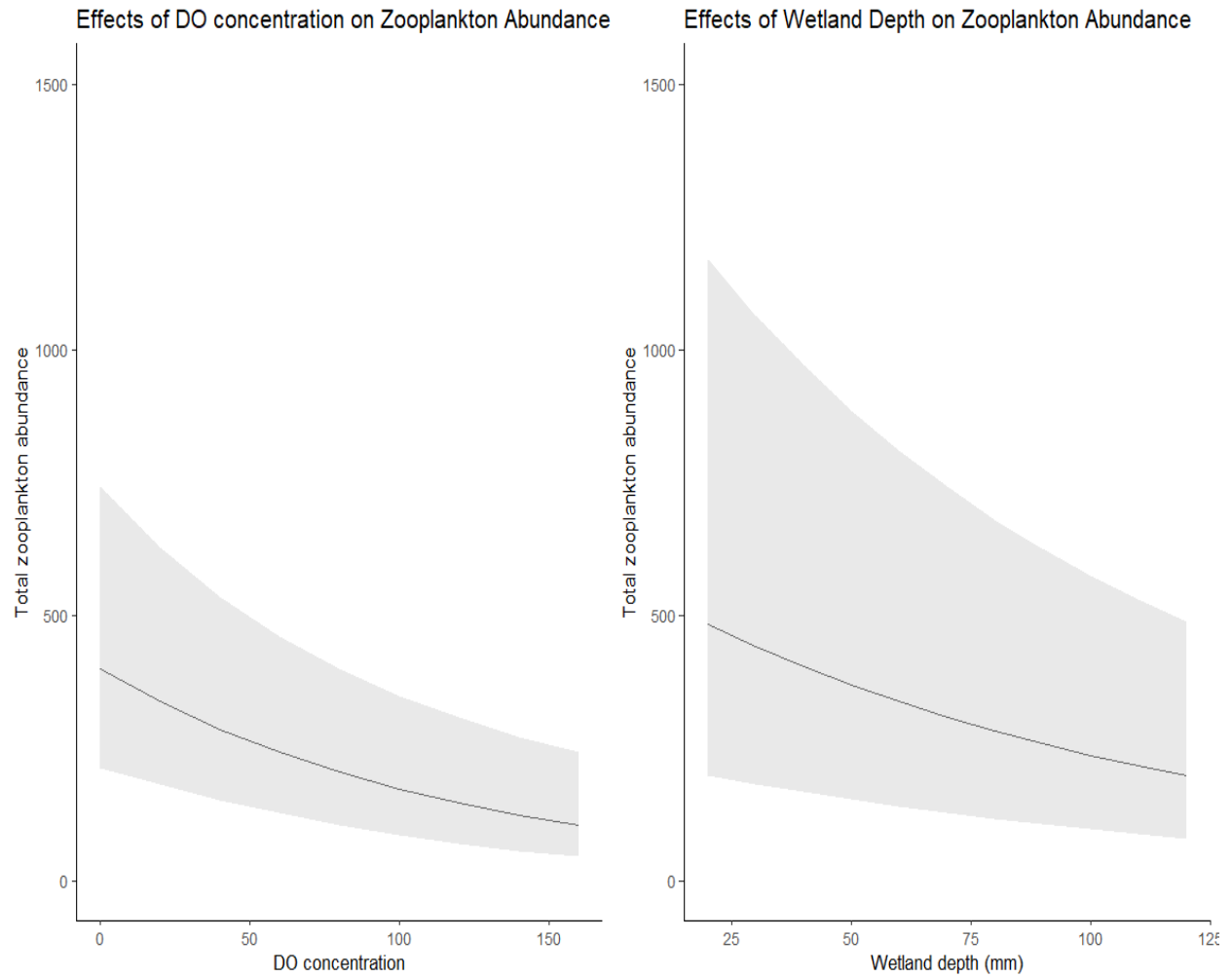


Figure 3.7. Predicted zooplankton abundance in relation to dissolved oxygen concentration and wetland depth, in wetlands sampled in 2019 and 2020 in crop-dominated landscapes of the Prairie Pothole Region of North Dakota and South Dakota, with 85% confidence intervals.

3.4. DISCUSSION

In my study, I sampled wetlands to determine which factors influenced aquatic invertebrates available to ducklings in crop-dominated landscapes during the late-summer brood season. The strongest and most consistent effect I uncovered was that invertebrate abundance decreased as DO concentration and wetland depth increased.

Depth was the biggest factor affecting aquatic invertebrate abundance. In my study, as wetland depth increased, available forage for ducklings decreased. This is potentially due to deeper wetlands having longer water permanence, potentially not exhibiting the characteristic wet/dry cycle of the PPR that increases productivity of aquatic invertebrates. Studies show that semi-permanent wetlands are becoming deeper and more permanent this can have a direct impact on available invertebrates and lead an overall reduction in production and taxa (McLean 2020).

Meyer et al. (2015) saw biomass decrease as permanence of a wetland increased. Driver (1977) found that Chironomidae abundance was most influenced by wetland depth, with increased depth causing a decrease in Chironomidae. Although, I only caught fish in 10% of the wetlands I sampled, deeper wetlands are more likely to hold fish populations which can reduce invertebrate abundance (Hanson et al. 2005). My most captured fish were brook sticklebacks (*Culaea inconstans*) followed by fathead minnows (*Pimephales promelas*); sticklebacks tend to exclusively eat *Daphnia* while fatheads are less selective (Laurich et al. 2003).

Dissolved oxygen was also a significant factor affecting aquatic invertebrates. In my study, as the concentration of dissolved oxygen increased, available forage for ducklings decreased. In my study, average DO decreased from the first round (2.01 mg/L) to the second round (1.13 mg/L), as summer progressed, potentially because wetlands were warmer in the second round. For example, Murkin et al. (1992) documented DO concentrations decreased as temperature

increased. The average DO in the wetlands I sampled is considered a hypoxic condition (<2.0 mg/L), with severe hypoxic conditions categorized as (<1.5 mg/L). Low DO concentrations can indirectly promote invertebrate abundance by reducing abundance of less tolerant species, i.e., fish and predacious invertebrates (Suthers and Gee 1986, Justus et al. 2014).

My wetlands were considered hypoxic but prior research has demonstrated Cladocera, Ostracoda, and Copepoda to be very tolerant of low DO (Barbour et al. 1999), and indeed, these were the most abundant invertebrates in my study. Concordantly, Odonata are considered intolerant of low DO concentration and were the least common order that I collected. Among Amphipoda, *Hyaella* are tolerant of low DO while *Gammarus* are intolerant of low DO (Barbour et al. 1999), and I encountered *Hyaella* much more frequently in my samples than *Gammarus*. These results are similar to Anteau and Afton (2006), who found *Hyaella azteca* and *Gammarus lacustris* present in 54% and 19% of the wetlands they sampled. SATs are designed to capture surface invertebrates and enabled me to capture invertebrates that do not rely on dissolved oxygen.

If DO concentrations are an accurate prediction of aquatic invertebrates in crop-dominated landscapes this could eliminate the need to undertake the laborious process of sampling invertebrates. I performed an post hoc linear regression analysis to determine which of my wetland and landscape parameters influenced DO concentration. My best fitting model included wetland depth, emergent vegetation, SAV, and the presence of crops within 20 m of the wetland edge. Dissolved oxygen was lower in deeper wetlands that had crops within 20 m of the wetland edge, and in wetlands with more emergent vegetation and less SAV. While most of these parameters did not directly impact the abundance of available forage for ducklings, they may have indirect effects by influencing DO concentrations that drive invertebrate abundance.

Buffer did not directly impact available forage for ducklings in my study, but most of my wetlands did not meet the 15 m buffer recommendation of Castelle et al. (1994) to reduce detrimental impacts from row-crops. Buffers remove excess nutrients before they enter wetlands, potentially preventing hypoxic conditions, and so (Hilsenhoff 1987, Castelle et al. 1994, Christianson et al. 2018), it is possible that my wetlands were hypoxic because they were surrounded by crops. This was particularly apparent when crops were within 20 m of the wetland edge, resulted in significantly lower DO concentrations.

The wetlands I sampled in crop-dominated landscapes exhibited hypoxic conditions during the brood rearing season. Hypoxic conditions can result from excess nutrients in the wetlands, which is exacerbated by heavy rains and hot temperatures (Hilsenhoff 1987). My study was conducted during summer, with precipitation much above average (NOAA), and most wetlands lacked buffers to help limit nutrients entering wetlands. The combination of these factors potentially swamped signals traditionally associated with aquatic invertebrate abundance, including emergent vegetation and SAV. Nevertheless, the hypoxic conditions found in wetlands surrounded by crops may have resulted in fewer predators of aquatic invertebrates, thereby increasing overall abundance.

Hypoxic wetlands may only support highly tolerant invertebrate taxa and thus support a lower diversity of aquatic invertebrates. If dissolved oxygen continues to be low during both wet and dry years, further studies should closely examine taxon-specific tolerance to hypoxic conditions to better understand which species will be available forage for ducklings. Additionally, depth was the most significant factor and if the shift from semi-permanent to permanent wetlands occurs this will impact the available forage for ducklings and these wetlands may not serve as brood rearing wetlands if permanent water regime reduces forage.

CHAPTER 4. GENERAL CONCLUSION

The PPR is a critically important nesting grounds for ducks but this landscape has been heavily altered due to the conversion of potholes and grasslands to row-crop agriculture (Dahl 2014). Reduction of prairies has consequently reduced available nesting habitat for ducks and degraded the remaining potholes. While most conservation efforts are geared towards wetlands surrounded by prairie grasses, grasslands continue to be converted to row-crops and it is essential to determine how these wetlands surrounded by row-crop contribute to duck production. The goal of my study was to evaluate wetlands embedded in row-crop and how these wetlands influence brood abundance and aquatic invertebrates.

Typical metrics that influence brood abundance did not affect broods in my study including emergent vegetation, SAV, and wetland depth. The abundance of aquatic invertebrates and the amount of grassland surrounding the wetland positively influenced brood abundance in my study. Higher abundance of food for ducklings has also been linked with higher duckling growth and survival (Hunter et al. 1984, Cox et al. 1998). With these results I investigated what influenced available forage for ducklings, typical wetland metrics that influence invertebrates were not pronounced in my study including buffer and emergent vegetation. Dissolved oxygen and wetland depth both negatively influenced invertebrate abundance. My study showed that most of the wetlands I sampled were hypoxic, but this can benefit invertebrates by decreasing their predators.

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study. Higher abundance of food for ducklings has also been linked with higher duckling growth and survival (Hunter et al. 1994, Cox et al. 1998). I then investigated what influenced available forage for ducklings, and typical wetland metrics that influence invertebrates were not pronounced in my study, such as buffer and emergent vegetation. Dissolved oxygen and wetland depth both negatively influenced invertebrate abundance. My study showed that most of the wetlands I sampled were hypoxic, but this can benefit invertebrates by reducing predator populations.

My study was conducted during two years of high precipitation in the region and kept wetlands full for most of the summer. This could potentially swamp the signals of typical wetland metrics that influence broods and invertebrates. Regardless, my study demonstrated that broods are being produced in a heavily modified landscape and these at-risk wetlands provide valuable habitat for broods through the summer months and should be conserved.

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VITA

Catrina V Terry was born in Sacramento, California in 1991. She graduated from University of California, Davis in the wildlife, fish, and conservation department. It was here she harvested her first duck, a drake American wigeon and started to pursue waterfowl ecology. After graduation, Catrina worked various waterfowl centric jobs around the country, working in both nationally important wintering and breeding grounds. In the spring of 2018, she began working with Dr. Kevin Ringelman to investigate the value of wetlands embedded in cropland to duck production. Catrina will finish her M.S. in 2021 after sampling wetlands and conducting brood surveys for three summers. She is currently a research scientist with Ducks Unlimited in Bismarck, North Dakota.