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Effects of Oil and Gas Development on Waterfowl Nesting Ecology in the Bakken Formation of North Dakota

Cassandra G. Skaggs
Louisiana State University and Agricultural and Mechanical College, skaggsc22@gmail.com

EFFECTS OF OIL AND GAS DEVELOPMENT ON WATERFOWL NESTING ECOLOGY IN THE BAKKEN FORMATION OF NORTH DAKOTA

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I would like to dedicate this thesis to my family and peers. You may be reading this as a template to write your own thesis or maybe you are reading this because you really like ducks, like me. Regardless, one thing that is not on the surface of this thesis is what it took to get here. There is no one that I know that makes it through this process without some help or guidance, I am no different. Some of my first memories of life are living in a three-bedroom, one-bathroom house in southwest Georgia with six other family members. My mother, sister, and I lived in a converted carport room that was always a little cooler. This was fantastic in the summer because my family only had two window a/c units to keep the entire house cool. I saw my grandmother, mom and aunt work multiple jobs to make ends meet, leaving little time to pursue higher education. These strong women taught me resilience and the value of hard work. By the time I was in elementary school, I saw my mom purchase her own home and do everything she could to support my sister and I. Once I graduated high school, I started to surpass the education in my household and a four-year degree passed everyone. This is not unique if you chat with other first-generation college students. By the time I reached graduate school, I had another family in addition to my biological family, my peers. My peers became the first network I leaned on and commiserated with about the struggles all college students face. During my second year of graduate school, a flood, fire, and tornado changed my life and perspective. That network of support that got me to graduate school, saw me through these times with an incredible outpouring of support. You all have shaped me into the person that I am now and I certainly would not have made it this far without all of you, thank you.

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ABSTRACT

The Prairie Pothole Region (PPR) is one of the most important areas on the continent for grassland-nesting birds. Thirty percent of the PPR overlaps the Bakken shale formation where rapidly accelerating oil and gas development has the potential to impact millions of breeding waterfowl. While oil and gas development has negatively affected other ground-nesting birds such as sagebrush passerines and Greater Sage-Grouse (*Centrocercus urophasianus)* in Wyoming, the potential impact on breeding waterfowl in the PPR is unknown. In addition, the PPR landscape is already heavily fragmented by agriculture, and increasing land conversion and disturbance from petroleum extraction may further exacerbate deleterious effects. The availability and quality of upland nesting habitat directly influences duck nest density and success, which have been shown to ultimately drive waterfowl populations.

In this study, I located and monitored waterfowl nests in survey plots that were stratified by intensity of energy development as measured by the number of well pads within four square miles. Over three years, we systematically searched 8,657 hectares of grassland and monitored 4,774 duck nests. Blue-winged Teal (*Spatula discors*), Gadwall (*Mareca strepera*), and Mallard (*Anas platyrhynchos*) comprised 75% of nests. I used program MARK through the RMARK package to build models of nest survival based on ecological variables measured at local and landscape scales, as well as various metrics of oil and gas activity. Metrics included age of nest when found, nest initiation date, species, year, Robel pole measurement, distance to nearest active oil well, county road, and major road, active oil well intensity, and number of wells at various distances (from 500 to 4000 meters in 500-meter increments) from each nest. Typical metrics such as number of wells and roads did not negatively affect waterfowl nest success and my top-ranked model, major roads showed a positive relationship suggesting that nests closer to major highways have higher nest survival.

Then, I investigated the effects of oil and gas development on nest density and area avoidance as estimated at two spatial scales: 1) a year-specific analysis of landscape-level density using survival-corrected nest densities calculated at the block level (four square miles) and 2) a within-replicate Monte-Carlo randomization analysis to evaluate used vs. available nest-site relationships in reference to locations of oil and gas activity at the replicate level (32 ha). Additional metrics included in the landscape-level density analysis were number of wetland basins, basin hectares, percent grassland within four square miles, and various measures of oil and gas production (e.g. amount of oil and gas produced, amount of gas flared, number of days each well produced, etc.). My top ranked model for nest density indicated detrimental effects of number of active wells within 1500m, resulting in a nest density decrease of 3.7% for every additional well added suggesting area avoidance. However, at the replicate scale (32 ha), area avoidance was not well supported based on a paired t-test analysis of real and simulated nests. I compared mean values of oil and gas covariates to determine whether real duck nests were placed non-randomly with respect to oil and gas infrastructure as compared to simulated nests.

Rapid oil and gas expansion in the Bakken formation of North Dakota continues to be of particular concern for waterfowl populations in the PPR and will be for the foreseeable future. While no strong impacts to nest success were detected, a decrease in nest density and area avoidance indicated detrimental effects to waterfowl populations in the region. Thus, my results show the need to investigate multiple oil and gas development factors that may drive wildlife populations. Long-term impacts on waterfowl populations will require combining datasets with pair and brood surveys to determine if oil and gas effects are detected at a population level.

CHAPTER 1. INTRODUCTION

In the early 1980s, declining waterfowl populations led to historic population lows from the averages of the 1970s (U.S. Fish and Wildlife Service 1986, Reynolds et al. 2007, Zimpfer et al. 2011). Of particular concern, Mallard (*Anas platyrhynchos*) (8.7 million to 5.5 million) and Northern Pintail (*Anas acuta*) (6.3 million to 2.9 million) breeding populations were at their lowest levels since surveys began in 1955 (U.S. Fish and Wildlife Service 1986). In 1986, the North American Waterfowl Management Plan (NAWMP) was created and identified key geographies and threats to waterfowl populations in North America. Out of these areas, the region of highest focus and importance for dabbling ducks was the Prairie Pothole Region (PPR). Dabbling ducks are the most recognizable and widespread waterfowl in North America (U.S. Fish and Wildlife Service 1986) and the PPR is responsible for producing more than half of the continental population in an average year, even though the PPR comprises only 10% of the total waterfowl breeding area in North America (Smith et al. 1964).

The PPR is characterized by millions of depressional wetlands formed during the Pleistocene epoch when glaciers scraped over the landscape in the northern United States and southern portions of Canada (Sloan 1972, Kantrud et al. 1989). As these glaciers retreated, they reshaped the landscape leaving low spots and ice block depressions (Sharitz and Batzer 2006) called "potholes" across a 777,000 km^2 extent (Smith et al. 1964). These wetlands vary in depth, size, and duration of flooding creating wetlands filled seasonally by snowmelt, precipitation, basin runoff, and seepage inflow of ground water (Sloan 1972). The majority of wetlands in the PPR are hydrologically-closed basins and operate on natural wet and dry cycles (Millett et al. 2009, Dahl 2014). These cycles increase the net primary productivity of wetlands and create turnover of wetland vegetation beneficial to waterfowl (Johnson et al. 2005, van der Valk 2005). In addition to wetlands, the Midwest climate historically supported vast prairie grasslands; extreme drought, natural fires, and ungulate herbivory preventing the establishment of trees (Samson et al. 2004). This prairie landscape is based on an east to west precipitation gradient indicated by tallgrass, mixed-grass or shortgrass prairie vegetation (Doherty et al. 2013). Generally, tallgrass prairies are associated with higher annual precipitation and subsequently, a greater risk of conversion to agriculture.

This wetland/prairie complex provides the ideal ecosystem for breeding dabblers when large numbers and acres of seasonal and semi-permanent potholes contain surface water (Stewart and Kantrud 1973, 1974). The primary dabbling species found in the PPR include Mallard, Northern Pintail, Blue-winged Teal (*Spatula discors*), Gadwall (*Mareca strepera*), and Northern Shoveler (*Spatula clypeata*) (Stewart and Kantrud 1974). All of these species are upland nesters, requiring nearby perennial upland cover to nest successfully (Baldassarre 2014). However, during the 1980s, habitat conversion to cropland and a multi-year drought caused waterfowl populations to decline in the PPR (U.S. Fish and Wildlife Service 1986, Reynolds et al. 2007).

For the U.S. portion of the PPR, 49% of upland-nesting waterfowl breed in North Dakota (Brice et al. 2017) and by the mid-1980s, North Dakota had lost 49% of its wetland area (971,245.5 ha) (Dahl 2014). Furthermore, by 2006, 54.2% of North Dakota's grasslands (7.2 million ha) had been converted to cropland (Doherty et al. 2013). Despite these continued losses of wetland and grassland habitat in North Dakota, waterfowl populations have reached historic highs within the last few decades due to an unprecedented wet cycle coupled with CRP habitat (Figure 1.1.) (Dyke et al. 2010).

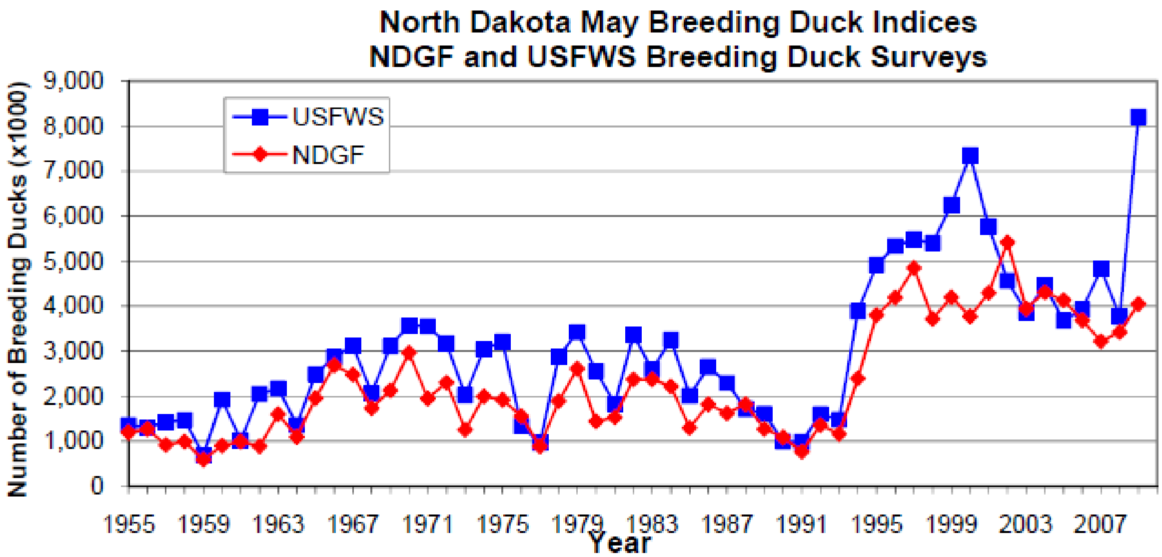

Figure 1.1. Unedited figure from Dyke et al. (2010) shows historically high breeding indices for North Dakota from two separate sources (United States Fish and Wildlife Service and North Dakota Game and Fish) calculated annually from 1955-2009.

In 1985, Congress passed the Food Security Act that authorized the Conservation Reserve Program (CRP) and implemented wetland conservation ("swampbuster") provisions for the U.S. (Reynolds et al. 2007). CRP paid landowners annually to convert cropland to undisturbed perennial cover for a contracted length of time (typically ten years) to reduce soil erosion, reduce crop surpluses, and improve wildlife habitat. The Swampbuster provision disqualified landowners from certain farm bill benefit programs if they drained or filled wetlands that were covered in the provision. These provisions subsequently increased waterfowl numbers and slowed grassland conversion and wetland loss rates. Reynolds et al. (2007) calculated that CRP was responsible for 25.9 million additional ducks between 1992-2004. In addition, it was estimated, by protecting at-risk wetlands from drainage, the Swampbuster provision potentially prevented a 37% population decrease of the most common PPR breeding waterfowl species. Unfortunately, these incentives can lose their value if landowner interest and acceptance of these programs is diminished (Doherty et al. 2013). For example, when commodity prices begin to rise in 2006 landowners allowed their CRP contracts to expire and subsequently, CRP lands in the

PPR have diminished from a 2008 peak of 8.35 million acres to 4.19 million acres in 2015 (Hellerstein and Malcolm 2011, Brice et al. 2017).

While these historic habitat threats have been well studied, a new threat has emerged in the PPR, modern oil and gas development. Specifically in North Dakota, a combination of oil discovery and the evolution of technology such as high pressure hydraulic fracturing and horizontal drilling (Wells 2007, Hicks 2012, Wells 2017) have led to vast changes in the PPR. In the early 1950s, exploratory drilling across North Dakota struck the first oil discovery after decades of effort (Wells 2018). This oil field became known as the Williston Basin and covers portions of Montana, South Dakota, the majority of North Dakota, and portions of the Canadian provinces Saskatchewan and Manitoba for a total of 770,000 km^2 (Pollastro et al. 2013, Wells 2018). Furthermore, the basin contains several oil-producing formations at varying depths, including the Bakken shale formation (Figure 1.2.) comprising ~510,000 km^2 of vast oil stores that are minimally recoverable from traditional vertical wells (Wells 2018).

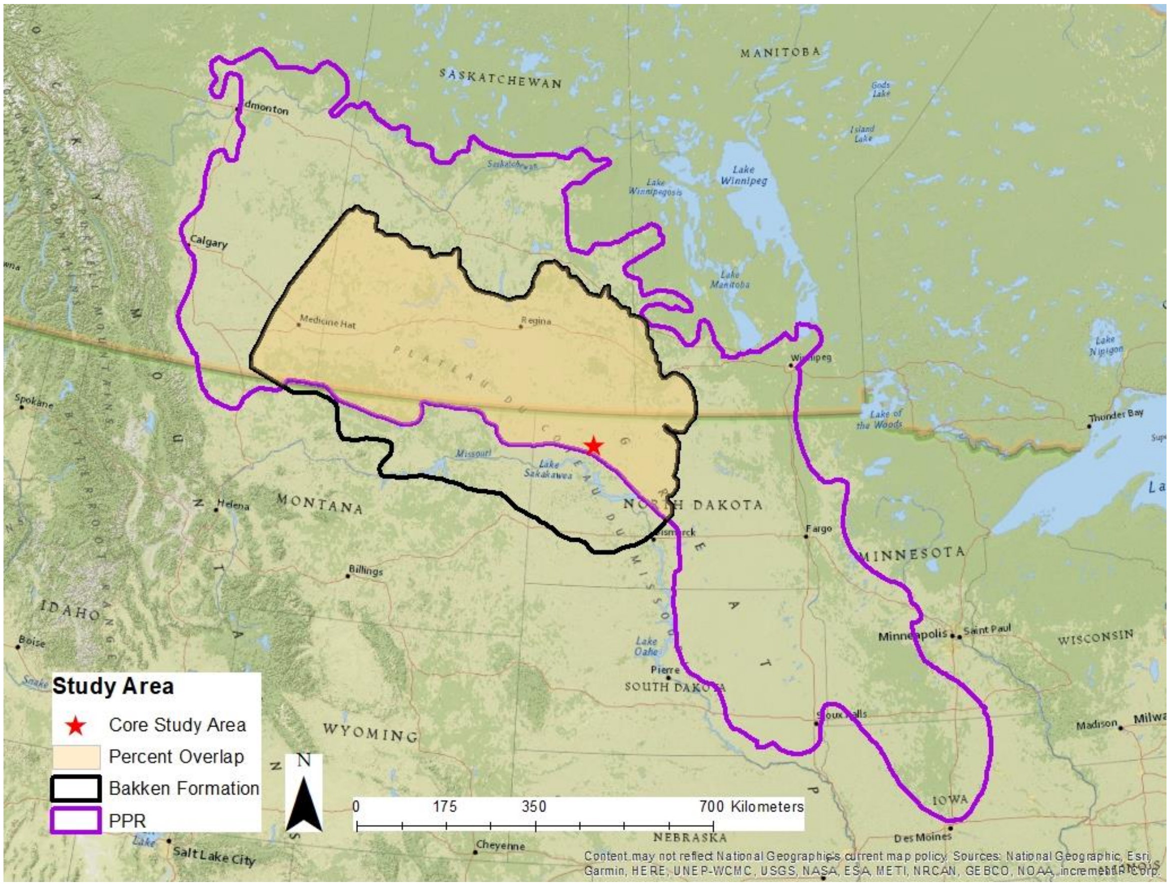

Figure 1.2. Overlap of PPR with the Bakken Shale Formation in relation to our core study area from 2015-2017. ArcGIS shapefile data was obtained from https://www.sciencebase.gov/catalog/item/54aeaef2e4b0cdd4a5caedf1 for the PPR boundary and https://www.sciencebase.gov/catalog/item/529fbb60e4b01942f4ab9f19 for the Bakken Formation extent <both accessed on September 23, 2018>.

In the 1990s, companies began to use high-pressure hydraulic fracturing and horizontal wells to access these shale deposits of oil and gas that were once unreachable due to cost (Manfreda 2015, Bohannon 2017). High-pressure hydraulic fracturing (fracking) is the process of pumping water, sand, gel and other chemicals into the well under high pressure to open perforated fissures and create channels in the reservoir rock to allow oil and gas flow outward to the well bore (Rapier 2014). The evolution of this technology coupled with horizontal drilling changed the amount of area an operator could contact underground for oil from 100 feet to 5,200 feet, thus exponentially increasing the productivity of one well (Blackmon 2013). Horizontal drilling began in the Bakken in 2000 (Jabbari 2013), however, it was not until 2008 when this began to pay dividends (Rapier 2017:201). Soaring oil demand and concomitant price increases eventually overcame the capital investment needed to drill through shale, resulting in an oil and gas boom in the Bakken region (Figure 1.3.) (Amadeo 2018).

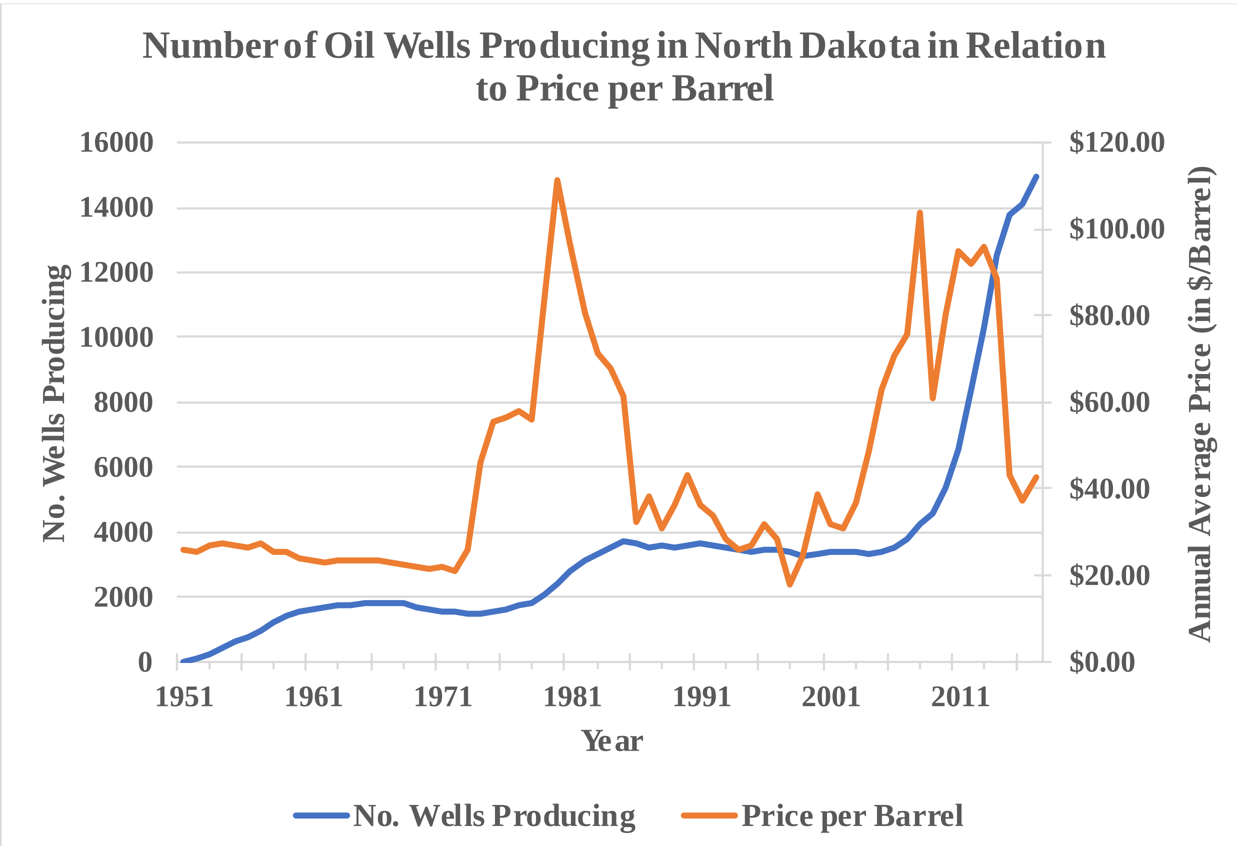

Figure 1.3. Number of wells producing in North Dakota in relation to the price per barrel of oil according to the Consumer Price Index (CPI-U). Prices are adjusted for inflation to July 2017 and represent averages for each year. Data was obtained from https://www.dmr.nd.gov/oilgas/stats/statisticsvw.asp <accessed on August 30, 2018> and https://inflationdata.com/inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp <accessed on February 10, 2019>.

During the height of the boom in 2014, the cost for a barrel of oil was over $100 and companies rushed to drill as many wells as possible (Curtis 2016). In 2008, the United States Geological Survey estimated a mean 3.65 billion barrels of oil were undiscovered and recoverable within the U.S. portion of the Bakken Formation (U.S. Geological Survey 2008). By 2013, this estimate would increase to 7.4 billion barrels (U.S. Geological Survey 2013). During

2008 in North Dakota, 4,221 wells were producing 171,949 barrels of oil a day, a record high at the time (North Dakota Industrial Commission 2017). By 2014, this number would nearly triple to 12,501 wells producing 1,088,194 barrels of oil a day (North Dakota Industrial Commission 2017). This rapid energy expansion was partly driven by the lifespan of each well which generally ran dry after two years of production (Amadeo 2018) and the two mile extent that an operator could horizontally drill out from the well (Braun C. E. et al. 2002). Oil prices began to decline in 2015 and dropped to $26.55 a barrel in January 2016 (Amadeo 2018). While this price drop slowed the drilling pace, it did not stop completely. Operators became more efficient and the cost to drill and complete a well dropped from $9 million to $5 million in 2016 (Curtis 2016). Operators continued to perfect techniques to cut costs while thousands of drilled, uncompleted wells waited for the market to rebound. By summer 2017, prices were up and the "Bakken Shale Boom 2.0" had begun (Rapier 2017) thus signaling the cycle would continue for the foreseeable future in the Bakken formation.

While the boom and bust cycle of the petroleum industry can be predicted from the price of oil, the potential effects of the boom and subsequent bust years on wildlife resources is less clear. During this Bakken boom, the space and infrastructure required for fracking and horizontal drilling began to convert millions of hectares in the PPR to an industrialized landscape (Allred et al. 2015). This drastic change is of particular interest for an area as important as the PPR. Thirty percent of the PPR overlaps the Bakken shale formation (Figure 1.2.) and has the potential to impact an estimated 9 million breeding waterfowl in an average production year (Casey et al. 2005). In addition, North Dakota has the largest number of breeding ducks in the contiguous USA (Dyke et al. 2010) and between 2015-2017, supported 3.31 million breeding waterfowl on average (North Dakota Game and Fish Department 2016, 2017).

While potential oil and gas development effects to waterfowl populations in the PPR is unknown, multiple studies have addressed the effects of oil and gas extraction on a variety of wildlife species such as Greater Sage-Grouse (*Centrocercus urophasianus)* (Braun C. E. et al. 2002, Doherty et al. 2008, Harju et al. 2010, Taylor et al. 2013), Sharp-tailed Grouse (*Tympanuchus phasianellus*) (Burr et al. 2017), passerines (Gilbert and Chalfoun 2011, Hamilton et al. 2011, Mutter et al. 2015, Thompson et al. 2015, Nenninger and Koper 2018), Pronghorn (*Antilocapra americana*) (Christie et al. 2015), Mule Deer (*Odocoileus hemionus*) (Ciuti et al. 2014, Kolar et al. 2015), and White-tailed Deer (*Odocoileus virginianus*) (Moratz 2016). Based on these studies, potential impacts on waterfowl include direct and indirect effects such as habitat fragmentation and loss, area avoidance, noise and light pollution, changes in predator/prey dynamics, direct mortality, and time lag effects on avian breeding ecology.

Habitat fragmentation and loss of grasslands and wetlands can occur directly through the construction of infrastructure (well pads, equipment lots, roads, powerlines, etc.) and indirectly through increased noise and vehicle disturbance at well sites. In Wyoming, Hethcoat and Chalfoun (2015*a*) investigated how landscapes change when well density increases. They calculated how the addition of wells contributes to absolute habitat loss, the amount of edge, patch shape complexity, and mean patch size. The most significant landscape transformation caused by the addition of wells was habitat loss within 1 km^2. This equated to an average of 1.2 (±0.6 SE) hectares lost for every well added per km^2 within their study area. Between 2003 to 2016, in the grasslands of western North Dakota, Bohannon (2017) found that on average the amount of grassland area directly impacted (i.e. Total study area - all development and roads) by oil and gas development increased by 12%. In addition, mean patch size decreased by 1.13% and the total perimeter and edge density increased by 2.73% each. In high waterfowl density areas of

North Dakota, construction of each well pad resulted in approximately 1.62 hectares of habitat loss with an additional 4,785 hectares of upland nesting cover projected to be lost by 2020 (Dyke et al. 2010). This estimate only included well pads and does not include the 1,591 hectares of nesting cover already lost in high duck density areas near isolated wetlands. Lastly, Shaffer et al. (2019) found that of the remaining grassland-bird habitat in the PPR in 2014, that 19% (2.1 million ha) was degraded by crop production within 0.1 km of grassland habitat and energy production degraded an additional 16% (1.9 million ha).

Biological effects from this type of habitat loss varied by analytical approach and species. In Wyoming, while Sage Thrasher (*Oreoscoptes montanus*) nest survival was uniform in relation to well density, nest survival decreased by 3.2% for every hectare lost within 1 km^2 (Hethcoat and Chalfoun 2015*a*). This suggests variation in drill pad sizes and the number of wells drilled per pad can drive demographic effects more strongly than analyses of well density alone. Habitat fragmentation in western North Dakota, had mixed results on grassland passerines including decreased average populations for the Sprague's Pipit (*Anthus spragueii*) and Vesper Sparrow (*Pooecetes gramineus*) (Bohannon 2017). Small, fragmented parcels may be avoided by some species (Dyke et al. 2010), and a high proportion of edge habitat can make nests more susceptible to predators (Batáry and Baldi 2004).

Furthermore, multiple studies have documented area avoidance of various avian species due to oil and gas activity and infrastructure of otherwise suitable habitat. In North Dakota, Thompson et al. (2015) found that grassland songbirds avoided areas within 150 m of roads, 297 m of single-bore well pads, and 150 m of multi-bore well pads. This result varied by species, with Clay-colored Sparrows (*Spizella pallida*) showing little effect while Sprague's Pipit avoided areas within 350 m of single-bore well pads. This study demonstrates the potential for grassland birds to avoid suitable habitat at smaller spatial scales and with differing types of oil and gas disturbance (i.e. secondary roads and single or multi-bore well pads). Beyond passerines, in Wyoming and Montana, Doherty et al. (2008) found that Greater Sage-Grouse avoided energy development within a four square mile radius. In addition, Fritz (2011) reported that higher road densities led to area avoidance by sage-grouse during the breeding season, potentially due to habitat loss and increased vehicle traffic. This avoidance behavior by sage-grouse was also documented to extend into the winter months when available resources and cover are reduced (Carpenter et al. 2010).

For waterfowl, Ludlow and Davis (2018) found that nest placement of upland-nesting ducks varied with distance to wells, roads, and trails in Alberta, Canada. Specifically, Mallard and Blue-winged Teal were more likely to nest near roads and within 100 m of wells while Northern Pintails and Northern Shovelers tended to nest within 200 m of wells. Their top-ranked model for nest survival included distance to nearest infrastructure but was not well supported. While this demonstrates the potential for oil and gas infrastructure to influence waterfowl nest selection, this analysis was based on a small sample size of 138 waterfowl nests with the caveat that more waterfowl focused research was needed to fully understand the potential effects at multiple spatial scales.

In addition, anthropogenic noise and light pollution can affect wildlife behavior. Generally, noise and light pollution occur during the construction and production phases of oil and gas activity (Hays et al. 2017). Specific noise and light sources include: access road construction, site and well pad preparation, truck traffic, drilling, hydraulic fracturing, flaring, and compressor stations. Noise and light pollution can alter avian behavior and risk perception causing birds to flush more frequently, leading to a tradeoff between vigilance and parental care

(Kleist et al. 2018). Kleist et al. (2018) discovered a link between chronic anthropogenic noise and hypocorticism leading to overall negative fitness consequences for breeding birds. For waterfowl, this could lead to decreased forage intake, increased alert and escape behaviors, nest abandonment, decreased adult and brood body condition and area avoidance (Dyke et al. 2010)

Furthermore, anthropogenic sounds can disrupt a breeding bird's ability to sense their surroundings, which could make them more vulnerable to predation (Francis et al. 2012, Kleist et al. 2016). On the other hand, anthropogenic noise may drive predators away leading to changes in predator/prey dynamics that could be beneficial to avian nest survival. Francis et al. (2012) found that an increase in noise amplitude can positively influence avian nest survival through a reduction of predators in a noisy environment, and subsequently predation. However, the avian breeding community may be reduced to only those species that are more tolerant of noisy environments. In the Bakken formation of North Dakota, Burr et al. (2017) found that Sharp-tailed Grouse nests were 1.95 times more likely to succeed in areas of higher energy development than areas of lower development. In addition, he found 56.7% of nest predators were Striped Skunks (*Mephitis mephitis*) and American Badgers (*Taxidea taxus*) and those mammalian predators were 6.9 times more likely to be found in areas of minimal oil and gas activity. However, Hethcoat and Chalfoun (2015*b*) reported reduced avian nest survival for songbirds in Wyoming with an increase in energy development. The majority of the predation events for this study were a result of rodents (75%) and Hethcoat and Chalfoun (2015*b*) noted that mesocarnivores were relatively rare at their study sites. In waterfowl, the majority of nest failure (54-85%) occurs because of mammalian predation (Klett et al. 1988), so mammalian predator reduction as a result of oil and gas activity in the Bakken formation could positively influence waterfowl nest success in the PPR.

Additionally, wetland degradation and loss could contribute to lower overall capacity for breeding waterfowl in North Dakota (Dyke et al. 2010). Hydraulic fracturing can lead to increased erosion and sedimentation, increased risk to aquatic ecosystems due to chemical spills or runoff, altered biogeochemical cycling, and a reduction of surface and hyporheic water volumes (Dyke et al. 2010, Entrekin et al. 2011, Vidic et al. 2013, Burton et al. 2014, Vengosh et al. 2014). Anthropogenic sources such as tillage of grasslands can accelerate erosion, prematurely fill wetlands and degrade wetland functions (Gleason and Euliss 1998). Typical sources of sediment inputs in the PPR are from water and wind erosion from agricultural fields. However, oil and gas activity could exacerbate this even further due to the removal of vegetation for well pads and access roads (Burton et al. 2014). In Texas, Williams et al. (2008) found that in areas with steep slopes (>6%) where vegetation was removed for gas well pad development, sediment runoff was comparable to small construction sites. Generally, small construction sites larger than 0.4 hectares are required to follow US EPA regulations to minimize sediment movement into water bodies. However, a majority of prairie pothole wetlands are geographically isolated and subsequently receive fewer such legal protections (Marton et al. 2015). Furthermore, even if these wetlands were protected, the rapid nature of expansion and growth of the industry makes regulation enforcement difficult (Entrekin et al. 2011).

In North Dakota, Creuzer et al. (2016) found that the majority of oil and gas development occurs along unpaved roads and increased dust deposition during the dryer, summer months can be expected up to 80 m from the centerline of the road. While this two-year study showed minimal effects to wetlands in the short-term there is potential to impact the lifespan of the wetland over the long-term. Dyke et al. (2010) estimated that by 2020 in North Dakota, 12,552 wetland basins with permanency greater than a "seasonal" regime will have oil and gas wells within 100 m. Howden et al. (2019) demonstrated that while few prairie potholes were directly impacted by oil and gas development, the distance to development decreased on average by 400 m. This suggests higher traffic volumes near more wetlands in the future, thus further increasing the potential for sedimentation of wetlands. Anthropogenic sedimentation may also suppress primary production and alter food chain interactions (Gleason and Euliss 1998).

Another concern includes increased risks to aquatic ecosystems due to chemical spills or runoff. Mechanical failure and human error during typical fracking operations can lead to accidental leaks and spills. Fracturing liquid is a mixture of water and other chemicals used to fracture underground rock formations while produced water is the water that returns to the surface as a by-product (U.S. Environmental Protection Agency 2016), such as brine (Entrekin et al. 2011). Typically, these fracking chemical cocktails include additives such as acid to clean out the wellbore, corrosion inhibitors to prevent pipe corrosion, iron control to prevent precipitation of metal oxides, biocides for bacterial control, gelling agents to thicken water to suspend sand and surfactants to decrease surface tension for water recovery (Vidic et al. 2013).

In 2010, near Killdeer, ND, a casing burst while fracking a well resulting in the release of fracturing and formation fluids impacting a groundwater resource (U.S. Environmental Protection Agency 2016). In 2015, multiple spills of produced water containing petroleum hydrocarbons occurred in North Dakota, with the largest at 2.9 million gallons (11 million liters) from a broken pipeline. This spill resulted in increased concentrations of chloride and electrical conductivity consistent with an increase in water salinity in nearby creeks and rivers. In North Dakota and Montana, Preston et al. (2018) documented a negative broad scale response of brine contamination on macroinvertebrate community structure, however, their results suggest that invertebrates in the PPR are adapted to considerable hydrological and chemical fluctuations concluding that they are not the most sensitive indicator for brine contamination.

Altered biogeochemical cycling from oil and gas contamination could lead to decreased functionality of impacted wetlands. Due to the geographic isolation of wetlands in the PPR, pothole wetlands function as gatekeepers to filter out sediment, nutrients and pollutants from reaching larger stream networks (Marton et al. 2015, Evenson et al. 2018). Sutter et al. (2015) suggests the biggest concern is the potential for an increase in dissolved salts (mainly Cl^-) that can lead to salinization of freshwater wetlands impacting plant growth and ecosystem function. Post van der Burg and Tangen (2015) reported spatial model predictions showing localized high chloride concentrations above what would be expected in the PPR. Links to potential biogeochemical changes can be inferred from Knight et al. (1999) study on the use of treatment wetlands for petroleum effluents. Organic chemicals that include petroleum products at high concentrations can be toxic to plants and microorganisms and have differing susceptibilities to aerobic and anaerobic degradation based on the molecule weight of different petroleum chemicals. Furthermore, wetlands can absorb and bind organics to the soil making widespread cleanup of future spills difficult. For produced water from natural gas processing, produced water volume reduction is obtained through the rhizosphere with a tradeoff of increased salinity. Change in salinity and pH influence the effectiveness of the cation exchange capacity in wetland soils or sediment because binding mechanisms are occupied by sodium and hydrogen cations. In addition, high nutrients can lead to increased plant growth and elevated carbon levels. Overall, this subject is highly controversial and needs further research (Sutter et al. 2015).

Lastly, a reduction of surface and hyporheic water volumes can be expected in North Dakota. Hydraulic fracking of a single well can use 2-8 million gallons of water, and in 2012, this equated to a demand of 4.3 billion gallons for fracking in North Dakota (Horner et al. 2016). Furthermore, fracking in North Dakota results in large volumes of high salinity wastewater as compared to other shale plays thus increasing the need for brine dilution and subsequently more freshwater. This demand is estimated to be comparable to the water need created to support the flux of seasonal workers, further straining the resource. After a review of freshwater resources available and the demand, state officials and the U.S. Army Corps of Engineers concluded that groundwater stores are not sufficient. Therefore, well operators are encouraged to withdraw from surface water instead of groundwater resources with the Missouri River and Lake Sakakawea identified as the only dependable sources in North Dakota (U.S. Environmental Protection Agency 2016). This creates accessibility issues from water sources to fracking wells often leading to increased vehicle traffic and increased potential to utilize pothole surface water near wells. For waterfowl, this could equate to loss of wetland habitat and an increased risk of direct mortality from vehicles.

Direct mortality to waterfowl can occur from vehicle collisions, containment ponds (open pits containing water and oil), powerline strikes, and hydrogen sulfide poisoning (Dyke et al. 2010). Oil and gas development in the Bakken formation has substantially increased the utilization of paved and unpaved roads on the landscape increasing the risk of wildlife collisions. Spiess (2017) reported that traffic counts of 300 to 400 mean daily vehicle passes have consistently occurred on unpaved roads since the oil and gas boom began in 2007. Road rights-of-way provide nesting habitat for waterfowl (Oetting and Cassel 1971) thus creating the potential for increased direct mortality in relation to an increase in traffic volumes. In addition, Sargeant (1981) found that hen dabbling ducks were slightly more vulnerable to vehicle collisions than drakes due to nest-site selection near road rights-of-way. Furthermore, he found that most collisions occurred during the peak breeding season along surfaced roads which allow for a greater speed and increased traffic volume.

Another direct mortality concern is hydrogen sulfide (H_2S), which is a common gas by-product of oil and gas activity (Skrtic 2006). H_2S can leak routinely or accidentally from oil and gas actions such as extraction, storage, transport, or processing which can lead to acute or chronic exposure. This exposure can cause persistent physiological and neurological effects that can be lethal to humans at acute exposures above 1,000 ppm. Thus, H_2S levels are usually monitored near oil and gas infrastructure. However, for wildlife species, concentrations as low as 1 ppm could negatively affect fitness and subsequently survival for migratory birds and mammals (Lusk and Kraft 2010). Lusk and Kraft (2010) found that concentrations greater than 25 ppm can pose a risk to avian species which could affect their olfactory senses, irritate their eyes and mucus membranes, dilate blood vessels, thereby causing a startle or stress response. Due to the chemical characteristics of H_2S being heavier than air, it is possible that undetected H_2S leaks could be locally detrimental to ground nesting waterfowl hens and all waterfowl utilizing wetlands that are present in the low spots of the landscape.

Lastly, time lag and threshold effects on avian breeding ecology have occurred for species such as the sage-grouse, with population declines occurring years after energy development starts in an area (Walker et al. 2007, Doherty et al. 2010, Harju et al. 2010). Walker et al. (2007) found an average time lag between coal-bed natural gas development and sage-grouse lek disappearance of 4.1 ± 0.9 years in Wyoming and Montana. Doherty et al. (2010) also reported a time-lag response in Wyoming around four years. In addition, he calculated that sage-grouse leks were 2-5 times more likely to disappear if a threshold of twelve wells or greater per 32.2 km^2 were present. The leks that remained past this threshold showed a decline in bird abundance of 32 to 77%. Furthermore, reclaimed areas (areas no longer in use) in some instances never recover the populations they once supported, such as with the sage-grouse (Aldridge 2000, Braun C. E. et al. 2002).

While a few studies report positive effects on avian nest success, the majority of studies on oil and gas development report negative impacts on wildlife. Given the large overlap of the Bakken formation with the PPR and the potential to impact a substantial portion of the breeding population in North Dakota, I designed a two-part study to investigate the possible effects of oil and gas activity on waterfowl nesting ecology. In Chapter 2, the specific objectives were to: 1) identify potential oil and gas covariates that may influence waterfowl nest ecology, and 2) investigate the effect of these covariates on waterfowl nest success. After determining the oil and gas effects on nest success, my objectives in Chapter 3 were to investigate the effects of oil and gas development on nest density as estimated at two spatial scales: 1) a year-specific analysis of landscape-level density using survival-corrected nest densities calculated at the block level and 2) a within-replicate Monte-Carlo randomization analysis to evaluate used vs. available nest-site relationships in reference to locations of oil and gas activity. By identifying the oil and gas drivers of nest success, density, and habitat selection, this study should provide wildlife managers the capacity to predict ideal locations to conserve and invest the dollars that are raised annually for waterfowl conservation. In addition, my thesis can provide guidance for future oil and gas extraction in areas that are important for continental wildlife populations.

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CHAPTER 2. EFFECTS OF OIL AND GAS DEVELOPMENT ON WATERFOWL NEST SUCCESS IN THE BAKKEN FORMATION OF NORTH DAKOTA

2.1. Introduction

In 1986, the North American Waterfowl Management Plan (NAWMP) was created and identified the Prairie Pothole Region (PPR) as the region of highest focus and importance for dabbling ducks. Dabbling ducks are the most recognizable and widespread waterfowl in North America (U.S. Fish and Wildlife Service 1986) and the PPR is responsible for producing more than half of the continental population in an average year, even though it composes only 10% of the total waterfowl breeding area (Smith et al. 1964). The PPR is characterized by millions of depressional wetlands and vast grasslands that stretch from the northern United States into the southern portions of Canada for a total of 777,000 km^2 (Smith et al. 1964, Sloan 1972, Kantrud et al. 1989, Doherty et al. 2013).

This wetland/prairie complex provides the ideal ecosystem for breeding dabblers. The primary dabbling species found in the PPR include Mallard, Northern Pintail, Blue-winged Teal, Gadwall, and Northern Shoveler (Stewart and Kantrud 1974). All of these species are upland nesters and require nearby perennial upland cover to successfully nest in any given year (Baldassarre 2014). For the U.S. portion of the PPR, 49% of upland-nesting waterfowl breed in North Dakota (Brice et al. 2017), however, by the mid-1980s, North Dakota had lost 49% of its wetland area (971,245.5 ha) (Dahl 2014) and by 2006, 54.2% (7.2 million ha) of its grasslands (Doherty et al. 2013).

While habitat conditions are important to maintain sustainable waterfowl populations, researchers have identified multiple population parameters that are just as essential. Hoekman et al. (2002) identified the relative importance of specific vital rates to the waterfowl population growth rate (λ) for midcontinent Mallards. The vital rates with the most influence on λ were nest success and hen survival. Nest success is the probability that at least one egg hatches. Furthermore, predation was identified as the proximate factor for nest failure and hen mortality that limits population growth. Cowardin and Johnson (1979) investigated multiple management models to increase waterfowl populations and found the most effective method would be predator reduction in conjunction with cover management in an effort to increase recruitment. Klett et al. (1988) also reported that mammalian predation was the major cause of nest failure (54-85%) and nest success will vary based on predator populations and farming practices. Some common egg predators in the PPR include Red Fox (*Vulpes vulpes*), Striped Skunk, Mink (*Mustela vison*), Raccoon (*Procyon lotor*), Badger, and Franklin's Ground Squirrel (*Spermophilus franklinii*).

While these historic habitat threats to waterfowl nesting ecology have been well studied, a new threat has emerged in the PPR, modern oil and gas development. A combination of oil discovery in the Bakken shale formation and the evolution of technology such as high-pressure hydraulic fracturing and horizontal drilling (Wells 2007, Hicks 2012, Wells 2017, 2018) have led to vast landscape changes in North Dakota. Horizontal drilling began in the Bakken in 2000 (Jabbari 2013), however, it was not until 2008 when this began to pay dividends (Rapier 2017:201) resulting in an oil and gas boom in the Midwest (Amadeo 2018). By 2008 in North Dakota, 4,221 wells were producing 171,949 barrels of oil a day, a record high at the time (North Dakota Industrial Commission 2017). By 2014, the height of the boom, this number would nearly triple to 12,501 wells producing 1,088,194 barrels of oil a day (Curtis 2016, North Dakota Industrial Commission 2017).

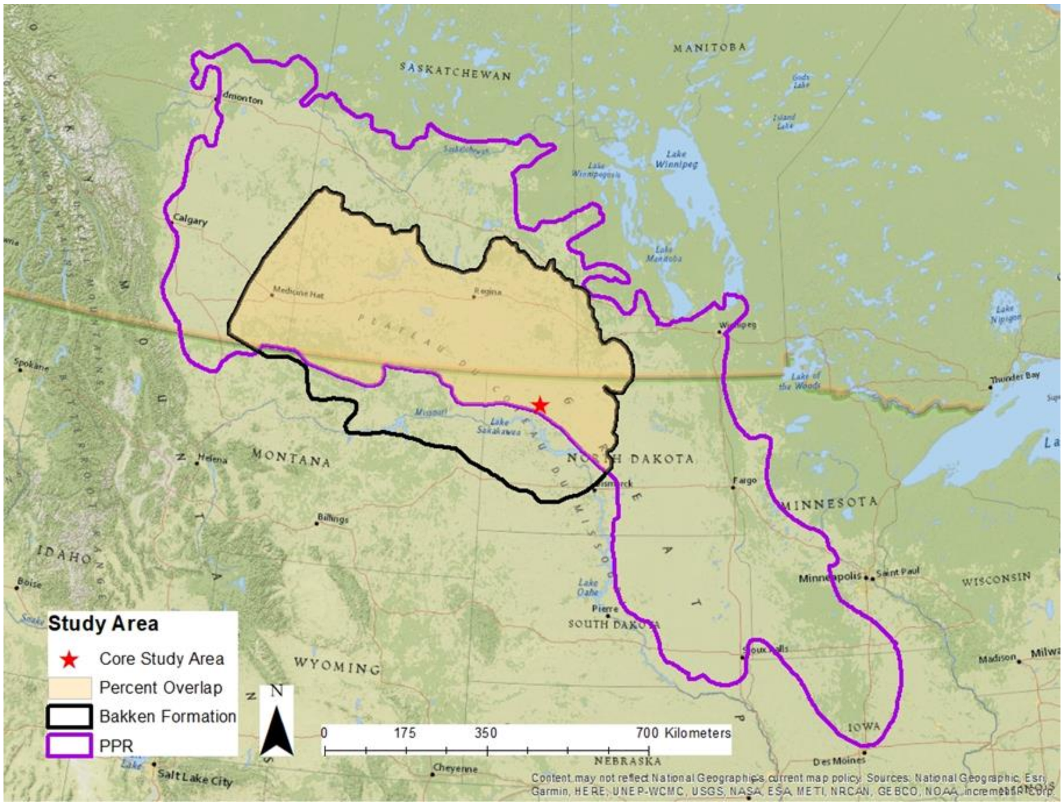

Figure 2.1. Overlap of PPR with the Bakken Shale Formation in relation to our core study area from 2015-2017. ArcGIS shapefile data was obtained from https://www.sciencebase.gov/catalog/item/54aeaef2e4b0cdd4a5caedf1 for the PPR boundary and https://www.sciencebase.gov/catalog/item/529fbb60e4b01942f4ab9f19 for the Bakken Formation extent <both accessed on September 23, 2018>.

Potential impacts of oil and gas development on waterfowl include direct and indirect effects such as habitat fragmentation and loss, noise and light pollution, area avoidance changes in predator/prey dynamics, direct mortality, and time lag effects on avian breeding ecology. Habitat fragmentation and loss of grasslands and wetlands can occur directly through the construction of infrastructure (well pads, equipment lots, roads, powerlines, etc.) and indirectly through increased noise and vehicle disturbance at well sites (Dyke et al. 2010, Hethcoat and Chalfoun 2015*a*, Bohannon 2017, Shaffer et al. 2019). Small, fragmented parcels may be avoided by some species (Dyke et al. 2010), and a high proportion of edge habitat can make nests more susceptible to predators (Batáry and Baldi 2004). In addition to terrestrial habitat loss and fragmentation, hydraulic fracturing near wetlands can lead to further degradation from erosion and sedimentation, chemical spills or runoff, altered biogeochemical cycling, and a reduction of surface and hyporheic water volumes (Dyke et al. 2010, Entrekin et al. 2011, Vidic et al. 2013, Burton et al. 2014, Vengosh et al. 2014).

Moreover, multiple studies have documented area avoidance of suitable habitat for various avian species due to oil and gas infrastructure and activity (Doherty et al. 2008, Carpenter et al. 2010, Fritz 2011, Thompson et al. 2015). In North Dakota, Thompson et al. (2015) found that grassland songbirds avoided areas within 150 m of roads, 297 m of single-bore well pads, and 150 m of multi-bore well pads. This result varied by species, with Clay-colored Sparrows (*Spizella pallida*) showing little effect while Sprague's Pipit avoided areas within 350 m of single-bore well pads. In addition, anthropogenic sounds can disrupt a breeding bird's ability to sense their surroundings, which could make them more vulnerable to predation (Francis et al. 2012, Kleist et al. 2016). On the other hand, anthropogenic noise may drive predators away leading to changes in predator/prey dynamics that could be beneficial to avian nest survival. In the Bakken formation of North Dakota, Burr et al. (2017) found that Sharp-tailed Grouse nests were 1.95 times more likely to succeed in areas of higher energy development than areas of lower development.

However, this increase in oil and gas activity and infrastructure can lead to direct waterfowl mortality from containment ponds (open pits containing water and oil), powerline strikes, vehicle collisions and hydrogen sulfide poisoning (Dyke et al. 2010, Lusk and Kraft 2010). Some studies demonstrated time lagged effects on avian breeding ecology for sage-grouse with population declines occurring years after energy development began in an area (Walker et al. 2007, Doherty et al. 2010, Harju et al. 2010). Furthermore, reclaimed areas (areas no longer in use) may never recover the populations they once supported such as with sage-grouse (Aldridge 2000, Braun C. E. et al. 2002). This suggests permanent habitat quality changes could occur in the PPR.

While a few studies report positive effects on avian nest success, the majority of studies on oil and gas development (i.e. wells and roads) report negative impacts on wildlife. Thirty percent of the PPR overlaps the Bakken shale formation (Figure 2.1.) where rapidly accelerating oil and gas development has the potential to impact approximately 9 million ducks in an average production year (Casey et al. 2005). Given this large overlap of the PPR with the Bakken formation and the potential to impact a substantial portion of the breeding population in North Dakota, my goal was to determine the possible effects of oil and gas activity on waterfowl nesting ecology. Specifically for waterfowl populations, nest success has been identified as a crucial indicator of production in the PPR (Cowardin and Johnson 1979, Klett et al. 1988, Greenwood et al. 1995). Therefore, my objectives were to 1) identify potential oil and gas covariates that may influence waterfowl nest ecology, and 2) investigate the effect of these covariates on waterfowl nest success.

2.2. Methods

2.2.1. Study Area

My study area was constrained to the overlap of the Bakken formation and PPR north of the Missouri River and west of the Souris River in northwest North Dakota, USA (Figures 2.1. and 2.2.). All survey sites were within Burke, Divide, Mountrail, Ward and Williams counties. This area is geologically classified as the Missouri Coteau and Missouri Slope and is dominated by grasslands and agriculture. Nest survey sites were selected based on grassland and wetlands present as indicated by land cover databases and aerial imagery to ensure an adequate sample of duck nests. My survey sites were selected collaboratively with the Ducks Unlimited (DU) pair and brood study. Ducks Unlimited constrained their survey areas to ≥47% perennial cover and ≥100 wetland basins (to minimize environmental variation) within four-square mile (FSM) blocks (Carrlson et al. 2018); the standard survey area for breeding pairs in the PPR (U.S. Fish and Wildlife Service 2019). To characterize oil and gas activity within these FSM blocks, DU calculated the number of well pads within FSM of the centroid of each wetland basin. To stratify these calculations into intensity categories, it was assumed that oil wells on the same well pad were one disturbance and that wells within 15.3 meters (average distance observed in 2014) of each other were on the same well pad. Intensity categories were control (no well pads within FSM of the basin centroid), low (1 well pad within FSM of the basin centroid), medium (2-3 well pads within FSM of the basin centroid), and high (>3 well pads within FSM of the basin centroid). The final classification for DU survey blocks were based on the intensity category of the majority of wetland basins on that block. 16 blocks were randomly selected per intensity category for pair and brood surveys that DU conducted in 2015, 2016, and 2017.

For my nesting research site selection, I targeted the area adjacent to at least 7 of the 16 DU blocks per an intensity category (n=28 total), with plans to search three 32-hectare replicates per block. We choose adjacent sites to limit potential influence of researcher disturbance from ATV nest drags on DU pair and brood survey blocks. Once these sites were identified, I contacted the USFWS and Department of North Dakota Trust Lands to obtain permission to survey publicly owned lands, and contacted private landowners. Final site selection was determined by verbal or written landowner permission each year.

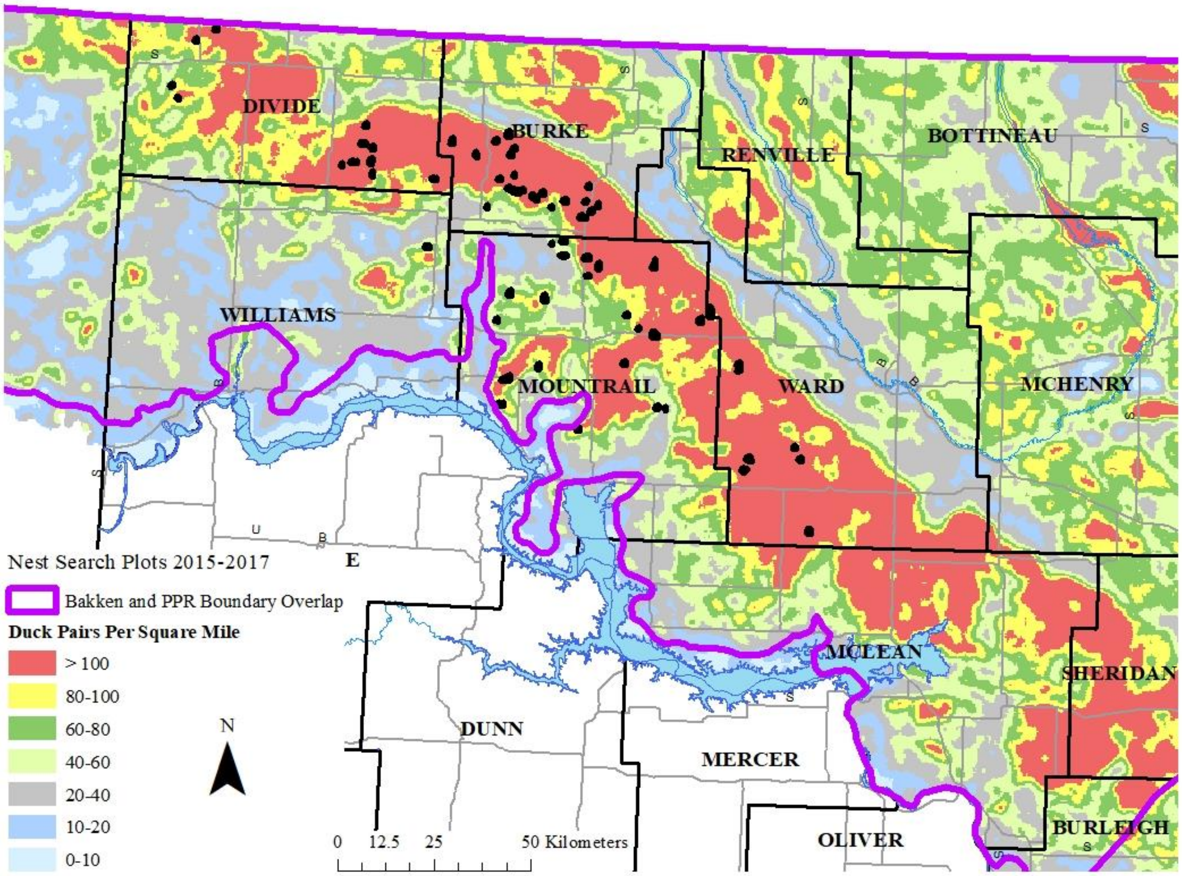

Figure 2.2. Study blocks from 2015-2017 (black dots) in relation to Prairie Pothole Region and waterfowl pair densities in the Bakken formation of northwest North Dakota. Duck pairs per square mile data obtained from the HAPET office in Bismarck, ND.

2.2.2. Field Methods

We attempted to search for nests on at least two 32-ha grassland replicates on each of the 28 plots (7 in each intensity category) during peak breeding season (late April to early July) in 2015, 2016, and 2017. Nest searches occurred during the morning hours (Gloutney et al. 1993) every three weeks using a chain-drag method (Klett et al. 1986). The chain-drag method is used to search for duck nests in grassland habitat by systematically pulling a ~60 m steel chain between two all-terrain vehicles (ATVs), subsequently flushing a hen from her nest. Once a nest was located, we flagged the vegetation 4 meters north of the nest bowl (Hein and Hein 1996) and recorded vegetation biomass (Robel et al. 1970) for the initial visit. Nests were identified to species and the eggs were counted and candled to determine incubation stage (Weller 1956) and nest initiation date. All nest locations were recorded with a GPS and revisited every 5-7 days on foot to determine nest fate, i.e. hatched or failed. Once a nest was fated, we recorded a second set of vegetation biomass measurements and estimated fate date. Nests that were found abandoned on the second visit were assumed to be influenced by investigator activity. These nests as well as nests with unknown fates were censored from the nest survival analysis. A nest was recorded as successful if ≥1 egg hatched. Other measurements recorded at the nest included number of well pads visible, active and inactive wells visible, main roads within sight, and any predation events or predator observations. All field work was completed under Louisiana State University Institutional Animal Care and Use permit #15-017, USFWS Special Use permit #2015-079M and North Dakota collecting permits: GNF03793985, GNF04051987, and GNF04337699.

2.2.3. Covariates

I identified potential oil and gas disturbance covariates based on field observations and a literature review (Table 2.1.). To estimate active wells, I downloaded monthly production reports of wells capable of producing during the peak breeding season (April to August) in 2015, 2016, and 2017 from the North Dakota Industrial Commission (NDIC) (North Dakota Industrial Commission 2018). I sorted these reports by county for the extent of my study area and aggregated monthly files to each corresponding year. I tallied the production totals for each well site and only included wells that were active for more than one day in my analysis.

I utilized the adehabitat package in program R (version 3.5.0) and ArcGIS 10.5 ModelBuilder to quantify the intensity of oil and gas development around each nest from the active well dataset. Because many of the wells in this Bakken oil data layer were not close to my replicates, I further restricted the spatial scope of my active well layer. I buffered each nest out to 5 miles, and connected the outmost edges of the total buffer using a minimum convex polygon approach. This constrained the oil and gas layer to a spatial extent relevant to my particular study sites. I then enumerated the number of wells at various distances (from 500 to 4000 meters in 500-meter increments) from each nest. Additionally, I created a landscape-level kernel density estimate (KDE) of active well density (reference bandwidth) and separated the KDE into 10% isopleths, "active.iso" (Table 2.1.). Each nest is associated with the minimum isopleth (maximum intensity) of oil and gas activity. The active.iso covariate is a quantitative and spatially continuous metric of development intensity within our sampling universe (Figures 2.3., 2.4., and 2.5.).

Finally, I quantified the distance to the nearest county road, major road, and active well in meters from each nest. County road data is maintained by the North Dakota Department of Transportation (ND DOT) and was based on original data digitized from hand drawn maps and registered to the 1:24000 USGS PLSS data for county and city roads. Subsequent updates included aerial observations and photos from the National Agriculture Imagery Program (NAIP). Major road data is also maintained by the ND DOT and is collected with GPS equipment from the centerline of the highway for interstate, US and ND highway systems. In addition, typical factors known to influence nest survival rates such as initiation date, age found, and species were also included in my final analysis (Ringelman et al. 2018). All covariates were calculated individually for each year (2015-2017) to control for potential landscape changes among field seasons.

Table 2.1. Covariate definition and data sources used in nest success analysis. Road data was obtained from https://www.dot.nd.gov/business/gis-mapping.htm <accessed on July 7, 2018> and well data was obtained from https://www.dmr.nd.gov/oilgas/mprindex.asp <accessed on July 4, 2018>.

Covariate	Description	Data Sources Used
active.iso	Isopleth based on active wells	Nest data; Active wells (NDIC)
AgeFound	Julian date when nest was found	Nest data
initiation	Julian date hen-initiated nest (one egg in nest)	Nest data
m500	Number of wells within 500m buffer of nest	Nest data; Active wells (NDIC)
m1000	Number of wells within 1000m buffer of nest	Nest data; Active wells (NDIC)
m1500	Number of wells within 1500m buffer of nest	Nest data; Active wells (NDIC)
m2000	Number of wells within 2000m buffer of nest	Nest data; Active wells (NDIC)
m2500	Number of wells within 2500m buffer of nest	Nest data; Active wells (NDIC)
m3000	Number of wells within 3000m buffer of nest	Nest data; Active wells (NDIC)
m3500	Number of wells within 3500m buffer of nest	Nest data; Active wells (NDIC)
m4000	Number of wells within 4000m buffer of nest	Nest data; Active wells (NDIC)
near.ctyrd	Distance in meters to nearest county road	Nest data; Roads (ND DOT)
near.mjrd	Distance in meters to nearest major road	Nest data; Roads (ND DOT)
near.well	Distance in meters to nearest active well	Nest data; Active wells (NDIC)
robel	Robel pole vegetation measurement in inches	Nest data
species	waterfowl species	Nest data
year	year of data collection	Nest data

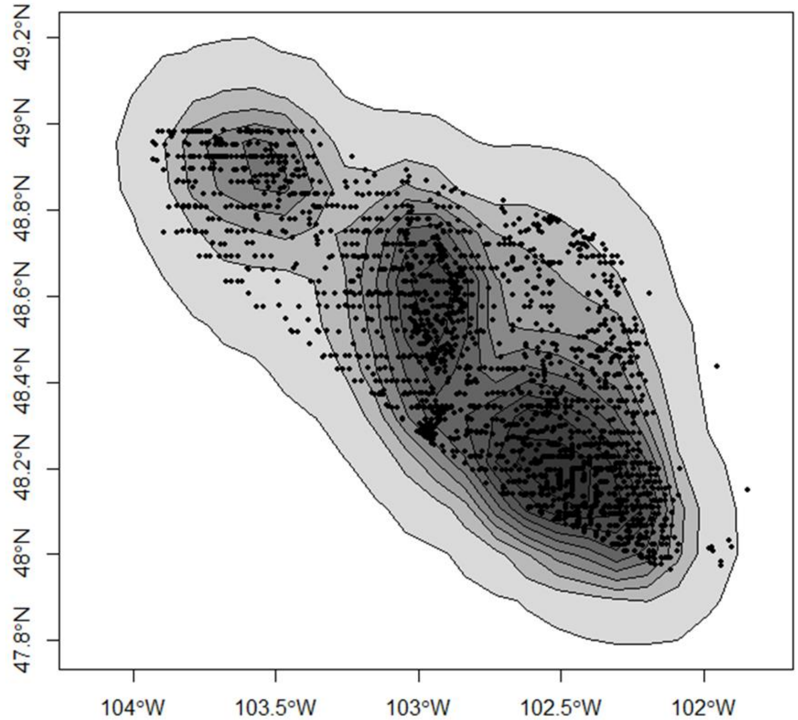

Figure 2.3. Isopleths (10% increments) in relation to active oil wells (black dots) in 2015.Darker area indicates a higher intensity of oil and gas development.

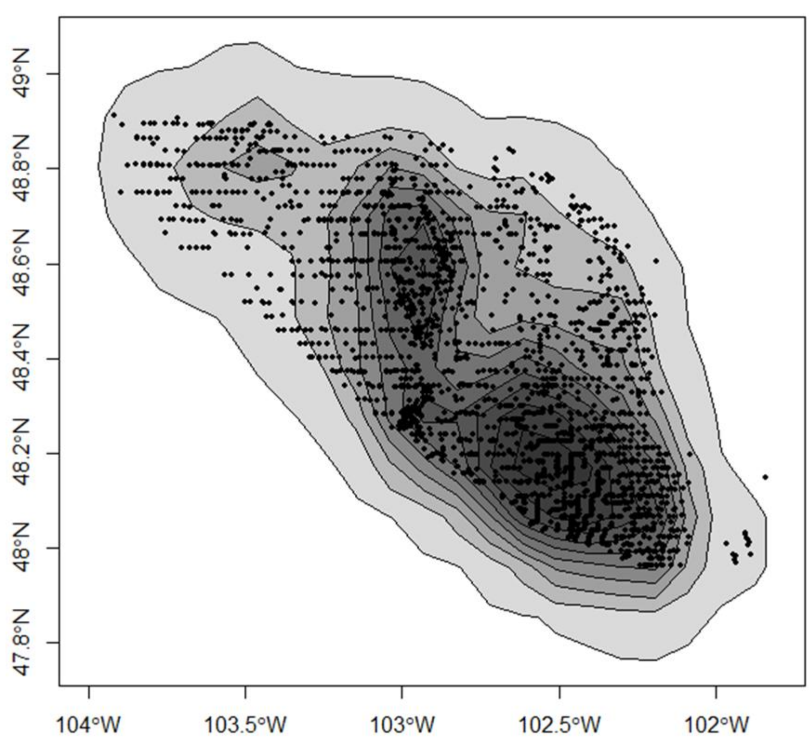

Figure 2.4. Isopleths (10% increments) in relation to active oil wells (black dots) in 2016. Darker area indicates a higher intensity of oil and gas development.

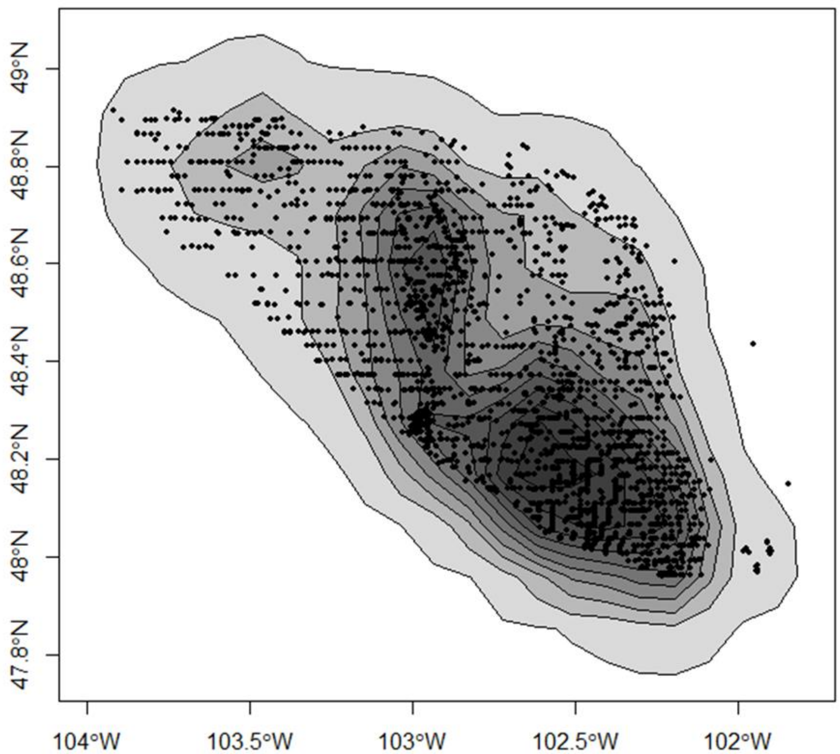

Figure 2.5. Isopleths (10% increments) in relation to active oil wells (black dots) in 2017. Darker area indicates a higher intensity of oil and gas development.

2.2.4. Nest Success Statistical Analysis

I conducted nest survival analyses (Dinsmore et al. 2002) in program MARK (White and Burnham 1999) through the RMark package (Laake 2013) and modeled daily survival rate (DSR) as a function of each covariate (Ringelman et al. 2018). RMark provides a formula-based interface to analyze capture-recapture data while reducing the development time and potential input errors from manual model creation of design matrices in program MARK (Laake 2013). RMark creates an input text file, runs program MARK to fit the model to the data and then outputs the results from program MARK in R. This allows for further interpretation and visualization of the output with various R packages. To calculate the encounter history in a live/dead format, program MARK requires the day the nest was found, the last day the nest known to be alive, the last day the nest was checked, and the fate of the nest (i.e. successful or depredated). Program MARK estimates the fate date as the midpoint between last alive and last checked for all nests. While this is reasonable for depredated nests when the true fate date is unknown, hatch date is estimable based on candling eggs in the field. Therefore, for hatched nests, I estimated the fate date based on the last incubation stage recorded and set the last present and last checked date as the same day to prevent an over estimation of exposure days. I combined all three years of data and modeled the DSR of each nest as a function of age of nest when found, nest initiation date, species, year, Robel pole measurement when the nest was found and various oil and gas metrics such as distance to nearest active oil well, county road, and major road, active oil well intensity, and number of wells at various distances (from 500 to 4000 meters in 500-meter increments) from each nest. I evaluated each model of nest survival for each parameter individually and dredged all possible combinations of the top models that were well-supported based on AICc scores (Johnson and Omland 2004, Ringelman et al. 2018). Models within 2 AICc units with additional parameters when compared to other models were considered uninformative (Arnold 2010). All nest survival analyses were calculated in R (version 3.5.0).

2.3. Results

2.3.1. Nest Data Collection

From 2015 to 2017, we searched for nests on 8,657 hectares across five counties and found 4,774 duck nests (Figures 2.6., 2.7., 2.8., Tables 2.2. and 2.3.). By order of abundance, Blue-winged Teal, Gadwall and Mallard species made up 75% of nests found. Other species included Northern Shoveler, Northern Pintail, Lesser Scaup (*Aythya affinis*), American Wigeon (*Mareca americana*), Green-winged Teal (*Anas carolinensis*), Canvasback (*Aythya valisineria),* and Redhead (*Aythya americana*) species in decreasing order of abundance.

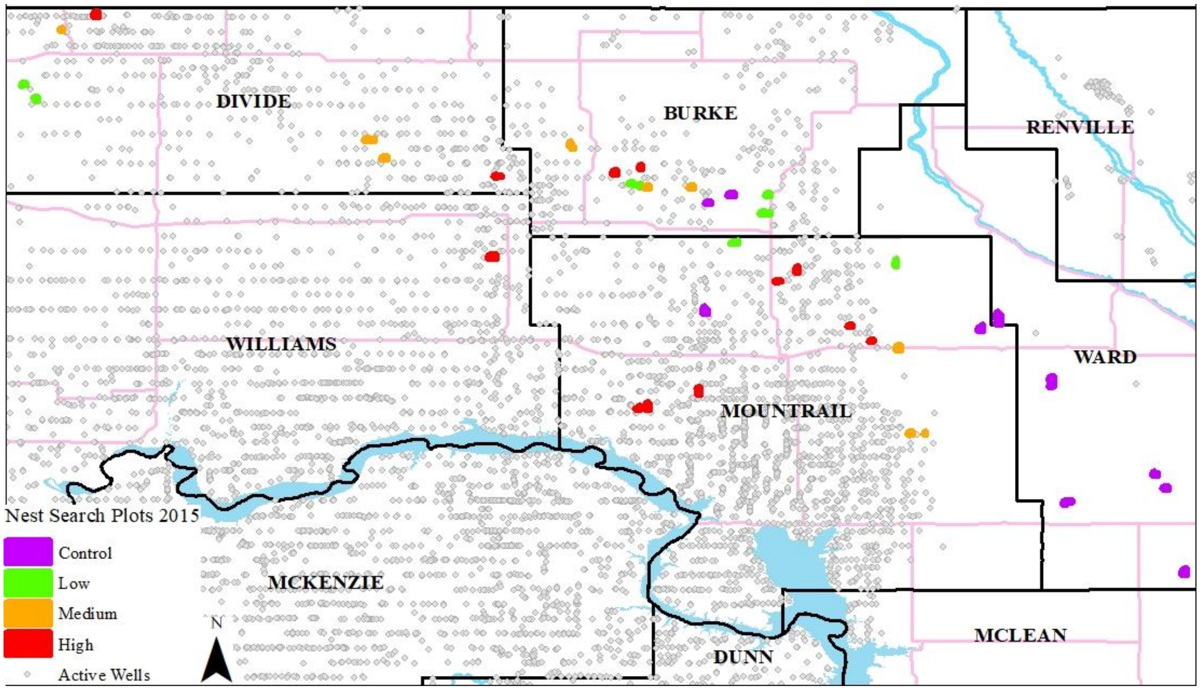

Figure 2.6. Study plots in relation to active wells in 2015, enlarged for visibility and zoomed in to core survey area. Intensity categories were control (no well pads), low (1 well pad), medium (2-3 well pads), and high (>3 well pads).

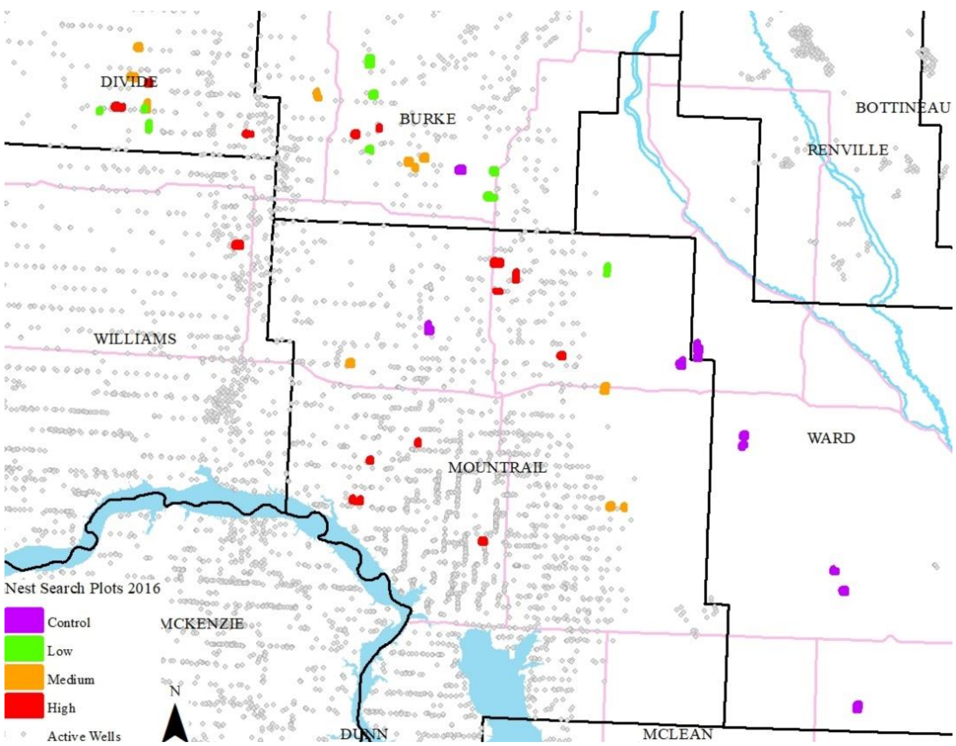

Figure 2.7. Study plots in relation to active wells in 2016, enlarged for visibility. Intensity categories were control (no well pads), low (1 well pad), medium (2-3 well pads), and high (>3 well pads).

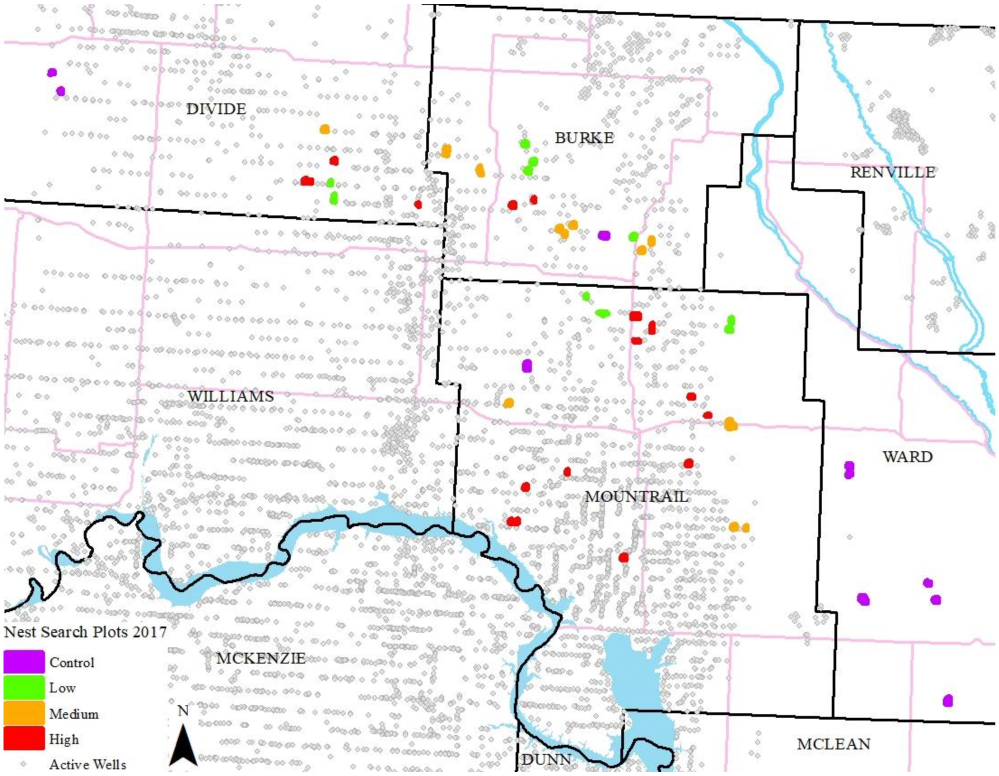

Figure 2.8. Study plots in relation to active wells in 2017, enlarged for visibility. Intensity categories were control (no well pads), low (1 well pad), medium (2-3 well pads), and high (>3 well pads).

Table 2.2. Block, replicate, number of nests and hectare totals for 2015, 2016, and 2017 field seasons.

	2015				2016				2017			
Category	Blocks	Reps	#Nests	Hectares	Blocks	Reps	#Nests	Hectares	Blocks	Reps	#Nests	Hectares
Control	7	23	498	858	8	23	333	879	6	18	254	661
Low	6	13	268	426	7	15	209	519	7	18	341	630
Medium	8	20	532	582	9	22	455	708	10	26	625	875
High	8	22	484	728	13	31	392	1004	11	24	383	787
Total	29	78	1,782	2,594	37	91	1,389	3,110	34	86	1,603	2,953

Table 2.3. Nest totals for 2015, 2016, and 2017 field seasons by duck species and abundance.

Species	2015	2016	2017	Total
Blue-winged Teal	615	367	442	1,424
Gadwall	313	394	407	1,114
Mallard	408	290	345	1,043
Northern Shoveler	151	109	143	403
Northern Pintail	168	103	102	373

(table cont'd.)

Species	2015	2016	2017	Total
Lesser Scaup	32	71	107	210
American Wigeon	73	43	40	156
Green-winged Teal	19	12	14	45
Canvasback	0	0	3	3
Redhead	3	0	0	3
Total	1,782	1,389	1,603	4,774

2.3.2. Nest Survival

Initially, I analyzed all parameters individually and ranked these values by AICc score (Table 2.4.). My top-ranked model, nearest major road (near.mjrd), showed nests found closer to interstate, US and ND highway systems had higher survival rates than nests found further away (Table 2.5. and Figure 2.9.). Specifically, near.mjrd, held 99.3% of the AICc weight (Table 2.4.). I dredged all possible combinations from the top six models based on AICc score (Table 2.5.). This resulted in considerable model uncertainty. My top model was a combination of isopleth (active.iso), age of nest when found, near.mjrd, year and species and my second top model was a combination of active.iso, age of nest when found, near.mjrd, nearest active well (near.well), year and species. However, the simplest model, a combination of age found, near.mjrd, year, and species was competitive and only differed by not including oil development parameters, active.iso and near.well. Therefore, I conclude that active.iso and near.well were uninformative parameters and my third ranked model was the most parsimonious fit to the data. In addition, models including other quantitative metrics of oil and gas development (e.g., number of wells) were highly correlated and not well supported (Table 2.7.). Furthermore, nest initiation was not a well-supported parameter in my models. Overall, survival varied by species, year and the age of the nest when found: nests found later in incubation (AgeFound) had higher survival than nests found earlier in incubation (Table 2.6. and Figure 2.10.). The most common waterfowl species found were Blue-winged Teal, Gadwall, Mallard, Northern Shoveler, and Northern Pintail species in decreasing order of abundance. All species coefficient confidence intervals bounded zero and in my univariate models held 1% of the AICc weight. Therefore, any species effect was relatively weak. I used model averaged coefficients to account for model uncertainty.

Table 2.4. Highest supported single-parameter models ranked by AIC values for all years.

Parameter	Deviance	AICc	ΔAICc	Weight
near.mjrd	-5242.1	10488.2	0.0	0.993
species	-5241.1	10498.2	10.0	0.007
year	-5254.1	10514.1	26.0	0.000
near.well	-5258.1	10520.3	32.1	0.000
AgeFound	-5258.2	10520.3	32.2	0.000
active.iso	-5261.6	10527.2	39.0	0.000
m1500	-5264.0	10532.1	43.9	0.000
m4000	-5264.3	10532.5	44.4	0.000
m2000	-5264.5	10532.9	44.8	0.000
near.ctyrd	-5264.6	10533.3	45.1	0.000
robel	-5264.7	10533.4	45.3	0.000
m2500	-5264.8	10533.5	45.4	0.000
m3000	-5264.8	10533.6	45.4	0.000
m3500	-5264.8	10533.6	45.5	0.000
m500	-5265.1	10534.3	46.1	0.000
m1000	-5265.5	10535.0	46.9	0.000
initiation	-5265.6	10535.2	47.0	0.000

Table 2.5. Model selection from top dredged models ranked by AIC value.

Parameters	Deviance	AICc	ΔAICc	Weight
active.iso+AgeFound+near.mjrd+year+species	-5201.4	10428.9	0.0	0.475
active.iso+AgeFound+near.mjrd+near.well+year+species	-5201.3	10430.7	1.8	0.191
AgeFound+near.mjrd+year+species	-5203.5	10430.9	2.0	0.170
AgeFound+near.mjrd+near.well+year+species	-5202.8	10431.6	2.7	0.121
active.iso+near.mjrd+year+species	-5205.9	10435.9	7.0	0.014
active.iso+near.mjrd+near.well+year+species	-5205.8	10437.7	8.8	0.006
active.iso+AgeFound+near.mjrd+species	-5207.9	10437.8	8.9	0.005
near.mjrd+year+species	-5208.0	10438.0	9.1	0.005
near.mjrd+near.well+year+species	-5207.3	10438.6	9.7	0.004
AgeFound+near.mjrd+species	-5209.4	10438.7	9.9	0.003
AgeFound+near.mjrd+near.well+species	-5208.7	10439.4	10.5	0.002
active.iso+AgeFound+near.mjrd+near.well+species	-5207.7	10439.5	10.6	0.002
active.iso+near.mjrd+species	-5212.5	10445.0	16.1	0.000

Table 2.6. Coefficient values for the top-ranked models of nest survival.

Parameter	Coefficient	Lower CI	Upper CI
Intercept	3.073675	3.001596	3.145754
near.mjrd	-0.000032	-0.000040	-0.000023
SpeciesAMWI	0.262112	-0.184376	0.708601
SpeciesBWTE	0.167520	-0.222686	0.557726
SpeciesGADW	0.155733	-0.236232	0.547699
SpeciesLESC	-0.060368	-0.486414	0.365678
SpeciesMALL	-0.130392	-0.522419	0.261636
SpeciesNOPI	-0.144628	-0.554460	0.265205
SpeciesNSHO	0.220995	-0.188050	0.630040
Year2016	-0.043827	-0.141439	0.053786
Year2017	0.186562	0.090085	0.283038
near.well	-0.000013	-0.000020	-0.000007
AgeFound	0.014440	0.007052	0.021828
active.iso	-0.003097	-0.005267	-0.000926
m1500	0.009678	-0.001090	0.020446
m4000	0.002109	-0.000421	0.004639
m2000	0.006353	-0.001863	0.014569
near.ctyrd	-0.000010	-0.000023	0.000003
robel	0.005189	-0.002282	0.012659
m2500	0.003658	-0.001830	0.009147
m3000	0.002714	-0.001389	0.006817
m3500	0.002095	-0.001142	0.005332
m500	0.017111	-0.017224	0.051447
m1000	0.004546	-0.012457	0.021548
initiation	0.000479	-0.002336	0.003293

Table 2.7. Coefficient values for the top-ranked models from dredge.

Parameter	Coefficient	Lower CI	Upper CI
Intercept	3.029599	2.580971	3.478227
active.iso	-0.002170	-0.004427	0.000088
AgeFound	0.011340	0.003873	0.018808
near.mjrd	-0.000028	-0.000038	-0.000018
Year2016	-0.034424	-0.133505	0.064657
Year2017	0.141340	0.041610	0.241071
speciesAMWI	0.166506	-0.283056	0.616067
speciesBWTE	0.135003	-0.256478	0.526485
speciesGADW	0.062843	-0.331599	0.457286

(table cont'd.)

Parameter	Coefficient	Lower CI	Upper CI
speciesLESC	-0.186422	-0.615557	0.242714
speciesMALL	-0.216940	-0.611131	0.177252
speciesNOPI	-0.204568	-0.616073	0.206938
speciesNSHO	0.135504	-0.275358	0.546367
near.well	-0.000003	-0.000011	0.000005

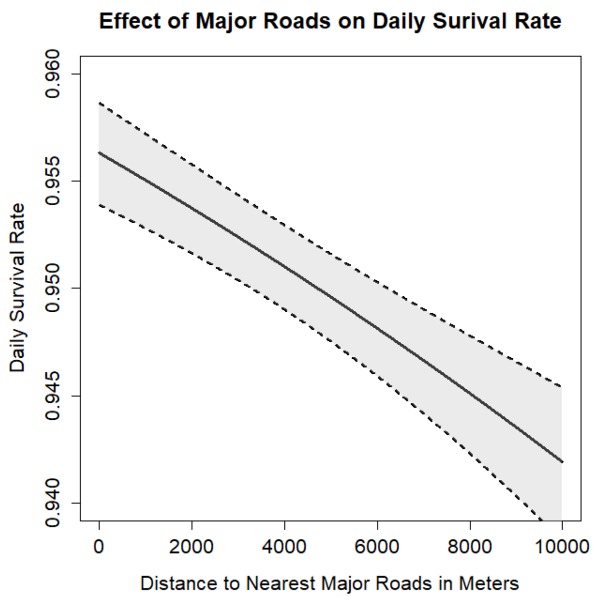

Figure 2.9. Overall nest survival in relation to distance to a major road across all species from 2015 to 2017 with upper and lower 95% confidence intervals.

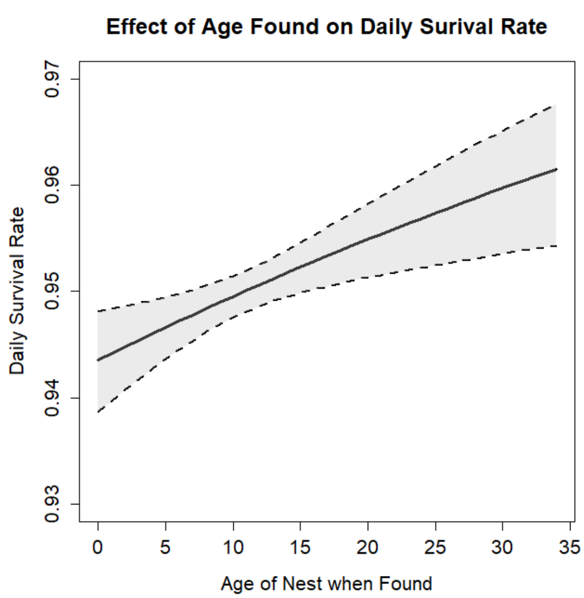

Figure 2.10. Overall nest survival in relation to age when nest found of all species from 2015 to 2017 with upper and lower 95% confidence intervals.

2.4. Discussion

The majority of studies have reported negative impacts on wildlife populations due to oil and gas activity. However, I found that typical metrics such as wells and roads did not negatively affect waterfowl nest success across multiple spatial scales (Table 2.7.). Furthermore, my top-ranked model, major roads showed a positive relationship with nest success and held 99.3% of the weight from my univariate models; nests closer to major roads had higher survival rates. Overall, survival varied by species, year and age of nest when found: nests found later in incubation (AgeFound) had higher survival than nests found earlier in incubation (Table 2.6. and Figure 2.10.).

Nest survival may have increased near major roads because increased oil and gas traffic .can lead to roadkill mortality and area avoidance of typical mammalian nest predators. Francis et al. (2012) found that an increase in noise amplitude can positively influence avian nest survival through a reduction of predators in a noisy environment, and subsequently predation. Burr et al. (2017) reported that meso-mammal predator abundances were 6.9 times less likely to be in areas of higher oil and gas intensity and suggested this could be due to the increased infrastructure, vehicle traffic and the subsequent noise associated with oil and gas development. Furthermore, Sharp-tailed Grouse nests were 1.95 times more likely to succeed in areas of higher energy development suggesting this landscape is beneficial to nest survival. Therefore, it is plausible that a reduction in predator abundance and/or area avoidance could be driving this increase in nest survival. However, another plausible explanation is a shift in predator prey selection from waterfowl to another species, such as rodents leading to an increase in nest survival. Ackerman (2002) reported a positive correlation in areas of higher rodent abundance and Mallard nest survival suggesting a rodent buffer for duck nests. This study suggests that the relationship between duck nest survival and predators depends on predator abundance, location, and behavior (i.e. how predators forage and food item preference), all factors that could be influenced by oil and gas development in my study area.

While distance to major roads increased nest survival in my study, distance to nearest county roads was not well supported within my models. This could be because there were fewer major roads than county roads and presumably made it difficult to detect if any county roads were utilized more than major roads. In my study area, there were approximately 13 major roads total within a minimum boundary of five miles from each nest as compared to 5,169 county roads. While, Spiess (2017) reported that traffic counts of 300 to 400 mean daily vehicle passes have consistently occurred on unpaved county roads since the oil and gas boom began in 2007, it is plausible that major roads are used disproportionally more because they are multi-lane paved roadways lending to greater speeds and volumes of traffic. Therefore, further research on predator/prey interactions and variable traffic patterns of both major and county roads (including surface type) of intensely developed areas are needed.

In addition, model averaged coefficients of nest survival varied by species and year. In my study, the most common waterfowl species found were Blue-winged Teal, Gadwall, Mallard, Northern Shoveler, and Northern Pintail species in decreasing order of abundance. All species coefficient confidence intervals bounded zero and in my univariate models held 1% of the AICc weight. Therefore, any species effect was relatively weak. Furthermore, nest initiation held the least amount of weight of all my models suggesting it was not an important predictor in nest success in my study. Variable nest survival by species and year is a common result in the literature due to differences in nesting chronology, habitat availability, nest site preference, and environmental variation (Klett et al. 1988, Crabtree et al. 1989, Beauchamp et al. 1996, Emery et al. 2005, Skone et al. 2016). Yearly variation was most likely due to variable spring and summer habitat conditions from 2015 to 2017. Total pond counts were variable with reported values of 6.3 million ponds in 2015, 5 million ponds in 2016 and 6.1 million ponds in 2017 (U.S. Fish and Wildlife Service 2015, 2016, 2017). Furthermore, in July 2017, North Dakota was in an extreme to exceptional drought (Lindsey 2017) in my study area which could impact late nesters such as Lesser Scaup. Total continental breeding duck populations continually dropped from 2015 to 2017 with 49.5 million in 2015, 48.4 million in 2016, and 47.3 million in 2017 (U.S. Fish and Wildlife Service 2015, 2016, 2017). In addition, Shaffer and Grant (2012) found that nest survival was rarely consistent among years, seasonally, or with age of nest.

In my study, age of nest when found was shown to be important in my top dredged model with confidence intervals that did not bound zero. Nests found later in incubation had higher survival than nests found earlier in incubation. Other studies have found similar results for Mallards (Klett and Johnson 1982, Shaffer and Grant 2012) and suggest this could be due to the presence of hens at nests (as it relates to daily mortality rate; hens flushing from nests), differences in vulnerability to predation or both (Klett and Johnson 1982). Another possibility that could influence this is the rationale that nests found at older ages are biased toward higher survival (Johnson 1979).

Overall, my study helps to determine the importance of specific oil and gas metrics (e.g. wells and roads) that may influence nest survival of waterfowl in the PPR. My analyses of nest survival indicated little detrimental effect of oil and gas development in relation to roads, wells, and intensity of development However, this does not account for possible declines in nest density or any potential area avoidance that could negatively influence waterfowl production.

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CHAPTER 3. EFFECTS OF OIL AND GAS DEVELOPMENT ON WATERFOWL NEST DENSITY AND AREA AVOIDANCE IN THE BAKKEN FORMATION OF NORTH DAKOTA

3.1. Introduction

The Prairie Pothole Region (PPR) is responsible for producing more than half of the continental waterfowl population in an average year, even though it composes only 10% of the total waterfowl breeding area (Smith et al. 1964). The PPR also overlays a valuable oil and gas shale play, the Bakken formation. Thirty percent of the PPR overlaps the Bakken shale formation and has the potential to impact an estimated 9 million breeding waterfowl in an average production year (Casey et al. 2005). In addition, North Dakota has the largest number of breeding ducks in the contiguous USA (Dyke et al. 2010) and between 2015-2017, supported 3.31 million breeding waterfowl on average (North Dakota Game and Fish Department 2016, 2017). During 2008 in North Dakota, 4,221 wells were producing 171,949 barrels of oil a day, a record high at the time (North Dakota Industrial Commission 2017). By 2014, this number would nearly triple to 12,501 wells producing 1,088,194 barrels of oil a day (North Dakota Industrial Commission 2017).

In Chapter 2, I focused on waterfowl nest survival in relation to oil and gas wells and roads and found little evidence for detrimental effects. Nevertheless, while nest success is a critical component of waterfowl population dynamics (Cowardin and Johnson 1979, Klett et al. 1988, Greenwood et al. 1995), a decrease in nest density and area avoidance could still indicate detrimental effects to waterfowl populations in the region. Studies have reported mixed results for the effects of oil and gas development on avian nest density. Gilbert and Chalfoun (2011) found that sagebrush songbird abundance in Wyoming varied by species in relation to oil and gas well density. Specifically, Brewer's Sparrow (*Spizella breweri*) and Sage Sparrow (*Amphispiza* *belli*) abundance declined while Horned Lark (*Eremophila alpestris*) abundance increased and Sage Thrasher abundance showed no response to energy development. Hamilton et al. (2011) also reported mixed results for grassland species in Alberta, Canada. Specifically, Savannah Sparrows (*Passerculus sandwichensis*) increased, Chestnut-collared Longspurs (*Calcarius ornatus*) showed no effect and Sprague's Pipit decreased in occurrence and abundance. In North Dakota, Thompson et al. (2015) found that grassland songbirds avoided areas within 150m of roads, 297m of single-bore well pads, and 150m of multi-bore well pads. This result varied by species, with Clay-colored Sparrows showing little effect while Sprague's Pipit avoided areas within 350m of single-bore well pads.

Beyond passerines, in Wyoming and Montana, Doherty et al. (2008) found that Greater Sage-Grouse avoided energy development within a four square mile radius. In addition, Fritz (2011) reported that higher road densities led to area avoidance by sage-grouse during the breeding season, potentially due to habitat loss and increased vehicle traffic. This avoidance behavior by sage-grouse was also documented to extend into the winter months when available resources and cover are reduced (Carpenter et al. 2010). Ludlow and Davis (2018) found that nest placement of upland-nesting waterfowl was actually closer to wells and roads in Alberta, Canada. Mallard and Blue-winged Teal were more likely to nest near roads and within 100m of wells while Northern Pintails and Northern Shovelers tended to nest within 200m of wells. While this demonstrates the potential for oil and gas infrastructure to influence waterfowl nest selection, this analysis was based on a small sample size of 138 waterfowl nests with the caveat that more waterfowl focused research was needed to fully understand the potential effects at multiple spatial scales.

Overall, studies have reported mixed results for avian abundance, and area avoidance in response to oil and gas development. Additionally, some studies only used well density as an indicator of oil and gas impacts potentially erroneously reporting no effect on avian populations. Therefore, in chapter 3, I included more oil and gas production covariates and habitat metrics to diagnose potential effects of both oil and gas development extent and intensity. I evaluated nest density and area avoidance at two spatial scales: 1) survival-corrected nest densities calculated at the block level (four square miles) and 2) a comparison of oil and gas covariates at used vs. available nest sites at the replicate level (32 ha).

3.2. Methods

Study area and field protocols were identical to chapter two. In chapter two we censored nests that were abandoned because of researcher disturbance, but because those nests do reflect a habitat selection decision, I re-included them in analyses for chapter 3.

3.2.3. Covariates

For this chapter, I ran two separate analyses to determine the potential effects of oil and gas activity at the block and replicate scale and subsequently had different covariate descriptions. First, common to both, I identified potential oil and gas disturbance covariates based on field observations and a literature review (Table 3.1. and 3.2.). To estimate active wells, I downloaded monthly production reports of wells capable of producing during the peak breeding season (April to August) in 2015, 2016, and 2017 from the North Dakota Industrial Commission (NDIC) (North Dakota Industrial Commission 2018). I tallied the production totals for each well site and only included wells that were active for more than one day in my analysis. I sorted these reports by county for the extent of my study area and aggregated monthly files to each corresponding year.

For the block density covariates (Table 3.1.), I utilized the adehabitat package in program R (version 3.5.0) and ArcGIS 10.5 ModelBuilder to quantify the intensity of oil and gas development for each replicate's centroid from the active well dataset. Because habitat can strongly influence nest density, I included number of wetland basins, basin hectares, and percent grassland within FSM of each centroid in my models. The upland habitat data was obtained from the HAPET office in Bismarck, ND and included 2011 HAPET landcover data, 2016 USDA cultivated land layer, and USDA FSA CRP data with an expiration date greater than 2018. Wetland data was obtained from the National Wetlands Inventory (NWI) database maintained by the USFWS. Then, I quantified the distance to the nearest county road, major road, and active well in meters from each centroid. Finally, density is a metric of the number of duck nests per hectare aggregated at the block level to achieve sufficient sample sizes for analysis. All covariates were calculated from each replicate centroid and then averaged by block for each year (2015-2017) to eliminate potential variation between field seasons. For within-replicate area avoidance covariates (Table 3.2.), methodology was similar, however, each calculation was from the nest instead of the replicate centroid and was not pooled to the block level.

Table 3.1. Covariate definition and data sources used in block density analysis (Please note initial calculations were from each replicate's centroid and then averaged to represent the block.). Road data was obtained from https://www.dot.nd.gov/business/gis-mapping.htm <accessed on July 7, 2018> and well data was obtained from https://www.dmr.nd.gov/oilgas/mprindex.asp <accessed on July 4, 2018>.

Covariate	**Description**	**Analysis**	**Data Sources Used**
active.iso	Isopleth based on active wells	R	Nest data; Active wells (NDIC)
basin.acres	Wetland acreage within 4mi^2 of centroid	ArcGIS	NWI (USFWS)
density	Nests per hectare (Arnold et al. 2007)	-	Nest data
near.well	Distance in meters to nearest active well	ArcGIS	Nest data; Active wells (NDIC)
near.ctyrd	Distance in meters to nearest county road	ArcGIS	Nest data and Roads (ND DOT)
near.mjrd	Distance in meters to nearest major road	ArcGIS	Nest data and Roads (ND DOT)

(table cont'd.)

Covariate	Description	Analysis	Data Sources Used
m500	No. wells within 500m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m1000	No. wells within 1000m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m1500	No. wells within 1500m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m2000	No. wells within 2000m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m2500	No. wells within 2500m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m3000	No. wells within 3000m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m3500	No. wells within 3500m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
m4000	No. wells within 4000m buffer of centroid	ArcGIS	Nest data; Active wells (NDIC)
No. Basins	No. wetlands within $4mi^2$ of centroid	ArcGIS	NWI (USFWS)
Per.grass	Percent grass within $4mi^2$ of centroid	ArcGIS	Landcover data (HAPET)
Total.Days	Number of days the well-produced	-	Prod. reports (April-August); NDIC
Total.Flared	amount of gas flared in million cubic feet	-	Prod. reports (April-August); NDIC
Total.Gas	amount of gas in million cubic feet	-	Prod. reports (April-August); NDIC
Total.GasSold	gas sold in million cubic feet	-	Prod. reports (April-August); NDIC
Total.Oil	Oil produced in barrels	-	Prod. reports (April-August); NDIC
Total.Runs	Barrels of oil sold from well	-	Prod. reports (April-August); NDIC
Total.Wtr	Water produced in barrels	-	Prod. reports (April-August); NDIC
year	year of data collection	-	Nest data

Table 3.2. Covariate definition and data sources used in area avoidance analysis at the replicate scale (Please note initial calculations were from each nest within a replicate.). Road data was obtained from https://www.dot.nd.gov/business/gis-mapping.htm <accessed on July 7, 2018> and well data was obtained from https://www.dmr.nd.gov/oilgas/mprindex.asp <accessed on July 4, 2018>.

Covariate	Description	Analysis	Data Sources Used
near.well	Distance in meters to nearest active well	ArcGIS	Nest data; Active wells (NDIC)
near.ctyrd	Distance in meters to nearest county road	ArcGIS	Nest data; Roads (ND DOT)
near.mjrd	Distance in meters to nearest major road	ArcGIS	Nest data; Roads (ND DOT)
m500	No. wells within 500m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m1000	No. wells within 1000m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m1500	No. wells within 1500m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m2000	No. wells within 2000m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m2500	No. wells within 2500m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m3000	No. wells within 3000m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m3500	No. wells within 3500m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)
m4000	No. wells within 4000m buffer of nest	ArcGIS	Nest data; Active wells (NDIC)

3.2.5. Analysis

To determine the density of duck nests at the block scale, I calculated survival-corrected nest density at the replicate level following the Arnold et al. (2007) method:

$$\text{no. estimated nests} = \frac{\text{no. nests found}}{\text{DSR}^{\text{Average age when found}}}$$

To pool these estimates to the block level, I summed all the estimated nests for replicates within a block and divided by the total area of the replicates in that block. This method was preferred over the standard Mayfield method because the sum of exposure days for nests at the replicate scale was less than 750 (Ringelman et al. 2017). Then, I combined all three years of data and used generalized linear models with a Gaussian error structure in Program R to evaluate how nest density varied with each covariate (Table 3.1.). Because many oil and gas extent variables (e.g., number wells within 1500 m and wells within 2000 m) and production variables (e.g., days operated, barrels produced) were highly correlated, I analyzed all covariates individually. Models with heavily skewed data were log transformed (+1) to meet assumptions of normality. Each model was ranked by AICc to determine which model was the best fit to the data. After initial model selection, I combined parameters from top models of well density and well production to evaluate whether well density per se or intensity of use was driving variation in nest density. Models within 2 AICc units with additional parameters when compared to other models were considered uninformative (Arnold 2010). To further investigate the top models, I reviewed each residual to determine goodness of fit, coefficients, and also tested combining highly correlated covariates (oil and gas production metrics) to limit the potential of splitting the variance.

To determine the potential area avoidance at the replicate level, I simulated nests with a random 1-1 pairing in ArcGIS 10.5 with the ‘create random points’ tool (Fritz 2011). After calculating oil and gas covariates for both real and simulated nests, I used a paired t-test in

Program R to compare mean values of oil and gas covariates to determine whether real duck nests were placed non-randomly with respect to oil and gas infrastructure. I reduced the number of covariates to nearest major road, county road, well and number of wells at various distances (from 500 to 4000 meters in 500-meter increments) commensurate with the smaller spatial scale being analyzed.

3.3. Results

3.3.1. Nest Data Collection

From 2015 to 2017, we searched for nests on 8,657 hectares across five counties and found 4,774 duck nests (Table 3.3. and 3.4.). By order of abundance, Blue-winged Teal, Gadwall and Mallard species made up 75% of nests found. Other species included Northern Shoveler, Northern Pintail, Lesser Scaup, American Wigeon, Green-winged Teal, Canvasback, and Redhead species (in decreasing order of abundance).

Table 3.3. Block, replicate, number of nests and hectare totals for 2015, 2016, and 2017 field seasons.

	2015				**2016**				**2017**			
Category	Blocks	Reps	#Nests	Hectares	Blocks	Reps	#Nests	Hectares	Blocks	Reps	#Nests	Hectares
Control	7	23	498	858	8	23	333	879	6	18	254	661
Low	6	13	268	426	7	15	209	519	7	18	341	630
Medium	8	20	532	582	9	22	455	708	10	26	625	875
High	8	22	484	728	13	31	392	1004	11	24	383	787
Total	29	78	1,782	2,594	37	91	1,389	3,110	34	86	1,603	2,953

Table 3.4. Nest totals for 2015, 2016, and 2017 field seasons by duck species and abundance.

Species	2015	2016	2017	Total
Blue-winged Teal	615	367	442	1,424
Gadwall	313	394	407	1,114
Mallard	408	290	345	1,043
Northern Shoveler	151	109	143	403
Northern Pintail	168	103	102	373
Lesser Scaup	32	71	107	210
American Wigeon	73	43	40	156

(table cont'd.)

Species	2015	2016	2017	Total
Green-winged Teal	19	12	14	45
Canvasback	0	0	3	3
Redhead	3	0	0	3
Total	1,782	1,389	1,603	4,774

3.3.2. Nest Density per block

Initially, I analyzed all oil and gas parameters individually in relation to nest density because my covariates were highly correlated. Subsequently, I combined Total.Gas, Total.Oil, Total.Wtr, and Total.Flare as a measure of intensity. In addition, Total.Days, Total.Runs, and intensity were heavily right-skewed so they were log transformed (+1) before analysis to meet assumptions of normality. To determine which oil and gas metrics were most important and at what scale these became biologically relevant, I ran multiple model combinations. Interestingly, nest density models based on number and hectares of wetland basins and percent grassland cover were not competitive. My top ranked models all indicated that the number of wells within 1500-4000m negatively influenced nest density, and all of these distance bands were competitive (Tables 3.5. and 3.6.). The number of wells within closer distance bands was poorly distributed, which is probably why they were not among top-ranked models. While all coefficient values for my top models indicated negative effects on nest density, addition of production metrics did not improve model fit. My top ranked model indicated that as the number of wells within 1500m increase, nest density (nests/ha) decreased by 3.7% for every additional well. In my dataset, the average number of wells within 1500m was 3.15, so at average levels of development, nest density would be predicted to decline by an average of 12%. This negative effect was most pronounced in the 1500 m distance band, but significant effects persisted in other bands as well (Figure 3.1.). Overall, my analyses across all oil and gas metrics appear to universally indicate a detrimental effect of oil and gas development on waterfowl nest density.

Table 3.5. Highest supported models ranked by AIC values for all years (intensity is a combination of Total.Gas, Total.Oil, Total.Wtr, and Total.Flare).

Parameters	df	Deviance	AICc	ΔAICc	Weight
1500m	3	-102.2	210.7	0.0	0.205
2500m	3	-102.4	211.0	0.4	0.171
2000m	3	-102.7	211.6	0.9	0.128
3000m	3	-103.0	212.3	1.7	0.09
4000m	3	-103.1	212.5	1.9	0.081
1500m+logTotal.Days	4	-102.1	212.7	2.0	0.074
1500m+logTotal.Runs	4	-102.2	212.8	2.1	0.071
1500m+logintensity	4	-102.2	212.8	2.2	0.069
3500m	3	-103.6	213.4	2.7	0.052
1000m	3	-104.4	215.1	4.4	0.023
logTotal.Days	3	-105.4	217.1	6.4	0.008
500m	3	-105.4	217.1	6.5	0.008
null	2	-106.6	217.3	6.7	0.007
logTotal.Runs	3	-105.6	217.5	6.8	0.007
logintensity	3	-105.9	218.0	7.4	0.005

Table 3.6. Coefficient values for the top-ranked models of nest density

Parameter	Coefficient	Lower CI	Upper CI
Intercept	1.27923	1.03569	1.52277
1500m	-0.03709	-0.06339	-0.01079
2500m	-0.02043	-0.03424	-0.00661
2000m	-0.02812	-0.04786	-0.00839
3000m	-0.01425	-0.02475	-0.00374
4000m	-0.00886	-0.01550	-0.00222
logTotal.Days	-0.01235	-0.06651	0.04181
logTotal.Runs	-0.00554	-0.04287	0.03178
logintensity	-0.00249	-0.03583	0.03085
3500m	-0.01106	-0.01995	-0.00218
1000m	-0.04440	-0.08649	-0.00232
500m	-0.12105	-0.27918	0.03707

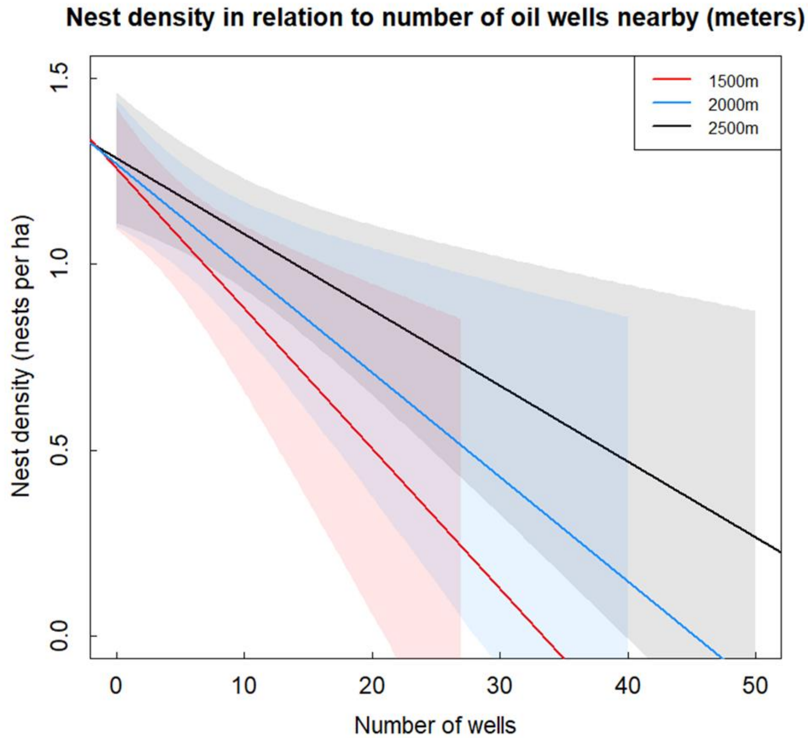

Figure 3.1. Nest density in relation to distance to active oil wells from 2015 to 2017 with upper and lower 95% confidence intervals.

3.3.3. Area avoidance per replicate

At the replicate scale, I used paired t-tests in Program R to compare oil and gas covariates calculated for real and simulated nests. If ducks were avoiding oil and gas infrastructure, I would expect lower mean levels of development at real nests as compared to simulated nests. I found that real nests were associated with fewer wells within 3000 m, more wells within 4000 m, and were closer to county roads (Table 3.7.). However, biological effect sizes were exceedingly small (e.g., 0.05 fewer wells in the 3000m distance band), and so in this case, statistical significance was likely driven by the enormous sample size of real and simulated nests. Therefore, I concluded that area avoidance at the replicate scale was not well supported based on my analysis.

Table 3.7. Pairwise comparison between real and simulated nests from 2015 to 2017.

Variable	t	df	p-value	Lower CI	Upper CI	Mean of Difference
near.well	1.1939	4586	0.2326	-3.159351	12.999525	4.920087
near.ctyrd	-2.3839	4586	0.0172	-16.486695	-1.606817	-9.046756
near.mjrd	-0.7307	4586	0.4650	-11.725878	5.358193	-3.183842
m500	0.4451	4586	0.6563	-0.028206	0.044774	0.008284
m1000	-1.2800	4586	0.2006	-0.067885	0.014255	-0.026815
m1500	-1.0572	4586	0.2905	-0.058495	0.017509	-0.020493
m2000	-0.6987	4586	0.4848	-0.049784	0.023623	-0.013080
m2500	-0.2341	4586	0.8149	-0.053139	0.041803	-0.005668
m3000	-2.3165	4586	0.0206	-0.100627	-0.008377	-0.054502
m3500	1.9139	4586	0.0557	-0.001458	0.121362	0.059952
m4000	2.2552	4586	0.0242	0.008377	0.119812	0.064094

3.4. Discussion

Based on my survival-corrected density analysis at the block level, my results indicate negative effects on nest density suggesting area avoidance. Typical habitat metrics such as number of wetland basins, wetland hectares and percent grassland cover were not competitive predictors of nest density. This suggests that oil and gas covariates are driving the negative effect and not habitat metrics. Furthermore, the addition of oil and gas production metrics and measures of intensity were not competitive nor did they improve model fit, suggesting that they were uninformative parameters. Production metrics were highly correlated and included number of days each well produced, amount of gas flared in million cubic feet, amount of gas produced in million cubic feet, gas sold in million cubic feet, oil produced in barrels, barrels of oil sold from each well, and water produced in barrels during the peak breeding season in North Dakota. This suggests that waterfowl are avoiding oil and gas infrastructure at a larger scale instead of activity associated with production such as pumping, traffic and noise. My study found evidence of area avoidance at 1500 m or greater with a reduction of nest density (nests/ha) of 3.7% for every additional well added.

Similar results were reported by Nenninger and Koper (2018) who found lower abundances of Baird's sparrows (*Ammodramus bairdii*) and Sprague's pipits (grassland songbirds) at all sites that contained oil and gas infrastructure. Furthermore, their results showed that noise, human activity, and traffic did not explain this lower abundance. In addition, ducks have been known to nest in highway rights-of-ways with a success of 57% (Oetting and Cassel 1971) suggesting some sort of tolerance for noise and traffic.

At a local scale, Thompson et al. (2015) in North Dakota, found that grassland songbirds avoided areas within 150m of roads, 297m of single-bore well pads, and 150m of multi-bore well pads. Interestingly, while I expected to see area avoidance at a similar spatial scale (e.g. 500 m or 1000 m), these models were not well supported. This could be because the average number of wells within 500 m and 1000 m were relatively low at 0.24 and 1.3 wells respectively as compared to 3.15 wells for 1500 m. This may indicate a distance or number of well threshold that negatively influences nest density. Because my distance bands are highly correlated, this negative trend continued to 4000 m (my last distance band). Furthermore, no area avoidance was detected at the replicate scale (32 ha) using a paired t-test. This result was expected because no effects were detected below 1500 m distance bands which equates to an area of 707 ha. Beyond passerines, in Wyoming and Montana, Doherty et al. (2008) found that Greater Sage-Grouse avoided energy development within a four square mile radius (1036 ha), a similar spatial scale as my results. Typical breeding home ranges for mallards in North Dakota are 307-719 ha (Zeiner et al. 1988), which aligns with an area avoidance extent of 1500 m (area of 707 ha). This suggests careful attention to wildlife breeding home ranges when determining distances and effects of any landscape disturbance such as oil and gas development.

Rapid oil and gas expansion in the Bakken formation of North Dakota continues to be of particular concern for waterfowl populations in the PPR and will be for the foreseeable future. A decrease in nest density and area avoidance indicates detrimental effects to waterfowl populations in the region. My study identifies nearby active well infrastructure at distances of 1500 m or greater as a factor that may drive waterfowl nest density and area avoidance. Further investigation is needed to determine if certain waterfowl species are more likely to avoid infrastructure at the block scale. In addition, collaborator studies on waterfowl pair densities in this region will give more insight if area avoidance is related to nest site selection or to a pair's entire breeding home range, which can include multiple wetlands across multiple kilometers. Long-term impacts on waterfowl populations will require combining datasets with pair and brood surveys to determine if oil and gas effects are detected at a population level.

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CHAPTER 4. SUMMARIES AND CONCLUSIONS

Thirty percent of the PPR overlaps the Bakken shale formation, coupled with the estimated 30 million breeding waterfowl in the PPR (Casey et al. 2005), the potential exists to impact approximately 9 million ducks in an average production year. Furthermore, multiple studies have reported negative impacts on wildlife populations due to oil and gas activity (Walker et al. 2007, Doherty et al. 2008, Carpenter et al. 2010, Harju et al. 2010, Fritz 2011, Christie et al. 2015, Hethcoat and Chalfoun 2015*a*, *b*, Thompson et al. 2015). My study helps to determine the importance of specific oil and gas metrics that may influence waterfowl nest survival, nest density, and area avoidance of oil and gas development in the PPR.

Typical metrics such as number of wells and roads did not negatively affect waterfowl nest success across multiple spatial scales including nearest distance analysis and number of wells within buffers of 500m - 4000m (500m increments). Furthermore, distance to major roads was related to an increase in nest survival. Increased traffic along major roadways leading to mammalian predator avoidance or roadkill mortality is a plausible explanation for this effect. However, my distance to nearest county road model was not well supported. While, Spiess (2017) reported that traffic counts of 300 to 400 mean daily vehicle passes have consistently occurred on unpaved county roads since the oil and gas boom began in 2007, it is plausible that major roads are used disproportionally more because they are multi-lane paved roadways lending to greater speeds and volumes of traffic.

While my analyses of nest survival indicated no detrimental effect of oil and gas development, my results for nest density showed that ducks avoided areas of high development at a landscape scale. My top ranked model indicated that at average levels of development, nest density declined by 12%. Although development is heterogeneous in space and time, clearly there is the potential for significant reduction in waterfowl carrying capacity where the PPR overlaps the Bakken. Area avoidance at the replicate scale was not biologically significant which suggests that ducks are more than likely influenced by oil and gas infrastructure on a landscape scale leading to area avoidance detected at 1500m or greater. Typical breeding home ranges for mallards in North Dakota are 307-719 ha (Zeiner et al. 1988). This aligns with an area avoidance extent of 1500 m (area of 707 ha). This suggests careful attention to wildlife breeding home ranges when determining distances and effects of any landscape disturbance such as oil and gas development.

Rapid oil and gas expansion in the Bakken formation of North Dakota continues to be of particular concern for waterfowl populations in the PPR and will be for the foreseeable future. While no strong impacts to nest success were detected, a decrease in nest density and area avoidance indicates detrimental effects to waterfowl populations in the region. In addition, the PPR landscape is already heavily fragmented by agriculture, and increasing land conversion and disturbance from petroleum extraction may further exacerbate deleterious effects. The availability and quality of upland nesting habitat directly influences duck nest density and success, which have been shown to ultimately drive waterfowl populations (Higgins 1977). Long-term impacts on waterfowl populations will require combining datasets with pair and brood surveys to determine if oil and gas effects are detected at a population level. Future research should include potential long-term impacts of oil and gas infrastructure, examination of reclaimed areas no longer in production, any time lag effects from brine contamination or other accidental spills, and predator/prey interactions with variable traffic patterns of both major and county roads (including surface type) of intensely developed areas. My research suggests that land managers and oil companies should try to reduce and concentrate oil and gas infrastructure along existing roads to minimize carrying capacity reduction.

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APPENDIX. ARCGIS MODELBUILDER FIGURES

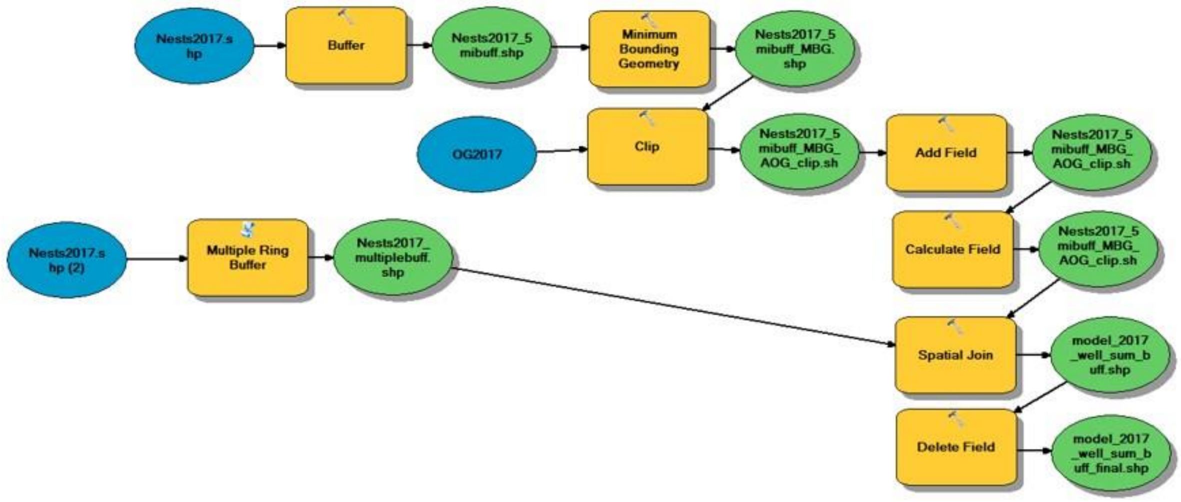

Figure A.1. ArcGIS 10.5 ModelBuilder diagram built to determine the oil and gas wells that are within 5 miles of each nest for 2017. The same methodology was used in 2015 and 2016.

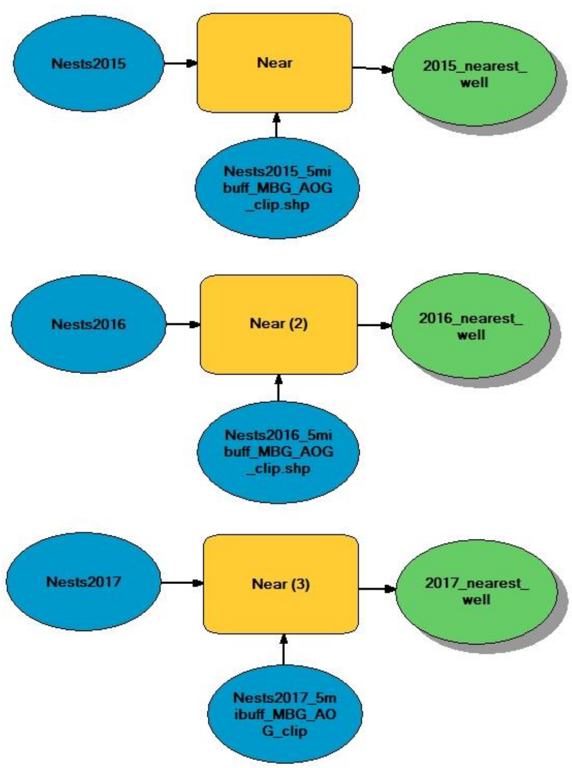

Figure A.2. ArcGIS 10.5 ModelBuilder diagram built to determine the distance to the nearest well from each nest in 2015, 2016, and 2017. The same methodology was used to determine the distance to the nearest county road and major road.

VITA

Cassandra Gail Skaggs was born in Tokyo, Japan in 1988. She graduated from the Warnell School of Forestry and Natural Resources at the University of Georgia in December 2011 with a Bachelor of Science in Forest Resources. She worked for the Georgia Legislature, the University of North Dakota, the United States Fish and Wildlife Service, and the United States Geological Survey before arriving at the School of Renewable Natural Resources at Louisiana State University. Following graduation, Cassandra plans to transition from a Career Pathways intern to a permanent, full-time employee with the United States Fish and Wildlife Service in the United States Department of the Interior at Crab Orchard National Wildlife Refuge in southern Illinois.