Habitat Fragmentation in Western North Dakota after the Introduction of Hydraulic Fracturing

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Habitat Fragmentation in Western North Dakota
after the Introduction of Hydraulic Fracturing

by

Richard R. Bohannon II

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Abstract

Western North Dakota has seen the largest boom in U.S. domestic oil production in recent history, starting just after the turn of the millennium. This study quantifies the amount of habitat fragmentation experienced since the introduction of hydraulic fracturing in the state, using the Little Missouri National Grasslands as a study area. All development in and immediately surrounding the Grasslands were digitized for successive years between 2003 and 2016, using available National Agriculture Imagery Program (NAIP) data as a primary resource. The populations of grassland bird species were used as a proxy for measuring the effects of development within the Grasslands during these same years. Results show hydraulic fracturing has had a measurable but small impact on the Grasslands overall; large portions of the Grassland have not yet seen large-scale oil development, while the northernmost portion of the Grassland has seen a substantial increase in fragmentation. Of the thirteen bird species investigated, two grassland bird species – the Sprague’s pipit (Anthus spragueii) and the vesper sparrow (Pooecetes gramineus) – decreased in average population as habitat fragmentation increases. An additional two species – western meadowlark (Sturnella neglecta) and brown-headed cowbird (Molothrus ater) – had significant regression models, but regional population trends were more significant than the amount of habitat fragmentation.

Hydraulic fracturing combined with horizontal drilling is a unique form of oil development, as oil can be extracted from surrounding areas up to two miles from each well pad; hydraulic fracturing thus can create a smaller footprint on the landscape than more conventional forms of oil extraction. This study concludes by considering the possible impact on oil development if the entirety of the Little Missouri National Grassland was designated as a roadless area, concluding the effect of a such a designation would only minimally affect the ability to extract oil from within National Grassland boundaries, while preserving important habitat.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>5</td>
</tr>
<tr>
<td>List of Figures</td>
<td>6</td>
</tr>
<tr>
<td><strong>Chapters</strong></td>
<td></td>
</tr>
<tr>
<td>1. Introduction</td>
<td>8</td>
</tr>
<tr>
<td>--- Oil Development in North Dakota’s Bakken Region</td>
<td>10</td>
</tr>
<tr>
<td>--- Prairie Landscapes and the Little Missouri National Grasslands</td>
<td>16</td>
</tr>
<tr>
<td>2. Methodology</td>
<td>25</td>
</tr>
<tr>
<td>--- Geodatabase Development</td>
<td>25</td>
</tr>
<tr>
<td>--- Fragmentation Statistics</td>
<td>31</td>
</tr>
<tr>
<td>--- Measuring Impact on Bird Populations</td>
<td>34</td>
</tr>
<tr>
<td>--- Conservation Potential</td>
<td>38</td>
</tr>
<tr>
<td>3. Results</td>
<td>41</td>
</tr>
<tr>
<td>--- Effect on Bird Populations</td>
<td>45</td>
</tr>
<tr>
<td>--- Habitat Conservation</td>
<td>49</td>
</tr>
<tr>
<td>4. Discussion</td>
<td>52</td>
</tr>
<tr>
<td>--- Impact on Bird Populations</td>
<td>52</td>
</tr>
<tr>
<td>--- Habitat Fragmentation and Conservation</td>
<td>58</td>
</tr>
<tr>
<td><strong>Works Cited</strong></td>
<td>63</td>
</tr>
</tbody>
</table>
Appendices

A. Breeding Bird Survey Population Statistics: Local Routes ....................... 72

B. Breeding Bird Survey Population Statistics: North Dakota and Montana ........................................................................................................... 73
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1. Availability of data from the North American Breeding Bird Survey (BBS) and NAIP imagery</td>
<td>37</td>
</tr>
<tr>
<td>3.1. Summary descriptive statistics showing the impact of hydraulic fracturing in the Little Missouri National Grassland</td>
<td>41</td>
</tr>
<tr>
<td>3.2. Summary descriptive statistics showing the impact of hydraulic fracturing in the northernmost patch of the Little Missouri National Grassland</td>
<td>43</td>
</tr>
<tr>
<td>3.3. Summary of regression results comparing bird population data to the developed habitat fragmentation statistics</td>
<td>46</td>
</tr>
<tr>
<td>3.4. Summary statistics showing the impact of designating the Grassland as a roadless area</td>
<td>50</td>
</tr>
</tbody>
</table>
### List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Little Missouri National Grassland</td>
<td>9</td>
</tr>
<tr>
<td>1.2</td>
<td>The Bakken shale play</td>
<td>11</td>
</tr>
<tr>
<td>1.3</td>
<td>Wells drilled in North Dakota between Jan. 2003 and Jun. 2017</td>
<td>13</td>
</tr>
<tr>
<td>1.4</td>
<td>Oil production in North Dakota, 2003-2016</td>
<td>15</td>
</tr>
<tr>
<td>1.5</td>
<td>Historic oil production in North Dakota, 1951-2016</td>
<td>15</td>
</tr>
<tr>
<td>1.6</td>
<td>Historic oil production in North Dakota and the United States, 1951-2016</td>
<td>16</td>
</tr>
<tr>
<td>1.7</td>
<td>Oil prices and North Dakota’s oil production, 2003-2017</td>
<td>16</td>
</tr>
<tr>
<td>1.8</td>
<td>Typical grassland habitat in the Little Missouri National Grassland</td>
<td>17</td>
</tr>
<tr>
<td>1.9</td>
<td>Typical badland habitat in the Little Missouri National Grassland</td>
<td>18</td>
</tr>
<tr>
<td>1.10</td>
<td>Oil well pads in the Little Missouri National Grassland</td>
<td>19</td>
</tr>
<tr>
<td>2.1</td>
<td>Example of digitization process</td>
<td>27</td>
</tr>
<tr>
<td>2.2</td>
<td>Calculation of land use over time</td>
<td>30</td>
</tr>
<tr>
<td>2.3</td>
<td>North American Breeding Bird Survey routes in North Dakota and Montana</td>
<td>36</td>
</tr>
<tr>
<td>2.4</td>
<td>Horizontal drilling paths in a northern portion of the Little Missouri National Grassland</td>
<td>39</td>
</tr>
<tr>
<td>3.1</td>
<td>The northernmost Grassland patch</td>
<td>42</td>
</tr>
<tr>
<td>3.2</td>
<td>Summary statistics showing key habitat fragmentation statistics</td>
<td>44</td>
</tr>
<tr>
<td>3.3</td>
<td>Linear regression plots showing annual oil development and its association with four habitat statistics</td>
<td>45</td>
</tr>
</tbody>
</table>
3.4. Linear regression plots for the two species with a significant association with edge density…………………………………………………………………… 47

3.5. Linear regression plots for the two species with a significant association with the overall population trend across North Dakota and Montana……………… 47

3.6. Areas currently inaccessible to hydraulic fracturing………………………… 51

3.7. Land made newly inaccessible by road if development ceased within National Grassland boundaries……………………………………………… 51

4.1. Breeding range for the Sprague’s pipit……………………………………….. 56
Chapter 1: Introduction

Western North Dakota has seen the largest boom in U.S. domestic oil production in recent history, starting just after the turn of the millennium. North Dakota’s oil boom has relied on hydraulic fracturing and horizontal drilling, a new combination of technologies (commonly called “fracking”) increasingly used for both oil and natural gas extraction. Multiple studies have considered the ecological impact of hydraulic fracturing, especially regarding water quality, but relatively few have looked at landscape effects in prairie habitats and wildlife (Souther et al. 2014).

This study quantifies the amount of habitat fragmentation experienced since the introduction of hydraulic fracturing in the Bakken region of North Dakota, using the Little Missouri National Grasslands as a study area (see Figure 1.1). All development in and immediately surrounding the Grasslands were digitized for successive years between 2003 and 2016, using available National Agriculture Imagery Program (NAIP) data as a primary resource. The populations of grassland bird species were used as a proxy for measuring the effects of development on the biological systems within the Grasslands during these same years. Results show hydraulic fracturing has had a measurable, but small, impact on the Grasslands overall; large portions of the Grassland have not yet seen large-scale oil development, while the northernmost portion of the Grassland has seen a substantial increase in fragmentation. Of the thirteen bird species investigated, two grassland bird species – the Sprague’s pipit (Anthus spragueii) and the vesper sparrow (Pooecetes gramineus) – decreased in average population as habitat fragmentation increases. An additional two species – western meadowlark (Sturnella neglecta) and brown-headed cowbird
Figure 1.1: The Little Missouri National Grassland. Map by author.
(Molothrus ater) – had significant regression models, but regional population trends were more significant than the amount of habitat fragmentation.

Hydraulic fracturing combined with horizontal drilling is a unique form of oil development, in that oil can be extracted from surrounding areas up to 3.2 km (two miles) from each well pad; hydraulic fracturing thus can create a smaller footprint on the landscape than more conventional forms of oil extraction. This study concludes by considering the possible impact on oil development if the entirety of the Little Missouri National Grassland was designated as a roadless area, concluding the effect of such a designation would only minimally affect the ability to extract oil from within National Grassland boundaries, while preserving important habitat.

**Oil Development in North Dakota’s Bakken Region**

The Bakken formation is a shale oil deposit, extending beyond western North Dakota and into eastern Montana, southeastern Saskatchewan, and southwestern Manitoba, though the overwhelming majority of current oil development lies in North Dakota (see Figure 1.2). The Bakken today rests roughly three kilometers below the current surface, and was formed during the late Devonian and early Mississippian periods (roughly 372 to 347 Mya), when this region was underwater and only 5 to 10 degrees north of the equator.

The Bakken formation incorporates three different layers. The two outermost layers are comprised of laminated mudstone (shale); the lower layer ranges from four to eighteen meters thick, while the larger, upper layer ranges from two to 6.5 meters thick. These layers were formed when the region was a shallow depression underneath a vast inland sea; the depression allowed organic material (primarily algae) in the sea to accumulate in an anaerobic environment.
The third layer (the Middle Bakken) is primarily sandstone, which averages nine meters in thickness (with a maximum of 27 meters). This layer was formed during an intermediate period during which the sea level dropped significantly, causing the area to be near the water’s shore and receive more organic material and higher oxygen levels (Smith and Bustin 1998, U.S. Geological Survey 2013). A fourth and earlier layer lies beneath these three, known as the Pronghorn Member; it also the target of oil extraction but is smaller than the rest of the Bakken formation and reaches a maximum thickness of eighteen feet.

Figure 1.2: The Bakken shale play, with the Little Missouri National Grassland partially overlapping. Map by author. Source: U.S. Energy Information Administration.
The Bakken lies on top of Three Forks Formation (from the Devonian period), and is beneath the Lodgepole formation (early Mississippian), both of which also receive some attention from oil developers. Oil was originally formed in the laminated mudstone of the upper and lower Bakken layers, and then “migrated locally into low-permeability and variable-porosity reservoirs of the middle Bakken member, the Pronghorn Member of the Bakken Formation, and dolomitized units of the Three Forks Formation” (U.S. Geological Survey 2013).

Extracting the Bakken’s oil deposits is not economically feasible using conventional drilling techniques, both because the layer is thin and because it is “tight oil,” with porous rock trapping the oil. However, by traveling horizontally along the formation, rather than simply piercing through it, contemporary horizontal hydraulic fracturing techniques expose the well shaft to the target formation several thousand times more effectively than a conventional vertical well would; in order to obtain the same amount of oil by conventional means, “an operator would have to drill hundreds or thousands more wellbores”, which is economically unfeasible (Fitzgerald 2013, 1342). Because the oil is also trapped within shale rock, the target rock is then fractured in multiple stages along the shaft – e.g., starting at the furthest end of the well, and incrementally fracturing the well until its bend and vertical climb. A typical new well will now have anywhere from 8 to 40 stages of fracturing (Montgomery and Smith 2010, 27; Aguilera 2014).

The combination of hydraulic fracturing and horizontal drilling is, as Rebecca Lave and Brian Lutz have noted, “perhaps the most substantive change in the landscape and practice of energy production in the U.S. since the advent of the fossil fuel economy” (Lave and Lutz 2014, 739). Advancements in seismology that allow for more accurate estimates of the depth and
extent of target formations have also been critical (Fitzgerald 2013, 1339). It is worth noting that none of these technologies are *new* to the past 10-15 years, but rather it is both the enhancement of techniques (e.g., with seismology, a company must have a highly accurate understanding of where a formation lies in order to be able to drill horizontally through it) and the combination of tools that have allowed for the recent oil boom. This technique is still largely concentrated in the United States, though it has been deployed on a more limited scale in Australia, South Africa, several European countries, and China, and it will likely expand to other countries as future oil prices rise (Lin 2016).

**Figure 1.3:** Wells drilled in North Dakota between Jan. 2003 and Jun. 2017. One dot represents the location of one well (oil, gas, or waste water). Map by author. Sources: USGS, ND Department of Mineral Resources.
While the modern fracking boom only began roughly in the last two decades, hydraulic fracturing was first commercially used in 1949 by Halliburton and the concept itself dates back as far as the 1860’s, when nitroglycerin was used to stimulate the initial flow of wells (Montgomery and Smith 2010, 27). By the 1980’s, it was a common means of extending the life of existing conventional, vertical wells. Hydraulic fracturing began to be used to extract oil and natural gas from “tight” deposits in the 1990’s first with the Barnett Shale formation in Texas, near Fort Worth; this area has largely yielded natural gas. Fracking began in the Bakken in the early 2000’s in far eastern Montana’s Elm Coulee field, and spread to North Dakota by the middle of the decade (Fitzgerald 2015, 86-88; see Figures 1.3 – 1.7). The majority of oil development in the region lay in Montana until 2008, after which North Dakota’s fields grew much more rapidly in number through 2014; 79.5% of new well pads in U.S. side of the Williston Basin between 2000 and 2015 were in North Dakota (Preston and Kim 2016, 1515).

As can be seen most clearly in Figure 1.7, oil production in North Dakota began to gradually decline in 2015 along with falling global oil prices, following the historic high of drilling activity in December 2014. This, combined with the current lower oil prices, might be a first indication of the boom-bust cycle predicted by some (e.g., McNally and Brandt 2015), though the current “bust” has been more of a plateauing in production than a collapse. The focus of this thesis is on the effects of this growth in oil development on local habitats and bird populations; as will be described in chapters three and four, this plateauing in production corresponds with a pause in the growth of habitat fragmentation in the region.
**Figure 1.4:** Oil production in North Dakota, 2003-2016. Map by author. Source: ND Department of Mineral Resources.

**Figure 1.5:** Historic oil production in North Dakota, 1951-2016. One barrel of oil equals 42 gallons. Source: ND Department of Mineral Resources.
Figure 1.6: Historic oil production in North Dakota and the United States, 1951-2016. Sources: ND Department of Mineral Resources and U.S. Energy Information Administration.

Figure 1.7: Oil prices and North Dakota oil production, 2003-2017. Sources: ND Department of Mineral Resources and U.S. Energy Information Administration.

Prairie Landscapes and the Little Missouri National Grasslands

North American prairies have suffered extensive habitat loss. As the largest National Grassland in the country, the Little Missouri National Grassland is also the largest assortment of protected prairie habitat in the region, covering 4,181 km². It is comprised primarily of mixed-grass prairie, along with small patches of forest in badland canyon walls and the river bottoms of the Little Missouri River (see Figures 1.8 and 1.9). The Grassland boundaries themselves are
highly fragmented and pock-marked with other federal, state, and privately-owned land (see Figure 1.1), most notably including the three units of Theodore Roosevelt National Park, themselves totaling an additional 285 km².

National Grasslands are administered by the U.S. Forest Service. Like National Forests, the National Grasslands are conserved as a natural resource and, in part, for potential resource extraction. While the Grassland is not used for agriculture or commercial development, it can be used for livestock grazing and hunting. It was initially unclear if mining and fossil fuel extraction

![Figure 1.8: Typical grassland habitat in the Little Missouri National Grassland. Photo by author, June 2016.](image-url)
were allowable land uses, but in 1973 the U.S. Office of General Counsel stated National Grassland could be used for oil, gas and coal extraction (not including processing or power plants), and in 1981 this decision was solidified by an act of Congress (Olson 1997). However, about 21.3% of the Grassland (888 km²) has been set aside as roadless areas, effectively creating significant tracks of preserved wilderness in addition to the neighboring National Parks.

Figure 1.9: Typical badland habitat in the Little Missouri National Grassland, here pictured along U.S. highway 85, immediately south of Theodore Roosevelt National Park’s northern unit. Photo by author, June 2016.
The Little Missouri National Grassland lies entirely within the Williston Basin, and a majority lies within the Bakken formation (see Figure 1.2). Oil is not evenly distributed throughout the Bakken, with only some areas holding reserves that can be profitably extracted. The Grassland has thus been variably affected by oil development; the southern region has largely been untouched, while the northernmost areas have and continue to see some of the densest development in the state.

Figure 1.10: Oil well pads in the Little Missouri National Grassland, here pictured just east of Theodore Roosevelt National Park’s southern unit. Photo by author, June 2016.
Drilling from fracking occurs largely underground, reaching depths of roughly 3 km in the Bakken region, and the effects at ground level are undeniably less than some other forms of fossil fuel extraction (such as strip-mining for coal or bituminous sands). Fracking does, however, result in habitat fragmentation caused by the development of larger well pads as well as an increase in roads, pipelines, and rail lines (and an increase in traffic) to service pads and transport oil. One recent study has shown that fracking for natural gas in the Marcellus and Utica shale region of Pennsylvania, for instance, has led to widespread fragmentation in forests within the region, which together with other sources of ecological risk (especially as tied to water) form a serious threat to biodiversity (Kiviat 2013). Farwell et al. (2016) have shown interior forest songbird species in this area have been impacted within 100 meters of fracking-related development in this region, with corresponding increases in edge-habitat specialists and songbirds not averse to human development.

Isolated patches of an ecosystem (e.g., scattered and non-contiguous patches of short-grass prairie) function similarly to islands (MacArthur and Wilson 1967) – individuals within patches are unable to genetically mix with those in other patches, increasing the risk of local extirpation (Harris 1984) and forming a threat to species with narrow ranges. Native prairies themselves are endangered habitats; increasing fragmentation lowers the biodiversity of existing remnants (e.g., Koper, Mozel and Henderson 2010) and poses a “major threat” to their conservation (Roch and Jaeger 2014).

Habitat fragmentation can stem from a variety of causes, both human and non-human, and “fragmentation” is an umbrella term encompassing several different types of phenomena. It is often conflated with habitat abundance or loss, for instance, but can be seen as its own
phenomenon (Fahrig 2003). Richard Forman describes five types of fragmentation: perforation, dissection, fragmentation in the narrow sense (the creation of isolated patches), shrinkage, and attrition (1995: 407ff). Two of these types are especially relevant to fracking: the land is increasingly dissected by new roads and rail lines, and the well pads themselves form perforations throughout the landscape. While fracking generally does not create isolated patches of grassland, the divisions and perforations caused by new roads and well pads shrink the amount of core, interior habitat that is preferred by some species and increase the amount of disturbed habitat preferred by others.

This thesis focuses on the effects of fragmentation for birds, but other organisms are undoubtedly affected as well. Brehme et al. (2013) have documented the effects of roads on populations of grassland reptiles and small mammals, especially mice. While there are industry practices to re-vegetate land disturbed by fracking (Preston and Kim 2016), bare soil from well pads and roads create vectors for non-native and invasive plant species, with significantly greater populations of invasive plants seen at or near well pads compared to control sites away from well pads in the Williston Basin (Preston 2015). Larger animals can be affected as well: pronghorn (Antilocapra americana) in western North Dakota have been seen to avoid roads and most human development, though not well pads (Christie, Jensen, and Boyce 2017).

The richness and abundance of bird species are influenced by anthropogenic changes in land cover (Rittenhouse et al. 2012), and a growing number of studies show grassland bird populations are affected by habitat fragmentation. Some research has shown that the size of habitat patches matter, as well as whether shrubs or trees exist (which provide habitat for other species as well as perches for predators) (Winter et al. 2006). A study in southern Saskatchewan
showed the prevalence of edges are particularly important, and in most cases their presence held more significance than patch size (Davis 2004, 1130).

The effects of edges also vary regionally, and depend upon what forms the edge. For instance, in a study of bobolinks and savannah sparrows nesting in fields and pastures in Vermont, Alexander Keyel, et al. (2013) found that openness affected nesting sites (some birds avoid edges that impede openness, such as forest boundaries), but edges that did not disrupt openness (such as fences) had no effect on nesting sites. Research in the Bowdoin National Wildlife Refuge in central Montana (Jones and White 2012) note that predation of nests is a primary cause of nest failure in the prairie, and roads (and some other forms of edges) can increase the chances of predation in nearby areas. As the number of edges increase, their effects can also shift as they interact with each other. Porensky and Young (2013) classify three kinds of effects that happen when multiple edges exist: the effect can be strengthened (e.g., increased edge avoidance by some species), weakened, or a new effect can emerge. The effects of multiple edges were not taken into account in this study – the corresponding breeding bird data cannot be meaningfully correlated at the scale of individual well pads or roadsides – but oil wells frequently appear in local clusters of multiple well pads in near proximity, which likely creates a different edge effect(s) than that of solitary roads or well pads.

As discussed above, hydraulic fracturing has only recently been widely implemented; while the effects of habitat fragmentation are generally understood, hydraulic fracturing’s specific landscape-level effects have not been studied extensively, especially in grassland ecosystems. Davis and Robinson (2012) observe that most research on the ecological effects of hydraulic fracturing has focused on water quality issues (e.g., Gagnon et al. 2016, Gleason and
Tangen 2014); because the technology is so new large gaps exist in our knowledge of how hydraulic fracturing effects prairie ecosystems and wildlife (Souther, et al. 2014). An emerging body of work is beginning to fill this lacuna, however.

To begin with, fragmentation from fossil fuel development does not affect all grassland birds (or other animals) equally, and the effects are not always straightforward. H.J. Kalyn Bogard, for instance, has observed cattle grazing closer to natural gas wells in southwest Saskatchewan and rubbing against the adjacent fences; this shortens the grass near the wells, which would subsequently affect which birds are willing to breed there (Bogard and Davis 2014, 472). Several species appeared to avoid oil and gas infrastructure in this same study, where the density of gas wells is significantly lower than the oil wells of the Bakken; they found that some surveyed bird species increased in presence as their distance from natural wells also increased, but the relationship was weak and did not hold for all species.

Other existing studies have found no measurable effect of hydraulic fracturing on some bird species. It would appear habitat fragmentation does not affect nesting ducks in the Canadian prairie (Pasitschniak-Arts, Clark, and Messier 1998), for instance, and Hamilton et al. (2011) saw no effect on chestnut-collared longspurs (*Calcarius ornatus*) from natural gas well sites in Alberta.

Some species increase in population in the disturbed environments surrounding well pads and roads. Gilbert and Chalfoun (2011) found horned lark (*Eremophila alpestris*) increased in response to the presence of natural gas wells in Wyoming. In gas wells in Alberta, Hamilton et al. (2011) saw a rise in Savannah sparrow (*Passerculus sandwichensis*) density and Rodgers (2013) found both Savannah sparrow and western meadowlark (*Sturnella neglecta*) positively affected. More recently, brown-headed cowbirds (*Molothrus ater*), a brood parasite, have been shown to increase four-fold in abundance near oil and natural gas infrastructure in Alberta (Bernath-Plaisted, Nenninger, and Koper 2017). In the presence of roads, some prey birds and small mammals might increase in populations due to the negative effects of roads on large predators (Rytwinski and Fahrig 2013). Sharp-tailed grouse (*Tympanuchus phasianellus*) in western North Dakota, for instance, increase in abundance in areas with more intense oil and gas development, likely due to the avoidance of those same areas by predators (Burr, et al. 2017). Other predators, such as birds of prey that take advantage of perches, might increase near wells pads and adversely affect some grassland birds (Bernath-Plaisted and Koper 2017).
Chapter 2: Methodology

In order to quantify the amount of habitat fragmentation occurring in the Little Missouri National Grassland and its effect on wildlife, this thesis involved four primary methodological steps: the development of a geodatabase extending across the study area, the use of that geodatabase to develop descriptive habitat statistics, a regression analysis comparing those statistics to local and regional bird populations, and modeling the impact of a roadless designation throughout the Grassland.

Geodatabase Development

I first created a file geodatabase (built using ArcMap 10.5) containing all development within the Little Missouri National Grassland along with neighboring Theodore Roosevelt National Park, which the National Grassland envelopes (Figure 1.1). The geodatabase included well pads, private and public roads and all other observable development. Data was developed or imported into feature datasets projected into a state plane projection, modified to center on the study area with standard parallels at 47.433° N and 48.733° N and a central meridian at 103.5° W.

To define the study area more precisely, National Grassland boundaries, including roadless areas, were obtained from the U.S. Fish and Wildlife Service (https://catalog.data.gov/dataset/national-grasslands, accessed 22 October 2017), and Theodore Roosevelt National Park boundaries were obtained from the North Dakota Game and Fish Department (https://gishubdata.nd.gov/dataset/national-parks, accessed 22 October 2017). Non-roadless areas of the National Grassland were the primary focus, as development is highly restricted within the National Park and roadless areas; accordingly, where minor topological
issues existed between these three datasets, roadless area and National Park boundaries were moved to match those of the National Grassland. After correcting all topological inconsistencies, a 500-meter buffer was created around all boundaries for use in developing fragmentation statistics. A new layer was then created that combined all three datasets (Grassland, roadless, and National Park) along with the 500-meter buffer, and attributed to show whether each polygon lies within the National Grassland, a roadless area, the National Park, and/or an outside buffer.

All roads (including railroads), well pads and all other discernable human development were digitized within this study area (see Figure 2.1). Including all development, instead of only well pads and roads, was a deliberate choice considering the region’s significant economic decline before the most recent oil boom; as recently as 2006, towns in northwestern North Dakota were giving away free land to people willing to move there (Rubin 2006). It is thus reasonable to infer the overwhelming majority of new development appearing during the surveyed years, including apartments, strip malls, or gas stations, was built to meet the needs of oil companies and the influx of oil workers, or development built as a secondary effect of the oil boom’s economic impact (Weber, Geigle, and Barkdull 2014). To confine the study to infrastructure specific only to infrastructure directly related to oil development, such as well pads, would underrepresent the overall impact of the oil boom on the landscape. The exact use of infrastructure also cannot always be determined from aerial imagery without extensive ground truthing. In order to test the assumption that the overwhelming majority of development is related to the oil boom (even if only secondarily), a simple bivariate linear regression was run using several habitat statistics calculated from the developed data as the dependent variable, and
Figure 2.1: Example of digitization process. Roads and all other development, including oil well pads, were digitized within National Grassland and National Park boundaries along with a 500-meter buffer. Map by author. Imagery source: NAIP.

annual oil production (obtained from the North Dakota Department of Mineral Resources) over the same period of time as an independent variable.

However, agricultural development was not taken into account in this study, as it is not permitted within Grassland boundaries (with the exception of rangeland, which also provides habitat for some birds and other animals in the absence of bison). A review of land cover data from the National Agricultural Statistics Service (NASS), developed by the U.S. Department of
Agriculture, additionally shows minimal agricultural development on land immediately adjacent to the National Grassland.

A statewide dataset showing all public roads in North Dakota was obtained from the North Dakota Department of Transportation (ND DOT; https://gishubdata.nd.gov/search/field_topic/transportation-50, accessed 22 October 2017); this dataset was clipped to the combined boundary layer described above to form an initial basis for this project’s roads layer developed.

Existing datasets for well pads and gravel roads were not available, and these features cannot be accurately obtained using remote sensing algorithms due to the large amount of exposed soil and rock along canyon and butte walls throughout the region, which give similar reflectance values to gravel well pads and roads (Garman and McBeth 2014). Instead, all development was hand-digitized into a vector format using NAIP (National Agriculture Imagery Program) data from 2003 and 2016. NAIP provides the highest resolution of publicly available imagery during this time span. Two-meter resolution imagery is available for 2004 and 2006, 1-meter resolution imagery is available for 2003, 2005, 2009, 2010, 2012, 2014, and 0.6-meter imagery is available for 2016. 2016 is the most recent year available, and 2003 was chosen because it clearly predates the fracking boom in the Bakken.

During this process, existing road lines obtained from the ND DOT were checked for spatial accuracy against NAIP imagery and for topological consistency with the Grassland, roadless area, and National Park boundaries. Missing roads were added, as the ND DOT dataset did not include all private access roads (e.g., for well pads), and many included roads were not visible in the aerial imagery and consequently deleted. As the soil in this area is easily disturbed,
there were also multiple informal paths visible in the aerial imagery, such as might occur from off-road trucks managing livestock. Distinguishing between these paths and “true” roads is an inherently subjective task, even when viewed from the ground. Roads were included if they held a relatively consistent width in the imagery and led to a destination – i.e., they did not gradually become indistinguishable from the surrounding landscape. More importantly, any decision to include or not to include any individual questionable road was consistently held throughout all of the study years; e.g., if a road was not included in 2003, it would also not be included in subsequent years unless a clear change in appearance justified a change. As the objective of this digitization process was not to create a road network but to analyze changes in habitat fragmentation, if a minor road or path did not change in appearance over the study period, the fact that there was no change mattered more than whether or not the road was included in the final datasets.

Roads, well pads and all other development were digitized first using 2016 imagery. Attribute fields were created to designate the first year a feature appears in the imagery and, as some roads and/or unproductive well pads are later abandoned, the last year a feature appeared. A 10km x 10km lattice was created to overlay the entire study area, with a field to mark when the area covered by each 10km square had been reviewed and digitized, ensuring no gaps in the coverage. After digitization of the first year was complete, each previous year was then reviewed to demarcate new roads and development as they appeared or were abandoned (see Figure 2.2). The redundancy of this process also allowed for a level of quality control to ensure the presence or absence of features was accounted for in each surveyed year. After roads and all other development were digitized for each year, a topological check was also performed to ensure
there were no duplicate road lines in the dataset; they were then broken along Grassland, roadless area, and National Park boundaries.

Road width in the region varies between a small number of multi-lane highways, two-lane paved and gravel roads, railroads, and smaller private access roads for well pads. Divided highways, such as found on Interstate 94 as it cuts through the Grasslands and Theodore Roosevelt National Park, were originally imported from the ND DOT dataset with separate lines for different traffic directions; this distinction was maintained, as it helps to more closely approximate the highway’s width and impact. The roads for each year were buffered by 30 feet (9.3 m), a common width for a two-lane gravel road in the area, though larger than private access roads (often only 15 to 20 feet, or 5 to 6.5 m, in width) and narrower than larger highways.
After this process was complete, all development and buffered roads were merged into a single multi-part polygon feature for each year. These features were then erased from the larger study area, creating a feature class only showing each year’s intact land; the amount of directly impacted land could be calculated by simply subtracting this amount from the study area’s total area. All intact grassland features within the resulting feature class were then merged into a single feature, excluding roadless areas, National Parkland and buffers; this was necessary to eliminate edges along 500-meter buffers outside of roadless areas and Parkland. The single grassland polygon was then broken again to ensure all contiguous areas were indeed shown as contiguous (and not broken by a buffer) and were located within the same feature, and disconnected areas were located in separate features; this distinction was necessary for calculating some statistics, such as patch size and edge density. This process was repeated for each year surveyed.

**Fragmentation Statistics**

A large and growing number of metrics for determining fragmentation exist. Based in part on reviews by Wang, Blanchet, and Koper. (2014), Jaeger (2000) and statistics used within Kevin McGarigal’s FRAGSTATS software (2015) the three indices described below were used, chosen for their ability to measure fragmentation as distinct from changes in habitat abundance. The percentage of land directly impacted was included a fourth metric. Each measure was calculated independently for each year, creating a record of change in habitat fragmentation from 2003 to 2016.

- **Core Area Percentage of Landscape (CPLAND)**, where $A$ is the total landscape area and $a_{ij}^c$ is the core area of each patch, based on a pre-determined edge depth:
Multiplying by 100 converts the number to a percentage; a score of 100 indicates a patch contains 100% core area, and score of zero indicates a patch contains no core area. For this and other statistics related to patch size, the patch was defined using roads and any development along with the artificial boundaries of the Grassland itself. An isolated one-mile square of Grassland, for instance, would be considered a single “patch”, whereas an identical one-mile square bisected by a road would be considered two patches.

Importantly, Grassland boundaries were not treated as edges when deriving core areas for CPLAND. Instead, core area was defined as all land at least 150 meters away from any road, well pad, or other development. 150 meters was chosen as a proxy for key grassland species aversion, based on existing literature discussed in the previous section (especially Thompson 2015). As data was originally developed for 500 meters beyond Grassland boundaries (see Figure 2.1), roads and development immediately adjacent but outside of Grassland boundaries were included in this calculation.

By including the Grassland boundaries when calculating patch size, but not when calculating core area, it was possible to isolate the impact of development alone. When a patch of Grassland contained no development within or near its boundaries, for instance, it could be calculated to have a score of 100, or as 100% core area.

- **Edge Density** (ED), measures the amount of linear edge per area. It is derived from taking the total length (m) of edges (e) divided by the total area (A), and multiplied by 1,000,000 to convert into square kilometers.
The results indicate the number of meters of edge per km$^2$. All edges were included in this measurement, including Grassland boundaries. As Grassland boundaries remained identical across all years, changes in ED values only reflect changes in the amount of development. However, as artificial political boundaries were counted as habitat edges, these calculations should not be used for comparison with other studies.

- **Road Density** (RD), is similar to Edge Density and measures the length of roads per area. It is derived from taking the total length (m) of roads (r) divided by the total area (A), and multiplied by 1,000,000 to convert into square kilometers.

$$\text{RD} = \frac{\sum_{k=1}^{m} r_{ik}}{A} \times (1,000,000)$$

Additional descriptive statistics were calculated for the Grassland, including mean and median patch size, total undisturbed and disturbed area, and mean and median perimeter. All statistics were derived from the developed vector data using a combination of ArcMap 10.5 and Microsoft Excel 2016 (i.e., data was not converted into raster format and processed in software such as FRAGSTATS.).

For later comparison to bird populations, only statistics for the non-roadless areas of the Grassland were used. This limits the results to the area where federal law currently allows development, and thus has more potential policy implications. There were also no significant changes in roadless areas or the National Park during the covered years, as would be expected due to restrictions on development.
Measuring Impact on Bird Populations

To access the impact of habitat fragmentation on the ecology of the region, I obtained data from the North American Breeding Bird Survey (BBS; https://www.pwrc.usgs.gov/bbs), a volunteer-based program organized the USGS that began in 1966. The BBS monitors the size and range of avian populations by collecting annual surveys along fixed routes throughout the continent.

Over 4,000 set routes exist in the U.S., including 50 in North Dakota and 76 in neighboring Montana. Each individual route is 24.5 miles (40 km) long, and during every breeding season trained volunteers conduct counts in half-mile increments throughout their route, for a total of fifty stops. Surveyors stop for three minutes at each stop, and the protocol calls for including total number of individuals for each bird species seen or heard within ¼ of a mile – with the exception of killdeer, the species included in this study (see below), would all be undetectable or unidentifiable beyond this distance. The collected data allows researchers to compare routes over multiple years and see if existing species’ ranges and/or populations are contracting, expanding, or moving.

To infer the impact habitat fragmentation has had on the regional ecology of the Bakken, BBS data was extracted from the years 2003 to 2016 for thirteen species, selected because of their prevalence in existing studies and their prevalence in the landscape (the latter based on three trips between 2015 and 2017 to the region, which included extensive but informal birdwatching):

- Killdeer (Charadrius vociferous)
- Sprague's pipit (Anthus spragueii)
- Chestnut-collared longspur (*Calcarius ornatus*)
- Spotted towhee (*Pipilo maculatus*)
- Clay-colored sparrow (*Spizella pallida*)
- Field sparrow (*Spizella pusilla*)
- Vesper sparrow (*Pooecetes gramineus*)
- Savannah sparrow (*Passerculus sandwichensis*)
- Grasshopper sparrow (*Ammodramus savannarum*)
- Baird's sparrow (*Ammodramus bairdii*)
- Bobolink (*Dolichonyx oryzivorus*)
- Western meadowlark (*Sturnella neglecta*)
- Brown-headed cowbird (*Molothrus ater*)

Eleven species are grassland-specific, while field sparrows and spotted towhees are common in the trees and shrubs along canyon and butte walls in the area. Two species – the Sprague’s pipit and Baird’s Sparrow – have regionally declining populations (BirdLife International 2017), but neither are currently listed for protection under the United States’ Endangered Species Act.

Three BBS routes overlap with the Little Missouri National Grasslands (see Figure 2.3); the annual average population for each species across these three routes served as a measure for estimating the local bird population. These annual averages were then compared to the developed habitat fragmentation metrics in order to discover if any association existed between fragmentation and local bird populations.
The average number of individuals for each species was also collected for all BBS routes surveyed each year in both North Dakota and Montana, providing a larger regional snapshot of population trends and helping to understand whether changes in population along local routes are simply a reflection of larger regional trends. Because the BBS is a volunteer-based effort, not all routes were surveyed each year, but every year was surveyed by at least one of the three routes overlapping the Grassland, and between 81 and 118 total routes were surveyed each year across North Dakota and Montana (see Table 2.1).

Multivariate regression analysis was performed using IBM’s SPSS statistical software (version 22) for each of the thirteen species, with the average population over the three local Grassland routes serving as the dependent variable. Two independent variables were used: edge density and the combined population average for North Dakota and Montana.
Table 2.1: Availability of data from the North American Breeding Bird Survey (BBS) and NAIP imagery. There are 126 BBS routes across North Dakota and Montana, but not all are surveyed every year; three routes overlap the Little Missouri National Grassland. Source: USGS.

There was a very high degree of collinearity between habitat statistics (edge density, road density, core area percentage of landscape, and the percentage of land undisturbed), with a Pearson’s $r$-value above 0.99 between each. As redundancy among independent variables lessens the reliability of regression analysis, edge density was used as a proxy for habitat fragmentation. The results were checked by running a regression using the other three metrics individually as well as together in a principle component analysis, each with almost identical results.

As edge density and other habitat statistics were derived from digitizing roads and development visible in NAIP imagery, there were corresponding gaps in the data for four years where NAIP imagery is not available (see Table 2.1). Statistics for missing years were inferred from neighboring years – e.g., the missing value for 2011 was created using the average of 2010 and 2012. As there is a clear and consistent trend in development for the available years, inferring missing years was preferable to eliminating those years from the BBS data and shrinking the already-small sample size, allowing for a sample size of fourteen years (versus ten). As a check, the reported statistics were run without inferring missing years and instead deleting them from the BBS data. While this did result in different outputs, both approaches only
yielded statistically significant results for the same four species (Sprague’s pipit, vesper sparrow, western meadowlark, and brown-headed cowbird).

**Conservation Potential**

As discussed in the previous chapter, hydraulic fracturing with horizontal wells allows for a potentially smaller footprint on the landscape when compared to conventional, vertical oil development. After drilling to the oil deposit’s depth (approximately two miles in the Bakken), current technology allows wells to continue for up to two miles horizontally along the deposit (see Figure 2.4). One possibility for habitat conservation would be to designate the entirety of the Little Missouri National Grassland as a roadless area; currently 21.3% is roadless, in addition to the neighboring National Park.

To estimate the impact this would have on oil development in the region, I created a dataset showing the areas not accessible to oil development if new well pads and roads were to be banned, using a two-mile internal setback created within Grassland boundaries. The Grassland boundaries included existing roadless areas and Theodore Roosevelt National Park – e.g., as the presence of the National Park already precludes any oil development, where a non-roadless area of the Grassland abuts the National Park, the setback began at the opposite National Park boundary and not the Grassland boundary.

As can be seen in the overview map of the Grassland (Figure 1.1), the Grassland boundaries are irregularly shaped and includes many “donut holes”, or small enclaves of private and state land completely surrounded by the National Grassland. Some of these enclaves would remain accessible after a roadless designation, as they have current roads already running through them. However, those *without* current road access would not be accessible by road in
Figure 2.4: Horizontal drilling paths in a northern portion of the Little Missouri National Grassland. Most wells in the region drill two miles (three km) below the surface, and can travel two miles (three km) horizontally along the oil deposit’s path Map by author. Sources: ND Dept. of Mineral Resources, USGS.

the future, as it would become surrounded by roadless land. To take these enclaves into account, before creating the two-mile internal setback I first visually reviewed all such enclaves, temporarily deleting from the feature class those not containing existing roads or other development.

These steps resulted in a setback showing areas more than two miles from a currently-accessible Grassland boundary, excluding undeveloped enclaves and boundaries currently abutting roadless and areas and National Parkland.
A more complex model would be required to take the geological and topographic reality of the area into full account. The underlying geology varies across the Bakken, and two miles of horizontal drilling is not always achievable as slight changes in underground topography create drilling difficulties in wells targeting a siltstone stringer within the Bakken that is only about two feet thick (Al-Yami 2012). The land immediately adjacent to the Grassland is also not always developable for oil production, either due to existing non-oil development (including two small towns) or because of unmanageable surface topography along canyon and butte walls. This method should thus be understood as a preliminary model for estimating the impact a Grassland-wide roadless designation would have on the ability to extract oil from the region.
Chapter 3: Results

Hydraulic fracturing has had a measurable impact on the level of habitat fragmentation in the Little Missouri National Grassland; results of summary statistics for the Grassland, not including roadless areas, are shown in Table 3.1.

Between 2003 and 2016, mean patch size decreased by 3.71% and median patch size decreased by 1.13%. The total amount of disturbed area, not including any buffer, increased by 12.39%, representing a shift from 0.51% to 0.57% of the Grassland being directly impacted by development of some kind.

The mean perimeter for a Grassland patch decreased from 7.58 km to 7.51 km, with the total amount of perimeter increasing by 213 km (or 2.73%). Edge density similarly increased by

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean Patch Size (km²)</th>
<th>Median Patch Size (km²)</th>
<th>Total disturbed area (km²)</th>
<th>Mean perimeter (km)</th>
<th>Total perimeter (km)</th>
<th>Road Length (km)</th>
<th>Road Density (m per km²)</th>
<th>Total Core Area (150m, km²)</th>
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<tr>
<td>2003</td>
<td>3.16</td>
<td>0.386</td>
<td>16.72</td>
<td>7.58</td>
<td>7,818</td>
<td>1,575</td>
<td>481</td>
<td>2,847</td>
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<td>2004</td>
<td>3.16</td>
<td>0.384</td>
<td>16.73</td>
<td>7.58</td>
<td>7,821</td>
<td>1,576</td>
<td>481</td>
<td>2,847</td>
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<td>2005</td>
<td>3.15</td>
<td>0.383</td>
<td>16.77</td>
<td>7.56</td>
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<td>16.97</td>
<td>7.55</td>
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<td>2009</td>
<td>3.12</td>
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<td>17.37</td>
<td>7.55</td>
<td>7,891</td>
<td>1,603</td>
<td>490</td>
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<tr>
<td>2010</td>
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<td>0.381</td>
<td>17.54</td>
<td>7.57</td>
<td>7,909</td>
<td>1,610</td>
<td>492</td>
<td>2,835</td>
</tr>
<tr>
<td>2012</td>
<td>3.08</td>
<td>0.379</td>
<td>18.31</td>
<td>7.57</td>
<td>7,997</td>
<td>1,648</td>
<td>503</td>
<td>2,821</td>
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<td>2014</td>
<td>3.05</td>
<td>0.381</td>
<td>18.71</td>
<td>7.57</td>
<td>8,032</td>
<td>1,665</td>
<td>508</td>
<td>2,815</td>
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<tr>
<td>2015</td>
<td>3.04</td>
<td>0.382</td>
<td>18.74</td>
<td>7.57</td>
<td>8,031</td>
<td>1,666</td>
<td>509</td>
<td>2,814</td>
</tr>
<tr>
<td>2016</td>
<td>3.04</td>
<td>0.381</td>
<td>18.79</td>
<td>7.57</td>
<td>8,032</td>
<td>1,668</td>
<td>509</td>
<td>2,813</td>
</tr>
</tbody>
</table>

Table 3.1: Summary descriptive statistics showing the impact of hydraulic fracturing in the Little Missouri National Grassland.
2.73% (from 2.39 to 2.45 km per km²), and 93 km of new roads were built within Grassland boundaries, representing a 5.5% increase between 2003 and 2016.

As stated in the previous chapter, all statistics measuring patch sizes or edges include the artificial political boundaries of the Grassland itself. While these calculations thus cannot be easily compared to other studies, the Grassland boundaries did not change across the study years, allowing for an accurate depiction of the amount of year-to-year change.

These statistics were also tempered by the relative lack of development in large portions of the Grassland, particularly in the south. Northern patches of the Grassland, and especially the far northeast, are likely much more representative of the impact high intensity development has had elsewhere in the state. To indicate the level of habitat disturbance seen in areas of more intensive development, the same descriptive statistics were compiled for the largest patch with substantial development (see Figure 3.1 and Table 3.2).

Figure 3.1: The northernmost Grassland patch, circled above, was much more heavily impacted by hydraulic fracturing than most of the Grassland. Map by author. Source: USGS.
Table 3.2: Summary descriptive statistics showing the impact of hydraulic fracturing in the northernmost patch of the Little Missouri National Grassland; location is shown in Figure 3.1.

As can be seen in Table 3.1 and Figure 3.2, all habitat metrics plateaued following 2014 for the Grassland overall, though small changes still occurred in the northernmost large patch. This corresponds with the state’s disruption in oil production following the plummet in oil prices in late 2014 (Figure 1.7).

The four habitat statistics calculated (percent of the landscape directly impacted, edge density, road density, and core area percentage of landscape) were all highly correlated with annual oil production in North Dakota, with Pearson r-values of 0.98, 0.97, 0.98, and −0.98, respectively. A simple bivariate linear regression between oil production (as the independent variable) and each habitat statistic (as dependent variables) likewise show very high associations (see Figure 3.3). P-values for each regression were below 0.00001, with r² values all above 0.93.
The geospatial data developed and used to compute the habitat statistics included all development, not just well pads. The high association between oil production and all habitat statistics indicates this decision was appropriate.

**Figure 3.2:** Summary statistics showing key habitat fragmentation statistics generated during this study, along with oil production (top), to which they are highly correlated. The paler line represents the most impacted large patch of the Grassland, located in the far northeast (see Figure 3.1), and the red line represents all non-roadless areas within the Grassland.
Figure 3.3: Linear regression plots showing annual oil development and its association with four habitat statistics. $P$-values for each regression were below 0.00001, with $r^2$ values all above 0.93.

Effect on Bird Populations

The model was statistically significant at the 90% level for four species: Sprague’s pipit, vesper sparrow, western meadowlark, and brown-headed cowbird; a summary of regression results for all thirteen species (compared to edge density and to the regional population trend
across Montana and North Dakota) can be found in Table 3.3, with regression plots for these four species in Figure 3.4 and 3.5.

Table 3.3: Summary of regression results comparing bird population data to the developed habitat fragmentation statistics. The dependent variable is the average population of the three local BBS routes (see Fig. 2.3); the independent variables are 1) Edge Density, and 2) the average population across all of North Dakota and Montana.
**Figure 3.4:** Linear regression plots for the two species with a significant association with edge density.

For the Sprague’s pipit, local populations declined as edge density increased. The model can account for 42% of the variability within the data, with edge density much more significant ($p = 0.039, r^2 = 0.38$) compared to the average population in Montana and North Dakota ($p =$...
0.374, \( r^2 = 0.13 \). Of the thirteen species covered, this represented the strongest association between habitat fragmentation and population.

The vesper sparrow had a more significant model overall (\( p = 0.02, \ r^2 = 0.52 \) ), but with nearly identical and relatively low significance to both independent variables. Edge density held a \( p \)-value of 0.0132, with population decreasing as edge density decreased, but accounted for only a small portion of the data (\( r^2 = 0.127 \) ) and was slightly less significant than the overall population trend in North Dakota and Montana (\( p = 0.0126, \ r^2 = 0.134 \) ).

The western meadowlark and brown-headed cowbird had similar models to each other. Both models were statistically significant, but in both cases the regional trend across North Dakota and Montana was much more significant than edge density; the \( p \)-value for edge density was 0.15 and 0.14 for the meadowlark and the cow-bird, respectively, with a corresponding \( r^2 \) of only 0.09 and 0.08. The association with the regional population goes in opposite directions, however; western meadowlarks increased in local population with increases in the regional population, while brown-headed cowbirds decreased locally against regional increases (see Table 3.3). While not significant, both species also had a positive relationship with edge density, with population increasing as edge density increased. Interestingly, when the western meadowlark’s local population is compared to edge density alone in a bivariate regression, the relationship between the two becomes negative (but also less statistically significant, with \( p = 0.30 \) and \( r^2 = 0.09 \) ), further indicating the relationship between these two variables is not meaningful; the cowbird’s positive association with edge density stays the same in a bivariate regression.

For five of the remaining nine species where the model does not show a significant association, edge density has a higher significance than the statewide average (see Table 3.3).
For the savannah sparrow and Baird’s sparrow the relationship is negative (i.e., as edge density increases, population decreases) whereas the relationship is positive for killdeer, clay-colored sparrow, and field sparrow (i.e., edge density and population increase together).

**Habitat Conservation**

If the entire National Grassland were designated as a roadless area, it would only have a relatively small impact on the total amount of land inaccessible to oil development. Taking into account current roadless areas and National Park units, the total area encompassing all Grassland and Parkland is 4,447 km² (1,717 sq. miles), 26.4% percent of which is protected as Parkland or as a roadless area.

Because of the highly irregular shape of the Grassland boundary, only 43.1 km² (16.6 sq. miles) of this land today is inaccessible to theoretical hydraulic fracturing wells beginning just outside grassland boundaries and travelling for two miles underneath the surface. This area represents just under 1% of the total area.

Were the entirety of the Grassland designated a roadless area, this would increase the land inaccessible to oil development by only 18.5 km² (7.1 sq. miles), all of which lies within pre-existing Parkland or roadless areas, and the majority of which is contiguous with land already inaccessible (see Table 3.4 and Figure 3.6). While this represents a 43% increase in the amount of inaccessible land, it is a rise from 0.97% to 1.38% of the total area being inaccessible.

As discussed in the previous chapter, a by-product of such a roadless designation would be to isolate existing enclaves which do not have current roads or development (see Figure 3.7). These enclaves a mix a privately-owned and state school trust land. Not including areas that already have roads, 75.0 km² (29.0 sq. miles) of private land would be made inaccessible, along
with 48.5 km² (18.7 sq. miles) of the state’s school trust land, for a total of 123.5 km² (47.7 sq.
miles). For context, this represents land 2.8% the size of area form by the combined Grassland
and Parkland, and all of this land would still be accessible by horizontal drilling.

<table>
<thead>
<tr>
<th>Total existing area (Grassland and National Park)</th>
<th>km²</th>
<th>miles²</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Grassland (non-roadless)</td>
<td>3,274</td>
<td>1,264</td>
</tr>
<tr>
<td>National Grassland (roadless)</td>
<td>888</td>
<td>343</td>
</tr>
<tr>
<td>National Park</td>
<td>285</td>
<td>110</td>
</tr>
<tr>
<td>Total protected land (roadless and/or National Parkland)</td>
<td>1,173</td>
<td>453</td>
</tr>
</tbody>
</table>

| Area inaccessible to horizontal drilling:          | km²  | miles² |
| (e.g., more than two miles from nearest non-roadless area) |
| Existing, in roadless areas and National Parkland  | 43   | 17     |
| Additional, if all Nat’l Grasslands became roadless | 18   | 7      |
| Total amount inaccessible, if all Grasslands became roadless | 62   | 24     |

Enclaves not accessible by road if all Grassland became roadless:

| North Dakota School Trust Land | 48   | 19     |
| Private                        | 75   | 29     |
| Total (3% of total area)       | 123  | 48     |

**Table 3.4:** Summary statistics showing the impact of designating the Grassland as a roadless area.
Figure 3.6: Areas currently inaccessible to hydraulic fracturing. Map by author.

Figure 3.7: Land made newly inaccessible by road if development ceased within National Grassland boundaries. Map by author.
Chapter 4: Discussion

The results outlined in the previous chapter raise at least two questions. First, how does the apparent impact on bird species, especially the Sprague’s Pipit, fit with what else is known about these species in this region? Second, given the clear impact of drilling on habitat fragmentation, this thesis is dealing with two rather unique situations: a very large conglomerate of federally-owned land, providing substantial conservation potential, and a relatively-new horizontal drilling technique which allows oil to be extracted from distances of up to two miles from a well pad. Is it possible to utilize these two features to reduce the impact of drilling on habitat in the region?

Impact on Bird Populations

Beyond their aesthetic value, birds are a helpful measure for the health of an ecosystem. Browder, Johnson and Ball (2002), for instance, compared the habitat composition of grasslands in the prairie pothole region of North Dakota (which lies near the Grassland to the north and east) with breeding bird data they collected. They determined the recorded presence or absence of bird species in the BBS data correctly identified the integrity of grassland habitats.

As described in the previous chapter, this research found significant associations between habitat fragmentation and four grassland species. The western meadowlark and brown-headed cowbird both had strong associations between local and regional populations as well a small, positive associations between the local population and fragmentation, but neither of these latter associations were statistically significant and both had low $r^2$ values. These trends are in concert with existing literature, however, and given the near-significance of their $p$-values (0.15 and 0.14), this is notable. The cowbird in particular had a negative relationship between local and
regional populations, indicating something in the area is causing the former to rise while the latter declines (summary population statistics are provided in Appendix A and B). In other studies, Rodgers (2013) found meadowlarks increased in number in near proximity to gas wells in southeastern Alberta, and, as mentioned in chapter 1, populations of brown-headed cowbirds in Alberta increased four-fold near oil and natural gas infrastructure (Bernath-Plaisted, Nenninger, and Koper 2017).

While rises in western meadowlark abundance might be interpreted as an ecological benefit, cowbirds are brood parasites, leaving their eggs in the nest of other grassland birds. When cowbirds chicks hatch, they are often able to out-compete their host’s own chicks, causing their host’s brood to fail while the cowbird survives. While a native species, an increase in brown-headed cowbirds can thus be detrimental to other grassland birds.

Shaffer et al (2004) outline multiple studies showing edge habitats increase cowbird abundance, in part because perches make it easier for them to find nests; while they do not mention well pads specifically, pads are commonly surrounded by chain-link fence. In a review of literature up to that time, they also cite multiple studies documenting brood parasitism among nests of all of the grassland birds covered in this thesis. An increase in the presence of cowbirds in this study should be considered a sign of declining habitat integrity and a possible threat to other species.

The negative relationship between local vesper sparrow population and edge density, which becomes more statistically significant when combined with the regional population trend (a combined $r^2$ of 0.52) is in concert with some, but not all, existing research. Gilbert and Chalfoun (2011) for instance, showed vesper sparrow experience a small negative affect with gas
drilling in Wyoming, whereas Bernath-Plaisted and Koper (2017) showed an increase in nesting density near wells.

The most significant relationship to edge density came from the Sprague’s pipit, whose local population also did not trend with the regional population. This agrees with much existing research. In a survey of the Bakken region specifically, Thompson, et al. (2015) found the Sprague’s pipit to have the strongest aversion to well pads of grassland birds surveyed. Hamilton et al. (2011) looked at the effect of gas well density on the Sprague’s pipit and two other species (savannah sparrow and chestnut-collared longspur) in southern Alberta, and found the strongest relationship with the pipit, which was negatively affected by the presence of wells. Two other studies of gas well in Alberta showed the same result. Dale, Wiens and Hamilton (2008) saw an avoidance of non-native vegetation near gas wells, and further noted that this species rarely crossed trails, and Rodgers (2013) found pipits increased in abundance with distance away from oil wells, and that artificial perches (e.g., oil infrastructure and fences) were the primary cause (Rodgers and Koper 2017). Similarly, Davis, et al. (2006) investigated 41 birds in southern Saskatchewan; only Sprague’s pipit increased in density with an increase in patch size, though several other species also had increased nest survival rates with larger patch sizes.

One study did not show a relationship between fragmentation and pipit abundance: research at Bowdoin National Wildlife Refuge in central Montana (Jones and White 2012) failed to find any significant edge-related effects on the nesting success rate of Sprague’s pipit. They noted this might be due to the very low and seasonal traffic on the refuge, however.

Brittingham et al. (2014) observe several characteristics of wildlife most at risk from hydraulic fracturing: they have a small population, live in a limited range, their range overlaps
substantially with a shale play’s extent, they have specialized habitat requirements, and they exhibit a sensitivity to human disturbance.

The Sprague’s pipit holds all of these characteristics to varying degrees. Its global population is between 500,000 and 1,000,000, and is decline between 30% and 49% per decade (BirdLife International 2017). It breeds exclusively in North America’s northern prairie, its core range overlaps significantly with the Bakken shale play (see Figure 4.1), it only nests in particular habitats within the prairie (Sutter 1997) and, as discussed above, it is sensitive to human disturbance, preferring patch sizes of at least 29 hectares (72 acres) according to one study (Davis 2004).

The Sprague’s pipit, is listed as “vulnerable” by the International Union for the Conservation of Nature, as “threatened” under Canada’s Species at Risk Act, and is Species of Conservation Priority (level 1) under North Dakota’s Wildlife Action Plan, and focal species of concern under the U.S. Fish and Wildlife Service’s Migratory Bird Program. It was recently reviewed for protection under the United States Endangered Species Act, but was withdrawn from being a candidate species in 2016 due in part to the pipit no longer being “as affected as once thought by energy development and connecting roads” (USFWS 2016). Given the results of this study alongside previous research, it points to a possible need for reevaluation for protection under the Endangered Species Act.

The low level of significance for some other species in this study, most notably the Baird’s sparrow, may be due to the limitations of BBS data – namely, the small sample size from the three local BBS routes and the inherent problem of measuring fragmentation-averse species using data collected along roadsides. Estimating the population based on three overlapping
**Figure 4.1:** Breeding range for the Sprague’s pipit, with the Bakken shale play for context, with bird ranges provided by BirdLife International. eBird sightings come from an online citizen science database (www.ebird.org) consisting of sighting recorded by amateur birders; one dot equals one sighting, and density may result from multiple birders reporting the same individual bird(s) and may not indicate a higher population density. Map by author. Sources: BirdLife International, eBird, USGS.

routes allows for only a rough approximation of the effects from hydraulic fracturing for several reasons. Each route only partially overlaps with the Grassland. Routes are also not affected equally, both between the three routes and among individual stops along each route. For instance, of the three local routes, only one route was surveyed every year covered by this study.
(see Table 2.1), and it travels through the northern unit of Theodore Roosevelt National Park. 29 out of 50 stops are within Park boundaries, and would not have experienced any direct impact from oil development (though development has occurred near several of the remaining stops within this route). However, the Grassland itself has experienced variable impact from oil development, with some areas essentially untouched (especially in the south) and other areas highly impacted (especially in the north) – the variability among stops in these three routes thus somewhat mimics the variability within the Grassland.

Niemuth et al. (2007) also show that because the routes are tied to roads, BBS data is biased toward anthropogenic landscapes – thus BBS data underrepresents species requiring deep water and species highly averse to landscape fragmentation. Despite the limited nature of BBS data, the Survey is cited in scientific literature with relative frequency and is valuable for understanding population change and thus consequently for making management and policy decisions (Tulloch, et al. 2013). BBS data has been used to create regional studies of bird habitat (Knick, Rotenberry, and Leu 2008), for instance, as well has investigations of how birds are affected by land-use change (Rittenhouse, et al. 2012) and how grassland birds in North Dakota are affected by moisture (Niemuth, Solberg, and Shaffer 2008).

The limitations of the BBS are perhaps most relevant for researching the piping plover (Charadrius melodus), a small shorebird listed as “threatened” under the U.S. Endangered Species Act and as “near threatened” by the IUCN. It is the most threatened avian species in the region, with total global population that is stable but small, at roughly 8,000 individuals, more than half of which are in a different subspecies from those found in North Dakota and breed along the Atlantic coast (BirdLife 2017). Piping plovers breed along sandy shores, such as found
along the edge of Lake Sakakawea, and their range overlaps with the northern and most-affected edge of the Grassland, which abuts Lake Sakakawea. Is it possible hydraulic fracturing is affecting the plover’s nesting in this area, but the BBS’s road-based methodology resulted in zero piping plovers recorded along the three local survey routes during the study years, and so an analysis of this species was not possible in this study.

**Habitat Fragmentation and Conservation**

The results show a very high association between fragmentation and oil production, but this is most likely related to *increases* in oil production and not to total production. As can be seen in Figures 1.7 and 3.4, oil production has plateaued since 2014, and growth in habitat fragmentation correspondingly stalled at the same time (with only small increases in the highly-affected northernmost patch) – that is, even though oil production remained very high compared to 2003 levels, habitat fragmentation did not increase as there was no increase in oil development. It is reasonable to assume that when oil production begins to consistently decline (whether soon or in several decades), increases in habitat fragmentation will stop altogether or even decline as well pads and access roads are vacated, even if overall production in a given future year is still considerably higher than 2003 levels.

In considering future needs to maintain native prairie habitat and reduce further habitat fragmentation, a key question revolves around the future development potential of the Bakken region. While oil production has not increased since the collapse in global oil prices in late 2014, it is reasonably likely oil prices will rise again at some point. Production and new development can then be expected to rise again in the region, but the ability to forecast the amount and
timetable of the region’s future oil development is hampered by the uncertainty of oil markets, the costs of technology, and variable well productivity.

The higher cost of hydraulic fracturing, in contrast to conventional oil, has largely been in engineering how to combine and customize existing technologies; as companies have come to better understand how to productively extract tight oil, this augmented technology can be replicated at an increasingly lower cost, sometimes to points lower than conventional oil Aguilera (2014). As Fitzgerald (2013) notes, the experimental nature of fracking makes economic analyses of fracking difficult – different levels of productivity can result not only from geological differences but also from technological differences and experimentation (e.g., two neighboring wells might extract oil at very different rates due to different proppants). As a result of this experimentation, unconventional wells have a much higher level of production variability than conventional wells (1343).

In part because fracking is a new method of production, there is not strong historical production record to use in predicting how successfully oil can be recovered from the region – e.g., the average estimated ultimate recovery (EUR) for individual wells steadily increased until 2010, well before the fall in global oil prices, but has since begun to steadily decrease, and the overall estimated productivity varies dramatically (McNally and Brandt 2015). It appears likely that this is due to the increased experience-based knowledge in well operators and contractors. In Timothy Fitzgerald’s study of the effects of partnerships and experience in well productivity and the Bakken, he also discovered a plateauing of productivity but linked it to experience (Fitzgerald 2015). Because horizontal, multi-stage hydraulic fracturing is a new technology, the increase in productivity is indicative of operators and contractors learning the most effective
recovery techniques (e.g., finding the optimal formula for fracking fluids); the slight decrease since 2010 is then not indicative of a change in the amount of oil in the ground, but a plateauing of knowledge and experience.

Despite the difficulty in estimating future development in the region, there have been multiple attempts to create such a forecast (outside of oil companies’ own estimates). McNally and Brandt (2015) applied curve-fitting statistical models to a large dataset of existing individual well data in the Bakken in order to estimate future productivity. They took the size of the Bakken region and averaged out the estimated number of average wells per square mile for three different scenarios (bust, business-as-usual, and boom, each weighted to account for some areas being inherently less productive than others); this gives them an estimated number of total wells that could be drilled in the region. They did not incorporate economic data, however, and so their model is not sensitive to changes in the price of oil. It also cannot account for changes in technology, as that is an unknowable factor. Within these constraints, their “business-as-usual” model show North Dakota continuing to produce over 1 million barrels of oil per day until the mid-2030’s. However, they do not predict that production will necessarily be steady, and propose North Dakota will experience a cycle of booms and busts as global oil prices rise and fall.

Rather than using economic and production data exclusively, Preston and Kim (2016) digitized a sampling of well pads across the Williston Basin. In their estimates, future energy development throughout the Basin will be 2.7 times greater than that seen between 2000 and 2015.

For the purposes of this thesis, the exact of amount of future development is less important (and arguably unknowable) than the assumption that some considerable level of
additional oil development will likely occur in the region as prices increase in the future. The Little Missouri National Grassland is the largest Grassland in the United States and the most significant collection of public land in western North Dakota, if not the entire Bakken region. As such, it provides a large potential in preserving prairie habitat in the region.

While much of the recent media coverage has (justifiably) been on pollution, climate change, and tribal relations, there have been some conservation efforts in the area. As Preston and Kim (2016) note, North Dakota has recently begun to encouragement oil development along energy corridors, which run parallel to each other in four mile increments – as horizontal drilling can stretch two miles, the four miles between the corridors can be covered by drilling from opposite directions on each side. Well pads are also encouraged to be placed close to the primary road (as opposed to along longer spur roads running away to those roads, which increases fragmentation).

If the entirety of the Grassland were designated as a roadless area, it would have a similar effect to using energy corridors placed four miles apart – it would help maintain open land and reduce fragmentation within a portion of the broader landscape, while only minimally affecting the ability to extract oil. A simple drilling ban would have a similar but weaker impact, as fragmentation is often caused by constructing new roads to connect well pads, and not just the well pads themselves. As mentioned in chapter 3 and shown in Figure 3.10, a Grassland-wide roadless designation would effectively cut off 123.5 km² of public and private land that are currently undeveloped and are completely surrounded by National Grassland. The majority of this land lies in isolated one square mile sections. Effectively incorporating this would help reduce the irregular shape of the grassland, creating slightly more solid and ecologically
beneficial swatches of protected land. While it is beyond the scope of this thesis to deal with the complexities of land ownership, there would be an obvious conflict of interest between private land owners who would find their land no longer developable and the federal government, and well as conflict with the state government, which owns the school trust land (land intended to bring revenue to help support the state’s public school systems).

These conflicts could perhaps be solved by financial remuneration or land swaps. Designating a roadless area would also not cut off all economic potential, as the land could still be used as range land for livestock and – as all of the land lies less than two miles from an accessible Grassland boundary – existing mineral rights could still be preserved.

Finally, while the overall minimal impact on oil development would help ease the passage of a roadless designation for all of the Little Missouri National Grassland, this same lack of impact points to its inability to address other serious ecological concerns, such as mitigating climate change or reducing the risk of oil and brine spills. It nevertheless remains a reasonable option for reducing fragmentation in an important habitat.
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## Appendix A: North American Breeding Bird Survey Statistics:
Average Population for Three Routes Intersecting the Little Missouri National Grassland

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### Appendix B: North American Breeding Bird Survey Statistics:
Average Population across North Dakota and Montana

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<td>Brown-headed Cowbird</td>
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