Wyoming

Sage-Grouse
Job Completion Report
2020

June 2020-May 2021

Leslie Schreiber
Wyoming Game & Fish Dept.

Table of Contents

Statewide Summary…………………………………………………………….……...….1

Attachment A – Lek Definitions……………………………………….………...…24

Attachment B – Funded Projects.……………………………………………………..27

Attachment C – Research in Wyoming in 2020..……………………………………..29

Bighorn Basin……………………………………………………………………....50

Bates Hole / Shirley Basin…………………………………………………….……61

Northeast………………………………………………………………………........81

South-Central……………………………………………………………….......303

Southwest…………………………………………………………………...…..319

Upper Green River Basin………………………………………………...…..332

Upper Snake River Basin……………………………………………………...…. 348

Wind River / Sweetwater Basin…………………………………………………...…362

Wyoming Sage-Grouse Job Completion Report

Conservation Plan Area: **Statewide Summary**
Period Covered: **6/1/2020– 5/31/2021**
Prepared by: **Leslie Schreiber – Sage-grouse/Sagebrush Biologist**

INTRODUCTION

Wyoming is home to more greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) than any other state. About 37% of the rangewide sage-grouse population lives in Wyoming and 90% of estimated historic habitat in Wyoming is still occupied by the bird. There are about 1,750 known occupied sage-grouse leks in Wyoming. Wyoming Game and Fish Department (WGFD) personnel and others surveyed 85% of these leks in the spring of 2021. Results of the survey indicate 994 leks were confirmed active, 316 confirmed inactive, and 171 unknown or unchecked. The average number of males observed on leks was 17/active lek, a 13% decrease from the 20/active lek observed in the spring of 2020, suggesting an overall population decrease. This figure is slightly higher than the low of 13/active lek reported in 1996.

Management of sage-grouse habitat in Wyoming is based on a “Core Area” strategy of limiting human disturbance in the most important sage-grouse habitats. This strategy is codified by a Governor’s executive order. The Executive Order and related materials are available at: https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management. The Core Areas are shown in Figure 1.

In 2015, the U.S. Fish and Wildlife Service issued a decision of “not warranted” for listing sage grouse as threatened or endangered under the Endangered Species Act. This means the State of Wyoming maintains management authority over sage-grouse in Wyoming and management emphasis focuses on implementation of the Core Area strategy. In its decision document, the Service specifically cited Wyoming’s Core Area strategy as a mechanism that, if implemented as envisioned, should ensure conservation of sage-grouse in Wyoming and therefore help preclude the need for a future listing. The Western Association of Fish and Wildlife Agencies planned to re-examine the issue in 2020 to ensure planned conservation efforts were implemented and the status of the species remains unwarranted for listing. WAFWA’s examination is not yet complete.

Since the mid-2000’s, the Wyoming Legislature biennially appropriated over $1 million of General Funds to the sage-grouse program for the state’s 8 local sage-grouse working groups (LWGs) (Figure 2) to allocate to local projects. The 2017 Legislature returned budget responsibility of the sage-grouse program back to the Department due to state budget shortfalls. This action shifted the funding burden from the state as a whole, based largely on mineral severance taxes, to hunters and anglers, the primary funding source of the WGFD. A hunting license fee increase specifically crafted to replace legislative funding was approved by the legislature and LWGs will maintain their existing role in recommending how funds will be allocated. The last of biennial legislative funds were allocated in FY 2017-2018.

The 2017 Legislature passed a bill allowing private bird farm operations to collect sage-grouse eggs from the wild for purposes of establishing a captive flock. The Department and Commission promulgated regulations in Chapter 60 to permit this activity. The WGFD permitted one captive bird facility in 2021. In April and May, 133 eggs were collected from the wild for this purpose. The eggs were incubated at the facility and chicks hatched in the summer of 2021. As of July 13, 2021, 94 live sage-grouse resided in the pens of the facility.

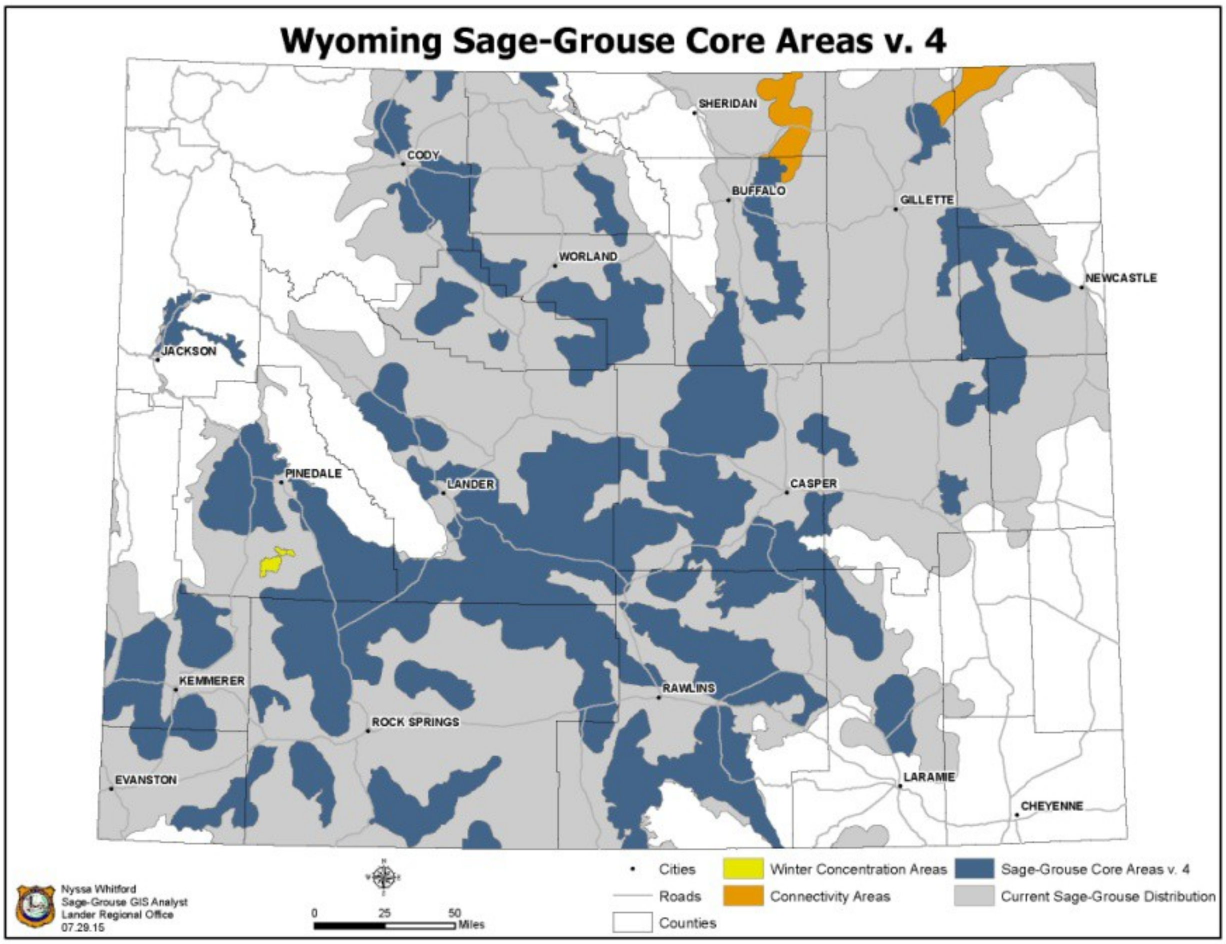


Figure 1. Wyoming Core Areas (version 4).

Figure 2. Wyoming Local Sage-grouse Working Group boundaries.

BACKGROUND

The sage-grouse is the largest species of grouse in North America and is second in size only to the wild turkey among all North American game birds. It is appropriately named due to its year-round dependence on sagebrush for both food and cover. Insects and forbs also play an important role in the diet during spring and summer and are critical to the survival of chicks. In general, the sage-grouse is a mobile species, capable of movements greater than 50 km between seasonal ranges. Radio telemetry studies conducted in Wyoming demonstrated that individuals or sub-populations within most sage-grouse populations in the state are migratory to varying extent. Despite this mobility, sage-grouse appear to display substantial amounts of fidelity to seasonal ranges. Sage-grouse populations are characterized by relatively low productivity and high survival. This strategy is contrary to other game birds such as pheasants that exhibit high productivity and low annual survival. These differences in life history strategy have consequences for harvest and habitat management.

Sage-grouse once occupied parts of 12 states within the western United States and 3 Canadian provinces (Figure 3). S age-grouse populations have undergone long-term population declines. The sagebrush habitats on which sage-grouse depend have experienced extensive alteration and loss. Consequently, concerns rose for the conservation and management of sage-grouse and their habitats resulting in petitions to list sage-grouse under the Endangered Species Act. Due to the significance of this species in Wyoming, meaningful data collection, analysis, and management is necessary whether or not the species is a federally listed species.

Sage-grouse are relatively common throughout Wyoming, especially southwest and central Wyoming, because sage-grouse habitat remains relatively intact compared to other states (Figures 3 and 4). However, available datasets and anecdotal accounts indicate long-term declines in Wyoming sage-grouse populations over the last six decades.

Past management of sage-grouse in Wyoming included:

- Population monitoring via lek counts and surveys, harvest statistics, and data derived from wing collections from harvested birds. Wyoming conducted lek counts and surveys since 1949.
- The protection of lek sites and nesting habitat on BLM lands by restricting activities within ¼ mile of a sage-grouse lek and restricting the timing of activities within a 2-mile radius of leks. The Core Area Strategy has expanded and strengthened these protections (described below).
- The authorization and enforcement of hunting regulations.
- Habitat manipulations, including water development.
- Conducting and/or permitting applied research.

Prior to 2004, Job Completion Reports (JCRs) for sage-grouse in Wyoming were completed at the WGFD Regional or management area level. In 2003, the Wyoming Game and Fish Commission approved the Wyoming Greater Sage-Grouse Conservation Plan (State Plan) and created a Sage-Grouse Program Coordinator position within the WGFD. The State Plan directed local conservation planning efforts to commence. In order to support the conservation planning efforts, JCRs across the State changed from reporting by WGFD Regional boundaries to those of the eight planning area boundaries (Figure 2). The 2004 JCR reviewed and summarized prior years' data in order to provide a historical perspective since that document was the first statewide JCR in memory. Additionally, Patterson (1952) provides an invaluable reference for sage-grouse in Wyoming and across their range.

Sage-grouse data collection and research efforts across Wyoming began to increase in the early 1990s due to the increasing concerns for sage-grouse populations and their habitats (Heath et al. 1996, 1997). Monitoring results suggest sage-grouse populations in Wyoming were at their lowest levels ever recorded in the mid-1990s. From 1996-2006 however, the average size of leks increased to levels not seen since the 1970s. From 2006-2013, average lek size declined though not to levels recorded in the mid-1990s. Average lek size increased 112% from 2013 to 2016, but declined 53% from 2016 to 2021 (Figure 5).

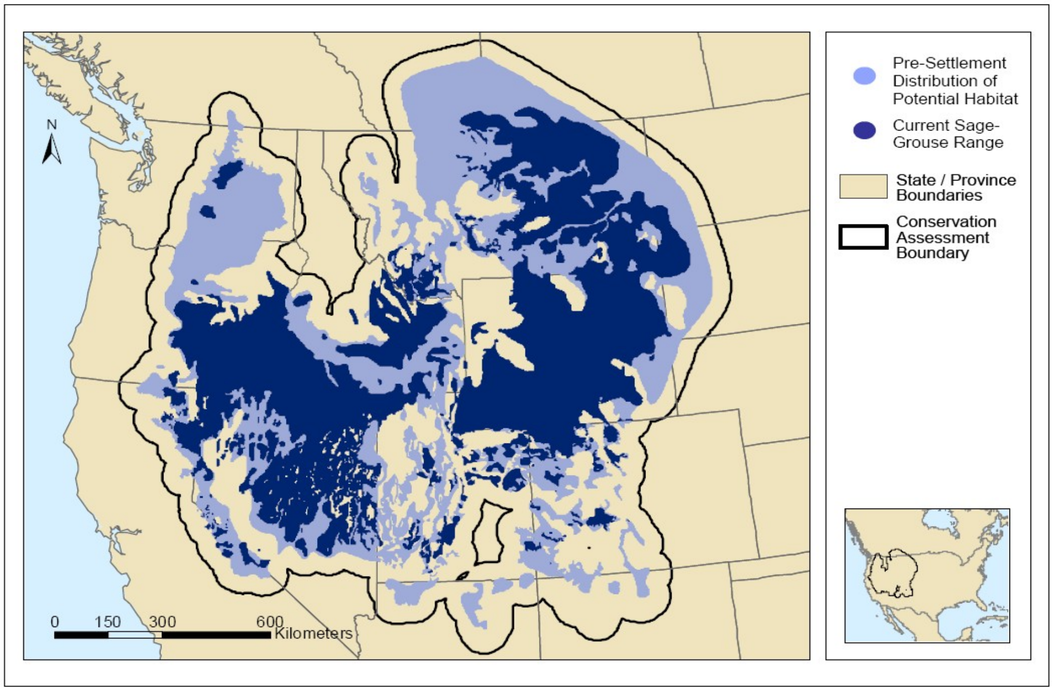


Figure 3. Current distribution of sage-grouse and pre-settlement distribution of potential habitat in North America (Schroeder 2004). For reference, Gunnison sage-grouse in SE Utah and SW Colorado are also shown.

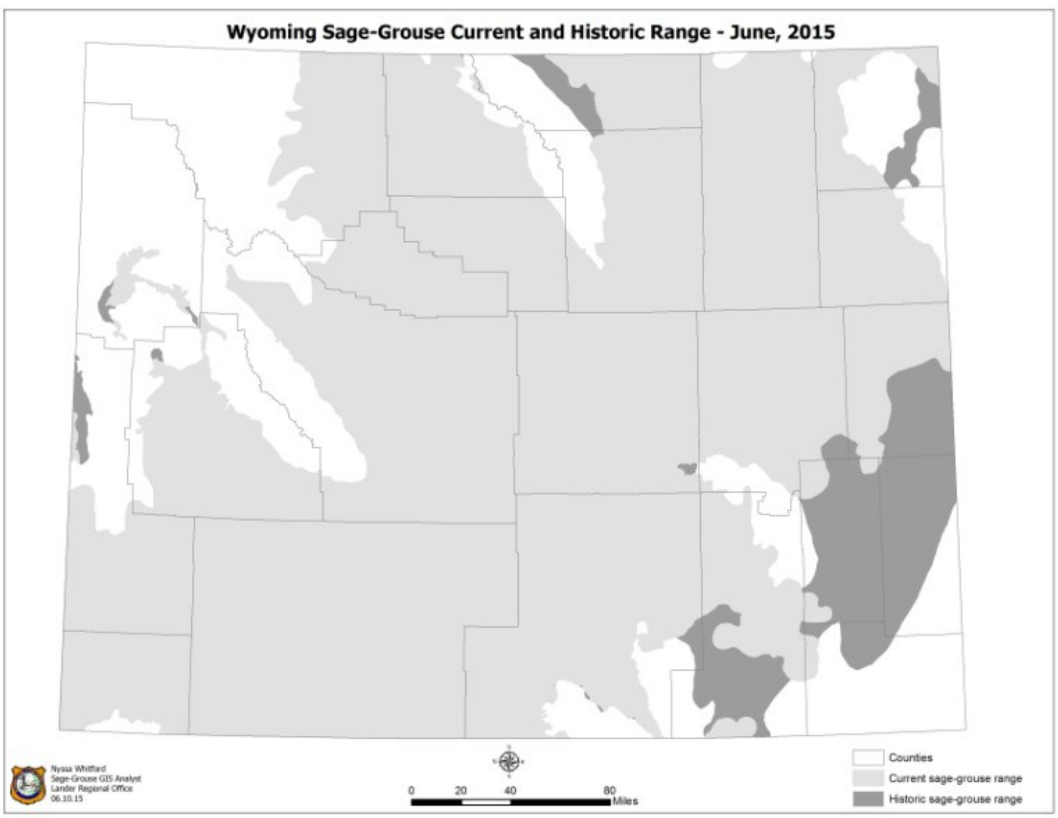


Figure 4. Sage-grouse range in Wyoming (updated 2015).

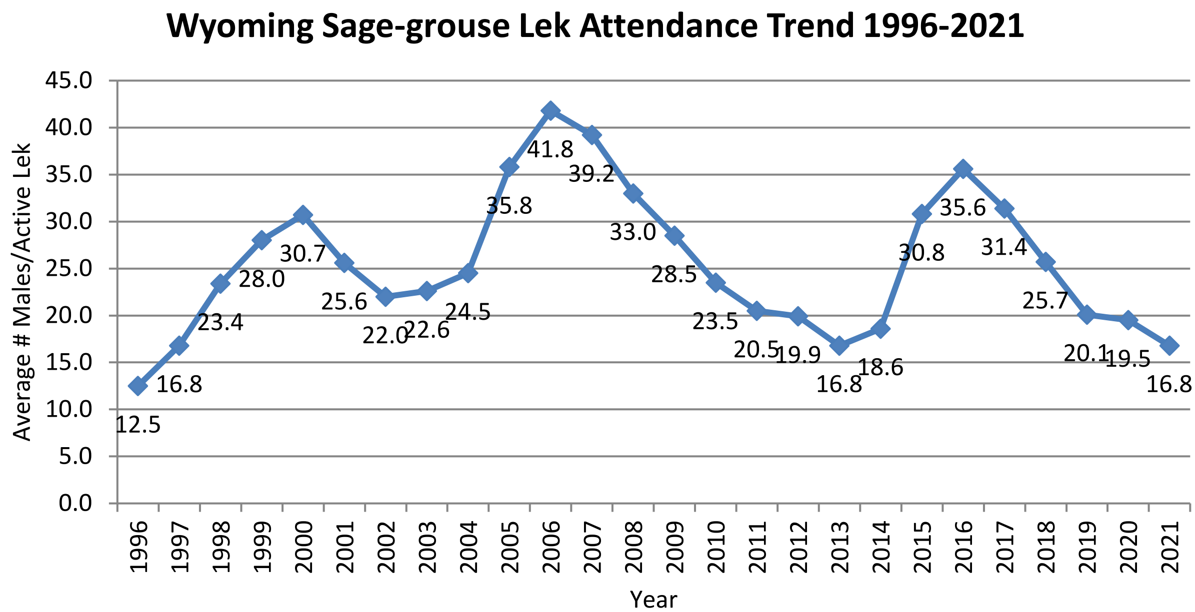


Figure 5. Wyoming sage-grouse lek attendance trend 1996-2021.

METHODS

Methods for collecting sage-grouse data are described in the sage-grouse chapter of the WGFD Handbook of Biological Techniques (Christiansen 2012), which is largely based on Connelly et al (2003). See Attachment A for the definitions used in lek monitoring.

RESULTS

Lek monitoring

While WGFD has been visiting leks to count sage-grouse since 1948, the most consistent statewide data were not collected until the mid-1990s. The number of leks checked in Wyoming has increased markedly since 1949. However, data from the 1950s through the 1970s is unfortunately sparse and by most accounts this is the period when the most dramatic declines of grouse numbers occurred. Some lek data collected during this period are historical reports with summary tables only, but the observation data for most individual leks are missing, making comparisons to current information difficult. Concurrent with increased monitoring effort over time, the number of male sage-grouse (hereafter, males) observed also increased (Figure 6). The increased number of grouse counted was not necessarily a reflection of a population increase, but rather a result of increased monitoring efforts.

The average number of males counted per lek decreased through the 1980s and early 1990s to an all- time low in 1995, but then recovered to a level similar to the late 1970s in 2006 (Figure 7). Again, fluctuations in the number of grouse observed on leks can be largely due to survey effort not to changes in grouse numbers exclusively, but certainly the number of males counted on leks exhibited recovery between 1995 and 2006 as the average size of leks increased and is generally interpreted to reflect an increasing population. The same cannot be said for the 2006-2013 period when effort stayed relatively constant, but the average number of males observed on leks declined, though not to levels documented in the mid-1990s. From 2013-2016, average lek size increased 112%. In 2021, average lek size declined to an average of 16.8 males/active lek which is 35% lower than the 10-year (2011-2020) average of 23.9 males/active lek. Thus, there has been a long-term decline and short-term cyclic increases and decreases in the statewide sage-grouse population. The short-term trends in statewide populations are believed to be largely weather related. In the late 1990s, and again in 2004-05, timely precipitation resulted in improved habitat conditions allowing greater numbers of sage-grouse to hatch and survive. Drought conditions from 2000-2003 and again later in that decade are believed to have caused lower grouse survival leading to population declines. These trends are valid at the statewide scale. Trends are more varied at the local scale. Sub-populations more heavily influenced by anthropogenic impacts (residential development, intensive energy development, large-scale conversion of habitat from sagebrush to grassland or agriculture, interstate highways, etc.) have experienced declining populations or extirpation.

Past analyses suggest Wyoming sage-grouse populations are cyclic (Fedy and Doherty 2010, Fedy and Aldridge 2011). While weather and climate undoubtedly influence sage-grouse population cycles, such influences have not been quantified and factors other than weather (predation, parasites) may also play a role. It is important to acknowledge and control for the cyclic nature of sage-grouse when conducting impact studies and monitoring grouse response to management.

Since only “occupied” leks are reported in Table 1, it is important to consider trends in the numbers of active versus inactive leks in addition to the average size of active leks (see Attachment A for definitions of occupied, inactive, etc.). During a period of population decline, the size of active leks typically declines and the number of inactive leks increases. The converse is typically true of an increasing population. Therefore, the magnitude of both increases and decreases is usually greater than indicated by the average lek size alone.

Average female lek attendance is not reported since our data collection techniques are not designed to accurately capture these data; therefore, the number of female sage-grouse is not a useful figure in assessing population trend.

WGFD bifurcates the lek data into two categories: lek *counts* and lek *surveys* (Attachment A). Lek counts are a census technique where a lek is visited at least 3 times a spring under ideal counting conditions. Lek surveys are a monitoring technique designed primarily to determine whether leks are active or inactive. However, male sage-grouse attending leks are often tallied during lek surveys, providing valuable data.

Lek monitoring data for the 2021 breeding season are summarized in Tables 1a-d and Figures 7-12. WGFD personnel and others checked 85% (1,481/1,746) of the known occupied leks in 2021 (Table 1c). Male attendance at all leks visited (counts and surveys) averaged 16.8 males per lek during spring 2021 (Table 1c). For the 10-year period (2012-2021), average male lek attendance ranged from 16.8 males/lek in 2013 and 2021, the lowest average males per lek since 1997, to a high of 35.6 males/lek in 2016. The proportion of active, occupied leks increased slightly from 74.9% in 2020 to 75.9% in 2021 (Table 1d).

In 2021, 2,932 fewer male sage-grouse were observed compared to 2020, even though more leks were visited in 2021 (Table 1c). Cumulatively, the lek attendance data suggest there were fewer grouse in bio-year 2020 than in 2021. It is important to note that the same leks were not checked from year to year over the last 10 years. However, leks that were checked consistently over the same period demonstrated the same trends except in some local areas as described in the Regional JCRs.

Small changes in the statistics reported between annual JCRs are due to revisions and/or the submission of data not previously available for entry into the database (late submission of data, discovery of historical data from outside sources, etc.). These changes have not been significant on a statewide scale and interpretation of these data has not changed.

While a statistically valid method for estimating population size for sage-grouse has not yet been applied in Wyoming, monitoring male attendance on leks provides a reasonable index of relative change in abundance in response to prevailing environmental conditions over time. However, lek data must be interpreted with caution for several reasons: 1) the survey effort and the number of leks visited has varied over time, 2) not all leks have been located, 3) sage-grouse populations cycle, 4) the effects of unlocated or unmonitored leks that have become inactive cannot be quantified or qualified, and 5) lek locations may change over time. Both the number of leks and the number of males attending these leks must be quantified in order to estimate population size.

Five independent analyses have assessed changes in long-term sage-grouse populations at rangewide, statewide, population and sub-population levels in recent years (Connelly et al. 2004, WAFWA 2008, 2015, Garton et al. 2011, Nielson et al. 2015, Coates et al. 2021). The trends reflected by these analyses are generally consistent with each other and with that shown in Figure 7. In 2013, WAFWA contracted with the University of Montana to develop better sampling designs and population trend estimators. This contract resulted in the development of a generalized integrated population model to estimate annual abundance from counts of males at breeding leks (McCaffrey and Lukacs 2016). This tool will be further tested and implemented as appropriate in Wyoming.

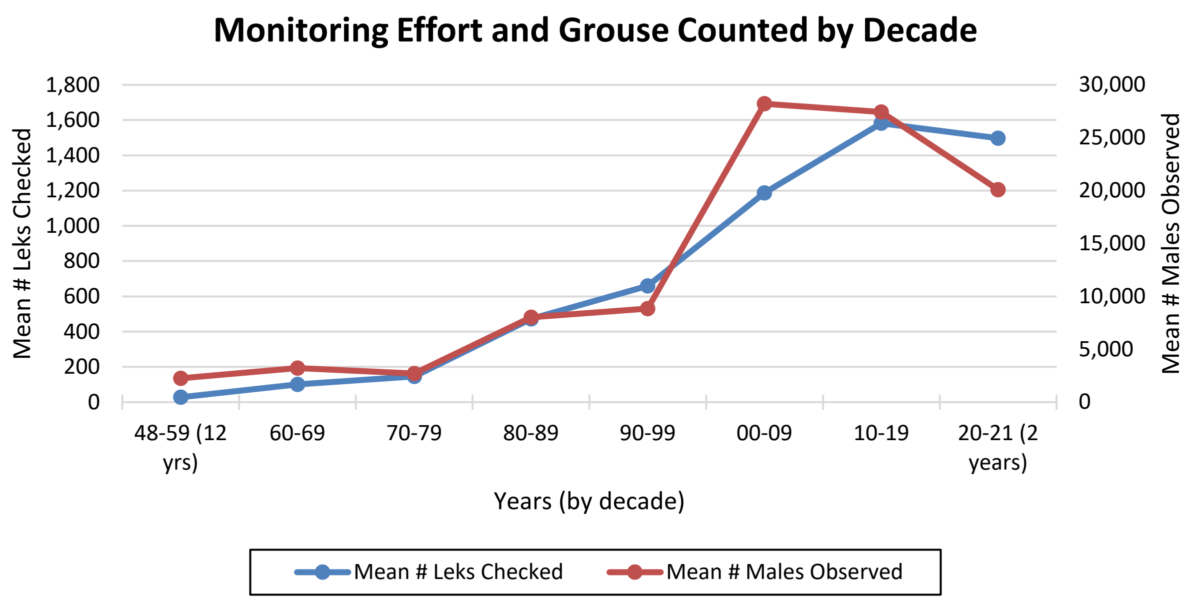


Figure 6. Mean annual numbers of leks checked (monitoring effort) and male grouse counted in Wyoming 1948-2021 by decade.

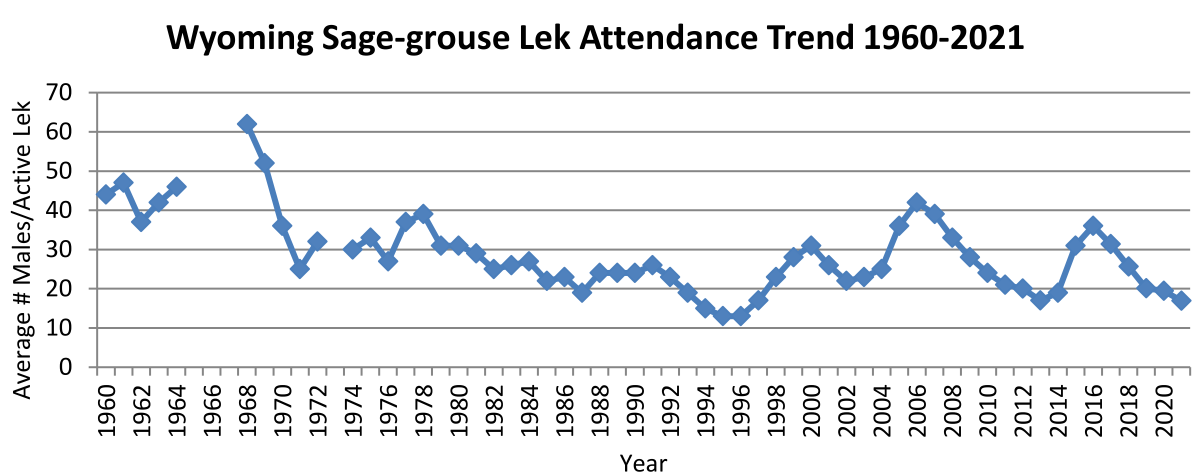


Figure 7. Average number of males per lek counted in Wyoming from 1960-2021 with a minimum of 100 leks checked each year.

Table 1a. Leks Counted

Year	Occupied[1]	Counted	Percent Counted	Peak Males	Avg Males / Active Lek[2]
2012	1779	716	40	12661	23.0
2013	1791	646	36	10628	20.7
2014	1794	773	43	11466	20.6
2015	1824	743	41	19505	34.2
2016	1839	733	40	23387	40.4
2017	1828	690	38	18701	35.4
2018	1817	800	44	17124	28.2
2019	1794	698	39	11884	21.9
2020	1764	776	44	12286	21.5
2021	1746	754	43	10108	19.0

Table 1b. Leks Surveyed

Year	Occupied[1]	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek[2]
2012	1779	817	46	8609	16.7
2013	1791	927	52	7646	13.4
2014	1794	837	47	8604	16.5
2015	1824	880	48	17029	27.7
2016	1839	948	52	19884	31.3
2017	1828	960	53	17893	28.1
2018	1817	808	44	12441	22.9
2019	1794	871	49	9558	18.2
2020	1764	651	37	6477	16.5
2021	1746	727	42	5723	14.1

Table 1c. Leks Checked

Year	Occupied[1]	Checked	Percent Checked	Peak Males	Avg Males / Active Lek[2]
2012	1779	1533	86	21270	19.9
2013	1791	1573	88	18274	16.8
2014	1794	1610	90	20070	18.6
2015	1824	1623	89	36534	30.9
2016	1839	1681	91	43271	35.6
2017	1828	1650	90	36594	31.4
2018	1817	1608	88	29565	25.7
2019	1794	1569	87	21442	20.1
2020	1764	1427	81	18763	19.5
2021	1746	1481	85	15831	16.8

Table 1d. Lek Status

Year	Active	Inactive[3]	Unknown	Known Status	Percent Active	Percent Inactive
2012	1117	246	170	1363	82.0	18.0
2013	1114	285	174	1399	79.6	20.4
2014	1105	352	150	1457	75.8	24.2
2015	1215	275	133	1490	81.5	18.5
2016	1258	276	147	1534	82.0	18.0
2017	1204	305	141	1509	79.8	20.2
2018	1179	300	129	1479	79.7	20.3
2019	1134	298	137	1432	79.2	20.8
2020	1006	337	84	1343	74.9	25.1
2021	994	316	171	1310	75.9	24.1

1) Occupied: Active during previous 10 years (see Attachment A for definitions)

2) Avg Males/Active Lek: Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented

3) Inactive: Confirmed no birds/sign present (see Attachment A for definitions)

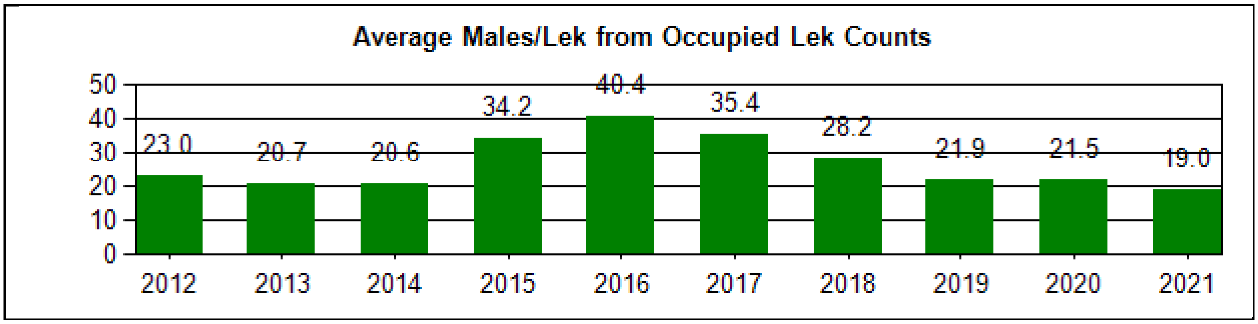


Figure 8. Average males/lek from occupied lek counts.

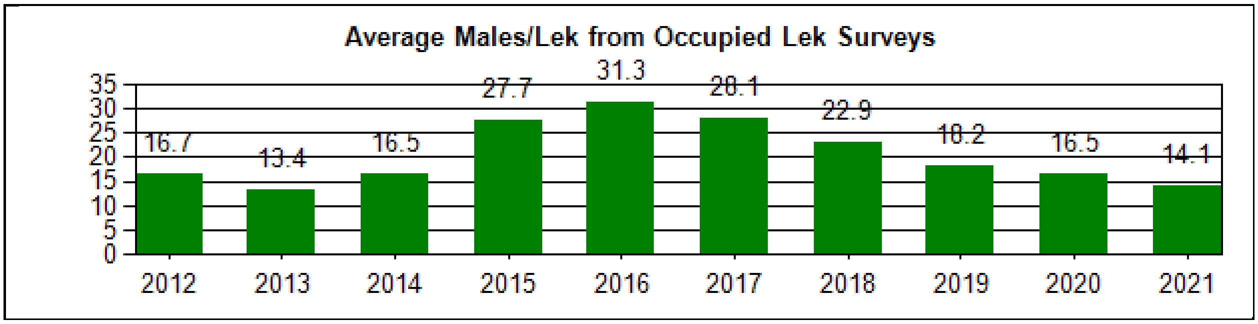


Figure 9. Average males/lek from occupied lek surveys.

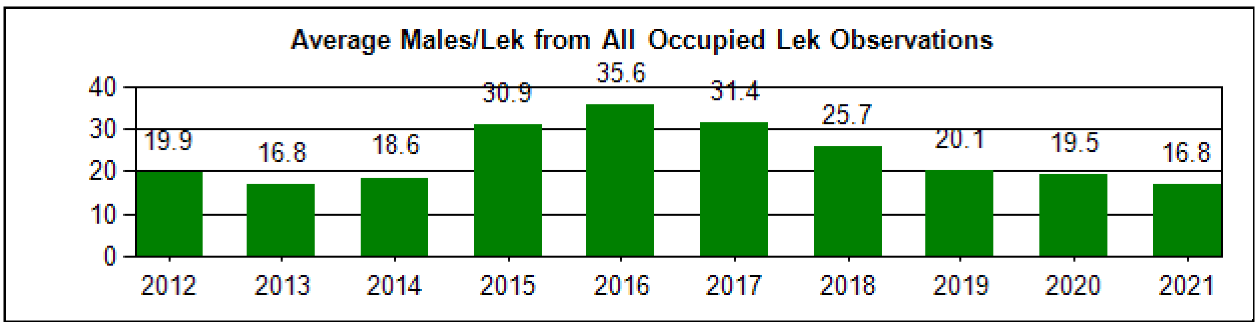


Figure 10. Average males/lek from all occupied leks checked (counts+surveys).

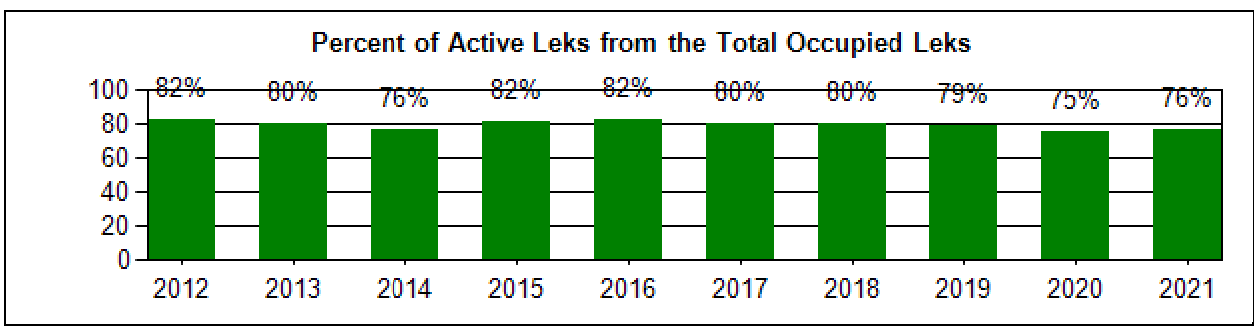


Figure 11. Percent active leks from the occupied leks checked with known status.

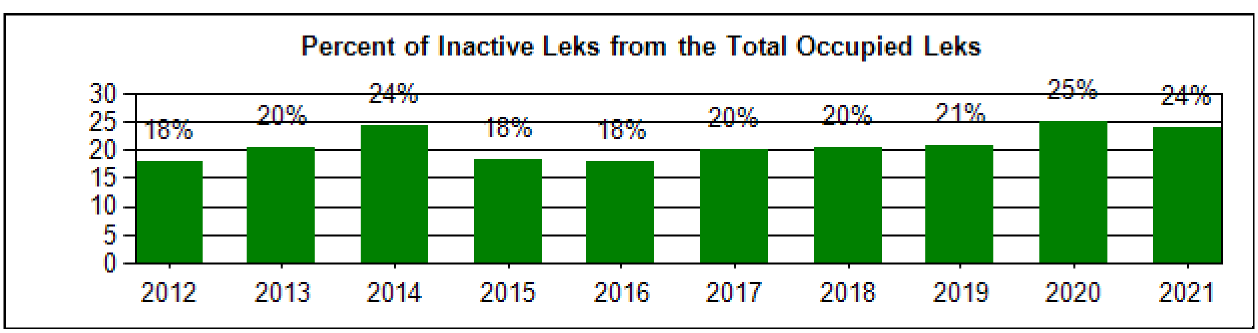
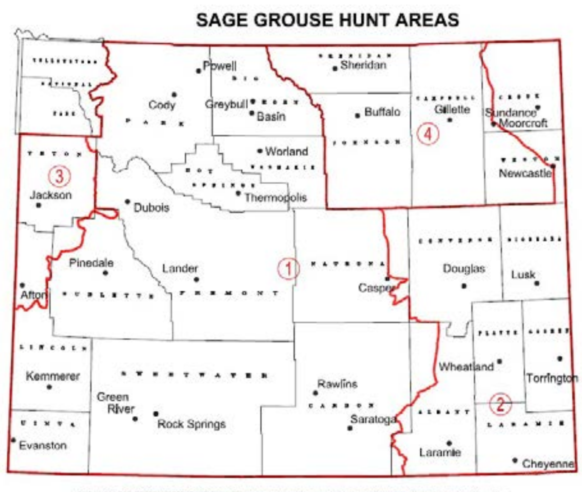


Figure 12. Percent inactive leks from the occupied leks checked with known status.

Hunting season and harvest

As a result of concerns about the issue of hunting and its impact to sage-grouse, a white paper was prepared in 2008 then revised in 2010 (Christiansen 2010), presented to the Wyoming Game and Fish Commission and distributed through the WGFD website. The science and public policy bases for managing sage-grouse harvest in Wyoming are covered in detail within that document. Similarly, the Western Association of Fish and Wildlife Agency directors adopted a policy statement on the topic in the summer of 2010 (Attachment D in Christiansen 2010).

The 2020 hunting season (Figure 13, Table 2) for most of the state (Area 1) was 2 days longer than 2019 due to the calendar effect of opening the season on the third Saturday of September. In 2019, the third Saturday was September 21, but in 2020, it was September 19.



Area	Season Dates	Daily/Poss. Limits	Falconry
1	Sept. 19-Sept. 30	2/4	Sept. 1-Mar. 1
2, 3	Closed	Closed	Closed
4	Sept. 19-Sept. 21	2/4	Sept. 1-Mar. 1

Figure 13 and Table 2. 2020 sage-grouse hunting season map and regulations.

Hunting seasons and harvest in Wyoming are shown in Tables 3a-b. Due to concerns over low populations, the statewide hunting season was shortened and the daily bag limit decreased to two sage-grouse in 2002 and has remained very conservative since that time. Two areas, eastern Wyoming and the Snake River Drainage in northwest Wyoming, are closed to sage-grouse hunting (Figure 13).

Delaying and shortening the season and decreasing the bag limit dramatically decreased the numbers of sage-grouse hunters and their harvest. Hunters were also sensitive to the plight of grouse populations and did not take the opportunity to hunt sage-grouse as much as they had in the past. The data presented in Table 3b and

Figures 14-17 are estimated from a voluntary hunter survey. However, the 2020 sage-grouse harvest estimates should be interpreted with caution, because that particular year's survey under-sampled potential sage-grouse hunters from certain license fee types, resulting in poor quality harvest estimates. Making comparisons between previous years' estimates and the 2020 estimates should be avoided, because the results from the voluntary survey were unreliable due to sampling issues.

Tables 3 a-b. Sage Grouse Hunting Seasons and Harvest Data

Year	Season Start	Season End	Length	Bag/Possesion Limit
2011-1	Sep-17	Sep-30	14	2/4
2011-4	Sep-17	Sep-19	3	2/4
2012-1	Sep-15	Sep-30	16	2/4
2012-4	Sep-15	Sep-17	3	2/4
2013-1	Sep-21	Sep-30	10	2/4
2013-4	Sep-21	Sep-23	3	2/4
2014-1	Sep-20	Sep-30	11	2/4
2014-4	Sep-20	Sep-22	3	2/4
2015-1	Sep-19	Sep-30	12	2/4
2015-4	Sep-19	Sep-21	3	2/4
2016-1	Sep-17	Sep-30	14	2/4
2016-4	Sep-17	Sep-19	3	2/4
2017-1	Sep-16	Sep-30	15	2/4
2017-4	Sep-16	Sep-18	3	2/4
2018-1	Sep-15	Sep-30	16	2/4
2018-4	Sep-15	Sep-17	3	2/4
2019-1	Sep-21	Sep-30	10	2/4
2019-4	Sep-21	Sep-23	3	2/4
2020-1	Sep-19	Sep-30	12	2/4
2020-4	Sep-19	Sep-21	3	2/4

Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2011	10,290	4,568	11,186	0.9	2.3	2.4
2012	9,869	4,700	11,342	0.9	2.1	2.4
2013	5,726	3,383	7,672	0.7	1.7	2.3
2014	7,094	3,526	8,642	0.8	2.0	2.5
2015	10,498	4,299	10,231	1.0	2.4	2.4
2016	10,526	4,674	11,476	0.9	2.3	2.5
2017	7,817	3,576	8,646	0.9	2.2	2.4
2018	10,422	5,035	13,092	0.8	2.1	2.6
2019	7,615	4,229	9,473	0.8	1.8	2.2
2020*	6,544	3,227	9,705	0.7	2.0	3.0
Average	8,640	4,122	10,147	0.8	2.1	2.5

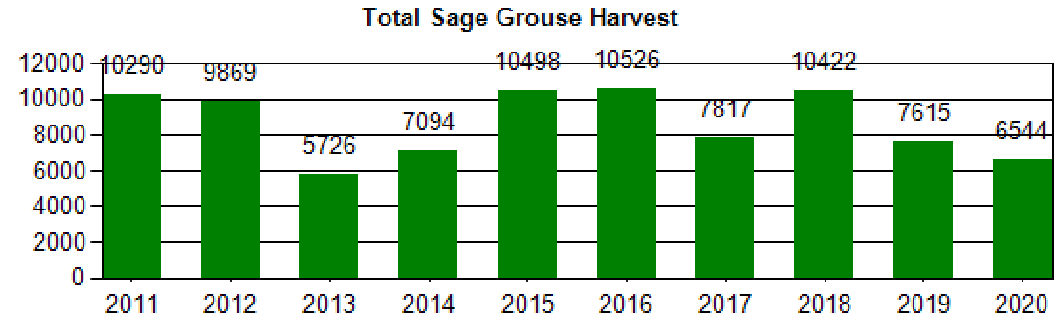


Figure 14. Wyoming statewide sage-grouse harvest 2011-2020.

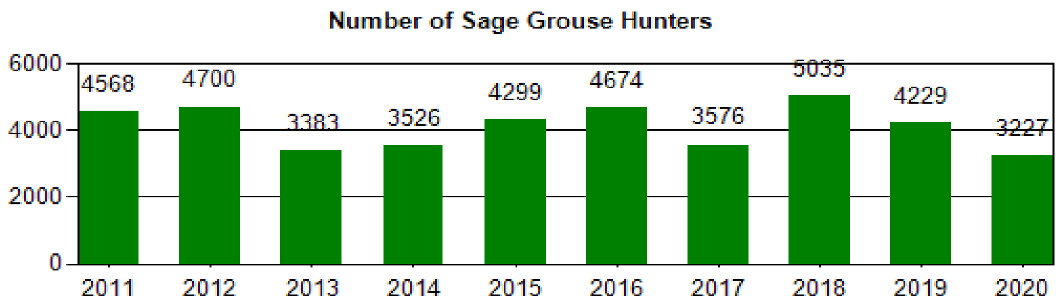


Figure 15. Wyoming statewide sage-grouse hunter numbers 2011-2020.

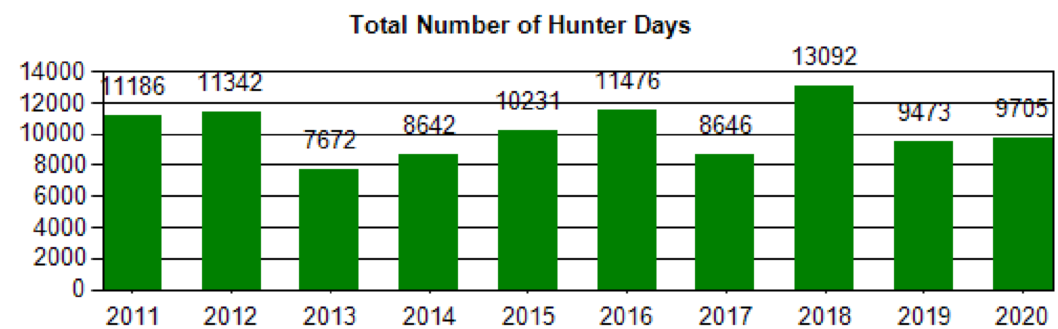


Figure 16. Wyoming statewide number of hunter days 2011-2020.

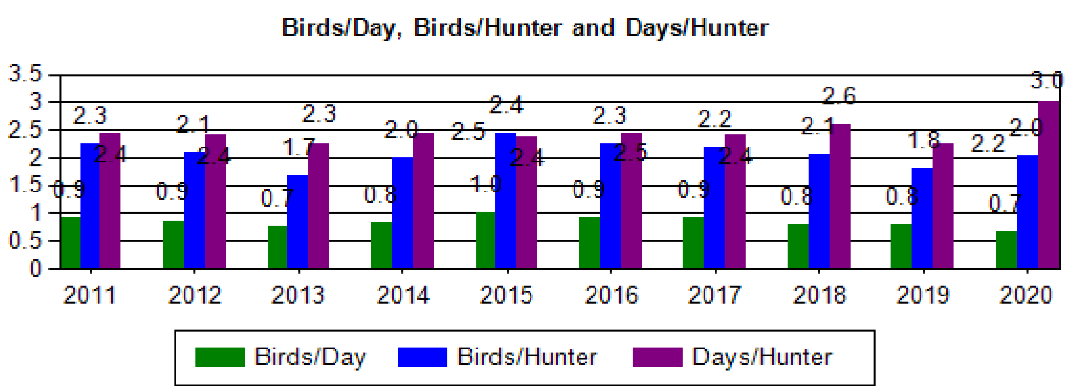


Figure 17. Wyoming statewide birds/day, birds/hunter and days/hunter 2011-2020.

Hunters voluntarily submit sage-grouse wings separately from the harvest survey, so 2020 wing data can be compared to previous years. The 2020 chick:hen ratio was 1.1 chicks per hen (Table 4 and Figure 17). This level of productivity is typically associated with a declining population. This is consistent with the 2021 lek data (all lek checked), which indicated a 13% decrease in the average numbers of males on leks (Table 5). When 1997-2020 data are pooled, average male lek attendance declined an average of 12% when chick:hen ratios the previous fall were less than 1.4:1, were closer to 0% change (-6%) when chick:hen ratios the previous fall were 1.4 to 1.6:1 and increased an average of 32% when chick:hens ratios were 1.7:1 or higher. Additional data are required to strengthen the statistical basis of these analyses.

Prior to 1997, wing analysis results may be questionable in some parts of the state, because most personnel were not well trained in techniques.

Year	Sample	Percent Adult		Percent Yearling		Percent Young		Chicks/
	Size	Male	Female	Male	Female	Male	Female	Hens
2011	2,425	8.9	31.2	4.0	5.6	21.3	29.0	1.4
2012	1,938	13.4	36.6	4.5	8.8	15.5	21.2	0.8
2013	1,258	12.0	35.8	2.3	6.5	18.8	24.4	1.0
2014	1,533	9.5	23.9	2.5	7.8	28.8	27.5	1.8
2015	2,300	12.7	25.8	3.6	5.4	24.8	27.7	1.7
2016	2,097	16.9	33.0	4.5	7.6	16.7	21.2	0.9
2017	2,047	13.8	31.7	3.3	6.0	20.7	24.6	1.2
2018	2,112	14.2	32.4	6.2	11.3	13.9	22.0	0.8
2019	1,631	10.4	31.5	3.2	9.7	14.9	30.3	1.1
2020	2,171	9.8	31.5	4.1	9.1	17.4	28.1	1.1

Table 4. Composition of harvest by wing analysis 2011-2020.

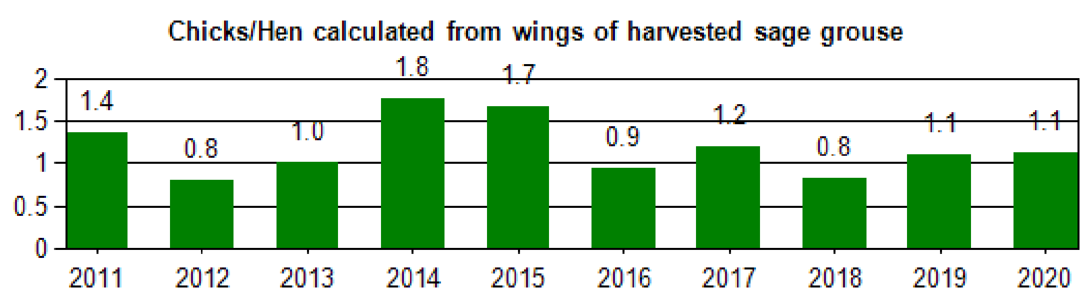


Figure 17. Average number of chicks per hen 2011-2020 based on wings from harvested sage-grouse.

Year	Chicks:Hen (based on wings from harvested birds)	Change in male lek attendance the following spring
1997	1.9	+36%
1998	2.4	+21%
1999	1.8	+13%
2000	1.1	-20%
2001	1.6	-15%
2002	1.6	+3%
2003	1.5	+4%
2004	2.4	+57%
2005	2.0	+17%
2006	1.2	-5%
2007	0.8	-16%
2008	1.5	-16%
2009	1.1	-21%
2010	0.9	-13%
2011	1.4	-7%
2012	0.8	-16%
2013	1.0	+11%
2014	1.8	+66%
2015	1.7	+16%
2016	0.9	-11%
2017	1.2	-18%
2018	0.8	-21%
2019	1.1	-2.5%
2020	1.1	-13%

Table 5. Potential influence of chick production, based on wings from harvested birds, on population trend as measured by male lek attendance.

Weather and Habitat

The ability of sage-grouse to successfully nest and raise chicks is linked to habitat condition, specifically shrub height and cover, grass cover, and forb cover. The shrubs (primarily sagebrush) and grasses provide screening cover from predators and weather while the forbs provide food in the form of the plant material itself and insects that use the forbs for habitat. Spring precipitation is an important determinant of the quantity and quality of these vegetation characteristics. Grass and forb cover are largely dependent on the current year's precipitation.

Research has shown weather and climate are linked to sage-grouse population trends (Heath et al. 1997, Blomberg et al 2014a/b, Caudill et al. 2014). In general, spring precipitation is positively linked to summer chick survival, autumn chick:hen ratios, which are in turn, linked to the next year's lek counts of males. However, periods of prolonged cold, wet weather may have adverse effects on hatching success, chick survival, and plant and insect phenology and production. Untimely late snow storms in May and early June of 2009, 2010, and 2016 likely contributed to reduced nesting success and chick survival. Efforts to quantify/qualify these effects in a predicable fashion over meaningful scales have largely failed.

Calendar year 2012 was the hottest, driest year documented in Wyoming since record keeping began 118 years previous (NOAA 2012). The lack of spring moisture in 2012 meant little production of important food plants and insects, therefore lower chick survival and more birds than usual were likely forced to move to either higher elevation or irrigated meadows and steam courses. Wyoming experienced significant drought in the spring of 2021 also. As of May 2021, 80% of Wyoming was in at least a moderate to extreme drought.

Habitat and seasonal range mapping

While we believe that most of the currently occupied leks in Wyoming have been documented, other seasonal habitats such as nesting/early brood-rearing and winter concentration areas have not been identified. Efforts to map seasonal ranges for sage-grouse will continue by utilizing winter observation flights and the on-going land cover mapping efforts of the USGS (Fedy et al. 2014), BLM, WGFD, the Wyoming Geographic Information Science Center (WYGISC) of the University of Wyoming and others.

CONSERVATION STRATEGIES

Governor's Core Area Strategy (CAS) and Executive Order

Management of greater sage-grouse habitat in Wyoming is based on a "core area" strategy of limiting human disturbance in the most important sage-grouse habitats. This strategy is codified by a Governor's executive order. The Executive Order and related materials are available at: https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management

The Core Area Strategy is being implemented across the state under the guidance of a state/federal interagency team of specialists (Sage-grouse Implementation Team; SGIT) who meet on a regular basis to discuss issues related to implementation of the strategy. A key component of the strategy's implementation is the Density and Disturbance Calculation Tool (DDCT). This tool was developed by agency GIS specialists as an interactive, on-line application through the University of Wyoming's Geographic Information and Science Center. Training sessions are provided to industry and agency staff required to use the DDCT.

Conservation Planning

In 2000, the WGFD formed a citizen/agency working group for the purpose of developing a statewide strategy for conservation of sage-grouse in Wyoming. The working group completed its task and in 2003 The Wyoming Greater Sage-Grouse Conservation Plan (WGFD 2003) was approved by the Wyoming Game and Fish Commission. The State Plan was largely reliant on implementation by local working groups. The state's eight LWGs all submitted final conservation plans between 2006 and 2008. In 2012, the local working groups began the process of updating their plans with current information to make them consistent with the Wyoming Core Area Strategy, address the Service's 2010 listing decision and incorporate new science. The updated plans were presented to the Wyoming Game and Fish Commission in

March 2014.

From 2005-2017, Local Working Groups were allocated approximately $6.3 million to support implementation of local sage-grouse conservation projects. The source of this funding was the State of Wyoming General Fund as requested by the Governor and approved by the legislature. The 2016 Legislature appropriated another $1.1 million for the 2017-18 biennium. Allocation of these funds began July 1, 2016. Subsequently, the 2017 legislature returned budget responsibility of the sage-grouse program back to the Department due to state budget shortfalls. This action shifted the funding burden from the state as a whole, based largely on mineral severance taxes, to hunters and anglers, the primary funding source of the WGFD. A hunting license fee increase specifically crafted to replace legislative funding was approved by the legislature and LWGs will maintain their existing role in recommending how funds will be allocated. The Wyoming Game and Fish Commission has allocated $548,000 annually since FY2019 to fund local working group projects.

During Fiscal Year 2021, twenty-five (25) projects (Attachment B) were funded. Most of the projects are supported by multiple cost-sharing partners. Cumulatively, two-hundred-ninety-three (293) projects have been approved since 2005. Projects include habitat treatments/restoration, improved range management infrastructure and grazing management plans, applied research, inventories, monitoring and public outreach.

OTHER ISSUES

Wyoming to North Dakota Translocation Project

In the spring of 2020 at the Bowman County, North Dakota study site, Utah State University (USU) researchers were actively monitoring n = 4 males that were captured and translocated in 2019, n = 2 females captured and translocated in 2018 (n = 1 GPS PTT and n = 1 VHF), n = 4 GPS PTT females captured and translocated in 2019, and n = 2 yearling males from the 2019 chicks that were recaptured and marked with adult VHF transmitters at 65 days old. USU added via translocation in 2020 n = 19 brood females marked with GPS PTT radios. One additional brood female was trapped but died due to capture myopathy. USU translocated 20 broods (n = 108 chicks) with the brood hens. USU marked each chick with 1.3 g VHF transmitters. Broods were released at multiple locations in Bowman County based on available brood habitat (big sagebrush grasslands). Of the 108 chicks translocated in 2020, USU confirmed: 38 (35%) survived to > 50 days (approximate age when chicks can survive independently), and 64 chicks (59%) died prior to 50 days. Six chicks were not able to be relocated after release. Of the 19 broods translocated to the Bowman County study site, chicks from 15 broods survived to post 50 days and were still alive when researchers left in early August 2020. Due to COVID-19 restrictions during the spring of 2020, we did not translocate 20 males as planned (males are captured during the mating season and captures involve larger crews). At the end of the 2020 field season

(August), in the Stewart Creek study area USU confirmed 18/25 (72%) marked females were still alive, including 4 broods. At the end of the 2020 field season in the Bowman County study site 4/20 (20%) males from the 2019 release were still alive, 2/40 (5%) yearlings translocated as chicks in 2019 were still alive (both males), 2/19 (11%) GPS PTT females from the 2019 release. The last two marked females from 2018 translocations went missing, likely due to radio failure. Additionally, 14/19 (73%) females and 38/108 (35%) chicks from the 2020 brood translocations were still alive.

Over the 4 years of this translocation project, initial thoughts by field managers are 1) translocations have had a positive impact for ND and little, if any, impacts to WY, but 2) translocations would need to occur on a longer time scale to ensure that translocations coincide with a rare "good" year, climate-wise and 3) brood translocations were the best hope and had the shortest dispersals and shortest time spent exploring the new habitat before settling into a localized behavior state; however 4) since hens did not explore when translocated with a brood, choosing a high-quality brood-rearing site is critical.

Sage-grouse Bird Farm Legislation

The 2017 state legislature passed a bill allowing private bird farm operations to collect sage-grouse eggs from the wild for purposes of establishing a captive flock. The Department and Commission promulgated regulations in Chapter 60 to permit this activity. One permit was issued to a facility in January 2019, January 2020, and January 2021. In April and May 2021, 133 eggs were collected from the wild for this purpose. The eggs were incubated at the facility and chicks hatched in the summer of 2021. As of July 13, 2021, 94 live sage-grouse resided in the pens of the facility.

West Nile Virus

West Nile virus (WNv) was first confirmed in sage-grouse in 2003 in the northern Powder River Basin and is considered a *potential* threat to sage-grouse populations. Research efforts have resulted in several published papers and theses that describe the disease and its potential impact to sage-grouse populations (Walker and Naugle 2011 and references therein).

Monitoring efforts in 2020 again included: 1) intensive monitoring of radio-collared sage-grouse during the late summer on study sites across Wyoming, 2) WGF field personnel were directed to collect late summer sage-grouse mortalities and submit them for testing, and 3) press releases were distributed requesting the general public, especially landowners, to report late summer sage-grouse mortalities. No West Nile virus mortality was documented during this reporting period.

Energy Development

The issue of energy development and its effects to sage-grouse and sagebrush habitats continues to be a major one in many portions of the state. The topic is of major interest in Local Working Group efforts and the JCRs for the local conservation areas contain additional detail on the issue. Research efforts continue on oil and gas development impacts. One area of research need identified during the 2015 Core Area Strategy revision is identifying natural gas development impact thresholds relative to sage-grouse winter concentration areas. That topic is being pursued by the SGIT. Research relative to wind energy development also continues. The results of these research efforts inform and guide management actions associated with the Wyoming Core Area Strategy.

RESEARCH AND PUBLICATIONS

Attachment C is a listing of Wyoming-based research reports and peer-reviewed publications to date.

MANAGEMENT RECOMMENDATIONS

1) Implement Wyoming Governor's Sage-Grouse Executive Order and Core Area Strategy.

2) Continue to implement local conservation plans in all 8 planning areas.

3) Test the sage-grouse population model developed by Paul Lukacs at the University of Montana in cooperation with USFWS and WAFWA.

4) Continue to refine and de-bug the sage-grouse database and Job Completion Report intranet program.

5) Continue to map lek perimeters and integrate these data into the WGF lek database. Priority for this effort should be based on the lek size of lek and impending development actions that may impact leks.

6) Personnel monitoring leks should review and consistently follow established lek monitoring protocol each year.

7) Map seasonal habitats (nesting/early brood rearing, winter concentration areas) for sage- grouse using data from the on-going land cover mapping project and sage-grouse observations.

8) Regulate and enforce the sage-grouse bird farm law (House Enrolled Act No. 91 of the 64th Legislature of the State of Wyoming) in a manner that is compliant with the intent of the law and protects wild populations of sage-grouse to the extent possible. Monitor and document the outcomes and implications of the law and regulations and report results to policy makers and the public.

LITERATURE CITED:

Blomberg, E.J., D. Gibson, M.T. Atamian, and J.S. Sedinger. 2014a. Individual and environmental effects on egg allocations of female greater sage-grouse. Auk 131:507–523.

Blomberg, E.J., J.S. Sedinger, D. Gibson, P.S. Coates, and M.L. Casazza. 2014b. Carry-over effects and climatic conditions influence the postfledging survival of greater sage-grouse. Ecology and Evolution doi: 10.1002/ece3.1139

Caudill, D., M.R. Guttery, B. Bibles, T.A. Messmer, G. Caudill, E. Leone, D.K. Dahlgren, and R. Chi. 2014. Effects of climatic variation and reproductive trade-offs vary by measure of reproductive effort in greater sage-grouse. Ecosphere 5(12):154. http://dx.doi.org/10.1890/ES14- 00124.

Christiansen, T. 2012. Chapter 12: Sage Grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S.A. Tessmann and J.R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne, WY.

Christiansen, T. 2010. Hunting and sage-grouse: a technical review of harvest management on a species of concern in Wyoming. Wyoming Game and Fish Department. Unpublished report. Cheyenne, WY.

Coates, P.S., B.G. Prochazka, M.S. O'Donnell, C.L. Aldridge, D.R. Edmunds, A.P. Monroe, M.A. Ricca, G.T. Wann, S.E. Hanser, L.A. Wiechman, and M.P. Chenaille. 2021. Range-wide greater sage-grouse hierarchical monitoring framework–Implications for defining population boundaries, trend estimation, and a targeted warning system: U.S. Geological Survey Open-File Report 2020-1154. https://doi.org/10.3133/ofr20201154.

Connelly, J.W., K.P. Reese and M.A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. Station Bulletin 80. University of Idaho College of Natural Resources Experiment State. Moscow, ID.

Connelly, J.W., S.T. Knick, M.A. Schroeder and S.J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies. Unpublished report. Cheyenne, WY.

Fedy, B.C. and K.E. Doherty. 2010. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage-grouse and cottontail rabbits. Oecologia 165:915-924.

Fedy, B.C. and C.L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Fedy, B.C., C.L. Aldridge, K.E. Doherty, M.S. O'Donnell, J.L. Beck**,** B. Bedrosian, M.J. Holloran, G.D. Johnson, N.W. Kaczor, C.P. Kirol, C.A. Mandich, D.

Marshall, G. McKee, C. Olson, C.C. Swanson, and B.L. Walker. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. Journal of Wildlife Management 76:1062–1071.

Fedy, B.C., K.E. Doherty, C.L. Aldridge, M.S. O'Donnell, J.L. Beck, B. Bedrosian, D. Gummer, M.J. Holloran, G.D. Johnson, N.W. Kaczor, C.P. Kirol, C.A. Mandich, D. Marshall, G. McKee, C. Olson, A.C. Pratt, C.C. Swanson, B.L. Walker. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: an example using greater sage-grouse in Wyoming. Wildlife Monographs 190:1–39.

Gamo, R.S. and J.L. Beck. 2017. Effectiveness of Wyoming's sage-grouse core areas: Influences on energy development and male lek attendance: Environmental Management 59(2)189-203.

Garton, E.O., J.W. Connelly, J.S. Horne, C.A. Hagen, A. Moser, and M. Schroeder. 2011. Greater sage-grouse population dynamics and probability of persistence. Pp. 293 – 382 *in* S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian biology (vol. 38). University of California Press, Berkeley, CA.

Green, A.W., C.L. Aldridge, and M.S. O'Donnell. 2017. Investigating impacts of oil and gas development on greater sage-grouse: Journal of Wildlife Management 81(1):46-57.

Heath, B.J., R. Straw, S.H. Anderson, J. Lawson. 1997. Sage-grouse productivity, survival and seasonal habitat use near Farson, Wyoming. Research Completion Report. Wyoming Game & Fish Dept., Cheyenne.

Juliusson, L.M. and K.E. Doherty. 2017. Oil and gas development exposure and conservation scenarios for greater sage-grouse: Combining spatially explicit modeling with GIS visualization provides critical information for management decisions. Applied Geography 80:98-111.

LeBeau, C.W., J.L. Beck, G.D. Johnson, R.M. Nielson, M.J. Holloran, K.G. Gerow, and T.L. McDonald. 2017a. Greater sage-grouse male lek counts relative to a wind energy development. Wildlife Society Bulletin 41:17-26.

LeBeau, C.W., G.D. Johnson, M.J. Holloran, J.L. Beck, R.M. Nielson, M.E. Kauffman, E.J. Rodemaker, and T.L. McDonald. 2017b. Greater sage-grouse habitat selection, survival, and wind energy infrastructure. Journal of Wildlife Management 81:690–711.

McCaffery, R. and P.M. Lukacs. 2016. A generalized integrated population model to estimate greater sage-grouse population dynamics. Ecosphere 7(11) art. e01585. http://doi.org/10.1002/ecs2.1585.

Nielson, R.M., L.L. McDonald, J. Mitchell, S. Howlin, and C. LeBeau. 2015. Analysis of greater sage-grouse lek data: Trends in peak male counts 1965-2015. Western EcoSystems Technology, Inc., Cheyenne, Wyoming, USA.

NOAA National Climatic Data Center. 2012. State of the Climate: National Overview for Annual 2012. http://www.ncdc.noaa.gov/sotc/national/2012/13.

Patterson, R. L. 1952. The Sage Grouse in Wyoming. Sage Books. Denver, CO.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S. J. Stiver. 2004. Distribution of sage-grouse in North America. The Condor 106:363-376.

Walker, B.L. and D.E. Naugle. 2011. West Nile virus ecology in sagebrush habitat and impacts on greater sage-grouse populations. Pp. 127 – 144 *in* S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian biology (vol. 38). University of California Press, Berkeley, CA.

Western Association of Fish and Wildlife Agencies (WAFWA). 2008. Greater sage-grouse population trends: An analysis of lek count databases 1965-2007. Unpublished Report. Sage and Columbian Sharp-tailed grouse Technical Committee, WAFWA. 126 pp.

Western Association of Fish and Wildlife Agencies (WAFWA). 2015. Greater sage-grouse population trends: An analysis of lek count databases 1965-2015. Unpublished Report. Western Association of Fish and Wildlife Agencies, Cheyenne, WY. 54 pp.

Wyoming Game and Fish Department. 2003. Wyoming Greater Sage-Grouse conservation plan. Wyoming Game and Fish Department, Cheyenne, WY. 97 pp.

Attachment A:
Wyoming Sage-Grouse Lek Definitions:
(Revised November 2012)

The following definitions have been adopted for the purposes of collecting and reporting sage-grouse lek data. See the sage-grouse chapter of the Wyoming Game and Fish Department's Handbook of Biological Techniques for additional technical details and methods.

Lek - A traditional courtship display area attended by male sage-grouse in or adjacent to sagebrush dominated habitat. A lek is designated based on observation of two or more male sage-grouse engaged in courtship displays. Before a suspected lek is added to the database, it must be confirmed by a survey conducted during the appropriate time of day, during the strutting season. Sign of strutting activity (tracks, droppings, feathers) can also be used to confirm a suspected lek. Sub-dominant males may display on itinerant (temporary) strutting areas during years when populations peak. Such areas usually fail to become established leks. Therefore, a site with small numbers of strutting males (<5) should be confirmed active for two years before the site is added to the lek database.

Satellite Lek – A relatively small lek (usually less than 15 males) within about 500 meters of a large lek often documented during years of relatively high grouse numbers. Locations of satellite leks should be encompassed within lek perimeter boundaries. Birds counted on satellite leks should be added to those counted on the primary lek for reporting purposes.

Lek Perimeter – The outer perimeter of a lek and associated satellite leks (if present). Perimeters of all leks should be mapped by experienced observers using accepted protocols (Section 1.b.v below); larger leks should receive higher priority. Perimeters may vary over time as population levels or habitat and weather conditions fluctuate. However, mapped perimeters should not be adjusted unless grouse use consistently (2+ years) demonstrates the existing perimeter is inaccurate. The lek location must be identified and recorded as a specific point **within** the lek perimeter. This point may be the geographic center of the perimeter polygon calculated though a GIS exercise, or a GPS waypoint recorded in the field, which represents the center of breeding activity typically observed on the lek.

Lek Complex - A cluster of leks within 2.5 km (1.5 mi) of each other, between which male sage-grouse may interchange from day to day.

Lek Count - A census technique that documents the number of male sage-grouse observed attending a particular lek, lek complex, or leks along a lek route based on repeated observation.

- Conduct lek counts at 7-10 day intervals over a 3-4 week period after the peak of mating activity. Although mating typically peaks in early April in Wyoming, the number of males counted on a lek is usually greatest in late April or early May when attendance by yearling males increases.
- Conduct lek counts only from the ground. Aerial counts are not accurate and are not comparable to ground counts.

- Conduct counts from ½ hour before sunrise to 1 hour after.
- Count attendance at each lek a minimum of three times annually during the breeding season.
- Conduct counts only when wind speeds are less than 15 kph (~10 mph) and no precipitation is falling.
- All leks within a complex should be counted on the same morning.

Lek Count Route – A lek route is a group of leks in relatively close proximity that represent part or all of a discrete breeding population/sub-population. Leks should be counted on routes to facilitate replication by other observers, increase the likelihood of recording satellite leks, and account for shifts in distribution of breeding birds. Lek routes should be set up so an observer following criteria described under "Lek Count" can count all leks within 1.5 hours.

Lek Survey - A monitoring technique designed primarily to determine whether leks are active or inactive. Obtaining accurate counts of males attending is secondary.

- Ideally, all sage-grouse leks would be counted annually. However, some breeding habitat is inaccessible during spring because of mud and snow, or the location of a lek is so remote it cannot be routinely counted. In other situations, topography or vegetation may prevent an accurate count from any vantage point. In addition, time and budget constraints often limit the number of leks that can be visited. Where lek counts are not feasible for any of these reasons, surveys are the only reliable means to monitor population trends. Lek surveys are designed principally to determine whether leks are active or inactive, requiring as few as one visit to a lek. Obtaining accurate counts of the numbers of males attending is not essential. Lek surveys involve substantially less effort and time than lek counts. They can also be done from a fixed-wing aircraft or helicopter. Lek surveys can be conducted from the initiation of strutting in early March until early-mid May, depending on the site and spring weather. When large numbers of leks are surveyed (50+) the resulting trends of lek attendance over time mirror that of lek counts.

Annual status – Lek status is assessed annually based on the following definitions:

- **active** – Any lek that has been attended by male sage-grouse during the strutting season. Acceptable documentation of grouse presence includes observation of birds using the site or signs of strutting activity.

- **inactive** – Any lek where sufficient data indicates no strutting activity took place throughout a strutting season. Absence of strutting grouse during a single visit is not sufficient documentation to establish a lek is inactive. This designation requires documentation no birds were present on the lek during at least 2 ground surveys separated by at least 7 days. The surveys must be conducted under ideal conditions (site visits between April 1 and May 7, no precipitation, light or no wind, ½ hour before to 1 hour after sunrise) or a ground check of the exact lek location late in the strutting season (after 4/15) during which sign (droppings/feathers) of strutting activity is not found. Data collected by aerial surveys cannot be used to designate inactive status.

- **unknown** – Leks for which active/inactive status has not been documented during the course of a strutting season. Excepting leks not scheduled to be checked in a particular year, the "unknown" status designation should be applied only in rare instances. Each lek should be checked enough times to determine whether it is active or not. It is preferable to conduct two good field checks every other year and confirm the lek is "inactive" rather than check it once every year and have it remain in "unknown" status.

Management status - Based on its annual status, a lek is assigned to one of the following categories for management purposes:

- **occupied lek** – A lek that has been active during at least one strutting season within the prior ten years. Occupied leks are protected through prescribed management actions during surface disturbing activities.

- **unoccupied lek** – Two classifications of unoccupied leks are "destroyed" and "abandoned" (defined below). Unoccupied leks are not protected during surface disturbing activities.

    - **destroyed lek** – A formerly active lek site and surrounding sagebrush habitat that has been destroyed and is no longer suitable for sage grouse breeding. A lek site that has been strip-mined, paved, converted to cropland or undergone other long-term habitat type conversion is considered destroyed. Destroyed leks are not monitored unless the site has been reclaimed to suitable sage-grouse habitat.

    - **abandoned lek** – A lek in otherwise suitable habitat that has not been active during a period of 10 consecutive years. To be designated abandoned, a lek must be "inactive" (see above criteria) in at least four non-consecutive strutting seasons spanning the ten years. The site of an "abandoned" lek should be surveyed at least once every ten years to determine whether it has been reoccupied by sage-grouse.

- **undetermined lek** – Any lek that has not been documented as active in the last ten years, but survey information is insufficient to designate the lek as unoccupied. Undetermined lek sites are not protected through prescribed management actions during surface disturbing activities until sufficient documentation is obtained to confirm the lek is occupied. This status should be applied only in rare instances (also see "unknown" above).

Project Name	Fiscal Year	Local Working Group	SG $	Project Description	Partners	Status
270-Geophagy Research	2021	Southwest	$10,000 approved	Research into winter habitat selection and geophagy	Utah State University, BLM Pinedale Field Office	On-going
271-Wind Energy Research	2021	Bates Hole/Shirley Basin, South-Central, Southwest	$54,048 approved	Research into the effect of wind energy infrastructure on population viability and connectivity	University of Wyoming	On-going
272-Littlefield Water Development	2021	South-Central	$4,600 approved	Replace stolen solar array and pump on WHMA water development	BLM	On-going
273-Pennock Guzzler	2021	South-Central	$11,352 approved	Pennock WHMA Big Game and Sage-grouse Water Development	BLM	On-going
274-Sierra Madre Cheatgrass	2021	South-Central	$25,000 approved	Cheatgrass treatments on the west slope of the Sierra Madre mountains	BLM	On-going
275-NE Core Weeds	2021	Northeast	$75,000 approved	Cheatgrass treatments in Northeast LWG core areas	Clear Creek Conservation District	On-going
276-Livestock and Predator Research	2021	Bighorn Basin	$55,000 approved	Research on the interactive effects of rotational livestock grazing, predator presence, and habitat on sage-grouse demography	BLM Cody Field Office, Oregon State University, private landowners	On-going
277-Kirby Creek Weeds	2021	Bighorn Basin	$20,000 approved	Treatment of invasive weeds in the Kirby Creek area	Hot Springs County Weed & Pest	On-going
278-Treatments in Wyoming Big Sage	2021	Southwest, Wind River/Sweetwater	$17,564 approved	Publishing research results of large Jeffrey City treatment research	University of Wyoming	On-going
279-NPL Adaptive Management	2021	Southwest, Upper Green River Basin	$77,000 approved	Telemetry research into the NPL gas field	University of Wyoming, University of Montana	On-going
280-Ollie Spring Water Development	2021	Southwest	$5,000 approved	Fencing for riparian enhancement	Lincoln County	On-going

					Conservation District	
281-SW Monitoring and Maintenance 2	2021	Southwest	$5,000 approved	Maintenance of previously implemented projects	Wyoming Wildlife Federation	On-going
282-Natrona Cheatgrass	2021	Bates Hole/Shirley Basin	$10,000 approved	Cheatgrass treatments in Natrona Core Area	BLM	On-going
283-Heward Zeedyk	2021	Bates Hole/Shirley Basin	$12,500 approved	Beaver dam analogues and zeedyk structures on private land	Medicine Bow Conservation District	On-going
284-Sagebrush Literacy Audubon	2021	Bates Hole/Shirley Basin	$10,000 approved	Audubon's sagebrush adventures: place-based literacy and programming	Audubon	On-going
285-Hat Six Infrared Flight	2021	Bates Hole/Shirley Basin	$27,500 approved	Infrared flights to detect strutting sage-grouse	Game and Fish	On-going
286-Lander/Hudson Weeds	2021	Wind River/Sweetwater River	$62,436 approved	Weed treatments	Fremont County Weed & Pest	On-going
287-Double Bar E Easement	2021	Upper Green River Basin	$10,000 approved	Conservation easement on private land	Jackson Hole Land Trust	On-going
288-One Rock Stream Restoration	2021	Upper Green River Basin	$8,000 approved	Zeedyk stream restoration	Sublette County Conservation District	On-going
289-Sublette Cheatgrass	2021	Upper Green River Basin	$22,000 approved	Cheatgrass spraying	Sublette County Weed & Pest	On-going
290-Winter Concentration Area Refinement	2021	Upper Green River Basin	$15,000 approved	Research on refining winter concentration area models in the Pinedale Region	researchers	On-going
291-Jackson Fence Inventory	2021	Upper Snake River Basin	$7,700 approved	Inventorying fence in sage-grouse habitat	Jackson Hole Wildlife Foundation	On-going
292-Gros Ventre Cheatgrass	2021	Upper Snake River Basin	$10,000 approved	Spraying cheatgrass from Jackson to the Gros Ventre	Teton County Weed and Pest Control District	On-going
293-Jackson Genetics	2021	Upper Snake River Basin	$5,300 approved	Genetics sampling on the Jackson Hole population	Teton Raptor Center	On-going

Attachment C:
Wyoming Sage-Grouse Research Reports (through May 31, 2021)

Part I. Final research reports from Wyoming sage-grouse research or theses and dissertations from university research efforts. It does not include annual agency monitoring reports or popular press articles.

Part II. Wyoming sage-grouse research articles published in peer-reviewed journals or books.

Only research reports concerning Wyoming sage-grouse are included. Studies on related subjects, (e.g. sagebrush, cheatgrass, other geographical areas) are important, but too numerous to include in this attachment.

Part I. Research theses, dissertations and reports.

Bedrosian, B. and D Craighead. 2010. Jackson Hole sage grouse project completion report: 2007-2009. Craighead Beringia South. Kelly, Wyoming. Includes 4 appended reports:
A: Common raven activity in relation to land use in western Wyoming: Implications for greater sage grouse reproductive success. B: Critical winter habitat characteristics of greater sage-grouse in a high altitude environment. C: Sage grouse baseline survey and inventory at the Jackson Hole Airport. D: Sage-grouse chick survival rates in Jackson Hole, Wyoming.

Brooks, M.L., J.R. Matchett, D.J. Shinneman and P.S. Coates. 2015. Fire patterns in the range of greater sage-grouse, 1984–2013 - Implications for conservation and management: U.S. Geological Survey Open-File Report 2015-1167, 66 p., http://dx.doi.org/10.3133/ofr20151167.

Brown, K. G. and K. M. Clayton. 2004. Ecology of the greater sage-grouse (*Centrocercus urophasianus*) in the coal mining landscape of Wyoming's Powder River Basin. Final Technical Report. Thunderbird Wildlife Consulting, Inc. Gillette, WY.

Bui, T.D. 2009. The effects of nest and brood predation by common ravens (*Corvus corax*) on greater sage-grouse (*Centrocercus urophasianus*) in relation to land use in western Wyoming. Thesis. University of Washington, Seattle.

Cagney J., E. Bainter, B. Budd, T. Christiansen, V. Herren, M. Holloran, B. Rashford, M. Smith and J. Williams. 2010. Grazing influence, objective development, and management in Wyoming's greater sage-grouse habitat. University of Wyoming College of Agriculture Extension Bulletin B-1203. Laramie. Available on-line at: http://www.wyomingextension.org/agpubs/pubs/B1203.pdf

Chambers, J.C., J.L. Beck, S. Campbell, J. Carlson, T.J. Christiansen, K.J. Clause, J.B. Dinkins, K.E. Doherty, K.A. Griffin, D.W. Havlina, K.E. Mayer, J.D. Hennig, L.L. Kurth, J.D. Maestas, M. Manning, B.A. Mealor, C. McCarthy, M.A. Perea and D.A. Pyke. 2016. Using resilience and resistance concepts to manage threats to sagebrush ecosystems, Gunnison sage-grouse, and greater sage-grouse in their eastern range—A strategic multi-scale approach: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-356, 143p. https://www.fs.fed.us/rmrs/publications/using-resilience-and-resistance-concepts-manage-threats-sagebrush-ecosystems-gunnison.

Christiansen, T. 2006. Monitoring the impacts and extent of West Nile virus on sage-grouse in Wyoming – final report. Wyoming Game and Fish Department, Cheyenne.

Christiansen, T. 2010. Hunting and sage-grouse: a technical review of harvest management on a species of concern in Wyoming. Wyoming Game and Fish Department, Cheyenne.

Christiansen, T.J. (*in press*). Wyoming's approach to sage-grouse Conservation – a shotgun wedding of science and policy. Transactions of the 82nd North American Wildlife and Natural Resources Conference. Wildlife Management Institute.

Clarke, L. F., H. Rahn and M.D. Martin. 1942. Seasonal and sexual dimorphic variations in the so-called "air sacs" region of the sage grouse. Sage Grouse Studies Part II. Wyoming Game and Fish Department Bulletin No. 2. Wyoming Game and Fish Department, Cheyenne.

Courtemanch, A., G. Chong and S. Kilpatrick. 2007. A remote sensing analysis of sage-grouse winter habitat in Grand Teton National Park and Bridger-Teton National Forest, Wyoming.

Crist, M.R., S.T. Knick and S.E. Hanser. 2015, Range-wide network of priority areas for greater sage-grouse—A design for conserving connected distributions or isolating individual zoos?: U.S. Geological Survey Open-File Report 2015-1158, 34 p., http://dx.doi.org/10.3133/20151158.

Daniel, J. 2007. Spring precipitation and sage grouse chick survival. Thesis. Department of Statistics – University of Wyoming, Laramie.

Deibert, P. A. 1995. Effects of parasites on sage-grouse mate selection. Dissertation. University of Wyoming, Laramie.

Dinkins, J.B. 2013. Common raven density and greater sage-grouse nesting success in southern Wyoming: potential conservation and management implications.

Dissertation. Utah State University, Logan.

Doherty, K.E. 2008. Sage-grouse and energy development: integrating science with conservation planning to reduce impacts. Dissertation. University of Montana, Missoula.

Doherty, M.K. 2007. Mosquito populations in the Powder River Basin, Wyoming: a comparison of natural, agricultural and effluent coal-bed natural gas aquatic habitats. Thesis. Montana State University, Bozeman.

Erickson, H.J. 2011. Herbaceous and avifauna responses to prescribed fire and grazing timing in a high-elevation sagebrush ecosystem. Thesis. Colorado State University, Ft. Collins.

Gamo, R.S. 2016. Effectiveness of Wyoming's Sage-Grouse Core Areas in conserving greater sage-grouse and mule deer and influence of energy development on big game harvest. Dissertation, University of Wyoming, Laramie.

Girard, G.L. 1935. Life history, habits, and food of the sage-grouse. Thesis. University of Wyoming, Laramie.

Girard, G.L. 1937. Life history, habits, and food of the sage-grouse. University of Wyoming Publication 3. University of Wyoming, Laramie.

Heath, B.J., R. Straw, S. Anderson and J. Lawson. 1996. Proceedings of the sage-grouse workshop, Pinedale, Wyoming, 6-7 September 1996. Wyoming Game and Fish Department. Cheyenne.

Heath, B. J., R. Straw, S.H. Anderson and J. Lawson. 1997. Sage-grouse productivity, survival and seasonal habitat use near Farson, Wyoming. Research Completion Report. Wyoming Game & Fish Dept., Cheyenne.

Heath, B.J., R. Straw, S.H. Anderson, J. Lawson and M. Holloran. 1998. Sage-grouse productivity, survival, and seasonal habitat use among three ranches with different livestock grazing, predator control, and harvest management practices. Research Completion Report. Wyoming Game & Fish Dept., Cheyenne.

Hess, J.E. 2010. Greater sage-grouse (*Centrocercus urophasianus*) habitat response to mowing and prescribed burning Wyoming big sagebrush and the influence of disturbance factors on lek persistence in the Bighorn Basin, Wyoming. Thesis. University of Wyoming, Laramie.

Hnilicka, P. and D. Skates. 2010. Movements and survival of sage-grouse on the Wind River Reservation, Wyoming. Completion Report. U. S. Fish and Wildlife Service Lander, Wyoming.

Holloran, M. J. 1999. Sage-grouse seasonal habitat use near Casper, WY. Thesis. University of Wyoming, Laramie.

Holloran, M.J. and S.H. Anderson. 2004. Greater Sage-grouse seasonal habitat selection and survival in Jackson Hole, Wyoming. Research Completion Report. University of Wyoming Cooperative Fish and Wildlife Research Unit, Laramie.

Holloran, M.J. 2005. Sage-grouse population response to natural gas field development in western Wyoming. Dissertation. University of Wyoming, Laramie.

Holloran, M.J. and S.H. Anderson. 2005a. Spatial distribution of Greater Sage-grouse nests in relatively contiguous sagebrush habitats. Attachment A in Holloran 2005 Dissertation. University of Wyoming, Laramie.

Holloran, M.J. and S.H. Anderson. 2005c. Greater Sage-grouse research in Wyoming: an overview of studies conducted by the Wyoming Cooperative Fish and Wildlife Research Unit between 1994 and 2005. Attachment C in Holloran 2005. Dissertation. University of Wyoming, Laramie.

Honess, R.F. and W.J. Allred. 1942. Structure and function of the neck muscles in inflation and deflation of the esophagus in the sage grouse. Sage Grouse Studies Part I. Wyoming Game and Fish Department Bulletin No. 2. Wyoming Game and Fish Department, Cheyenne.

Honess, R. F. and G. Post. 1968. History of an epizootic in sage-grouse. Science Monograph 14. University of Wyoming Agricultural Experiment Station, Laramie.

Jensen, B.M. 2006. Migration, transition range and landscape use by greater sage-grouse (*Centrocercus urophasianus*). Thesis, University of Wyoming, Laramie.

Johnson, G. 2010. Field evaluation of larvivorous fish for mosquito management in the Powder River Basin, Wyoming. Grant summary completion report. Montana State University, Bozeman.

Johnson, G.D. 1987. Effects of rangeland grasshopper control on sage-grouse in Wyoming. Thesis, University of Wyoming, Laramie.

Kaiser, R.C. 2006. Recruitment by greater sage-grouse in association with natural gas development in Western Wyoming. Thesis, Department of Zoology and Physiology, University of Wyoming, Laramie.

King, L. and J. Petty. 2008. Investigations of a gravity-fed supplemental irrigation system to enhance sagebrush seedling establishment on reclaimed bentonite mine lands in Wyoming's Big Horn Basin. Shell Valley Consulting Associates, Inc. Shell, WY.

King, L., E. Dunklee and J. Petty. 2009. Use of supplemental watering gels to enhance Wyoming big sagebrush establishment on Big Horn Basin bentonite reclamation. Shell Valley Consulting Associates, Inc. Shell, WY.

Kirol, C.P. 2012. Quantifying habitat importance for greater sage-grouse (*Centrocercus urophasianus*) population persistence in an energy development landscape. Thesis. University of Wyoming, Laramie.

Klott, J.H. 1987. Use of habitat by sympatrically occurring sage-grouse and sharptailed grouse with broods. Thesis. University of Wyoming, Laramie.

Kuipers, J.L. 2004. Grazing system and linear corridor influences on Greater Sage-grouse habitat selection and productivity. Thesis. University of Wyoming, Laramie.

LeBeau, C.W. 2012. Evaluation of greater sage-grouse reproductive habitat and response to wind energy development in South-Central, Wyoming. Thesis. University of Wyoming, Laramie.

LeBeau, C., G. Johnson, M. Holloran, J. Beck, R. Nielson, M. Kauffman, E. Rodemaker, and T. McDonald. 2016. Effects of a Wind Energy Development on Greater Sage-Grouse Habitat Selection and Population Demographics in Southeastern Wyoming. Unpublished report. Prepared for: National Wind Coordination Collaborative, Washington, DC. Prepared by: Western EcoSystems Technology, Inc., Cheyenne, WY.

LeVan, J.R. 2018. Habitat selection and short-term demographic response of greater sage-grouse to habitat treatments in Wyoming big sagebrush. Thesis, University of Wyoming, Laramie.

Lyon, A.G. 2000. The potential effects of natural gas development on sage grouse near Pinedale, Wyoming. Thesis, University of Wyoming, Laramie.

Mabray, S.T. 2015. Microhabitat Selection by Greater Sage-Grouse Hens in Southern Wyoming. Thesis. Utah State University, Logan.

Mandich, C.A. 2011. Seasonal habitat distribution and parasite survey of greater sage-grouse in western Natrona County, Wyoming. Thesis. University of Wyoming, Laramie.

McDonald, D.B. 2006. Demographic population assessment of greater sage-grouse in Jackson Hole Wyoming. University of Wyoming Department of Zoology, Laramie.

Orning, E.K. 2013. Effect of predator removal on greater sage-grouse (*Centrocercus* *urophasianus*) ecology in the Bighorn Basin Conservation Area of Wyoming. Thesis. Utah State University. Logan.

Parsons, L.A. 2019. Greater sage-grouse survival, breeding ecology, resource selection, and West Nile virus prevalence on the eastern fringe of their range. Dissertation. South Dakota State University. Brookings, SD.

Patricelli, G.L., J.L. Blickley and S.L. Hooper. 2012. The impacts of noise on greater sage- grouse: A discussion of current management strategies in Wyoming with recommendations for further research and interim protections. Prepared for: The Bureau of Land Management, Lander Field Office and Wyoming State Office, Cheyenne and Wyoming Game and Fish Department.

Patterson, R.L. 1952. The sage grouse in Wyoming. Sage Books.

Peebles, L.W. 2015. Winter ecology of common ravens in southern Wyoming and the effects of raven removal on greater sage-grouse populations. Paper 4617. Thesis. Utah State University, Logan, UT.

Pratt, A.C. 2017. Partial migration, habitat selection, and the conservation of greater sage-grouse in the Bighorn Basin of Montana and Wyoming. Dissertation, University of Wyoming, Laramie.

Postovit, B.C. 1981. Suggestions for sage grouse habitat reclamation on surface mines in northeastern Wyoming. Thesis. University of Wyoming, Laramie.

Revekant, C.L. 2021. Comparison of Common Ravens in Sage-grouse Core and Non-Core. Oregon State University, Corvallis.

Rothenmaier, D. 1979. Sage-grouse reproductive ecology: breeding season movements, strutting ground attendance and site characteristics, and nesting. Thesis. University of Wyoming, Laramie.

Schmidtmann, E. 2007. Mosquitoes, West Nile virus and Wyoming Wildlife – Powder River Basin. Arthropod-Borne Animal Diseases Research Laboratory, USDA, ARS, Laramie, WY.

Schmidtmann, E. 2007. Mosquitoes, West Nile virus and Wyoming Wildlife – Fremont and Sublette Counties. Arthropod-Borne Animal Diseases Research Laboratory, USDA, ARS, Laramie, WY.

Schreiber, L.A. 2013. Greater sage-grouse nest site selection, brood-rearing site selection and chick survival in Wyoming. Thesis, Univ. of Missouri, Columbia.

Slater, S.J. 2003. Sage-grouse use of different aged burns and the effects of coyote control in southwestern Wyoming. Thesis. University of Wyoming, Laramie.

Smith, K.T. 2016. Identifying habitat quality and population response of greater sage-grouse to treated Wyoming big sagebrush habitats. Dissertation. University of Wyoming, Laramie.

Spurrier, M.F. 1989. Courtship behavior in *Centrocercus urophasianus*. Thesis. University of Wyoming, Laramie.

Schulwitz, S.E. 2016. Informing conservation management using genetic approaches: greater sage-grouse and Galápagos short-eared owls as case studies. Dissertation. University of North Texas, Denton.

Taylor, R.L., D.E. Naugle and L.S. Mills. 2012. Viability analyses for conservation of sage-grouse populations: Buffalo Field Office, Wyoming Final Report 27 February 2012. BLM Contract 09-3225-0012 Number G09AC00013 (8/10/10). University of Montana, Missoula**.**

Thompson, K.M., M.J. Holloran, S.J. Slater, J.L. Kuipers and S.H. Anderson. 2005. Greater Sage-grouse early brood-rearing habitat use and productivity in Wyoming. Attachment B in Holloran 2005. Dissertation. University of Wyoming, Laramie.

Walker, B.L. 2008. Greater sage-grouse response to coal-bed natural gas development and West Nile virus in the Powder River Basin, Montana and Wyoming, U.S.A.. Dissertation. University of Montana, Missoula.

Watchorn, R. 2015. Biological control of disease vectors: a case study evaluating the efficacy of fathead minnows (*Pimephales promelas*) for mosquito control in northeast Wyoming. Thesis. University of Waterloo. Waterloo, Ontario, Canada.

Wetzel, W., G. Chong, A. Courtemanch and N. Pope. 2007. Composition and structure of sage grouse winter habitat in the Upper Snake River Basin, Wyoming.

Wiley, R.H. 1970. Territoriality and non-random mating in sage grouse *Centrocercus urophasianus*. Dissertation. The Rockefeller University, New York, New York.

Wilms, D. and A. Alexander. 2014. The North American model of wildlife conservation in Wyoming: understanding it, preserving it, and funding its future. Wyoming Law Review 14(2).

Wyoming Wildlife Consultants, LLC. 2012. Greater sage-grouse winter habitat selection relative to natural gas field infrastructure in northern portions of the Pinedale Anticline Project Area Sublette County, Wyoming. Final report. Prepared for*:* Shell Western Exploration and Production, LP, QEP Energy Company and Ultra Petroleum.

Part II. Peer reviewed journal articles or book chapters.

Ambrose, S, C. Florian, J. Olnes, J. Macdonald, T. Hartman. 2021. Sagebrush Soundscapes and the effects of gas-field sounds on greater sage-grouse. Western Birds 52:23-46.

Applegate, D.H. and N.L. Owens. 2014. Oil and gas impacts on Wyoming's sagegrouse: summarizing the past and predicting the foreseeable future. Commentary. Human–Wildlife Interactions 8(2):284–290.

Beck, J.L., J.W. Connelly and C.L. Wambolt. 2012. Consequences of treating Wyoming big sagebrush to enhance wildlife habitats. Rangeland Ecology & Management 65(5):444-455.

Beck, J.L., D.T. Booth and C.L. Kennedy. 2014. Assessing greater sage-grouse breeding habitat with aerial and ground imagery. Rangeland Ecology and Management 67(3):328-332.

Bergquist, E., P. Evangelista, T. J. Stohlgren and N. Alley. 2007. Invasive species and coal bed methane development in the Powder River Basin, Wyoming. Environmental Monitoring and Assessment 128:381-394.

Blickley, J.L. and G.L. Patricelli. 2010. Impacts of anthropogenic noise on wildlife: research priorities for the development of standards and mitigation. Journal of International Wildlife Law
& Policy 13:274-292.

Blickley, J.L. and G.L. Patricelli. 2012. Potential acoustical masking of greater sage-grouse display components by chronic industrial noise. Ornithological Monographs 74:23-35.

Blickley, J.L., D. Blackwood and G.L. Patricelli. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. Conservation Biology 26: 461-471.

Blickley, J.L., K.R. Word, A.H. Krakauer, J.L. Phillips, S.N. Sells, J.C. Wingfield and G.L. Patricelli.. 2012. Experimental chronic noise is related to elevated fecal corticosteroid metabolites in lekking male greater sage-grouse (*Centrocercus urophasianus*). PLoS ONE 7(11): e50462. doi:10.1371/journal.pone.0050462

Boyce, M.S. 1990. The red queen visits sage-grouse leks. American Zoologist 30:263-270.

Boyd, C.S., J.L. Beck and J.A. Tanaka. 2014. Livestock grazing and sage-grouse habitat: impacts and opportunities. Journal of Rangeland Applications 1:58-77.

Bui, T-V. D., J.M. Marzluff and B. Bedrosian. 2010. Common raven activity in relation to land use in Western Wyoming: implications for greater sage-grouse reproductive success. The Condor 112(1):65-78.

Burkhalter, C., M.J. Holloran, B.C. Fedy, H.E. Copeland, R.L. Crabtree, N.L. Michel, S.C. Jay, B.A. Rutledge, and A.G. Holloran. 2018. Landscape-scale habitat assessment for an imperiled avian species. Animal Conservation 21:241-251.

Cardinal, C.J. and T.A. Messmer. 2016. Ecology of greater sage-grouse populations inhabiting the northwestern Wyoming Basin: Human-Wildlife Interactions 10(2):188–204.

Christiansen, T.J. and L.R. Belton. 2017. Wyoming sage-grouse working groups: Lessons learned. Human-Wildlife Interactions 11:274-286.

Conover, M.R., J.S. Borgo, R.E. Dritz, J.B. Dinkins and D.K. Dahlgren. 2010. Greater sage- grouse select nest sites to avoid visual predators but not olfactory predators. The Condor 112(2):331-336.

Copeland, H.E., K.E. Doherty, D.E. Naugle, A. Pocewicz and J.M. Kiesecker. 2009. Mapping oil and gas development potential in the US intermountain west and estimating impacts to species. PLoS ONE 4(10): e7400. doi:10.1371/journal.pone.0007400. 7 pp.

Copeland, H.E., A. Pocewicz, D.E. Naugle, T. Griffiths, D. Keinath, et al. 2013. Measuring the effectiveness of conservation: a novel framework to quantify the benefits of sage-grouse conservation policy and easements in Wyoming. PLoS ONE 8(6): e67261.

Cross, T.B., M.K. Schwartz, D.E. Naugle, B.C. Fedy, J.R. Row, S.J. Oyler-McCance. 2018. The genetic network of greater sage-grouse: Range-wide identification of keystone hubs of connectivity. Ecology and Evolution 8:1-19.

Dahlgren, D.K., R.T. Larsen, R. Danvir, G. Wilson, E.T. Thacker, T. Black, D.E. Naugle, J.W. Connelly and T.A. Messmer. 2015. Greater sage-grouse response to range management: insights from a 25-year case study in Utah. Rangeland Ecology & Management: 68:375-382. (Corrigendum in Rangeland Ecology & Management 69:235).

Dahlgren, D.K., E.J. Blomberg, C.A. Hagen, and R.D. Elmore. 2021. Upland game bird harvest management. Chapter 21 in K.L. Pope and L.A. Powell eds. Harvest of fish and wildlife: new paradigms for sustainable management. CRC Press, Taylor and Francis Group, LLC, Boca Raton, FL, USA.

Decker, K.L., A. Pocewicz, S. Harju, M. Holloran, M.M. Fink, T.P. Toombs, and D.B. Johnston. 2017. Landscape disturbance models consistently explain variation in ecological integrity across large landscapes. Ecosphere 8(4):e01775.

10.1002/ecs2.1775.

Deibert, P.A. and M.S. Boyce. 1997. Heritable resistance to malaria and the evolution of lek behaviour in sage-grouse. Wildlife Biology 3:284.

Dinkins, J.B., M.R. Conover, C.P. Kirol and J.L. Beck. 2012. Greater sage-grouse (*Centrocercus urophasianus*) select nest-sites and brood-sites away from avian predators. The Auk 129:600–610.

Dinkins, J.B., M.R. Conover and S.T. Mabray. 2013. Do artificial nests simulate nest success of greater sage-grouse? Human–Wildlife Interactions 7(2):299–312.

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck and S.N. Frey. 2014. Greater sage-grouse (Centrocercus urophasianus) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology. doi:10.1139/cjz-2013-0263

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck and S.N. Frey. 2014. Greater Sage-Grouse (Centrocercus urophasianus) select habitat based on avian predators, landscape composition, and anthropogenic features. The Condor 116 (4), 629-642.

Dinkins, J.B., K.T. Smith, J.L. Beck, C.P. Kirol, A.C. Pratt and M.R. Conover. 2016. Microhabitat conditions in Wyoming sage-grouse core areas: effects on selection and nest success. PLoS ONE 11:e0150798.

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck and S.N. Frey. 2016. Effects of common raven and coyote removal and temporal variation in climate on greater sage-grouse nesting success. Biological Conservation 202:50–58.

Dinkins, J.B., K.J. Lawson, K.T. Smith, J.L. Beck, C.P. Kirol, A.C. Pratt, M.R. Conover, and F.C. Blomquist. 2017. Quantifying overlap and fitness consequences of migration strategy with seasonal habitat use and a conservation policy. Ecosphere 8(11):e01991.

Dinkins, J.B., K.J. Lawson, and J.L. Beck. 2021. Influence of environmental change, harvest exposure, and human disturbance on population trends of greater sage-grouse. PLOS ONE.

Dinkins, J.B., C.J. Duchardt, J.D. Hennig, and J.L. Beck. 2021. Changes in hunting season regulations (1870s-2019) reduce harvest exposure on greater and Gunnison sage-grouse. PLOS ONE.

Doherty, K.E., D.E. Naugle and B.L. Walker. 2008. Sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187-195.

Doherty, K.E., D.E. Naugle and B.L. Walker. 2010. Greater sage-grouse nesting habitat: the importance of managing at multiple scales. Journal of Wildlife Management 74(7):1544-1553.

Doherty, K.E, D.E. Naugle and J.S. Evans. 2010. A currency for offsetting energy development impacts: horsetrading sage-grouse on the open market. PLoS ONE 5(4):e10339.

Doherty, K.E., J.L. Beck and D.E. Naugle. 2011. Comparing ecological site descriptions to habitat characteristics influencing greater sage-grouse nest site occurrence and success. Rangeland Ecology and Management 64(4):344-351.

Doherty, K.E., D.E. Naugle, J.D. Tack, B.L. Walker, J.M. Graham and J.L. Beck. 2014. Linking conservation actions to demography: grass height explains variation in greater sage-grouse nest survival. Wildlife Biology 20(6):320-325.

Donnelly, J.P., B.W. Allred, D. Perret, N.L. Silverman, J.D. Tack, V.J. Dreitz, J.D. Maestas, D.E. Naugle. 2018. Seasonal drought in North America's sagebrush biome structures dynamic mesic resources for sage-grouse. Ecology and Evolution 8:12492-12505.

Dzialak, M.R., C.V. Olson, S.M. Harju, S.L. Webb, J.P. Mudd, J.B. Winstead and L.D. Hayden-Wing. 2011. Identifying and prioritizing greater sage-grouse nesting and brood rearing habitat for conservation in human-modified landscapes. PLoS ONE 6(10): e26273.

Dzialak, M.R., C.V. Olson, S.L. Webb, S.M. Harju and J.B. Winstead. 2012. Temporal and hierarchical spatial components of animal occurrence: conserving seasonal habitat for greater sage-grouse. Ecosphere 3:art30.

Dzialak, M.R., S.L. Webb, S.M. Harju, C.V. Olson, J.B. Winstead and L.D. Hayden-Wing. 2013. Greater sage-grouse and severe winter conditions: identifying habitat for conservation. Rangeland Ecology and Management 66:10-18.

Dzialak, M.R., C.V. Olson, S.L. Webb, S.M. Harju and J.B. Winstead. 2015. Incorporating within- and between-patch resource selection in identification of critical habitat for brood-rearing greater sage-grouse. Ecological Processes v.4 art. 5. https://doi.org/10.1186/s13717-015-0032-2.

Edmunds, D.R., C.L. Aldridge, M.S. O'Donnell, and A.P. Monroe. 2017. Greater sage-grouse population trends across Wyoming. Journal of Wildlife Management 82:397-412.

Fedy, B.C. and K.E. Doherty. 2010. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage-grouse and cottontail rabbits. Oecologia 165:915-924.

Fedy, B.C. and C.L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Fedy, B.C., C.L. Aldridge, K.E. Doherty, M. O'Donnell, et al. 2012. Interseasonal movements of greater sage- grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. Journal of Wildlife Management 76:1062–1071.

Fedy, B.C., K.E. Doherty, C.L. Aldridge, M. O'Donnell, et al. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: an example using greater sage-grouse in Wyoming. Wildlife Monographs 190:1–39.

Fedy, B.C., C. P. Kirol, A.L. Sutphin and T.L. Maechtle. 2015. The influence of mitigation on sage-grouse habitat selection within an energy development field. PLoS ONE 10(4): e0121603. doi:10.1371/journal.pone.0121603

Fedy, B.C., M.S. O'Donnell and Z.H. Bowen. 2015. Large-scale control site selection for population monitoring - An example assessing sage-grouse trends: Wildlife Society Bulletin 39:700–712.

Fedy, B.C., J.R. Row, and S.J. Oyler-McCance. 2017. Integration of genetic and demographic data to assess population risk in a continuously distributed species. Conservation Genetics 18:89-104.

Forbey, J.S., G.L. Patricelli, D.M. Delparte, A.H. Krakauer, P.J. Olsoy, M.R. Fremgen, J.D. Nobler, L.P. Spaete, L.A. Shipley, J.L. Rachlow, A.K. Dirksen, A. Perry, B.A. Richardson, and N.F. Glenn. 2017. Emerging technology to measure habitat quality and behavior of grouse: examples from studies of greater sage-grouse. Wildlife Biology 10..2981.

Fremgen, A.L., C.P. Hansen, M.A. Rumble, R.S. Gamo and J.J. Millspaugh. 2016. Male greater sage-grouse detectability on leks. Journal of Wildlife Management 80:266–274.

Fremgen, A.L., C.T. Rota, C.P. Hansen, M.A. Rumble, R.S. Gamo, and J.J. Millspaugh. 2017. Male greater sage-grouse movements among leks. Journal of Wildlife Management 81:498-508.

Gamo, R.S. and J.L. Beck. 2017. Effectiveness of Wyoming's sage-grouse core areas: Influences on energy development and male lek attendance: Environmental Management 59(2)189-203.

Green, A.W., C.L. Aldridge and M.S. O'Donnell. 2017. Investigating impacts of oil and gas development on greater sage-grouse: Journal of Wildlife Management 81:46-57.

Gregory, A.J. and J.L. Beck. 2014. Spatial heterogeneity in response of male greater sage- grouse lek attendance to energy development. PLoS ONE 9(6):e97132. doi:10.1371/journal.pone.0097132

Harju, S.M., M.R. Dzialak, R.C. Taylor, L.D. Hayden-Wing., J.B. Winstead. 2010. Thresholds and time lags in effects of energy development on greater sage-grouse populations. Journal of Wildlife Management 74:437-448.

Hansen, C.P., L.A. Schreiber, M.A. Rumble, J.J. Millspaugh, R.S. Gamo, J.W. Kehmeier and N. Wojcik. 2016. Microsite selection and survival of greater sage-grouse nests in south-central Wyoming: Journal of Wildlife Management 80:862–876.

Harju, S.M., C.V. Olson, M.R. Dzialak, J.P. Mudd, J.B. Winstead. 2013. A flexible approach for assessing functional landscape connectivity, with application to greater sage-grouse (*Centrocercus urophasianus*). PLoS ONE 8(12): e82271. doi:10.1371/journal.pone.0082271

Harju, S.M., C.V. Olson, L. Foy-Martin, S.L. Webb, M.R. Dzialak, J.B. Winstead and L.D. Hayden-Wing. 2013. Occurrence and success of greater sage-grouse broods in relation to insect vegetation community gradients. Human–Wildlife Interactions 7(2):214–229.

Harmon, L. and D. Hirchert. 2016, Managing safety and wildlife at Jackson Hole Airport: Journal of Airport Management 10:381–401.

Heinrichs, J.A., C.L. Aldridge, M.S. O’Donnell, and N.H. Schumaker. 2017. Using dynamic population simulations to extend resource selection analyses and prioritize habitats for conservation. Ecological Modelling 359:449-459.

Heinrichs, J.A., M.S. O’Donnell, C.L. Aldridge, S.L. Garman, and C.G. Homer. 2019. Influences of potential oil and gas development and future climate on sage-grouse declines and redistribution. Ecological Applications 0(0):e01912.

Hess, J.E. and J.L. Beck. 2012. Disturbance factors influencing Greater Sage-grouse lek abandonment in north-central Wyoming. Journal of Wildlife Management 76:1625-1634.

Hess, J. E. and J. L. Beck. 2012. Burning and mowing Wyoming big sagebrush: do treated sites meet minimum guidelines for greater sage-grouse breeding habitats? Wildlife Society Bulletin 36:85–93.

Hess, J.E and J.L. Beck. 2014. Forb, insect, and soil response to burning and mowing Wyoming big sagebrush in greater sage-grouse breeding habitat. Environmental Management 53:813-822.

Holloran, M.J. and S.H. Anderson. 2003. Direct identification of Northern sage-grouse, *Centrocercus urophasianus*, nest predators using remote sensing cameras. Canadian Field- Naturalist 117:308-310.

Holloran, M.J., and S.H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. Condor 107:742-752.

Holloran, M.J., B.J. Heath, A.G. Lyon, S.J. Slater, J.L. Kuipers and S.H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. Journal Wildlife Management 69:638-649.

Holloran, M.J., R.C. Kaiser and W.A. Hubert. 2010. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65-72.

Holloran, M.J., B.C. Fedy and J. Dahlke. 2015. Winter habitat use of greater sage-grouse relative to activity levels at natural gas well pads. Journal of Wildlife Management 79:630-640.

Hopken, M.W., E.K. Orning, J.K. Young, and A.J. Piaggio. 2016, Molecular forensics in avian conservation—A DNA-based approach for identifying mammalian predators of ground-nesting birds and eggs: BMC Research Notes v.9, art.14, https://doi.org/10.1186/s13104-015-1797-1.

Johnson, G.D. and M.S. Boyce. 1990. Feeding trials with insects in the diet of sage-grouse chicks. Journal of Wildlife Management 54:89-91.

Juliusson, L.M. and K.E. Doherty. 2017. Oil and gas development exposure and conservation scenarios for greater sage-grouse: Combining spatially explicit modeling with GIS visualization provides critical information for management decisions. Applied Geography 80:98-111.

Kiesecker, J.M., J.S. Evans, J. Fargione, K. Doherty, K.R. Foresman, T.H. Kunz, D. Naugle, N.P. Nibbelink, N.D. Neimuth. 2011. Win-win for wind and wildlife: a vision to facilitate sustainable development. PLoS ONE 6(4): e17566. doi:10.1371/journal.pone.0017566

Kirol, C.P., J.L. Beck, J.B. Dinkins and M.R. Conover. 2012. Microhabitat selection for nesting and brood-rearing by the greater sage-grouse in xeric big sagebrush. The Condor 114:75-89.

Kirol, C.P., A.L. Sutphin, L. Bond, M.R. Fuller and T.L. Maechtle. 2015. Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development. Wildlife Biology 21: 98-109.

Kirol, C.P., J.L. Beck, S.V. Huzurbazar, M.J. Holloran, S.N. Miller. 2015. Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape. Ecological Applications 25:968–990.

Kirol, C.P., K.T. Smith, N.E. Graf, J.B. Dinkins, C.W. LeBeau, T.L. Maechtle, A.L. Sutphin, J.L. Beck. 2020. Greater Sage-grouse Response to the Physical Footprint of Energy Development. Journal of Wildlife Management 84:989-1001.

Klott, J.H., and F.G. Lindzey. 1989. Comparison of sage and sharp-tailed grouse leks in south central Wyoming. Great Basin Naturalist 49:275-278.

Klott, J.H. and F.G. Lindzey. 1990. Brood habitats of sympatric sage grouse and Columbian sharp-tailed grouse in Wyoming. Journal of Wildlife Management 54:84-88.

Koch, R.E., A.H. Krakauer and G.L. Patricelli. 2015. Investigating female mate choice for mechanical sounds in the male greater sage-grouse. The Auk 132:349-358.

Krakauer, A. H., M. Tyrrell, K. Lehmann, N. Losin, F. Goller and G. Patricelli. 2009. Vocal and anatomical evidence for two-voiced sound production in greater sage-grouse *Centrocercus urophasianus*. Journal of Experimental Biology 212:3719-3727.

Krakauer, A.H., M.A. Blundell, T.N. Scanlan, M.S. Wechsler, E.A. McCloskey, J.H. Yu and G.L. Patricelli. 2016. Successfully-mating male sage-grouse show greater laterality in courtship and aggressive interactions. Animal Behaviour. 111: 261-267.

Lazenby, K.D., P.S. Coates, S.T. O'Neil, M.T. Kohl, D.K. Dahlgren. 2020. Nesting, brood rearing, and summer habitat selection by translocated greater sage-grouse in North Dakota, USA. Ecology and Evolution 11:2741-2760.

LeBeau. C.W., J.L. Beck, G.D. Johnson and M.J. Holloran. 2014. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management 78:522-530.

LeBeau, C.W., J.L. Beck, G.D. Johnson, R.M. Nielson, M.J. Holloran, K.G. Gerow and T.L. McDonald. 2017. Greater sage-grouse male lek counts relative to a wind energy development. Wildlife Society Bulletin 41:17-26.

LeBeau, C.W., G.D. Johnson, M.J. Holloran, J.L. Beck, R.M. Nielson, M.E. Kauffman, E.J. Rodemaker and T.L. McDonald. 2017. Greater sage-grouse habitat selection, survival, and wind energy infrastructure. Journal of Wildlife Management 81:690–711.

LeBeau, C.W., K.T. Smith, M.J. Holloran, J.L. Beck, M.E. Kauffman, and G.D. Johnson. 2019. Greater sage-grouse habitat function relative to 230-kV transmission lines. Journal of Wildlife Management 83:1773-1786.

Lyon, A.G. and S.H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. Wildlife Society Bulletin 31:486-491.

Mabray, S.T. and M.R. Conover. 2015, Microhabitat selection by greater sage-grouse hens during brood rearing: Human-Wildlife Interactions, 9(2)219–228.

McCaffery, R. and P.M. Lukacs. 2016. A generalized integrated population model to estimate greater sage-grouse population dynamics. Ecosphere 7(11) art. e01585. http://doi.org/10.1002/ecs2.1585.

Meyerpeter, M.B., K.D. Lazenby, P.S. Coates, M.A. Ricca, S.R. Mathews, S.C. Gardner, D.K. Dahlgren, D.J. Delehanty. 2021. Field methods for translocating female greater sage-grouse (*Centrocercus urophasianus*) with their broods. Wildlife Society Bulletin, DOI: 10.1002/wsb.1199.

Monroe, A.P., Edmunds, D.R. and Aldridge, C.L. 2016. Effects of lek count protocols on greater sage-grouse population trend estimates. Journal of Wildlife Management, 80:667–678.

Monroe, A.P., C.L. Aldridge, T.J. Assal, K.E. Veblen, D.A. Pyke and M.L. Casazza. 2017. Patterns in greater sage-grouse population dynamics correspond with public grazing records at broad scales: Ecological Applications 27:1096–1107, https://doi.org/10.1002/eap.1512.

Monroe, A.P., C.L. Aldridge, M.S. O'Donnell, D.J. Manier, C.G. Homer, and P.J. Anderson. 2019. Using remote sensing products to predict recovery of vegetation across space and time following energy development. Ecological Indicators 110: e105872.

Monroe, A.P., G.T. Wann, C.L. Aldridge, and P.S. Coates. 2019. The importance of simulation assumptions when evaluating detectability in population models. Ecosphere e02791.

Naugle, D.E., C.L. Aldridge, B.L. Walker, T.E. Cornish, B.J. Moynahan, et al. 2004. West Nile virus: pending crisis for Greater Sage-grouse. Ecology Letters 7:704-713.

Naugle, D. E., C. L. Aldridge, B. L. Walker, K. E. Doherty, M. R. Matchett, J. McIntosh,

T. E. Cornish and M. S. Boyce. 2005. West Nile virus and sage-grouse: What more have we learned? Wildlife Society Bulletin 33:616-623.

Naugle, D.E., K.E. Doherty, B. Walker, M. Holloran and H. Copeland. 2011. Greater sage- grouse and energy development in western North America. Pp 489-503 in S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian biology (vol. 38). University of California Press, Berkeley, CA.

Naugle, D.E., K.E. Doherty, B.L. Walker, H.E. Copeland, M.J. Holloran, and J. D. Tack. 2011. Sage-grouse and cumulative impacts of energy development. Pp. 55-70 in D.E. Naugle, (editor). Energy development and wildlife conservation in western North America. Island Press, Washington, D.C., USA

Oh, K.P., C.L. Aldridge, J.S. Forbey, C.Y. Dadabay, and S.J. Oyler-McCance. 2019. Conservation genomics in the sagebrush sea: population divergence, demographic history, and local adaptation in sage-grouse (*Centrocercus* spp.). Genome Biological Evolution 11(7):2023-2034.

Orning, E.K., and J.K. Young, 2016. Impacts of coyote removal on space use by greater sage-grouse: Human-Wildlife Interactions 10(2):144–156.

Orning, E.K., and J.K. Young. 2017. Coyote removal: can the short-term application of a controversial management tool improve female greater sage-grouse survival or nest success? Wildlife Biology:wlb.00345. doi: 10.2981/wlb.00.45.

Oyler-McCance, S.J., S.E. Taylor and T.W. Quinn. 2005. A multilocus population genetic survey of Greater sage-grouse across their range. Molecular Ecology 14:1293-1310.

Oyler-McCance, S.J., R.S. Cornman, K.L. Jones, J.A. Fike. 2015. Genomic single-nucleotide polymorphisms confirm that Gunnison and greater sage-grouse are genetically well differentiated and that the Bi-State population is distinct: The Condor 117:217–227, https://doi.org/10.1650/CONDOR-14-174.1.

Patricelli, G.L. and A.H. Krakauer. 2010. Tactical allocation of effort among multiple signals in sage grouse: an experiment with a robotic female. Behavioral Ecology 21:97-106.

Patricelli, G.L., J.L. Blickley and S.L. Hooper. 2013. Recommended management strategies to limit anthropogenic noise impacts on greater sage-grouse in Wyoming. Journal of Human- Wildlife Interactions 7: 230–249.

Peebles, L.W. and M.R. Conover. 2016. Effectiveness of the toxicant DRC-1339 in reducing populations of common ravens in Wyoming: Wildlife Society Bulletin 40:281–287.

Peebles, L.W., M.R. Conover, and J.B. Dinkins. 2017. Adult sage-grouse numbers rise following raven removal or an increase in precipitation. Wildlife Society Bulletin 41:471-478.

Post, G. 1951. Effects of toxaphene and chlordane on certain game birds. Journal of Wildlife Management 15:381-386.

Pratt, A.C., K.T. Smith, and J.L. Beck. 2017. Environmental cues used by greater sage-grouse to initiate altitudinal migration. Auk 134:628-643.

Pratt, A.C. and J.L. Beck. 2019. Greater sage-grouse response to bentonite mining. Journal of Wildlife Management 83:866-878.

Pratt, A.C., K.T. Smith, and J.L. Beck. 2019. Prioritizing seasonal habitats for comprehensive conservation of a partially migratory species. Global Ecology and Conservation 17: e00594.

Row, J.R., S.J. Oyler-McCance, J.A. Fike, M.S. O'Donnell, K.E. Doherty, C.L. Aldridge, Z.H. Bowen and B.C. Fedy. 2015. Landscape characteristics influencing the genetic structure of greater sage-grouse within the stronghold of their range: a holistic modeling approach. Ecology and Evolution 5(10): 1955–1969.

Row, J.R., S.J. Oyler-McCance and B.C. Fedy. 2016, Differential influences of local subpopulations on regional diversity and differentiation for greater sage-grouse (*Centrocercus urophasianus*): Molecular Ecology 25:4424–4437.

Row, J.R. and B.C. Fedy. 2017. Spatial and temporal variation in the range-wide cyclic dynamics of greater sage-grouse. Oecologia 185:687-698.

Schreiber, L.A., C.P. Hansen, M.A. Rumble, J.J. Millspaugh, R.S. Gamo, J.W. Kehmeier, N. Wojcik. 2015. Microhabitat selection of brood-rearing sites by greater sage-grouse in Carbon County, Wyoming. Western North American Naturalist 75: 348–363.

Schreiber, L.A., C.P. Hansen, M.A. Rumble, J.J. Millspaugh, S. Gamo, J. Kehmeier and N. Wojcik. 2016. Greater sage-grouse apparent nest productivity and chick survival in Carbon County, Wyoming. Wildlife Biology 22:37-44.

Schulwitz, S., B. Bedrosian and J.A. Johnson. 2014. Low neutral genetic diversity in isolated Greater Sage-Grouse (*Centrocercus urophasianus*) populations in northwest Wyoming. The Condor 116:560-573.

Severson, J.P., P.S. Coates, B.G. Prochazka, M.A. Ricca, M.L. Casazza, and D.J. Delehanty. 2019. Global positioning system tracking devices can decrease greater sage-grouse survival. Condor, DOI: 10.1093/condor/duz032.

Smith, K.T., C.P. Kirol, J.L. Beck and F.C. Blomquist. 2014. Prioritizing winter habitat quality for greater sage-grouse in a landscape influenced by energy development. Ecosphere 5(2):15.

Smith, J.T., J.S. Evans, B.H. Martin, S. Baruch-Mordo, J.M. Kiesecker and D.E. Naugle. 2016. Reducing cultivation risk for at-risk species—Predicting outcomes of conservation easements for sage-grouse: Biological Conservation 201:10–19.

Smith, K.T., J.L. Beck and A.C. Pratt. 2016. Does Wyoming's core area policy protect winter habitats for greater sage-grouse? Environmental Management 58:585–596.

Smith, K.T. and J.L. Beck. 2017. Sagebrush treatments influence annual population change for greater sage-grouse. Restoration Ecology 26:497-505.

Smith, K.T., J.L. Beck, C.P. Kirol. 2018. Reproductive state leads to intraspecific habitat partitioning and survival differences in greater sage-grouse: implications for conservation. Wildlife Research 45:119-131.

Smith, K.T., J.L. Beck. 2018. Sagebrush treatments influence annual population change for greater sage-grouse. Restoration Ecology 26:497-505.

Smith, K.T., J.S. Forbey, and J.L. Beck. 2018. Effects of mowing and tebuthiuron on the nutritional quality of Wyoming big sagebrush. Rangeland Ecology and Management 2018:417-423.

Smith, K.T., A.C. Pratt, J.R. LeVan, A.M. Rhea, and J.L. Beck. 2019. Reconstructing greater sage-grouse chick diets: diet selection, body condition, and food availability at brood-rearing sites. Condor 121:1-12.

Spence, E.S, J.L. Beck, and A.J. Gregory. 2017. Probability of lek collapse is lower inside sage-grouse Core Areas: Effectiveness of conservation policy for a landscape species. PLos ONE 12(11): e0185885. https://doi.org/10.1371/journal.pone.0185885.

Spurrier, M.F., M.S. Boyce and B.F. Manly. 1994. Lek behaviour in captive sage grouse *Centrocercus urophasianus*. Animal Behaviour 47:303-310.

Spurrier, M.F., M.S. Boyce and B.F. Manly. 1991. Effects of parasites on mate choice by captive Sage Grouse. Pages 389-398 *in* J. E. Loye and M. Zuk, editors. Bird-Parasite Interactions: Ecology, evolution, and behaviour. Oxford Ornithological Series 2.

Slater, S.S. and J.P. Smith. 2010. Effectiveness of raptor perch deterrents on an electrical transmission line in southwestern Wyoming. Journal of Wildlife Management 74:1080-1088.

Taylor, R.L., B.L. Walker, D.E. Naugle and L.S. Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76:336-347.

Taylor, R.L., J.D. Tack, D.E. Naugle, L.S. Mills. 2013. Combined effects of energy development and disease on greater sage-grouse. PLoS ONE 8(8): e71256. doi:10.1371/journal.pone.0071256

Thompson, K.M., M.J. Holloran, S.J. Slater, J.L. Kuipers and S.H. Anderson. 2006. Early brood-rearing habitat use and productivity of greater sage-grouse in Wyoming. Western North American Naturalist 66:332-342.

Walker, B.L., D.E. Naugle, K.E. Doherty and T.E. Cornish. 2004. Outbreak of West Nile virus in greater sage-grouse and guidelines for monitoring, handling, and submitting dead birds. Wildlife Society Bulletin 32:1000-1006.

Walker, B.L., D.E. Naugle and K.E. Doherty. 2007. Greater sage-grouse population response to energy development and habitat loss. Journal of Wildlife Management 71:2644-2654.

Walker, B.L., D.E. Naugle, K.E. Doherty and T.E. Cornish. 2007. West Nile virus and greater sage-grouse: estimating infection rate in a wild bird population. Avian Diseases 51:691- 696.

Webb, S.L., C.V. Olson, M.R. Dzialak, S.M. Harju, J.B. Winstead and D. Lockman. 2012. Landscape features and weather influence nest survival of a ground-nesting bird of conservation concern, the greater sage-grouse, in human-altered environments. Ecological Processes 1:art4.

Wiley, R.H. 1973. The strut display of male Sage Grouse: A "fixed" action pattern. Behaviour 47:129-152.

Wiley, R.H. 1973. Territoriality and non-random mating in sage grouse, *Centrocercus urophasianus*. Animal Behavior Monographs 6:87-169.

Wiley, R.H. 1974. Evolution of social organization and life-history patterns among grouse. Quarterly Review of Biology 49:201-227.

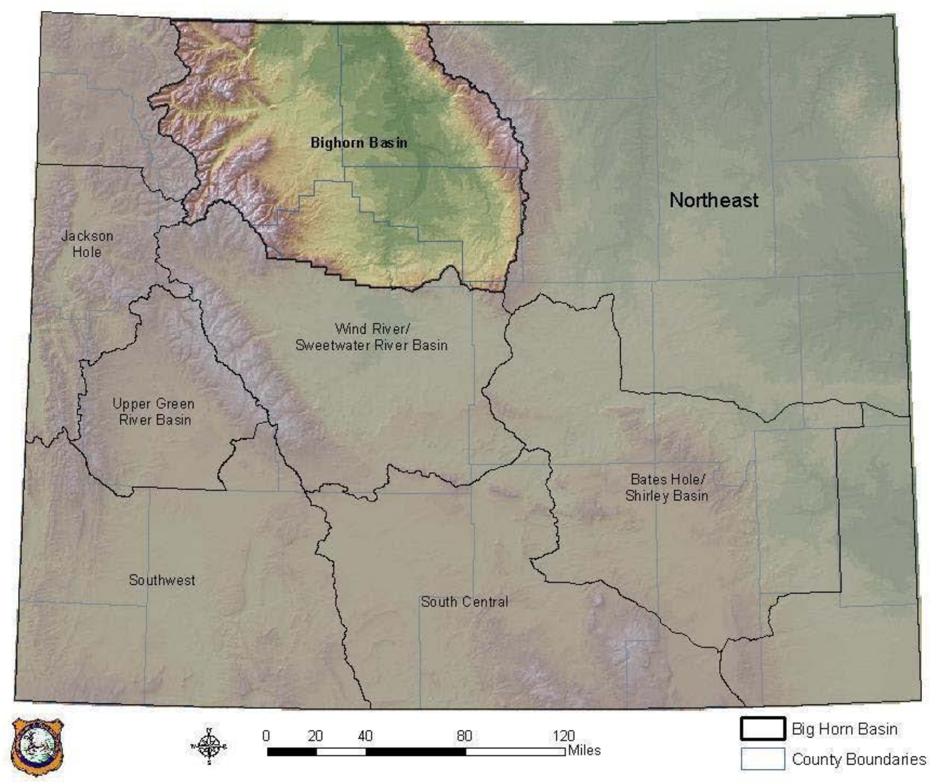
Wiley, R.H. 1978. The lek mating system of the sage grouse. Scientific American 238:114-125.

Zabihi, K., G.B. Paige, A.L. Hild, S.N. Miller, A. Wuenschel and M.J. Holloran. 2017. A fuzzy logic approach to analyze the suitability of nesting habitat for greater sage-grouse in western Wyoming. Journal of Spatial Science 62:215–234.

Zou, L., S. Miller and E. Schmidtmann. 2006. Mosquito larval habitat mapping using remote sensing and GIS: implications of coal-bed methane development and West Nile virus. Journal of Medical Entomology 43:1034-1041.

Cody Region Sage-Grouse Job Completion Report

Conservation Plan Area: **Big Horn Basin**
Period Covered: **6/1/2020 – 5/31/2021**
Prepared by: **Sam Stephens**



Sage Grouse Lek Characteristics

Working Group: Big Horn Basin

Region	Number	Percent
Cody	309	100.0

Working Group	Number	Percent
Big Horn Basin	309	100.0

Classification	Number	Percent
Occupied	220	71.2
Undetermined	44	14.2
Unoccupied	45	14.6

BLM Office	Number	Percent
Worland	195	63.1
Cody	114	36.9

Biologist	Number	Percent
Cody	85	27.5
Greybull	52	16.8
Worland	172	55.7

Warden	Number	Percent
Greybull	23	7.4
Lovell	31	10.0
Meeteetse	32	10.4
North Cody	24	7.8
Powell	13	4.2
South Cody	28	9.1
Ten Sleep	52	16.8
Thermopolis	48	15.5
Worland	58	18.8

County	Number	Percent
Big Horn	48	15.5
Hot Springs	61	19.7
Park	104	33.7
Washakie	96	31.1

Land Status	Number	Percent
BOR	3	1.0
State	19	6.1
Private	82	26.5
BLM	205	66.3

Management Area	Number	Percent
B	309	100.0

Lek Status	Number	Percent
Active	144	46.6
Inactive	112	36.2
Unknown	53	17.2

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Big Horn Basin

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	234	53	23	815	17.0
2013	236	42	18	501	12.5
2014	233	68	29	823	14.4
2015	243	53	22	1108	26.4
2016	249	86	35	2258	30.5
2017	251	56	22	1636	34.8
2018	242	60	25	1115	24.2
2019	241	58	24	873	17.1
2020	233	69	30	863	16.6
2021	232	113	49	1082	14.2

b. Leks Surveyed

Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	234	126	54	777	8.8
2013	236	148	63	749	8.2
2014	233	90	39	517	9.2
2015	243	141	58	2297	20.3
2016	249	140	56	2053	23.3
2017	251	175	70	2286	19.2
2018	242	153	63	1434	14.2
2019	241	139	58	835	9.6
2020	233	127	55	617	7.9
2021	232	81	35	292	7.5

1) Occupied - Active during previous 10 years (see official definitions)

2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

3) Inactive - Confirmed no birds/sign present (see official definitions)

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Big Horn Basin

1. Lek Attendance Summary (Occupied Leks) (1) Continued

c. Leks Checked

Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	234	179	76	1592	11.7
2013	236	190	81	1250	9.5
2014	233	158	68	1340	11.9
2015	243	194	80	3405	22.0
2016	249	226	91	4311	26.6
2017	251	231	92	3922	23.6
2018	242	213	88	2549	17.3
2019	241	197	82	1708	12.4
2020	233	196	84	1480	11.4
2021	232	194	84	1374	11.9

d. Lek Status

Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	143	10	26	153	93.5	6.5
2013	132	9	49	141	93.6	6.4
2014	115	23	20	138	83.3	16.7
2015	156	27	11	183	85.2	14.8
2016	173	26	27	199	86.9	13.1
2017	171	35	25	206	83.0	17.0
2018	152	34	27	186	81.7	18.3
2019	148	42	7	190	77.9	22.1
2020	136	58	2	194	70.1	29.9
2021	124	53	17	177	70.1	29.9

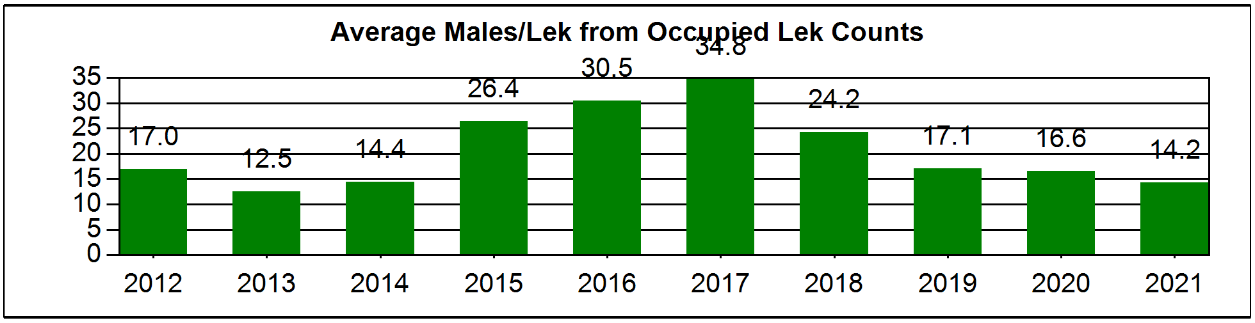
1) Occupied - Active during previous 10 years (see official definitions)

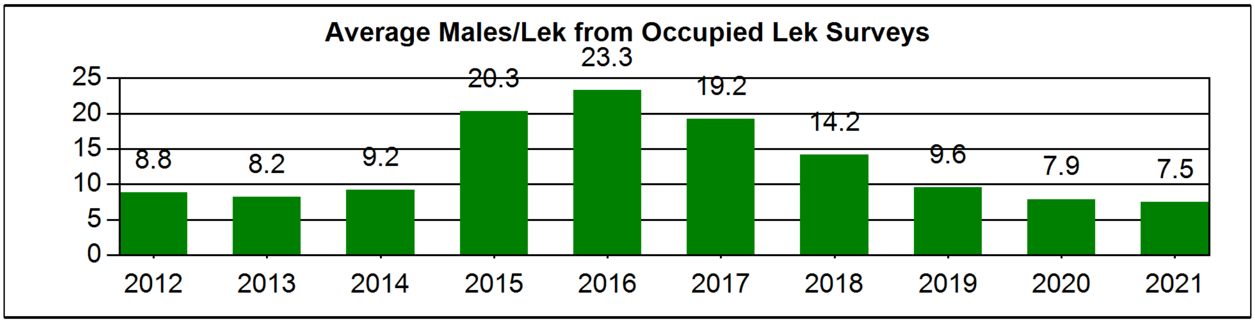
2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

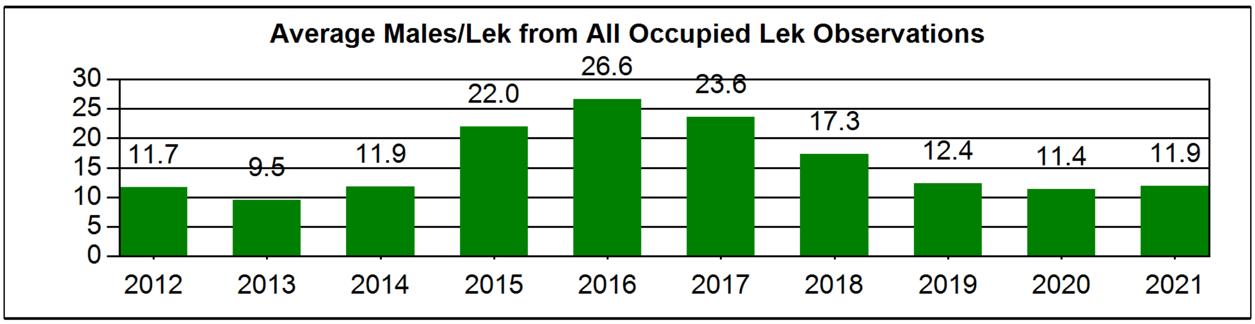
3) Inactive - Confirmed no birds/sign present (see official definitions)

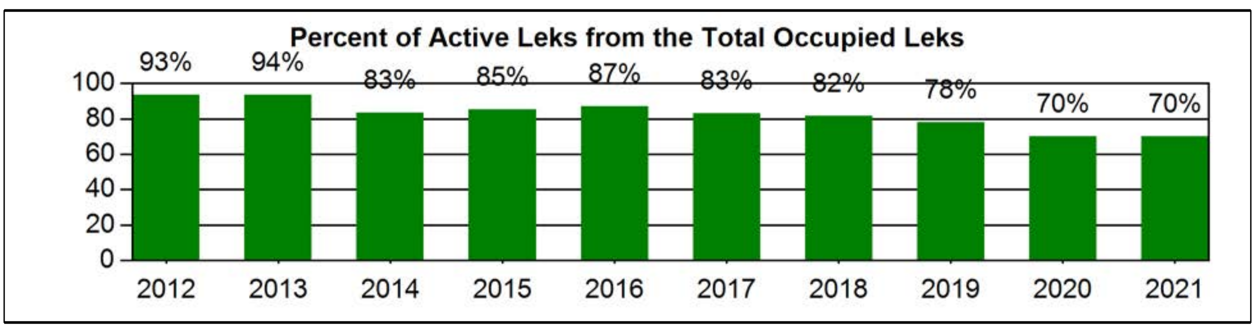
Sage Grouse Occupied Lek Attendance Summary

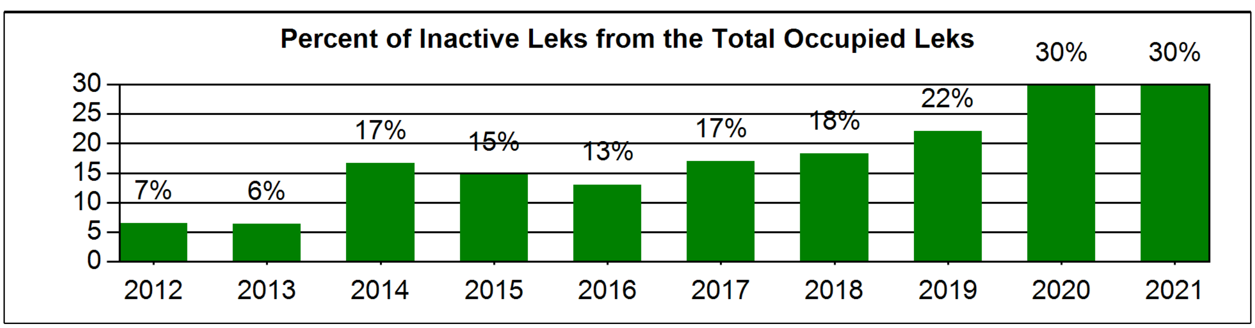
Year: 2012 - 2021, Working Group: Big Horn Basin











Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Big Horn Basin

3. Sage Grouse Hunting Seasons and Harvest Data

a. Season

Year	Season Start	Season End	Length	Bag/Possesion Limit
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

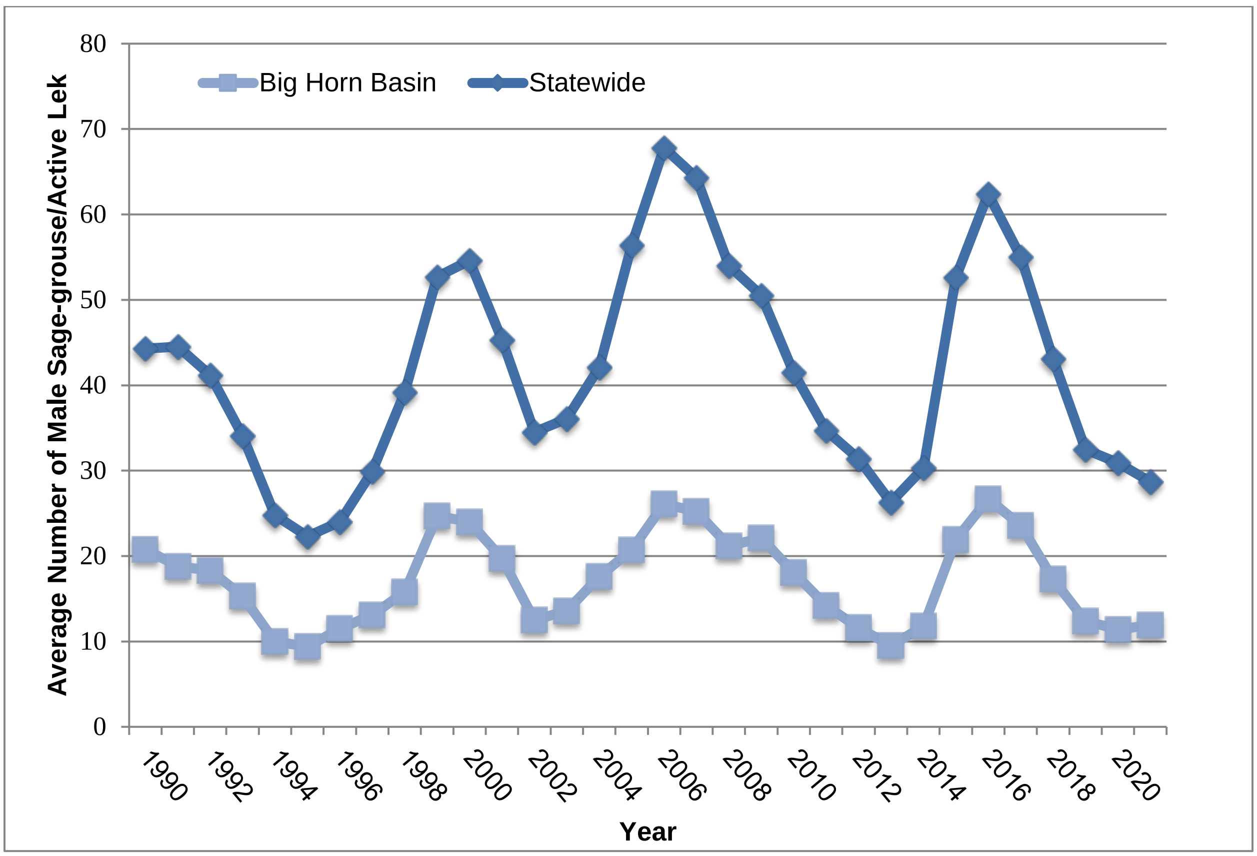
b. Harvest

Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2012	457	290	609	0.8	1.6	2.1
2013	206	206	513	0.4	1.0	2.5
2014	524	303	708	0.7	1.7	2.3
2015	729	411	947	0.8	1.8	2.3
2016	594	302	868	0.7	2.0	2.9
2017	635	300	745	0.9	2.1	2.5
2018	648	418	1351	0.5	1.6	3.2
2019	312	244	463	0.7	1.3	1.9
2020	767	331	1037	0.7	2.3	3.1
Avg	541	312	805	0.7	1.7	2.5

Lek Monitoring
In spring 2021, 113 occupied leks were counted in the Basin, resulting in an average of 14.2 males per lek (Table 2a). We surveyed 81 leks for a total of 194 leks checked during the 2021 season (2012-21 average=198; Table 2c). To evaluate long-term population trends, we combine and average survey and count lek data since the count protocol was not used during the late 1980s and early 1990s. Fortunately, long-term data sets from Wyoming and neighboring states indicate similar trends from both counts and surveys (Fedy and Aldridge 2011; Figure 2).

The average number of male sage-grouse on all occupied leks showed a slight increase from the 2020 count of 11.4 to 11.9 in 2021 (Table 2c). Sage-grouse populations cycle on approximate 7 to 10-year intervals (Fedy and Doherty 2010; Figure 2). During a suppression in population performance, we would expect an increase in the number of inactive leks. In 2021 the number of inactive leks showed a decrease from 58 (2020) to 53. Although these metrics show positive reversals of recent (declining) trends it's unlikely to be significant enough to override low chick recruitment both within the Bighorn Basin (Table 4.) and statewide.

Figure 2. Trends in male attendance for all sage grouse lek observations in the Big Horn Basin vs Statewide Averages 1990-2021.



Production Surveys

Four sage-grouse broods were documented in 2021 (Table 4). Low sample sizes are likely a product of lack of effort by field personnel, because sage-grouse brood data is opportunistically collected while performing other duties during July and August. A direct connection between effort (time spent surveying for broods) and number of broods observed was presented in previous Job Completion Reports.

Table 4. Brood survey data collected by Wyoming Game & Fish Department personnel in the Bighorn Basin, 2012-21.

Year Observed	Broods	Chicks	Hens	Chicks/brood	Chicks/hen
2012	8	26	8	3.3	3.3
2013	8	30	9	3.8	3.3
2014	6	31	27	5.2	1.1
2015	13	69	24	5.3	2.9
2016	8	21	5	2.6	4.2
2017	5	32	7	6.4	4.6
2018	5	22	6	4.4	3.7
2019	4	15	4	3.8	3.8
2020	4	22	4	5.5	5.5
2021	4	22	4	5.5	5.5
2012-21 average	**6.5**	**29**	**9.8**	**4.6**	**3.8**

Harvest

Average (1982-1994) annual harvest in the Basin was 3,756 sage-grouse taken by 1,300 hunters during 3,118 hunter days (2.8 birds/hunter, 2.4 days/hunter). During 1995-2001 an average of 549 hunters took 1,056 sage-grouse during 1,567 days of hunting (1.9 birds/hunter, 2.8 days/hunter). During the most recent period (2012-2020), hunters averaged 1.7 birds/hunter and 2.5 days/hunter. In 2020, 331 hunters in the Big Horn Basin harvested 767 sage-grouse (2.3 birds/hunter); spending 1037 hunter-days afield (3.1 days/hunter) during the 12-day hunting season (Table 3). The significant increase in sage grouse harvest from 2019 to 2020 (312 to 767) is likely due to the cumulative impact of increased season length, sage grouse hunters, and hunter effort (Table 3b). The lengthened season likely contributed to additional hunters seen in 2020 than in 2019: 331 to 244 respectively, however increased hunter effort (1.9 to 3.1 days/hunter) also played a role (Table 3b).*

Habitat

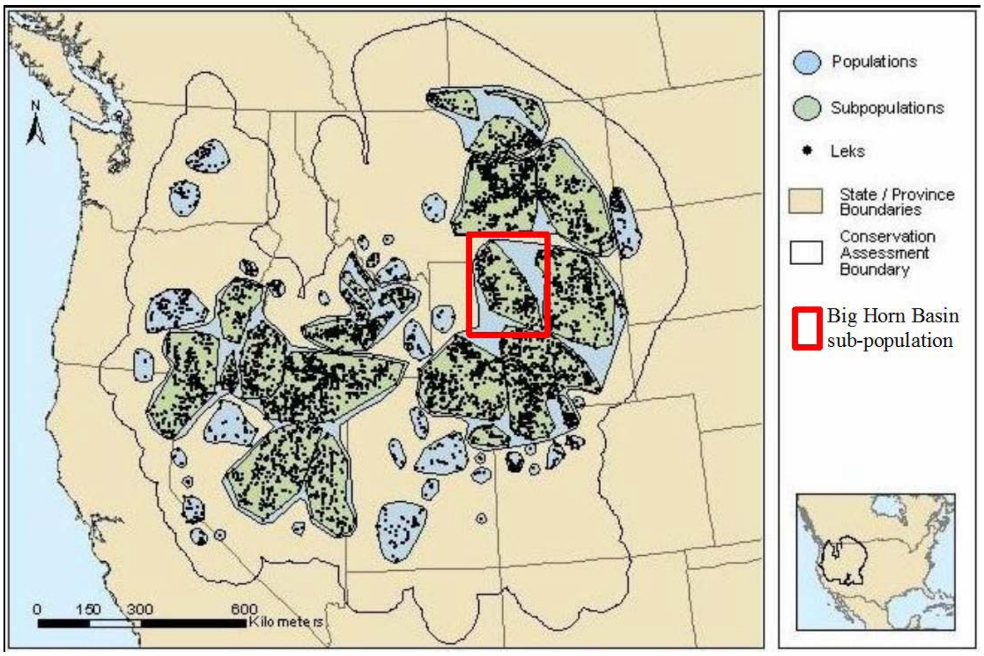
Sage grouse habitat within the Bighorn Basin exists predominantly in low precipitation zones ranging from 5-9" to 7-12" annually. Vegetation communities within the Basin are diverse and vary according to soil type, annual precipitation, and elevation. Major vegetation communities in the Basin include sagebrush steppe, saltbush badlands, irrigated agricultural lands, cottonwood dominated riparian corridors, mixed mountain shrub, and mixed conifer forests with interspersed aspen stands at higher elevations.

Connelly et al. (2004) recognized sage-grouse in the Basin as a distinct sub-population (Figure 3). Mountain ranges to the east and west restrict most sage-grouse movement due to unsuitable habitat. There are several leks near the Wyoming/Montana state line with movement between states occurring. Copper Mountain, the Owl Creek Mountains, and the southern Bighorn Mountains provide suitable habitat serving as travel corridors to adjacent populations.

*The 2020 sage-grouse harvest estimates should be interpreted with caution, because that particular year's survey under-sampled potential sage-grouse hunters from certain license fee types, resulting in poor quality harvest estimates. Making comparisons between previous years' estimates and the 2020 estimates should be avoided, because the results from the voluntary survey were unreliable due to sampling issues.

In 2021, 309 sage-grouse leks are known to occur in the conservation area with 220 leks known to be occupied and 45 leks known to be unoccupied (Table 1). Undetermined leks (n=44) need additional observations before being reclassified as occupied or unoccupied. A majority of leks (66%) occur on BLM managed land and 27% of leks occur on private land (Table 1). There are potentially other leks in the Basin not yet discovered.

Figure 3. Discrete populations and subpopulations of sage-grouse in western North America, with the Big Horn Basin sub-population surrounded by the red rectangle. (Adapted from Connelly et. al. 2004).



Conservation Planning

The BHBLWG was formed in September 2004 to develop and implement a local conservation plan for sage-grouse and sagebrush habitats. The BHBLWG's mission statement is, "*Through the efforts of local concerned citizens, recommend management actions that are based on the best science to enhance sagebrush habitats and ultimately sage-grouse populations within the Big Horn Basin*."

The BHBLWG's local plan identifies factors and impacts that may influence sage-grouse populations in the Basin, and outlines goals and objectives to address habitats, populations, research and education. Strategies and commitments in the local plan are designed to improve sage-grouse habitats and populations in the Basin. The local plan was updated in 2013 and highlights completed and ongoing projects in the Basin in addition to summarizing state- and nation-wide policy and programs. The updated plan can be viewed at the WGFD website: https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management.

Most recently, the BHBLWG met in August of 2021 to discuss project funding allocation to sage grouse research and habitat improvement projects. The group agreed to grant the $55,700 amongst to Oregon State University and the USDA for research conducted in Park County investigating the interactive effects of livestock, predators, and habitat on sage-grouse demography.

Conclusions and Recommendations

For the 2020 biological year sage grouse populations in the Bighorn Basin appear to continue on a downward trend from the previous two years. Although the sample size is limited the 2021 brood count survey data suggest that for the 2021 biological year, sage grouse populations in the Bighorn Basin will likely continue along the same declining trend. Sage-grouse in the Basin face threats, but are not in danger of foreseeable extirpation, and on-going conservation efforts are intended to mitigate some anthropogenic impacts. Research and monitoring are important to help identify limiting factors, important habitats, and to track populations.

- Formalize winter use area mapping in coordination with Worland and Cody BLM offices
- Serve an advisory role to the Bighorn Basin Sage Grouse Local Working Group in their annual efforts to review and determine whether soft or hard triggers have been tripped in accordance with Adaptive Management practices outlined in the Wyoming State Executive Order 2019-3.
- Continue to be WGFD liaison for ongoing and new research projects, as much as possible.
- Work closely with local ranchers, farmers, energy companies, and other landowners whenever possible on sage-grouse habitat (especially early brood-rearing) and riparian enhancement projects.
- Assist the Shoshone National Forest, Bighorn National Forest and Bureau of Land Management Bighorn Basin/Wind River District with prescribed burning plans targeting sage-grouse habitats in the Basin.

Literature Cited

Christiansen, T. 2012. Chapter 12: Sage-grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S.A. Tessmann (ed). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne, WY.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming.

Fedy, B. C. and C. L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75:1022-1033.

Fedy, B. C. and K. E. Doherty. 2010. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage-grouse and cottontail rabbits. Oecologia 165:915-924.

Hess, J. E. 2010. Greater sage-grouse (*Centrocercus urophasianus*) habitat response to mowing and prescribed burning Wyoming big sagebrush and the influence of disturbance factors on lek persistence in the Big Horn Basin, Wyoming. Thesis, University of Wyoming, Laramie, USA.

Hess, J. E. and J. L. Beck. 2012a. Burning and mowing Wyoming big sagebrush: Do treated sites meet minimum guidelines for greater sage-grouse breeding habitats? Wildlife Society Bulletin 36:85-93.

Hess, J. E., and J. L. Beck. 2012b. Disturbance factors influencing greater sage-grouse lek abandonment in north-central Wyoming. Journal of Wildlife Management 76:1625-1634.

Orning, E. K. 2013. Effect of predator removal on greater sage-grouse (Centrocercus urophasianus) ecology in the Bighorn Basin conservation area. Thesis, Utah State University, Logan, USA.

Orning, E. K. and J. K. Young. 2012. Bighorn Basin greater sage-grouse project. Annual Report, Utah State University, Logan, USA.

Orning, E. K. and J. K. Young. 2012a. Bighorn Basin greater sage-grouse project. Summary report for Major Basin, Utah State University, Logan, USA.

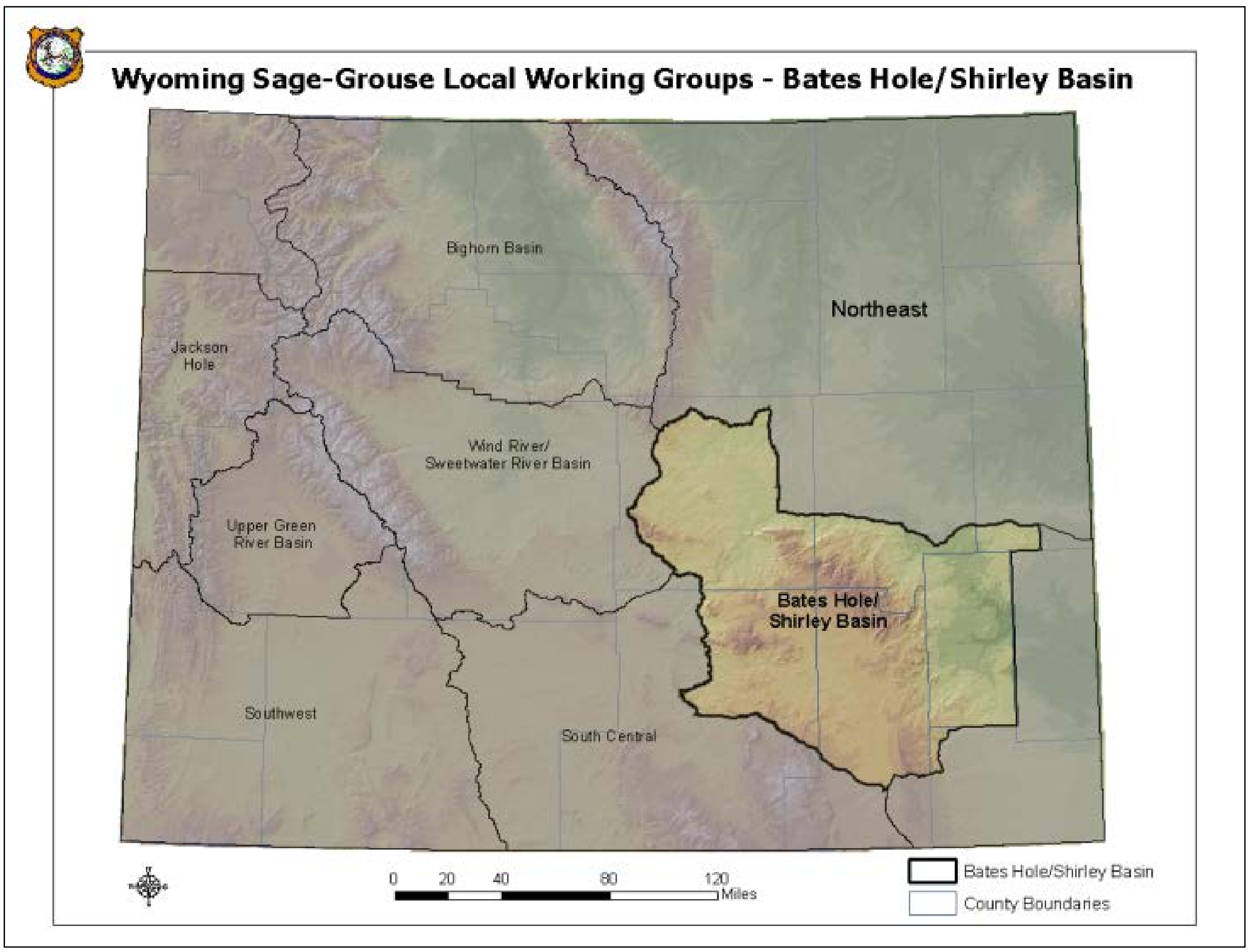
Pratt, A. C. and J. L. Beck. 2012. Greater sage-grouse migration ecology and response to bentonite mining in the Bighorn Basin, Wyoming. Annual Report, University of Wyoming, Laramie, USA.

Taylor, J. D. 2016. Monitoring causes of mortality, predation rates, and space use of greater sage-grouse in the Bighorn Basin. Final report to the Meeteetse Conservation District, USDA APHIS Wildlife Services, National Wildlife Research Center, Oregon Field Station, Corvallis, USA.

Taylor, J. D. and R. D. Holt. 2016. An assessment of greater sage-grouse (Centrocercus urophasianus) population demographics in the Bighorn Basin, Wyoming, 2011-2014. Report to the Wyoming Wildlife and Natural Resources Trust, Oregon State University, Corvallis, USA.

Bates Hole – Shirley Basin Conservation Area
Job Completion Report

Species: Greater Sage-grouse
Management Area(s): F – (portions of Casper and Laramie Regions)
Period Covered: June 1, 2020 – May 31, 2021
Prepared By: Willow Bish, Casper Region Habitat Biologist



Sage Grouse Lek Characteristics

Working Group: Bates Hole

Region	Number	Percent
Casper	127	40.1
Lander	2	0.6
Laramie	188	59.3

Working Group	Number	Percent
Bates Hole	317	100.0

Classification	Number	Percent
Occupied	208	65.6
Undetermined	17	5.4
Unoccupied	92	29.0

BLM Office	Number	Percent
Casper	128	40.4
Lander	2	0.6
Newcastle	1	0.3
Rawlins	186	58.7

Biologist	Number	Percent
Casper	117	36.9
Douglas	9	2.8
Laramie	109	34.4
Saratoga	72	22.7
Sinclair	2	0.6
Wheatland	8	2.5

Warden	Number	Percent
Douglas	3	0.9
East Casper	37	11.7
East Rawlins	2	0.6
Elk Mountain	69	21.8
Glenrock	8	2.5
Lusk	1	0.3
Medicine Bow	71	22.4
North Laramie	40	12.6
West Casper	78	24.6
West Cheyenne	2	0.6
Wheatland	6	1.9

County	Number	Percent
Albany	77	24.3
Carbon	107	33.8
Converse	11	3.5
Laramie	2	0.6
Natrona	113	35.6
Niobrara	1	0.3
Platte	6	1.9

Land Status	Number	Percent
BLM	106	33.4
BOR	1	0.3
Private	182	57.4
State	28	8.8

Management Area	Number	Percent
F	317	100.0

Lek Status	Number	Percent
Active	139	43.8
Inactive	127	40.1
Unknown	51	16.1

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Bates Hole

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	215	77	36	1222	20.0
2013	220	77	35	969	16.4
2014	221	86	39	1261	19.4
2015	222	102	46	2869	33.0
2016	223	86	39	2893	40.2
2017	224	79	35	2213	35.7
2018	219	109	50	1944	24.0
2019	217	89	41	1474	21.1
2020	213	116	54	1513	18.2
2021	211	105	50	1260	16.6

b. Leks Surveyed

Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	215	89	41	779	13.0
2013	220	98	45	814	14.0
2014	221	120	54	928	13.4
2015	222	94	42	1677	26.6
2016	223	103	46	2298	31.9
2017	224	124	55	2143	29.0
2018	219	80	37	1105	20.5
2019	217	99	46	1060	20.4
2020	213	57	27	639	18.8
2021	211	73	35	649	16.6

1) Occupied - Active during previous 10 years (see official definitions)

2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

3) Inactive - Confirmed no birds/sign present (see official definitions)

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Bates Hole

1. Lek Attendance Summary (Occupied Leks) (1) Continued

c. Leks Checked

Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	215	166	77	2001	16.5
2013	220	175	80	1783	15.2
2014	221	206	93	2189	16.3
2015	222	196	88	4546	30.3
2016	223	189	85	5191	36.0
2017	224	203	91	4356	32.0
2018	219	189	86	3049	22.6
2019	217	188	87	2534	20.8
2020	213	173	81	2152	18.4
2021	211	178	84	1909	16.6

d. Lek Status

Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	131	25	10	156	84.0	16.0
2013	123	39	13	162	75.9	24.1
2014	138	48	20	186	74.2	25.8
2015	154	33	9	187	82.4	17.6
2016	146	22	21	168	86.9	13.1
2017	148	45	10	193	76.7	23.3
2018	138	43	8	181	76.2	23.8
2019	133	37	18	170	78.2	21.8
2020	124	38	11	162	76.5	23.5
2021	120	36	22	156	76.9	23.1

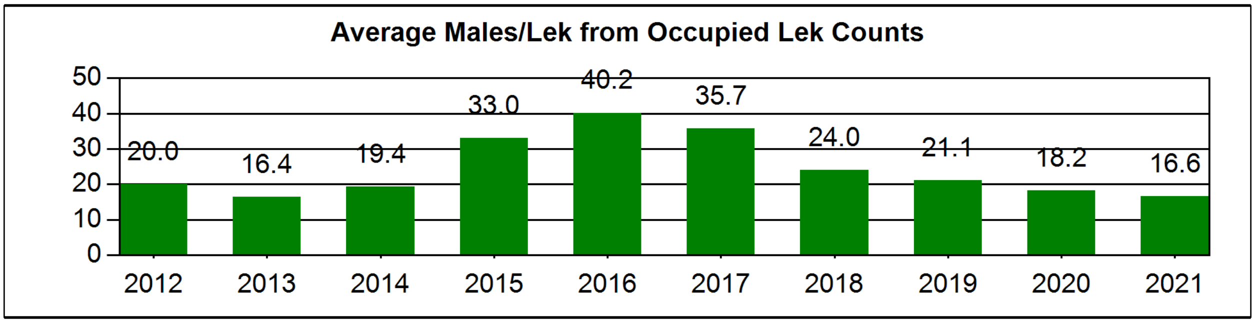
1) Occupied - Active during previous 10 years (see official definitions)

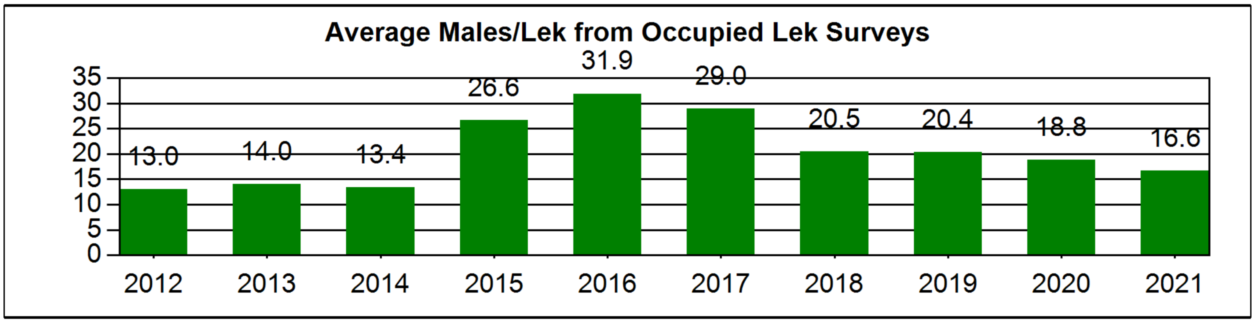
2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

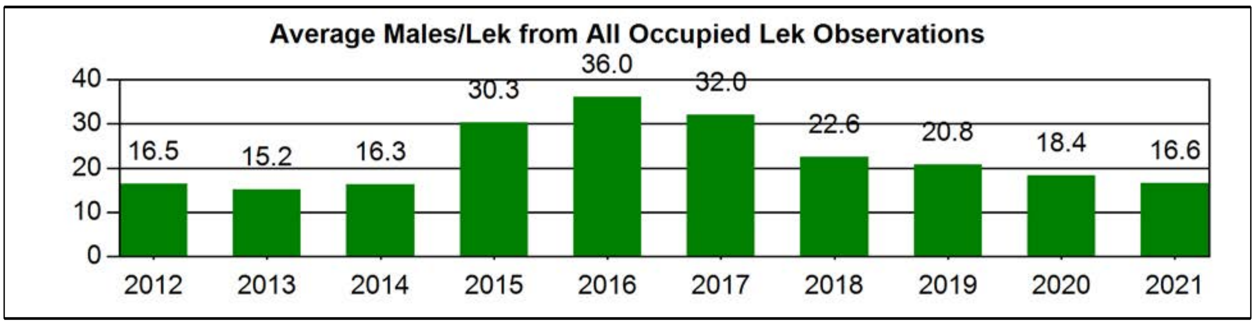
3) Inactive - Confirmed no birds/sign present (see official definitions)

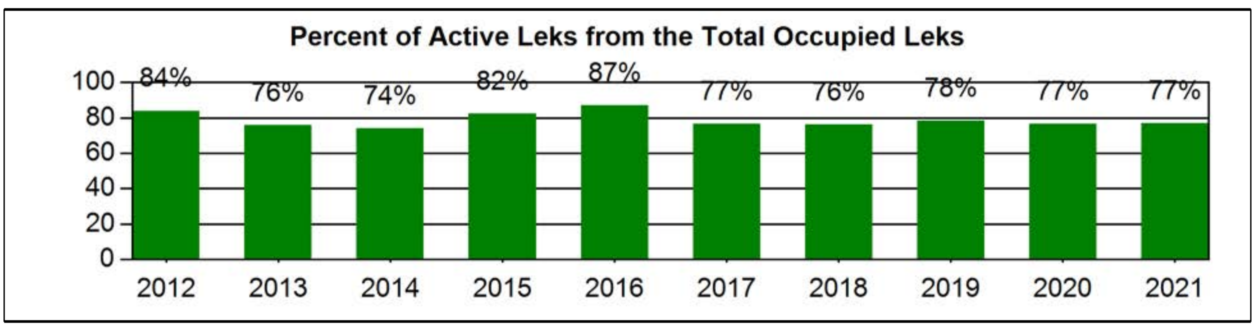
Sage Grouse Occupied Lek Attendance Summary

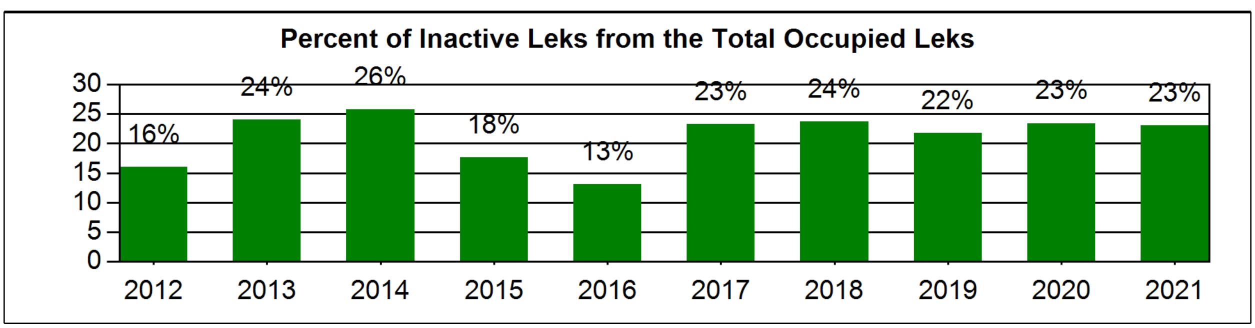
Year: 2012 - 2021, Working Group: Bates Hole











Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Bates Hole

3. Sage Grouse Hunting Seasons and Harvest Data

a. Season

Year	Season Start	Season End	Length	Bag/Possesion Limit
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

b. Harvest

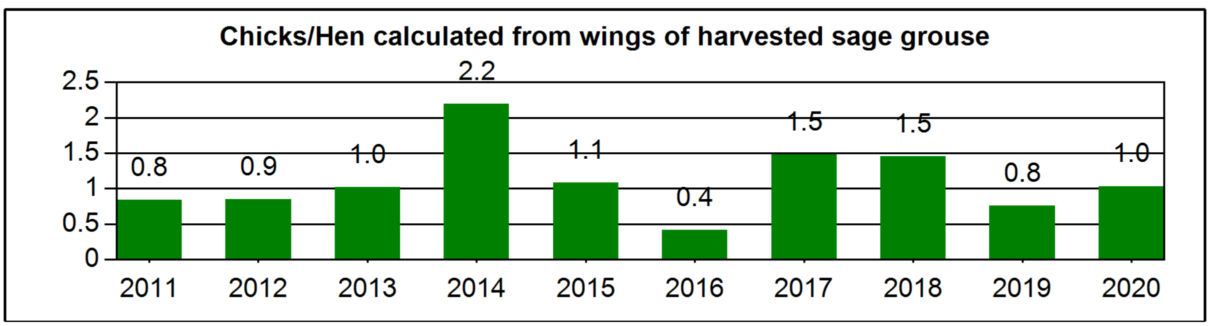
Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2012	688	415	852	0.8	1.7	2.1
2013	488	399	670	0.7	1.2	1.7
2014	588	352	804	0.7	1.7	2.3
2015	837	380	889	0.9	2.2	2.3
2016	869	466	869	1.0	1.9	1.9
2017	621	315	688	0.9	2.0	2.2
2018	805	464	993	0.8	1.7	2.1
2019	723	403	736	1.0	1.8	1.8
2020	252	212	595	0.4	1.2	2.8
Avg	652	378	788	0.8	1.7	2.1

Sage Grouse Job Completion Report

Year: 2011 - 2020, Working Group: Bates Hole

4. Composition of Harvest by Wing Analysis

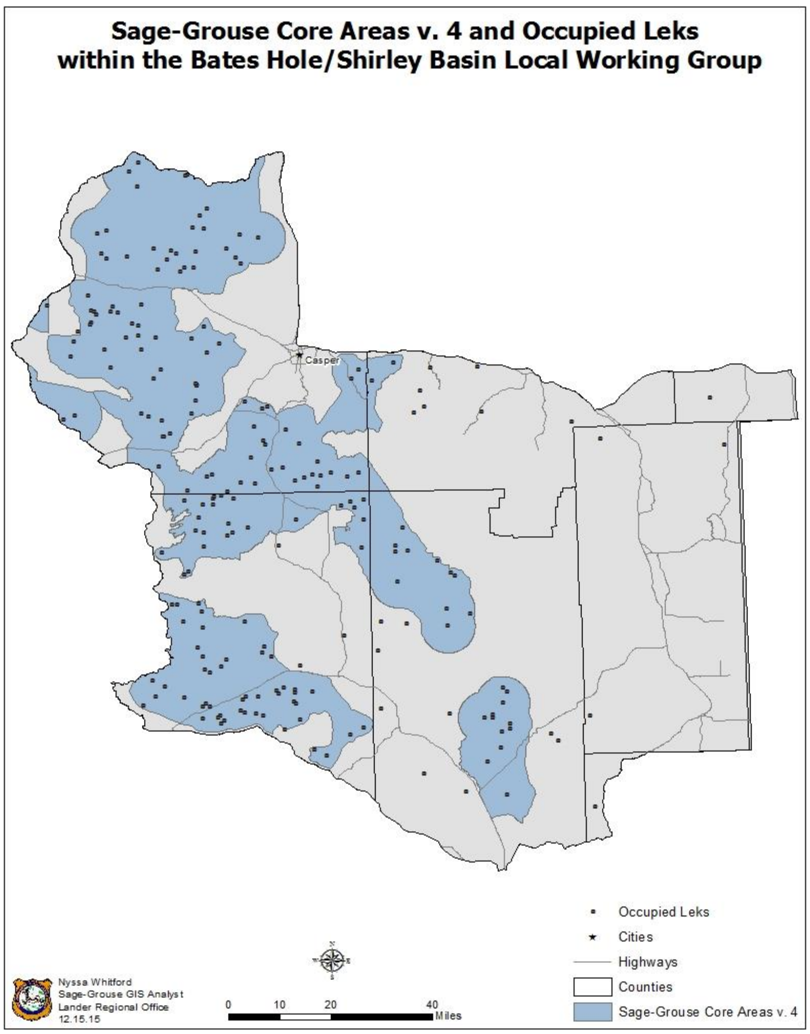
Year	Sample	Percent Adult		Percent Yearling		Percent Young		Chicks/
	Size	Male	Female	Male	Female	Male	Female	Hens
2011	224	17.9	34.8	4.9	7.1	15.6	19.6	0.8
2012	145	20.7	33.8	1.4	8.3	19.3	16.6	0.9
2013	187	9.1	26.2	4.3	16.6	24.1	19.8	1.0
2014	190	10.5	16.8	2.1	10.5	30.5	29.5	2.2
2015	253	14.6	31.6	5.5	6.7	22.9	18.6	1.1
2016	217	19.4	33.2	10.1	16.6	11.5	9.2	0.4
2017	145	20.0	23.4	4.8	6.9	20.0	24.8	1.5
2018	168	15.5	25.0	4.2	7.7	19.0	28.6	1.5
2019	212	13.2	32.5	3.8	14.6	12.3	23.6	0.8
2020	273	8.8	30.8	4.8	11.7	10.6	33.3	1.0



Lek Monitoring

Sage-grouse, and therefore occupied leks, are well distributed throughout most of the BHSBLWG area, although much of the Laramie Range does not provide suitable habitat and most of the historic range in Platte County is no longer occupied due to large scale conversions of sagebrush grasslands to cultivated fields (Figure 1). The Wyoming Game and Fish Department summarizes lek monitoring data each year. As of spring 2021, there are 211 known occupied leks, 92 unoccupied leks, and 17 leks of an undetermined classification within the BHSBLWG area. Lek definitions are presented each year in the statewide Job Completion Report and are included in the monitoring protocol (Christiansen 2012). Undoubtedly, there are leks within the BHSBLWG area that have not yet been identified, while other un-discovered leks have been abandoned or destroyed. The majority of leks classified as "undetermined" lack sufficient data to make a valid status determination. In these cases, historic data indicates these leks were viable at one point, with the leks subsequently being either abandoned or moved. However, location data is either generic or suspect in many of these cases, further confounding the ability to determine the status of these leks.

Figure 1. Sage-grouse lek distribution and core areas within the BHSBLWG area, 2015.



Lek counts and lek surveys have been conducted within the area since the late 1950's, although historically on only a small number of leks. Since 2000, lek monitoring effort has expanded significantly, resulting in increasing numbers of leks being monitored over time and enabling meaningful comparisons of current sage-grouse data to a running 10-year average. In 2021, WGFD personnel, BLM personnel, volunteers and consultants combined efforts to check 178 of the 211 (84%) known occupied leks in the BHSBLWG area. A total of 105 occupied leks were counted while 73 were surveyed, with annual status being confirmed on 156 occupied leks in 2021. Of these, 120 (77%) were active and 36 (23%) were inactive.

It is important to consider trends in the numbers of active versus inactive leks in addition to average male lek attendance when analyzing population trend. During a period of population decline, male lek attendance decreases while the number of inactive leks typically increases. The converse occurs with an increasing population. The percentage of active occupied leks (that were checked) generally decreased in the BHSBLWG area as sage-grouse numbers declined from 2006-2013. Conversely, the percentage of active occupied leks increased for three consecutive years from 2014-2016 as this population grew. In addition, some new leks were discovered during this timeframe while other smaller leks again became active after periods of inactivity. Following a recent population peak in 2016, the percentage of active occupied leks declined rapidly through 2018 and has since declined slowly. Generally declining trends in the percentage of occupied leks being active, coupled with declines in male lek attendance, suggest sage-grouse numbers are continuing to trend downward within the BHSBLWG area.

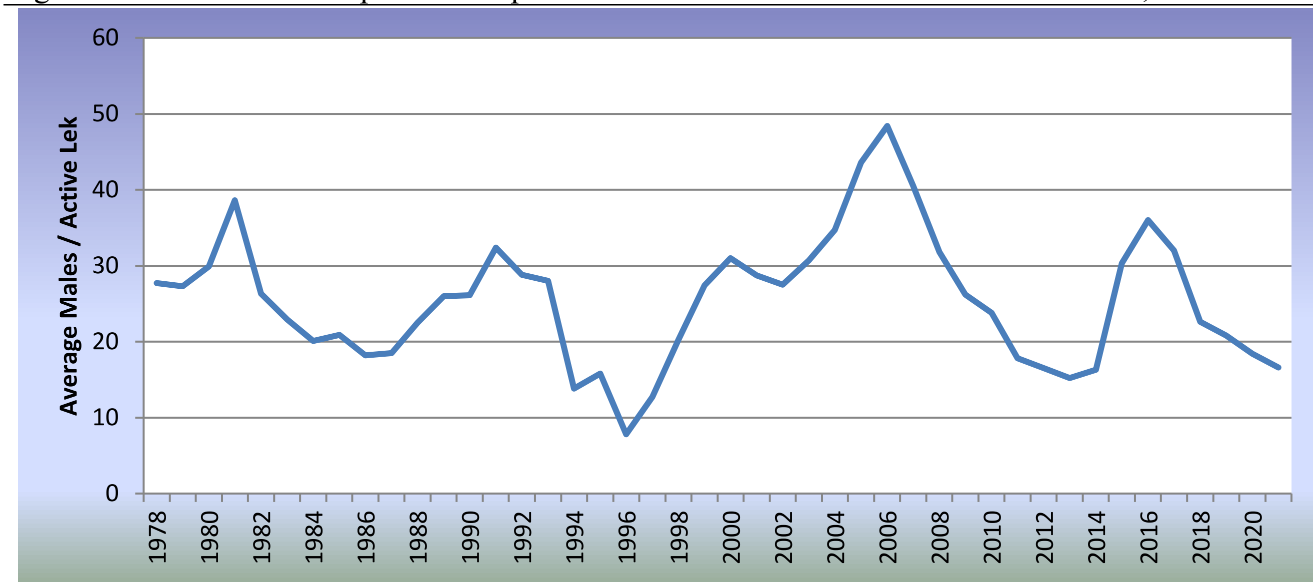
There is always some variation in the annual percentage of occupied leks being active. This variation can be attributed to both population fluctuations and survey effort. Survey effort has been relatively consistent over the past 10 years in the BHSBLWG area, with the total number of occupied leks checked ranging from 211 – 225. However, leks that are not checked in some years tend to be smaller, more difficult to access, or have been compromised in some manner (e.g. due to disturbance). Both disturbed and smaller leks have a higher probability of becoming inactive during a population nadir, such as that of 2013. Regardless, it is important to continue to monitor as many leks as possible, including smaller and marginal leks, to ensure they are classified appropriately (i.e. occupied, unoccupied or undetermined). Where sufficient monitoring data has shown a lek is no longer occupied, it is reclassified as unoccupied as per established protocol.

Population Trend

Monitoring male attendance on leks provides a reasonable index of sage-grouse population trend over time. Nevertheless, these data must be interpreted with caution for several reasons: 1) the survey effort and the number of leks surveyed/counted has varied over time; 2) it is assumed that not all leks in the area have been located; 3) sage-grouse populations exhibit cyclic patterns (Fedy and Doherty 2010); 4) the effects of unlocated or unmonitored leks that have become inactive cannot be quantified; and 5) lek sites may change over time. Both the number of active leks and the number of males attending these leks must be quantified over time to estimate population trend. Fluctuations in the number of grouse observed on leks over time are not exclusively a function of changing grouse numbers. These data also reflect changes in lek survey effort due to weather conditions dictating access to monitor leks.

Despite the aforementioned considerations regarding the interpretation of male lek attendance data, average peak male lek attendance obtained through surveys are strongly correlated with those obtained via lek counts in years when sample sizes exceed 50 leks (Fedy and Aldridge 2011). Since 1978, a minimum of 50 leks have been checked within the BHSBLWG area in all but 4 years (1992-1995) to determine annual population trend. The average number of males observed per active surveyed lek has fluctuated substantially over that time frame within the BHSBLWG area (Figure 2).

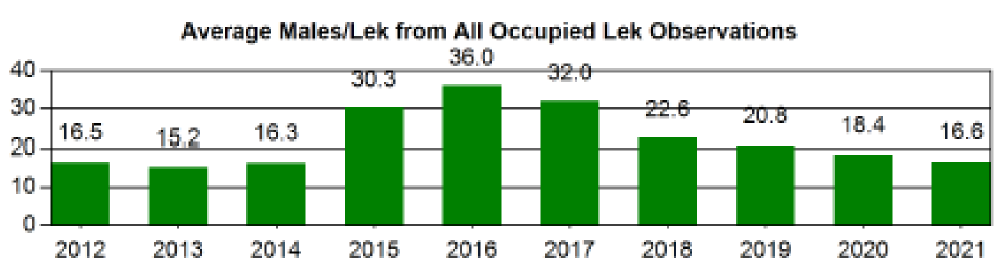
Figure 2. Mean number of peak males per active lek checked within the BHSBLWG area, 1978 – 2021.



*From 1978-1990, an average of 86 leks were checked each year.
*From 1991-1999, an average of 54 leks were checked each year.
*From 2000-present, an average of >160 leks were checked each year.

Based on the mean maximum number of males observed per counted lek, sage-grouse populations declined considerably from 2006 through 2013 in the BHSBLWG area (Figure 3). In fact, the 2013 nadir was the lowest average recorded male lek attendance since intensive lek monitoring began in 2000. However, male lek attendance increased significantly through 2016, which marked a cyclical peak with a mean maximum number of males per counted lek increasing to 40.2. Male lek attendance has since declined sharply over the past four years, with an average of 16.6 in 2021. This steep decline was likely a function of declining chick production and/or survival in 2015 and 2016, followed by only moderate chick production in 2017 and 2018, and poor production in 2019 and 2020. Based on long-term cyclical trends in male lek attendance in the BHSBWLG area (and for sage-grouse populations in general), the current decline in male lek attendance will likely continue, although this population should be nearing its nadir within the long-term cycle.

Figure 3. Mean number of peak males per count lek within the BHSBLWG area, 2011 – 2021.



Productivity

Classifying wings based on sex and age from harvested sage-grouse provides a meaningful indicator of annual sage-grouse chick productivity. During fall hunting seasons, hunters predominantly select for hens and chicks, and typically do not differentiate between the two. Sampling bias is therefore assumed to be minimal when analyzing the ratio of chicks per hen in hunter harvested sage-grouse wings. However, hunter selectivity and sage-grouse habitat use do result in adult and yearling males being under-represented in the harvest compared to their proportion of the population. Summer brood surveys are also conducted periodically, but do not provide as reliable an indicator of chick productivity given they are not conducted in a systematic and repeatable manner and sample sizes are low. In addition, many observations of sage-grouse occur along riparian areas during summer brood surveys, which may under-represent the number of barren hens occurring on uplands, thus biasing the actual chick:hen ratio. Brood survey data will therefore not be discussed here.

In general, chick/hen ratios of about 1.5:1 result in relatively stable lek counts the following spring, while chick/hen ratios of 1.8:1 or greater result in subsequent increased lek attendance and ratios below 1.2:1 result in decline (WGFD 2007). These thresholds do not seem to directly apply in the BHSBLWG area as sage-grouse populations increased from 2013-2016 despite relatively poor chick production (as measured by wing data) in all but one year. Obviously, additional factors must be considered when assessing changes in population trend such as fluctuations in adult female survival, changes in predation, sample size of hunter-harvested wings, etc. In addition, as populations are increasing, relatively less chick production is needed to fuel continued population growth. Over the last 10 years, estimated productivity from wing-barrel data has fluctuated between 0.4 and 2.2 chicks per hen within the BHSBLWG area, although this ratio has only exceeded 1.5 in one of the past 10 years. Reasons for continued relatively low chick production (as measured by wing data) in the BHSBLWG area are unknown. Spring / early summer weather conditions have been relatively normal, and have not experienced any unusual cold, wet conditions that can cause widespread elevated chick mortality following hatch.

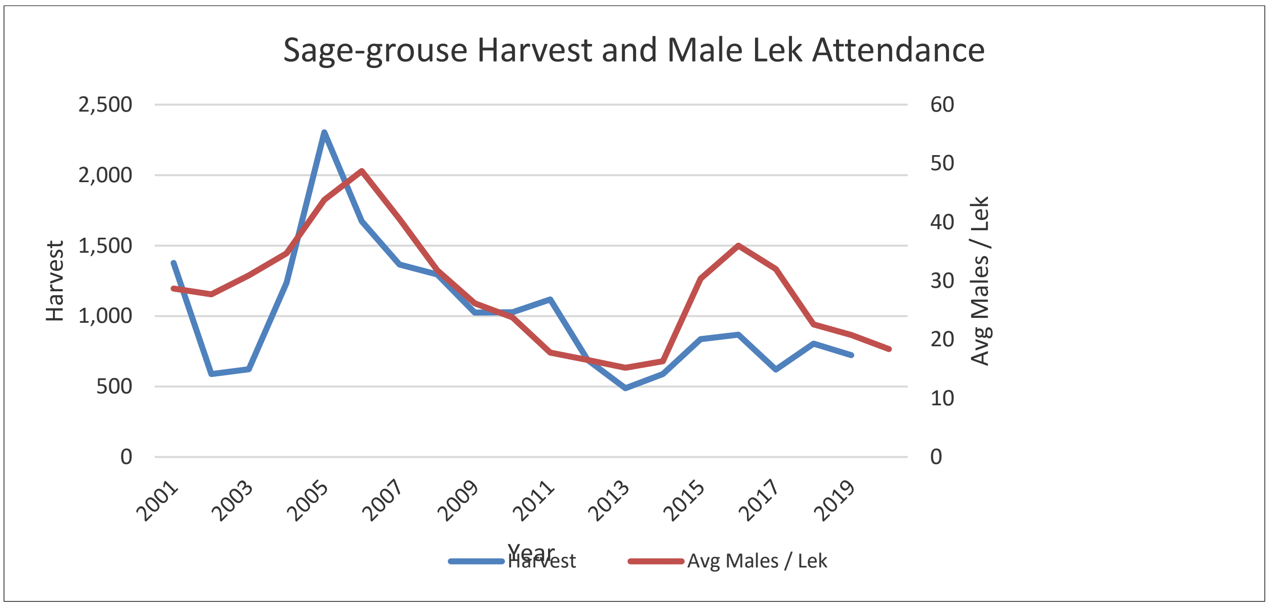
Based on wing data within the BHSBLWG area, moderate to poor sage-grouse juvenile recruitment over the past five years has resulted in continued population decline as evidenced by declining male lek attendance. Chick productivity/survival was excellent in 2014 with an observed 2.2 chicks per hen, which allowed for significant population increase, but has since declined. The chick:hen ratio of 0.4 (using wing data) in 2016 was the lowest chick/hen ratio ever recorded within the BHSBLWG area dating back to 1976. While chick production/survival increased to moderate levels in 2017 and 2018 (1.5 chicks/hen), chick production was poor in 2019 at 0.8 chicks/hen and 2020 at 1.0 chicks/hen.

Harvest

Hunter and harvest statistics provide insight into trends in wildlife populations. Typical of upland game bird populations, there is usually a direct correlation between sage-grouse population levels and hunter effort/harvest when hunting seasons are consistent over time. As sage-grouse numbers decrease, hunter harvest generally declines. Conversely, when populations increase, sage-grouse hunting effort and harvest generally increases. Harvest data specific to the BHSBLWG area was obtainable starting in 1982. Prior to 1982, harvest data was recorded by county and not by management areas. Since 1982, overall sage-grouse harvest has declined considerably within the BHSBLWG area.

Harvest peaked in 1983 at ~14,200 birds and subsequently declined to a previous historic low of 488 in 2013. Following a period of steadily increasing harvest from 2013-2016, sage-grouse harvest has since remained relatively static in the BHSBLWG area from 2017-2019, averaging 716. Total harvest in 2020 was reported as 252 birds, however, due to sampling errors, harvest data from 2020 is unreliable. Over the past 20 years, trends observed in harvest data generally mirror those observed in male lek attendance within the BHSBLWG area (Figure 5). However, it is interesting to note that harvest from 2018 to 2019 was similar to that of 2016 (N=869) during the last population peak. Despite an uptick in sage-grouse populations through 2016, hunter harvest did not increase commensurately as compared to the previous population peak in 2006. Although there has been a long history of hunter effort being correlated with sage-grouse population trends, the recent disparate gap between hunter harvest and sage-grouse population trend over this past cycle may be signifying a waning overall general interest in sage-grouse hunting. Hunter numbers have declined considerably over the long-term, which is also due to conservative seasons being implemented over the past two decades. Hunter participation and harvest declined dramatically in Wyoming when the Wyoming Game and Fish Commission moved the hunting season to later in September in 1995, and then reduced the bag limit and shortened the hunting season in 2002 (WGFD 2008). This reduced hunter harvest occurred in spite of a concurrent sage-grouse population increase (based on males/lek), demonstrating the effects increasingly conservative hunting seasons have had on hunter participation in recent years.

Figure 5. Total sage-grouse harvested per year and the average number of males per active lek checked within the BHSBLWG area, 2001 – 2019.*2020 unreported due to significant sampling errors.



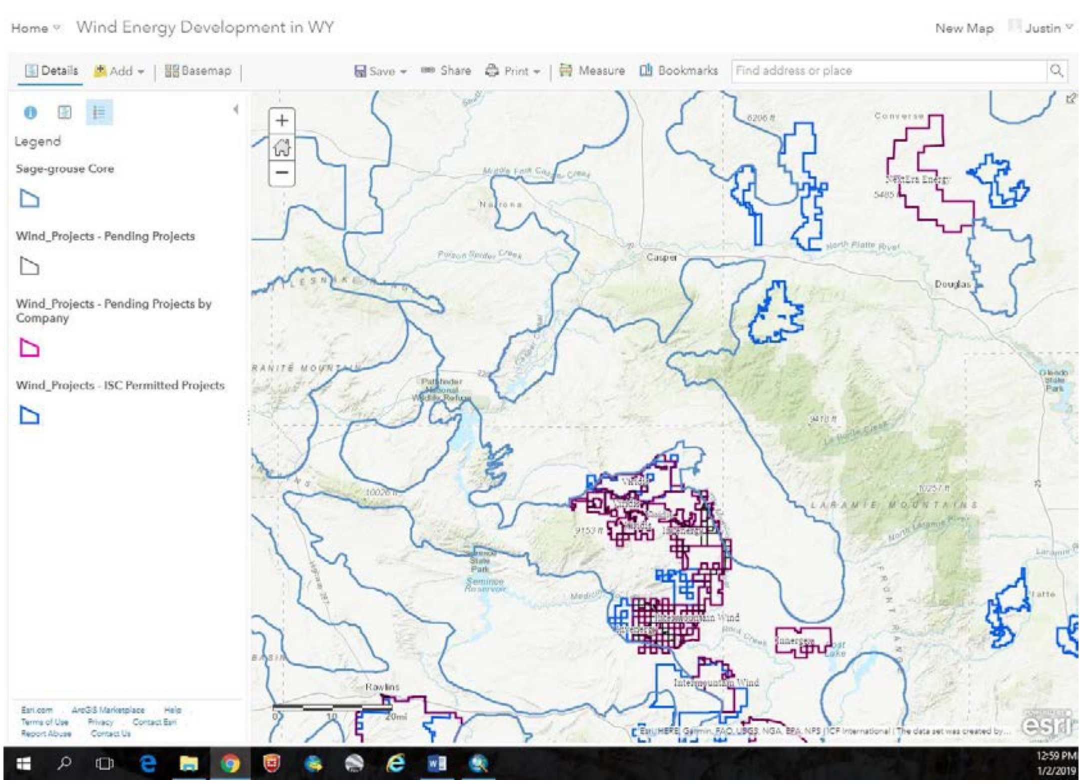
Managers are unable to quantify population response to changes in harvest levels within the BHSBLWG area. Research suggests harvest pressure can be an additive source of mortality within small isolated sage-grouse populations, but is generally compensatory at levels under 11% of the preseason population (Braun and Beck 1985, Connelly et al. 2000, Sedinger et al. 2010).

Habitat

There is little doubt sage-grouse habitat quality has declined over the past several decades throughout the BHSBLWG area. Increased human-caused disturbance (i.e., oil/gas, coal, uranium, and wind energy development), improper grazing by livestock and wildlife, sagebrush eradication programs, and long-term drought have all combined to negatively impact sage-grouse and their habitats. As the level of concern for sage-grouse and sagebrush ecosystems has risen, large-scale sagebrush eradication programs have been largely abandoned, and significant portions of the landscape are now enrolled in grazing systems which are designed to be sustainable and promote healthy rangelands. In addition, various habitat improvement projects have been planned and/or implemented throughout the BHSBLWG area. However, there is much debate among wildlife managers, habitat biologists, researchers, and rangeland specialists as to the efficacy of various forms of habitat treatments within sagebrush ecosystems. Given the long timeline required to reestablish sagebrush following treatment and the difficulty in measuring sage-grouse population level response to such treatments, habitat projects designed to improve sagebrush ecosystem function should be conducted with extreme caution, especially in xeric sagebrush stands or in habitats containing isolated sage-grouse populations.

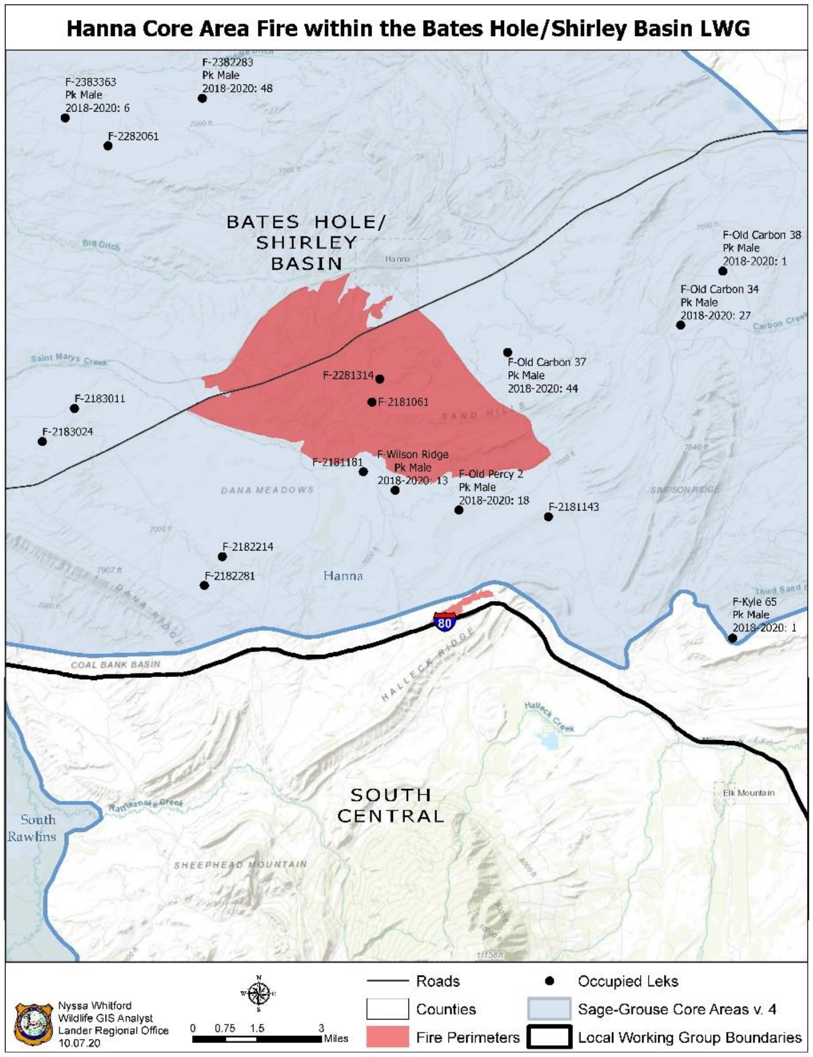
Of particular concern to sage-grouse within the BHSBLWG area is the substantial expansion of large-scale industrial wind development within Shirley Basin. Several new projects are currently in various stages of permitting, with construction ongoing for one large wind farm in eastern Shirley Basin, and more being planned for additional new wind developments over the next two years (Figure 6). Should all or most of these projects come to fruition, they could cumulatively result in the installation of several thousand new wind turbines throughout Shirley Basin. Some of the larger proposed developments are slated to occur within sage-grouse habitat, and could pose significant cumulative impacts to sage-grouse over a large landscape depending upon project scale and siting. Although the current Executive Order (2015-4) prohibits wind development within core areas pending further research, some substantial sage-grouse habitats within Shirley Basin were not included within the most recent version (Version 4) of core areas as wind development was already in the permitting stage. Much of the proposed development is immediately adjacent to core areas.

Figure 6. Existing and proposed (in permitting process) wind development within the BHSBLWG area, 2018.



The RR316 wildfire burned 14,200 acres outside of Hanna, Wyoming in late summer 2020. High fire severity resulted in substantial loss of sagebrush cover in sage-grouse core area. Two leks were within the fire perimeter. Both leks (F-2181061 and F-2281314) were checked by BLM personnel and are mostly intact, however F-2281314 was surrounded by "moonscape." F-2281314 has been classified as inactive since 2014, but used to host 30-50 birds.

Figure 7. RR316 fire map, 2020.



Disease

There were no confirmed cases of West Nile virus (WNv) in sage-grouse within the BHSBLWG area during this reporting period. Normal monitoring efforts were in place. These consisted of requesting researchers with radio-marked birds to monitor for mortality in late summer and attempt to recover and submit carcasses of dead birds to the Wyoming State Vet Lab for necropsy. WGFD field personnel, other agency personnel and the public (via press release), especially ranchers and hay farmers, were also asked to report dead sage-grouse in a timely fashion. The extent of WNv infection and its effects on sage-grouse populations throughout the BHSBLWG area is unknown, but potentially significant in years when outbreaks occur.

Bates Hole / Shirley Basin LWG Conservation Plan Addendum

The BHSBLWG Conservation Plan was updated to reflect major state and federal policy changes in 2013. A Conservation Plan Addendum was completed in July 2013 and is available on the Wyoming Game and Fish Department website at:

https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Sage%20Grouse/SG_BSBASIN_CONSVPLAN.pdf.

Special Studies

The following special studies have been or are currently being conducted within the reporting period within the BHSBLWG area:

In 2020, WEST, Inc. submitted a funding application to evaluate population-level responses of sage-grouse to wind energy facilities in Wyoming in two ways. First, sage-grouse lek count data are the primary monitoring method used for informing sage-grouse management across their range. Lek count data are relevant for assessing landscape-scale relationships between habitat attributes and population trends (Connelly et al. 2003, Edmunds et al. 2018). Evaluating lek count trends have been used to evaluate population level responses of sage-grouse to energy development (Harju et al. 2010, Gregory and Beck 2014) and wind energy development at one location (LeBeau et al. 2017). They proposed to incorporate population trend information from 9 wind-energy facilities (7-Mile Hill, Campbell Hill, Evanston, Foote Creek Rim, Glenrock, Mountain Wind, Pioneer, Rock River, Top of the World; Figure 1) that occur within 4 miles of sage-grouse leks in central, eastern, and southwest Wyoming to evaluate the effects of wind energy facilities on sage-grouse populations. Second, they proposed to evaluate fine-scale sage-grouse data to investigate mechanisms to explain potential behavioral responses associated with sage-grouse occurring in environments influenced by wind energy infrastructure. Specifically, there is uncertainty in how placement of turbines influence connectivity between important sage-grouse habitats. They have recorded over 60,000 sage- grouse locations near turbines that can be used to assess habitat connectivity limitations if they exist (Figure 2). Work is on-going.

The following two abstracts were included in the "Greater Sage-grouse Research Conducted in Wyoming in 2019" summary compiled by Dr. Jeff Beck from the University of Wyoming. An update to the sage-grouse treatments research was provided

1. RESPONSE OF GREATER SAGE-GROUSE TO TREATMENTS IN WYOMING BIG SAGEBRUSH

Kurt T. Smith[1], Jeffrey L. Beck[1], Jason LeVan[1], Anna D. Chalfoun[2], Jason D. Carlisle[3], Jen S. Forbey[4], Stan Harter[5], and Leah Yandow

[1]University of Wyoming, Department of Ecosystem Science and Management, 1000 East University Avenue, Laramie, WY 82071

[2]University of Wyoming, Department of Zoology and Physiology, USGS Wyoming Cooperative Fish and Wildlife Research Unit, 1000 East University Avenue, Laramie, WY 82071

[3]Western Ecosystems Technology, Inc., 200 South 2nd St., Suite B, Laramie, WY 82070

[4]Boise State University, Department of Biological Sciences, Boise, Idaho 83725

[5]Wyoming Game and Fish Department, Lander Regional Office, 260 Buena Vista Drive, Lander, Bureau of Land Management, Lander Field Office, 1335 Main Street, Lander, WY 82520

Wyoming big sagebrush (Artemisia tridentata wyomingensis) has been treated through chemical application, mechanical treatments, and prescribed burning to increase herbaceous forage species released from competition with sagebrush overstory. Originally intended to provide more forage for livestock, these techniques have been applied to improve habitat for sagebrush wildlife species including greater sage-grouse (Centrocercus urophasianus). Treatments are intended to rejuvenate sagebrush plants and increase herbaceous production. Studies evaluating habitat treatments have reported varied results and generally lack the replication necessary for evaluation of demographic rates and fine-scale habitat use of sage-grouse in response to treatments. Our study, centered near Jeffrey City, Wyoming is designed as a Before-After Control-Impact study with 3 years of pre-treatment and 6 years of post-treatment data comparing demographic rates and habitat selection patterns within treated and non-treated sites. We initiated our study in spring 2011 by capturing female sage-grouse and affixing VHF necklace-mounted or GPS rump-mounted transmitters to measure nest and brood-rearing success, and adult female survival. During winter 2014, we mowed 489 ha (1,208 acres) of sagebrush habitats across 2 mowing treatment areas and applied tebuthiuron to 607 ha (~1,500 acres) across 2 herbicide treatment areas in May 2014. We have monitored demographic parameters from n = 625 marked females. Identifying sage-grouse demographic and habitat use responses will aid in determining the efficacy of habitat treatments intended to enhance habitat for sage-grouse and other species associated with the sagebrush biome. Our field study was funded through summer 2019; we will perform final analyses during 2020.

From the update report provided in 2021: Specifically, our study sought to evaluate 1) if specific treatments or levels of treatments influence sage-grouse reproductive demographic response, 2) if nesting, brood-rearing, and adult sage-grouse resource selection was influenced by treatments, 3) the vegetation response to treatments compared to untreated areas and treated areas that received rest from livestock grazing, and 4) the response of forb and invertebrate dry matter in areas treated with mowing and tebuthiuron. Our final report detailing these findings will be submitted as a manuscript to Wildlife Monographs. In addition, we were also funded to continue to evaluate sage-grouse post-fledging survival and measure vegetation responses at treatment exclosure locations for an additional year (2020). While we had limited ability to evaluate how sagebrush treatments influenced juvenile survival, survival estimates from our study will add to a limited literature base on this important vital rate. We intend to submit findings from this research to a peer-reviewed outlet in the future. We recently received funding to continue monitoring vegetation at these same temporary and permanent exclosures in 2021.

2. GREATER SAGE-GROUSE MOVEMENT PATTERNS NEAR AN EXISTING WIND FARM

Jennifer Hess[1], Chad Olson[1], Darren Long[2]

[1]HWA Wildlife Consulting, LLC, 2308 South 8th Street, Laramie, Wyoming 82070

[2] Bureau of Land Management, Wyoming State Office, Cheyenne, Wyoming

Existing peer-reviewed research on the potential effects of wind energy on greater sage-grouse is fairly limited. Currently there is little to no information on site fidelity, recruitment or dispersal of sage-grouse in relation to energy development, specifically wind energy. Adult sage-grouse are known to have a high site fidelity, which can limit their ability to adapt to changes in their environment. But no information exists for sage-grouse movement from natal to initial breeding areas. For our research project, the specific objectives were to: (1) quantify multi-scale resource selection/avoidance in sage-grouse within the wind farm, (2) generate data-driven high-resolution maps of seasonal habitat (nesting, late brood-rearing/summer, and winter) at the landscape scale, and (3) investigate natal dispersal while also examining brood-rearing habitat use, fecundity, survival, and second year use by chicks in wind farm areas.

Female sage-grouse were captured by nocturnal spot-lighting in spring 2019. We equipped female greater sage-grouse with solar-powered ARGOS/GPS transmitters in and around the wind farm near Hanna, Wyoming. Following successful hatching and chicks surviving to 75 days, a total of were outfitted with a 6g ARGOS/GPS transmitter. The project is currently ongoing and we hope future funding will allow us to create several peer-reviewed publications from the research work.

Recommendations

1. Enhance understanding of *long-term* impacts to sage-grouse from large-scale industrial wind through continued research in addition to the research that was conducted within the 7-Mile Hill / Simpson Ridge wind development areas (LeBeau et al., 2016).

    a. NOTE: As of Dec. 2020, Dr. Jeff Beck (along with WEST, Inc.) is proposing to conduct a thorough analysis of potential long-term impacts to sage-grouse populations from industrial wind developments.

2. Continue efforts to document seasonal habitat use throughout the BHSBLWG area, with emphasis on nesting, early-brood rearing, and winter habitats.

3. Continue efforts to document sage-grouse use in ephemeral / mesic drainages where sagebrush has been removed to enhance herbaceous grass and forb production for the benefit of early and late brood rearing habitats.

4. The BHSBLWG should continue to solicit conservation projects that will benefit sage-grouse. These include but are not limited to projects designed to enhance sagebrush understory herbaceous vegetation production, riparian corridor protection, wind energy related research, water development, livestock grazing management planning, etc.

5. Ensure monitoring of all count leks is conducted properly and consistently as per WGFD protocol on an annual basis (WGFD 2010). In addition, maximize overall lek monitoring efforts (including lek surveys) each year to ensure lek sample sizes are significant enough to adequately detect population change.

6. If possible, attempt to survey all leks each year while maintaining counts on all designated count leks. Encourage the public, volunteers, and especially landowners to report lek activity and assist with lek surveys and counts.

7. Continue to monitor inactive or unoccupied leks to adjust classification designation as appropriate.

8. Continue to update and refine UTM coordinates (using NAD83) of leks and map lek perimeters where needed.

9. Continue to inventory abandoned leks to ensure they are appropriately classified and determine whether or not they should continue to remain in the database as per protocol.

Relevant Research

Bates Hole/Shirley Basin Local Working Group (BHSBLWG). 2007. Bates Hole/Shirley Basin Sage-grouse Conservation Plan. January, 2007.

Braun, C. E., and T.D.I. Beck. 1985. Effects of changes in hunting regulations on sage-grouse harvest and populations. Pages 335-344 in S.L. Beasom and S. F. Roberson, editors. Game harvest management. Caesar Kleberg Wildlife Research Institute, Kinsville, Texas, USA.

Christiansen, T. 2010. Hunting and Sage-grouse: A Technical Review of Harvest Management on a Species of Concern in Wyoming. Revised September, 2010. Wyoming Game and Fish Department. Cheyenne, WY.

Christiansen, T. 2012. Chapter 12: Sage Grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S. A. Tessmann and J. R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne, WY.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage-grouse populations and their habitats. Wildl. Soc. Bull. 28(4): 967-985.

Fedy, B. C. and K. E. Doherty. 2010. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage-grouse and cottontail rabbits. Oecologia 165:915-924.

Fedy, B. C. and C. L. Aldridge. 2011. The Importance of Within-Year Repeated Counts and the Influence of Scale on Long-Term Monitoring of Sage-Grouse. Journal of Wildlife Management 75(5):1022–1033.

Heath, B., R. Straw, S. Anderson, and J. Lawson. 1997. Sage-grouse productivity, survival, and seasonal habitat use near Farson, Wyoming. Wyoming Game and Fish Department, Completion Report. Cheyenne, WY. USA.

LeBeau, C. W. 2012. Evaluation of Greater Sage-Grouse Reproductive Habitat and Response to Wind Energy Development in South-Central, Wyoming. Thesis. Department of Ecosystem Science and Management. University of Wyoming, Laramie.

LeBeau. C. W., J. L. Beck, G. D. Johnson, M. J. Holloran. 2014. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management 78:522-530.

LeBeau, C., G. Johnson, M. Holloran, J. Beck, R. Nielson, M. Kauffman, E. Rodemaker, and T. McDonald. 2016. Effects of a Wind Energy Development on Greater Sage-Grouse Habitat Selection and Population Demographics in Southeastern Wyoming. Prepared for: National Wind Coordination Collaborative, Washington, DC. Prepared by: Western EcoSystems Technology, Inc., Cheyenne, WY. January 2016.

LeBeau, C.W., Beck, J.L., Johnson, G.D., Nielson, R.M., Holloran, M.J., Gerow, K.G., and McDonald, T.L., 2017a, Greater sage-grouse male lek counts relative to a wind energy development: Wildlife Society Bulletin 41(1): 17-26.

LeBeau, C.W., Johnson, G.D., Holloran, M.J., Beck, J.L., Nielson, R.M., Kauffman, M.E., Rodemaker, E.J., and McDonald, T.L., 2017b, Greater sage-grouse habitat selection, survival, and wind energy infrastructure: Journal of Wildlife Management 81(4): 690-711.

Mandich, Cheryl, A., Seasonal Habitat Distribution and Parasite Survey of Greater Sage-Grouse in Western Natrona County, Wyoming, M.S., Zoology and Physiology, May, 2011.

Naugle, D. D. 2005. West Nile Virus and sage-grouse: What more have we learned? University of Montana. Missoula, MT. 27 pp.

Pratt, A. C., K. T. Smith, and J. L. Beck. Prioritizing seasonal habitats for comprehensive conservation of a partially migratory species. *Global Ecology and Conservation* 17:e00594.

Sedinger, J.S., G.C. White, S. Espinosa, E.T. Partee, C.E. Braun. 2010. Assessing compensatory versus additive harvest mortality: An example using greater sage-grouse. Journal of Wildlife Management 74(2): 326-332.

Smith, K. T., J. R., LeVan, and J. L. Beck. 2019. Forb and invertebrate response to treatments for greater sage-grouse in Wyoming big sagebrush. *Rangeland Ecology and Management* 72:791–795.

Smith, K. T., A. C. Pratt, J. L. LeVan, A. M. Rhea, and J. L. Beck. 2019. Reconstructing greater sage-grouse chick diets: diet selection, body condition, and food availability at brood- rearing sites. *The Condor: Ornithological Applications* 121: 1–12

Smith, K. T., J. S. Forbey, and J. L. Beck. 2018. Effects of mowing and tebuthiuron treatments on the nutritional quality of Wyoming big sagebrush. *Rangeland Ecology and Management* 71:417–423.

Smith, K. T., J. L. Beck, and C. P. Kirol. 2018. Reproductive state leads to intraspecific habitat partitioning and survival differences in greater sage-grouse: implications for conservation. *Wildlife Research* 45:119–131.

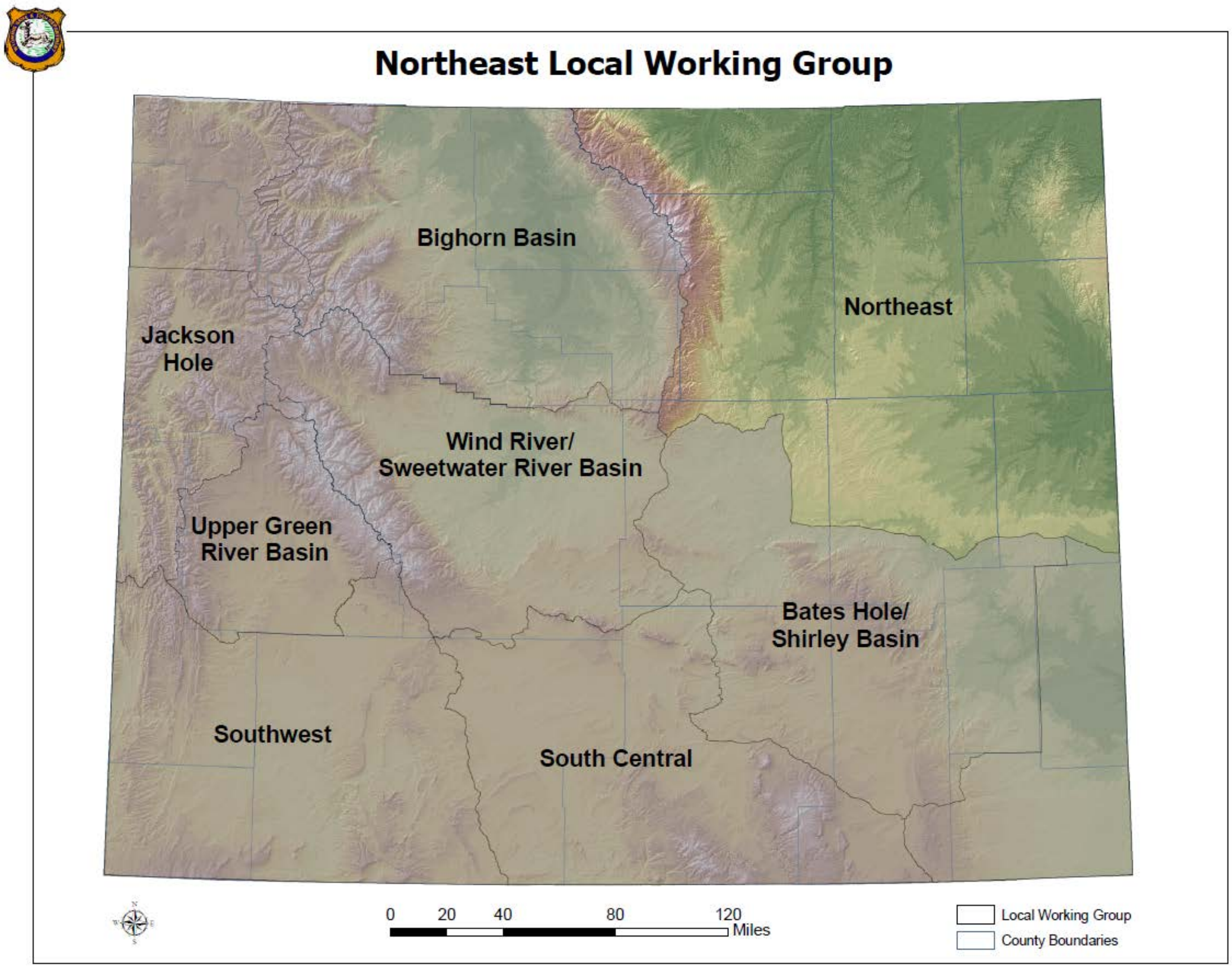
Smith, K. T., and J. L. Beck. 2018. Sagebrush treatments influence annual population change for greater sage-grouse. *Restoration Ecology* 26:497–505.

Smith, K. T., J. L. Beck, and A. C. Pratt. 2016. Does Wyoming's Core Area Policy protect winter habitats for greater sage-grouse? *Environmental Management* 58:585–596.

Northeast Conservation Area

Job Completion Report

SPECIES: **Sage-grouse**
DAU NAME: **Northeast Wyoming Working Group; Area C**
Period Covered: **6/1/2020 – 5/31/2021**
Prepared by: **Cheyenne Stewart**, **Sheridan Wildlife Management Coordinator**



Sage Grouse Lek Characteristics

Management Area: C

Region	Number	Percent
Casper	154	26.1
Sheridan	435	73.9

Working Group	Number	Percent
Northeast	589	100.0

Classification	Number	Percent
Occupied	337	57.2
Undetermined	86	14.6
Unoccupied	166	28.2

BLM Office	Number	Percent
Casper	73	12.4
Buffalo	388	65.9
Newcastle	128	21.7

Biologist	Number	Percent
Buffalo	75	12.7
Casper	14	2.4
Douglas	63	10.7
Gillette	269	45.7
Newcastle	77	13.1
Sheridan	91	15.4

Warden	Number	Percent
Buffalo	77	13.1
Dayton	24	4.1
Douglas	27	4.6
East Casper	5	0.8
Glenrock	30	5.1
Kaycee	60	10.2
Lusk	23	3.9
Moorcroft	78	13.2
Newcastle	62	10.5
North Gillette	68	11.5
Sheridan	12	2.0
South Gillette	116	19.7
Sundance	6	1.0
West Casper	1	0.2

County	Number	Percent
Big Horn, MT	1	0.2
Campbell	208	35.3
Carter, MT	1	0.2
Converse	58	9.8
Crook	27	4.6
Johnson	144	24.4
Natrona	15	2.5
Niobrara	23	3.9
Powder River, MT	1	0.2
Sheridan	34	5.8
Weston	77	13.1

Land Status	Number	Percent
State	41	7.0
USFS	35	5.9
Private	459	77.9
BLM	54	9.2

Sage Grouse Lek Characteristics

Management Area: C

Management Area	Number	Percent
C	589	100.0

Lek Status	Number	Percent
Active	183	31.1
Inactive	218	37.0
Unknown	188	31.9

Sage Grouse Job Completion Report

Year: 2012 - 2021, Management Area: C

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	415	239	58	1860	13.0
2013	407	107	26	713	10.5
2014	404	197	49	932	9.7
2015	396	189	48	1933	16.2
2016	391	167	43	1961	20.4
2017	374	163	44	1845	20.1
2018	369	175	47	1376	13.8
2019	361	151	42	1112	12.5
2020	355	160	45	1534	15.7
2021	348	147	42	1048	14.0

b. Leks Surveyed

Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	415	148	36	499	9.8
2013	407	249	61	940	8.5
2014	404	161	40	700	10.0
2015	396	146	37	1057	16.3
2016	391	179	46	1708	19.2
2017	374	163	44	1375	16.4
2018	369	107	29	654	12.3
2019	361	144	40	833	11.3
2020	355	77	22	465	14.1
2021	348	135	39	783	13.1

1) Occupied - Active during previous 10 years (see official definitions)

2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

3) Inactive - Confirmed no birds/sign present (see official definitions)

Sage Grouse Job Completion Report

Year: 2012 - 2021, Management Area: C

1. Lek Attendance Summary (Occupied Leks) (1) Continued

c. Leks Checked

Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	415	387	93	2359	12.2
2013	407	356	87	1653	9.3
2014	404	358	89	1632	9.8
2015	396	335	85	2990	16.3
2016	391	346	88	3669	19.8
2017	374	326	87	3220	18.3
2018	369	282	76	2030	13.3
2019	361	295	82	1945	11.9
2020	355	237	67	1999	15.3
2021	348	282	81	1831	13.6

d. Lek Status

Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	200	113	74	313	63.9	36.1
2013	180	120	56	300	60.0	40.0
2014	168	134	56	302	55.6	44.4
2015	187	94	54	281	66.5	33.5
2016	191	109	46	300	63.7	36.3
2017	179	99	48	278	64.4	35.6
2018	157	97	28	254	61.8	38.2
2019	165	79	51	244	67.6	32.4
2020	133	88	16	221	60.2	39.8
2021	140	84	58	224	62.5	37.5

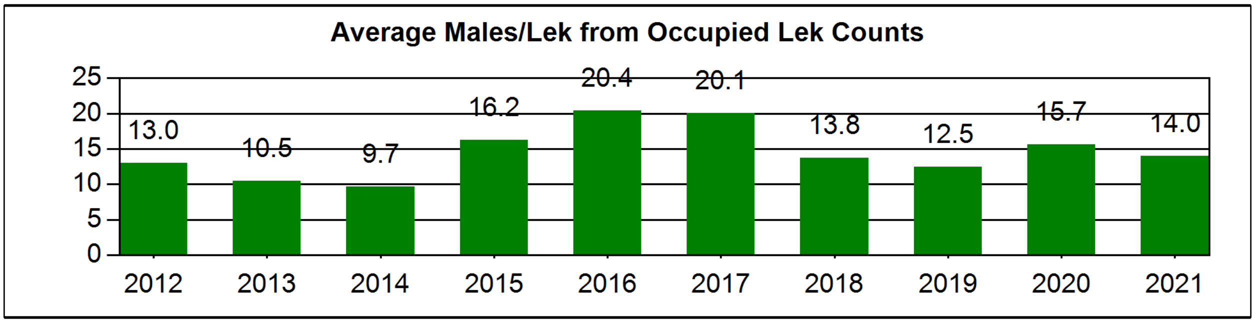
1) Occupied - Active during previous 10 years (see official definitions)

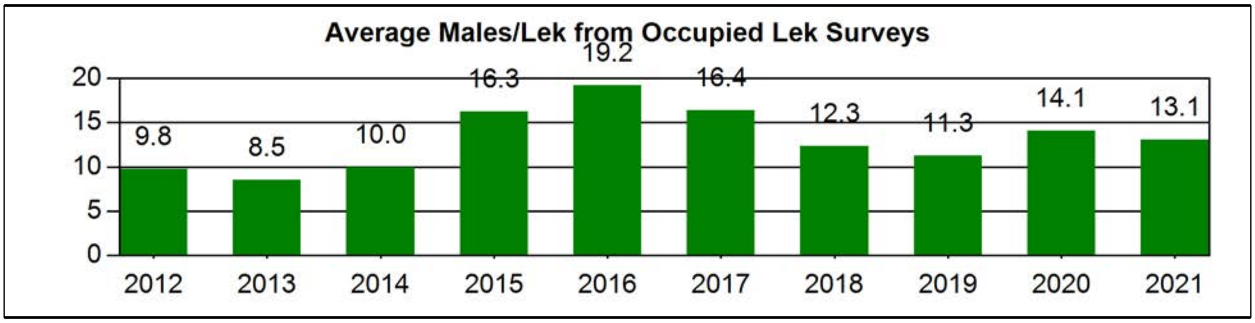
2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

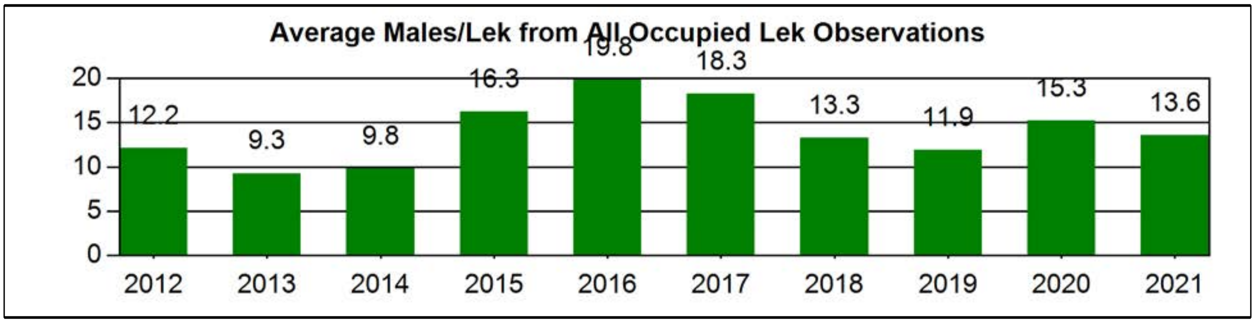
3) Inactive - Confirmed no birds/sign present (see official definitions)

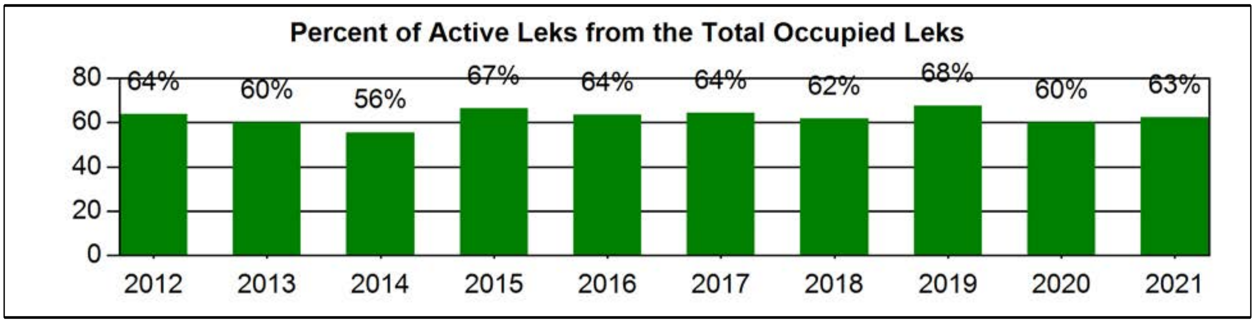
Sage Grouse Occupied Lek Attendance Summary

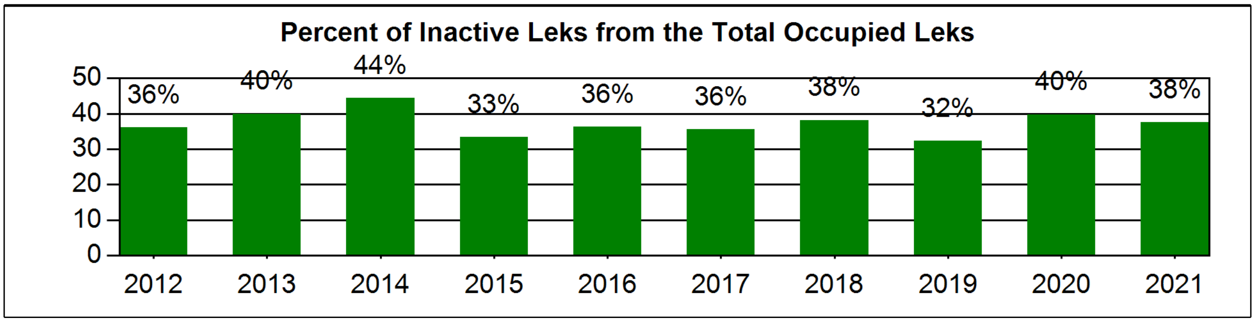
Year: 2012 - 2021, Management Area: C











Sage Grouse Job Completion Report

Year: 2011 - 2020, Management Area: C

3. Sage Grouse Hunting Seasons and Harvest Data

a. Season

Year	Season Start	Season End	Length	Bag/Possesion Limit
2011	Sep-17	Sep-30	14	2/4
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

b. Harvest

Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2011	158	124	173	0.9	1.3	1.4
2012	405	218	404	1.0	1.9	1.9
2013	27	82	249	0.1	0.3	3.0
2014	123	137	242	0.5	0.9	1.8
2015	314	228	400	0.8	1.4	1.8
2016	89	129	265	0.3	0.7	2.1
2017	118	145	344	0.3	0.8	2.4
2018	245	200	479	0.5	1.2	2.4
2019	129	122	203	0.6	1.1	1.7
2020	126	168	798	0.2	0.8	4.8
Avg	173	155	356	0.5	1.0	2.3

Lek Monitoring – Background

The number of males per active lek provides a reasonable index of abundance of the sage-grouse population over time, particularly given the rigorous methods and long-term nature of the dataset in Wyoming. However, it must be noted that lek data must be interpreted with caution for several reasons: 1) the survey effort and the number of leks surveyed/counted has varied over time, 2) it is assumed that not all leks in the area have been located, 3) sage- grouse populations can exhibit cyclic patterns over approximately a decade, 4) the effects of unlocated or unmonitored leks that have become inactive cannot be quantified or qualified, and lek sites may change over time.

In the Northeast Working Group Area, lek monitoring efforts increased substantially since 2000 due to concerns over range wide declines in sage-grouse populations. Additionally, coalbed natural gas (CBNG) development in the Powder River Basin resulted in extensive survey work to meet federal permitting requirements. The WGFD, BLM, U.S. Forest Service, private consultants, landowners and volunteers participate in annual lek monitoring. A significant portion of leks in Northeast Wyoming are checked using a helicopter or fixed-wing plane and many leks are on private land where access might be difficult to attain. In recent years, CBNG development has slowed, resulting in a reduction of lek survey work being completed by private consultants. In response, WGFD personnel are re-examining our annual coordination efforts with the goals of increasing consistency with the leks that are counted each year and the number of leks that are counted each year, as well as targeting undetermined and long-term inactive occupied leks to update management status to unoccupied as appropriate based on our lek monitoring protocols and definitions.

Lek Monitoring – Results

Following the 2021 lek monitoring period, there are 589 documented leks in the Northeast Wyoming Working Group area. Of this total, 337 (57%) are occupied and of those, 183 (31%) were active during the 2021 breeding season. There are 86 (15%) undetermined leks and 166 (28%) unoccupied leks (Table 1 & Table 2).

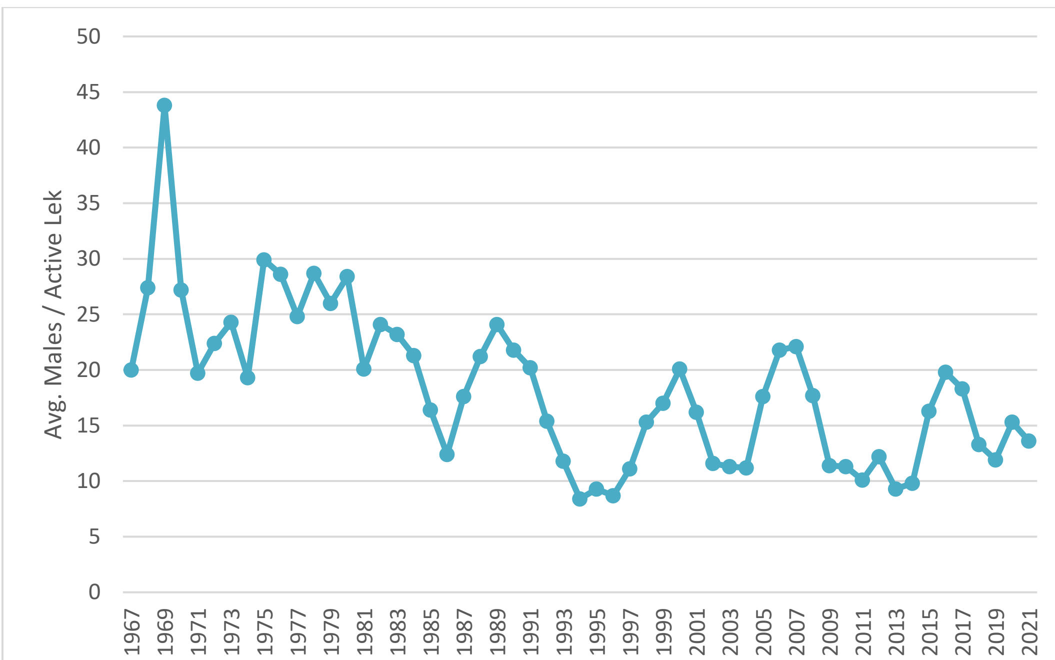
The number of known occupied leks checked by lek counts and lek surveys combined was 282 leks, or 81% of the known occupied leks, and meets the objective of 80% of occupied leks checked (Table 2c). The number of occupied leks counted peaked at 239 in 2012 and has steadily declined since. In 2021, 147 occupied leks were counted . The percent of occupied leks counted has remained between 40% and 50% since 2010, with the exception of 2012 (58%) and 2013 (26%); prior to 2010 less than 40% of occupied leks were counted each year. In 2021, 42% of occupied leks were counted (Table 2a).

Northeast Wyoming has one of the lowest average male lek attendance rates in the state, averaging 14 males per active lek in 2021 compared to the statewide average of 19 males per active lek (Table 1a & Table 3). Most leks in northeast Wyoming are small with less than 20 males. In years when grouse are at the peak of their population cycle less than 10% of the active leks have greater than 50 males at peak count. Two leks exceeded 50 males in 2021 while all four leks that exceeded 50 males in 2020 had less than 50 in 2021. No lek has exceeded 100 males since 2007. This is important because regular population stochastisity presents small leks with a greater risk of becoming inactive in poor years and greater difficulty rebounding in productive years.

Average male lek attendance in northeast Wyoming has decreased significantly over time. Average male attendance has decreased by more than half over the last 30 years. With the exception of the 2006 peak, subsequent peaks in the average male lek attendance are usually lower, or similar, to previous peaks. Likewise, periodic lows in the average male attendance are generally lower, or similar, to the previous low. The long-term trend suggests a steadily declining population (Figure 1). This concern is confounded by the decreasing number of occupied leks, despite new leks still being discovered. There were 41 more total leks in 2021 (589) as compared to ten years ago (548 in 2012), however the number of occupied leks has decreased by 79 leks over the same time period (337 in 2021 and 416 in 2012). This is why it is important to note that Table 2 only reports on the status of occupied leks. This worsens the trends seen in average lek size because the total number of occupied leks are also on a downward trend.

The 2021 lek count suggests the sage-grouse population decreased after peaking in 2016 at 20 males per active lek. The previous cycle peaked at 28 males per active lek in 2006. With 14 males per active lek in 2021, lek attendance was down from last year (16 males per active lek in 2020).

Figure 1. Northeast Wyoming Working Group male sage-grouse lek attendance for all occupied leks checked (counts and surveys) 1967-2021.



Annual lek status was confirmed for 224 leks in 2021. Where status was determined, 140 (62.5%) were active and 84 (37.5%) were inactive (Table 2d). There are 58 leks with an unknown activity status in 2021. The annual lek status determination follows the statewide JCR and the Biological Techniques Manual (Christiansen 2012). Many leks are checked each year that do not meet the standards to confirm inactivity of a lek. Ground checks for sign (droppings/feathers), for example, can be a challenge due to inaccurate locations based on legal descriptions.

The number of inactive leks is on a decreasing ten-year trend, which is likely a reflection of inactive leks being re-designated as not occupied over that time. The number of active leks is also on a decreasing trend, which is not reflected in the percent inactive due to the decrease in known status leks (Table 2d). With WGFD efforts to re-examine annual coordination efforts, we expect to see an increase in the number of known-status leks. Continued efforts at determining the exact location and status of these leks are needed.

Comparisons of core and non-core area lek monitoring results shows that core areas have a slightly higher number of males per active lek (14.5 vs 12.7), and confirmed lek activity is higher in core areas (66% vs. 59%). This suggests the core area policy may be successful at maintaining lek persistence. However, WGFD, the Northeast Wyoming Local Working Group, and the 2020-2021 Northeast Wyoming Technical Team (Appendix A) have all noted that core areas in Northeast Wyoming do not encompass all priority leks and sage-grouse habitats. Consequently, lagging metrics for non-core leks in Northeast Wyoming has more significant impacts to the Northeast Wyoming populations as they would in other management areas in the state.

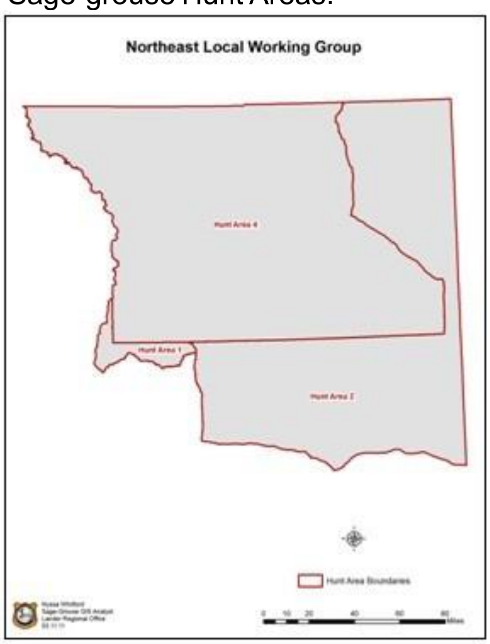
Production

Composition of the harvest, as determined by analysis of wings deposited by hunters in wing barrels, can provide insight into current year's chick production. In past years a limited number of sage-grouse wings were collected during the hunting season, primarily in the eastern portion of the area. Sample sizes were small due to the low harvest and the difficulty to strategically placing enough collection barrels along the many roads and highways within the area. In most years the sample was too small to allow for reliable results. No wings were collected during the 2020 hunting season.

Harvest

The Northeast Working Group area is comprised of Hunt Area 4 and portions of Hunt Areas 1 and 2 (Figure 2). Hunt Area 2 is closed to hunting. In Hunt Area 4, a very conservative hunting season has been in place since 2010 due to continuing concerns of decreasing lek attendance trends.

Figure 2. Northeast Wyoming Sage-grouse Hunt Areas.



Over 1,800 males were observed during 2021 lek monitoring efforts with most of these birds in Hunt Area 4 (Table 2c). The 2020 harvest survey estimated 126 sage-grouse were harvested by 168 hunters, which are similar to the ten-year averages. However, the total number of hunting days reported for Area C was 798 days, which is unreasonably high and therefore makes the rest of the 2020 harvest data results questionable (Table 4). This highlights the challenges of obtaining statistically valid harvest survey data with a very small sample size of hunters. Given current survey methods and license structures it is particularly difficult to target sage-grouse hunters specifically. *

Habitat

Most occupied habitat for sage-grouse is held in private ownership. Approximately 75 percent of known leks are found on private land with the remaining 25 percent found on Bureau of Land Management, U.S. Forest Service and State owned lands. Because most sage-grouse are found on private land, little direct control exists to protect important habitats, including breeding and nesting areas, brood rearing areas, and major wintering areas.

The primary economic uses of lands currently or historically providing sage-grouse habitat are agriculture and energy. Livestock grazing, mainly cattle along with sheep production, is the primary agriculture use. Some crop production occurs as irrigated and dry land hay and some small grains. Historically, large parcels of sagebrush habitat were converted either to grasslands or crops. Limitations of remote sensing technology have prevented quantifying and mapping these conversions.

Two years of drought conditions have generally resulted in poor range conditions in 2021, with little residual cover in many areas of the region. Cheatgrass continues to thrive in the Powder River Basin, competing with native grasses and forbes in sagebrush understory. The increased wildfire risk due to cheatgrass invasion is being realized. In 2020, the Reno Fire burned through the middle of the Buffalo Core Area, splitting the north half from the south half. In 2021, the Cellars, Wild Horse Creek, and Dry Fork wildfires cumulatively burned almost 7,500 acres in and around the Thunder Basin Core Area. Sagebrush restoration and invasive species management following fires like these is still experimental and will take decades for the sagebrush to recover.

Vast coal reserves are being developed with surface pit mines in eastern Campbell County and northern Converse County.

Oil and natural gas production has occurred in portions of the area since the early 20th century. An unprecedented energy boom began in the Powder River Basin in the late 1990's with the exploration and development of CBNG reserves. The BLM predicted 51,000 wells could be drilled in the Powder River Basin Oil and Gas Project Record of Decision (BLM 2003). At the peak of the CBNG play, more than 18,300 wells were in production (August 2008) with production peaking in January 2009 at 49,459,629 Mcf of methane gas (WOGCC 2019). Much of the development in the energy play involves federal minerals with private surface. Wells, roads, power lines, produced water, activity and dust are components of development which affect sage-grouse habitat at a broad scale. Since 2009, development and production has declined as CBNG leases have been drilled and natural gas prices decreased. Many wells drilled early in the play have completed the production phase of development and are now being plugged and abandoned. Furthermore, low gas prices currently hamper the economic viability of CBNG production operations. Drilling new wells is occurring primarily to hold existing leases.

*The 2020 sage-grouse harvest estimates should be interpreted with caution, because that particular year's survey under-sampled potential sage-grouse hunters from certain license fee types, resulting in poor quality harvest estimates. Making comparisons between previous years' estimates and the 2020 estimates should be avoided, because the results from the voluntary survey were unreliable due to sampling issues.

Deep well oil and gas development has increased in recent years with new technologies enabling horizontal and directional drilling. While CBNG activity decreased, the interest in deep drilling has fluctuated with inconsistent oil prices. The vast majority of the drilling is occurring in Converse and Campbell Counties. Exploration utilizing horizontal drilling has increased markedly from 10 wells in 2007 to 365 wells in 2014 after which activity decreased to 118 wells in 2016. Deep wells require large well pads and large amounts of truck traffic to deliver water, sand, etc for drilling and fracking.

Considerable debate occurred on the effects of energy development on sage-grouse. Peer reviewed research findings show significant impacts (Walker et al. 2007, Doherty et al. 2008, Doherty et al. 2010, Harju et al. 2010 and others). These findings have yet to be accepted by some people and this has contributed to uncertainty in the public and political arenas as to the real effects of energy development. Furthermore, many continue to blame predation or harvest for sage-grouse population declines, which have much lower population impacts than habitat fragmentation, direct loss, and indirect loss.

A population viability analysis by Taylor et al. (2012) found that energy development had the greatest influence on male grouse lek attendance within 12.4 miles of a lek. At 8 wells per section (80 acre spacing), only 39% of males persisted while the number of large leks significantly decreased. Subjecting suppressed populations in developed areas to West Nile virus outbreaks or other stressors threatens local populations with extirpation.

Disease

No West Nile virus (WNv) mortality was reported for northeast Wyoming in 2021 and no major mortality events have been documented since 2003 when WNv was first documented in sage-grouse in the Powder River Basin. Because of the difficulty in monitoring WNv in sage- grouse, human and livestock cases can provide an indication of WNv prevalence in a given year. As of 20 October 2021, the Wyoming Department of Health reported two positive mosquito pools of 14 tested in Natrona County, of which a small area is within the Northeast Working Group area. One animal tested positive in both Campbell and Converse Counties. Conversely, zero mosquito pools, humans, or animals tested positive for WNv in 2020 (Wyoming Department of Health 2021).

Taylor et al. (2012) predicted that the low elevation population of northeast Wyoming is susceptible to West Nile virus outbreaks which can decrease a population by more than 50%. Furthermore, even with no additional energy development the authors predict that one outbreak year could result in the extirpation of some local populations due to the small lek sizes in the area.

Conservation Planning - Northeast Local Working Group

In 2021, the Northeast Working Group (hereafter, working group) was asked to review multiple 2020 datasets to assess if adaptive management triggers had been tripped and the group identified multiple soft triggers and one hard trigger. The working group also highlighted concerns with the process, particularly related to the lack of response to the working group and Technical Team's work related to the 2018 soft trigger (Appendix A and Appendix B).

Sage-grouse are influenced by many factors, both individually and cumulatively. Habitat loss and fragmentation, direct mortality and disturbance affect sage-grouse populations. In 2006, the Northeast Wyoming Working Group identified and ranked those factors believed to be most influencing the northeast Wyoming sage-grouse population, as well as actions that might provide the greatest benefit for sage-grouse conservation in northeast Wyoming. In the opinion of the group, conservation efforts targeting oil, gas and CBNG development, vegetation management, invasive plants, local residential land use, and livestock grazing would be most effective in benefiting sage-grouse. As a follow-up, in 2021 the Working Group initiated a GIS mapping exercise to spatially overlay these key factors influencing sage-grouse populations under their area of responsibility. The goal is to have a tool to solicit more funding applications that address the most pressing needs for regional sage-grouse populations as well as create project ranking priorities.

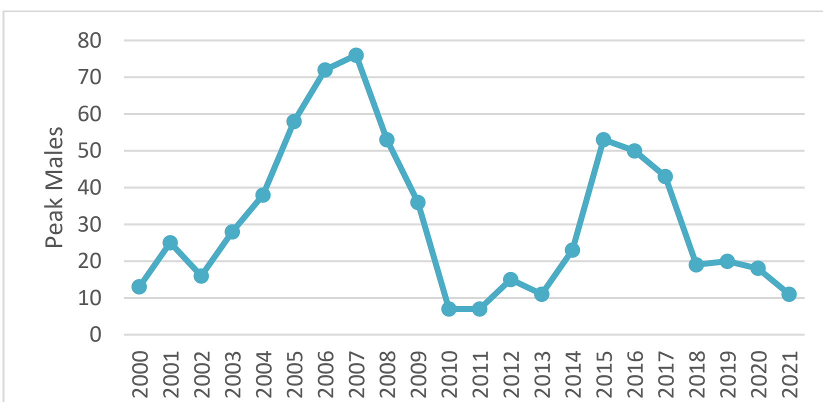
Conservation Planning – Northeast Technical Team

In April 2021, the Northeast Wyoming Sage-grouse Technical Team (hereafter technical team) submitted recommendations to address the soft trigger identified in 2018. The group met over 11 months and 11 meetings. One key finding was that recent genetic connectivity research demonstrates that the current core and connectivity boundaries are not acting as intended; some protected areas are not as important to range wide populations as initially thought while other areas that are not currently protected have critical conservation value. The technical team recommended that the Statewide Adaptive Management Team determine if this meets the definition of new, substantive, and compelling information to qualify for an interim core area review, pursuant to Executive Order 2019-3. The technical team identified the most immediate and pressing concerns relating to the long-term viability of sage-grouse populations in Northeast Wyoming as 1) maintaining and/or enhancing genetic connectivity and 2) the potential for long-term loss of substantial acreage of sagebrush habitats due to wildfire. The technical team provided six recommendations (Appendix A).

Special Reports - Douglas Core Area

Sage-grouse peak lek attendance within the Douglas Core Area (DCA) totaled 11 males at one active lek in 2021 (Figure 3). Three of the four leks were inactive, which increases long-term concerns about the viability of this core area population. There have been no changes in lek classifications since 2016.

Figure 3. Peak males from all leks in the Douglas Core Area 2000-2021.



The DCA has experienced a substantial increase in energy development over the past several years. Due to the high density of oil and gas development coupled with a large wildfire that eliminated sagebrush cover over the landscape, all permitted disturbance within the DCA exceeds thresholds established by Wyoming Governor's Sage-grouse Executive Order. Because the majority of the permitted activities are being developed under valid and existing rights secured prior to core area designation, development has continued to occur despite exceeding disturbance thresholds. To mitigate this, the Wyoming Governor's Office, the Department and other partners have worked closely with industry to identify a plan of development and establish a large industry funded restoration effort guided by a multi-disciplinary restoration team. The plan of development, which was renewed in 2018 and is valid until 2022, includes practices such as avoiding key habitat areas, minimizing disturbance and significantly reducing traffic during breeding and nesting seasons. The Restoration Team has identified, and is currently implementing, multiple projects beneficial to sage-grouse within the DCA including sagebrush restoration, cheatgrass control and a West Nile virus management program. Additionally, the team has sponsored multiple research projects through two graduate research students with the goal of developing best management practices for sagebrush restoration. The team has recently been working to disseminate results from these projects. To date, the team has planted over 100,000 sagebrush plants and has leveraged additional partner funds to continue sagebrush restoration, cheatgrass management and mesic habitat improvement work. Lastly, the team refined the disturbance data layer for the DCA by documenting suitable habitat per the 2015 Executive Order guidelines.

RECOMMENDATIONS – Time Sensitive Needs

Habitat management

The concern of invasive annual grasses and wildfire frequencies in sagebrush habitats is an immediate threat to the long-term viability of sage-grouse habitats in Northeast Wyoming. *We need to figure out how to treat cheatgrass in viable sagebrush habitats at a large scale.* This is vital for the long-term viability of sagebrush habitats in Northeast Wyoming. This will require managers to find ways to engage with landowners on a massive scale. Additionally, work to increase brood-rearing habitats would help address low chick recruitment rates reported (Kirol 2021).

Prepare for core area review

Core areas were designated with the objective of identifying habitats that supported most of Wyoming's sage-grouse. Statewide, core areas encompass leks with 78% of the 2012-2014 peak males. However, in the Northeast Wyoming Working Group area, core areas were designated based on CBNG development patterns along with lek density data thereby encompassing leks supporting only 49% of the 2012-2014 peak males. Recent genetic connectivity research as well as work completed by the Northeast Working Group and Technical Teams confirm that the core area in Northeast Wyoming do not accurately reflect the areas of greatest conservation need. All relevant groups, stakeholders, and managers should *be prepared to propose revisions to the currently delineated core and connectivity areas* in 2024, if not sooner, pursuant to Executive Order 2019-3.

Lek monitoring coordination

In recent years, CBNG development has slowed, resulting in a reduction of lek survey work being completed by private consultants. In response, WGFD personnel are spearheading efforts to *re-examining the annual coordination efforts* with the goals of increasing consistency with the leks that are counted each year and the number of leks that are counted each year, as well as targeting undetermined and long-term inactive occupied leks to update management status to unoccupied as appropriate based on our lek monitoring protocols and definitions. This project should be conducted with the cooperation of the BLM and the Northeast Working Group.

Recommendations – Continue Long-Term Work

- Assist the BLM with developing and implementing the sage-grouse monitoring program as prescribed by the Powder River Basin CBNG EIS Record of Decision (April 2003).
- Annually monitor 80% of the occupied leks in the local working group area.
- WNv monitoring.
- Assist the BLM with coordinating sage-grouse population monitoring efforts with the private consultants doing work for energy development companies.
- Use any additional flight money for lek searches and surveys. Check all leks at least once every three years. All leks should be recorded in UTMs (NAD 83) using GPS.
- Review the sage-grouse database to eliminate leks without adequate documentation to support a lek designation.
- The Working Group should continue to solicit habitat projects on private lands that will have benefit for sage-grouse.
- The WGFD Regions should continue to recommend protection of occupied sage-grouse leks during environmental commenting and promote their protection on private land projects.
- Additional effort is needed to document the status of undetermined leks. Encourage reporting of lek activity from the public and landowners.
- Better document wintering sage-grouse locations and develop a seasonal range map for sage-grouse for the Working Group Area.
- Continue to map lek perimeters to ensure adequate buffer distance in protecting leks.

Report Notice

Variation in this report from previous years' reports is expected because of new data added to the lek database. Old records are added each year as data become available and newly discovered leks are added to the database. New lek count routes may also be added. Data adjustments should be taken into consideration when the current report and tables are compared to previous editions.

Relevant Research

The following publications have been conducted in the Powder River Basin of Wyoming and Montana. Citations published in 2021 are noted with an asterisk (*) and appended (Appendix 3).

Copeland, H.E., K.E. Doherty, D. E. Naugle, A. Pocewicz, and J.M. Kiesecker. 2009. Mapping Oil and Gas Development Potential in the US Intermountain West and Estimating Impacts to Species. PLoS ONE 4(10): e7400. doi:10.1371/journal.pone.0007400.

Doherty, K. E., D. E. Naugle and B. L. Walker. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. Journal of Wildlife Management 74(7):1544–1553.

Doherty, K. E. 2008. Sage-grouse and Energy Development: Integrating Science with Conservation Planning to Reduce Impacts. Ph.D. Dissertation. Fish and Wildlife Biology, University of Montana. 125 pp.

Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage- grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

Doherty, K. E, D. E. Naugle and J. S. Evans. 2010. A currency for offsetting energy development impacts: horse trading sage-grouse on the open market. PLoS ONE 5(4):e10339.

Doherty, K. E., J. L. Beck and D. E. Naugle. 2011. Comparing ecological site descriptions to habitat characteristics influencing greater sage-grouse nest site occurrence and success. Rangeland Ecology and Management 64(4):344-351.

Doherty, M.K. 2007. Comparison of Natural, Agricultural and Effluent Coal Bed Natural Gas Aquatic Habitats. Master of Science. Montana State University. Boseman, MT.

Fedy, B. C. and K. E. Doherty. 2010. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage- grouse and cottontail rabbits. Oecologia 165:915-924.

Fedy, B.C. and C.L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Foster, M. A.. J. T. Ensign, W. N. Davis, and D. C. Tribby. 2014. Monitoring Greater Sage-Grouse in the Southeast Montana Sage-grouse Core Area. Final Report. February 2014. Montana Fish Wildlife and Parks *in partnership* with the Bureau of Land Management. Miles City, MT. 108 pp.

Gregory, A. J. and J. L. Beck. 2014. Spatial Heterogeneity in Response of Male Greater Sage-Grouse Lek Attendance to Energy Development. PLoS ONE 9(6): e97132. doi:10.1371/journal.pone.0097132

Harju, S.M., M.R. Dzialak, R.C. Taylor, L.D. Hayden-Wing, and J.B. Winstead. 2010. Thresholds and Time Lags in Effects of Energy Development on Greater Sage- Grouse Populations. Journal of Wildlife Management 74:437- 448.

Naugle, D. E., C. L. Aldridge, B. L. Walker, T. E. Cornish, B. J. Moynahan, M. J. Holloran, K. Brown, G. D. Johnson, E. T. Schmidtmann, R. T. Mayer, C. Y. Kato, M. R. Matchett, T. J. Christiansen, W. E. Cook, T. Creekmore, R. D. Falise, E. T. Rinkes, M. S. Boyce. 2004. West Nile virus: pending crisis for Greater Sage-grouse. Ecology Letters. Volume 7, Issue 8, p. 704-713.

Kirol, C. P. 2014. Powder River Basin Radio-Marked Greater Sage-Grouse Study— Mammal Nest Predator DNA Identification. Project Report *prepared for the* Northeast Wyoming Sage-grouse Local Working Group. 13 pp.

*Kirol, C. P. 2021. Patterns of nest survival, movement, and habitat use of sagebrush-obligate birds in an energy development landscape. Thesis presented to the University of Waterloo. https://uwspace.uwaterloo.ca/handle/10012/16844. Accessed December 2021.

Kirol, C. P., Sutphin, A.L., Bond, L.S., Maechtle, T.L., Fuller, M.R., 2015. Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development. DOI- 10.2981/wlb.00002: Wildlife Biology, v. 21, p. 98-109.

Kirol, C. P., K. T. Smith, N. E. Graf, J. B. Dinkins, C. W. LeBeau, T. L. Maechtle, A. L. Sutphin, and J. L. Beck. 2020. Greater sage-grouse response to the physical footprint of energy development. Journal of Wildlife Management 84: 989-1001.

Naugle, D. E., C. L. Aldridge, B. L. Walker, K. E. Doherty, M. R. Matchett, J. McIntosh, T. E. Cornish, and M. S. Boyce. 2005. West Nile virus and sage-grouse: What more have we learned? Wildlife Society Bulletin, 33(2):616-623.

Naugle D. E., K. E. Doherty, B. L. Walker, M. J. Holloran, and H. E. Copeland. 2011. Energy development and greater sage-grouse. Pages 489-529 in Greater sage- grouse: ecology and conservation of a landscape species and its habitats, S. T. Knick, J. W. Connelly, C. E. Braun (editors). Studies in Avian Biology, Number 38, University of California Press, Berkeley, CA, USA.

Taylor, R. L., D. E. Naugle, and L. S. Mills. 2010. Viability analyses for conservation of sage-grouse populations. Completion report, Miles City Field Office, Montana, USA.

Taylor, R. L., D. E. Naugle, and L. Scott Mills. 2012. Viability analyses for conservation of sage-grouse populations: Buffalo Field Office, Wyoming Final Report 27 February 2012. BLM Contract 09-3225-0012 Number G09AC00013 (8/10/10). University of Montana, Missoula.

Taylor, R. L., B. L. Walker, D. E. Naugle, and L. Scott Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76:336-347.

Walker, B. L., D. E. Naugle, K. E. Doherty, and T. E. Cornish. 2004. Outbreak of West Nile Virus in Greater Sage-grouse and Guidelines for Monitoring, Handling, and Submitting Dead Birds. Wildlife Society Bulletin 32(3): 1000–1006.

Walker, B. L., D. E. Naugle, and K. E. Doherty. 2007a. Greater sage-grouse population response to energy development and habitat loss. Journal of Wildlife Management 71:2644-2654.

Walker, B.L. D.E. Naugle, K.E. Doherty, and T.E. Cornish. 2007b. West Nile Virus and greater sage-grouse: estimating infection rate in a wild bird population. Avian Diseases 51:691-696.

Walker, B. L. 2008. Greater Sage-grouse Response to Coalbed-Natural Gas Development and West Nile Virus in the Powder River Basin, Montana and Wyoming, USA. Dissertation. University of Montana. Missoula, MT.

Zou, L., S.N. Miller, and E.T. Schmidtmann. 2006. Mosquito larval habitat mapping using remote sensing and GIS: Implications of coalbed methane development and West Nile virus. Journal of Medical Entomology 43:1034–41.

Literature Cited

BLM 2003. Record of Decision and Resource Management Plan Amendments for the Powder River Basin Oil and Gas Project. U.S. Department of Interior, Bureau of Land Management. Wyoming State Office/Buffalo Field Office. WY-070-02-065.

Christiansen, T. 2012. Chapter 12: Sage Grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S.A. Tessmann and J.R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne, WY.

Doherty, K. E. 2008. Sage-grouse and Energy Development: Integrating Science With Conservation Planning to Reduce Impacts. Dissertation. University of Montana. Missoula, MT.

Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187-195.

Doherty, K. E., D. E. Naugle, and J. S. Evans. 2010. A currency for offsetting energy development impacts: horse-trading sage-grouse on the open market. PLoS One 5:e10339.

Gamo, R. S., and J. L. Beck. 2017. Effectiveness of Wyoming's sage-grouse core areas: influences on energy development and male lek attendance. Environmental Management 59:189–203.

Harju, S.M., M.R. Dzialak, R.C. Taylor, L.D. Hayden-Wing, and J.B. Winstead. 2010. Thresholds and Time Lags in Effects of Energy Development on Greater Sage- Grouse Populations. Journal of Wildlife Management 74:437- 448.

Kirol, C. P. 2021. Patterns of nest survival, movement, and habitat use of sagebrush-obligate birds in an energy development landscape. Thesis presented to the University of Waterloo. https://uwspace.uwaterloo.ca/handle/10012/16844. Accessed December 2021.

Knick, S.T., and J.W. Connelly, editors. 2011. Ecology and Conservation of Greater Sage-Grouse: A Landscape Species and its Habitats. Volume 38. Studies in Avian Biology. Cooper Ornithological Society. University of California Press.

Naugle, D. E., B. L. Walker, and K. E. Doherty. 2006a. Sage-grouse Population Response to Coal-bed Natural Gas Development in the Powder River Basin: Interim Progress Report on Region-wide Lek-count Analyses. Wildlife Biology Program, College of Forestry and Conservation, University of Montana. 10 pp.

Naugle, D. E., K. E. Doherty and B. L. Walker. 2006b. Sage-grouse Winter Habitat Selection and Energy Development in the Powder River Basin: Completion Report. June 2006. Unpublished Report, University of Montana, Missoula, MT. 23 pp.

Taylor, R. L., D. E. Naugle and L. S. Mills. 2012. Viability Analysis for Conservation of Sage-grouse Populations: Buffalo Field Office, Wyoming. Wildlife Biology Program, University of Montana, Missoula, MT. 46 pp.

Walker, B. L. 2007. Greater Sage-grouse Population Response to Energy Development and Habitat Loss. Journal of Wildlife Management. 71(8):2644–2654.

Wyoming Department of Health. 2021. Website at https://health.wyo.gov/publichealth/infectious-disease-epidemiology-unit/disease/west-nile-virus/. Accessed December, 2021.

Wyoming Oil and Gas Conservation Commission (WOGCC). 2019. Website at www.wogcc.state.wy.us. Accessed December, 2019.

APPENDIX A

Northeast Wyoming Technical Team Report

April 20, 2021

Statewide Adaptive Management Working Group
c/o Bob Budd, Chair, Sage-grouse Implementation Team
Cheyenne, WY

**Subject: Northeast Wyoming Sage-grouse Technical Team
2017 Tidwell/Deer Creek Wildfire - Soft Trigger Status Review
and Recommendations for the Buffalo Connectivity Area**

To whom it may concern:

The Northeast Wyoming Sage-grouse Technical Team (NEWSGTT), comprised of ten (10) individuals representing various local stakeholder groups, respectfully submits its analysis and recommendations regarding the soft trigger event of the 2017 Tidwell/Deer Creek Wildfire in the Buffalo sage-grouse Connectivity Area.

The NEWSGTT developed the recommendations over the course of eleven (11) months, eleven (11) meetings, and approximately five (5) drafts. While consensus is not required to draft the final recommendations of the NEWSGTT, all members of the group agreed with the report conclusions. A copy of the NEWSGTT report was provided to and reviewed by the Northeast Wyoming Local Sage-grouse Working Group (NEWLWG). The NEWLWG members did provide comments on the report, all of which were considered, but were not necessarily fully incorporated into the document.

Members of the NEWSGTT and the NEWLWG will be in attendance, both physically and virtually, at the May 5, 2021 Sage-grouse Implementation Team (SGIT) meeting, to answer questions and provide further commentary on the report, as necessary.

Please direct any questions prior to the May 5th SGIT meeting to Rebecca Byram, (Rebecca.Byram@dvn.com) for consideration by the full Technical Team.

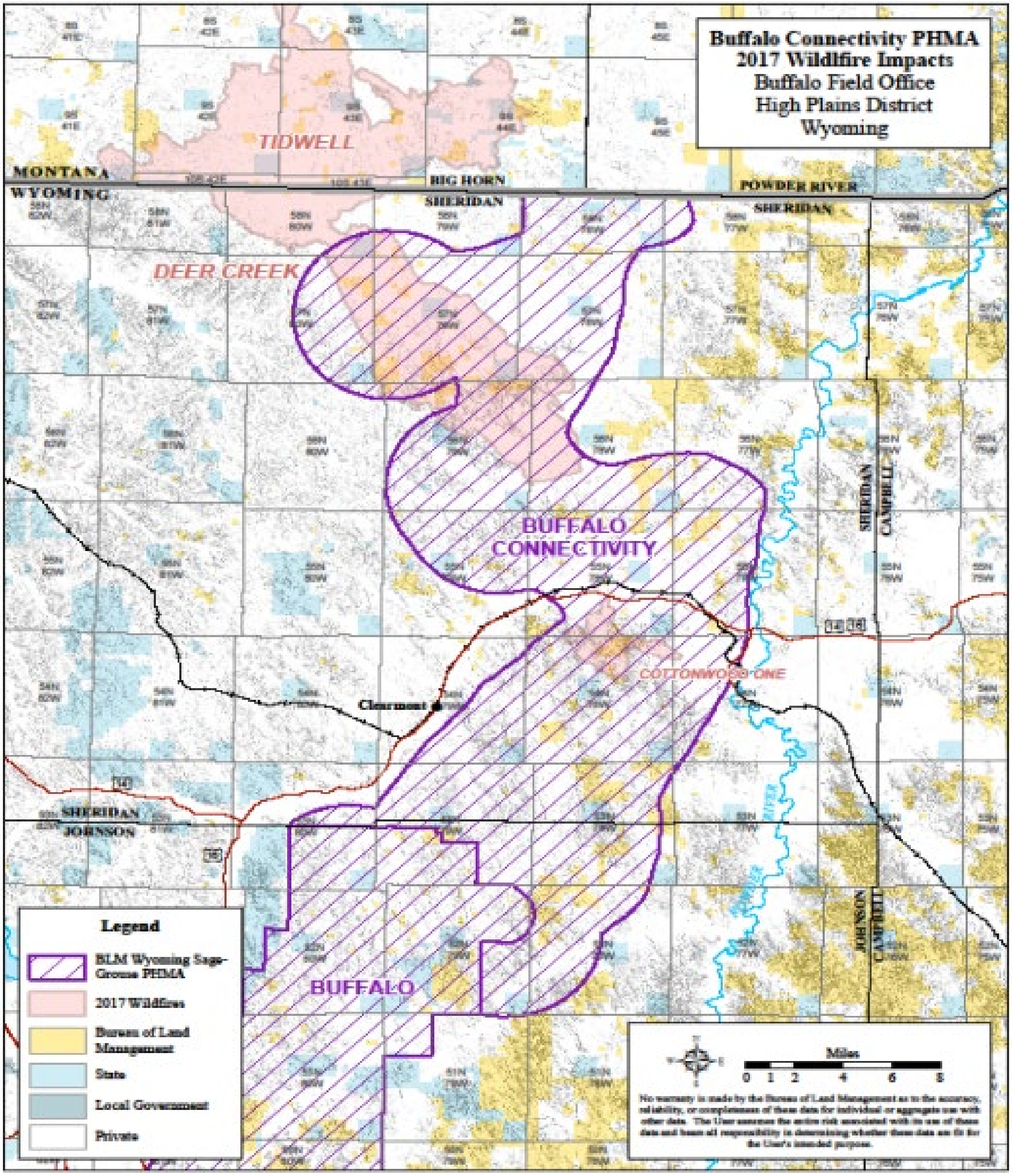
Sincerely,

Rebecca Byram

Rebecca Byram
Regulatory Advisor
Devon Energy Production Co. LP.
Northeast Wyoming Sagegrouse Technical Team Member

Northeast Wyoming Sage-grouse Technical Team

2017 Tidwell/Deer Creek Wildfire - Soft Trigger Status Review and Recommendations for the Buffalo Connectivity Area
April 20, 2021



Location of 2017 Tidwell/Deer Creek Wildfire in the Buffalo Connectivity Area

TABLE OF CONTENTS **Page Number**

Technical Team Members 1
Introduction 1
Technical Team Purpose and Objectives 3
Northeast Wyoming Local Working Group Assessment 5
Contributing/Baseline Factors 6
  Population Status 6
  Existing Disturbance 11
  Genetic Connectivity 15
  Landowner Relationships 20
Situational Assessments 21
  2017 Tidwell/Deer Creek Wildfire (Soft Trigger Causal Factor) 21
    Background Information 21
    Rehabilitation, Restoration, and Prevention Efforts to Date 21
    Technical Team Conclusions 23
  Wildfire and Invasive Plant Species 25
  West Nile Virus 27
  Predators 28
SUMMARY OF FINDINGS 29
  Key Findings 29
  2017 Tidwell/Deer Creek Wildfire (Soft Trigger Causal Factor) 30
  RECOMMENDATIONS 31
    Recommendation 1: Priority areas identified for wildfire and invasive species management 31
    Recommendation 2: Landowner outreach 31
    Recommendation 3: Research needs 32
    Recommendation 4: Monitor fire restoration efforts 32
    Recommendation 5: Address “compelling information” in Wyoming EO 2019-3, Page 5, No. 18 32
    Recommendation 6: Suggestions for future Technical Teams 33
Acknowledgments 33
References 34

TABLES

Table 1. Timeline for the 2017 Tidwell/Deer Creek Wildfire Soft Trigger Analysis Process 3
Table 2. Disturbance within the Buffalo Connectivity Area prior to the 2017 Tidwell/Deer Creek wildfire 14

EXHIBITS

Exhibit 1. Location of July 2017 Tidwell/Deer Creek wildfire relative to the NE Wyoming Local Working Group jurisdiction, occupied leks, and designated Core and Connectivity Areas 2
Exhibit 2. New and expanded sage-grouse Core Areas proposed by the NE Wyoming Local Working Group to facilitate East-West genetic connectivity between Wyoming populations, and with adjacent sage-grouse populations in Montana. 5
Exhibit 3. Map of main disturbance types in the Buffalo Connectivity Area before the 2017 soft trigger. 12

TABLE OF CONTENTS **Page Number**

Exhibit 4. Map of fires within the Buffalo Connectivity Area prior to the 2017 soft trigger. 13

Exhibit 5. Sage-grouse Management Zones.. 15

Exhibit 6. Genetic connectivity among sage-grouse leks in Wyoming and neighboring states................ 17

Exhibit 7. Genetic connectivity among sage-grouse leks in NE Wyoming and neighboring states (zoomed).. 18

Exhibit 8. Sage-grouse genetic connectivity between NE Wyoming and SE Montana 19

Exhibit 9. 2017 Battle Complex (Brush Flats, Tidwell, and Deer Creek) wildfires resulting in a soft trigger response for sage-grouse habitat management in the Buffalo Connectivity Area in NE Wyoming.. 22

Exhibit 10. Locations of wildfires in the NE Wyoming Local Working Group jurisdiction from 2017 through 2020 26

Exhibit 11. Locations of wildfires in the NE Wyoming Local Working Group jurisdiction from 2006 through 2020 27

FIGURES

Figure 1. Average peak male sage-grouse lek attendance for all occupied active leks checked in the NE Wyoming Local Working Group jurisdiction and Statewide (excluding NEWLWG leks), 1967 – 2020 7

Figure 2. Occupied leks in the NE Wyoming Local Working Group jurisdiction grouped by Core/Connectivity Area leks and non-Core/Connectivity Area leks.. 7

Figure 3. Management status of non-Core/Connectivity Area leks in the NE Wyoming Local Working Group jurisdiction showing a decrease in occupied leks and increase in unoccupied leks 8

Figure 4. Percent of active leks within each Wyoming population from 1995 to 2013. 9

Figure 5. Estimated percent population change based on trend models for the four Wyoming populations over a 5-year and 16-year time frame (Fedy et al. 2017). 9

Figure 6. Probability of lek collapse in Core and non-Core Areas in Wyoming from 2001-2013 (Spence et al. 2017) 10

APPENDICES

Appendix 1: Implementation Strategies for Recommendations 1 and 2 38

Appendix 2: Appended Literature Cited 41

Technical Team Members

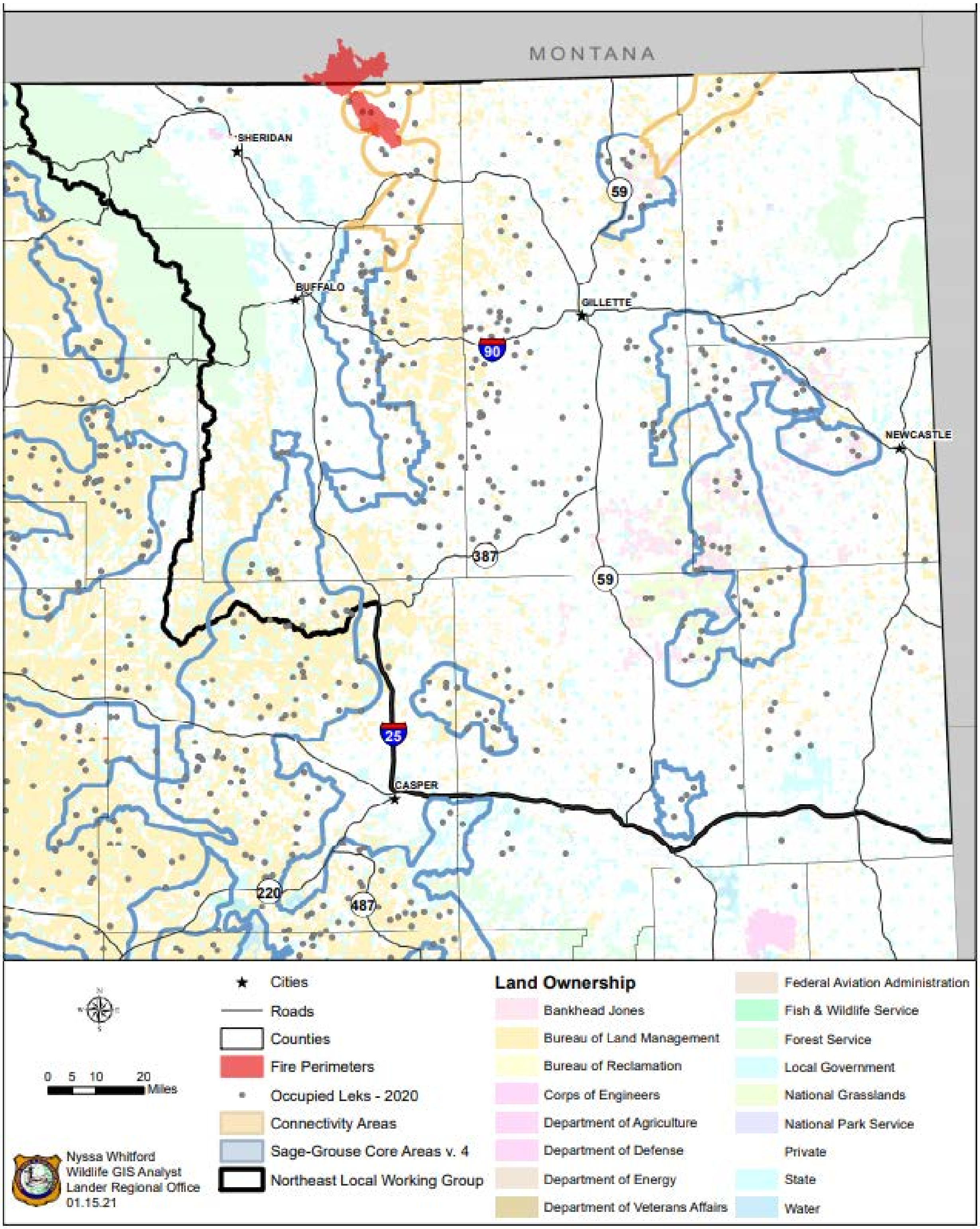
Bob Perry (Chair), Johnson County Commission
Janelle Gonzales, Bureau of Land Management
Carli Kierstead, The Nature Conservancy - Northeast Wyoming
Gwyn McKee, Great Plains Wildlife Consulting, Inc.
Thad Stoltz, Landowner
Carrie Rogaczewski, Sheridan County Conservation District
Becky Byram, Devon Energy
Cheyenne Stewart, Wyoming Game and Fish Department
Dr. Brad Fedy, University of Waterloo
Geri Proctor, US Forest Service

Introduction

In July 2017, lightning ignited the Tidwell wildfire in an area east of the town of Decker, in southeastern Montana. That fire continued to burn southeast toward the town of Leiter, Wyoming, where it was designated as the Deer Creek wildfire (hereafter, Tidwell/Deer Creek wildfire). This combined wildfire event, along with other smaller wildfires that summer, burned more than 15,000 acres (about 6.3%) of the Buffalo Connectivity Area (243,632 acres) for greater sage-grouse (*Centrocercus urophasianus*, hereafter, sage-grouse) in northeastern (NE) Wyoming (Exhibit 1), for a total disturbance level of 34 percent in that Connectivity Area.

In response to that series of wildfires, the Wyoming Bureau of Land Management (BLM) State Director pronounced in 2018 that a soft trigger had been tripped relative to management of sage-grouse and sage-grouse habitat in the Buffalo Connectivity Area. That determination was again referenced in the BLM's April 3, 2019 internal Information/Briefing Memorandum for the Director (provided in Appendix 2). Per the Wyoming Greater Sage-grouse Adaptive Management Plan (Appendix I of Wyoming Executive Order [EO] 2019-3), soft triggers are indicators that unanticipated changes to sage-grouse populations or habitats have occurred that might place one or both of those parameters at risk, either due to management practices or other unexpected factors (e.g., wildfire).

Exhibit 1. Location of July 2017 Tidwell/Deer Creek wildfire relative to the NE Wyoming Local Working Group jurisdiction, occupied leks, and designated Core and Connectivity Areas.



Data source and mapping: Wyoming Game and Fish Department. 2021.

Technical Team Purpose and Objectives

Adaptive management triggers are considered as essential for identifying when changes in management might be needed to continue meeting sage-grouse conservation objectives identified in EO 2019-3. Such triggers are based on three metrics in the affected area: 1) number of active leks; 2) acres of available habitat; and 3) population trends based on annual lek counts.

Appendix I of EO 2019-3 states soft triggers require immediate monitoring and surveillance to determine their causal factors. The Appendix also outlines the mechanisms and processes to be used in response to a trigger being identified; including the formation of a Technical Team to identify and attempt to address negative impacts to sage-grouse and their habitats before consequences become severe or unavoidable.

As the first step in addressing the Tidwell/Deer Creek wildfire soft trigger, the Northeast Wyoming Local Sage-grouse Working Group (NEWLWG) performed an updated status assessment for sage-grouse populations, Core and Connectivity Areas, and threats to sage-grouse in NE Wyoming. During the assessment (Table 1), the NE Wyoming Technical Team (Technical Team) was formed to further evaluate the situation. This Technical Team includes a variety of local representatives charged with identifying and evaluating the potential causal factors for the soft trigger determination and, where appropriate, suggesting a response strategy aimed at mitigating those factors. The Technical Team's Status Review and Recommendations will be submitted to the Statewide Adaptive Management Working Group (SAMWG), which will then make recommendations to the appropriate agency(ies) regarding an interim adaptive management strategy to be implemented in response to the soft trigger.

Table 1. Timeline for the 2017 Tidwell/Deer Creek Wildfire Soft Trigger Analysis Process

Jul 2017	Tidwell/Deer Creek wildfires
Apr 3, 2018	BLM Adaptive Management internal memo identified soft-trigger
Jun 14, 2018	Local Working Group began assessment of soft-trigger and adaptive management strategies
Aug 21, 2019	EO 2019-3 outlines process to address triggers
Oct 2019	Technical Team members identified
Jun 25, 2020	NE Wyoming Local Working Group (NEWLWG) finalized Management Assessment Summary
Technical Team Meetings and Processes	
May 15, 2020	Introductions and understanding the task at hand
Jul 28, 2020	Background information on triggers, sage-grouse administrative groups and acronyms, Local Working Group Assessment

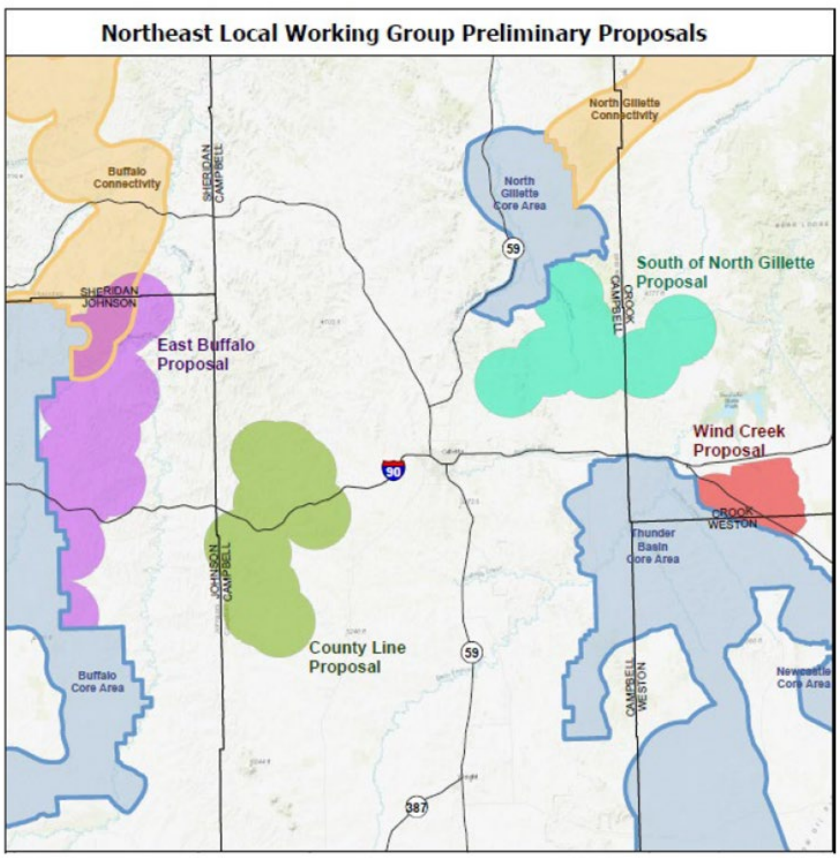
Table 1. Continued.

Aug 24, 2020	Informational presentations: Sage-grouse populations (C. Stewart & D. Thiele), Local Working Group (NEWLWG) Update (L. Vicklund), Genetic Connectivity & Research (Dr. Fedy), NE Wyoming fire & annual invasive grass positive feedback loop (B. Ostheimer)
Sep 21, 2020	Brainstorm potential solutions for any/all causal factors with emphasis on fire and annual invasive grasses
Oct 21, 2020	Revisited causal factor assessment with emphasis on connectivity issues
Nov 18, 2020	Drafted recommendations as a group
Dec 9, 2020	Assessed draft recommendations; discussed/developed final recommendation document with emphasis on providing sufficient background information to justify the Technical Team's recommendations; assigned sections for individuals to complete for the final report
Jan 19, 2020	Draft Technical Team summary and recommendations provided to team members for review and input
Feb 23, 2021	Technical Team group review of revised draft document
Mar 18, 2021	Revised draft summary and recommendations provided to Technical Team members for review
Mar 23, 2021	Revised draft summary and recommendations provided to NEWLWG members for review
Mar 26, 2021	Technical Team members provide individual comments on revised draft document
Mar 31, 2021	NEWLWG returns comments on revised draft document to Technical Team
Apr 7, 2021	Technical Team group review of revised draft document and NEWLWG comments
Apr 9, 2021	Revised draft summary and recommendations provided to Technical Team members for review
Apr 16, 2021	Final input on "2017 Tidwell/Deer Creek Wildfire- Soft Trigger Status Review and Recommendations for the Buffalo Connectivity Area" provided by Technical Team members
Apr 20, 2021	Submittal of Technical Team document to Statewide Adaptive Management Group
May 5, 2021	Technical Team presents 2017 Tidwell/Deer Creek Wildfire- Soft Trigger Status Review and Recommendations for the Buffalo Connectivity Area to Sage-grouse Implementation Team

Northeast Wyoming Local Working Group Assessment

In its June 2020 Management Assessment Summary (Appendix 2), the NEWLWG determined the main concern for the long-term viability of the NE Wyoming sage-grouse population was protecting East-West connectivity between the Buffalo and North Gillette Core Areas which, in turn, maintains genetic interchange with Montana's sage-grouse populations adjacent to the North Gillette Connectivity Area. The determination was based on research (see *Genetic Connectivity*, below) completed in that region after Wyoming's most recent Core/Connectivity Area review in 2015. To address that concern, the NEWLWG proposed to expand the existing boundaries for three Core Areas and add one new Core Area in NE Wyoming (Exhibit 2). The proposal was intended to protect the quality and quantity of sage-grouse habitat in the region based on lek data, and to ensure connectivity with neighboring sage-grouse populations. The goal of the proposal was to sustain sage-grouse numbers and distribution in NE Wyoming, and to protect and enhance the integrity of the state-wide Core Area strategy relative to its value toward precluding or minimizing the likelihood of a future sage-grouse listing decision by the U.S. Fish and Wildlife Service under the Endangered Species Act (ESA).

Exhibit 2. New and expanded sage-grouse Core Areas proposed by the NE Wyoming Local Working Group to facilitate East-West genetic connectivity between Wyoming populations, and with adjacent sage-grouse populations in Montana.



Source: Northeast Wyoming Sage-grouse Local Working Group's Northeast Wyoming Management Assessment Summary. June 2020. Proposed expanded Core Areas = East Buffalo, South of North Gillette, and Wind Creek. Proposed new Core Area = County Line.

Contributing/Baseline Factors

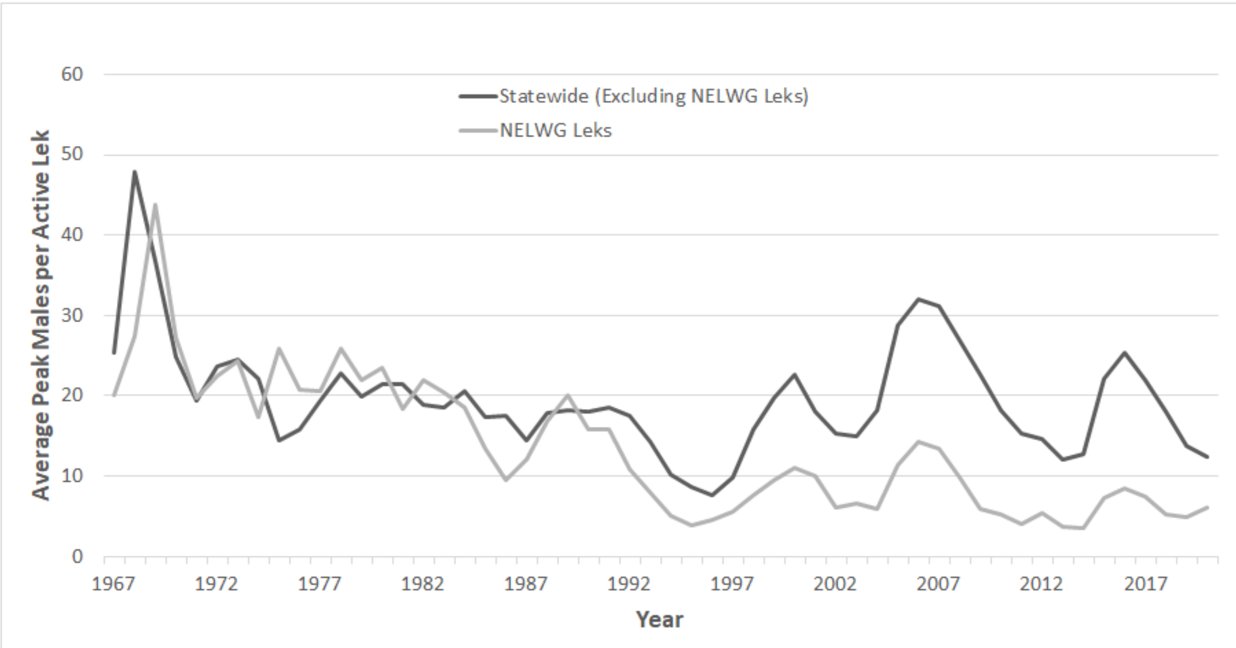
The following subsections describe important factors that have contributed to the current status of sage-grouse populations and habitat conditions in NE Wyoming. They provide context to better understand the causal factors and the recent soft trigger management determination in the Buffalo Connectivity Area.

Population Status

The Wyoming Game and Fish Department (WGFD) applies two metrics to evaluate sage-grouse populations. The metrics are mean peak male counts observed at active (annual status of occupied leks) leks, and the number of active and occupied (lek management status) leks. These metrics are analyzed annually to assess short- and long-term population trends at individual leks sites, within specific analysis areas, and statewide. While the lek monitoring data is a robust and relevant dataset, it is important to note some nuances to the data; survey effort is difficult to account for statistically, new leks are being discovered simultaneously to others becoming unoccupied or undetermined, and calculations of average peak males can be artificially inflated over time as leks change management status from occupied to unoccupied or undetermined.

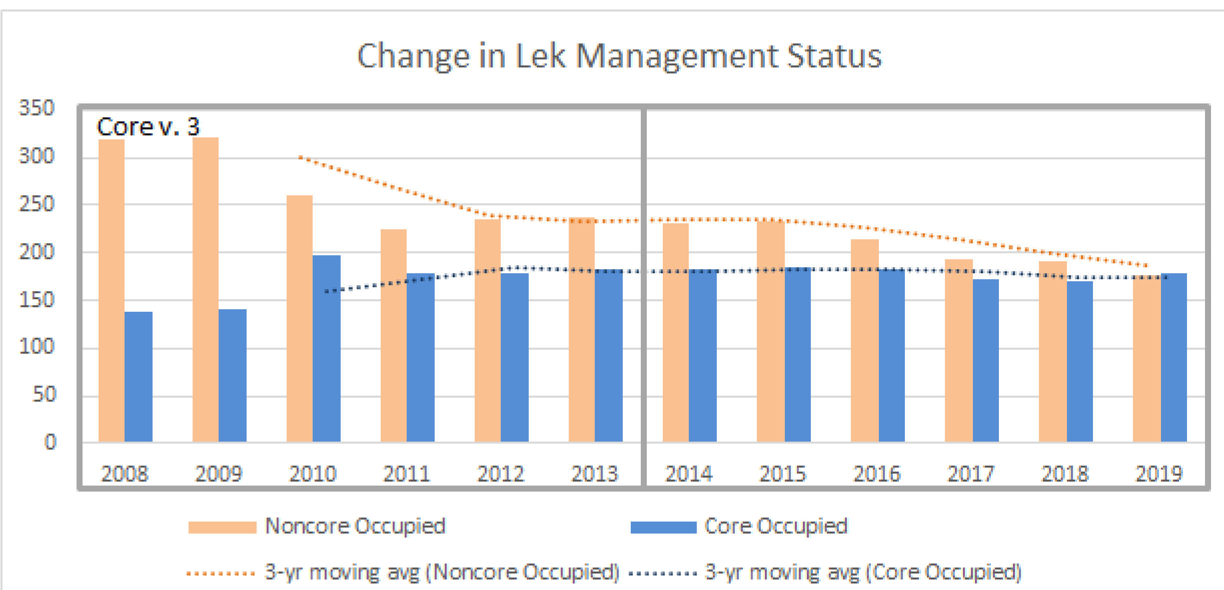
Average mean peak male counts at active leks in NE Wyoming have been lower than the statewide average over the last three decades (Figure 1). For example, in 2019, an average of 13 males per active lek was recorded in that region compared to the statewide average of 22 males per active lek that year (2020 data is not used in this example of annual status due to the reduced surveillance efforts in that year due to the COVID-19 pandemic). Overall, more sage-grouse leks have been recorded in NE Wyoming since 2006, primarily due to increased search effort associated with coalbed natural gas (CBNG) monitoring requirements from the late 1990s through the mid-2000s. This makes it difficult to interpret occupied lek numbers because new leks were discovered simultaneous to occupied leks meeting thresholds to become unoccupied or inactive. Still, the number of occupied non-Core leks in that region has decreased over the last 10 years (Figure 2) and the number of non-Core leks that qualify to change from occupied to unoccupied or undetermined has increased (Figure 3). Other metrics, comparisons, and trends such as those discussed below are also useful to examine, particularly concerning the cyclical nature of sage-grouse populations in Wyoming and, especially, the overall decline in cyclic peaks over time. However, such additional metrics will require more rigorous analyses that are beyond the scope of this analysis.

Figure 1. Average peak male sage-grouse lek attendance for all occupied active leks checked in the NE Wyoming Local Working Group jurisdiction and Statewide (excluding NEWLWG leks): 1967 - 2020.



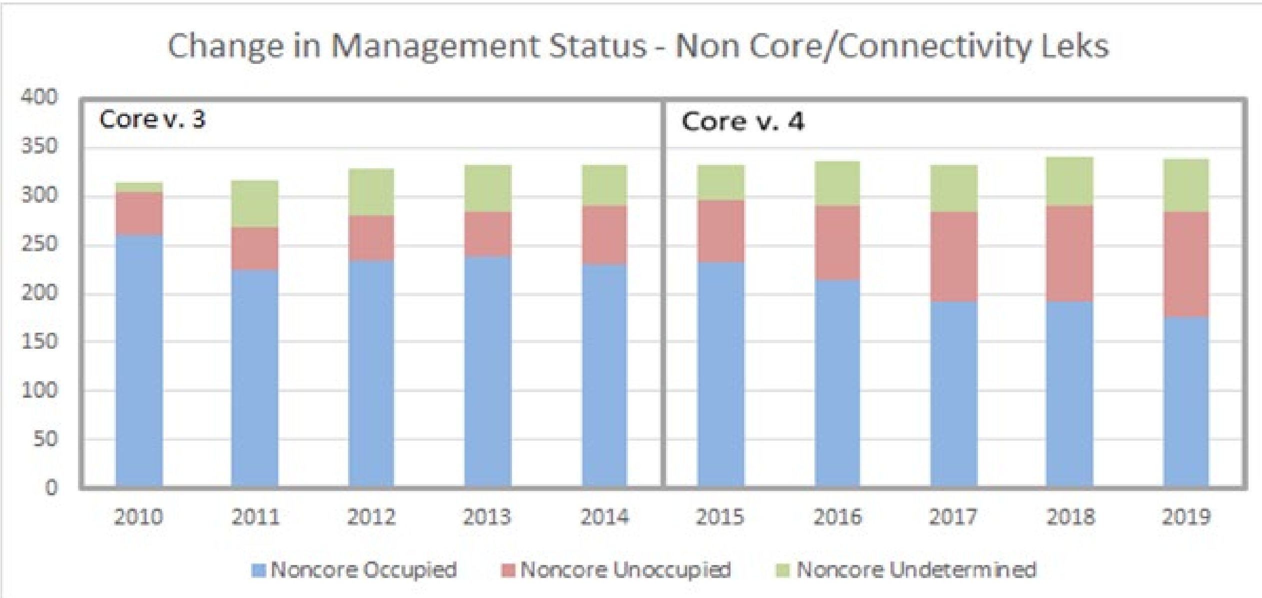
Data source: Wyoming Game and Fish Department. 2021.

Figure 2. Occupied leks in the NE Wyoming Local Working Group jurisdiction grouped by Core/Connectivity Area leks and non-Core/Connectivity Area leks. Some former occupied leks have changed status to unoccupied or undetermined, while some new leks have been discovered. The number of occupied non-Core leks has declined.



Data source: Wyoming Game and Fish Department. 2021.

Figure 3. Management status of non-Core/Connectivity Area leks in the NE Wyoming Local Working Group jurisdiction showing a decrease in occupied leks and increase in unoccupied leks. Unoccupied status requires at least four non-consecutive inactive annual designations over a 10-year period and undetermined status means the surveillance efforts have not met the thresholds to qualify the lek as unoccupied.



Data source: Wyoming Game and Fish Department. 2021.

The comparison of non-linear population trends between two areas (e.g., NE Wyoming and the remainder of Wyoming) can be challenging. The main difficulties include accounting for the cyclic nature of sage-grouse population trends in Wyoming, selecting the relevant 'reference' leks to use for identifying population trends, and the accurate estimation of the error associated with the trend data. Like all assessments of population trends, it is beneficial to consider the influence of random variation and to assess our level of confidence in the estimates provided. These concerns were addressed in a study (Fedy et al. 2015) that compared lek trends within an energy development area in SW Wyoming with control sites selected across the state to answer the question: do lek trends within the Atlantic Rim Project Area differ significantly from lek trends at non-impacted leks in Wyoming? The original study assessed trends from 1995 through 2012, and did not detect any statistically significant difference in the population trends. However, the analysis was updated for the BLM in 2016 and 2020, and significant shifts in terms of cycle duration, amplitude, and percent population change are now evident in the analysis. A similar type of analysis could be conducted comparing NE Wyoming with the remainder of Wyoming, and could lead to greater insights into the particularities of lek trends in the region. This type of analyses could enhance our understanding of how cyclical trends in lek attendance influence overall population trends, particularly in areas with lower density populations. The only peer-reviewed research that specifically assesses trends in NE Wyoming found that estimated population change from 1996 through 2012 were much lower than the positive estimates of percent population change for the other three genetic subpopulations within Wyoming (Figures 4 and 5; Fedy et al. 2017). Additional research conducted by Garton et al. (2015) and Taylor et al. (2013) corroborates the concerns for population persistence in NE Wyoming, with a useful summary provided by Conover and Roberts (2016).

Figure 4. Percent of active leks within each Wyoming population from 1995 to 2013. Circles with solid line represent data from the NE Wyoming population (Fedy et al. 2017).

Fig. 7 Percent of active leks within each population from 1995 to 2013. The *value* represents the percent of leks surveyed that were active for each year divided by the sum of all leks that were surveyed with sufficient intensity to classify as whether active or inactive. Leks of unknown status were not included in the calculation

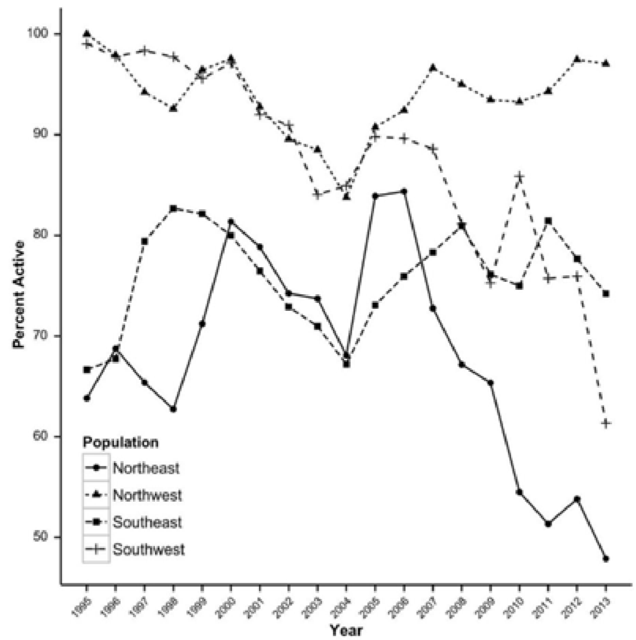
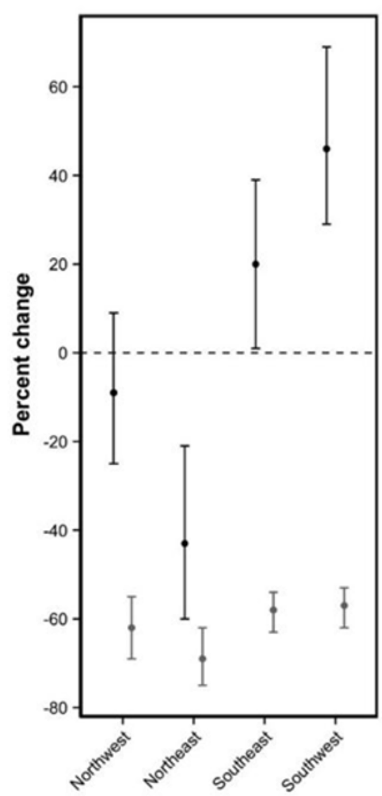


Figure 5. Estimated percent population change based on trend models for the four Wyoming populations over a 5-year and 16-year time frame (Fedy et al. 2017).

Fig. 6 Estimated percent population change based on the trend models for all four populations. *Black dots* and associated error bars represent the percent change and 95 % confidence intervals from 1996 to 2012. *Grey dots* and associated *error bars* represent the percent change and 95 % confidence intervals from 2007 to 2012. Populations are indicated along the x-axis *NW* Northwest, *NE* Northeast, *SE* Southeast, *SW* Southwest



In general, Wyoming's Core Area strategy has been effective in maintaining occupied Core Area leks. The probability of lek collapse is significantly lower within sage-grouse Core Areas in Wyoming (Figure 6; Spence et al. 2017), and landscape conditions within Core Areas support medium to large populations and seem to stabilize population trends (Burkhalter et al. 2018). The increased probability of lek collapse outside of Core Areas is a major concern if these leks have high conservation value. When Core Areas were designated in August 2008, some leks in the NEWLWG jurisdiction with high lek attendance were excluded from Core designation due to on-going or planned oil and gas development at that time. This resulted in a disproportionately lower percentage of high attendance leks included in the NEWLWG Core Areas (43.8% peak male leks) than in the rest of the state (86.7% peak male leks) in the 2008 designations. New genetic data (see *Genetic Connectivity* section below) has demonstrated that some of these non-Core leks have very high conservation value.

Figure 6. Probability of lek collapse in Core and non-Core Areas in Wyoming from 2001-2013 (Spence et al. 2017).

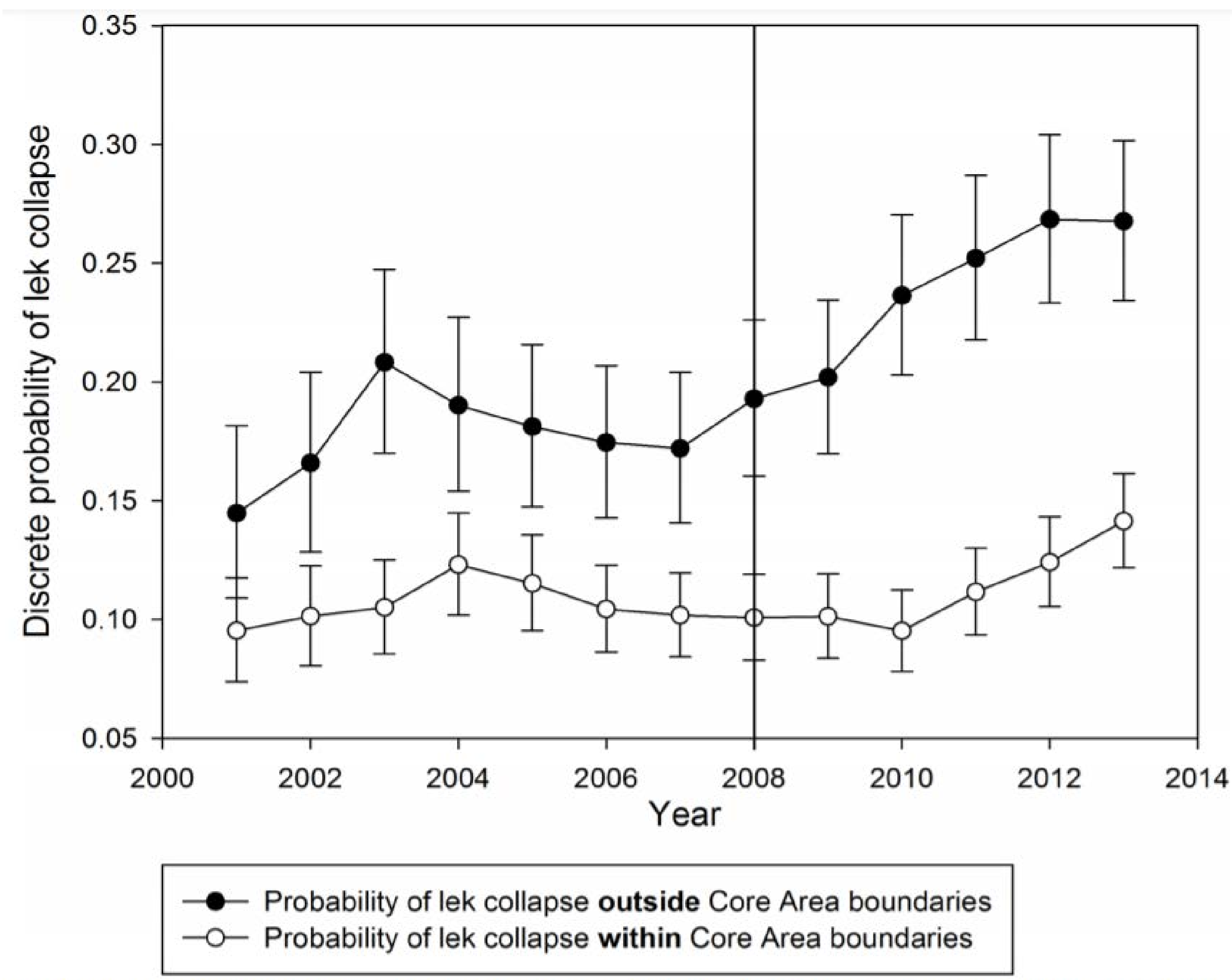


Fig 3. Probability of lek collapse was calculated independently for each year using a Bayesian binomial probability function of the Core Area leks and non-core area leks in Wyoming, 2001–2013. All probabilities are independent probabilities of collapse, however probabilities have been displayed as continuous for easier viewing. The vertical line at 2008 indicates the year in which the SGEO was enacted. The 95% credibility interval is given for each year.

FINDING: Population trends in the NEWLWG area are concerning, particularly for occupied leks in non-Core Areas and outside Connectivity Areas. This is especially true when considering the greater number of occupied leks located outside of those protective designations in this region compared to the rest of the state, and their importance for maintaining genetic connectivity in NE Wyoming. More refined and statistically robust analyses that account for the non-linearity of lek trends in the region would provide greater insights into the patterns of differentiation among NE Wyoming trends and the remainder of the state, and between Core and non-Core Areas within NE Wyoming. Additionally, targeted analysis aimed at elucidating the mechanisms underlying the processes of extinction and recolonization of leks would provide valuable insights for potential adaptive management actions, particularly given the pronounced decrease in the number of active non-Core leks in this region.

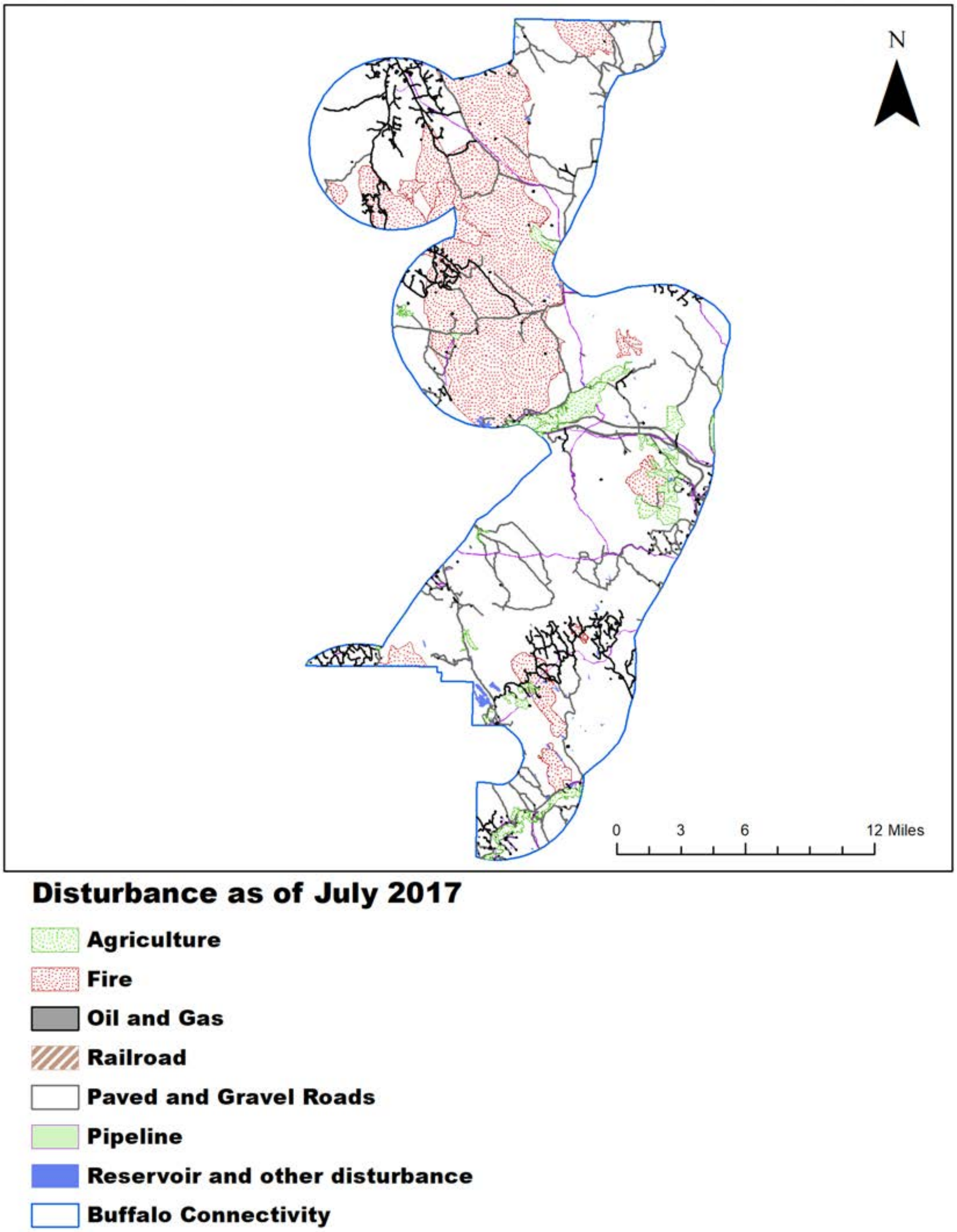
Existing Disturbance

While the Tidwell/Deer Creek wildfire increased the disturbance level (6.3%) in the Buffalo Connectivity Area enough to trip a soft trigger, the Technical Team believed it was also important to examine the 27.7 percent (about 67,490 acres) of previous disturbance in that Connectivity Area. Assessing prior disturbances facilitates a more landscape-scale approach, and helps the group better understand the context of the causal factors associated with this soft trigger, as well as the potential for developing a response strategy for those factors.

The Buffalo Connectivity Area, like the rest of NE Wyoming, has experienced a relatively high level of disturbance through recent decades (Exhibit 3). A variety of natural and anthropogenic threats (historical or current) occur on the landscape that can accrue disturbance over time including, but not limited to: fire (wildfires and escaped controlled burns), invasive plant species, energy development (permitted prior to designating Connectivity Areas), sagebrush removal, grazing, poor range management practices relative to conditions (e.g., drought), Rocky Mountain juniper expansion, agricultural conversion, recreation, ex-urban development, and various forms of supporting infrastructure (roads, utilities, etc.). In addition to these factors, some of the best quality sagebrush habitats were excluded from Core and Connectivity Area designations in NE Wyoming due to on-going or planned disturbance at the time of those delineations.

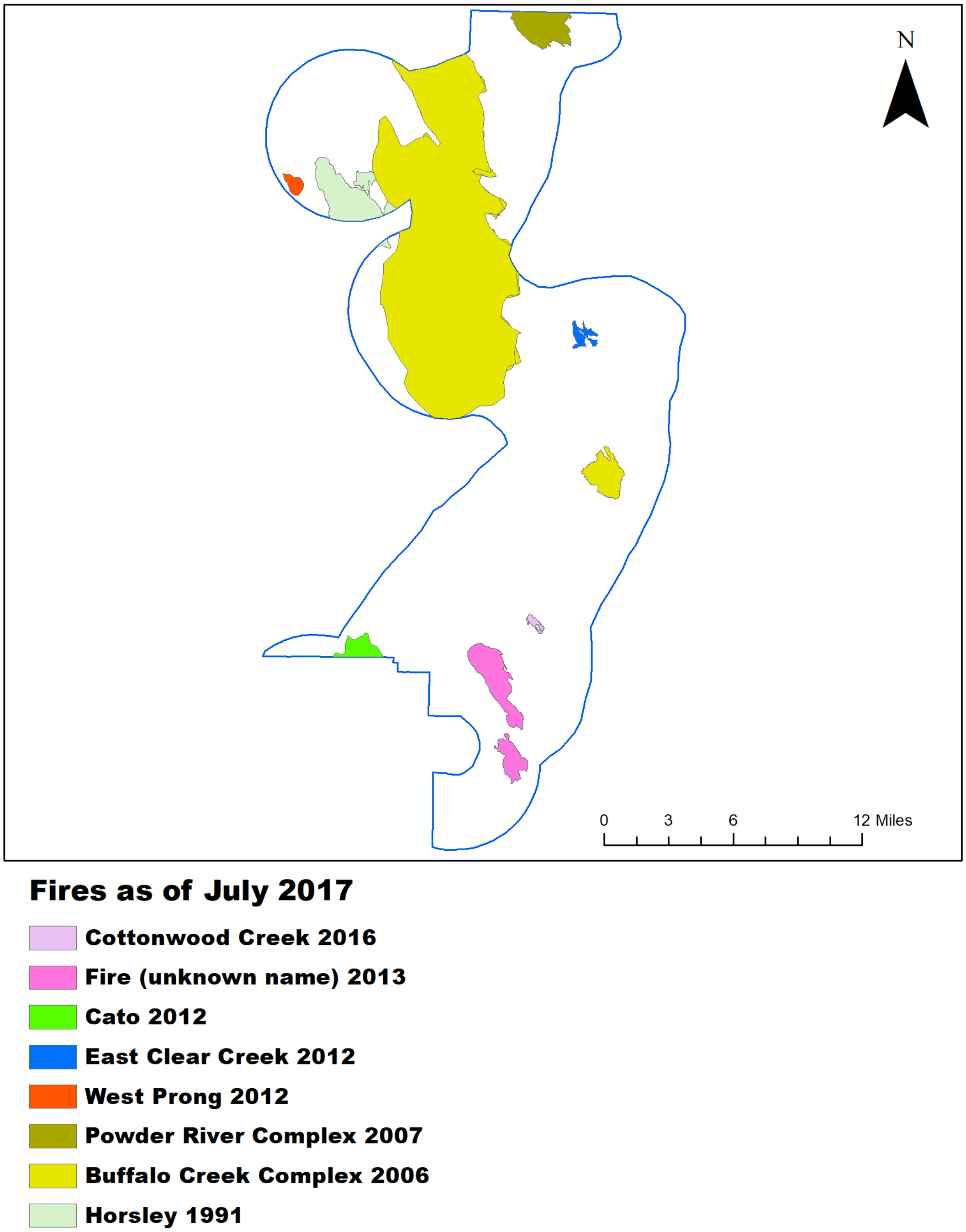
Within the Buffalo Connectivity Area specifically, 86 percent of disturbance (prior to the soft trigger) can be attributed to wildfires (Exhibit 3). These wildfires disturbed a total of 24 percent (58,441 acres) of this Connectivity Area prior to the Tidwell/Deer Creek wildfire of 2017 (Exhibit 4). The other main disturbance types on the landscape represented a substantially lower percentage (3.8%) of surface disturbance in the area (Table 2). Unfortunately, the persistent trend of wildfires continued after the Tidwell/Deer Creek wildfire event, resulting in a total of at least 87,799 burned acres in the Buffalo Connectivity Area since 2006. Given this disturbance history, the current delineation of the Buffalo Connectivity Area may not be serving its original purpose of providing the NE Wyoming population with genetic connectivity to the Montana population. The area may need to be re-delineated, or potentially removed, and new areas considered for designation to facilitate genetic connectivity. This cannot be done without the explicit recognition that, regardless of administrative designations, the loss of functioning connectivity in the Buffalo Connectivity Area would reduce or eliminate genetic connectivity to an adjacent cluster of leks in Montana.

Exhibit 3. Map of main disturbance types in the Buffalo Connectivity Area before the 2017 soft trigger.



Data Source: WYGISC; Mapping: Chris Kirol, PhD.

Exhibit 4. Map of fires within the Buffalo Connectivity Area prior to the 2017 soft trigger.



Data Source: WYGISC; Mapping: Chris Kirol, PhD.

Table 2. Disturbance within the Buffalo Connectivity Area prior to the 2017 Tidwell/Deer Creek wildfire.

Disturbance Type	% Disturbance of Total Area	Landcover Disturbed (acres)
Fire	24%	58,441
Agriculture	2.8%	7,317
Roads (graveled and paved)	0.4%	1,047
Oil and gas	0.2%	847
Oil and gas pipelines	0.2%	608
Reservoirs and range	0.2%	660
Railroads	0.03%	85
TOTAL	**27.8%**	**69,005**

Data source: WYGISC; Data analysis and mapping: Chris Kirol, PhD.

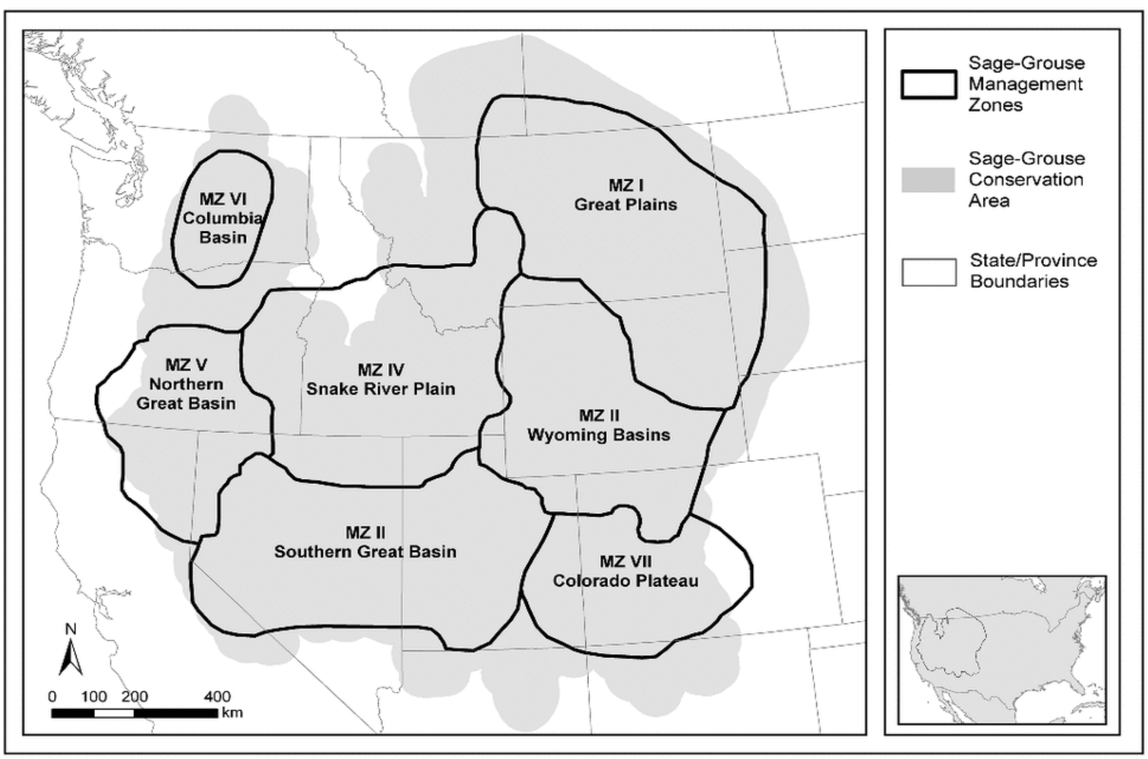
It is worth noting, the disturbance that accrues on a landscape over time is dynamic and complex. Assessments related to the physical footprint of disturbance can be misleading and can misrepresent the ecological footprint. For example, when a fire (wildfire or controlled burn) disturbance occurs, a perimeter is traced and a finite area of acres is attributed to the event. On the ground, fires often burn in a mosaic pattern that spares some sagebrush cover, sustaining a portion of functional habitat in the area, though that functionality may be reduced depending on the proportion of sagebrush remaining. Fire intensity is also a helpful indicator in assessing how much functional habitat in a given area might have been impacted within a fire perimeter. Additionally, the ecological footprints of both wildfires and oil and gas disturbances are often much larger than their respective physical footprints. Research (Aldridge and Boyce 2007; Kirol et al. 2015; Kirol et al. 2020) has shown that the functional habitat loss around an oil and gas related disturbance (e.g., road or well pad) can extend more than 1 kilometer around the disturbance due to supporting infrastructure such as power lines and increased human activity and vehicle traffic. Specific disturbances can also disseminate other disturbance feedback loops; for example, cheatgrass (*Bromus tectorum*) introduced by human activity can spread out from an initial disturbance area and alter fire cycles on a much larger footprint. Finally, the dynamics observed within the Buffalo Connectivity Area do not necessarily reflect the disturbance history, wildfire impacts, and invasive species dynamics of the rest of NE Wyoming.

FINDING: The Technical Team does not have specific recommendations to address existing disturbances that would substantially enhance on-going work with appropriate surface owners and agencies on reclamation planning and implementation for the Tidwell/Deer Creek wildfire. The technical team recognizes the role that existing disturbance plays in current and future sage-grouse management discussions in the Buffalo Connective Area as well as the rest of NE Wyoming.

Genetic Connectivity

The first genetic assessment of population structure for sage-grouse in Wyoming was published in 2017 (Fedy et al. 2017). This research identified the NE subpopulation as unique in Wyoming. The boundary between the NE population and the remainder of the state corresponded generally with the boundary between sage-grouse Management Zones I and 2 (Exhibit 5). Range-wide analyses of genetic clustering are on-going, but preliminary results confirm the isolation of the NE population from other sage-grouse in Wyoming. When genetic information is used to group the range of sage-grouse into only two populations (excluding Washington and the Bi-state population along the California-Nevada border), the NE Wyoming population groups with birds in Montana in a single cluster, and the remainder of the species' range forms the second cluster. Many other subdivisions can be made based on genetic information. However, this result clearly indicates that gene flow within sage-grouse populations occurred more frequently between the Montana and NE Wyoming subpopulations than among the NE Wyoming and other subpopulations within the state.

Exhibit 5. Sage-grouse Management Zones.



Source: Garton et al. 2011.

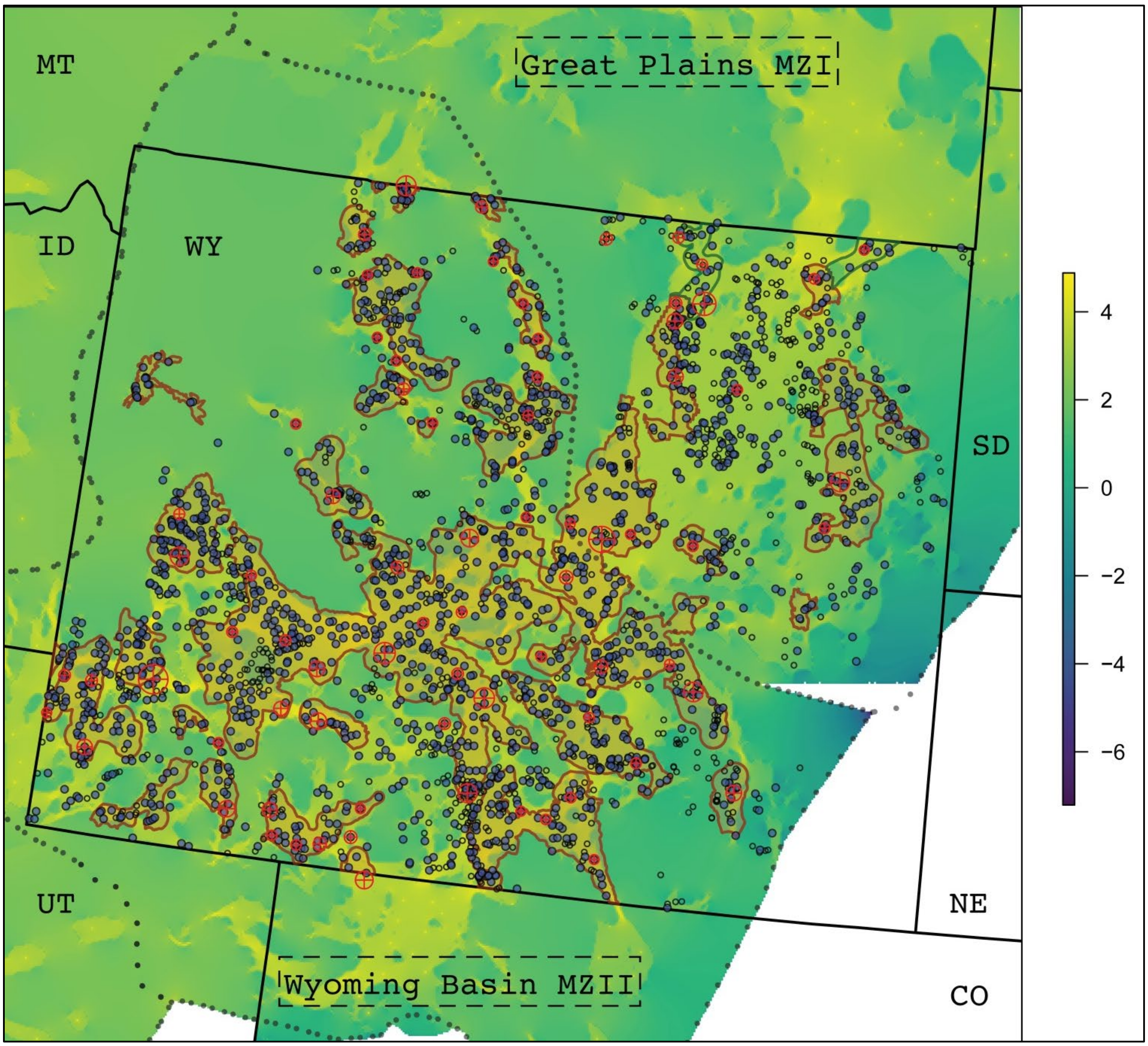
As described under *Population Status*, above, sage-grouse in NE Wyoming are experiencing greater population declines than in other regions of the state, both in terms of the number of males attending lek sites and the number of active leks. Small and highly variable population sizes, combined with genetic isolation and a suite of potentially negative impacts from both natural and anthropogenic sources, are the hallmarks of an extinction vortex (Gilpin and Soule 1986, Caughley 1994, Fagan and Holmes 2006). The maintenance and improvement of connectivity with Montana sage-grouse populations will be necessary to maintain genetic diversity and avoid the negative impacts of inbreeding depression on long-term population persistence in NE Wyoming.

Recent range-wide analyses (Cross et al. 2018, Row et al. 2018) of landscape genetics and connectivity highlighted the importance of connectivity corridors crossing the Wyoming-Montana border to gene flow in the region (Exhibit 6, Exhibit 7, Exhibit 8). The maintenance and further facilitation of East-West habitat connectivity, particularly in NE Wyoming, will help maintain genetic connectivity with larger sage-grouse populations in Montana that apparently serve as a source population for the declining NE Wyoming sage-grouse population.

The Buffalo Connectivity Area was intended to facilitate gene flow with Montana sage-grouse populations. It has recently been discovered, however, that this Montana sage-grouse population acts as a genetic cul-de-sac ending just north of the state line, rather than providing connectivity to the greater Montana populations. Population genetic studies (Cross et al. 2018, Row et al. 2018) indicate that the North Gillette Connectivity Area farther to the east provides essential connectivity between NE Wyoming sage-grouse populations and the greater Montana sage-grouse population. These results emphasize the importance of maintaining East-West connectivity between the North Gillette Core Area and the other NE Wyoming sage-grouse populations (Exhibit 2, Exhibit 6, Exhibit 7, Exhibit 8).

FINDING: Maintaining population-wide genetic connectivity is one of the most immediate and pressing concerns relating to the long-term viability of sage-grouse populations in NE Wyoming. The Buffalo Connectivity Area is not providing genetic connectivity to the greater Montana populations, as intended, and therefore does not support the necessary genetic connectivity to the Buffalo Core Area. The North Gillette Connectivity Area, however, does provide essential genetic connectivity between NE Wyoming sage-grouse and the greater Montana populations within Management Zone 1. The North Gillette Core Area is adjacent to the North Gillette Connectivity Area. Ensuring genetic connectivity between the North Gillette Core Area and the rest of NE Wyoming, including the Buffalo Core Area, is vital to preventing these populations from becoming genetically isolated (Exhibit 6, Exhibit 7, Exhibit 8). The Technical Team believes that the genetic connectivity data presented in this summary, in the NEWLWG Management Assessment Summary, and in the cited literature qualify as new, substantive, and compelling information (refer to EO 2019-3, Appendix A, page 1) regarding the long-term viability of sage-grouse populations in NE Wyoming since the most recent Core Area review was performed in 2015.

Exhibit 6. Genetic connectivity among sage-grouse leks in Wyoming and neighboring states. Landscape conductivity of gene flow is natural log transformed so that positive values (lighter colors) indicate landscapes that facilitate gene flow (adapted from Row et al. 2018). Lek sites and/or lek complex centroids (red circle-crosses) identified as important to range-wide genetic network connectivity are scaled in size to represent said importance (Cross et al. 2018). Also shown are Wyoming Core Areas (brown polygons), Wyoming Connectivity Areas (green polygons), occupied lek sites (filled points), unoccupied or undetermined lek sites (open points), greater sage-grouse Management Zone boundaries (dotted black lines), and state boundaries (solid black lines).



Source: Compiled by Dr. B. Fedy and Dr. T. Cross for this document in 2021; adapted from Row et al. 2018 and Cross et al. 2018.

Exhibit 7. Genetic connectivity among sage-grouse leks in NE Wyoming and neighboring states (zoomed). Landscape conductivity of gene flow is natural log transformed so that positive values (lighter colors) indicate landscapes that facilitate gene flow (adapted from Row et al. 2018). Lek sites and/or lek complex centroids (green circles) identified as important to range-wide genetic network connectivity are scaled in size to represent said importance (Cross et al. 2018). Also shown are Wyoming Core Areas (red polygons), approximate Wyoming Connectivity Areas (purple polygons), Wyoming lek sites (smaller points, not distinguished by management status; Montana lek sites not represented), and state boundaries (solid black lines).

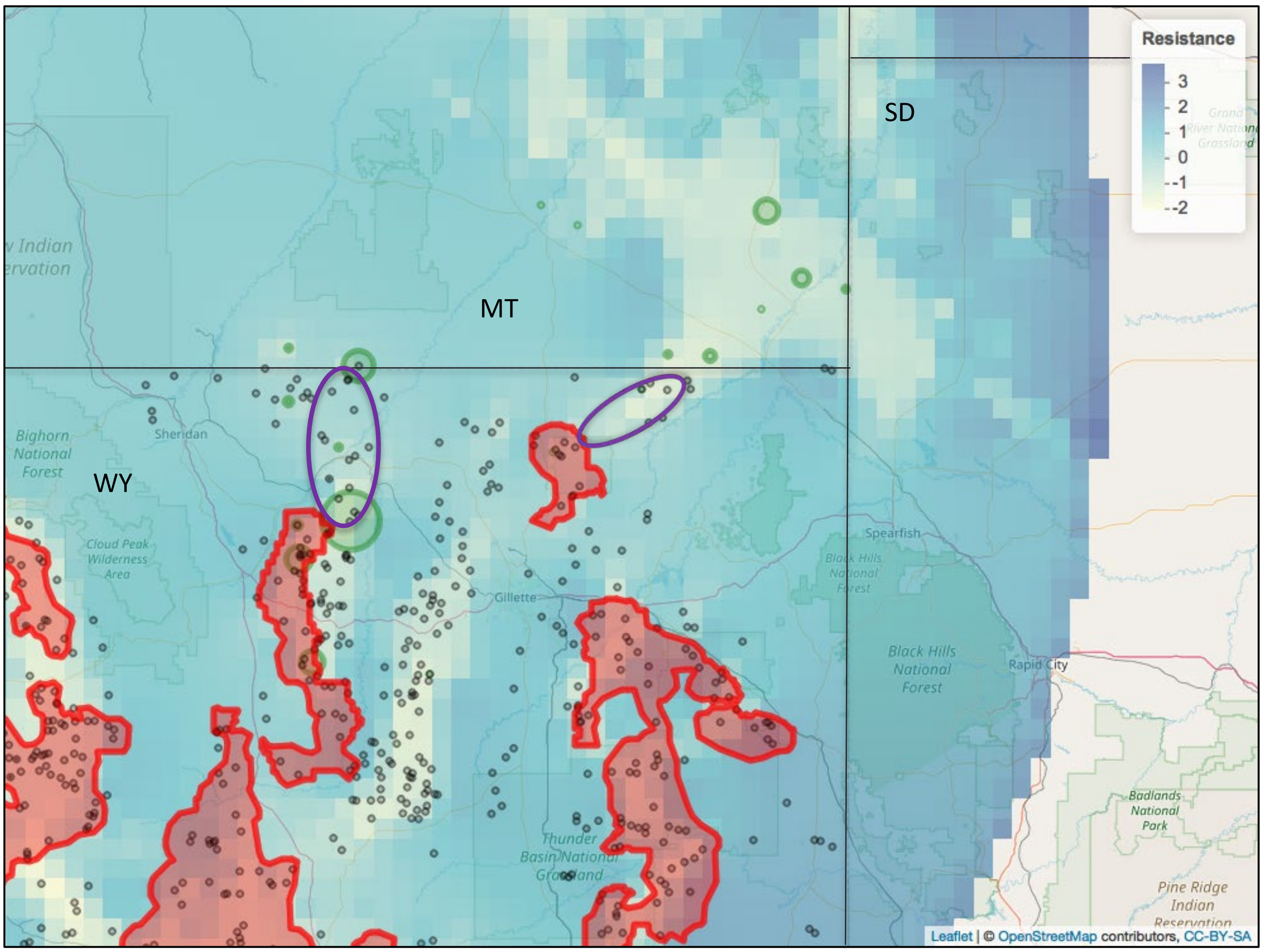
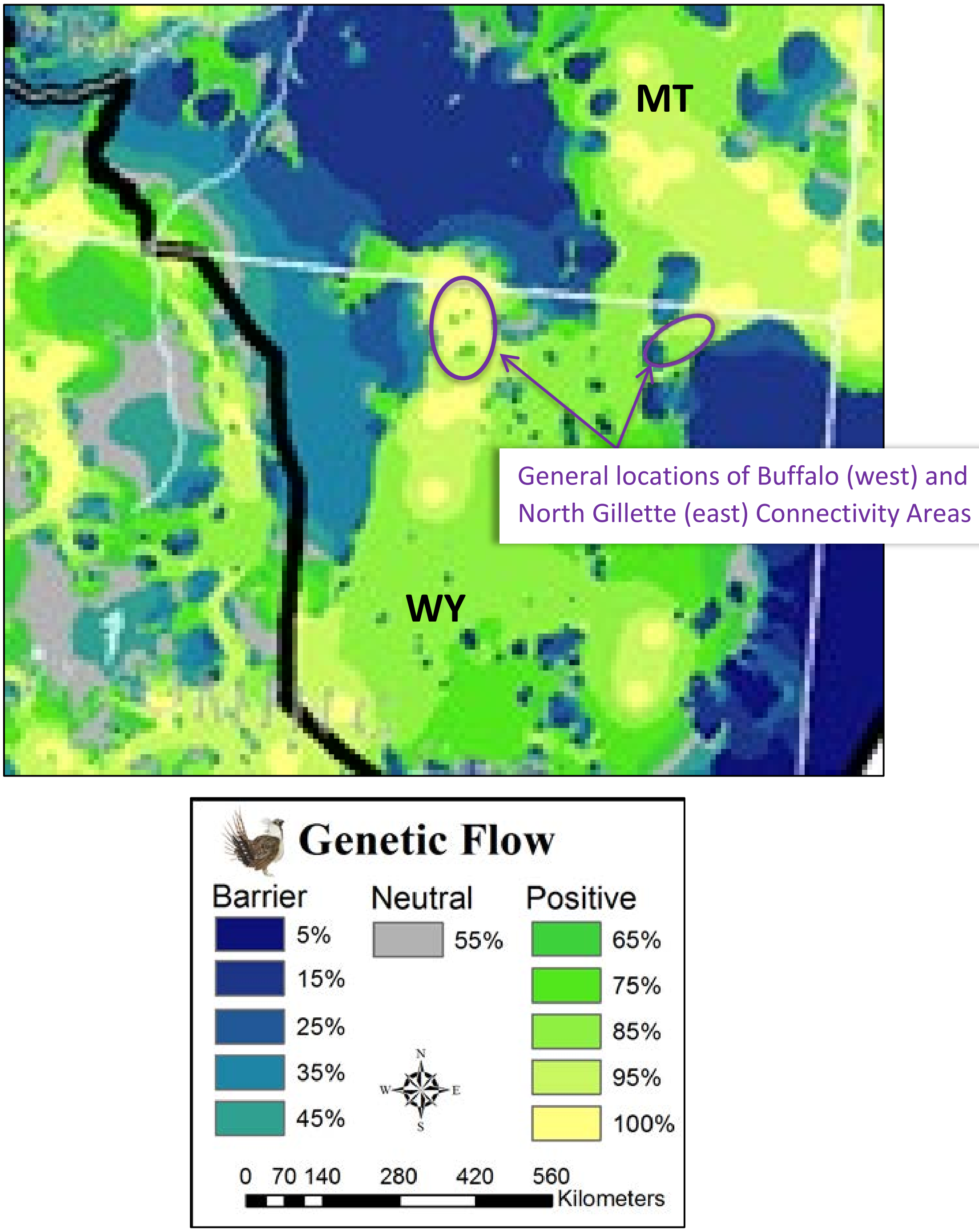


Exhibit 8. Sage-grouse genetic connectivity between SE Montana and NE Wyoming. Range-wide gene-flow map showing low (dark blue) to high (yellow) connectivity among sage-grouse lek groups. Gene flow percentile bin labels represent upper bounds. The general locations of the Buffalo and North Gillette Connectivity Areas are shown with purple circles. The Buffalo Connectivity Area can be interpreted as a genetic "cul-de-sac," ending just north of the state line.



Source: Row et al. (2018), Figure 4, page 1315.

Landowner Relationships

Northeastern Wyoming, including the area encompassed by the NEWLWG, is dominated (80%) by Federal minerals, though the surface is primarily under private or other non-federal ownership. Consequently, impacts to sage-grouse habitat in this region and efforts to address such impacts largely affect and rely upon private landowners, respectively.

As part of its assessment process, the NEWLWG issued multiple public announcements and sent numerous written notifications to private landowners and other interested parties to inform them of its proposal to expand and add Core Areas in the region. All written correspondence received by the NEWLWG represented opposition to expanding or adding Core Areas on private surface within the targeted areas. Other landowners expressed their disagreement with such proposals through NEWLWG representatives. Reasons for resistance included the known or perceived lack of suitable sage-grouse habitat and/or low sage-grouse numbers in the general area, and the potentially negative impacts on mineral development and other private property rights in expanded or new Core Areas. Only a single responding landowner expressed support for the proposal to expand and add Core Areas in the region. The response generated from the NEWLWG outreach efforts caused concern from the Technical Team that a lack of understanding by and support from private surface owners might have negative implications for sage-grouse management in NE Wyoming. For this reason, the results from the NEWLWG outreach efforts were very useful to the Technical Team.

When working with private landowners, it is important to recognize that impacts to sage-grouse habitat and the associated protection and enhancement efforts vary based on both the number (single vs. multiple) and type (private vs. agency) of surface owners involved. Likewise, the size and location (e.g., accessibility) of the affected property play a role in the type and scale of action necessary to address the impact(s). The Technical Team has drafted a comprehensive list of factors and approaches for consideration to maximize landowner participation in, and contributions to, sage-grouse habitat projects in NE Wyoming. The three main concepts are listed below, with a more comprehensive list provided in Appendix 1 of this document.

1. Engage landowners to develop partnerships.
2. Solicit information, input, and experiences from landowners/land managers.
3. Develop/enhance/incentivize proactive actions to benefit sage-grouse on private lands.

FINDINGS: Private landowner support is a basic foundation and essential component for successful sage-grouse management in NE Wyoming. For future conservation efforts to be effective in this region, considerations should be provided that seek to incentivize, foster, and maintain transparent relationships with private landowners in an effort to build genuine bi-lateral (if not multi-lateral) partnerships. New and existing outreach and incentive programs can be employed or enhanced, respectively, to encourage and expand landowner interest and participation in habitat conservation and enhancement projects in targeted areas. Those efforts can and should begin well before the next scheduled (2024) review of Core and Connectivity Area boundaries in the state. Such proactive efforts involving private landowners and their supporting partners could potentially achieve the desired habitat improvements and enhancements for local sage-grouse populations, regardless of the outcome of future reviews of current Core and Connectivity Area boundaries. At the very least, those actions could potentially increase landowner support for sage-grouse protection and management

actions through enhanced education, communication, and collaboration. It is important to engage with multiple representative landowners and provide multiple avenues for collaboration and outreach efforts when trying to accomplish sage-grouse management activities, particularly in areas dominated by private surface (e.g., NE Wyoming). Such efforts will allow for the best chance of success and sustainability of any conservation measures implemented in such regions.

Situational Assessments

The original causal factor for tripping the soft trigger was the Tidwell/Deer Creek wildfire. In order to assess adaptive management concerns and solutions, the Technical Team examined additional factors that might impact sage-grouse habitat and populations in NE Wyoming, including the Buffalo Connectivity Area. The goal was to determine the potential impacts of these various factors on the sustainability of local sage-grouse populations in this region, and whether they could become causal factors for soft or hard triggers in the future, if not addressed in the near-term.

2017 Tidwell/Deer Creek Wildfire (Soft Trigger Causal Factor)

Background Information

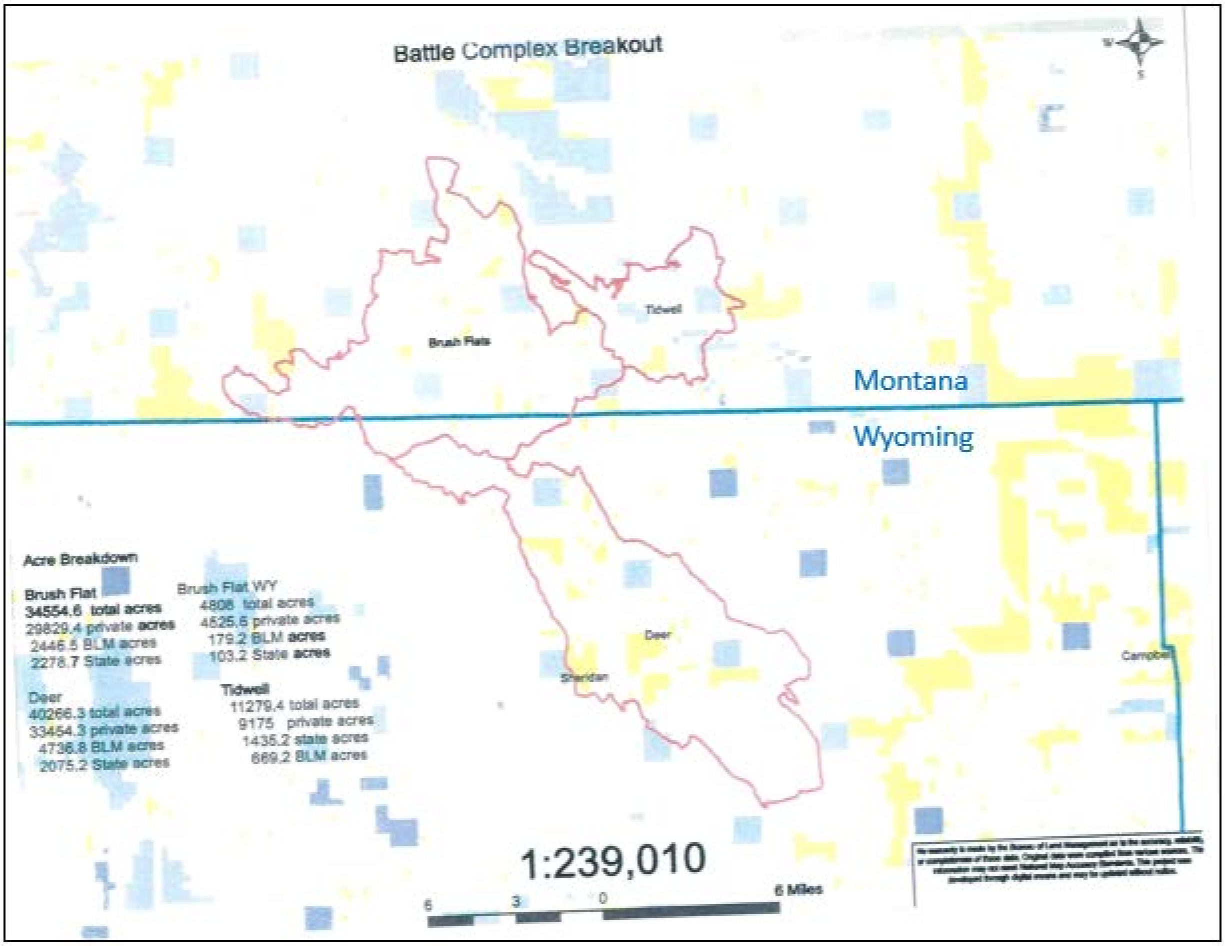
Collectively known as the Battle Complex, the 2017 soft trigger wildfire was made up of the Brush Flat and Tidwell fires in Montana, and the Deer Creek fire in Wyoming (Exhibit 9). More than 90,900 total acres burned in the complex that year, with the Deer Creek wildfire accounting for about 40,266 acres (44%). Surface ownership affected by the Deer Creek wildfire included: 33,454 acres (83%) private; 4,737 acres (12%) BLM surface; and 2,075 acres (5%) Wyoming State Lands. Most of the private surface is owned by one landowner.

In the late fall of 2017, personnel from the Natural Resources Conservation Service, WGFD, BLM, and University of Wyoming Sheridan Research & Extension (hereafter, wildfire resource group) voluntarily convened to meet with the main affected landowner to discuss the resource concerns created by the Tidwell/Deer Creek wildfire. The group identified potential needs to manage, improve, or restore important habitats for several wildlife species, including sage-grouse. Other considerations included the need to address fuels mitigation and ranching operations. One major concern was the potential response of invasive annual grasses such as cheatgrass to the wildfire.

Rehabilitation, Restoration, and Prevention Efforts to Date

Since the Tidwell/Deer Creek wildfire occurred within the Buffalo Connectivity Area and crossed the state line, Montana BLM was contacted to determine if wildfire rehabilitation and/or habitat restoration efforts were planned for their portion of the burned area. That agency indicated that it planned to reclaim and seed the berms that resulted from the bulldozer lines created during fire suppression efforts; otherwise it was focusing efforts on other higher priority fire-affected sage-grouse habitat areas in the state.

Exhibit 9. 2017 Battle Complex (Brush Flats, Tidwell, and Deer Creek) wildfires resulting in a soft trigger response for sage-grouse habitat management in the Buffalo Connectivity Area in NE Wyoming.



Source: Cost share agreement between the BLM, Montana Department of Natural Resources and Conservation, and the Wyoming State Forestry (2017); http://dnrc.mt.gov/divisions/forestry/docs/fire-and-aviation/business/cost-share/2017_cs_battlecomplex-final.pdf.

The Wyoming wildfire resource group developed both a reactive and proactive approach to addressing resource concerns resulting from the wildfire. The reactive approach consists of applying an annual (cheatgrass) grass-inhibiting herbicide within a 1.5-mile radius of both active leks and areas of high vegetative production with low cheatgrass density. The proactive response entails the use of livestock grazing as a management tool during late spring/early summer to reduce fine fuels and litter accumulation before the active wildfire season (July- September) begins; the affected pastures have traditionally been used in late fall/early winter. Another reason for changing to a spring/summer grazing period, at least during the restoration period, is the lack of reliable sources of good quality water during the traditional fall/winter grazing period.

To maximize its potential for success, the grazing approach will require supporting activities and infrastructure such as drilling a new water well, constructing stock water pipelines, and placing storage tanks appropriately to provide and adequately distribute water for livestock. To reach the affected unit of the private landowner requires a drive of 1.5 hours (one way) from ranch headquarters, adding to the challenges of using livestock as a habitat management and restoration tool in the Buffalo Connectivity Area.

Planning for these wildfire rehabilitation and restoration activities was initiated in the spring of 2020. To aid in fighting future wildfires, the private landowner has been applying herbicide to strategic two-track trails to create fire breaks. The wildfire resource group is currently seeking funding sources for the herbicide application project. Local funding opportunities for such projects are somewhat hindered by the fact that the majority of impacted surface from the Tidwell/Deer Creek wildfire occurred on private land, though other partners are being sought. Due to financial challenges with some partnership options, the private landowner will pursue the watering system on its own.

The wildfire resource group has struggled with balancing effort against resource gain during its response planning process. During its assessment of the vast area impacted by the Tidwell/Deer Creek wildfire, the resource group determined that the eastern side of the Buffalo Connectivity Area has more intact sage-grouse habitat and occupied leks. The western portion of that area has experienced multiple fires over the past 40 years, with a recurring burn interval of 6 to 15 years, according to the Casper Interagency Dispatch Center (n.d.) that has been mapping fires in NE Wyoming since 1980.

Due to the frequency of wildfires in a substantial portion of the Buffalo Connectivity Area, it is recognized as an area with low potential for fire restoration (Pyke et al. 2015 and 2017, Jones et al. 2018, Lewis et al. 2018). Recovery of burned shrublands is also influenced by fire size and the availability of seed sources. Other resource concerns for the area include, but are not limited to, the reduced number of occupied leks in the Connectivity Area and their historically low attendance by displaying males, potential impacts of soil characteristics on sagebrush recovery, and the low and extremely slow (many years to decades) potential for natural sagebrush recovery in the affected area.

The process undertaken by the wildfire resource group has illuminated some concerns about the Buffalo Connectivity Area. Discussions of post-fire sagebrush plantings with the primary affected landowner have been met with little interest. An immense area of invasive annual grass also occurs in the area. Repetitive wildfires, periodic and sometimes lengthy periods of drought (i.e., unpredictable climatic influences), and a pattern of receiving the majority of precipitation in the fall all are conducive to a continued presence and likely expansion of invasive species in the remaining and adjacent native plant communities. Furthermore, the overall habitat disturbance level in the Buffalo Connectivity Area is currently at 34 percent following the Tidwell/Deer Creek wildfire.

Technical Team Conclusions

- Given these factors, and the level of resource investment that would be necessary to restore or rehabilitate the impacted area to a point below the 5 percent disturbance threshold outlined in EO 2019-3, the wildfire resource team determined that the obstacles to successful restoration of the target area are too substantial to overcome at a level that would be necessary to benefit sage-grouse and sagebrush habitats in a meaningful way.
- The key questions considered by the Technical Team during the soft trigger evaluation process were whether or not the disturbance resulting from the Tidwell/Deer Creek wildfire could be restored and, if so, should it be restored. The Technical Team also considered the potential to develop recommendations that would add to the ongoing work by the wildfire resource group.

Based on the information gathered, it does not appear that restoration of the impacted area is feasible, at least not to the extent that would be necessary to overcome the numerous obstacles inherent to the area. Additionally, even if the area could be restored, it does not appear that it facilitates genetic connectivity between sage-grouse in NE Wyoming and the greater Montana populations, as intended.

FINDING: The Technical Team did not focus on restoration or rehabilitation of the areas impacted by the Tidwell/Deer Creek wildfire in the Buffalo Connectivity Area. The investments of time, money, and other necessary components (e.g., infrastructure) are not aligned with the level of resource value likely to be gained (or lack thereof). Additionally, the repeated wildfire history in the area strongly suggests that attempts to prevent future wildfires, or possibly other negative impacts to sage-grouse populations and habitat, are unlikely to succeed. The Technical Team commends the wildfire resource group for its efforts and supports the on-going work being done to address wildfire impacts in the area, but the Team did not identify additional recommendations to support that group's efforts at this time.

Aerial survey of a sage-grouse lek in the Deer Creek wildfire area within the broader Tidwell/Deer Creek wildfire region.
Source: Wyoming Game and Fish Department; photograph taken on April 1, 2021.

Wildfire and Invasive Plant Species

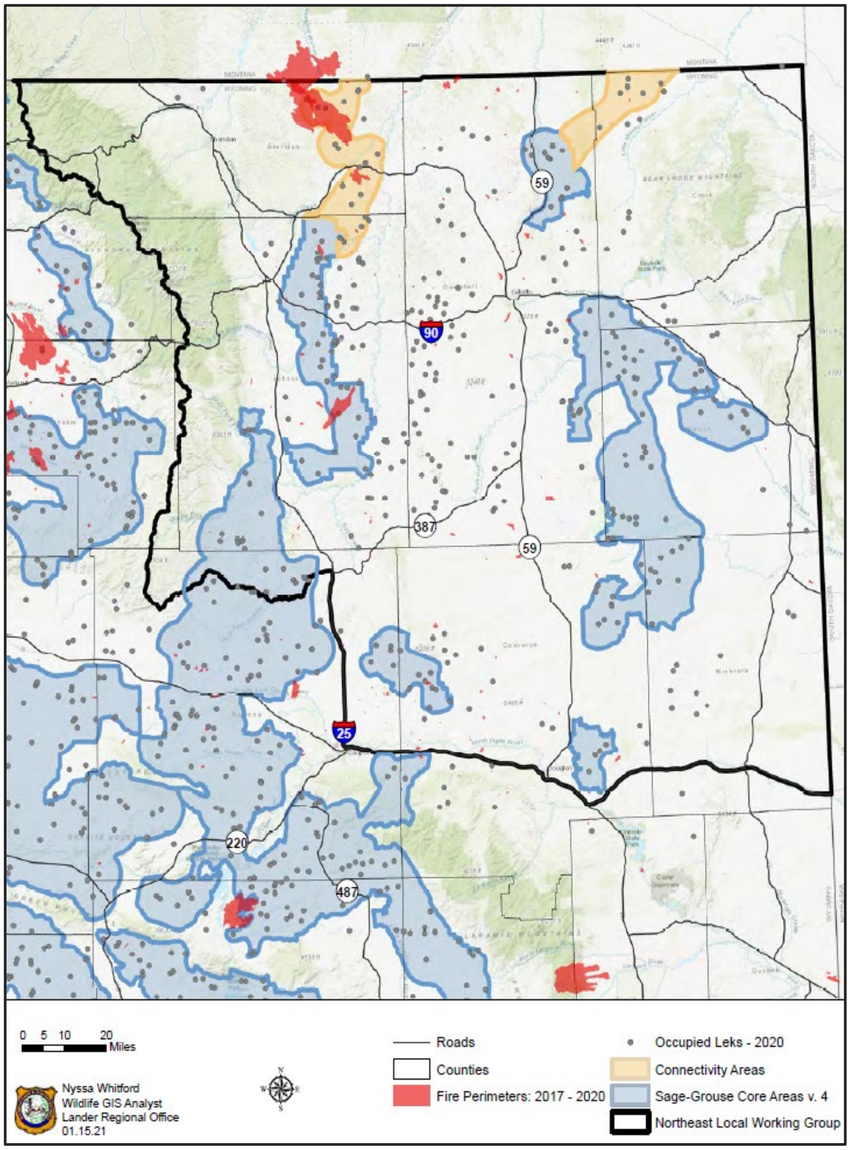
The primary threat to sage-grouse in NE Wyoming is the loss of substantial parcels (i.e., habitat fragmentation) of sagebrush habitats (Correll et al. 2017). Such losses are due to multiple causes, including the proliferation of invasive annual grasses and the associated increases in the intensity, scale, and frequency of wildfires in sagebrush ecosystems (Davies et al. 2011, Chambers et al. 2014). In many areas, frequent and repetitive wildfires have destroyed areas of sagebrush and native perennial grasses and forbs beyond a point where they can restore themselves. According to the Casper Interagency Dispatch Center, the northern and western borders of the Buffalo Connectivity Area have proven to be a wildfire 'magnet,' with 6 to 10 mid- to large-scale fires occurring in that region over the past 40 years.

Infestations of invasive, non-native plants like cheatgrass in NE Wyoming can be ecosystem disruptors because they spread quickly and are hard to control; instances of invasion are steadily increasing in NE Wyoming and are now joined by two newer species, Medusahead (*Taeniatherum caput-medusae*) and Ventenata (*Ventenata dubia*). These annual grasses germinate early in the fall, overwinter as a seedling, and are among the first plants to commence growth in the spring; capitalizing soil nutrients and moisture and outcompeting native perennial grasses and forbs for space, water, and nutrients. This layer of fine fuels leaves thousands of acres of rangeland and habitats highly susceptible to wildfires. Also, in this area of low rainfall and high density of annual grasses, it is difficult for new sagebrush to generate from seed; consequently, successful seedlings remain highly susceptible to subsequent wildfires. These factors combine to perpetuate a costly cycle that agricultural producers, land managers, county Weed and Pest Districts, and many other agencies and entities struggle to control. In general, annual invasive grass invasions in the Buffalo Connectivity Area choke out perennial grasses and forbs in addition to adding to the wildfire/annual invasive grass positive feedback loop. In the more Eastern parts of NE Wyoming, habitat type conversion is less common but increased fire intervals and intensity as well as post-fire sagebrush restoration are still concerns.

Increased wildfire intervals and intensity, which have increased due to the spread of annual invasive grasses, is a concern throughout NE Wyoming. To demonstrate the immediacy of the threat, it should be noted that since the 2017 Tidwell/Deer Creek wildfire, subsequent wildfires have burned 59,219 additional acres within Core and Connectivity Areas in NE Wyoming, through early fall 2020 (Exhibit 10, Exhibit 11). It is challenging for local managers to secure resources to develop wildfire prevention and post-fire restoration plans when new wildfires pose a continual threat that requires immediate attention and resources.

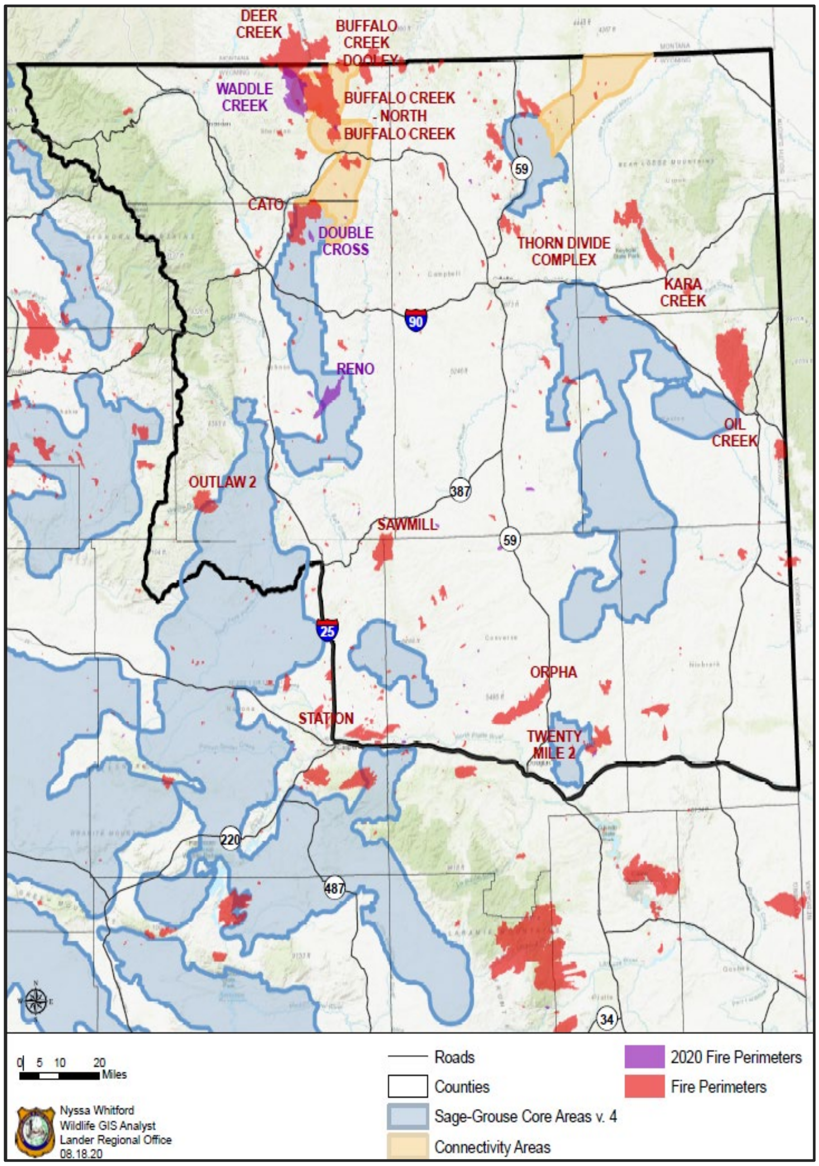
FINDING: The Buffalo Connectivity Area has a vast expanse of cheatgrass which has contributed to increased fire intensity, scale, and frequency. Due to the investments needed to manage annual invasives and rehabilitate impacted sagebrush habitats in that region, habitat projects will be concentrated in areas of high value habitat for sage-grouse including, but not limited to, historically active leks. The Technical Team considers the relationship between invasive plant species and wildfires to be one of the most important causal factors and immediate concerns to the long-term sustainability of sage-grouse in the Buffalo Connectivity Area and elsewhere in NE Wyoming.

Exhibit 10. Locations of wildfires in the NE Wyoming Local Working Group jurisdiction from 2017 through 2020. Wildfires burned 59,219 additional acres in Core/Connectivity Areas in that region since the 2017 Tidwell/Deer Creek wildfire. The total acres reported does not account for the same areas burned by multiple wildfires.



Data source: Wyoming Game and Fish Department. 2021.

Exhibit 11. Locations of wildfires in the NE Wyoming Local Working Group jurisdiction from 2006 through 2020. Wildfires have burned 412,571 acres (red and purple shaded areas) in that region during that period. The total acres reported does not account for the same areas burned by multiple wildfires.



Data source: Wyoming Game and Fish Department. 2021.

West Nile Virus

West Nile virus (WNv) is a vector-borne pathogen that is spread by mosquitoes and can infect and have a high mortality rate in certain avian species, including sage-grouse (Clark et al. 2006, McLean 2006). WNv emerged on the east coast of North America in the summer of 1999 and, by the summer/fall of 2002, was present in the Rocky Mountain region, including Wyoming. Development of CBNG resources in NE Wyoming was increasing in the early to mid-2000s. In order to release natural gas from the shallow coal seams found in NE Wyoming, the water filling the interstitial spaces in the coal seams had to be pumped to the surface. In many cases, water discharged by CBNG operations was relatively fresh, and most producers released the water into small stock ponds located on private surface. While often useful to the agricultural industry, the increase in surface water in a typically arid environment also resulted in an increase in available mosquito breeding habitat. *Culex tarsalis*, an important vector of WNv, had been documented to be present at higher levels in CBNG ponds and outfalls (a.k.a. outlets) in NE Wyoming during the height of CBNG development in 2004 and 2005 (Doherty et al. 2007).

During the most intense period of CBNG development and production in 2007 and 2008, the number of permitted CBNG outfalls discharging water to ponds or streams in NE Wyoming ranged from 3,392 to 3,496, respectively (K. Wells, WDEQ, personal communication). In 2020, only 230 permitted CBNG outfalls were discharging water, a significant decrease in surface water that could be available habitat for the *Culex tarsalis* vector. Landowners have the option to retain the small ponds that were used to store CBNG produced water, but without a consistent source of water, former CBNG ponds may not be as suitable for mosquito breeding. Additionally, reclamation of CBNG reservoirs is an ongoing effort. While the exact extent of habitat availability for *Culex tarsalis* relative to CBNG development and subsequent reclamation is unknown, reclamation efforts associated with former CBNG ponds are expected to reduce overall breeding habitat for this mosquito vector.

Even as such reclamation efforts continue, natural and anthropomorphic sources of mosquito habitat unrelated to CBNG development still occur on the landscape. Treatments such as larvicide and minnow introduction are effective (Watchorn et al. 2018), but limited in scale. Following a pilot year in 2020, the WGFD plans to begin a disease-surveillance program to monitor WNv through blood samples collected from sage-grouse that are harvested by hunters and captured for research.

FINDING: WNv is a continued threat to sage-grouse populations in NE Wyoming. Although anthropogenic features that could aid in propagation of the transmitting vector have been greatly reduced or mitigated over the last several years, other sources still persist on the landscape.

Predators

Sage-grouse co-evolved with a variety of predators that frequent sagebrush habitats. However, this species is not a primary prey source for predators typically found in NE Wyoming. Instead, sage-grouse are secondary prey species for predators that typically hunt rodents, rabbits, and hares (Western Association of Fish and Wildlife Agencies [WAFWA] 2017). Predators of chicks and adult sage-grouse in NE Wyoming include a wide variety of species including, but not limited to: multiple raptor species, coyotes (*Canis latrans*), American badgers (*Taxidea taxus*), red fox (*Vulpes vulpes*), and bobcats (*Lynx rufus*) (WAFWA 2017). Badgers, bobcats, coyotes, red fox, and striped skunks (*Mephitis mephitis*) were documented via hair samples at multiple depredated sage-grouse ground nest sites in the Powder River Basin during a recent study (Kirol et al. 2018). Other species known to eat sage-grouse eggs include weasels (*Mustela* spp.), racoons (*Procyon lotor*), corvids, and snakes, among others (WAFWA 2017).

Sage-grouse are susceptible to predation through every phase of their life cycle (egg to adult). However, populations as a whole are typically the most vulnerable to predation in areas with a greater presence of anthropogenic features and/or those impacted by habitat degradation or fragmentation (Hagen 2011, U.S. Fish and Wildlife Service [Service] 2013, WAFWA 2017). Overall, predator removal has not been shown to be a viable or sustainable management tool for sage-grouse populations over broad geographic or temporal scales, though limited information suggests that predator management might provide short-term relief for specific nesting sites in localized study areas, in situations with extremely low (sink) sage-grouse populations and higher densities of predators, and/or in especially degraded habitat conditions (Stiver et al. 2006, Hagen 2011, Service 2013, Conover and Roberts 2017, WAFWA 2017).

Common Raven (*Corvus corax*) numbers are increasing as human subsidies continue to facilitate range expansion across the western United States. Ravens have been found to cause increased rates of nest failure in sage-grouse in the Bighorn Basin and could become an issue in NE Wyoming (Taylor 2017).

FINDING: No evidence has been documented, to date, to suggest that predators are causing substantial impacts to sage-grouse populations in NE Wyoming. Should predators become a problem for sage-grouse in the future, local personnel from State or Federal wildlife management agencies, county Predator Boards, or the U.S. Department of Agriculture Animal and Plant Health Inspection Service should be available to provide predator-control services in that region.

SUMMARY OF FINDINGS

Key Findings

Through its evaluation process for the Tidwell/Deer Creek wildfire soft trigger event, the Technical Team came to the conclusion that **the most immediate and pressing concerns relating to the long-term viability of sage-grouse populations in NE Wyoming are:**

1) **maintaining and/or enhancing genetic connectivity between both:**
    a. **the North Gillette sage-grouse Core Area populations and the NE Wyoming (including Buffalo Core Area) sage-grouse populations; and**
    b. **the North Gillette Connectivity Area sage-grouse and greater Montana sage-grouse populations; and**
2) **the real potential for destruction and long-term loss of substantial acreages of sagebrush (sage-grouse) habitat due to the existing regularity of, and potential for increases in, wildfire intervals and intensity.**

New, substantive, and compelling information regarding sage-grouse genetic connectivity issues in NE Wyoming has been published since the most recent Core/Connectivity Area review in 2015. The Tidwell/Deer Creek wildfire is not an isolated or singular incident and, therefore, provides insight into the known history and likely future of fire events within the Buffalo Connectivity Area.

The priority sage-grouse management issues identified by our team were also highlighted by an independent group of stakeholders in the NEWLWG. We agree with the NEWLWG that further actions are required to ensure sage-grouse connectivity and population persistence in the region. The NEWLWG proposal encountered some challenges associated with implementation and local support. We provide novel recommendations and further refinement of the NEWLWG's efforts to prioritize habitats and management actions for the benefit of sage-grouse. Our recommendations generally address fire management in prioritized habitat areas, landowner engagement, addressing specific research needs, and a decision on what constitutes compelling information for altering Core and Connectivity Areas prior to the next scheduled review.

2017 Tidwell/Deer Creek Wildfire (Soft Trigger Causal Factor)

The original soft-trigger identified in the Buffalo Connectivity Area was related to the combined Tidwell/Deer Creek wildfire (causal factor). Because the Technical Team's recommendations do not include a response strategy to the causal factor, we believe it is important to discuss the implications of our approach.

The original intent of the Buffalo Connectivity Area designation was to protect habitat that could facilitate genetic connectivity (interchange) between the eastern Wyoming and the eastern Montana populations of sage-grouse. Importantly, subsequent genetic research has demonstrated that the Connectivity Area does not, in fact, facilitate the desired genetic interchange between those populations. Instead, the Connectivity Area is a genetic "cul-de-sac," or dead end (Exhibit 8). This revelation raises important questions that need to be evaluated: a) at its best, has the Buffalo Connectivity Area shown itself to have the potential to function as intended; b) if so, is it feasible and worth the resource investments to restore it to a functioning status; and c) if not, should the habitat continue to be protected as a designated Connectivity Area under EO 2019-3?

It has become apparent that, regardless of the disturbance history and restoration potential, the northern portion of the Buffalo Connectivity Area does not provide the necessary genetic interchange with the greater Montana population, as intended. The question then becomes, can improved genetic exchange between eastern Wyoming and Montana sage-grouse populations be achieved by different means and, if so, what are they? If not, then new or improved areas of habitat that could provide connectivity will likely need to be identified to help sustain the eastern Wyoming sage-grouse population into the future. If it is decided that the Buffalo Connectivity Area can provide valuable wildlife habitat even if it does not or cannot offer meaningful genetic connectivity for sage-grouse to the north, then restoring the burned areas and creating better fire prevention and response systems, might be worth the various resource investments that would be required. However, one must weigh the known history of frequent wildfires in the Connectivity Area against their potential to negate any future restoration efforts undertaken to address the Tidwell/Deer Creek wildfire. The data trends show that wildfire is the most common disturbance type in the Buffalo Connectivity Area, and will likely continue to decrease viable sage-grouse habitat in NE Wyoming.

Importantly, even the most effective post-fire restoration and proactive fire prevention will not improve or otherwise address the genetic cul-de-sac at the northern end of the Buffalo Connectivity Area. Given the broader NE Wyoming landscape relative to both sage-grouse populations and habitat, investing in the Buffalo Connectivity Area is not likely to contribute to sage-grouse management goals in that area. Instead, resource managers will likely need to look to new or improved areas of habitat that could provide connectivity between the eastern Wyoming and Montana populations to achieve feasible and durable genetic interchange in the future.

As a Technical Team, we did not develop specific answers to or recommendations for these questions, other than to recognize that restoration and protection efforts are already underway (see *Tidwell/Deer*

Creek Wildfire section, above) and to emphasize that these questions will need to be addressed during the 2024 Core/Connectivity Area review.

RECOMMENDATIONS

Recommendation 1: Priority areas identified for wildfire and invasive species management

Prioritize sagebrush-habitat health projects in Habitat Management Priority Areas. We define Habitat Management Priority Areas as currently designated Core and Connectivity Areas and the NEWLWG's proposed expanded and additional Core Areas (Exhibit 2).

a) Determine the appropriate entity (or entities) to spearhead these efforts as soon as possible. This step will be extremely important to implement in order to accomplish this recommendation.

b) Proactive approach: Develop fire prevention, sagebrush health, and invasive annual grass management projects. Complete long-term planning.

c) Reactive approach: Develop post-fire response, with the goal of rapid response (immediate invasive annual grass management), as well as long-term monitoring and management (continued invasive species management and sagebrush restoration).

d) Work with landowners within the Habitat Management Priority Areas (see Recommendation 2) to accomplish b) and c).

e) Have separate funding mechanisms available for b) and c). These two types of funding needs should not compete. Due to the urgency of post-fire rapid response, funding options should be flexible and expedited for rapid response projects.

Recommendation 2: Landowner outreach

Sage-grouse Implementation Team (SGIT) or Statewide Adaptive Management Working Group (SAMWG) develop an educational/outreach committee to provide educational materials and address landowner concerns related to sage-grouse and their habitats.

a) Initial outreach to provide general information on sage-grouse management in NE Wyoming, with potential applicability throughout the state. Important topics: impacts on private lands located within sage-grouse Core, Connectivity, or Winter Concentration Areas; interpretation of most recent lek data; consequences of ESA listing to private landowners; fire and invasive plant impacts; genetic connectivity importance and concerns; split-estate factors (e.g., Federal minerals and leases vs. private and non-federal surface ownership); and current partnership programs and incentive opportunities.

b) Conduct multiple local meetings to solicit input from landowners. Important topics: preferred methods and levels of involvement/interaction; concerns related to sage-grouse management; why they do or do not participate in currently available partnership and incentive programs; what incentives would be motivating but are not currently available; other issues identified during meetings. We would like to emphasize the need to solicit ideas to effectively develop, enhance, and incentivize proactive actions to benefit sage-grouse on private lands.

c) Include landowners in decision-making processes and increase landowner participation on working groups and other conservation groups, (e.g., those mentioned in Recommendations 1, 2, and 3).

d) Generate an annual report available to the public detailing landowner outreach efforts conducted and outcomes accomplished.

Recommendation 3: Research needs

Sage-grouse management decisions in NE Wyoming should consider and incorporate, as appropriate, the most recent research completed in the area, as well as applicable research conducted elsewhere in Wyoming, of which a tremendous amount of work has already been completed. While additional research needs should not inhibit management actions, specific research efforts could significantly increase our understanding of population dynamics in NE Wyoming and therefore better inform future management decisions.

a) SGIT to arrange for one or more synopsis presentations by local and regional experts and researchers regarding recent sage-grouse research in Wyoming to determine their potential value to the next Core/Connectivity/Winter Concentration Area boundary review. Suggested topics include, but are not limited to: 1) work in SW Wyoming to develop an algorithm-based model to quantitatively rank and prioritize areas in which to focus habitat protection, enhancement, and restoration efforts; 2) range-wide genetic connectivity; 3) accounting for cyclical population trends; and 4) underlying mechanisms resulting in lek extinction and recolonization of Core and non-Core leks.

b) SGIT and/or SAMWG pursue additional research in NE Wyoming (and other areas of interest), similar to those discussed in a), and determine funding mechanism for that work. We would like to emphasize that completing the type of research discussed in a) can take 1-2 years to complete and could be useful when reviewing Core and Connectivity designations.

Recommendation 4: Monitor fire restoration efforts

Monitor restoration efforts and progress related to the Tidwell/Deer Creek wildfire. Use knowledge learned to determine future fire management efforts related to the other Recommendations.

Recommendation 5: Address "compelling information" in Wyoming EO 2019-3, Page 5, No. 18

SGIT and/or SAMWG consider the factors presented in this document, in addition to other appropriate resources (e.g., NEWLWG 2020 Management Assessment Summary and research published since last Core/Connectivity Area version), to determine whether these factors qualify as compelling enough to warrant a review of current Core/Connectivity Area boundaries in NE Wyoming prior to the next scheduled review in 2024. This approach would be consistent with language in EO 2019-3, Page 5, No. 18.

Recommendation 6: Suggestions for future Technical Teams

The following suggestions are respectfully offered to assist future Technical Team's efforts and processes.

a) Items to address at the first meeting:

   1. Introduce the members and their affiliations. Clarify roles and responsibilities of the Chair and designate a note-taker. Clarify how the team wants to interact, meet, and if the process is unanimous or otherwise.

   2. SGIT Chair or convener of the Technical Team:

      i. Provide clear descriptions of the process by which the Technical Team was formed, desired outcomes, and timeline. Provide background information on sage-grouse management and the associated management teams, how they are related, and who makes what decisions.
      ii. Provide information on how other Technical Teams proceeded, and whom should be included in the review process for drafting recommendations. It was made quite clear to us that our assessment should include any/all potential causal factors, and not limit ourselves to the specific event that caused the trigger. If this continues to be the direction, please continue to be especially clear about this at the outset.

   3. Local working group representatives provide a brief overview of the trigger that led to formation of the Technical Team, including clear maps showing the location of the triggering event (e.g., wildfire), if applicable.

b) Assign a SGIT liaison to participate in the entire process, beginning with the first meeting.

c) Provide a staff support person to assist the Technical Team with compiling recommendations and other functions, as appropriate and requested by the Team.

d) Have an information-gathering meeting where local experts present data, including any/all relevant subjects related to sage-grouse populations and habitat in the area of interest.

e) It was extremely useful to have NEWLWG members, a SGIT liaison, and WGFD Sage-grouse/sagebrush representation at our meetings throughout our entire process. They provided clarification on processes, timelines, expectations, research updates, and population and habitat conditions.

f) Make reports from studies funded by the statewide Local Working Groups readily available.

Acknowledgments

We were provided invaluable assistance in understanding the process, acronyms, and background information that helped us complete our assessment and this report. We would like to thank Leslie Schreiber (WGFD), Dave Pellatz (TBGPEA, SGIT), Laurel Vicklund (NEWLWG), and Bill Ostheimer (BLM, NEWLWG) for their time, knowledge, and patience.

References

Aldridge, C. and M. Boyce. 2007. Linking occurrence and fitness to persistence: Habitat-based approach for endangered Greater Sage-grouse. Ecological applications: a publication of the Ecological Society of America. 17.508-26. Available at http://doi.org/10.1890/05-1871 (pdf provided in Appendix 2 because on-line journal does not allow access without a subscription).

Bureau of Land Management. 2019. Information/Briefing Memorandum for the Director. April 2, 2019 memorandum provided by Bill Ostheimer, BLM Buffalo, Wyoming Field Office (pdf provided in Appendix 2).

Burkhalter C., M. J. Holloran, B. C. Fedy, H. E. Copeland, R. L. Crabtree, N. L. Michel, S. C. Jay, B. A. Rutledge, A. G. Holloran. 2018. Landscape-scale habitat assessment for an imperiled avian species. Animal Conservation 21(3): 241-251. doi: 10.1111/acv.12382 (pdf provided in Appendix 2 because on-line journal does not allow access without a subscription).

Casper Interagency Dispatch Center. n.d. Available at https://gacc.nifc.gov/rmcc/dispatch_centers/r2cpc

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology. 63(2):215-244. Available at https://besjournals.onlinelibrary.wiley.com/pb-assets/hub-assets/besjournals/1365-2656_animal_ecology/bio-demography/Caughley%201989%20JAE%2063_%20215-244-1510761238417.pdf.

Chambers, J. C., D. A. Pyke, J. D. Maestas, M. Pellant, C. S. Boyd, S. B. Campbell, S. Espinosa, D. W. Havlina, K. E. Mayer, and A. Wuenschel. 2014. Using Resistance and Resilience Concepts to Reduce Impacts of Annual Grasses and Altered Fire Regimes on the Sagebrush Ecosystem and Sage-grouse - A Strategic Multi-scale Approach. General Technical Report RMRS-GTR-326. Fort Collins, Colorado. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 73 pp. Available at https://www.fs.fed.us/rm/pubs/rmrs_gtr326.pdf.

Clark, L., J. Hall, R. McLean, M. Dunbar, K. Klenk, R. Bowen, and C. Smeraski. 2006. Susceptibility of Greater Sage-grouse to Experimental Infection with West Nile Virus. Journal of Wildlife Diseases, 42(1): 14-22. Available at https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1092&context=icwdm_usdanwrc.

Conover, M. R., and A. J. Roberts. 2016. Declining populations of Greater Sage-grouse: where and why. Human-Wildlife Interactions. Vol. 10: Issue 2, Article 8. Available at https://digitalcommons.usu.edu/hwi/vol10/iss2/8.

Conover, M. R. and A. J. Roberts. 2017. Predators, Predator Removal, and Sage-grouse: A Review. The Journal of Wildlife Management, 81(1), 7-15 (pdf provided in Appendix 2 because on-line journal does not allow access without a subscription).

Correll, L. L., R. M. Burton, J. D. Scasta, and J. L. Beck. 2017. Landowner Guide to Sage-grouse Conservation in Wyoming: A Practical Guide for Land Owners and Managers. University of Wyoming Agricultural Experiment Station and University of Wyoming Extension. ISBN: 978-0-9987080-6-5. 72 pp. Available at https://www.sagegrouseinitiative.com/wp-content/uploads/2013/07/Correll-et-al.-2017-UW-Extension-Bulletin-B-1295.pdf.

Cross, T. B., M. K. Schwartz, D. E. Naugle, B. C. Fedy, J. R. Row, and S. J. Oyler-McCance. 2018. The Genetic Network of Greater Sage-grouse: Range-wide Identification of Keystone Hubs of Connectivity. Ecology and Evolution, 8, 5394–5412. Available at https://www.fs.fed.us/rm/pubs_journals/2018/rmrs_2018_cross_t001.pdf.

Davies, K. W., C. S. Boyd, J. L. Beck, J. D. Bates, T. J. Svejcar, and M. A. Gregg. 2011. Saving the Sagebrush Sea: An Ecosystem Conservation Plan for Big Sagebrush Plant Communities. Biological Conservation 144: 2573-2584. Available at http://www.sagegrouseinitiative.com/wpcontent/uploads/2013/07/Davies_SavingSageBrushSea-2.pdf.

Doherty, M. 2007. Mosquito populations in the Powder River Basin, Wyoming: A comparison of natural, agricultural and effluent coal bed natural gas aquatic habitats. Master's thesis. Available at https://scholarworks.montana.edu/xmlui/bitstream/handle/1/1184/DohertyM1207.pdf?sequence=1&isAllowed=y.

Fagan, W. F. and E. E. Holmes. 2006. Quantifying the extinction vortex. Ecology Letters. Volume 9(1): 51-60. Available at https://faculty.washington.edu/eeholmes/Files/FaganHolmes2006.pdf.

Fedy, B. C., M. S. O'donnell, and Z. H. Bowen. 2015. Large-scale control site selection for population monitoring: An example assessing sage-grouse trends. Wildlife Society Bulletin 39:700-712. Available at https://wildlife.onlinelibrary.wiley.com/doi/abs/10.1002/wsb.601.

Fedy, B. C., J. R. Row, and S. J. Oyler-McCance. 2017. Integration of Genetic and Demographic Data to Assess Population Risk in a Continuously Distributed Species. Conservation Genetics 18:89-104. Springer Netherlands. Available at https://doi.org/10.1007/s10592-016-0885-7 (pdf provided in Appendix 2 because on-line journal does not allow access without a subscription).

Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2011. Greater Sage-grouse Population Dynamics and Probability of Persistence. Studies in Avian Biology 38:293-382. Available at https://www.nap.edu/read/21829/chapter/10#80.

Garton, E. O., A. G. Wells, J. A. Baumgardt, and J. W. Connelly. 2015. Greater Sage-grouse population dynamics and probability of persistence; Final Report to Chew Charitable Trusts. Available at https://www.eenews.net/assets/2015/04/24/document_daily_03.pdf.

Gilpin, M. E. and M. E. Soulé. 1986. Minimum viable populations: processes of extinction. *In* Conservation Biology: The Science of Scarcity and Diversity (ed. M. E. Soulé). Sinauer Associates, Sunderland, Massachusetts. Pp 19-34. Available upon request from NE Wyoming Sage-grouse Technical Team; not available on-line or by submittal date.

Hagen, C. A. 2011. Predation on Sage-grouse: Facts, Effects, and Process. Pp. 95-100 *in* S. T. Knick and J. W. Connelly. Greater Sage-grouse: Ecology and Conservation of a Landscape Species and its Habitat. Studies in Avian Biology 38. University of California Press, Berkeley, California. Available at https://www.researchgate.net/publication/300773667_Predation_on_Greater_Sage-Grouse_Facts_Process_and_Effects/link/576b18df08ae6e772780b832/download.

Jones, M. O., B. W. Allred, D. E. Naugle, J. D. Maestas, J. D. Donnelly, L. J. Metz, J. Karl, R. Smith, B. Bestelmeyer, C. Boyd, J. D. Kerby, and J. D. McIver. 2018. Innovation in rangeland monitoring: annual, 30m, plant functional type percent cover maps for US rangelands, 1984-2017. Ecosphere 9:e02430 *in* Lewis et al. 2018.

Kirol, C. P., J. L. Beck. S. V. Huzurbazar, M. J. Holloran, and S. N. Miller. 2015. Identifying Greater Sage-grouse source and sink habitats for conservation planning in an energy development landscape. Ecological Applications. 25.968-990. http://doi.org/10.1890/13-1152.1 (pdf provided in Appendix 2 because on-line journal does not allow access without a subscription).

Kirol, C. P., K. L. Pilgrim, A. L. Sutphin, and T. L. Maechtle. 2018. Using DNA from Hairs Left at Depredated Greater Sage-grouse Nests to Detect Mammalian Nest Predators. Wildlife Society Bulletin. 42(1):160-165 Available at https://www.fs.fed.us/rm/pubs_journals/2018/rmrs_2018_kirol_c001.pdf.

Kirol, C. P., K. T. Smith, N. E. Graf, J. B. Dinkins, C. W. Lebeau, T. L. Maechtle, A. L. Sutphin, and J. L. Beck. 2020. Greater Sage-grouse response to the physical footprint of energy development. Journal of Wildlife Management. 84:989-1001. https://doi.org/10.1002/jwmg.21854 (pdf provided in Appendix 2 because on-line journal does not allow access without a subscription).

Lewis, R., L. Smith, B. Boepple, and C. Gray. 2018. Vegetation Response to Recent and Historical Fires on the Padlock Forks Unit. A Technical Report in Partial Fulfillment for the Western Land Management Practicum. 32 pp (pdf provided in Appendix 2 because no on-line access).

McLean, R.G. 2006. West Nile Virus in North American Wildlife. Proceedings of the 22nd Vertebrate Pest Conference, pp. 311-317. Published at the University of California, Davis. Available at https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1420&context=icwdm_usdanwrc.

Northeast Wyoming Local Working Group. 2020. Management Assessment Summary for the 2017 Tidwell/Deer Creek Wildfire in the Buffalo Connectivity Area. Submitted June 25, 2020 (pdf provided in Appendix 2).

Pyke, D. A., S. T. Knick, J. C. Chambers, M. Pellant, R.F. Miller, J. L. Beck, P. S. Doescher, E. W. Schupp, B. A. Roundy, M. Brunson, and J. D. McIver. 2015. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 2. Landscape level restoration decisions: U.S. Geological Survey Circular 1418. 21 p. Available at https://pubs.usgs.gov/circ/1418/circ1418.pdf.

Pyke, David A., J. C. Chambers, M. Pellant, R. F. Miller, J. L. Beck, P. S. Doescher, B. A. Roundy, E. W. Schupp, S. T. Knick, M. Brunson, and J. D. McIver. 2017. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat - Part 3: Site level restoration decisions. U.S. Geological Survey Circular 1426. Reston, VA: U.S. Geological Survey. 62 p. Available at https://www.fs.fed.us/rm/pubs_journals/2017/rmrs_2017_pyke_d001.pdf.

Row, J. R., K. E. Doherty, T. B. Cross, M. K. Schwartz, S. J. Oyler-McCance, D. E. Naugle, S. T. Knick, and B. C. Fedy. 2018. Quantifying Functional Connectivity. The Role of Breeding Habitat, Abundance, and Landscape Features on Range-wide Gene Flow in Sage-grouse. Evolutionary Applications, 11(8), 1305-1321. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6099827. https://dx.doi.org/10.1111/eva.12627.

Spence, E. S., J. L. Beck, and A. J. Gregory. 2017. Probability of lek collapse is lower inside sage-grouse Core Areas: Effectiveness of conservation policy for a landscape species. PLoS ONE 12:1-15. Available at http://www.uwyo.edu/esm/faculty-and-staff/beck/_files/docs/publications/spence-et-al-2017-plos-one.pdf.

State of Wyoming. 2019. Wyoming Executive Order 2019-3. Greater Sage-grouse Core Area Protection. Appendix I - Wyoming Greater Sage-grouse Adaptive Management Plan. Available at https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Sage%20Grouse/Governor-Gordon-Greater-Sage-Grouse-EO-2019-3_August-21-2019_Final-Signed_2.pdf (pdf of Appendix I provided in Appendix 2).

Stiver, S. J., A. D. Apa, J. R. Bohne, S. D., Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater Sage-grouse Comprehensive Conservation Strategy. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming. Available at http://www.sagegrouseinitiative.com/wp-content/uploads/2013/07/WAFWA-comprehensive-strategy.pdf.

Taylor, R. L., J. D. Tack, D. E. Naugle, and L. S. Mills. 2013. Combined effects of energy development and disease on Greater Sage-grouse. PLoS ONE 8(8): e71256. Available at https://doi.org/10.1371/journal.pone.0071256.

Taylor, J. D., R. D. Holt, E. K. Orning, and J. K. Young. 2017. Greater Sage-grouse Nest Survival in Northwestern Wyoming. Journal of Wildlife Management 81(7). Available at https://www.researchgate.net/publication/318177917_Greater_sage-grouse_nest_survival_in_Northwestern_Wyoming_Sage-Grouse_Nest_Survival.

U.S. Fish and Wildlife Service (Service). 2013. Greater Sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report. U.S. Fish and Wildlife Service, Denver, Colorado. February 2013. Available at https://www.fws.gov/greatersagegrouse/documents/COT-Report-with-Dear-Interested-Reader-Letter.pdf.

Watchorn, R. T., T. Maechtle, and B. C. Fedy. 2018. Assessing the efficacy of fathead minnows (*Pimephales promelas*) for mosquito control. PLoS ONE 13:30194304. Available at https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0194304.

Wells, K. Wyoming Department of Environmental Quality. Personal communication, March 1, 2021.

Western Association of Fish and Wildlife Agencies - Sagebrush Initiative. 2017 (Updated 2020). White Paper: Predator Control as a Conservation Measure for Sage-grouse. Available at https://wafwa.org/wpdm-package/white-paper-predator-control-as-a-conservation-measure-for-sage-grouse/.

APPENDIX B

Northeast Working Group Trigger Assessment

2021 Adaptive Management Triggers Assessment
Northeast Wyoming Local Working Group
July 8, 2021

The Northeast Wyoming Local Working Group (NELWG) met on June 16 and July 8 2021 to review data and assess if soft or hard adaptive management triggers have been tripped based on data through 2020.

We have identified some areas that we believe have tripped an adaptive management trigger and we would like to highlight the conservation concern related to these areas. Conversely, we have some additional questions about the data analysis presented (see below). We also have some concerns with the lack of action associated with the 2020-2021 Technical Team's product and recommendations based on the soft trigger identified by the LWG in 2018. We are hesitant to identify triggers without addressing our questions/concerns noted below because we are sensitive to the time and effort required to convene and conclude a Technical Team. We are also cautious in our review of triggers by core and connectivity areas, based on the LWG and Technical Team assessments that core areas in the LWG jurisdiction should be re-assessed.

We present our findings with the following clarifications, concerns, and requests:

1. For the trigger calculations, if the standard deviation is greater than the 20-year average, this could result in areas not tripping a trigger calculation but having 0 birds (or <0 birds by the math). This does not make sense biologically. With the understanding that the NELWG requested additional areas be analyzed, the South of North Gillette Priority Area would fall under this scenario.
2. What is the current process to address "small leks", as defined in the Sage-grouse EO? There are a number of "small leks" in the NELWG jurisdiction, which may be complicating some of the trigger calculations. In addition, is there any guidance available for dealing with core areas with small numbers of leks? In terms of trigger calculations, the mathematical implications for "small leks" may be similar to core areas with a small number of leks. See Douglas Core and Newcastle Core notes below.
3. Wind Creek Priority Area- there appears to be an outlier number of peak males (104) recorded in 2016. Can you confirm this is accurate and not an error? This observation in conjunction with many null values is likely driving the soft trigger result.
4. Can you please clarify how to interpret a USGS "watch" or "warning" that goes away in subsequent years? Are there tools to assess if those lek clusters have re-coupled with the neighboring cluster trends or if they have de-coupled far enough that they no longer trip a watch or warning?
5. We are particularly concerned with having some assessment of effort, especially given the number of "small leks" and the number of important or core areas with a small number of leks. Would it be possible to fill one of the following data requests?
    a. Run the trigger calculations for the 13 areas assessed (below) for "Annual Count" leks identified in the sage-grouse database. This would help us compare the full dataset to a dataset with fairly consistent effort, albeit with a smaller sample size.
    b. Provide % occupied leks visited and contributing to the dataset for each year from 1998-2020, for a qualitative examination of effort by the LWG members.
6. Can you provide the LWG with a list of the Statewide Adaptive Management Team members as well as their anticipated meeting schedule?

2021 Adaptive Management Trigger Assessment:

Area	Trigger Assessment	Notes
Buffalo Core	Soft trigger- Habitat	2020 Wildfire
Buffalo Connectivity	Soft trigger- Active Leks Soft trigger- Habitat	Reviewed by Technical Team, waiting action from Statewide Adaptive Management Team
Douglas Core	Hard trigger- Active Leks Soft trigger- Peak Males	Only 2-4 active leks 1998-2020
Natrona Core (portion that is in NELWG area)	Soft trigger- Active Leks Soft trigger- Peak Males Soft trigger- Habitat	Hard triggers tripped for Peak Males and Active Leks within the NELWG portion of Natrona Core
Newcastle Core	Soft trigger- Peak Males	Only 3-7 active leks 1998-2020
North Gillette Core	None	
North Gillette Connectivity	None	
North Glenrock Core	None	
Thunder Basin Core	None	
County Line Priority Area	None	
East Buffalo Priority Area	None	
South of North Gillette Priority Area	None	
Wind Creek Gillette Priority Area	Soft trigger- Peak Males	Lots of null data and outlier high peak male count in 2016

We would like to express our sincere appreciation for Nyssa Whitford's continued efforts to fill our data requests with exceptional quality and punctuality.

Thank you,
Northeast Local Working Group
7/8/2021

APPENDIX C

Relevant 2021 Publications

Patterns of nest survival, movement and habitat use of sagebrush-obligate birds in an energy development landscape

by

Christopher Paul Kirol

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Social and Ecological Sustainability

Waterloo, Ontario, Canada, 2021

Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

External Examiner:

Supervisor:	Bradley C. Fedy Associate Professor, School of Environment, Resources and Sustainability, University of Waterloo
Internal Member:	Stephen D. Murphy, School of Environment, Resources and Sustainability, University of Waterloo
Internal-External Member:	Rebecca C. Rooney Associate Professor, Department of Biology, University of Waterloo
Other Members(s):	Kevin E. Doherty U.S. Fish and Wildlife Service, Lakewood, Colorado, USA

AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Christopher Paul Kirol was the sole author of Chapters 1 and 6, that were written under the supervision of Bradley Fedy and were not written for publication.

This thesis consists of four (4) manuscripts that have been published or prepared for publication. I was a lead author of three (3) of these manuscripts. As lead author, I contributed to developing the study design, applying for funding, applying for research permits, procuring field equipment, organizing field logistics, hiring seasonal technicians, supervising technicians, carrying out data collection and analysis, writing reports for funding and permitting agencies and drafting and submitting manuscripts. My supervisor and coauthors provided guidance and feedback during each step of the research process and manuscript drafting.

Exceptions to sole authorship of material are as follows:

Chapter 2 of this thesis was published in 2018 in the Wildlife Society Bulletin (citation below). Andrew L. Sutphin was the lead author of this manuscript. As a coauthor I contributed to carrying out data collection and analysis and drafting and submitting the manuscript.

Sutphin, A. L., T. L. Maechtle, C. P. Kirol, and B. C. Fedy. 2018. A mobile tool for capturing greater sage-grouse. Wildlife Society Bulletin 42:504–509.

Chapter 3 of this thesis was published in 2020 in the Wildlife Society Bulletin (citation below). I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthors Bradley Fedy, Dylan Kesler and Brett Walker.

Kirol, C. P., D. C. Kesler, B. L. Walker, and B. C. Fedy. 2020. Coupling tracking technologies to maximize efficiency in avian research. Wildlife Society Bulletin 44:406–415.

Chapter 4 of this thesis has been submitted to an avian ecology journal. I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthor Bradley Fedy.

Chapter 5 of this thesis is being prepared for submission. I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthor Bradley Fedy.

In addition to the chapters included in this thesis, I coauthored two (2) manuscripts. Both of these manuscripts were led by Natasha Barlow. As a coauthor I contributed to many of the aspect of the preparation of these manuscripts outlined above. The first manuscript was published in the Journal of Wildlife Management in 2019 and the second was in Biological Conservation in 2020 (citations below).

Barlow, N. L., C. P. Kirol, K. E. Doherty, and B. C. Fedy. 2019. Evaluation of the umbrella species concept at fine spatial scales. The Journal of Wildlife Management 84:237–248.

Barlow, N. L., C. P. Kirol, and B. C. Fedy. 2020. Avian community response to landscape-scale habitat reclamation. Biological Conservation 252:108850.

Throughout this thesis I use the pronoun 'we' in place of 'I' to reflect the collaborative nature of this work. Specifically, the collective 'we' refers to my collaborators and coauthors of each independent manuscript. I follow the Journal of Wildlife Management style guidelines throughout the thesis.

Abstract

The sagebrush ecosystem in western North America provides habitat for approximately 350 plant and animal species, many of which are species of conservation concern. The sage-grouse and several species of sagebrush associated songbirds have undergone population declines over the last fifty years. Energy development has been identified as one of the leading causes of sagebrush landcover loss and fragmentation and has contributed to declines of sagebrush dependent bird species. Our research represented management-oriented science related to the conservation of sagebrush associated species. We used a sagebrush-obligate songbird, the Brewer's sparrow (*Spizella breweri breweri*), and the greater sage-grouse (*Centrocercus urophasianus*, hereafter sage-grouse) to address questions related to habitat selection, space use, reproductive rates and movements in an established energy field in the Powder River Basin (PRB) in Wyoming, USA.

Attaching global positioning system (GPS) tags to wildlife can provide a tremendous amount of information that can be used to better understand many aspects of a species' ecology and how wildlife may be responding to anthropogenic disturbances. Information gathered from tracking wildlife is critical to inform management and conservation actions designed to benefit species that are being effected by anthropogenic activities. To minimize impacts and increase capturing efficiency when capturing sage-grouse to attach GPS tags, we developed a new mobile capturing technique. We had a 71% capture success rate. The capturing method we describe proved effective in our study and we believe this method can be applied to other bird species with similar behavioral traits.

For most wildlife species, researchers must select between multiple tracking technologies that represent trade-offs among data requirements, mass, and cost. Options tend to be more limited for smaller species and those that fly. To address our research question, we developed and tested a unique combination of a store-on-board GPS logger with an independent very-high-frequency (VHF) tag (hereafter hybrid tag) fitted on sage-grouse with a modified harness design. We compared the hybrid tag we designed with other tracking technologies commonly used in bird research, namely VHF and Argos satellite relay tags. Given our research objectives, that required both frequent location data and field-based observational data, we found hybrid tags were the most cost-effective option and capable of collecting more location data compared with Argos tags because of power savings associated with data transmission. Cost savings allowed us to avoid sacrificing sample size while still obtaining high-resolution location data in addition to field-based observational data such as the presence of sage-grouse chicks. We believe our hybrid tags

and harness design would be beneficial to research on other bird species of comparable size to sage-grouse and those that are relatively localized year-round, including many other Galliformes.

Habitat selection in wildlife occurs across multiples spatial scales from selection for broad geographic areas to fine-scale habitat components. Therefore, the selection scale of interest in a study must dictate the spatial extent of the area considered as available to the species and availability should be based on biologically realistic movements of that species or individual. Habitat selection studies are usually conducted at a population level. Habitat selection analyses at an individual level can reveal patterns in selection that are not apparent when using population-level approaches. The hybrid tag, that allowed for gathering high-resolution location and movement data, and new data analyses approaches allowed us to explore individual-level movements, space use (e.g., home ranges) and habitat selection of female sage-grouse that raised chicks (brood-rearing sage-grouse) in a coal-bed natural gas (CBNG) development area. We used integrated step selection analysis (iSSA) that permit the quantification of the effects of environmental and anthropogenic covariates on the movement and selection process simultaneously to evaluate habitat selection and avoidance behaviors. On average, brood-rearing female sage-grouse established home ranges in areas with a majority of the home range comprised of sagebrush landcover (mean = 77.4%) and a minimal proportion of the area comprised of anthropogenic surface disturbance (mean = 3.5%). Individual-level selection analyses helped us uncouple some aspects of energy development that influence habitat selection that likely would not have been detected at broader spatial scales. Brood-rearing females consistently selected for natural vegetation and avoided disturbed surfaces, including reclamation surfaces, at fine spatial scales. Power line visibility generally led to avoidance behavior; however, much shorter (3m) CBNG well structures generally did not. We found that individual variability was partially explained by age (adult or first year), or previous experience of the landscape. Our results do not support individual uniformity in brood-rearing sage-grouse and reiterate the importance of accounting for, or at least recognizing, individual variability in population-level modeling efforts.

Reclamation is increasingly emphasized as a means of mitigating impacts on species that have been affected by oil and gas development; however, the response of sagebrush species to reclamation has largely been untested. We used the Brewer’s sparrow nest survival as an indicator of population fitness responses to early-stage reclamation in sagebrush habitat. Addressing the question: does early-stage reclamation of energy disturbance provide a population benefit for the Brewer’s sparrow? We assessed oil and gas reclamation approximately five years after reclamation, but sagebrush reestablishment is a slow process; thus, the legacy of these disturbances (i.e., disturbance scars) will likely remain for decades. We compared Brewer's sparrow nest survival across a gradient of oil and gas development from undisturbed and active development to areas that have undergone oil and gas reclamation. Nest survival was assessed at multiple scales from microhabitat to landscape. Our study was designed to also help us better understand the mechanisms that act to depress songbird nest survival in oil and gas development fields (i.e., physical footprint of disturbance or infrastructure features). The distribution of nest sites in the active CBNG development and reclamation treatments suggested local avoidance of disturbance, both active disturbance and reclamation, when establishing nesting territories. We found that reclamation benefited nest survival at a local scale which suggests that infrastructure, and associated human activity, may be more influential on Brewer's sparrow nest predation risk than the physical footprint of disturbance alone. Our findings demonstrated scale-dependent nest survival relationships. Across microhabitat and landscape scales, sagebrush canopy cover and composition are important to Brewer's sparrow reproductive success. Combined, these findings emphasize the importance of avoiding the removal of sagebrush habitat whenever possible and expediting sagebrush regeneration in disturbed areas to maintain suitable sagebrush habitat for breeding songbird populations.

Acknowledgements

I have learned a tremendous amount from my advisor Dr. Brad Fedy. Thank you for the opportunity to continue my educational growth and for sharing your passion for research and your statistical expertise with me. As a nontraditional student with a family, I am grateful for your flexibility and understanding throughout this process. I was also fortunate to have a very knowledgeable graduate team. Thank you to my committee members Drs. Stephen Murphy, Rebecca Rooney, Kevin Doherty and thank you to my external examiner Dr. Anna Chalfoun. I want to thank Natasha Barlow who was a student partner on this project. In addition to being a natural leader and doing exceptional research, Natasha was a pleasure to work with.

I enjoyed engaging and talking research with my fellow Fedy lab mates; Matt Dyson, Natasha Barlow, Marcus Maddalena, Jeff Row, Kris Winiarski, Ryan Johnstone, Kelly McLean, Todd Cross and Marie Raciocoppa. Special thanks to Matt Dyson for your help and support. As the first PhD student in the Fedy lab, you really helped blaze the trail for the rest of us.

I want to thank Bill Ostheimer, Janelle Gonzales, Ryan Fieldgrove, Chris Keefe, Dan Thiele, Darren Long, Chris Sheets and Tom Christiansen for helping us get this project off the ground and for your continued support. Thank you to our project funders for their support; Bureau of Land Management, Northeast Sage-Grouse Local Working Group and Natural Sciences and Engineering Research Council of Canada.

The School of Environment, Resources and Sustainability administrative manager Jennifer Nicholson was pivotal in helping us implement this project. She was always ready to assist with purchasing, hiring and a ton of other field logistics. Thank you for all your help and for being so good at your job.

I would like to express my gratitude for our hard working and talented field technicians; Mirabai Alexander, Julie Galloway, Hannah Watkins, Tyler Giesler, Tony Mort, Trevor Thorvaldson, Sean Jenniskens, Jordan Lange, Layton McAndrew, Nathan Joakim and Dave Malutich. Also special thanks to Drs. Jason Carlisle, Julie Rieder and Kurt Smith for helping with research design and field work. I would like to thank all of the landowners who allowed us to conduct research on their properties.

Most of all I want to thank my wife and children. My wife, Sara, provided unwavering support through this process and was amazingly understanding when I had to leave our home in Wyoming (USA) for months on end. I know you made many sacrifices and took on a lot to make this possible. I really appreciate it! You are the best. I love you. My kids Brynn and Evan were also super supportive and

understanding throughout this process. They are great field assistants, as well. I am so lucky to have such a wonderful family. I look forward to our many family adventures to come.

I also received a lot of support and encouragement from my extended family, for which I am very grateful. My Mom spent her summers helping with the kids, when my wife and I were spending long days in the field at our respective jobs. We could not have done this without you, Mom. Also thank you for listening and providing advice when I vented about the trials and tribulations of juggling graduate school with being a father and husband.

Table of Contents

Examining Committee Membership ii
AUTHOR'S DECLARATION iii
Statement of Contributions iv
Abstract vi
Acknowledgements ix
List of Figures xiv
List of Tables xvii
Chapter 1 Introduction 1
1.1 Sagebrush ecosystem 1
1.2 Sagebrush reclamation 3
1.3 Wildlife tracking and capture 4
1.4 Study background 6
1.5 Dissertation organization 7
Chapter 2 A mobile tool for capturing greater sage-grouse 9
2.1 Abstract 9
2.2 Introduction 9
2.3 Methods 11
2.3.1 Study area 11
2.3.2 Materials 12
2.3.3 Spring captures 13
2.3.4 Late summer/fall captures 15
2.3.5 Use of a herder 15
2.4 Results 15
2.5 Discussion 16
Chapter 3 Coupling tracking technologies to maximize efficiency in avian research 19
3.1 Abstract 19
3.2 Introduction 19
3.3 Methods 22
3.3.1 Study area 22
3.3.2 Field methods 22
3.3.3 Technology and equipment 24

3.3.4 Cost comparison........ 29
3.4 Results........ 32
3.4.1 Cost comparison........ 33
3.5 Discussion........ 33
Chapter 4 Does habitat reclamation following energy development benefit songbird nest survival?........ 39
4.1 Abstract........ 39
4.2 Introduction........ 40
4.3 Methods........ 43
4.3.1 Study area........ 43
4.3.2 Songbird indicator species........ 45
4.3.3 Nest monitoring........ 45
4.3.4 Treatment and control plots........ 46
4.3.5 Nest plot selection........ 47
4.3.6 Microhabitat covariates........ 48
4.3.7 Microhabitat sampling........ 51
4.3.8 Spatial covariates........ 51
4.3.9 Modeling approach........ 53
4.4 Results........ 54
4.4.1 Base model........ 55
4.4.2 Anthropogenic covariates........ 56
4.5 Discussion........ 59
Chapter 5 Individual variation in the response of a declining population of birds to anthropogenic disturbance in an established energy field........ 66
5.1 Abstract........ 66
5.2 Introduction........ 67
5.3 Methods........ 70
5.3.1 Study area........ 70
5.3.2 Captures and monitoring........ 72
5.3.3 Movement data........ 73
5.3.4 Spatial covariates........ 73
5.3.5 Home range estimates, home range characteristics and movements........ 78
5.3.6 Movement linked habitat selection analysis........ 79

5.4 Results 80
5.4.1 Monitoring 80
5.4.2 General space use and movement 80
5.4.3 Home range landcover and anthropogenic disturbance 82
5.4.4 Home range, space use and movement comparisons 83
5.4.5 Movement linked habitat selection 83
5.5 Discussion 94
5.5.1 Brood-rearing life stage 95
5.5.2 Home range, space use and movements 95
5.5.3 Movement linked habitat selection 97
5.5.4 Conclusions 100
Chapter 6 Discussion 102
6.1 Sage-grouse tracking and capturing advances 102
6.2 Brewer's sparrow 104
6.2.1 Caveats, research considerations and future research 104
6.3 Sage-grouse 106
6.3.1 Caveats, research considerations and future research 106
6.1 Final remarks 109
References 111
Appendix A Photographs of coal-bed natural gas (CBNG) disturbance in northeastern Wyoming, USA 136

List of Figures

Figure 2.1: Bumper-mounted CODA (CODA Enterprises, Mesa, AZ, USA) net launcher side view and dimensions, which was used to capture greater sage-grouse in Wyoming, USA, during spring and autumn 2008–2011 12

Figure 2.2: Bumper-mounted CODA (CODA Enterprises, Mesa, AZ, USA) net launcher on pickup truck. We developed this method to capture greater sage-grouse in Wyoming, USA, during spring and autumn 2008–2011 14

Figure 2.3: Bumper-mounted CODA (CODA Enterprises, Mesa, AZ, USA) net launcher on ATV. We developed this method to capture greater sage-grouse in Wyoming, USA, during spring and autumn 2008–2011 14

Figure 3.1: The tag (hybrid tag) positioned dorsally at the rump (rump-mounted) of a female sage-grouse northeastern Wyoming, USA, 2017–2018. The harness is secured snugly around the legs between the abdomen and the thigh (the harness in curved in the sketch to show how it forms around the grouse's body). 25

Figure 3.2: Components of the harness used to fit the rump-mounted tag (hybrid tag) on a sage-grouse. The pieces of 4-mm-wide 3-mm neoprene were cut to a length of 10 cm (a), inserted into the tubular Teflon ribbon, and stitched in place 4 cm from the elastic stitch marks. The 6.5-cm length of elastic (b) was inserted within the ribbon and stitched at 5-cm marks on each side of the center of the harness. The center of the harness, with the elastic insert, was bunched up between the 5-cm stitch marks to allow the center of the harness to flex with the elastic. The harness was secured on the sage-grouse by crimping approximately 0.64-cm-diameter (1/4 inch), 0.64-cm-wide rings made from copper tubing. 26

Figure 3.3: Hybrid tag fitted on a female sage-grouse in northeastern Wyoming, USA, 2017–2018. 27

Figure 3.4: The components of the hybrid tag fitted on sage-grouse. The very-high-frequency (VHF) tag (RI-2B; Holohil Systems Ltd, ON, Canada) was centered and glued to the base of the Global Positioning System (GPS) logger (solar Harrier-L [long range download] GPS–UHF [ultra-high frequency]; Ecotone Telemetry Lech Iliszko, Sopot, Poland). The piece of 5-mm neoprene, with a cut out of the VHF outline, is glued to the base of the logger with the VHF nested within the neoprene. A piece of 3-mm neoprene is then glued to the bottom and the harness ribbon is threaded through the holes in the neoprene. 28

Figure 4.1: Map of study area and nest-searching plots for Brewer's sparrow in northeastern Wyoming, USA, 2016-2018. 45

Figure 4.2: The physical footprint of disturbance quantified using heads-up digitizing and converted to a 1-m raster for analysis. Selected Brewer's sparrow nests (blue dots) and 50m radius scale (blue circles), northeastern Wyoming, USA. Panel A shows the area digitized as active disturbance and panel B shows area digitized as reclamation with imagery in the background. The disturbance polygons encompassed all of the area disturbed (e.g., sagebrush removed) for the well pads and access roads (panels a, b). Some of the disturbed habitat around active development (A) had filled in with grass and forb cover. The reclaimed surface was dominated by grass and forb cover and did not contain sagebrush (B). Nests were exposed to 25% active disturbance (panels A, a) and 23% reclamation (Panels B, b) within 50m. 47

Figure 4.3: Brewer's sparrow nest survival risk and the percent active disturbance exposure at a 50m radius scale, northeastern Wyoming, USA. Dashed lines represent 85% confidence intervals. 57

Figure 4.4: Brewer's sparrow nest survival risk and the percent reclamation exposure at a 50m radius scale, northeastern Wyoming, USA. Dashed lines represent 85% confidence intervals. 58

Figure 4.5: Standardized risk ratios and associated 85% confidence intervals for all covariates that were predictive of Brewer's sparrow nest survival in northeastern Wyoming, USA, 2016-2018. JulianDay is a temporal covariate, NestHeight and DenseARTRL (5m) are microhabitat covariates measured in the field, BigSage (100m) and ActiveDist (50m) are spatial covariates derived in Geographic Information Systems (GIS). 59

Figure 5.1: Map of study area land cover and 99% home ranges for brood-rearing greater sage-grouse (*n* = 18; 2017-2019) in northeastern, Wyoming, USA. Home ranges estimated using adaptive sphere-of-influence local convex hull nonparametric kernel method (a-LoCoH). The red areas are the lower home range percentiles (~ 20%) or 'core areas' within each home range. 71

Figure 5.2: Example of 99% home ranges estimated using adaptive sphere-of-influence local convex hull nonparametric kernel method (a-LoCoH) for six brood-rearing greater sage-grouse in northeastern Wyoming, USA. Color gradient for each individual indicates ~10 to ~99 percentile isopleths. The lightest areas are the lower home range percentiles (≤ 20%) or 'core areas' within each home range. 81

Figure 5.3: Net-squared displacement (NSD) for each individual from its nest site. We plotted NSD against post-hatch days (days since the female and chicks left the nest) to 40 days. NSD allows for detection of change-points that indicate movement shifts to different areas. Movement data is from brood-rearing greater sage-grouse in northeastern Wyoming, USA. 82

Figure 5.4: Beta coefficients and 85% confidence intervals (CI) for environmental covariates included in all individual models. Each color represents an individual (n = 18). The terms Sage + SageQ is the quadratic form of sagebrush cover and NDVI + NDVIQ is the quadratic form of NDVI. Covariates plotted for high- and low-exposure brood-rearing greater sage-grouse in northeastern Wyoming, USA. . 86

Figure 5.5: Beta coefficients and 85% confidence intervals (CI) for all individual models in which Landcover factor was supported. A negative coefficient for Landcover factor indicates selection for undisturbed natural vegetation (coded as 0) and against disturbed areas (coded as 1). Covariates plotted for high- and low-exposure brood-rearing greater sage-grouse in northeastern Wyoming, USA. 88

Figure 5.6: Comparison between the percent exposure of experienced (adult) and inexperienced (first year) brood-rearing greater sage-grouse to anthropogenic covariates within their availability domain in northeastern Wyoming, USA. 93

Figure 5.7: Beta coefficients and 85% confidence intervals (CI) for all individual models in which the covariates power line visibility and active disturbance were supported. Covariates plotted for experienced and inexperienced hens. Brood-rearing greater sage-grouse in northeastern Wyoming, USA.................. 94

List of Tables

Table 3.1: Cost estimates (USD) are for 30 female sage-grouse tagged with different technologies. Estimates are based on 4 months (May–Aug) of data collection. Cost estimates for very-high-frequency (VHF) necklaces (A4060; Advanced Telemetry Systems, Isanti, MN, USA) and tracking come from our previous research using these tags on sage-grouse (Fedy et al. 2015, Kirol et al. 2015*b*). Cost estimates for our hybrid tag (rump-mounted Global Positioning System [Solar GPS–UHF (ultra-high-frequency) tag, Harrier-L; Ecotone Telemetry Lech Iliszko, Sopot, Poland] fitted with a VHF [RI-2B; Holohil Systems Ltd, Ontario, Canada] add-on) come from our current study. All costs associated with field tracking and monitoring have been combined to provide a liberal estimate of costs. We derived cost estimates for the rump-mounted Argos tags (satellite up-link Argos, GPS Solar Platform Transmitter Terminal [PTT–100, Microwave Telemetry Inc., Columbia, MD, USA]) from previous sage-grouse research (Hansen et al. 2014, Shyvers et al. 2019). The estimates for the Argos tags assume that all data would come from remote data downloads and no field tracking would be necessary, northeastern Wyoming, USA, 2017-2018. 30

Table 4.1: Covariates assessed in Brewer's sparrow nest survival models representing multiple scales from the individual nest shrub to a 100m radius around a nest, Wyoming, USA...................................... 50

Table 4.2: Final Cox proportional hazard model describing relationships between temporal, microhabitat, spatial and anthropogenic covariates and Brewer's sparrow nest survival. The base-model accounted for environmental variation in Brewer's sparrow nest survival to allow for interpretation of the influence of anthropogenic disturbance covariates on Brewer's sparrow nest survival, Wyoming, USA..................... 56

Table 5.1: Covariates that were assessed in our integrated step selection analysis (iSSA) models used to model habitat selection in brood-rearing female sage-grouse. The movement covariate cos_ta was present in all individual models. The environmental covariates that had the most support across individual models formed the base environmental model. The anthropogenic covariates were assessed in conjunction with the base model for each individual. 76

Table 5.2: Beta coefficients for environmental and movement-related covariates that were significant (85% confidence interval [CI]) in our individual base models for brood-rearing female sage-grouse. Cos_ta explains the directional persistence of movements and was the only movement-related covariate that was significant in any of our individual models. Vector roughness measure (VRM) is a measure of terrain roughness. Sage + $Sage^2$ is the quadratic form of sagebrush cover. Normalized difference

vegetation index (NDVI) is a measure of "greenness" or live green vegetation. NDVI + $NDVI^2$ is the quadratic form of NDVI. All covariates were modeled at a 30 x 30 m resolution. Cells shaded grey with an asterisk (*) by the coefficient indicate that the covariate was statistically supported (85% CI did not include zero).. 85

Table 5.3: Beta coefficients and 85% confidence intervals (CI) for anthropogenic surface disturbance covariates that were the most informative in our individual models for brood-rearing female sage-grouse. Active disturbances were areas stripped of natural vegetation (e.g., sagebrush shrubs) that remain devegetated or are partially vegetated with interim reclamation seed mixes. Reclamation were areas revegetated with reclamation seed mixes but largely devoid of sagebrush land cover. Active disturbance and reclamation covariates were quantified as the percent of disturbance per landscape pixel (0-100% active disturbance or reclamation). The Landcover factor covariate represented areas categorized into discrete classes of undisturbed natural vegetation or disturbed (active disturbance + reclamation). A negative coefficient for Landcover factor indicates selection for undisturbed natural vegetation (coded as 0) and against disturbed areas (coded as 1). All covariates were modeled at a 30 x 30 m resolution. An NA indicates that the individual was not exposed to that covariate. A dash (—) indicates that the individual was exposed to that covariate but the covariate was not statistically supported....................... 89

Table 5.4: Beta coefficients and 85% confidence intervals (CI) for anthropogenic infrastructure covariates that were the most informative in our individual models for brood-rearing female sage-grouse. Power line viewshed represented the number of power poles that were visible from any given pixel on the landscape. Structure viewshed represented the number of infrastructure features, such as coal-bed natural gas (CBNG) wells and compressor stations, that were visible from any given pixel on the landscape. We calculated how many power poles or structures were visible within a 1.0 km viewshed distance. These covariates were modeled at a 30 x 30 m resolution. Reservoir distance represents linear distances to man-made reservoirs transformed using a decay function ($e^{-d/\alpha}$) where 100 was a decay constant (α) and d was the distance in meters from each pixel to the reservoir edge which allowed the effect to decay as distance to the reservoir increased. An NA indicates that the individual was not exposed to that covariate. A dash (—) indicates that the individual was exposed to that covariate but the covariate was not statistically supported.. 91

Chapter 1
Introduction

1.1 Sagebrush ecosystem

Sagebrush (*Artemesia* spp.) vegetation communities occurs in cold semi-deserts across the intermountain west and these vegetation communities form the largest shrub ecosystem in North America (Anderson and Inouye 2001, Knick et al. 2003). However, anthropogenic disturbance including conversion to agriculture, urban expansion and industrial development have reduced the sagebrush ecosystem extent by ~50% (Connelly et al. 2004, Schroeder et al. 2004). Much of the remaining sagebrush ecosystem is extensively fragmented by anthropogenic disturbances and degraded by the invasion of non-native plant species (Knick et al. 2011 and Leu and Hanser 2011). Recent estimates suggest that in North America, the area disturbed by oil and gas development built from 2000 to 2012 is equivalent to the land area of three Yellowstone National Parks (~3 million ha; Allred et al. 2015) and much of this energy disturbance overlaps the sagebrush ecosystem. For instance, the Powder River Basin (PRB) in northeastern Wyoming, USA is within the sagebrush ecosystem and energy development that occurred in this area in the early 2000s involved the drilling of more than 27,522 natural gas wells and associated supporting infrastructure including an estimated 9,656 km of overhead power lines (Knick et al. 2011). The state of Wyoming contains about 21% of remaining sagebrush landcover in North America and; therefore, is critical to the long-term conservation of the sagebrush ecosystem (Connelly et al. 2004). Wyoming is also one of the largest producers of domestic energy in the United States and much of the current and forecasted energy development, both renewable and nonrenewable, overlaps the sagebrush ecosystem in the state (Knick et al. 2011, Copeland et al. 2013, Kirol et al. 2020a).

This sagebrush ecosystem provides habitat for approximately 350 plant and animal species, many of which are species of conservation concern (Davies et al. 2011, Rowland et al. 2011). The greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) has become a flagship species representing the plight of the sagebrush ecosystem in the face of an expanding anthropogenic footprint (Hebblewhite 2017). The sage-grouse and several species of sagebrush associated songbirds have undergone population declines over the last 50 years (Knick et al. 2003, Garton et al. 2011, Rosenberg et al. 2016). Sagebrush associated songbirds that have declined and are species of conservation concern include Brewer's sparrow (*Spizella breweri breweri*) and the sage thrasher (*Oreoscoptes montanus*; Rosenberg et al. 2016).

Energy development has been identified as one of the leading causes of sagebrush landcover loss and fragmentation and has contributed to declines in co-occurring bird populations (USFWS 2010, Knick et al. 2011). Energy development can directly affect bird populations through direct mortality and reduced reproductive rates (e.g., nest success; Bayne and Dale 2011, Naugle et al. 2011, Bernath-Plaisted and Koper 2016, Kirol et al. 2020*a*). The physical footprint of energy development results in the direct loss of sagebrush habitat and the fragmentation of sagebrush landcover into smaller patches. However, the ecological footprint of energy development is often much larger than the physical footprint because energy infrastructure, industrial noise and human activity (e.g., vehicle traffic) cause birds to avoid otherwise suitable habitats at local and landscape scales (sensu Naugle et al. 2011, Bayne and Dale 2011, Blickley et al. 2012). The indirect loss of habitat due to avoidance behaviour is often referred to as functional habitat loss.

Studies designed to uncouple the diverse impacts of energy development on co-occurring species are critical to inform effective mitigation strategies and conservation planning. A more mechanistic understanding of energy impacts on wildlife will help us more effectively mitigate these impacts (Northrup and Wittemyer 2012). A lot has been learned about impacts of energy development on co-occurring sagebrush birds through studies on presence/absence, species richness and population trends (e.g., Walker et al. 2007, Gilbert and Chalfoun 2011, Barlow et al. 2020). However, studies assessing behavioral and reproductive responses to energy development, like habitat selection, avoidance behavior, movement, space use, and reproductive outcomes, help us better understand the mechanisms and specific components of energy development that drive negative trends in sagebrush bird populations (e.g., Doherty et al. 2008, Bernath-Plaisted and Koper 2016).

Energy development in the form of oil and gas typically includes clearing natural vegetation for well pads and compressor sites, a network of roads to connect infrastructure, pipeline corridors to transport the fluid minerals and, in some cases, wastewater reservoirs (Walker et al. 2007, Allred et al. 2015). Studies have shown that sage-grouse nest success is consistently lower in oil and gas development areas when compared to non-developed areas (Connelly et al. 2011*a*). Previous research on the effects of coal-bed natural gas (CBNG) found little evidence for relationships between nest success and the proximity to roads and CBNG wells or road and well densities as hypothesized, but found that the presence of CBNG reservoirs was driving reduced nest success of sage-grouse in development areas (Kirol et al. 2015*b*). While acknowledging that a combination of multiple energy-related factors led to negative responses in birds and some of these impacts may be synergistic (Naugle et al. 2011, Bayne and Dale 2011), it is important to understand if certain components of energy development are particularly detrimental to co-occurring bird species. With this information management can target the most detrimental energy components to increase the effectiveness of mitigation and conservation actions (Northrup and Wittemyer 2012). In addition, knowledge of impacts of specific energy development components can often be transferable between energy development types, both renewable and nonrenewable, because different energy development types share many characteristics and infrastructure components (Naugle et al. 2011). For instance, oil and gas and wind energy both require a network of roads to access sites and power lines to transport electricity. Unlike other energy sources, oil and gas development is generally considered a temporary disturbance because of the finite capacity of oil and gas production within areas and post-development reclamation that is usually mandated under conditions of approval (Andersen et al. 2009, Clement et al. 2014).

1.2 Sagebrush reclamation

Because of the continued loss and fragmentation of sagebrush landcover, state and federal agencies are putting greater emphasis on reclamation of disturbed sites and restoration of sagebrush vegetation communities as a mitigation strategy to reduce impacts of energy development and moderate the net loss of sagebrush habitat (BLM 2004, USFWS 2010, Clement et al. 2014, State of Wyoming 2019). Yet, there is a lack of information to determine if site reclamation and habitat restoration can effectively mitigate impacts of development on wildlife, especially in sagebrush habitat (Bayne and Dale 2011, Pyke 2011, Pyke et al. 2015). The idea that wildlife species will respond immediately to habitat restoration has been described as the "if you build it, they will come" assumption (Perring et al. 2015). But the response of wildlife to site reclamation and habitat restoration is often slow (Schaid et al. 1983, Evangelista et al. 2011), and highly specialized species, such as the greater sage-grouse, may be even slower to respond. Reclamation generally refers to the rebuilding of soil profiles to reestablish plant communities (Pyke et al. 2015). In areas disturbed by energy development, reclamation is the first step in habitat restoration efforts (BLM 2004, Pyke et al. 2015, State of Wyoming 2019). In the context of sagebrush habitat management, habitat restoration refers to the process of recovering sagebrush vegetation communities that has been degraded, damage, or destroyed with a goal of achieving pre-disturbance structure and function (BLM 2004, USFWS 2010, State of Wyoming 2019). Reestablishment of sagebrush and the associated vegetation communities is challenging because succession proceeds slowly in these arid systems (Baker 2011). For instance, big sagebrush (*Artemisia tridentata*), the dominate shrub species in sagebrush ecosystems, can take from 25 to 125 years to return to pre-disturbance size and structure through natural reestablishment (Baker 2011, Avirmed et al. 2015). Consequently, the legacy of energy disturbance ─ disturbance scars that fragment and reduce patch size of sagebrush landcover ─ will also persist for decades in these areas unless active restoration (e.g., sagebrush planting) is applied to the reclaimed surfaces (Pyke et al. 2015).

Restoration of sagebrush vegetation communities after disturbance is often complicated by invasive plants that can become established on and adjacent to energy development areas and may slow or prevent the reestablishment of sagebrush plants (Evangelista et al. 2011, Miller et al. 2011). Invasion by the invasive cheatgrass (*Bromus tectorum*), for example, can increase the frequency and intensity of fires which can lead to potentially irreversible loss of sagebrush landcover (Miller et al. 2011, Reisner et al. 2013, Coates et al. 2016).

1.3 Wildlife tracking and capture

Marking and tracking of wildlife using telemetry is an important tool in wildlife research and data gathered from telemetry studies have substantially expanded our understanding of impacts of anthropogenic development on wildlife. For smaller and lighter volant species, telemetry options are more limited because of restrictions in the mass and size of the transmitter relative to the mass and size of the study species (Barron et al. 2010, Fair et al. 2010). However, technology advances are allowing for the production of smaller and lighter transmitters (hereafter tags; Bridge et al. 2011). The most appropriate tracking technology for a study depends on the study objectives, which dictate study needs such as required sample size, frequency of location data, and precision of locations. For most studies, costs of the different transmitter technologies are often a deciding factor because of budget limitations. Researchers often end up sacrificing sample size (number of tagged individuals) to allow for the purchase of tags that gather frequent and precise GPS location data because of the high costs associated with these tracking technologies. The higher cost satellite-based tracking technologies do not require any tracking or monitoring in the field and the location data is sent to your computer. Hebblewhite and Haydon (2010) argue that emerging GPS-tracking technologies should not replace field biology but be used in a way that augments data gathered through field work, allowing for a more complete understanding of animal behavior and ecology.

Sage-grouse are one of the most extensively researched species in North America. The first sage-grouse were fitted with radio transmitters in 1965 (Eng and Shladweiler 1972). Consequently, this species provides valuable information on implementation of new and old tracking technologies and attachment methods that are applicable to many less-studied avian species. The earliest radio transmitter or very-high-frequency (VHF) tags fitted on sage-grouse weighed 70 grams and had a battery life of less than a month (Connelly et al. 2003). The mass of VHF tags commonly used on sage-grouse today are 17 to 22 g (≥ 1.5% of the mass of an adult female) and have a battery lifespan of approximately 2 years (Walker et al. 2016). VHF tags generally require researchers to track the study species in the field to collect location data by using hand-held GPS units to mark the approximate location where they find the animal. Location data obtained from VHF tags are labor-intensive, infrequent, and prone to human error and may also be constrained by limits on access due to weather, road conditions, or land ownership (Withey et al. 2001, Hebblewhite and Haydon 2010). Sage-grouse studies using VHF tags generally only gather one or two GPS locations per week per individual (Walker et al. 2016, Kirol et al. 2020*a*).

More recently, solar powered Argos satellite relay tags (hereafter Argos tags) are being used in sage-grouse research (Smith et al. 2016, Pratt et al. 2017). The Argos tags fitted on sage-grouse can transmit >9–15 locations/day directly to the researcher's computer, via satellite relay, and; therefore, require no field work to obtain the location data (Smith et al. 2016, Pratt et al. 2017). Argos tags have an unlimited battery life expectancy because the batteries are charged by a solar panel positioned on the top of the unit. The initial purchase cost of Argos tags are approximately 20 times greater than VHF tags and costs of Argos systems increase with the download frequency because of additional satellite data download fees (Hebblewhite and Haydon 2010, Thomas et al. 2011).

To address my research questions, I needed to gather observational data in the field to know, for example, if a female sage-grouse had a successful nest attempt and if she raised her chicks to independence. My study objectives required gathering frequent location data while also having a suitable sample size of tagged sage-grouse and, like most studies, my study had a limited budget. None of the existing tags were ideal for my study needs. Therefore, I designed a tag that coupled two types of tracking technologies into one tag that had initial purchase costs that were 2.5 times less than Argos tags, allowing us to have a larger sample of tagged female sage-grouse. The 'hybrid' tag I designed was a combination of a store-on-board GPS logger with an independent VHF tag. Sage-grouse fitted with the hybrid tag were tracked in the field using traditional VHF tracking techniques. Once tagged sage-grouse were located, location data was downloaded from the GPS loggers using mobile UHF base stations and unidirectional antennas. Estimating the net cost per datum (e.g., GPS location) of different tracking technologies has been shown to be a valid way to compare costs of different tracking technologies (Thomas et al. 2011). Based upon the objectives of my study, I compared costs per datum of VHF tags, Argos tags, and hybrid tags. In addition, I described advantages and disadvantages of each type of tag in the context of research that require both field-based observational data and high-frequency and precise GPS location data.

Over the last five decades there have been several methods developed to capture sage-grouse for tagging. The most common methods used are rocket- or cannon-netting and spotlighting (Lacher and Lacher 1964; Wakkinen et al. 1992). Spotlighting has been widely used and proven effective for capture in many areas. This method of capture involves locating sage-grouse at night with a spotlight from truck, all-terrain vehicle, or on foot and capturing them with a hoop net. However, spotlighting is largely ineffective in areas with low sage-grouse population densities because of the difficulty in locating roosting sage-grouse at night is areas with few grouse. Rocket-netting involves deploying a large net (~37m long x ~12m wide) over a sage-grouse lekking site in the early morning when the lek is most active. Black powder charges detonate projectiles attached to the net, carrying the large net over the target. Compared to other methods, rocket-netting has a higher probability of resulting in injury or mortality of captured grouse (Silvy et al. 1990). Rocket-netting can also be dangerous to the capture crews and presents a fire hazard because of the use of black powder charges that must be stored and handled under strict safety protocols (Silvy et al. 1990).

Spotlighting was ineffective in my study area because of the low densities of sage-grouse. Furthermore, I elected not to use rocket-netting for many reasons including the increased likelihood of injuring sage-grouse during capture. I collaborated with others to develop a new method to capture sage-grouse that proved effective in my study area and alleviated some of the concerns I had with other capture methods including minimizing potential injuries in captured grouse, reducing set-up time and difficulty, and reducing disturbance of lekking activities. While modifying existing tracking technologies to design a tag that met my research needs and creating a new more cost-effective capturing technique, I hope to advance capturing and tracking technologies in bird research.

1.4 Study background

My study was in the PRB in northeastern Wyoming, USA. The PRB is on the eastern edge of the sagebrush ecosystem. The sage-grouse population in this region provides a critical genetic link to sage-grouse populations on the edge of the current sage-grouse range in North Dakota, South Dakota and eastern Montana, USA (Row et al. 2018). The PRB has a long history of energy development, primarily in the form of oil and gas and coal mining. Coal-bed natural gas (CBNG) development became widespread throughout the PRB between 2000 and 2015 and many previously undisturbed sagebrush habitats were developed for CBNG reserves during this timeframe (Walker et al. 2007, Doherty et al. 2008). While CBNG reserves were being developed (i.e., CBNG development phase) several research projects were conducted that explored impacts of the largescale CBNG development on sage-grouse and the effectiveness of on-site mitigation measures that were being used (Walker et al. 2007, Doherty et al. 2008, Fedy et al. 2015, Kirol et al. 2015*b*). Over this period of development, researchers documented substantial population declines in sage-grouse, which questions the long-term viability of sage-grouse in the PRB (Walker et al. 2007, Garton et al. 2011, Taylor et al. 2013).

It is common for studies of impacts of energy development to take place during the early stages of development (i.e., development phase) when the impacts are first occurring (Hebblewhite et al. 2011, Naugle et al. 2011). Studies on impacts of energy development on co-occurring wildlife that occur during the production phase of development, when the infrastructure is in place and construction has largely subsided, are much less common (Sawyer et al. 2009, Hebblewhite 2011, Kalyn Bogard and Davis 2014). Because of the reduction in traffic, heavy machinery (e.g., drilling rigs), industrial noise and human presence, the environment experienced by the animal is much different during the production phase than during the development phase (Ingelfinger and Anderson 2004, Sawyer et al. 2009). Therefore, studies conducted during the later stages of energy development (i.e., production phase) are needed to form a more holistic understanding of energy impacts on wildlife species (Hebblewhite 2011). The sage-grouse and Brewer's sparrow used in my research represent multiple generations that have survived and reproduced in this industrial landscape. Therefore, the history of energy development and research in my study area provides for a unique opportunity to explore long-term effects of energy development on successive generations of sagebrush associated birds and build upon the early research conducted in this area.

1.5 Dissertation organization

The overarching goal of my dissertation research was to increase our collective understanding of the responses of sagebrush associate birds to established energy development and early-stage reclamation to inform management and conservation of birds impacted by energy development. In Chapter 2, I discuss a new method to capture sage-grouse. This method increased capturing efficiency in my study area, that contained a low density of sage-grouse, and minimized capturing impacts on sage-grouse when compared to other commonly used capturing methods. This work was published in the Wildlife Society Bulletin journal in 2018 (Sutphin et al. 2018). In Chapter 3, I discuss a unique transmitter I designed for this research that combined existing tracking technologies into one tag and a harness I designed to reduce negative effects of attaching rump-mounted tags on sage-grouse. I compared the tag I designed (hybrid tag) to other tracking technologies commonly used in prairie grouse research, namely VHF and Argos satellite relay tags. Through a cost assessment, I compared costs of each tracking technology. This work was published in the Wildlife Society Bulletin journal in 2020 (Kirol et al. 2020*b*). In Chapter 4, I use nest survival of the Brewer's sparrow to understand how this critical reproductive rate in birds is affected by early-stage reclamation of energy disturbance sites in sagebrush habitats. I compare nest survival across a gradient of oil and gas development from undisturbed and active development to development areas that have undergone site reclamation. I assess nest survival across multiple scales and explore both anthropogenic and environmental factors that affect nest survival in this sagebrush-obligate songbird. This work is in review at an avian ecology journal. In Chapter 5, I explore individual-level movements, space use (e.g., home ranges) and habitat selection of female greater sage-grouse that raised chicks (brood-rearing sage-grouse) in this energy development landscape. Using an analysis method that simultaneously incorporates the movement and selection processes, I explore effects of environmental and anthropogenic covariates on habitat selection and avoidance behaviors. I use these individual-based models to uncouple the impacts of different components of energy development on sage-grouse during the brood-rearing life stage. Finally, in Chapter 6, I discuss the management and conservation implications of my research findings and discuss future research needs.

Chapter 2

A mobile tool for capturing greater sage-grouse

2.1 Abstract

Capturing greater sage-grouse (*Centrocercus urophasianus*) using standard approaches can be challenging and inefficient, particularly in areas with relatively small populations and patchy habitat. In areas with low population densities, traditional trapping techniques such as drop netting and spotlighting have been largely ineffective. To increase trapping efficiency in such situations, we developed a new method to capture greater sage-grouse in Wyoming, USA, during spring and fall 2008-2011. We captured 92 sage-grouse (30 adult hens, 57 yearling hens, 3 hatch year hens, and 2 adult males) using a CODA net launcher modified to mount on a front receiver of a truck or all-terrain vehicle (ATV). We had 71% success (82 successful captures of one or more grouse in 115 attempts). We captured grouse during spring on the periphery of leks, to reduce disturbance of lekking behavior, and during fall along gravel roads. Capture mortality was <1.0%. We recorded low mortality (4.6%) up to 2 weeks post capture that may have been attributed to capture and handling stress. This technique proved effective at capturing greater sage-grouse and we believe this method can be effective at capturing other lekking species of prairie grouse with similar behavioral traits.

2.2 Introduction

Sage-grouse (*Centrocercus* spp.) have been the subject of numerous research projects in the western United States and Canada (Knick and Connelly 2011). Greater sage-grouse (*C. urophasianus*; hereafter sage-grouse) were listed as "warranted but precluded" in 2010 under the 1973 Endangered Species Act (as amended; USFWS 2010). However, on October 2, 2015 sage-grouse were removed from consideration of being listed as threatened or endangered; their status will be reviewed again in 2020 (USFWS 2015). Because sage-grouse continue to be a species of conservation concern, research requiring trapping and marking of sage-grouse will likely continue.

Common capture techniques for sage-grouse include rocket/cannon-netting (Lacher and Lacher 1964), drop-netting (Giesen et al. 1982, Bush 2008), walk-in traps (Schroeder and Braun 1991), and spotlighting (Wakkinen et al. 1992). These techniques have been widely used and have proven effective for capture in many areas, but each method has limitations and associated costs (Lacher and Lacher 1964, Giesen et al 1982).

The most widely used method for capturing sage-grouse is spotlighting from truck, all-terrain vehicle (ATV), or on foot (Giesen et al. 1982, Wakkinen et al. 1992). Spotlighting (sometimes termed night-lighting) involves locating sage-grouse at night with a spotlight and capturing them with a hoop net. This technique has proven successful in many areas (Holloran et al. 2005, Kirol et al. 2012), yet has had limited success in sparsely populated areas and when few grouse roost on or near a lek (B.L. Walker, Colorado Division of Parks and Wildlife, personal communication). Also, researchers studying the same population for multiple years have noted that sage-grouse seem to become progressively more difficult to capture using spotlighting, possibly because individuals become acclimated to the technique (M. J. Holloran, Operational Conservation LLC, personal communication). Spotlighting can only be done at night, working through the night several nights in a row is exhausting for technicians and presents logistical and safety challenges. Spotlighting is also less effective on nights with substantial lunar illumination, in high winds, and when it is snowing (B.L. Walker, Colorado Division of Parks and Wildlife, personal communication).

Rocket/cannon-netting involves deploying a large net (e.g., 36.5 m long x 12.2 m wide) on an area where sage-grouse concentrate, generally a lek. Black powder charges detonate projectiles attached to the net carrying it over the target. Rocket/cannon-netting can result in injuries or mortality of the targeted species, and disrupt breeding behavior if employed on a lek (Silvy et al 1990). Rocket/cannon-netting can also be dangerous to the capture crews and presents a fire hazard due to the use of black powder charges (Silvy et al. 1990; A.L. Sutphin and T.E. Maechtle personal observation). A rocket/cannon net can take up to 2 hr to set up with 4-6 individuals (Moynahan et al 2006; A.L. Sutphin and T.E. Maechtle personal observation). In addition, with rocket/cannon-netting, investigators capture nontarget grouse, for example capturing males, when females are the focal sex. Working with black powder charges presents significant logistical challenges. Black powder charges need to be stored and handled under strict safety protocols. Additional challenges exist relating to misfires, fire hazards, special permitting in most jurisdictions, and shipping (Silvy et al. 1990, B.L. Walker, Colorado Division of Parks and Wildlife, personal communication). Giesen et al. (1982) attempted to capture sage-grouse using rocket/cannon net mounted on the front of a truck and noted safety concerns regarding detonations within the vehicle. They had minimal success (6% of captures) and approximately half of the sage-grouse captured sustained broken wings.

Drop-netting involves a net that is erected above a lek and supported by poles; once sage-grouse are under the net, a rope is pulled dropping the net (Leonard et al. 2000). Drop-netting is a useful means of trapping sage-grouse in some areas (Bush 2008), but is infrequently used because setup can be complex and time consuming, individual birds cannot be targeted, and individuals often move lekking activities from under the stationary nets after they are erected (Connelly et al. 2003; K.T. Smith, University of Wyoming, personal communication). The final traditional method of sage-grouse capture is walk-in traps that are typically set up on or near leks to capture prairie grouse with have a funnel-shaped opening where birds can enter but not easily exit the trap (Schroeder and Braun 1991, Aldridge and Brigham 2002, Smith 2010). Walk-in traps are also time consuming to set up and are generally less effective at capturing birds than other methods (B.L. Walker, Colorado Division of Parks and Wildlife, personal communication).

We describe a mobile capture technique for sage-grouse. We modified a net launcher for mounting on a vehicle and used the technique to capture sage-grouse in northeastern Wyoming, USA. The mobile net launcher addresses concerns associated with the other methods described by minimizing injuries, reducing set-up time and difficulty, minimizing disturbance of lekking activities, allowing for targeting of specific individuals, and providing mobility. Together these benefits increased capture of birds in areas with low population densities, and allowed for capture during daylight.

2.3 Methods

2.3.1 Study area

Our research occurred in the Powder River Basin (PRB), primarily in Johnson County with the northern portion extending slightly into Sheridan County, Wyoming (106°20'2.538"W, 44°18'35.431"N). The study area encompassed 937-km^2 of which 61% was private land, 33% public land administered by the U.S. Bureau of Land Management, and 6% Wyoming state land. Cattle and sheep ranching were the primary agricultural uses and energy development, predominantly in the form of coal bed natural gas, was the primary energy extraction activity occurring in the study area. The study area was within the Great Plains Sage-Grouse Management Zone, which included part of the Powder River sage-grouse population and provided year-round habitat for sage-grouse (Doherty et al 2008, USFWS 2010, Fedy et al. 2015, Kirol et al. 2015*b*). The climate in the study area was semi-arid. Monthly average temperatures ranged from 21.6° C in the summer to –5.8° C in the winter. Annual precipitation averaged 33 cm to 43 cm and average annual snowfall ranged from 84 cm to 170 cm. The majority of the study area was shrub-steppe habitat dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*). Plains silver sagebrush (*A. cana cana*) was present, but at much lower abundance and is limited to drainage corridors.

2.3.2 Materials

The CODA Net launcher (CODA Enterprises, Mesa, AZ, USA; hereafter net launcher) uses expanding gas from a blank .308 caliber rifle cartridge to propel 4 projectiles (~300 g/projectile) attached to a net that rests in a fiberglass canister. An electronic detonator activates the net launcher and deploys the net. Four projectiles are propelled from 4 barrels and carry the net over the target. The barrels are easily adjusted or removed with a wrench and the net launcher can be set up by one person in <5 min. The net must be folded accordion-style to deploy correctly.

The Bureau of Alcohol, Tobacco and Firearms (ATF) of the U.S. Department of Justice determined the net launching device was not designed as a weapon and is not readily converted to a weapon. Therefore, it is not subject to the provisions of the Gun Control Act (GCA) (Bureau of Alcohol, Tobacco and Firearms, Washington, D.C. 20226, October 30, 1981, File # T:T:F:CSL 7540). This allows for interstate transportation and shipping without restriction.

Figure 2.1: Bumper-mounted CODA (CODA Enterprises, Mesa, AZ, USA) net launcher side view and dimensions, which was used to capture greater sage-grouse in Wyoming, USA, during spring and autumn 2008–2011.

From 2008 to 2011, we used the net launcher (Figure 2.1) to capture sage-grouse in the PRB in Wyoming. We used the device to capture sage-grouse near leks in the mornings (≥200 m from lek center) during the breeding season and along roadways later in the year, both at dusk and dawn. Although the net launcher has been used as a stationary unit to capture sage-grouse on leks (Hausleitner 2003); we modified the unit to be mounted to the front receiver of a truck or ATV to make it mobile (Figures 2.2 and 2.3). We welded 5.08-cm steel square tubing to the net launcher and welded a 5.08-cm hitch receiver to the front of a truck or ATV. The receiver protruded 5 cm beyond the front of the truck or ATV and remained parallel to the ground. The steel square tubing was inserted into the receiver and secured with a receiver pin. (Figure 2.1). We used a 9.14-m x 9.14-m net with 5.08-cm mesh in the net launcher. Net launchers ranged in cost from US$3600.00 to $4300.00, and a box of 100 blank .308 cartridges cost US$105.00. Costs of welding labor and materials varied depending on regional differences in labor costs (we paid < $100).

2.3.3 Spring captures

Sage-grouse females around lek perimeters (both from roads and fields) that were not interacting with males were targeted for capture from 1 hr before to 3 hr after sunrise. Once positively identified, the vehicle operator attempted to keep the grouse in front of the vehicle while the passenger controlled the detonator switch (with ATVs, one person controlled both the vehicle and the detonator). Females were approached at ≤20 km/h and kept directly in front of the truck or ATV. Once females were in range (5-8 m), the driver and passenger released anchor weights (dropped from their hands out of the truck windows) secured to the back of the net, followed immediately by detonation of the net launcher and deployment of the net. Following capture, sage-grouse were restrained to minimize risk of injury by quickly removing them from under the net for processing and release. If multiple grouse were captured, each individual was placed in a cardboard box until they were processed.

Figure 2.2: Bumper-mounted CODA (CODA Enterprises, Mesa, AZ, USA) net launcher on pickup truck. We developed this method to capture greater sage-grouse in Wyoming, USA, during spring and autumn 2008–2011.

Figure 2.3: Bumper-mounted CODA (CODA Enterprises, Mesa, AZ, USA) net launcher on ATV. We developed this method to capture greater sage-grouse in Wyoming, USA, during spring and autumn 2008–2011.

2.3.4 Late summer/fall captures

Sage-grouse do not congregate on leks in the fall, so during late summer and fall we used a different approach to capture sage-grouse. We slowly drove along dirt roads at dusk and dawn in sage-grouse habitat with the net launcher mounted on the vehicle or ATV. We chose to search for grouse at dusk and dawn as they are more active during these time periods and likely to be in the open. Once we located one or more females in an accessible area, we followed the same procedures described above. We stayed on roads and borrow ditches to minimize habitat disturbance.

2.3.5 Use of a herder

Similar to other trapping techniques (Giesen et al. 1982), attempting to move birds into areas where the likelihood of capture is greater (i.e., herding) could increase capture success with the net launcher. In our study, herders sometimes drove an ATV or a truck, whereas at other times they were on horseback or on foot. Grouse that were calm and not paying particular attention to the vehicle could often be herded whereas hens that frequently looked at the vehicle or quickly walked out of reach were likely to flush. Herding proved effective at moving birds out of areas with a high density of sagebrush or other areas where the net launcher was not as effective.

The Wyoming Game and Fish Department issued a Chapter 33 Permit for this research and the researchers who directed trapping and monitoring of sage-grouse were trained under the Animal Care and Use Protocol of the University of Montana when working on previous sage-grouse research in the PRB (e.g., Doherty et al. 2008). This same protocol was followed when conducting this research.

2.4 Results

During our 4-year study, we focused on capturing female sage-grouse and captured 92 sage grouse (82 captures of ≥1 grouse in 115 attempts, 71%) using the net launcher, including 30 adult females, 57 yearling females, 3 hatch-year females, and 2 adult males. The mean number of grouse caught per successful attempt was 1.30 (give range). Capture success was 69% and 71% for morning and evening capture attempts, respectively. We attempted 70 captures in the spring and 45 captures in the fall. Capture success in both seasons was 71%. Mortality and injuries associated with capture were low. One captured sage-grouse sustained a broken wing and had to be euthanized, but no other birds were injured. We conducted biweekly monitoring of 87 females captured with the net launcher. Four of the 87 females died from unknown causes within 4 weeks after capture (95% survival).

Of our 33 unsuccessful capture attempts, we were unsuccessful in our capture efforts due to poor net deployment during 4 capture attempts. In these cases, the net was either folded incorrectly or debris was entangling the net. On 2 separate occasions, sage-grouse walked out from under the net that was held up by shrubs. Wind (>24 km/hr) adversely affected net deployment on 4 capture attempts resulting in failed attempts as the net was blown off-target. Slope of the ground (>10°) was responsible for 3 failed capture attempts. On 2 occasions, we attributed failure to repetitive attempts on the same flock of females on the same capture day, although this is hard to determine conclusively and could have been the cause for numerous other failures. Other failed attempts (n = 18) were due to hens quickly escaping to the side or front of the net before it contacted the birds.

2.5 Discussion

Our mobile net launcher resulted in high capture rates and caused minimal mortality or injury of sage-grouse. This method is likely most useful in areas of low sage-grouse density in which spotlighting can be time consuming and less effective (B.L. Walker, Colorado Division of Parks and Wildlife, personal communication). The approach we present addresses 2 of the main goals of animal capture in that it minimizes effects on the species and maximizes capture success. The effectiveness of our capture approach can be influenced by a number of factors, but overall, provides many advantages over alternatives.

Researchers can maximize the probability of successful captures by considering factors that influence the net launcher effectiveness. High cross or head winds (≥24 km/hr) prevented bird capture and we concluded that in winds ≥ 24 km/hr, we needed a tail wind or we would not attempt captures. Giesen et al. (1982) also noted that wind adversely affected the deployment of their vehicle-mounted cannon net. As in most avian capture approaches we advise against capture attempts during precipitation events as the moisture will increase the weight of the net and handling birds in snow or rain can be unduly stressful for the species. Terrain, particularly slopes greater than 10°, can affect net deployment by causing the net to shift with the slope. Thus, when positioned on a side slope the vehicle should be oriented to fire higher on the slope than the target individuals as the net will drop with the contour of the land. Time of day and season had no apparent influence on our success rates. However, we did not attempt mid-day captures as grouse were typically in thick sagebrush and thus, out of reach of the net launcher. Finally, the net must be folded properly and kept clean of debris such as twigs and pieces of vegetation to ensure successful deployment.

Biotic factors, including bird behavior, and habitat structure can also influence capture success. Woody vegetation (e.g., sagebrush) prevents the net from completely collapsing over the target. During our research, grouse walked out from under the edges of nets suspended on sagebrush on 2 occasions. Nonwoody vegetation such as grasses and forbs did not adversely influence our capture success. Bird behavior, flock size, and capture history (i.e., previous attempted capture on grouse) also affect capture success. Multiple capture attempts in the same area may result in birds becoming habituated. Researchers should be aware of species-specific behavioral cues that indicate probable flushing and unsuccessful capture attempts. If the researchers can predict the direction of flush, it is advisable to 'lead' the birds when deploying the net launcher. Foraging birds that displayed minimal vigilance in response to the approaching vehicle were easier to capture. We suggest captures of 3 or fewer sage-grouse per attempt because larger groups are harder to capture due to group vigilance and to reduce the potential for injury. Attempting captures on multiple birds can also lead to injury from the net projectiles (the metal weights that carry the net over the target) striking the birds.

The mobile net launcher approach we describe here presents a number of advantages when compared to alternative common capture approaches. These advantages include greater targeting precision and trapping efficiency, and lower disturbance and injury. The mobile net launcher allowed investigators to be selective, reducing disturbance of non-target individuals. In contrast, rocket-nets and drop-nets are both stationary capture methods and less selective. Trapping efficiency was increased due to lower set up time compared to much more labor intensive approaches (Connelly et al. 2003, Walker 2008).

The mobile net launcher decreased disturbance by allowing us to focus our capture efforts on the periphery of leks (≥200 m) as compared to drop-netting (Giesen et al. 1982, Bush 2008), rocket-netting (Lacher and Lacher 1964), and walk-in traps which are typically set-up directly on leks (Schroeder and Braun 1991). Additionally, we had only one serious injury in 92 total captures. Rocket-netting can result in a higher proportion of injuries and deaths to the target species (Silvy et al.1990). Sell (1979) suggested not using rocket-nets on lesser prairie-chickens (*Tympanuchus pallidicinctus*) because of the high likelihood of injuries and deaths with this method. Haukos et al. (1990) reported that injuries to lesser prairie-chickens with walk-in traps can be higher than rocket-netting. Schroeder and Braun (1991) stated that greater prairie-chickens (*T. cupido*) were in walk-in traps for 30-45 min prior to extraction and 8 of their 231captures resulted in death. Birds in traps can be susceptible to predation or sustain injuries from the chicken wire due to attempted escapes, or fighting over territories in a confined space (Haukos et al. 1990, Schroeder and Braun 1991). Overall, survival was high post-capture and comparable to Hausleitner

(2003) who documented 96% survival in the first month post-capture on 26 sage-grouse captured using a stationary net launcher and 90% survival of 116 grouse captured using spotlighting techniques. The net launcher caught a comparable percentage of yearling birds when compared to rocket netting, suggesting the approach is not biased towards capture of young birds (Doherty 2008). Although our capture efforts focused on females, similar behavioral responses during previous capture efforts and on-going research on males (B.C. Fedy and C.P. Kirol personal observation) suggest this method would be effective on males as well.

Our mobile net launcher is only appropriate for species that are approachable by vehicle. Sage-grouse are easily approached by vehicle and more to likely flush when approached on foot. Sharp-tailed grouse (*T. phasianellus*) are also approachable by vehicles while they are on their breeding grounds and thus, are potentially susceptible to capture with our approach (B.C. Fedy and C.P. Kirol personal observation). Cope (1992) reported that capture success using spotlighting was limited for sharp-tailed grouse in British Columbia, Canada. Other capture methods such as rocket-netting can yield greater numbers per attempt compared to the net launcher, but also capture non-targeted birds. We typically captured 3 or fewer birds per attempt with the net launcher, compared to 30 hens in one attempt with the rocket-net. Although, Haukos et al. (1990) reported capturing 2 or fewer lesser prairie-chickens on most attempts using rocket-nets.

Our research suggests that the vehicle-mounted net gun described here is an effective technique to capture sage-grouse while reducing handling time, injury, and stress-related mortality to targeted and non-targeted individuals. This holds true especially in areas of low sage-grouse densities where other methods prove less effective. Based on our trapping experience, we feel that this method could be effective for capturing other lekking grouse species such as Gunnison sage-grouse (*C. minimus*) and sharp-tailed grouse.

Chapter 3
Coupling tracking technologies to maximize efficiency in avian research

3.1 Abstract

Direct marking and tracking of wildlife using telemetry is widespread and critical to understanding many aspects of wildlife ecology. For most species, researchers must select between multiple tracking technologies that represent trade-offs among data requirements, mass, and cost. Options tend to be more limited for smaller, volant species. We developed and tested a unique combination of a store-on-board Global Positioning System logger with an independent very-high-frequency (VHF) tag (hereafter hybrid tag) fitted on the greater sage-grouse (*Centrocercus urophasianus*) with a modified harness design in northeastern Wyoming, USA, 2017-2018. We compared hybrid tags with other tracking technologies commonly used in avian research, namely VHF and Argos satellite relay tags. Given our research objectives, that required both frequent location data and field-based observational data, we found the hybrid tags were the most cost-effective option and capable of collecting more location data compared with Argos tags because of power savings associated with data transmission. Cost savings allowed us to avoid sacrificing sample size while still obtaining high-resolution location data in addition to field-based observational data such as the presence of chicks. We believe our hybrid tags and harness design would be beneficial to research on other avian species of comparable size to the greater sage-grouse and those that are relatively localized year-round, including many other Galliformes.

3.2 Introduction

Wildlife ecology has a long history of using biotelemetry to track and study animals. Very-high-frequency (VHF) tags were first designed and tested for animal studies in 1959 (LeMunyan et al. 1959) and have been critical tools to understanding many aspects of species ecology. More recently, biotelemetry technologies using internal GPS (Global Positioning System) to collect high-resolution location data have become widely available. Technological advancements have reduced effects on telemetered animals, increased data availability and reliability, and decreased costs. Reductions in the mass and size of transmitters and improved attachment methods, have opened up opportunities for researching small animals and, particularly, those that fly. With a variety of telemetry systems now available, selecting the most appropriate system for a study requires careful considerations of tradeoffs associated with different technologies and study objectives (Hebblewhite and Haydon 2010, Thomas et al. 2011, Taylor et al. 2017).

Sage-grouse (*Centrocercus* spp.) are one of the most extensively researched species in North America and the first birds were fitted with VHF radiotransmitters in 1965 (Eng and Shladweiler 1972). Since then, researchers have tested various telemetry devices and configurations as well as attachment methods on sage-grouse. Consequently, this species provides valuable information on implementation of new and old tracking technologies and attachment methods that are applicable to many less-studied avian species.

When attaching a telemetry device (hereafter tag) to an animal, careful consideration of the ratio of mass of the tag to the body mass of the study species is necessary (Aldridge and Brigham 1988, Samuel and Fuller 1994, Fair et al. 2010). Tag options are more limited for small, volant species (Barron et al. 2010). Research on volant species fitted with tags has shown that the additional mass of the tag can affect flight patterns and increase energetic costs (Barron et al. 2010, Vandenabeele et al. 2012). Although there is not a consensus on a specific tag-to-body mass ratio that is appropriate for all volant species (e.g., 3% or 5%), there is a general consensus that detrimental effects are reduced with proportionally lighter tags (Fair et al. 2010, Vandenabeele et al. 2012). The earliest VHF tags fitted on sage-grouse weighed 70 grams, had a battery life of less than a month (Kenward 2001, Connelly et al. 2003). By the late 1970s, mass of VHF tags commonly used on sage-grouse were reduced to 25 g (~2% of the mass of an adult female) and the battery life was extended to ≥6 months (Connelly et al. 2003).

Researchers require secure attachment of tags that does not harm the animal or affect the animal in ways that may cause systematic bias in the data (Barron et al. 2010). Over the past 50 years, sage-grouse researchers have experimented with a variety of attachment methods including neck-mounted poncho and necklace tags, backpack tags secured around the wings, and rump-mounted tags secured around the legs (Connelly et al. 2003, Bedrosian and Craighead 2010). Tags secured around the neck of the sage-grouse (hereafter VHF necklace) have become the most commonly used tag and currently weigh between 17 and 22 g with a lifespan of approximately 2 years (Frye et al. 2014, Dinkins et al. 2016, Walker et al. 2016).

More recently, satellite relay (Argos; www.argos-system.org), GPS solar-powered Platform Transmitter Terminal (PTT) tags fitted to sage-grouse using a rump-mount harness system has become a more common used tool (Bedrosian and Craighead 2010, Dzialak et al. 2011, Hansen et al. 2014, Smith et al. 2016). Argos PTT tags weigh between 22 and 30 g (Dzialak et al. 2011, Hansen et al. 2014, Smith et al. 2016, Pratt et al. 2017) with approximately 10 additional grams in harness and attachment materials (Pratt et al. 2017). These light-weight Argos PTT tags gather and transmit GPS data via Argos satellites and are powered by batteries that recharge by solar panels (Thomas et al. 2011). The solar panel is positioned on top of the Argos unit, so these tags are fitted on the back of the grouse as a rump-mount to allow for direct sunlight to charge the battery. Unlike a backpack-style harness, the rump-mount method places the tag dorsally on the rump of the bird and the harness material is secured around the legs rather than the wings (Bedrosian et al. 2007, Smith et al. 2016).

The purchase cost of Argos PTT tags are approximately 20 times greater than VHF tags and costs of Argos systems increase with the download frequency because of satellite data download fees (Hebblewhite and Haydon 2010, Thomas et al. 2011, Hansen et al. 2014). Argos PTT tags collect a large amount of location data at frequent intervals and, in general, do not require a researcher to visit study sites to track the animals (Hebblewhite and Haydon 2010, Kays et al. 2015). However, research budget restraints and high cost of Argos PTT tags often limits the number of study animals that can be marked, which may influence statistical power and capacity of the marked population to represent the larger population of interest (Hebblewhite and Haydon 2010). The comparatively low-cost VHF units allows for larger numbers of marked birds given the same budget, and are well-suited for gathering data that require field-based observations such as nest success or brood size (Hebblewhite and Haydon 2010, Kirol et al. 2015*a*). Yet, location data obtained from VHF tags are labor-intensive, infrequent, and prone to human error and may also be constrained by limits on access due to weather, road conditions, or land ownership (Withey et al. 2001, Hebblewhite and Haydon 2010, Gerber et al. 2018). Sage-grouse studies using VHF tags usually track and collect locations for individual birds once or twice per week (Fedy et al. 2012, Walker et al. 2016). Conversely, sage-grouse studies using Argos PTT tags have collected >9–15 locations/day (Dzialak et al. 2011, Smith et al. 2016, Pratt et al. 2017, Foster et al. 2018).

In practice, the most appropriate tracking technology for a given study is highly dependent on the study objectives, which dictate factors such as required sample size, sampling rate, and precision of locations needed. Yet, many studies have the goal of population-level inference over large landscapes, and require precise and frequent location data to quantify space use and movement patterns, but may also need observational data to assess population fitness rates (e.g., nest success). In these cases, tradeoffs between GPS satellite tags and VHF tags are substantial. A hybrid technology that eliminates some of these tradeoffs would be beneficial to many studies that require both frequent location data and field-based observational data. We assessed the functionality of a new approach to tracking sage-grouse that provides frequent and accurate GPS locations, at a cost that does not severely limit sample size, and allows for field-based observational data. Specifically, we required tags that would 1) allow for a sample of ≥40 individuals, 2) cost <US$100,000 (≤US$2,500/unit), 3) have a life span of ≥2 years, 4) provide accurate GPS location data across seasons, 5) provide frequent GPS locations throughout a 24-hour period, 6) weigh <3% of body mass (Fair et al. 2010), and 7) allow real-time tracking in the field to gather observational data. In addition to these considerations, we wanted to ensure we could recover tags if they stopped transmitting for any reason (e.g., malfunction, power loss, damage due to depredation).

We developed and tested a unique combination of a store-on-board GPS logger with an independent VHF tag (hereafter hybrid tag) to meet our research requirements. We detail a hybrid tag we developed and assessed its capacity to meet project goals and outcomes. Specifically, we present 1) the utility of the combined GPS logger and VHF tag, 2) a cost comparison among Argos PTT tags, VHF necklace tags, and hybrid tags, 3) realized benefits of the VHF add-on with an independent battery, and 4) our modified harness system to reduce effects of attaching a rump-mounted tags to greater sage-grouse (Centrocercus urophasianus).

3.3 Methods

3.3.1 Study area

Our study was in the Powder River Basin, primarily in Johnson County with the northern portion extending into Sheridan County, Wyoming, USA. The area was characterized by rugged terrain bisected by deep drainages with prominent hogback ridges, knolls, and escarpments. The majority of the study area was shrub-steppe habitat dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*). The climate in the study area was semiarid. Monthly average temperatures ranged from 21.6° C in the summer to −5.8° C in the winter. Annual precipitation averaged 33 cm to 43 cm and average annual snowfall ranged from 84 cm to 170 cm. More details on study area characteristics are available in Fedy et al. (2015).

3.3.2 Field methods

We captured female sage-grouse in 2017–2018 using spot-light and hoop-net methods (Giesen et al. 1982) and a mobile CODA net launcher (Sutphin et al. 2018). We fitted females with rump-mounted 13-g solar LRD (long range download) GPS-UHF (ultra-high frequency) tags (Harrier-L; Ecotone Telemetry Lech Iliszko, Sopot, Poland) combined with independent 10-g VHF tags (RI-2B; Holohil Systems Ltd, ON, Canada). Only females that weighed >1,000 g were fitted with hybrid tags. We deployed tags with approval from the University of Waterloo (Animals for Research Act and the Canadian Council on Animal Care guidelines, AUPP# 16-06).

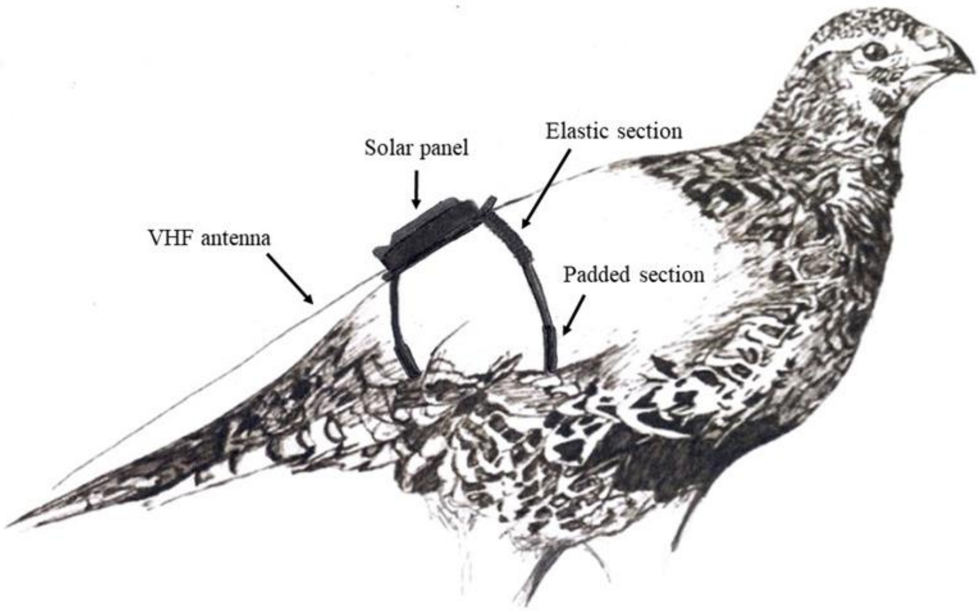
We monitored tagged female sage-grouse weekly from April through August and bimonthly throughout the winter (Sep–Mar). We tracked females using the VHF signal with a R-1000 hand-held receivers and 3-element Yagi antennas (Communication Specialists, Orange, CA, USA) and downloaded the GPS data from GPS loggers using mobile UHF base stations and unidirectional antennas (Ecotone Telemetry Lech Iliszko). Radio activity intervals can be programed to 1, 5, or 10 minutes. We programed our GPS loggers to attempt to communicate (i.e., radio activity interval) every minute. The manufacturer of the GPS loggers (Harrier-L) suggested managing the power at a voltage >3.7. The GPS loggers were originally programed to collect GPS locations every 4 hours (6 locations/24-hr period) and maintained high voltage. The transmitters maintained high voltage when set to collect a location every 4 hours; therefore, we transmitted new settings to the loggers instructing that they record GPS locations every 30 minutes (48 locations/24-hr period), in late-summer 2008. The GPS loggers require line-of-sight for communication and download. The rough terrain in our study area dictated that we commonly had to be within ≤300 m of the female to establish line-of-site communication with the GPS logger. On occasion, if there was rock outcrops or thick vegetation obstructing line-of-site communication, we needed to get much closer than 300 m to download stored data. We used VHF tracking to isolate tagged females to a particular draw or sagebrush patch. After isolating the bird, we pointed the UHF antenna in the direction of the VHF signal and attempted to download the GPS data. If we failed to establish communication with GPS logger, we continued to track the bird and attempted to download again from a different position. We used tablet computers to power the base station, which also allowed us to visually confirm communication with GPS loggers, view location data, and adjust logger settings in the field, when needed. The base stations can be powered by any power source that has a USB port, such as cell phone boosters. The tablets allowed for real-time monitoring because we could view the GPS logger data using Google Earth (Google LLC, Mountain View, CA, USA) software while tracking. After we downloaded the GPS data from the logger, we maintained a distance of ≥50 m from the tagged sage-grouse unless we needed to visually confirm reproductive state or survival. In those cases, we downloaded the GPS data before we attempted to observe the bird. During the nesting period (mid-Apr–Jun) we used VHF tracking to approach within ≥20 m of the female to verify nesting. Once we confirmed a female was on a nest by getting a visual with binoculars, we monitored her and downloaded data weekly from ≥50 m until she was no longer on the nest. If the GPS data showed that a female was on a nest for the entire incubation period (26–28 days), we verified nest survival (i.e., nests with ≥1 hatched egg) by examining eggshells and other diagnostic signs

(Wallestad and Pyrah 1974). Following a successful nesting effort, we attempted to get a visual of the female every second week to confirmed chick presence by visually locating chicks with binoculars or observing brooding behavior by the female (e.g., distraction displays, feigning injury, and clucking). We confirmed brood fate at approximately 35 days posthatch by VHF ground-tracking at night and conducting spotlight counts (Dahlgren et al. 2010). We confirmed brood survival at 35 days posthatch because the majority of chick mortality has already occurred by this age; consequently, chicks alive at 35 days are more likely to survive to breeding age (Gregg et al. 2007). We considered a brood to have survived if we observed ≥1 chick during spotlight counts (Kirol et al. 2015*a*).

We located nests that were initiated early or failed quickly, and not found during VHF ground-tracking, by using the GPS data downloaded from the female's tag to identify clusters of points suggesting a nest attempt. We then surveyed these areas to verify a nesting attempt. If we were tracking a female and suspected that she may have died, we would download and view the GPS data to determine whether the logger was stationary for an extended period of time. When GPS data suggested that the tagged sage-grouse was not moving, we would track the bird to conclusively assess fate and document any diagnostic evidence at mortality locations.

3.3.3 Technology and equipment

Hybrid tags were fitted on sage-grouse with custom-made harnesses. Our harness design allowed for expansion to accommodate growth and reduced abrasion along the inside of the legs (Figure 3.1). We made the harnesses from 0.64-cm tubular Teflon (Chemours, Wilmington, DE, USA) ribbon with 0.64-cm elastic inserted within the ribbon to provide for expansion. We cut the Teflon ribbon to 70 cm and cut the elastic insert to 6.5 cm. We placed marks on the ribbon at the center and at 5.0 cm on either side of the center. We used fine wire to pull the cut pieces of elastic into the ribbon. We stitched the elastic in place at one of the 5.0-cm marks with strong thread. We then used the wire to pull the elastic tight and bunch up the ribbon until the other end of the elastic reached the second 5.0-cm mark. We stitched the elastic in place at the second mark and removed the wire (Figure 3.2). This allowed the center of the harness to flex with the elastic insert.



Sketch by Megan Wilcox

Figure 3.1: The tag (hybrid tag) positioned dorsally at the rump (rump-mounted) of a female sage-grouse northeastern Wyoming, USA, 2017–2018. The harness is secured snugly around the legs between the abdomen and the thigh (the harness in curved in the sketch to show how it forms around the grouse's body).

After retrieving rump-mounted tags from sage-grouse during earlier research, in some instances, we would find abrasions and scabbing under the legs that we suspected were caused by the tubular Teflon material folding onto itself and bunching under the legs. To provide padding and some rigidity to the tubular webbing and prevent the ribbon from folding over, we cut strips of 4-mm-wide pieces of 3-mm neoprene (L Foam Neoprene Fabric; Rockywoods Fabrics, Loveland, CO, USA) to a length of 10 cm. We used needle and thread to pull the pieces of neoprene through the tubular webbing. When the neoprene strip was approximately 4 cm from the elastic stitch mark, on each side of the harness, we pulled the needle through the outside of the webbing and stitched the neoprene in place. This secured the 10-cm neoprene segment within the portion of the harness that runs between thigh and abdomen (Figures 3.1 and 3.2). Once the harness was adjusted to the bird, we secured it with approximately 0.64-cm- (one-quarterinch) diameter copper tubing cut into 0.64-cm-wide rings. We crimped the copper rings on the harness near the back loops of the tag to hold the harness in place (Figures 3.2 and 3.3).

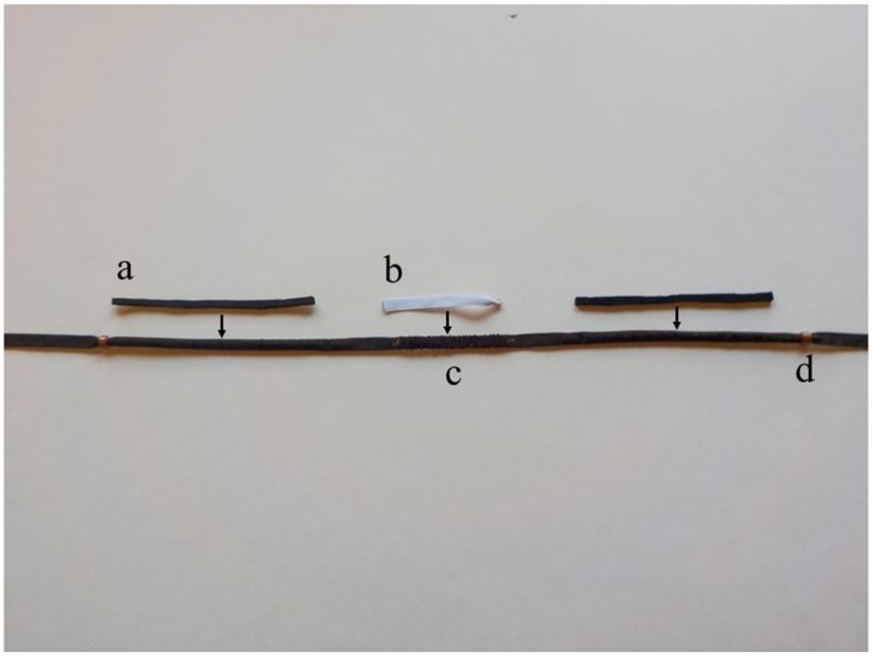


Figure 3.2: Components of the harness used to fit the rump-mounted tag (hybrid tag) on a sage-grouse. The pieces of 4-mm-wide 3-mm neoprene were cut to a length of 10 cm (a), inserted into the tubular Teflon ribbon, and stitched in place 4 cm from the elastic stitch marks. The 6.5-cm length of elastic (b) was inserted within the ribbon and stitched at 5-cm marks on each side of the center of the harness. The center of the harness, with the elastic insert, was bunched up between the 5-cm stitch marks to allow the center of the harness to flex with the elastic. The harness was secured on the sage-grouse by crimping approximately 0.64-cm-diameter (1/4 inch), 0.64-cm-wide rings made from copper tubing.

Figure 3.3: Hybrid tag fitted on a female sage-grouse in northeastern Wyoming, USA, 2017–2018.

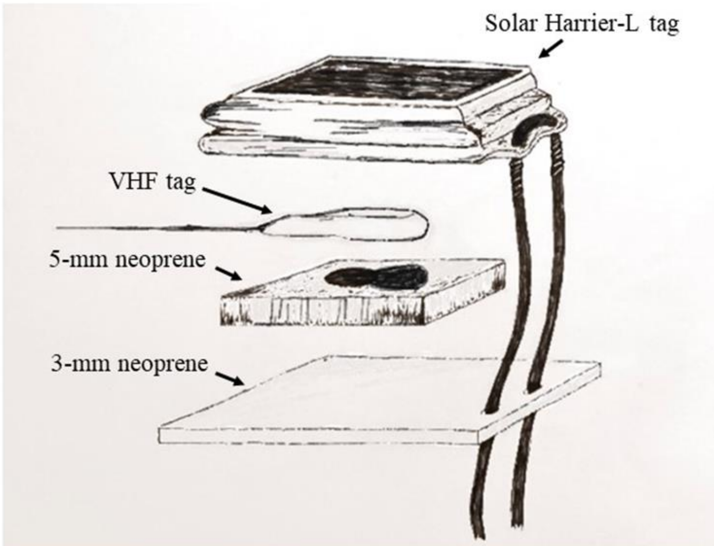


Figure 3.4: The components of the hybrid tag fitted on sage-grouse. The very-high-frequency (VHF) tag (RI-2B; Holohil Systems Ltd, ON, Canada) was centered and glued to the base of the Global Positioning System (GPS) logger (solar Harrier-L [long range download] GPS–UHF [ultra-high frequency]; Ecotone Telemetry Lech Iliszko, Sopot, Poland). The piece of 5-mm neoprene, with a cut out of the VHF outline, is glued to the base of the logger with the VHF nested within the neoprene. A piece of 3-mm neoprene is then glued to the bottom and the harness ribbon is threaded through the holes in the neoprene.

We attached the VHF underneath the GPS logger, rather than on the side, to keep the center of gravity over the middle of the sage-grouse laterally to reduce any potential impact on flight (Caccamise and Hedin 1985, Bedrosian and Craighead 2010). The dimensions of the VHF tag (L 40 × W 23 × H 5 mm) allowed the VHF to easily fit underneath the base of the GPS logger (L 60 × W 26 × H 14 mm; Figures 3.4). When building the hybrid tags, we first centered the VHF unit and glued it to the base of the logger. We then cut a piece of 5-mm neoprene to the dimensions of the GPS logger base and cut out the outline of the VHF within the piece of neoprene. We then glued this piece of neoprene to the base of the GPS logger with the VHF nested within the neoprene (Figures 3.4). We then glued a piece of 3-mm neoprene padding cut to 70 mm long and 40 mm wide onto the underneath side of the hybrid tag and completely covered the VHF tag. We cut this piece of neoprene to protrude 10 mm beyond the front and 7 mm on each side of the tag to act as a feather shield to prevent feathers from shading the solar panel. We made 2 holes in the front of this piece of neoprene to allow the harness to thread through the neoprene and front logger loops (Figures 3.3 and 3.4).

Based on concerns outlined in Bridge et al. (2011), we attempted to minimize aerodynamic drag by keeping the profile above the back of the hybrid tag as low as possible and positioning the VHF antenna parallel to the tail (Figure 3.1). Unlike Argos PTT tags, the GPS loggers did not have an antenna protruding out of the back of the unit.

3.3.4 Cost comparison

Estimating the net cost per datum of different tracking technologies has been shown to be a valid way to compare costs of different tracking technologies (Thomas et al. 2011). We compared costs per datum based upon the objectives of our study that required both location data and reproductive state information. Through the collective experience of the authors of this paper, we have used all of the tracking technologies being compared in this cost comparison while researching sage-grouse (Kirol et al. 2015*b,* Shyvers et al. 2019) We used realized costs from previous research and our current research project to provide a cost comparison per datum between VHF necklace tags (Fedy et al. 2015, Kirol et al. 2015*b*), Argos PTT tags (Hansen et al. 2014, Smith et al. 2016, Shyvers et al. 2019), and the hybrid tags used in this study. We standardized cost comparison across technologies based on marking and tracking 30 female sage-grouse for 4 months over a summer (May–Aug). To provide a conservative cost comparison of Argos technology, we assumed that sage-grouse fitted with Argos tags would require no tracking or monitoring in the field (i.e., no field visits) and satellite transmissions would occur on 5-day intervals. When using Argos technology, some field monitoring of the tagged sage-grouse might be necessary; however, some researchers have relied primarily on interpreting location and movement data to identify nesting attempts and reproductive state information (e.g., brooding or nonbrooding female sage-grouse) with few field visits (e.g., Webb et al. 2012). For VHF necklace tags, we assumed a twice per week ground-tracking would be needed. This is a common monitoring interval in VHF sage-grouse studies occurring during the reproductive season because some nest attempts—nests that are initiated early and fail quickly—can be missed when grouse are monitored less frequently (Walker et al. 2016). The cost comparison included all expenses related to each technology and, based upon our current and previous research, assumed that 2 research technicians would be required to track 30 sage-grouse fitted with hybrid tags once per week and 3 research technicians would be required to track 30 sage-grouse fitted with VHF necklace tags twice per week (Table 1). For instance, costs of 3 telemetry flights used to locate missing grouse that were fitted with VHF necklace and hybrid tags were included in the cost comparison.

Table 3.1: Cost estimates (USD) are for 30 female sage-grouse tagged with different technologies. Estimates are based on 4 months (May–Aug) of data collection. Cost estimates for very-high-frequency (VHF) necklaces (A4060; Advanced Telemetry Systems, Isanti, MN, USA) and tracking come from our previous research using these tags on sage-grouse (Fedy et al. 2015, Kirol et al. 2015*b*). Cost estimates for our hybrid tag (rump-mounted Global Positioning System [Solar GPS–UHF (ultra-high-frequency) tag, Harrier-L; Ecotone Telemetry Lech Iliszko, Sopot, Poland] fitted with a VHF [RI-2B; Holohil Systems Ltd, Ontario, Canada] add-on) come from our current study. All costs associated with field tracking and monitoring have been combined to provide a liberal estimate of costs. We derived cost estimates for the rump-mounted Argos tags (satellite up-link Argos, GPS Solar Platform Transmitter Terminal [PTT–100, Microwave Telemetry Inc., Columbia, MD, USA]) from previous sage-grouse research (Hansen et al. 2014, Shyvers et al. 2019). The estimates for the Argos tags assume that all data would come from remote data downloads and no field tracking would be necessary, northeastern Wyoming, USA, 2017-2018.

Tag type	Tags	Satellite download fee	Tracking equipment[a]	Tracking personnel[b]	Field transportation[c]	Telemetry flights[d]	Total
VHF necklace	$6,000	NA	$4,000	$29,520	$16,600	$4,500	$60,620
Argos PTT	$118,500	$6,872	NA	NA	NA	NA	$125,372
Hybrid tag	$48,000	NA	$6,500	$20,880	$14,400	$4,500	$94,280

[a] Tracking equipment for VHF tags included 3 receivers, 4 folding Yagi antennas, 3 personal GPS units, and $600 for miscellaneous and researcher safety equipment. Tracking equipment for the GPS logger–VHF included all the equipment listed above in addition to 2 UHF base stations, 2 unidirectional antennas, and 2 field tablets.

[b] For VHF necklace tags, requiring ground-tracking twice per week, we assumed that 3 researchers would be required to track 30 tagged sage-grouse. VHF necklace tag costs included hiring 3 research technicians and technician housing for 4 months. For Hybrid tags, that require ground-

tracking only once per week, costs are for 2 researchers to track 30 tagged sage-grouse. Hybrid tag costs included hiring 2 research technicians and technician housing for 4 months.

[c] Field transportation costs for VHF necklace tags, included 1 truck rental and 3 ATV rentals and fuel for 4 months of biweekly ground-tracking. Field transportation costs for Hybrid tags, included 1 truck rental and 2 ATV rentals and fuel for 4 months of weekly ground-tracking.

[d] On the basis of our current and previous research, we assumed that 3 telemetry flights would be required to locate missing grouse over a 4-month tracking season. Costs are for VHF tracking from a fixed-wing aircraft for 6 hours/flight.

We explored cost comparisons for 2 GPS logger sampling frequencies. First, given the inherent disparities in the frequency of location collection of the GPS units, we compared the cost per datum based on standard collection frequencies associated with each technology. We based the estimated costs on 35 locations (i.e., 5/day) for the Argos PTT and hybrid tags and 2 locations/week for VHF necklaces. An Argos PTT tag sampling frequency of 5 points/day is a standard sampling frequency in the summer for sage-grouse studies using solar Argos PTT tags that occurred at a similar latitude (e.g., similar solar energy potential; Pratt et al. 2017). For the second comparison, we used the highest collection frequency we found in the sage-grouse literature of 15 points/day for Argos PTT solar tags (Dzialak et al. 2011) and compared this frequency with the highest collection frequency used in our research of 48 points/day. We only needed to ground-track our hybrid tagged sage-grouse once per week in this study, so we used this monitoring frequency in our cost comparison. It is important to note, weekly ground-tracking is not necessary if the study intent is only to collect GPS locations because, according to the manufacture, the GPS loggers (Harrier-L) can store 30,000 GPS locations on board. In fact, projects using the same equipment on other species (e.g., northern goshawk [*Accipiter gentilis*]) are designed around encountering birds twice per year to download data (Blakey et al. 2020).

3.4 Results

Hybrid tags were fitted on 38 and 39 female sage-grouse in 2017 and 2018, respectively. The average body mass of the adult female (including first-year adults) sage-grouse was 1,428 ± 165 g. The GPS logger–VHF units (including the harness), weighed 29 g, which was approximately 2.0% the body mass of all tagged females. The hybrid tag had a profile above the back of the bird of 21 mm. For comparison, the Argos PTT tags fitted on sage-grouse have a profile of approximately 20 mm, which includes 5 mm of padding. We did not find evidence of scabbing or tissue on the harness of any of the hybrid tags we retrieved after mortality events.

Throughout the year, the GPS loggers maintained high voltage (mean voltage = 4.04 ± 0.10) when set to collect 6 GPS points/24-hour period. The voltage dropped very minimally (average voltage = 4.02 ± 0.11) when set to collect 48 locations/24-hour period, even through the winter when annual solar radiation is lowest. When ground-tracking sage-grouse, the average distance to download GPS data from the loggers was 148.29 ± 14.04 m (range = 8.57–718.57 m).

As of October 2018, the independent VHF allowed us to recover 32 missing tags that had power loss or damage due to a predation event, unknown mortality, or, possibly, slipped tags. The majority of these were found undamaged but with the solar panel facing the ground or obstructed by vegetation. Grouse remains or evidence of depredation were present at the locations where the majority (n = 25) of these tags were retrieved. We did not find evidence of mortality at locations for 7 retrieved tags; therefore, it is possible these were slipped tags.

3.4.1 Cost comparison

The overall costs for tags and data collection for a sample of 30 sage-grouse was highest for Argos PTT tags (US$125,372), followed by the hybrid tags (US$94,280), and VHF necklaces (US$60,620; Table 1). For the first comparison, with Argos PTT and hybrid tags standardized at 5 locations/day, the costs per datum for VHF necklaces (US$63.15) was 8 times greater than Argos PTT tags (US$7.46) and 11 times greater than hybrid tags (US$5.61). Costs per datum diverged more when hybrid tags were collecting 336 locations/week (every 30 min) versus Argos PTT tags collecting 105 locations/week (15/day) and VHF necklaces with 2 locations/week. At this collection frequency, cost per datum of Argos PTT tags (US$2.48) was 4 times more than hybrid tags (US$0.60) and costs per datum of VHF necklaces (US$63.15) was 105 times the cost of hybrid tags and 25 times the cost of Argos PTT tags.

3.5 Discussion

The extensive testing and history of biotelemetry use on sage-grouse provides valuable information applicable to other, less studied, species. We tested a unique combination of a solar GPS logger coupled with an independent VHF tag to maximize our return on investment. For our research, this return resulted in frequent and reliable location data and a robust sample of tagged individuals to better inform population-level inference and demography. Coupling a GPS logger with a VHF tag proved to be beneficial in several ways, some of which were not anticipated. The hybrid tag was ideal for weekly tracking in the field to collect demographic data while simultaneously collecting high-resolution temporal and spatial data. The VHF tag, with an independent battery, proved critical in retrieving tags after a mortality. Further, our cost comparison demonstrated that the hybrid tag was the most cost-effective option given our research objectives.

Technological advances have reduced the mass and size of tags, resulting in more opportunities to collect location data from smaller species and species that fly (Bridge et al. 2011). However, combining 2 technologies into one unit, while maintaining independent power sources, is often not feasible because of the mass of the combined units exceeds tag mass-to-body mass ratio recommendations. Researchers have added independent VHF to Argos PTT tags, primarily to aid in tag recovery (Bedrosian and Craighead 2010, Hansen et al. 2014). Hansen et al. (2014) experimented with 2 types of VHF add-ons with and combined unit mass of 35–40 g, which is ≥5 g heavier than our hybrid tags and >3% body mass of an average adult female sage-grouse (Connelly et al. 2003). However, tag mass limitations were less restrictive for their research because the tags were fitted on male sage-grouse with average mass >1,000 g more than females (Beck and Braun 1978). The low mass of the GPS logger (Harrier-L) we used permitted the addition of a VHF tag with a battery life expectancy of 2 years and a pulse rate adequate for efficient tracking while staying below the commonly recommended tag to bird ratio of ≤3% (Bridge et al. 2011).

As with Argos PTT tags fitted on sage-grouse, the GPS loggers we used are dependent on the solar panel receiving enough light to maintain battery power. As a result of mortalities and obstructed solar panels, Hansen et al. (2014) lost 7 Argos PTT tags (~US$28,000) during the first year of their sage-grouse study. Some of their Argos PTT tags were retrieved by extensively searching the last GPS location that was transmitted to the satellite; however, these 7 tags were not found at the last transmitted location. The VHF add-on allowed us to retrieve 32 hybrid tags the first 2 years of our study. Without the independent VHF, we would have lost approximately US$51,000 in transmitter costs in addition to the location data stored on these loggers. Unlike Argos PTT tags, we generally did not have a GPS location to focus our searching efforts because we were manually downloading data in the field, not receiving location data remotely (e.g., remote download from satellite relay). Therefore, if the GPS logger shut off because of a lack of power, we did not have a recent location to focus our searching efforts. We did not anticipate this many tags would have power loss due to obstructed solar panels; however, similar to Hansen et al. (2014), it was common after a predation event for us to find the tag upside down with the solar panel facing the ground. Also, depending on the amount of damage inflicted on the tag, most can be refurbished for a fraction of the cost of purchasing new tags.

Power-management is an important consideration when choosing a tracking technology. The amount of sun exposure a solar tag receives changes seasonally with shorter days and low light conditions in temperate and polar winters and can also be affected by a species' behavior. For example, when tagged sage-grouse were on nests, which were underneath vegetation, the solar panels received less light and voltage dropped (≤0.2 V). Wintering sage-grouse will snow-burrow during severe winter weather, which has the potential to reduce voltage over the short-term (Back et al. 1987). Researchers using Argos PTT tags on sage-grouse have set the tags to collect from 3 to 9 locations/day (Dzialak et al. 2011, Hansen et al. 2014, Smith et al. 2016, Pratt et al. 2017, Foster et al. 2018). Dzialak et al. (2011) increased their Argos PTT tags to collect 15 locations/day from 15 May to 15 July when the solar panels were receiving sufficient sunlight. Compared with satellite systems, our GPS loggers use much less power for data transmission because these data are transmitted over a much shorter distance (Bridge et al. 2011). With a sampling frequency of 6 locations/day, our GPS loggers maintained high voltage year-round. We saw a small decrease in average voltage (voltage ~0.02) when the hybrid tags were collecting 48 locations/day. When compared with Argos PTT tags, the GPS loggers–VHF tags were able to collect 3 times the amount of location data while maintaining adequate battery power. Based on our experience, we suspect we could increase the locational frequency while maintaining power above manufacturer recommended minimum voltage.

Both the Argos PTT tags and the Harrier-L GPS loggers provide options that allow for ground-tracking using a UHF or VHF signal with additional equipment. However, the ground-tracking option is powered by the same battery; therefore, is also dependent on the solar panel receiving adequate sunlight to maintain power. Further, the ground-tracking option requires additional power from the battery that reduces the power available for gathering GPS locations and transmitting locations to a satellite or a base station.

Prior to the development of GPS tracking systems, relocation data were often impossible to collect in large enough quantities or at fine enough resolutions to answer many research questions for free-ranging wildlife (Hebblewhite and Haydon 2010, Thomas et al. 2011, Kays et al. 2015). Satellite relay GPS technology (e.g., Argos) provides highly precise spatial and temporal location data to a degree never before possible with VHF tracking (Hebblewhite and Haydon 2010, Kays et al. 2015). However, Hebblewhite and Haydon (2010) caution that there are also disadvantages of choosing GPS tracking technology over traditional VHF when researching animal ecology. Primary disadvantages, they discuss, include increased costs per tag leading to small sample sizes and poor population-level inference (Hebblewhite and Haydon 2010). Solely relying on obtaining data remotely from a computer can result in missed information and divorces ecologist from a field-based understanding of animal ecology (Hebblewhite and Haydon 2010). By coupling these 2 technologies, we believe we alleviated these tradeoffs.

Researcher presence in the field remains a necessary component of studies that require observational data. Yet, researcher presence does have a greater effect on study species, compared with data from tagged individuals that is only collected remotely (Fair et al. 2010). We took several steps to minimize adverse effects on sage-grouse in our study. For example, with the hybrid tags, we only needed to get in close proximity of tagged sage-grouse to confirm reproductive state or gather data such as the presence of chicks. Otherwise, we were able to download data from a distance that was unlikely to disturb the tagged grouse and their flock mates.

We maintained reasonable sample sizes because of the cost savings associated with using a ground-based GPS logger (data retrieved by mobile base station instead of satellite; Thomas et al. 2011) instead of a satellite relay unit. The upfront costs of our hybrid tags were less than half the costs of Argos PTT tags. These cost savings allowed us to tag twice as many individuals ($n \sim 40$) as we would have using Argos PTT tags. When considering the net cost per datum of these different tracking technologies, we found that VHF necklaces were the most expensive choice, followed by Argos PTT tags and hybrid tags. When we assessed common GPS location collection frequencies associated with these different technologies used in sage-grouse research, we found that costs per datum for our hybrid tags was 25% less than Argos PTT tags. The cost per datum diverged more when we compared our highest GPS acquisition frequency (48 points/day) with the highest Argos PTT tag frequency we found in the literature (15 points/day). We wanted to provide a conservative comparison between Argos PTT tags and our hybrid tags; therefore, we assumed that no field visits would be required when using Argos PTT tags and that reproductive state would be determined based on location and movement data alone (Webb et al. 2012). However, if researchers using Argos PTT tags wanted to collect demographic data (e.g., brood survival) consistent with the data we collected using hybrid tags, a similar amount of field effort would likely be required. This, of course, would further increase the costs associated with Argos PTT tags and result in an even greater discrepancy between cost per datum.

The number of hybrid marked sage-grouse that went missing due to our inability to locate the VHF signal was relatively few during our study. However, we acknowledge the potential for large unexpected movements that would have resulted in an increase in the number of missing hybrid tags, which could impact cost comparisons for other research studies. Further, we recognize that VHF battery life, especially given the small size of VHF units used (i.e., ≤ 10 g), as it relates to study duration and objectives is an important issue when considering cost comparisons.

Cost per datum is a valuable way to compare different tracking technologies when high-frequency location data are required to meet research objectives (Thomas et al. 2011). However, if frequent location data are not necessary to meet the objectives of a study than cost per datum is not a valid comparison metric. For example, drawing from the sage-grouse literature, if the intent of the study is to assess how female survival rates are affected by anthropogenic features over a large landscape then a robust sample of VHF-tagged individuals is preferable to a much smaller sample fit with Argos PTT tags or hybrid tag

(Dinkins et al. 2014*a*). In this case, having an adequate sample of individuals to model survival outcomes is much more important to the objectives of the study than having frequent location data from fewer individuals. If one just looks at initial costs of the tracking technologies compared in this paper, 240 VHF necklaces could be purchased for the same price as 30 hybrid tags.

To achieve our research objectives, we regularly tracked hybrid-tagged sage-grouse in the field to verify reproductive state and gather demographic data (Kirol et al. 2015*a*, Smith et al. 2018). For instance, by ground-tracking sage-grouse weekly we were able to confirm the fate of sage-grouse nests (nest survival), confirm whether a female was brooding chicks or whether she was no longer with chicks (brood survival and reproductive state), and gather information on depredation events (causes of mortality). These data were not only important to our research objectives, but also helped us to better understand fitness outcomes associated with habitat selection, which are often overlooked in ecological research (Kays et al. 2015).

The hybrid tag we designed would be most beneficial for species of which tag mass is a limiting factor (i.e., smaller, volant species) and for species that do not undergo long-distance migrations. The hybrid tag would be less effective on a long-distance migratory species because of the effort and costs associated with using a VHF to track birds over large areas (Cochran 1987, Bridge et al. 2011). For long-distance migrants, either satellite-relay GPS (e.g., Argos) or a cellular-relay GPS (GPS data is transmitted through cellar networks) tags would likely be a more appropriate choice because GPS location data could be acquired while the bird was migrating and location data would not be lost if the bird died at an unknown location during migration or did not return to the area of original capture (Bridge et al. 2011). However, researchers studying migratory raptors with high site fidelity are using Harrier-L GPS loggers to collect location data when the species returns to a breeding territory by setting up stationary base stations in these territories (Blakey et al. 2020).

Sage-grouse typically move short distances within seasonal habitats (Fedy et al. 2012). In our study region, the longest movements recorded (~12 km) occurred when sage-grouse moved to wintering areas (Fedy et al. 2012). Consequently, our tag design would be best applied to research on largely resident or short-distance migratory populations and species. Many Galliformes are either nonmigratory or only make short-distance movements. Therefore, we believe the hybrid tag would be beneficial for research on many Galliformes, especially when observation data are needed in conjunction with high-resolution location data. A few examples include the lesser and greater prairie-chicken (*Tympanuchus pallidicinctus*, *T. cupido*) and Columbia sharp-tailed grouse (*T. phasianellus columbianus*), in North America; the black grouse (*Tetrao tetrix*), capercaillie (*Tetrao urogallus*), and red grouse (*Lagopus lagopus*) in Europe; and Reeves's pheasants (*Syrmaticus reevesii*) in Asia, all of which are relatively localized year-round (Johnsgard 1983, Giesen and Connelly 1993, Hagen and Giesen 2005, Xu et al. 2009, Johnson et al. 2011*a*).

Many new tracking technologies have become available to wildlife researchers over the past few decades, and each has strengths and weaknesses (Bridge et al. 2011, Thomas et al. 2011, Kays et al. 2015). In designing our hybrid tag and harness system, we hoped to reduce effects on sage-grouse, increase the amount and reliability of collected location data, maintain our ability to track birds in real-time from the ground, and decrease costs and increase sample size compared with satellite GPS transmitters. Our hybrid tags proved to be the most cost-effective option to meet the objectives of our study. Cost savings compared with satellite systems allowed us avoid sacrificing sample size while still gathering high-resolution location data. Hebblewhite and Haydon (2010) argue that emerging GPS-tracking technologies should not replace field biology but be used in conjunction to effectively research animal behavior and ecology. Our hybrid tags accomplish this by coupling traditional VHF tracking methods and field-based observational data with newer GPS tracking that provides accurate and more frequent location data.

Chapter 4

Does habitat reclamation following energy development benefit songbird nest survival?

4.1 Abstract

Songbird communities that rely on sagebrush habitat for breeding are experiencing steep population declines, while a large amount of the sagebrush ecosystem continues to be impacted by energy development. Reclamation is increasingly emphasized as a means of mitigating impacts on species that have been affected by oil and gas development; however, the response of sagebrush species to reclamation has largely been untested. We used nest survival of the Brewer's sparrow (*Spizella breweri breweri*), a sagebrush-obligate songbird of conservation concern, as an indicator of reproductive responses to early-stage reclamation in sagebrush habitat. Addressing the question: does early-stage reclamation provide a population benefit for the Brewer's sparrow? We assessed oil and gas reclamation ~5 years after reclamation, but sagebrush reestablishment is a slow process; thus, the legacy of these disturbances (i.e., disturbance scars) will likely remain for decades. We compared Brewer's sparrow nest survival across a gradient of oil and gas development from undisturbed and active development to areas that have undergone oil and gas reclamation. Nest survival was assessed at multiple scales from microhabitat to landscape. Additionally, our study was designed to help us better understand the mechanisms that affect songbird nest survival in oil and gas development fields such as the disturbance scare (e.g., the physical footprint of development) or infrastructure features. The distribution of nest sites in the active and reclamation areas suggested local avoidance of disturbance, both active disturbance and reclamation, when establishing nesting territories. We found that early-stage reclamation benefited nest survival at a local scale which suggests that infrastructure, and the associated human activity, may be more influential on Brewer's sparrow nest predation risk than the disturbance scar. Our findings demonstrated scale-dependent nest survival relationships. Across microhabitat and landscape scales, sagebrush canopy cover and composition are important to Brewer's sparrow reproductive success. Combined, these finding emphasize the importance of avoiding the removal of sagebrush habitat whenever possible and expediting sagebrush regeneration in disturbed areas to maintain high quality sagebrush habitat for breeding songbird populations.

4.2 Introduction

Sagebrush ecosystems in North America provide habitat for approximately 350 plant and animal species, many of which are species of conservation concern (Knick et al. 2003, Davies et al. 2011). A large amount of the sagebrush ecosystem has been – or has the potential to be – impacted by energy development, primarily in the form of oil and gas (Copeland et al. 2011, Allred et al. 2015). Songbirds that rely on sagebrush habitat for breeding are one of the bird communities in North America experiencing the steepest population declines (Sauer et al. 2013, Rosenberg et al. 2016). Sagebrush specialist songbirds including the Brewer's sparrow (*Spizella breweri breweri*) and sage thrasher (*Oreoscoptes montanus*) have declined by 35% and 44%, respectively, since 1970 (Rosenberg et al. 2016). During the same timeframe, grassland specialist songbirds that often use sagebrush habitat for nesting such as the vesper sparrow (*Pooecetes gramineus*) and lark bunting (*Calamospiza melanocorys*) have also declined by 30% and 86%, respectively (Rosenberg et al. 2016). When nests of these different species co-occur in sagebrush patches, they are exposed to similar environmental conditions and predation risks during the nesting period.

Energy development fields can be risky for songbirds because of direct mortalities and reduced fitness rates (Bayne and Dale 2011, Hethcoat and Chalfoun 2015*a*, Bernath-Plaisted and Koper 2016). Anthropogenic habitat modification can lead to maladaptive breeding strategies in birds in which behavioral cues become mismatched with survival and reproductive outcomes (Robertson and Hutto 2006). Nest productivity is a critical component of population persistence in birds (Saether and Bakke 2000) and increased predation is the primary mechanism that lowers nest survival in many habitats affected by anthropogenic development (DeGregorio et al. 2014, Hethcoat and Chalfoun 2015*a*, Bernath-Plaisted and Koper 2016). Anthropogenic habitat modification can result in heightened risk of nest predation due to changes in predator communities (e.g., expansion of novel predators that benefit from human subsidies), predator abundance, and predator-prey interactions (Winter et al. 2000, Chalfoun et al. 2002, Howe et al. 2014, Kirol et al. 2018). The specific mechanisms that drive impacts of energy development (i.e., increased predation risk) on songbird nest survival are not well understood. Impacts of energy development on songbird nest survival have been attributed to the physical footprint of development (native habitat removal, fragmentation and anthropogenic edge; Hethcoat and Chalfoun 2015*a*, Bernath-Plaisted and Koper 2016, Sanders and Chalfoun 2018) and to specific energy infrastructure features such as power lines (DeGregorio et al. 2014).

Habitat fragmentation describes reduced habitat patch size, greater distance between patches, and increases in novel, often non-native, vegetation types (Andrén 1994). Edges are the transition zones between vegetation types and increase with habitat fragmentation (Murcia 1995). Research has demonstrated that changes in ecological conditions near edges can directly affect birds (Murcia 1995, Bayne and Dale 2011). For example, natural vegetation removal, habitat fragmentation, and anthropogenic edge can depress nest survival by increasing exposure to nest predators (Winter et al. 2000, Vander Haegen 2007, Hethcoat and Chalfoun 2015*b*).

Infrastructure features can negatively influence nest survival by giving nest predators a competitive advantage (DeGregorio et al. 2014, Howe et al. 2014, Bernath-Plaisted and Koper 2016). For instance, infrastructure (e.g., oil and gas structures and power lines) that can increase the abundance of perching predators and mid-sized mammalian predators (Liebezeit et al. 2009, DeGregorio et al. 2014, Howe et al. 2014). DeGregorio et al. (2014) found that indigo bunting (*Passerina cyanea*) nest survival was strongly and negatively influenced by distance to power lines. They also found that two primary nest predator species (American crows [*Corvus brachyrhynchos*] and brown-headed cowbirds [*Molothrus ater*]) used power lines as perching structures and frequently preyed on songbird nests near the power lines.

Research has demonstrated the importance of considering multiple spatial scales when evaluating population fitness rates; habitat fragmentation may affect fitness rates through different mechanism at different spatial scales (Robinson et al. 1995, Chalfoun et al. 2002, Stephens et al. 2004, Llyod et al. 2005). At landscape scales, nest predation of forest-nesting songbirds increases as the forests become more fragmented (Robinson et al. 1995). At a local scale, Bernath-Plaisted and Koper (2016) found that grassland-nesting vesper sparrows had lower nest success when nest sites were within 1 km of oil and gas infrastructure and nest success rates continued to decrease as the proximity to infrastructure decreased.

Development of oil and gas reserves requires the clearing of vegetation for well pads and supporting infrastructure including access roads, facilities, and pipelines (sensu Walker et al. 2020). Oil and gas development is often considered a temporary disturbance because of the finite capacity of oil and gas production within areas and the mandated post-development reclamation that is generally required under conditions of approval by state and federal agencies (Andersen et al. 2009, Clement et al. 2014).

Reclamation generally refers to the rebuilding of soil profiles to reestablish plant communities (Pyke et al. 2015). Reclamation of oil and gas disturbances is associated with specific regulations which involve the removal of infrastructure, recontouring (reshaping the disturbed area to the original contour of the surrounding landform), preparation of topsoil surface and broadcasting of authorized native seed mixes over the reclaimed areas (U.S. Bureau of Land Management 2003, Rottler et al. 2018).

Post-development reclamation is increasingly emphasized as a means of mitigating declines of sagebrush associated species of conservation concern (U.S. Fish and Wildlife Service 2013, Clement et al. 2014). Reclamation is assumed to provide some immediate benefits to negatively impacted wildlife by removing potential population stressors, such as industrial noise, and above ground infrastructure. Much research has focused on the recovery of soil and vegetation following reclamation of disturbances in the sagebrush ecosystem (Avirmed et al. 2015, Davies et al. 2013, Gasch et al. 2016, Rottler et al. 2018). Yet, little research has looked at the response of sagebrush associated wildlife to reclamation following oil and gas disturbance (Barlow et al. 2020). To our knowledge no research has tested the effectiveness of reclamation as a mitigation measure. The recovery of plant communities in sagebrush ecosystems is particularly challenging because succession proceeds slowly in these arid habitats (Baker 2011, Rottler et al. 2018). Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), the dominant sagebrush species in our study area, can take more than 80 years to return to pre-disturbance size and structure (Baker 2011, Gasch et al. 2016, Avirmed et al. 2015, Rottler et al. 2018). Consequently, the legacy of oil and gas disturbance in sagebrush stands and the associated habitat fragmentation (contiguous areas of sagebrush broken into smaller, distinct and separate sagebrush patches) will also persist for decades after post-development reclamation takes place.

Brewer's sparrows are a short-lived sagebrush-obligate (i.e., dependent on sagebrush during critical life stages) songbird species that, under the right conditions, will attempt two and sometimes three nests per season (double and triple brood; Baker et al. 1976, Ehrlich et al. 1988, Rotenberry et al. 1999, Rowland et al. 2006). The sagebrush dependence during breeding and high potential reproductive output of the Brewer's sparrow makes them an ideal indicator species to assess the potential mitigating effects of reclamation on bird populations breeding in sagebrush habitat (Niemi and McDonald 2004).

In this study, we assess early-stage reclamation in sagebrush landscapes approximately 5 years after oil and gas infrastructure was removed. Reclamation areas in our study were revegetated with reclamation seed mixes but did not contain the sagebrush overstory component. Consequently, the vegetation structural characteristics of reclaimed areas in our study were similar to active oil and gas disturbances in that they both no longer contained the sagebrush overstory component. The primary difference between reclaimed areas and active disturbances was that reclamation no longer had the infrastructure features and, instead of graveled roads or hard surface well pads, had seeded grass and forb ground cover.

Therefore, comparing active oil and gas and reclamation soon after it took place provided a unique opportunity to better understand the mechanisms that affect songbird nest survival in oil and gas development areas. If, for example, infrastructure features or industrial noise are the primary drivers of increased nest predation in active oil and gas areas, we would expect nest survival rates to respond quickly and positively to reclamation. Conversely, if the primary causes of increased nest predation were driven more by increased edge and fragmentation, we would expect that oil and gas reclamation would not immediately benefit nest survival because of the legacy of the disturbance due to the slow reestablishment of the sagebrush overstory component.

We designed this study to address this question: how effective early-stage reclamation is at removing or minimize reproductive stressors (e.g., increased nest predation) that act on sagebrush breeding songbirds during oil and gas development and production? We explored this question across multiple spatial scales from landscape to microhabitat. We used nest survival of the Brewer's sparrow as an indicator of potential reproductive responses of sagebrush nesting birds to oil and gas reclamation treatments. At the landscape scale, we hypothesized that nest survival rates would be the highest within undisturbed (i.e., control) sites and the lowest within our active oil and gas sites. Because of the legacy of fragmentation and edge that remained in the reclamation areas, we expected that nest survival would also be lower in reclamation sites compared to undisturbed sites.

At local scales, we hypothesized that nests exposed to greater amounts of oil and gas disturbance and those in closer proximity to oil and gas infrastructure would have the lowest nest survival rates when compared to nests farther from the disturbance footprint. Furthermore, in the reclamation areas, we hypothesized that edge and fragmentation factors may continue to act to reduce nest survival of nests located in closer proximity to reclaimed areas. At the microhabitat scale, we hypothesized that sagebrush structure and cover immediately surrounding a nest would be predictive of nest survival and nests surrounded by less sagebrush cover, such as those immediately adjacent to reclamation or active edge, would have lower nest survival. Addressing these hypotheses will help us better understand the mechanisms that act to depress songbird nest survival in oil and gas development fields.

4.3 Methods

4.3.1 Study area

Our study area was located in sagebrush-steppe habitat in northeastern Wyoming, USA, within the Powder River Basin (PRB) region (44.2603ºN, -106.3095Wº; Figure 4.1). Dominant shrubs included big sagebrush, black greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* and *Ericameria* spp.). Common grasses included native species such as blue grama (*Bouteloua gracilis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and invasive species such as Japanese brome (*Bromus japonicas*) and cheatgrass (*B. tectorum*). In addition to the Brewer's sparrow, other bird species we documented nesting in sagebrush stands in our study area included: Brewer's blackbird (*Euphagus cyanocephalus*), greater sage-grouse (*Centrocercus urophasianus*), lark bunting, lark sparrow (*Chondestes grammacus*), loggerhead shrike (*Lanius ludovicianus*), mourning dove (*Zenaida macroura*), sage thrasher, spotted towhee (*Pipilo maculatus*), vesper sparrow and western meadowlark (*Sturnella neglecta*). Land use in the region was mainly oil and gas production and cattle ranching. Elevation ranged between 1268 m – 1442 m. Detailed descriptions of the region are available in previous publications that focused on the greater sage-grouse (e.g., Doherty et al. 2010, Fedy et al. 2015).

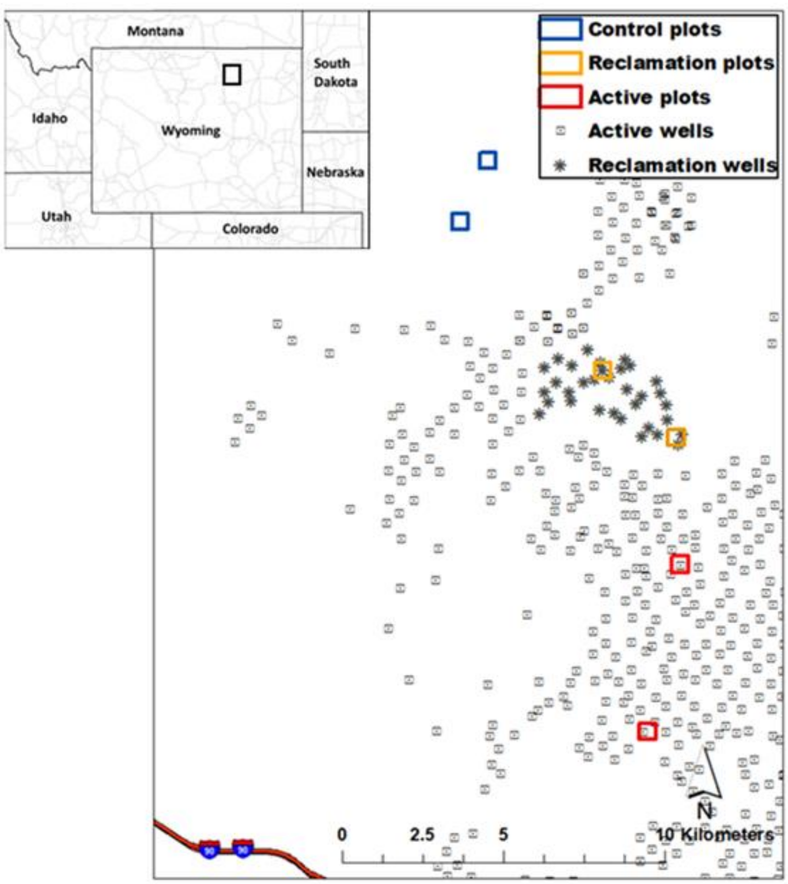


Figure 4.1: Map of study area and nest-searching plots for Brewer's sparrow in northeastern Wyoming, USA, 2016-2018.

4.3.2 Songbird indicator species

Brewer's sparrows begin arriving on their breeding grounds in late-April and depart by October (Walker 2004, Harrison and Green 2010). Brewer's sparrows defend territories and maintain spacing between nests (Rotenberry et al. 1999). In some areas, Brewer's sparrows have been shown to cluster their nesting territories in loose aggregations (Rotenberry et al. 1999, Harrison and Green 2010). Brewer's sparrows are thought to be monogamous (Hansley and Beauvais 2004). Males establish breeding territories and pairs are formed when the females arrive a few weeks later (Walker 2004, Harrison and Green 2010). The size of Brewer's sparrows breeding territories vary between regions, sites and years (Rotenberry et al. 1999). Reported territory sizes range between 0.25 - 2.0 hectares (Rotenberry et al. 1999, Walker 2004, Hansley and Beauvais 2004, Harrison et al. 2009). Brewer's sparrows build a small open-cup nest (~8cm diameter) with 3 to 6 eggs per clutch and will, generally, initiate two or three nests per season (Ehrlich et al. 1988, Rotenberry et al. 1999, Mahony et al. 2001). However, following nest failures, Brewer's sparrows have been observed nesting more than three times per season (Chalfoun and Martin 2007). Egg-laying to fledging takes about 20-22 days (Rotenberry et al. 1999, Hansley and Beauvais 2004).

4.3.3 Nest monitoring

We searched for Brewer's sparrow nests in six 500 x 500 m (0.25 km^2) plots distributed across the study area from 2016-2018 (Figure 4.1). Nest searching took place between early May and mid-July each season. We used auditory and visual clues to locate nests and recorded the location of all active nests. Most nests were found during egg laying and incubation periods. We monitored nests every second day and increased monitoring to every day as fledging approached (Martin and Geupel 1993). We used nestling morphology to determine hatching date (Martin and Geupel 1993, Jongsomjit et al. 2007) and nest age, if we found the nest during the nestling period (Nur et al. 2004, Jongsomjit et al. 2007). Nests were considered depredated if eggs or young chicks were absent from the nest or if there were other signs of predation such as damaged nest, fledgling remains or egg fragments. If a nest was close to the estimated fledging date and we did not identify any sign of fledging (e.g., feces, fledglings in area) we considered the nest depredated (Martin and Geupel 1993). Successful nests produced at least one Brewer's sparrow fledgling. If we believed a nest had fledged, we verified fledging by locating fledglings, observing adults carrying food or by listening for adult and fledgling communication calls close to the nest.

We calculated the nest initiation date (i.e., date the first egg was laid) on the basis of date of discovery of the nest and estimated age of the nest at discovery (Shaffer 2004). When the exact fate date (success or failed nest) was not known we assigned the nest fate date as the midpoint between the last monitoring intervals (Nur et al. 2004). Hatched nests, nests that survived the entire period, and nests with unknown fates, were right-censored (Hosmer and Lemeshow 2008). The exposure period (t) for our nest survival analysis was t = 22 days (egg laying = 3 days, incubation = 10 days, nestling stage = 9 days; Petersen et al. 1986, Rotenberry et al. 1999).

4.3.4 Treatment and control plots

Nest plots were selected across a gradient of energy development that included three categories: 1) reclaimed oil and gas, 2) active oil and gas, and 3) non-developed habitat. We refer to the active oil and gas and the reclaimed oil and gas as "treatments" and the non-developed habitat as the "control". Our study area contained coal-bed natural gas (CBNG) wells that were developed at 3.1 well pads per km^2 (80-acre spacing; Kirol et al. 2015*b*). On average, CBNG well pads required the clearing of 0.5 ha of natural vegetation. Two nest searching plots were positioned in each treatment and control area. All nest plots were in sited in areas dominated by sagebrush landcover and were separated by >2 km to ensure independence (Figure 4.1).

4.3.4.1 Reclamation and active disturbances

Active disturbances are surfaces that have been stripped of natural vegetation and are associated with producing CBNG wells (i.e., active wells), graveled access roads and other supporting infrastructure (Figure 4.2). We refer to previously active disturbances (e.g., wells and access roads) that have been reclaimed as reclamation or reclamation surfaces (Figure 4.2). Reclamation surfaces have undergone reclamation that included the removal of all infrastructure, stripping and re-spreading topsoil, and re-contouring well pads, access roads and other infrastructure disturbances (U.S. Bureau of Land Management 2003). Once these reclamation surfaces were prepared, seeding was completed with a no-till drill (U.S. Bureau of Land Management 2003). The reclamation site in our study contained 30 CBNG wells that were plugged and reclaimed in 2013 (Figures A1 and A2). The area influenced directly by reclamation of these 30 CBNG wells was ~8.6 km^2.

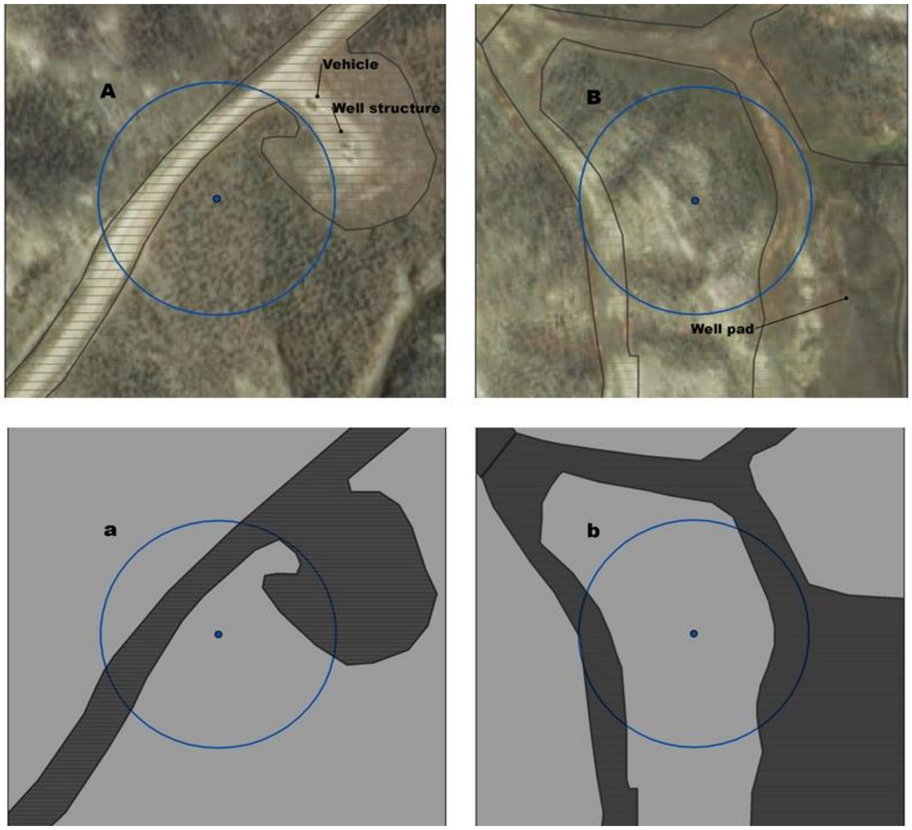


Figure 4.2: The physical footprint of disturbance quantified using heads-up digitizing and converted to a 1-m raster for analysis. Selected Brewer's sparrow nests (blue dots) and 50m radius scale (blue circles), northeastern Wyoming, USA. Panel A shows the area digitized as active disturbance and panel B shows area digitized as reclamation with imagery in the background. The disturbance polygons encompassed all of the area disturbed (e.g., sagebrush removed) for the well pads and access roads (panels a, b). Some of the disturbed habitat around active development (A) had filled in with grass and forb cover. The reclaimed surface was dominated by grass and forb cover and did not contain sagebrush (B). Nests were exposed to 25% active disturbance (panels A, a) and 23% reclamation (Panels B, b) within 50m.

4.3.5 Nest plot selection

We selected control, active and reclamation nest plots that contained similar vegetation types, such as being dominated by sagebrush landcover, to minimize influences of natural variation (e.g., elevation, topography and vegetation community) and maximize the isolation of the treatment effects of interest (i.e., active oil and gas and reclaimed oil and gas disturbances). Because the reclamation site was the most spatially limited treatment, we first selected plots within this treatment and used the habitat characteristics of the reclamation treatment plots to guide the selection of the active treatment and control plots. Using geographic information systems (GIS), we first selected reclamation plots based on four primary criteria: 1) sagebrush was the dominant landcover, 2) contained at least one reclaimed CBNG well, 3) ≥600m from an active natural gas wells, ≥300 m from gravel access roads and overhead power lines, and 4) located predominantly on public land (Wyoming State or BLM). These influence distances for wells, roads and power lines were informed by previous research on the response of songbirds to development (Ingelfinger and Anderson 2004, Bayne and Dale 2011, Yoo 2014, Thompson et al. 2015).

We then used spatial layers representing elevation, and vegetation cover in GIS to match active and control treatment plots to the range of vegetation and topographic characteristics of the reclamation plots. Based on the values derived from the reclamation plots, the active treatment and control plots we selected had average sagebrush cover of 10-14%, terrain roughness values between 50-550, and an average elevation between 1,200-1,400 m. Additionally, the active treatment plots contained ≥1 well(s) to provide a direct comparison to the reclamation plots that contained ≥1 well(s) that had been reclaimed. This GIS assessment provided a candidate set of control and active plots that were randomly numbered. We then sequentially went through these plots and selected the first plots that we confirmed met all of these criteria and that were accessible for field work. Sagebrush spatial layers for site selection were processed from Wyoming sagebrush products (Homer et al. 2012). Roughness values were based upon a terrain roughness index (Evans et al. 2014), derived from a Digital Elevation Map (DEM). Average elevations within plots were also calculated from a DEM (Evans et al. 2014). All plots were separated from each other by >1 km.

4.3.6 Microhabitat covariates

In most bird species, nest predation is the foremost cause of nest failure; consequently, birds select habitats to hinder detection by potential predators (Ricklefs 1969, Martin 1993). Microhabitat characteristics can influence nest survival of sagebrush associated birds (Coates and Delehanty 2010, Ruehmann et al. 2011). We measured and compiled a suite of biologically-relevant microhabitat covariates at nest locations (Table 4.1). At microhabitat scales, research has demonstrated that vegetation components contributing to greater vertical and horizontal nest concealment of ground and shrub-nesting birds often has a positive relationship with nest survival in real and experimental nests (Martin 1998, Harrison and Green 2010, Latif et al. 2012, Maresh Nelson et al. 2018). Covariates directly related to nest concealment assessed in our nest survival models included: total visual obstruction (VisualObst), nest shrub vigor (Vigor), grass height (GrassHeight), percent sagebrush cover (PercARTRL), sagebrush plant density (DenseARTRL), average sagebrush height (HeightMean) and variability in sagebrush height (HeightSD). Greater proportions of bare ground (BareSoil) surrounding a nest site can influence nest survival in passerines in both positive and negative directions (Martin 1998). Latif et al. (2012) found that experimental yellow warbler (*Dendroica petechia*) nests that were higher above the ground (e.g., positioned higher in the shrub or in a taller nest shrub) experienced higher avian predation rates. Covariates related to nest height assessed in our nest survival analysis were nest shrub height (ShrubHeight) and height from ground to the nest (NestHeight). Greater grass and forb cover can be positively associated with the abundance of deer mice (*Peromyscus maniculatus*), which are known to depredate Brewer's sparrow nests (Hanser et al. 2011, Heathcoat and Chalfoun 2015*a*, Sanders and Chalfoun 2018). Additionally, the establishment of nonnative grasses can alter Brewer's sparrow nest predation risk. Ruehmann et al. (2011) found that Brewer's sparrow nesting in areas with an understory dominated by smooth broom (*B. inermis*), an exotic grass, had higher nest survival than those nesting in areas with a native understory. They propose that this nonnative grass may have provided greater nest concealment (Ruehmann et al. 2011). In our nest survival models, we assessed a native grass cover covariate (Grass) and a nonnative grass cover covariate (InvasiveGrass) as well as a forb cover covariate (Forbs).

Table 4.1: Covariates assessed in Brewer's sparrow nest survival models representing multiple scales from the individual nest shrub to a 100m radius around a nest, Wyoming, USA.

Covariate	Scale	Description
Microhabitat		
ShrubHeight	Nest shrub	Height of shrub, excluding inflorescences (cm)
NestHeight	Nest shrub	Height to the bottom of nest cup from ground (cm)
Vigor	Nest shrub	% of alive foliage (nearest 10%)
Grass	5m radius	% grass cover, excluding invasive grass
InvasiveGrass	5m radius	% invasive grass cover (*Bromus tectorum* and *B. japonicas*)
Forbs	5m radius	% forb cover
BareSoil	5m radius	% bare ground cover
GrassHeight	5m radius	Average grass droop height (cm), excluding invasive grass
VisualObst	5m radius	Visual obstruction (horizontal cover; dm)
PercARTRL	5m radius	% live big sagebrush (*Artemisia tridentata*) canopy cover
DenseARTRL	5m radius	Average live big sagebrush density (plants/m^2)
HeightMean	5m radius	Average big sagebrush height (cm)
HeightSD	5m radius	Variability (standard deviation [SD]) in sagebrush height
Spatial		
NDVI	30, 50, 100 (m) radii	Mean NDVI (Normalized Difference Vegetation Index) value per scale (30-m resolution; Robinson et al. 2017)
ForbGrs	30, 50, 100 (m) radii	Mean forb and grass understory cover per scale (30-m resolution; Jones et al. 2018)
BigSage	30, 50, 100 (m) radii	% big sagebrush cover per scale (30-m resolution; Xian et al. 2015)
SageHgt	30, 50, 100 (m) radii	Average big sagebrush height per scale (30-m resolution; Xian et al. 2015)
SDSageHgt	30, 50, 100 (m) radii	Variability (SD) in sagebrush height per scale (30-m resolution; Xian et al. 2015)
Anthropogenic		
ActiveDist	30, 50, 100 (m) radii	% active disturbance footprint per scale (1-m resolution)
RDist	30, 50, 100 (m) radii	% reclamation footprint per scale (1-m resolution)
PwrLine	30, 50, 100 (m) radii	Distance to nearest overhead power line as a decay per scale

Temporal		
Year	NA	Study year
JulianDay	NA	Julian date of start of nest incubation

4.3.7 Microhabitat sampling

We sampled microhabitat characteristics of the nest shrub and the immediate area surrounding the nest shrub (i.e., nest patch). The nest shrub formed the center of two perpendicular 10m transects. We measured vegetation characteristics such as shrub canopy cover, shrub density, shrub heights, ground vegetation cover and visual obstruction. Barlow et al. (2019) provides a detailed description of our microhabitat sampling methods (Table 4.1). To minimize detrimental effects on nest initiation and egg and chick survival, we sampled Brewer's sparrow nest sites after the Brewer's sparrow nesting season concluded each year.

4.3.8 Spatial covariates

In addition to our microhabitat data collected in the field, we also quantified habitat structure by summarizing GIS data across three larger spatial scales because songbird nest survival can be influenced at multiple spatial scales (Stephens et al. 2004). The spatial scales we assessed were informed by previous research on Brewer sparrows (Rotenberry et al. 1999, Carlisle et al. 2018*a*). The radii of these three scales were 30m, 50m and 100m. Within these scales we used zonal statistics to calculate vegetation covariates including mean Normalized Difference Vegetation Index (NDVI), mean forb and grass understory cover, percent big sagebrush canopy cover, average sagebrush height (cm) and the standard deviation of sagebrush height (Table 4.1; Xian et al. 2015, Robinson et al. 2017, Jones et al. 2018, Yang et al. 2018). NDVI is as a measure of primary productivity (Robinson et al. 2017). The standard deviation in sagebrush height represented sagebrush height variability. Higher standard deviation values were associated with greater horizontal heterogeneity and lower values with lower horizontal heterogeneity in sagebrush plants (sensu Williams et al. 2011).

In addition to grass and forb cover, NDVI has been shown to be predictive of deer mice abundance (Hanser et al. 2011). Greater deer mice abundance negatively affects Brewer' sparrow nest survival (Heathcoat and Chalfoun 2015*a*, Sanders and Chalfoun 2018). We used dynamic 30-m resolution NDVI products generated every 16 days (Robinson et al. 2017) to calculate Mean NDVI layers. We obtained four NDVI composites from approximately May 9th to June 26th to overlap the Brewer's sparrow nesting period each year (2016 – 2018). We then averaged these four composites to generate NDVI values to match with those year's nests. We used available 30-m resolution annual forb and grass and perennial forb and grass percent cover layers for each year of the study (Jones et al. 2018). We summed the annual and perennial forb and grass layers to generate a forb and grass percent cover value per scale (Table 4.1). We used 2016 shrubland layers (30-m resolution) available through the U.S. National Land Cover Database (NLCD) to calculate vegetation concealment covariates including percent big sagebrush canopy cover, average sagebrush height (cm) and the standard deviation of sagebrush height per scale (Xian et al. 2015, Yang et al. 2018).

Predation is the most important process affecting nest survival of songbirds and anthropogenic modifications of nesting habitat can increase nest predation risk (Vander Hagen 2007, Heathcoat and Chalfoun 2015*a*, Bernath-Plaisted and Koper 2016). We quantified disturbances at each scale that were associated with active oil and gas (e.g., wells) or reclamation (e.g., reclaimed roads) surfaces. We used National Agriculture Imagery Program (NAIP) imagery to heads-up digitize the physical footprint of disturbance at a 1:1000 screen resolution and converted these disturbance polygons to a 1-m resolution raster layer (http://datagateway.nrcs.usda.gov). We quantified active disturbance and reclamation as the percent area per scale (Figure 4.2). All GIS data was processed using ArcGIS Desktop 10.7 (http://www.esri.com) and QGIS 3.10 (qgis.osgeo.org).

Overhead power lines are a type of supporting infrastructure that is generally not associated with a physical footprint or removal of habitat. In oil and gas development areas, including our study area, power lines often span undisturbed sagebrush habitat with minimal surface disturbance (i.e., a power pole approximately every 100m). Proximity to power lines can negatively influence songbird nest survival because some avian nest predators use power lines and poles as perching structures (DeGregorio et al. 2014). We quantified distance from nests to power line using exponential distance decay functions to account for decreasing magnitude of influence with an increasing distance from the power line on nest survival (Fedy and Martin 2011). Decay values were calculated using the form $e^{(-d/\alpha)}$ where d was the distance in meters (from nest to power line) and α was set to correspond to each radii – 30m, 50m and 100m (Table 4.1; Kirol et al. 2015*b*).

4.3.9 Modeling approach

To assess relationships between covariates and Brewer's sparrow nest survival we used a mixed-effects Cox proportional hazards model (function: *coxme*) in R (R version 3.6.0; Therneau 2020). We modeled environmental covariates that potentially influenced Brewer's sparrow nest survival from four categories that included temporal, microhabitat, spatial and anthropogenic disturbance. Temporal covariates included year and Julian date. We modeled year to account for potential variability in nest survival between years and Julian date because nest survival may be related to when the nest was initiated (Dinsmore et al. 2002). We selected models in three steps using sample-size-adjusted Akaike's Information Criteria (AIC_c), to compare and rank models within each step (Burnham and Anderson 2002) as described below. We standardized all covariates prior to modeling. We considered both linear and quadratic terms for the physical footprint of disturbance covariates because avian fitness metrics can have nonlinear relationships with exposure to increasing amounts of surface disturbance (Kirol et al. 2015*a*). We tested for potential correlation between covariates using Pearson's correlation matrix, we did not include any two co-varying variables ($|r| \geq 0.6$) in any model. When covariates were correlated, we selected the covariate with the lowest AIC_c in a single covariate model comparison. The single covariate model also contained the random effects plot and treatment described below. At each stage, the best-fit AIC_c model, that only contained informative parameters (Arnold 2010), was brought forward to the next model selection step. We disregarded models differing from the best-fit model by one parameter and within 2 ΔAIC_c if the slope coefficient was uninformative with 85% confidence limits overlapping zero (Burnham and Anderson 2002, Arnold 2010).

To account for the spatial clustering of our nest data and allow us to share information across the sample of nests (Bolker et al. 2009, Kéry and Royle. 2016), our first step involved developing a model with plot identification and treatment type as categorical covariates (Figure 4.1). Plot was included as a random effect within treatment (nested structure) because our data were obtained from different nest plots ($n = 6$) within treatment areas ($n = 3$). This random-effect model structure was included in all subsequent modeling steps. For spatial covariates measured at multiple spatial scales, we first optimized the scale by comparing single covariate models, in combination with our random effects, and brought forward the covariate scale with the lowest AIC_c to the next modeling step.

In the second modeling step, we modeled the temporal covariates Julian date and year with our random effects to determine if these covariates improved model fit (Table 4.1). This model moved forward to the third modeling step, in which we considered microhabitat and spatial covariates. The best-fit model from this step, with the lowest AIC_c and only containing informative parameters, formed our base-model (Webb et al. 2012, Kirol et al. 2015*b*). The purpose of the base-model was to account for environmental variation in Brewer's sparrow nest survival (i.e., as statistical control covariates; Hosmer and Lemeshow 2008) to facilitate interpretation of the anthropogenic covariates.

In our final modeling step, we tested decay distance to power lines and different functional relationships (linear and quadratic) of our surface disturbance covariates, at each scale, with our base-model. We assessed support for decay distance to power lines and different functional forms (i.e., linear or quadratic) of the disturbance covariates based on AIC_c and the coverage of the 85% confidence intervals. If an anthropogenic covariate was influencing Brewer's sparrow nest survival, we expected the anthropogenic covariate would be informative, have 85% confidence interval coverage that did not overlap 0, when combined with the base-model (Arnold 2010, Bernath-Plaisted and Koper 2016).

We reported 85% confidence intervals for parameters to be consistent with the AIC_c model selection process (Arnold 2010). For interpretation of the effect of a unit change in individual covariates on Brewer's sparrow nest survival, we modeled the non-standardized form of the supported covariates. To ensure that the proportional hazards assumption was not violated, we plotted Schoenfeld residuals for our final model as well as each individual covariate in our final model (Hosmer and Lemeshow 2008). For the purpose of reporting nest survival estimates for each treatment type and year we modeled them as fixed effects in univariate models (function: *coxph*; Therneau 2019).

4.4 Results

Our survival analysis included 107 Brewer's sparrow nests monitored between 2016-2018 ($n = 31$ in 2016, $n = 41$ in 2017 and $n = 35$ in 2018). Nest predation was the cause of nest failure in all of the nests included in our analysis. We did not identify a single nest that was located within the active disturbance or reclamation footprint. Model adjusted nest survival estimates for a 22 day Brewer's sparrow nest survival period for the entire sample were 54% (85% CI: 48–62%). Model adjusted Brewer's sparrow nest survival did not differ significantly ($P \geq 0.714$) between years (2016 = 56% [85% CI: 45–71%], 2017 = 53% [85% CI: 43–65%], 2018 = 54% [85% CI: 44–67%]) or differ significantly ($P \geq 0.257$) between active treatment (61% [85% CI: 51–72%]), reclamation treatment (51% [85% CI: 41–63%]) and control (47% [85% CI: 34–65%]).

4.4.1 Base model

Our best-fit model that formed our base-model contained temporal, microhabitat and spatial covariates: JulianDay, NestHeight (nest shrub), DenseARTRL (5m radius), and BigSage (100m radius). The predictive microhabitat covariates were live big sagebrush plant density (DenseARTRL; plants/m^2) and the height from the ground to the bottom of the nest cup (NestHeight). BigSage represents the percent of big sagebrush cover surrounding a nest. JulianDay, DenseARTRL, NestHeight and BigSage had 85% CIs that slightly overlapped 0 when combined with the other covariates in the best-fit model. We decided to retain these because they were present in the majority of the 2 ΔAIC_c model set and did not have overlapping 85% CIs unless all 4 of these covariates were in the same model (Table 4.2). BigSage and DenseARTRL were both positively associated with Brewer's sparrow nest survival. Our base-model predicts that as the amount of big sagebrush cover within 100 m of a nest and as the density of live big sagebrush shrubs within 5m of a nest increase the likelihood of that nest surviving also increases. Julian date (JulianDay) suggests that nests initiated later in the season are at greater risk of failure. Nest height suggests that nests built higher in the nest shrub experience higher risk than those built lower in the nest shrub (Table 4.2). When compared to the null model, the base-model (i.e., covariate adjusted model) explained much of the variability in nest survival between the active treatment (59% [85% CI: 49–71%]) and reclamation treatment (56% [85% CI: 46–69%]), but little variability between the two treatments and control (45% [85% CI: 32–64%]).

Table 4.2: Final Cox proportional hazard model describing relationships between temporal, microhabitat, spatial and anthropogenic covariates and Brewer's sparrow nest survival. The base-model accounted for environmental variation in Brewer's sparrow nest survival to allow for interpretation of the influence of anthropogenic disturbance covariates on Brewer's sparrow nest survival, Wyoming, USA.

			Risk ratio 85% CI	
Covariate (scale)	Coefficient	Risk ratio	Lower	Upper
Base-model with plot nested in treatment as a random effect				
JulianDay	0.224	1.251	1.015	1.543
NestHeight (nest shrub)	0.170	1.185	0.972	1.445
DenseARTRL (5m radius)	-0.248	0.781	0.626	0.973
BigSage (100m radius)	-0.156	0.856	0.673	1.088
Base-model + % active disturbance				
ActiveDist +	-0.523	0.592	0.346	1.013
ActiveDist^2 (50m radius)	0.642	1.901	1.127	3.210

4.4.2 Anthropogenic covariates

When combined with our base-model, decay distance to power lines (PwrLine) was not supported as having a relationship with nest survival at any of the scales assessed. We did not find support for a linear relationship between the amount of active disturbance (ActiveDist) and nest survival at any scale. At the 50m scale, the quadratic form of active disturbance (ActiveDist + ActiveDist^2) had the most support as having a relationship to Brewer's sparrow nest survival (Figure 4.3 and Table 4.2). The 85% CIs of the squared term did not overlap 0. But the linear term had 85% CIs that slightly overlapped 0 (Table 4.2). The quadratic form suggests that exposure of Brewer's sparrow nests to active disturbance within 50m initially did not influence nest risk until disturbance reached ~15%. Nest survival risk increased steeply when disturbance reached ~30% (Figure 4.3). At the 50m scale, 20% of our nest sample in the active treatment were exposed to ≥15% disturbance. The low sample size at the high end of the distribution (≥15%) increased uncertainty as demonstrated by the widening CIs (Figure 4.3). Our nest survival model predicted that the probability of a nest being successful is approximately 16% higher for nests not exposed to active disturbance compared to nests exposed to 30% active disturbance within 50m.

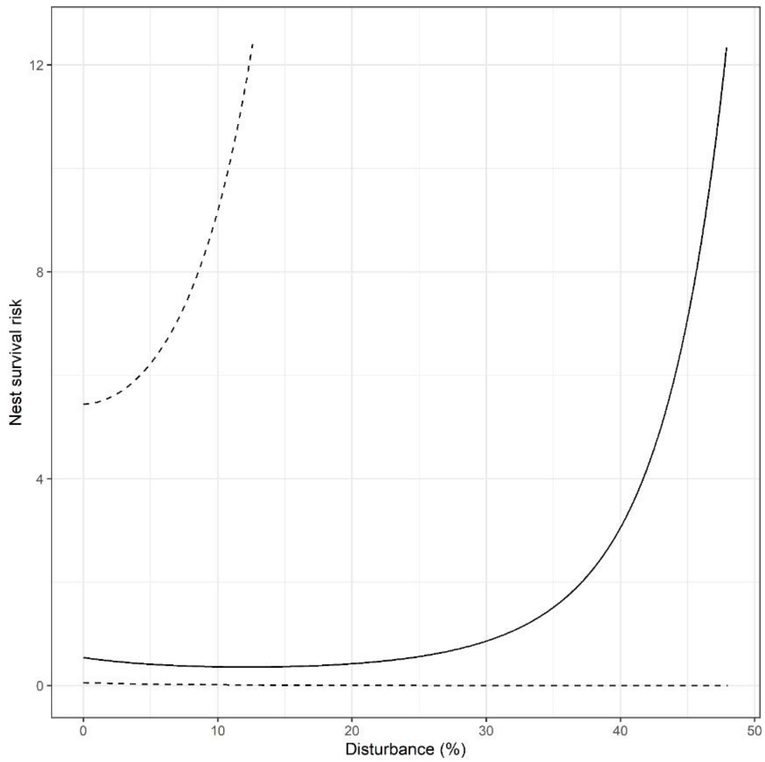


Figure 4.3: Brewer's sparrow nest survival risk and the percent active disturbance exposure at a 50m radius scale, northeastern Wyoming, USA. Dashed lines represent 85% confidence intervals.

Sixty-six percent of the active treatment nests were exposed to 0% disturbance at the 30m scale. At the 50m and 100m scales, 48% and 25% of the nests were exposed to 0% disturbance. The mean distance (± SE) from nests to the nearest active disturbance was 62.87 ± 7.12 m (range = 3.16–181.73 m). Across the two active nest-searching plots an average of 7.59 ± 0.80% (range = 6.79–8.40%) of the plot contained active disturbance. This amount of disturbance introduced an average of 2.38± 0.34 km (range = 2.04–2.72 km) of edge.

We did not find support for a linear or quadratic relationship between reclamation (ReclDist) and nest survival at the 50m scale or the other scales (30m and 100m radii) assessed. Exposure to reclamation is similar to that of active disturbance with 17% of the sample of nests in the reclamation treatment being exposed to ≥15% disturbance. To further examine potential differences in Brewer's sparrow nest survival when exposed to reclamation instead of active disturbance, we modeled the quadratic term at the same scale (50m radius) as the supported active disturbance relationship and found that in addition to the lack of statistical support the coefficient slope is relatively flat (Figure 4.4).

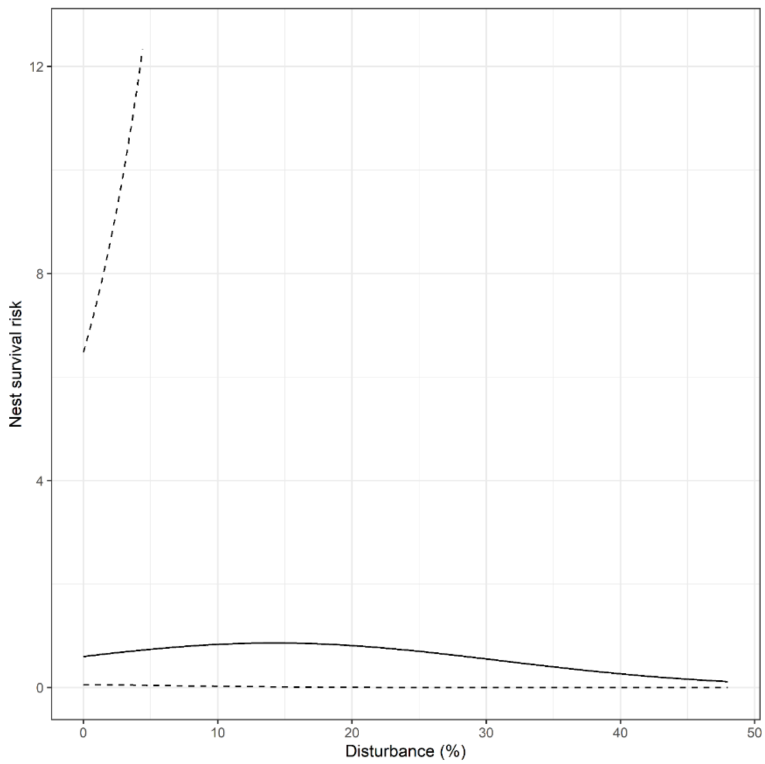


Figure 4.4: Brewer's sparrow nest survival risk and the percent reclamation exposure at a 50m radius scale, northeastern Wyoming, USA. Dashed lines represent 85% confidence intervals.

Of the reclamation treatment nests, 78% were exposed to 0% disturbance at the 30m scale, 46% were exposed to 0% disturbance at the 50m scale and 23% were exposed to 0% disturbance at the 100m scale. The mean distance from nests to the nearest reclamation surface was nearly equivalent to the active treatment nests (61.41 ± 6.47 m [range = 3.00–161.28 m]). Across the two reclamation nest-searching plots an average of 9.47 ± 2.31% (range = 7.17–11.78%) of the plot contained reclamation. This amount of reclamation surface introduced an average of 2.26 ± 0.27 km (range = 1.98–2.53) of edge.

Our final model explaining Brewer's sparrow nest survival included multiple scales from the individual nest shrub to the amount of big sagebrush cover in a 3.14 hectare (100 m radius) area around a nest (Figure 4.5).

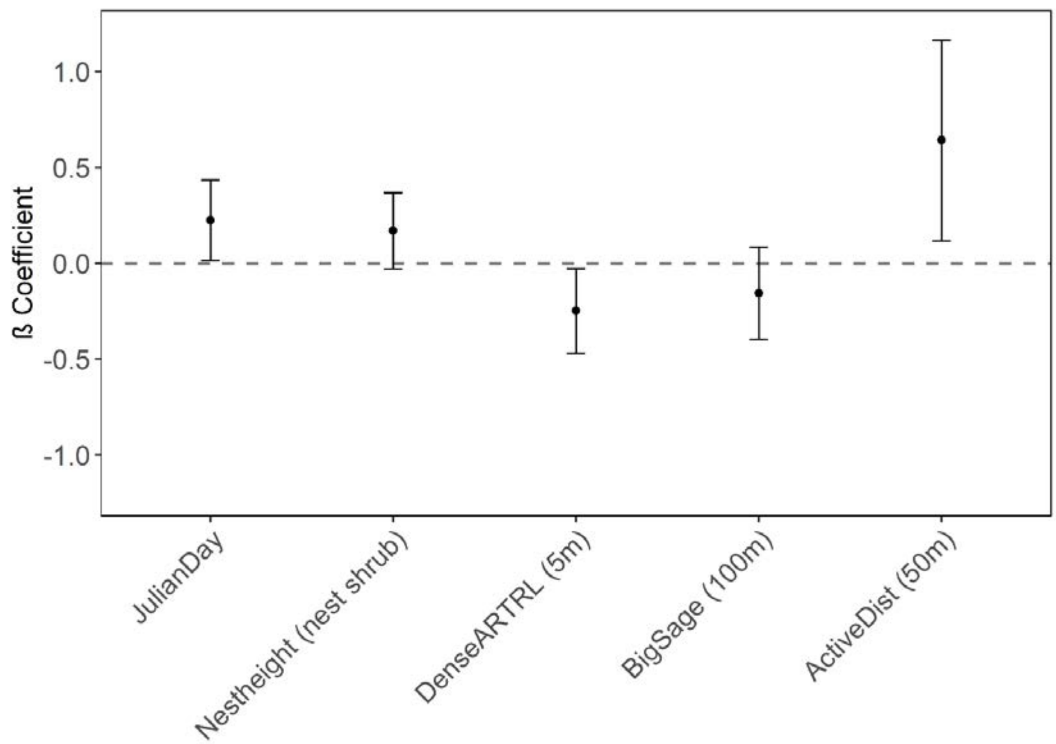


Figure 4.5: Standardized risk ratios and associated 85% confidence intervals for all covariates that were predictive of Brewer's sparrow nest survival in northeastern Wyoming, USA, 2016-2018. JulianDay is a temporal covariate, NestHeight and DenseARTRL (5m) are microhabitat covariates measured in the field, BigSage (100m) and ActiveDist (50m) are spatial covariates derived in Geographic Information Systems (GIS).

4.5 Discussion

Habitat quality is a function of an occupied habitat's conduciveness to survival and reproduction (Hall et al. 1997). Therefore, the effectiveness of reclamation as a mitigation measure should be gauged not only by occurrence of an animal in a reclaimed habitat but also by fitness outcomes. We found that survival of Brewer's sparrow nests was influenced by factors at multiple spatial scales. At a local scale, post-development reclamation reduced a reproductive stressor that was acting on Brewer's sparrow nesting in the active oil and gas development area. Covariates representing sagebrush density and canopy cover were positively related to Brewer's sparrow nest survival at more than one scale, emphasizing the reproductive benefits of unfragmented sagebrush stands to Brewer's sparrow populations.

Microhabitat choices, such as nest placement, are expected to be adaptive and; therefore, be positively correlated to fitness rates (Latif et al. 2012, Chalfoun and Schmidt 2012). We conducted a companion study concurrently at the same study site that examined nest-site selection in Brewer's sparrows (Barlow et al. 2019). This study found that Brewer's sparrow were selecting microhabitat characteristics such as greater visual obstruction surrounding the nest site and taller, more vigorous, sagebrush shrubs for nesting (i.e., greater live foliage and branching density; Barlow et al. 2019). Given the importance of these microhabitat features to the nest site selection process (Barlow et al. 2019), we included these variables in this assessment of the nest survival process. Nest survival was not correlated with the microhabitat characteristics that were supported in our nest-site selection analyses and only two microhabitat covariates were supported in our nest survival modeling, the density of live sagebrush surrounding the nest and the height of the nest bowl in the nest shrub. These findings suggest a potential mismatch between Brewer's sparrow nest-site selection preferences and nest survival outcomes (Latif et al. 2012, Chalfoun and Schmidt 2012). On possible explanation is the adaptive peak hypothesis that suggests nest-site selection may not be correlated with fitness because birds occupy nest sites that minimize predation risk (i.e., achieving an "adaptive peak"). Therefore, this hypothesis suggests that it may be difficult to detect relationships among microhabitat characteristics that should minimize predation (e.g., concealment) because the range of natural variation within which birds place their nests is constrained. However, there are multiple options that maximize reproductive fitness in birds and nest survival is just one of these fitness metrics (Chalfoun and Schmidt 2012). The availability of food resources for the high-quality offspring, that are more likely to survive to adulthood, could be driving microhabitat selection more than predation risk (e.g., microhabitat characteristic related to concealment), for example (Chalfoun and Schmidt 2012).

We found that the density of sagebrush shrubs surrounding a nest were positively correlated with nest survival. At a similar microhabitat scale, Chalfoun and Martin (2007), at an identical microhabitat scale, found that as the density of potential nest shrubs (sagebrush shrubs of similar height and crown width as shrubs used for nesting) increased the Brewer's sparrow nest predation risk decreased. Our results suggest that nests constructed higher in the nest shrub were at greater risk of predation. Brewer's sparrow nests higher in the nest shrub likely had less overhead concealment which may increase the likelihood of being discovered by avian predators. Unfortunately, few studies of shrub-nesting passerines have quantitatively assessed the impact of nest height on the probability of survival (but see Latif et al. 2012). Avian predators known to depredate Brewer's sparrow nests were present in our study area including blackbilled magpies (*Pica hudsonia*) and loggerhead shrikes (*Lanius ludovicianus*; Vander Haegen et al. 2002, Hethcoat and Chalfoun. 2015*b*, Barlow et al. 2020).

At a larger scale (100m radius), Brewer's sparrow nests were more successful in areas with higher mean sagebrush canopy cover which represented more contiguous sagebrush stands. Chalfoun and Martin (2007) found increased number of nesting attempts per Brewer's sparrow pair with increased shrub cover (primarily sagebrush shrubs) within approximately 300m of the nest. Nest survival of a larger, ground-nesting bird, the greater sage-grouse (*Centrocercus urophasianus*), also benefits from greater sagebrush cover surrounding nest sites. Sage-grouse nests in our study area were more likely to be successful if the surrounding habitat (~340m radius) had more sagebrush canopy cover (Kirol et al. 2015*b*). The reduced predation risk of Brewer's sparrow nests in areas with greater amounts of sagebrush highlights the importance of sagebrush reestablishment in reclamation areas. Yet, the long-term prospects of sagebrush recovery in disturbed habitats are uncertain. For instance, natural sagebrush reestablishment (i.e., without planting), on reclamation surfaces in our study area will likely take 80 to 125 years (Davies et al. 2013, Avirmed et al. 2015, Rottler et al. 2018). Thus, some level of impact of oil and gas development on Brewer's sparrow nest survival will also likely persist for a similar timeframe until the disturbance scars have filled in with sagebrush.

Predator-prey dynamics are complex and context-specific. The relationships among energy-related habitat modification and nest survival vary across ecosystems, infrastructure types, and development intensities (sensu Francis et al. 2009 and Bernath-Plaisted and Koper 2016). In sagebrush ecosystems, nest survival rates of ground- and shrub-nesting birds tend to be higher in undisturbed habitats when compared to habitats that have been modified by energy development activities (Heathcoat and Chalfoun 2015*a*, Kirol et al. 2015*b*). At the broadest spatial scale we assessed (i.e., nest-searching plots within different treatments), we found no evidence of differences in nest survival between nests that were within the energy development field, both active and reclaimed treatments, and those in our control. Further, we did not find a difference in nest survival between plots in the active and reclamation development areas. The oil and gas development in our study area was in the production phase and had been in place for approximately 8 years at the beginning of the study. The amount of human activity and vehicle traffic is at its peak when oil and gas fields are first being developed and subsides once the wells are drilled and the infrastructure is in place (Ingelfinger and Anderson 2004, Sawyer et al. 2009). In our study, active wells were generally monitored by vehicle every 1-2 days. Gilbert and Chalfoun (2011) did not observe a decline in Brewer's sparrow abundance in response to greater well densities. Similar to our active treatment, their study area experienced low traffic volumes of about 5 vehicles per day (Gilbert and Chalfoun 2011). Therefore, it is possible that the unexpected similarity across sites could have been influenced by reduced human activity associated with the active oil and gas sites in our study (Barlow et al. 2020).

At a more localized scale (50m radius), we detected a relationship between the amount of active disturbance and nest survival. The likelihood of a Brewer's sparrow nest being depredated increased when the physical footprint of active disturbance increased beyond a certain level (~15% active disturbance). Nest survival did not appear to be influenced by exposure to active disturbance below 15%; however, once active disturbance surpassed this level, nest predation risk began to increase and increased more dramatically when disturbance exceeded 30% of the surrounding habitat patch. This finding suggests there is a level of active disturbance beyond which nest predators are either more abundant or more efficient at discovering nests. Although at a much larger scale (1-km^2 area), nest predation risk in sagebrush breeding songbirds increases as the physical footprint of energy disturbance increases (Heathcoat and Chalfoun 2015*a*). Heathcoat and Chalfoun (2015*a*) demonstrated that with every percent (1 hectare) disturbance within a 1-km^2 area the probability of Brewer's sparrow nest survival decreased by 1.3% and the probability of Sage Thrasher nest survival decreased by 3.2%. Using video monitoring at nest sites and predator surveys, they attribute the elevated nest predation rates to an increased abundance and a different assemblage of nest predators associated with increasing energy disturbances (Heathcoat and Chalfoun 2015*b*).

The majority of Brewer's sparrows in the active treatment area (~80%) nested in sagebrush patches that were exposed to ≤15% disturbance and the average distance from active disturbance edge was 60m. Assuming an average Brewer's sparrow territory size of 0.25 hectares and assuming that nests were generally positioned more centrally within territories, rather than at the edge of the territories (Rotenberry et al. 1999, Harrison et al. 2009), 66% of the nests in the active treatment had no anthropogenic disturbance within their territories. That is, 66% of nests were farther than 30m from active edge. This nest distribution pattern suggests some avoidance of active disturbance by Brewer's sparrow when choosing nest sites. The pattern we observed of nest placement farther from active disturbance likely contributed to the lack of strong support for the relationship we detected between the amount of active disturbance and nest survival. This is reflected in the widening confidence intervals in Figure 4.3 as disturbance levels increase and the data becomes thinner (i.e., there fewer nests to inform the survival model at these higher active disturbance levels). Other species of shrub and grassland birds also avoid anthropogenic development features at scales similar to the territory size of each species (Bayne and Dale 2011, Ludlow et al. 2015, Thompson et al. 2015). Ludlow et al. (2015) found that Baird's sparrows (*Ammodramus bairdii*), a grassland specialist, selected nest sites at least 100m from well access roads which corresponds to their territory size. Therefore, most often Baird's sparrows were selecting nesting territories that did not overlap roads or road edges.

Birds will alter their nest site choices in response to predator pressure across scales (Peluc et al. 2008, Lima 2009). Recognition by Brewer's sparrows of increased risk of nesting in areas with higher levels of active disturbance may explain why the majority of nest sites in the active development area were in sagebrush patches that had less surrounding disturbance. Harrison and Green (2010) found that previous reproductive success was highly correlated with Brewer's sparrow territory choices. Seventy-one percent of returning Brewer's sparrows that had successful nests the previous year returned to the same territory while only 28% of birds that were unsuccessful the previous year returned to the same territory (Harrison and Green 2010).

The pattern of nest site placement relative to reclamation was very similar to the active treatment area. Nest sites in the reclamation treatment were primarily in less disturbed areas with only 17% of nests in sagebrush patches with higher levels of disturbance (15-45% disturbance) within 50m and 78% of nest territories (i.e., 0.25 hectares or 30m radius) did not contain any reclamation. The consistency in the nest distribution suggests that when choosing territories Brewer's sparrow are responding similarly to active disturbance and reclamation. No other research has examined sagebrush songbird responses to reclamation; however, Carlisle et al. (2018*a*) found that Brewer's sparrows nested approximately 35m from mowed sagebrush edges. The mowing treatments created edges and surfaces similar to our reclamation sites in that the majority of mature sagebrush in mowed areas was removed but grasses and forb ground cover remained (Carlisle et al. 2018*a*). Similar to our reclamation treatment, the mowing disturbance fragments sagebrush stands and increases edge but was not associated with devegetated surfaces, persistent human activity, and infrastructure as in our active oil and gas areas.

Despite the similarities in the spatial distribution of nests throughout both active and reclamation areas, our findings provide some evidence that nest predation risk differed. Nesting in sagebrush patches with >15% disturbance appeared to be maladaptive in active areas but inconsequential to nest survival in reclamation areas. That is, when we applied our active disturbance survival model to reclamation there was no relationship between Brewer's sparrow nest survival and the physical footprint of reclamation. This finding provides evidence that, at a local scale, removal of oil and gas infrastructure and the associated activity had a positive influence on Brewer's sparrow nest survival in the reclaimed treatment area. Similarly, Carlisle et al. (2018*a*) found that vicinity to a mowed treatment was not negatively correlated with Brewer's sparrow nest survival and nests closer to mowed edges actually had marginally higher survival rates.

Indicator species are used to "indicate" condition or a response to environmental stressors that may apply to other species with similar ecological requirements (Neimi and McDonald 2004). The relationships we detected between Brewer's sparrows nest survival and oil and gas development and reclamation, as well as sagebrush cover, are likely indicative of other songbird species breeding in these same sagebrush habitats. At the broader spatial scales, these species are exposed to similar environmental conditions and similar nest predation pressures as Brewer's sparrows (Vander Haegen et al. 2002, Heathcoat and Chalfoun 2015*b*). Other songbird nests that we recorded in our nest-searching plots included lark bunting (n = 17), lark sparrow (n = 22) and vesper sparrow (n = 12). These species all built open-cup nests on the ground under the shelter of sagebrush shrubs (Barlow et al. 2019, Fedy and Kirol *unpublished data*). In sagebrush habitats in Washington and Wyoming, lower nest survival in habitats fragmented by human activities was consistent across a suite of ground- and shrub-nesting songbirds (e.g., Brewer's sparrows, sagebrush sparrows [*Artemisiopiza nevadensis*], sage thrashers). The increased nest predation in these fragmented habitats was attributed to rodent nest predators achieving greater abundance in these areas (Vander Haegen et al. 2002, Hethcoat and Chaloun 2015*b*, Sanders and Chalfoun 2019). Therefore, we suggest that because Brewer's sparrow nests are experiencing greater predation risk in sagebrush patches with less sagebrush cover and higher levels of active disturbance, it is probable that these co-occurring songbird species were also experiencing greater nest predation risk.

Our research is the first to explore a fitness response to oil and gas reclamation in a sagebrush breeding songbird. We demonstrated that sagebrush canopy cover and composition is important to Brewer's sparrow reproductive success at the nest site and surrounding areas. We did not find direct evidence that fragmentation of sagebrush habitat effected nest survival rates at a landscape scale. Brewer's sparrow generally avoided reclamation surfaces similar to active disturbance; however, nest survival was affected differently by the two types of disturbance with the greater negative impact on survival in the active areas. At a local scale, we found different nest survival responses in the active and reclamation treatment areas, providing some evidence that infrastructure and human activity associated with active disturbance may be more influential on Brewer's sparrow nest predation risk than the physical footprint of disturbance. It is important to emphasize that we identified a short-term fitness response to reclamation but the legacy of oil and gas disturbances in sagebrush areas will remain for decades. That is, successful reclamation of sagebrush landcover—restoring sagebrush to its pre-disturbance size and structure—is a long-term process (Baker 2011, Avirmed et al. 2015). Given the absence of sagebrush directly within the disturbance scars, it is unsurprising that we did not find a single Brewer's sparrow nest in reclamation areas ≤ 5 years after reclamation took place. Because sagebrush reclamation is a long-term process, studies on decades old reclamation areas are needed to provide a more complete understanding of bird responses to mitigation. Our research demonstrates scale-dependent nest survival relationships and reiterate the importance of looking at multiple scales when assessing fitness outcomes (Stephens et al. 2004, Ibáñez-Álamo et al. 2015).

Chapter 5
Individual variation in the response of a declining population of birds to anthropogenic disturbance in an established energy field

5.1 Abstract

Habitat selection in animals occurs across spatial scales from selection for broad geographic areas to fine-scale habitat components. Therefore, the scale of interest must dictate the spatial extent of the area considered as available to the animal and availability should be based on biologically realistic movements of that species or individual. Habitat selection studies are usually conducted at a population level. Habitat selection analyses at an individual level can reveal patterns in selection that are not apparent when using a population-level approaches. Advances in transmitter technology, allowing for high-resolution location and movement data, and data analyses allowed us to explore individual-level movements, space use (e.g., home ranges) and habitat selection of female greater sage-grouse (*Centrocercus urophasianus*) that raised chicks (brood-rearing sage-grouse) in an energy development landscape. To evaluate habitat selection and avoidance behaviors, we used integrated step selection analysis (iSSA) that permit the quantification of the effects of environmental and anthropogenic covariates on the movement and selection process simultaneously. On average, brood-rearing female sage-grouse established home ranges in areas with a majority of the home range comprised of sagebrush landcover (mean = 77.4%) and a minimal proportion of the area comprised of anthropogenic surface disturbance (mean = 3.5%). We did not find a difference in space use (e.g., home range area) and movements (e.g., step lengths) between individuals exposed to higher proportions of anthropogenic disturbance (high-exposure females) and those exposed to lower proportions of disturbance (low-exposure females) within their home ranges. Individual-level selection analyses helped us uncouple some aspects of energy development that influence habitat selection that likely would not have been detected at broader spatial scales. Brood-rearing females consistently selected for natural vegetation and avoided disturbed surfaces, including reclamation surfaces, at fine spatial scales. Power line visibility generally led to avoidance behavior; however, much shorter (3m) wells structures generally did not. We found that individual variability was partially explained by age (adult or first year), or previous experience of the landscape. Adults were more likely than first year females to demonstrate avoidance of energy features and adults were also less likely than first year females to establish home ranges in areas with energy infrastructure. Our results do not support individual uniformity in brood-rearing sage-grouse and reiterate the importance of accounting for, or at least recognizing, individual variability in population-level modeling efforts.

5.2 Introduction

The selection of habitats by animals can be viewed as a hierarchical process that results in the disproportionate use of some habitat components and the avoidance of others across multiple scales (Johnson 1980). Fundamental to habitat selection is the implicit assumption that evolution has shaped these behaviors to maximize survival and fitness (Jones 2001). The habitat selection process in animals is often conceptualized as four selection orders (Johnson 1980, Meyer and Thuiller 2006). These orders are nested and progress from the broadest first-order (the geographic range of a species) through the second-order home range of an individual, third-order selection of patches within the home range, and finally the fourth-order representing the selection fine-scale habitat components (Johnson 1980, Meyer and Thuiller 2006). The specific order of selection of interest must dictate the spatial extent of the area considered as available to the animal and availability should be based on biologically realistic movements of that species or individual (Jones 2001, Meyer and Thuiller 2006, Avgar et al. 2016). There is a long history of habitat selection analysis and typically, these studies aim to predict the habitat selection behavior of a species by modeling the aggregate responses of multiple individuals (i.e., population-level inference) across an area of interest.

However, animals exhibit individual variation in movement, habitat selection and space use (Durell 2000, Hertel 2020, Shipley et al. 2020). Individuals from the same species and population may adopt different habitat-use strategies and these differences can be influenced by factors such as social status (e.g., exclusion of subdominant individuals from preferred habitats) or by an individual's exposure to particular habitats based on availability or previous experience (Durell 2000, Leclerc et al. 2016). Individual variation in habitat-use strategies can, of course, be studied across multiple scales of selection. An animal’s home range (i.e., second-order) represents the distribution of an animal during a specified time period or life stage (Kernohan et al. 2001) and home range size can be affected by biotic interactions and intrinsic factors. Biotic interactions might include territorial behavior and intrinsic factors might include the sex or age of the individual (Börger et al. 2008). At a finer scale, it is common for individuals to vary in their selection of particular habitat patches and responses to particular habitat features (Goss-Custard and Durell 1983, Durell 2000). Therefore, it is possible for individual variation to manifest across multiple scales and understanding this variation can reveal important aspects of a species’ ecology, expand on our previous understanding of habitat selection, and potentially inform management and conservation of a species.

Our capacity to refine our understanding of habitat selection from population-level assessments to modeling individual behaviors has been driven by technological advancements in both data collection (i.e., transmitter and tracking technologies; Kirol et al. 2020*b*) and data analyses (Avgar et al. 2016). This permits the quantification of the effects of environmental and anthropogenic covariates on the movement and selection process simultaneously. Habitat selection and movement processes are interlinked because habitat and availability affect an animal's movements (e.g., an animal has to move farther to take advantage of resources that are farther away) and an animal's movement capacity affects its habitat use patterns (e.g., an animal can only use resources that it can realistically travel to; Forester et al. 2009, Avgar et al. 2016, Prokopenko et al. 2017). Integrated step selection analyses (iSSA) use a matched design where each individual location at each time point is associated with a specific set of random locations within a spatial domain limited by that individuals observed movements. Therefore, iSSA allow for a realistic assessment of what is truly available to that individual at that time (Thurfjell et al. 2014, Avgar et al. 2016, Muff et al. 2020). In combination with high-frequency animal relocation data, iSSA models allow us to explore individual behavioral differences related to habitat selection and movements (Dickie et al. 2020, Muff et al. 2020). Quantification of habitat selection at an individual level can reveal patterns in selection that are not apparent when using a population-level approach (Muff et al. 2020).

The greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) has been the subject of many habitat selection studies across its range in sagebrush steppe habitats throughout the intermountain west of North America. These past studies have quantified habitat selection behavior of sage-grouse across their annual cycle at a population-level and; thus, provide a foundation for the examination of more refined, individual-level, assessments of habitat selection. Our study focused on a population of sage-grouse in the Powder River Basin (PRB) in northeastern Wyoming. Multiple population-level habitat selection studies were conducted during the onset of oil and gas development in this region (Walker et al. 2007, Doherty et al. 2008). To date, the PRB sage-grouse population has persisted in this energy development landscape; however, it has declined considerably over the last three decades and the outlook for this population is uncertain (Garton et al. 2011, Taylor et al. 2013, Fedy et al. 2017). Persistence of this population is critical to maintaining genetic connectivity to populations in North Dakota, South Dakota and Montana, USA (Cross et al. 2018, Row et al. 2018).

The survival of sage-grouse chicks from hatch to independence is an important component of overall population performance (Taylor et al. 2012). Additionally, female sage-grouse with chicks can be particularly sensitive to anthropogenic disturbances and sage-grouse chicks have lower survival rates in landscapes altered by energy development (Aldridge and Boyce 2007, Lebeau et al. 2017, Kirol et al. 2020*a*). Previous research has demonstrated that at the second order of selection brood-rearing females will avoid anthropogenic disturbance when there is suitable undisturbed brood-rearing habitat available to them (Kirol et al. 2015*a*, Lebeau et al. 2017). We used iSSA to explore movements and habitat selection within the home ranges of female sage-grouse that successfully raised chicks (i.e., brood-rearing females) which corresponds to the third-order of selection (Johnson 1980). Our study site was located primarily within an oil and gas development and allowed us to assess finer scale effects of environmental and anthropogenic covariates on individual brood-rearing sage-grouse (Thurfjell et al. 2014). Female sage-grouse are likely under strong selection pressure to balance predation risk to themselves and their chicks with the need to provide foraging opportunities and high-quality nutrition for their dependent chicks (Hagen 2011, Smith et al. 2018).

Studies have demonstrated that avoidance of energy disturbance reduces the spatial distribution of sage-grouse because sage-grouse avoid otherwise suitable habitat after infrastructure is introduced (termed functional habitat loss; Aldridge and Boyce 2007, Naugle et al. 2011). In addition, avoidance behavior tends to increase with increasing densities of energy development (Aldridge and Boyce 2007, Walker et al. 2007, Naugle et al. 2011, Kirol et al. 2015*a*). However, despite multiple studies on the impacts of energy development (both renewable and non-renewable) on sage-grouse, the specific mechanisms that drive avoidance behavior are not well understood (Naugle et. al. 2011). For instance, is avoidance behavior in oil and gas fields driven primarily by the tall structure components of development, such as wells and power lines, or primarily by habitat loss (i.e., the physical footprint of development), or is it the aggregate of all these components that drive avoidance? Furthermore, we have less information on long term avoidance because most research has been conducted when the energy disturbance was first occurring (i.e., development phase). Much less research has focused on the production phase when construction has largely subsided and there is less human activity (Sawyer et al. 2009, Naugle et al. 2011, Holloran et al. 2015).

We used sage-grouse raising chicks in an established energy field to evaluate several interrelated research questions. First, are there differences in home range size and movements of brood-rearing sage-grouse in highly developed areas compared to those in less developed areas? Second, does third-order selection analyzed at the individual level suggest similar habitat selection patterns as analyses conducted at a population level? Third, are there differences in habitat selection or avoidance behavior of females exposed to higher densities of oil and gas disturbance compared to those exposed to lower densities? Fourth, are there differences in habitat selection or avoidance behavior related to the age of individuals (e.g., first year versus adult)? Finally, can individual-level third-order selection analyses help us uncouple the specific components of oil and gas development (e.g., well structures or power lines) that may be driving avoidance behavior?

5.3 Methods

5.3.1 Study area

Our study area was located in sagebrush-steppe habitat in northeastern Wyoming, USA, within the PRB region (44.2603ºN, -106.3095Wº; Figure 5.1). Dominant shrubs included big sagebrush (*Artemisia tridentata*) and silver sagebrush (*A. cana*), black greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* and *Ericameria* spp.). Common native grasses included blue grama (*Bouteloua gracilis*), and bluebunch wheatgrass (*Pseudoroegneria spicata*). Common invasive grasses include cheatgrass (*Bromus tectorum*) and Japanese brome (*B. japonicas*). In addition to sage-grouse, other bird species occupying sagebrush stands in our study area included: Brewer's sparrow (*Spizella breweri*), Brewer's blackbird (*Euphagus cyanocephalus*), lark bunting (*Calamospiza melanocorys*), lark sparrow (*Chondestes grammacus*), loggerhead shrike (*Lanius ludovicianus*), mourning dove (*Zenaida macroura*), sage thrasher (*Oreoscoptes montanus*), spotted towhee (*Pipilo maculatus*), vesper sparrow (*Pooecetes gramineus*) and western meadowlark (*Sturnella neglecta*; Barlow et al. 2020).

Our study area primarily contained coal-bed natural gas (CBNG) disturbance. CBNG wells were developed at a density of 3.1 well pads per km^2 (80-acre spacing; Walker et al. 2007). On average, CBNG well pads required the clearing of 0.5 ha of natural vegetation per pad. This estimate does not include access roads of various lengths and other supporting infrastructure (e.g., compressor stations and pipelines). In addition to well pads, CBNG development at this spacing generally requires 2-7 km of road construction per km^2 (Walker et al. 2007). CBNG wells are about 3 m tall while other supporting infrastructure like compressor stations are much taller (5-8 m). Livestock ranching was another major land use in the area. Elevation ranged between 1260 – 1450 m. Detailed descriptions of the region and CBNG development patterns are available in previous publications (e.g., Walker et al. 2007, Kirol et al. 2015*b*).

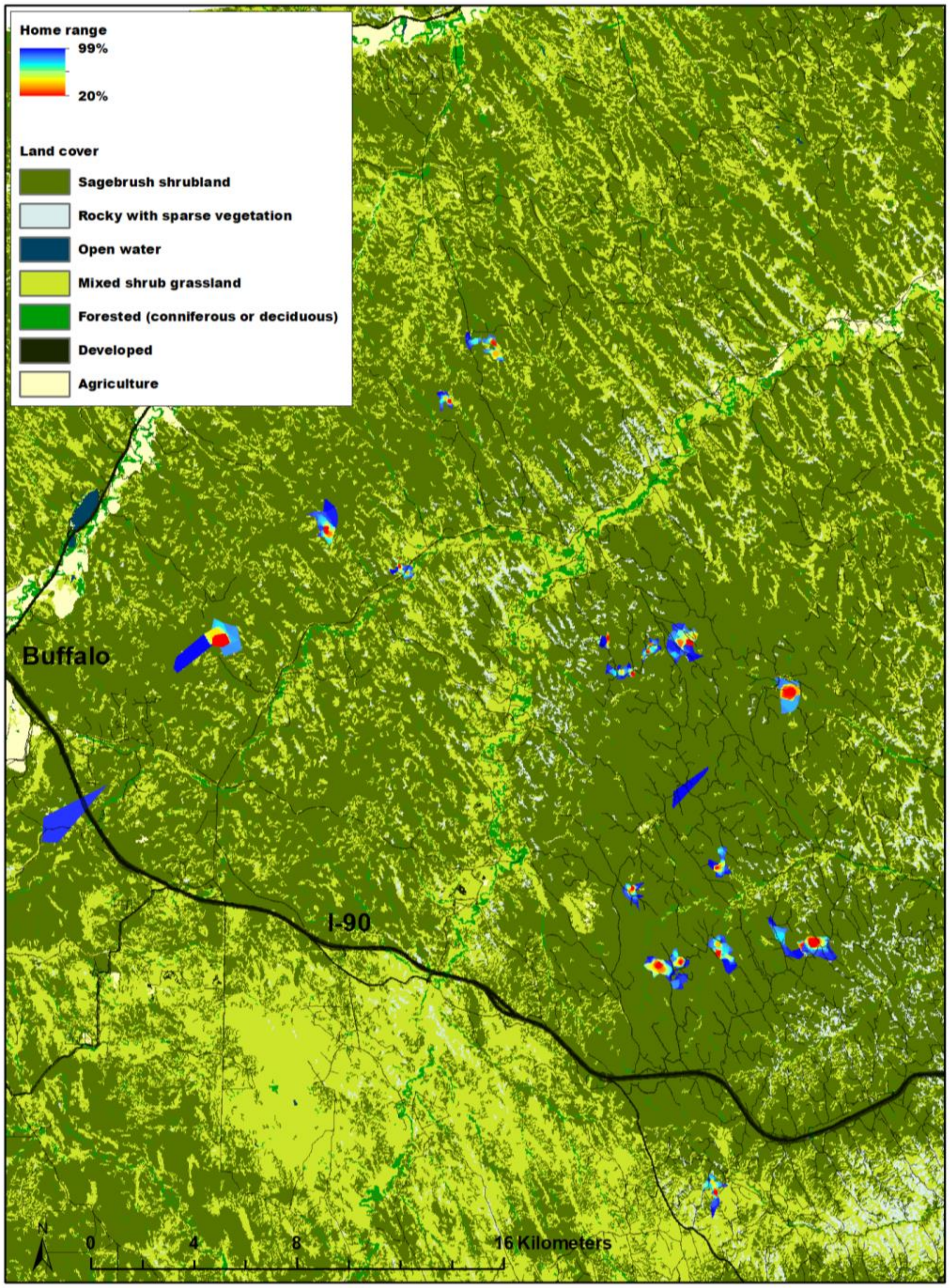


Figure 5.1: Map of study area land cover and 99% home ranges for brood-rearing greater sage-grouse (n = 18; 2017-2019) in northeastern, Wyoming, USA. Home ranges estimated using adaptive sphere-of-influence local convex hull nonparametric kernel method (a-LoCoH). The red areas are the lower home range percentiles (~ 20%) or 'core areas' within each home range.

5.3.2 Captures and monitoring

We captured female sage-grouse in 2017–2019 using mobile CODA net launchers and nighttime spot-lighting with hoop nets (Wakkinen et al. 1992, Sutphin et al. 2018). We targeted capturing at sage-grouse leks within and on the periphery of a large natural gas field in the spring and searched for female sage-grouse within and adjacent to the natural as field in the fall. We aged females as yearlings (first breeding season) or adults (second breeding season or older) based on the shape and condition of the outermost wing primaries, the outline of the primary tail feathers, and coloration of undertail coverts (Eng 1955, Dalke et al. 1963). We termed first year females 'inexperienced' and second year or older females 'experienced'. We fitted females with rump-mounted 13-g solar LRD (long range download) GPS-UHF (ultra-high frequency) GPS loggers (Ecotone Telemetry Lech Iliszko, Sopot, Poland) with independent 10-g VHF transmitters. Kirol et al. (2020*a*) provides a detailed description of the tracking devices (hereafter tags) and tracking procedures. The tags collected GPS locations every 4 hours. All research was conducted with approval from the University of Waterloo (Animals for Research Act and the Canadian Council on Animal Care guidelines, AUPP# 16-06).

We monitored tagged female sage-grouse weekly from April through August. Females that successfully hatched nests were considered brood-rearing females. At each visit, we determined if the female was still with her brood (i.e., brood-rearing) by visually locating the chicks with binoculars or by observing brooding behavior (e.g., distraction displays, feigning injury, clucking, and hesitation to flush). We considered a brood successful if we confirmed the female was with ≥1 chick at this date. We confirmed brood fate at 40 days post-hatch because the majority of chick mortality has occurred by this age and chicks are more likely to survive to breeding age after this time (Gregg et al. 2007). We used a FLIR Scout II-640 Thermal Monocular (FLIR Systems, Inc. Wilsonville, Oregon, USA) and spot-lighting (Walker et al. 2006, Dahlgren et al. 2010) to verify brood fate at 40 days. Our study only included locations from females that were caring for broods from nest hatch (0 days) to ~40 days.

We estimated the error of our tags by placing two tags at fixed locations in our study area. The tags were set to gather location data every 30min for a one-month period. We calculated location error as the median linear distance between tag recorded GPS points and the true tag location as determined by placing a hand-held Garmin 64s GPS unit (Garmin International, Olathe, Kansas, USA) at the tag location and averaging waypoints for 15 min to improve waypoint accuracy.

5.3.3 Movement data

Tags were set to collect GPS locations every 4 hours (6 locations/24-hr period). High-resolution movement data (i.e., frequent relocation intervals) can be highly autocorrelated, resulting in poor estimates of home range area and biased model and error terms (Calabrese et at. 2016). Prior to estimating home ranges and modeling our brood-rearing data we assess autocorrelation with the continuous-time movement modeling ('ctmm') package (Calabrese et at. 2016). With the ctmm package, we inspected the autocorrelation structure of relocation data for each individual using variograms. Autocorrelation was not an issue with 4-hour relocation intervals, therefore we did not resample our data.

5.3.4 Spatial covariates

All of the environmental covariates we included in our models were relevant to sage-grouse brood-rearing ecology and supported by previous studies on sage-grouse habitat selection during brood-rearing (Table 5.1). Vegetation cover variables including, sagebrush cover, sagebrush height (cm) and herbaceous cover were derived from the 2016 shrubland layers (30-m resolution) available through the U.S. National Land Cover Database (Xian et al. 2015, Yang et al. 2018). The importance of sagebrush cover and herbaceous cover to brood-rearing sage-grouse has been demonstrated by many studies (e.g., Aldridge and Boyce 2007, Cassaza et al. 2011, Kirol et al. 2015*a*). Brood-rearing sage-grouse also avoid rough terrain at landscape and local scales (Dinkins et al. 2014*a*, Fedy et al. 2014, Kirol et al. 2015*a*). We calculated terrain roughness (vector roughness measure [VRM]) at a 30-m resolution using a 10-m digital elevation model (Sappington et al. 2007). Low VRM values indicate flat terrain while high values indicate rugged terrain. Normalized difference vegetation index (NDVI) is a measure of live green vegetation or 'greenness' (Robinson et al. 2017). NDVI has proved predictive of sage-grouse habitat selection during brood-rearing and can be related to population productivity (Blomberg et al. 2012, Smith et al. 2018). We calculated time-varying NDVI covariates using dynamic 30-m resolution NDVI products generated every 16 days (Robinson et al. 2017). For each year (2017–2019), we averaged four NDVI composites that temporally overlapped the brood-rearing period in our study, approximately May 15th to July 31th. The highest NDVI values, in our study area, were indicative of live herbaceous ground cover with little to no sagebrush cover. Low NDVI values were indicative of bare ground.

Habitat modification and infrastructure associated with energy development can influence habitat use patterns during all sage-grouse life stages (Naugle et al. 2011). Development of gas reserves requires the clearing of vegetation for well pads and supporting infrastructure such as roads, wastewater holding reservoirs, facilities and pipelines (sensu Walker et al. 2007, Finn and Knick 2011, Walker et al. 2020).

We created covariates related to natural gas development that fell into two broad categories: 1) natural vegetation removal (i.e., disturbance) and; 2) infrastructure features (Table 5.1).

We obtained disturbance layers that were digitized (head's up digitizing at a min. 1:5000 screen resolution; https://ddct.wygisc.org/ddct-procedure.aspx) following the Disturbance Calculation Tool (DDCT) process used to quantify disturbances in the sagebrush ecosystem in Wyoming, USA (State of Wyoming 2019). With the DDCT disturbance data, we created surface disturbance layers at a 1-m resolution that represented active and reclaimed disturbances that quantified the direct loss of natural vegetation. Active disturbances were areas stripped of vegetation that remain devegetated or are partially vegetated with interim reclamation seed mixes (e.g., disturbance areas surrounding active wells pads; Kirol et al. 2020*a*). Examples of active disturbance in our study area included graveled access roads, well pads and compressor sites (Figure A3). Reclamation surfaces included areas without above ground infrastructure that had been revegetated with reclamation seed mixes but were largely devoid of sagebrush (Kirol et al. 2020*a*). Reclamation surfaces in our study area were primarily reclaimed well pads, access roads and pipeline corridors (Figure A4). Active disturbance and reclamation covariates were quantified as the percent of disturbance per 30-m pixel on the landscape (0-100% active disturbance or reclamation). We also used the DDCT layer to produce a layer that categorized landscape pixels into discrete classes of undisturbed natural vegetation or disturbed (active + reclamation). We termed this covariate Landcover factor. In some cases, categorical habitat classifications can be better at detecting selection and movement behaviors (Thurfjell et al. 2014).

Infrastructure covariates included power transmission lines (hereafter power lines), CBNG features (e.g., wells and compressor stations) and man-made reservoirs (Table 5.1). Power line data were obtained from the Powder River Energy Corporation and active and plugged and abandoned well data were obtained the Wyoming Oil and Gas Conservation Commission (http://wogcc.wyo.gov/). Well data included location, type, status, status date and spud date (initiation of drilling). Man-made reservoirs were extracted from the DDCT disturbance layers. All infrastructure was verified, and in some cases corrected, using ESRI world imagery
(https://services.arcgisonline.com/arcgis/rest/services/World_Imagery/MapServer)

Visible structures can be negatively associated with sage-grouse habitat use and chick survival (Aldridge and Boyce 2007, Kirol et al. 2015*a*, Lebeau et al. 2019). We developed viewshed surfaces to determine the number of infrastructure features and power lines that were visible by sage-grouse from any given pixel on the landscape (Table 5.1). Power lines can uniquely influence habitat use and fitness rates in sage-grouse (Gillian et al. 2013, Gibson et al. 2018, Lebeau et al. 2019). Therefore, we developed a viewshed covariate for power lines and a second viewshed covariate for all other structures in our study area. We calculated how many structures were visible within a 1.0 km viewshed distance (Kirol et al. 2015*a*, Lebeau et al. 2019). Each type of structure received a specific height above ground value. For instance, well structures were given a height of 3 m, compressor or pumping stations a height of 5 or 8 m and power lines a height of 27 m (Figures A5-A7). The height values were based on the average heights of these structures measured in the field.

Mesic habitats adjacent to water are often selected by brood-rearing sage-grouse but these areas can also be riskier for sage-grouse chicks, likely due to increased predation (Aldridge and Boyce 2007, Connelly et al. 2011*b*, Kirol et al. 2015*b*). We were interested in fine-scale relationships with wetter habitats surrounding man-made reservoirs in our study area. We transformed continuous distance variables using a decay function ($e^{-d/\alpha}$) where d was the distance in meters from each pixel to man-made reservoir edge which allowed the effect to decay as distance to the reservoir increased (Fedy and Martin 2011). We used 100 as the decay constant (α) which decays to zero at ~300 m (Walker et al. 2016).

The resolution or scale of the spatial covariates used in our analysis were informed by the median location error of our tags (median = 14.46 m). To properly account for tag error the finest resolution assessed was a 30 x 30 m pixel or a 15-m radius circular scale. Spatial variables were processed using ArcGIS 10.7.0 – 10.7.1 (http://www.esri.com) and R statistical software (R Core Team 2020).

Table 5.1: Covariates that were assessed in our integrated step selection analysis (iSSA) models used to model habitat selection in brood-rearing female sage-grouse. The movement covariate cos_ta was present in all individual models. The environmental covariates that had the most support across individual models formed the base environmental model. The anthropogenic covariates were assessed in conjunction with the base model for each individual.

Covariate	**Covariate type**	**Description**
Cos_ta	Movement	Cosine of the turn angle that describes the directionality of movements
Sage	Environmental	% sagebrush cover (all *Artemisia* spp.; Xian et al. 2015)
Sage + SageQ	Environmental	Quadratic form of % sagebrush cover
ShrubHeight	Environmental	Shrub height (cm; all woody stemmed shrubs; Xian et al. 2015)
ShrubHeight + ShrubHeightQ	Environmental	Quadratic form of shrub height
NDVI	Environmental	Biweekly Normalized Difference Vegetation Index (NDVI) representing live green vegetation averaged over study period (May 15th to July 31th each year; Robinson et al. 2017)
NDVI + NDVIQ	Environmental	Quadratic form of NDVI
Herb	Environmental	% herbaceous cover (consists of grasses, forbs and cacti; Xian et al. 2015)
Herb + HerbQ	Environmental	Quadratic form of % herbaceous cover
VRM	Environmental	Vector roughness measure (VRM; low values indicate flat terrain, high values indicate rugged terrain; Sappington et al. 2007)

Active disturbance	Anthropogenic	% active disturbance (areas stripped of natural vegetation that are associated with infrastructure or access roads)
Reclamation	Anthropogenic	% reclamation (formally active disturbances that have been reclaimed and revegetated with reclamation seed mixes)
Landcover factor	Anthropogenic	Categorical covariate of undisturbed natural vegetation (coded as 0) or disturbed (active + reclamation; coded as 1)
Power line viewshed	Anthropogenic	A count of the number of power poles that were visible from any given pixel on the landscape based on a 1.0 km viewshed distance
Structure viewshed	Anthropogenic	A count of the number of CBNG infrastructure features that were visible from any given pixel on the landscape based on a 1.0 km viewshed distance
Reservoir distance	Anthropogenic	Linear distances to man-made reservoirs transformed using a decay function ($e^{-d/\alpha}$) where 100 was a decay constant (α) and d was the distance in meters from each pixel to the reservoir edge

5.3.5 Home range estimates, home range characteristics and movements

We estimated brood-rearing home ranges using the local convex hull (LoCoH) nonparametric kernel method and, specifically, the adaptive sphere-of-influence LoCoH method (*a*-LoCoH; Getz et al. 2007). We generated 99% *a*-LoCoH home range for each individual.

We quantified the proportion of sagebrush landcover and all anthropogenic disturbance within each individual's home range. All anthropogenic disturbance included any disturbance that replaced natural vegetation (e.g., active disturbance, reclamation and man-made reservoirs). We inspected the 2016 sagebrush cover layer with high-resolution imagery (Google Earth, Google LLC, Mountain View, CA, USA) and determined that 30-m landscape pixels that had sagebrush raster values ≤6%, in our study area, generally contained little to no sagebrush cover. To approximate the extent of sagebrush within home ranges, we created discrete classes of non-sagebrush (raster values = 0–6%) and sagebrush (raster values = 7–36%) pixels. Consequently, pixels classified as sagebrush encompassed a range of sagebrush canopy cover from sparse to dense.

We calculated two movement metrics, step lengths and net-squared displacement (NSD), to explore movement patterns and detect changes in movement behavior (Edelhoff et al. 2016). We generated step lengths (i.e., the distance between the start-point and end-point of a given step) and NSD using the 'move' package; Kranstauber et al. 2020). NSD calculates the squared distance between each location along an individual's track and the its original location. We calculated NSD from each individual's nest.

We plotted NSD against days since the female and chicks left the nest (hatch day) to detect any significant change-points that might be suggestive of a shift from early to late brood-rearing areas during the first 40 days after hatch. Sage-grouse studies have suggested distinct early and late brood-rearing periods that correspond to movements between different habitat types and some research suggests a transition from early to late brood-rearing habitat between14 and 21 days post-hatch (Thompson et al. 2006, Connelly et al. 2011*b*).

To test if sizes of brood-rearing home ranges differed between sage-grouse raising chicks in areas with minimal disturbance and those within a producing CBNG field, we separated female sage-grouse into two groups based on disturbance exposure. Sage-grouse with ≤ 3% disturbance within their home range were grouped as low-exposure hens, while those in areas with > 3% were grouped as high-exposure hens (Kirol et al. 2020*a*). We also tested if there were differences in movement characteristics between low-exposure and high-exposure hens by comparing the step lengths of the individuals in each group. We used a 2-tailed t-test to assess potential differences in home range sizes and step lengths between groups.

5.3.6 Movement linked habitat selection analysis

We used iSSA ('amt' package; Signer et al. 2019) to simultaneously model movement and habitat selection of brood-rearing sage-grouse (Avgar et al. 2016). The iSSA establishes an availability domain that corresponds directly to each used location and; therefore, restrains availability to an area the animal could potentially use such as availability corresponding to an individual's home range (Thurfjell et al. 2014, Prokopenko et al. 2017). Using the iSSA model we compared each used movement step with a set of conditional available steps (n = 100) that were randomly sampled from a distribution parameterized based on the observed steps (Avgar et al. 2016). Movement steps were characterized by their length (i.e., step length) and direction defined as the angular deviation (i.e., turn angle) between successive steps. Available steps and turn angles were sampled from a Gamma distribution and a von Mises distribution, respectively (Signer et al. 2019). Environmental and anthropogenic covariates were extracted from the end point of each step to assess the direct effect of anthropogenic and environmental covariates on the selection process (Signer et al. 2019).

Each individual model contained the movement-related covariates including the log of step length (log_sl) and the cosine of the turn angle (cos_ta). The log_sl term is included as a modifier of the shape parameter of the underlying gamma distribution and the cos_ta is used to describe the directionality of an individual's movement (Signer et al. 2019). We fit a conditional logistic regression model to the data using the 'survival' package (Therneau 2020).

To evaluate movement and habitat selection responses to anthropogenic features and habitat alteration we first modeled environmental covariates, in combination with the movement-related covariates, that are known to influence habitat selection during the sage-grouse brood-rearing period. We also considered both linear and quadratic terms for vegetation covariates to allow us to detect selection for intermediate values of these covariates, such as selection for intermediate sagebrush cover (Doherty et al. 2010). All covariates, other than decay distances and the movement-related covariates, were standardized. To assess model support and identify the most informative parameters we relied on Akaike's Information Criteria (AIC) scores and 85% confidence limits at each stage of the model building process (Burnham and Anderson 2002, Arnold 2010). When environmental variables were correlated ($r \geq |0.70|$), we chose the most informative covariate or covariate representation (i.e., linear or quadratic) based on the degree of AIC support across individual models. The covariates that had the most support across individual models formed our base environmental model (hereafter base model; Scrafford et al. 2018).

We used the base model to assess the relative contribution of each anthropogenic covariate while accounting for environmental variation (i.e., statistical control; Hosmer and Lemeshow 2008). When assessing support for anthropogenic covariates for each individual model we used the same base model and combined it with each anthropogenic covariate of interest (base model + anthropogenic covariate). Anthropogenic covariates that had 85% confidence limits that did not overlap zero were modeled in our final candidate set. Using AIC, the candidate sets were compared to each other and to the base model. The candidate model with the lowest AIC score was identified as the most parsimonious model for that individual. However, if the candidate model was not at least 2 AIC better than the base model, we assumed that the addition of the anthropogenic covariate(s) did not improve model fit (i.e., the anthropogenic covariates were not informative; Arnold 2010). Note, not all individuals were exposed to all anthropogenic covariates of interest. For example, several brood-rearing sage-grouse did not settle in home ranges that were near power lines. When the anthropogenic covariate was not within the availability domain of that individual it was not assessed in the candidate set. We considered anthropogenic covariates to not be within the availability domain if > 95% of available locations contained zero values for that covariate. All analyses were conducted using R statistical software (R Core Team 2020).

5.4 Results

5.4.1 Monitoring

Our analysis included 18 female sage-grouse that we verified successfully raised chicks (i.e., brood-rearing) to 40 days post-hatch (n = 4 in 2017, n = 5 in 2018 and n = 9 in 2019). The mean number of relocations per individual (± SE) was 236.22 ± 2.60 (range = 204–244).

5.4.2 General space use and movement

The average 99% home range size for all individuals was 0.85 ± 0.21 km^2 (range = 0.26–4.02 km^2). The majority of home ranges were immediately adjacent to or included the females nest site (Figure 5.2). For most individuals, NSD from the nest plotted against time showed little variation over the first 40 days after hatch (Figure 5.3). Only two individuals (RAP27 and PAR09) had NSD distributions that signaled pronounced shifts in their movement states. RAP27 moved ~3.5 km on day 5 post-hatch. PAR09 moved ~ 8 km between days 37 and 38 post-hatch (Figure 5.3). NSD plots did not demonstrate any temporally consistent movement shifts across individuals that would suggest movements from early to late brood-rearing areas at a certain day post-hatch (Figure 5.3).

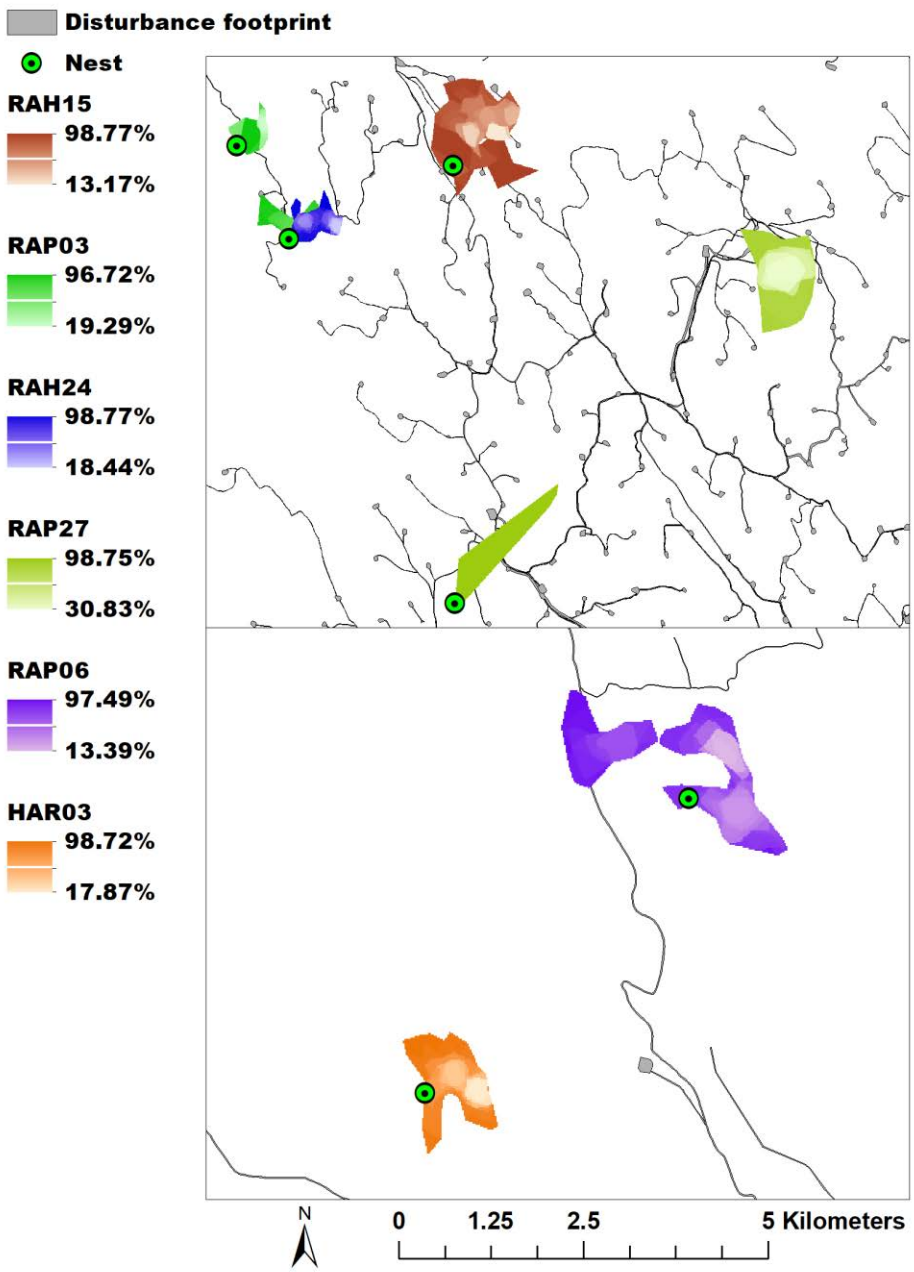


Figure 5.2: Example of 99% home ranges estimated using adaptive sphere-of-influence local convex hull nonparametric kernel method (*a*-LoCoH) for six brood-rearing greater sage-grouse in northeastern Wyoming, USA. Color gradient for each individual indicates ~10 to ~99 percentile isopleths. The lightest areas are the lower home range percentiles (≤ 20%) or 'core areas' within each home range.

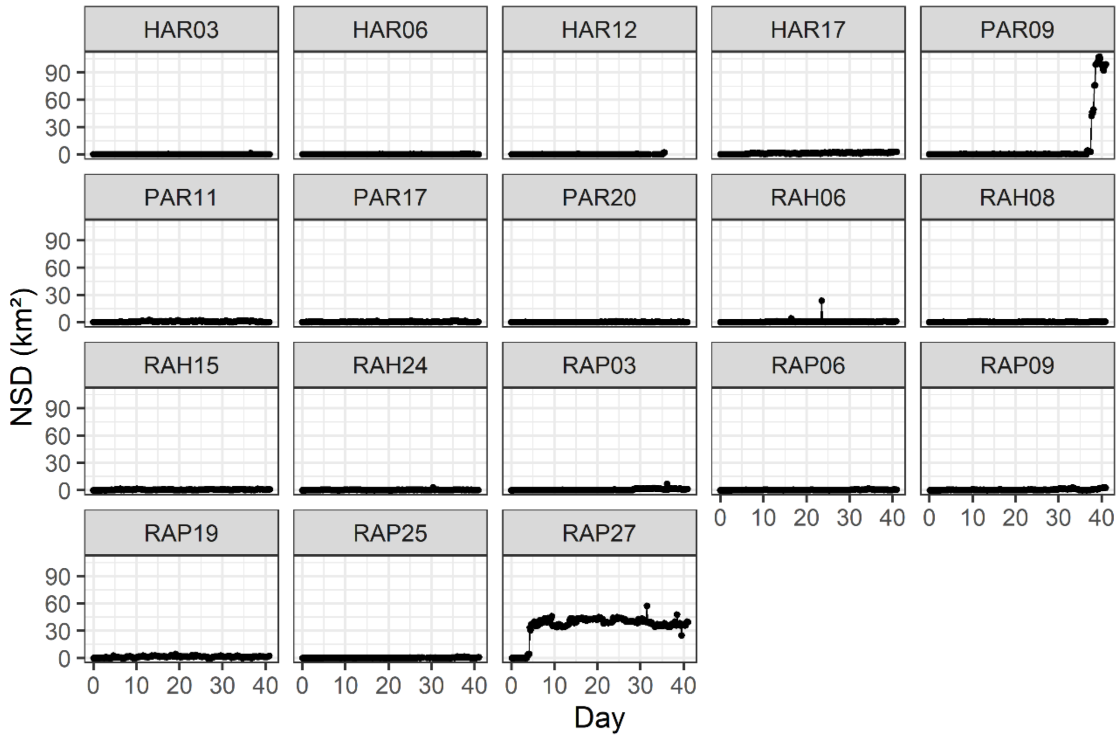


Figure 5.3: Net-squared displacement (NSD) for each individual from its nest site. We plotted NSD against post-hatch days (days since the female and chicks left the nest) to 40 days. NSD allows for detection of change-points that indicate movement shifts to different areas. Movement data is from brood-rearing greater sage-grouse in northeastern Wyoming, USA.

5.4.3 Home range landcover and anthropogenic disturbance

The extent of sagebrush landcover within individual home ranges was never less than 40% (range = 40.28–98.20%). Across individual home ranges, the mean proportion of sagebrush landcover was 77.37 ± 3.36%. The mean proportion of anthropogenic surface disturbance for all home ranges was 3.59 ± 0.75%. The greatest proportion of anthropogenic disturbance for any home range was 14.65%, which was an outlier and twice as high as the second highest proportion of disturbance (6.68%) for any individual. Of the 14.65% disturbance within this individual's home range, 5.33% was reclamation which was also the highest amount of reclamation surface within any individual's home range. Seventeen out of the 18 brood-rearing females had at least some anthropogenic disturbance within their home ranges (range = 1.38–14.65%). Of these 17 individuals, seven (41%) had reclamation (range = 0.21–2.76%), in addition to active disturbance, within their home ranges.

5.4.4 Home range, space use and movement comparisons

The mean proportion of surface disturbance within individual home ranges was 1.96 ± 0.28% for low-exposure hens and 5.63 ± 1.38% for high-exposure hens. We did not detect a statistical difference between space use, quantified as home range area, of low-exposure hens ($n = 10$) and high-exposure hens ($n = 8$; $t = 2.31$, df = 10, $P \leq 0.297$). Mean home range size for low-exposure hens was 0.63 km^2 (85% CI: 0.45–0.80 km^2) compared to 1.13 km^2 (85% CI: 0.43–1.84 km^2) for high-exposure hens. The movement metric step length also did not differ between groups ($t = 2.23$, df = 10, $P \leq 0.246$). Mean 4-hour step lengths were 155.45 m (85% CI: 144.22–166.69 m) for low-exposure hens and 177.87 m (85% CI: 150.81–204.93 m) for high-exposure hens.

5.4.5 Movement linked habitat selection

In the iSSA models the only movement-related covariate that had support was cos_ta. In 27% of the models a negative cos_ta coefficient indicated that the movements of these individuals were characterized by turning back rather than having a forward directional persistence (Table 5.2). There did not seem to be any relationship between the importance of cos_ta and whether the individual was a high- or low-exposure female. The quadratic form of sagebrush cover and NDVI were the most consistent predictors of habitat selection. Sagebrush cover was important in 33% and NDVI was important in 50% of the individual models. Support for the quadratic form of sagebrush cover and NDVI suggests that females were showing a selection preference for intermediate values of these covariates and not extremely high or low values within their availability domain (Table 5.2 and Figure 5.4). The importance of NDVI was consistent across the high- or low-exposure groups while sagebrush cover was supported in 46% of the high-exposure and only 14% of the low-exposure individual models. The terrain roughness covariate (VRM) was supported in 22% of the individual models (Table 5.2 and Figure 5.4). The VRM coefficient was negative in all but one of these individual models suggesting brood-rearing females were consistently selecting for less rugged areas.

Grouse Id	Cos_ta	VRM	Sage	Sage^2	NDVI	NDVI^2
Low-exposure hens	***β*** **(85% CI)**	***β*** **(85% CI)**	***β*** **(85% CI)**	***β*** **(85% CI)**	***β*** **(85% CI)**	***β*** **(85% CI)**
HAR03	-0.196* (-0.348, -0.044)	0.054 (-0.043, 1.150)	0.179 (-0.573, 0.930)	-0.129 (-0.867, 0.609)	4.521* (1.705, 7.336)	-4.418* (-7.191, -1.646)
PAR11	0.011 (-0.125, 0.146)	0.040 (-0.066, 0.146)	0.121 (-0.318, 0.559)	-0.040 (-0.470, 0.390)	0.375 (-1.228, 1.977)	-0.728 (-2.347, 0.890)
PAR17	-0.078 (-0.215, 0.059)	-0.447* (-0.596, -0.297)	0.859* (0.386, 1.333)	-0.591* (-1.000, -0.181)	-0.077 (-1.389, 1.235)	0.011 (-1.286, 1.307)
PAR20	-0.139* (-0.274, -0.004)	0.036 (-0.079, 0.151)	-0.648 (-0.991, -0.304)	0.296 (-0.061, 0.653)	2.128* (0.927, 3.329)	-2.428* (-3.688, -1.168)
RAH06	-0.354* (-0.524, -0.184)	0.171* (0.042, 0.301)	0.494 (-0.056, 1.044)	-0.492 (-0.995, 0.011)	3.257* (1.112, 5.402)	-3.526* (-5.716, -1.336)
RAH15	0.168* (0.029, 0.308)	-0.075 (-0.197, 0.047)	-0.408* (-0.801, -0.016)	0.472* (0.121, 0.823)	-1.105 (-2.470, 0.260)	1.217 -0.103, 2.536)
RAH24	-0.095 (-0.228, 0.039)	0.007 (-0.092, 0.107)	-0.625* (-0.924, -0.325)	0.547* (0.257, 0.837)	-0.523 (-1.555, 0.508)	0.450 (-0.590, 1.490)
RAP03	-0.048 (-0.184, 0.087)	0.012 (-0.099, 0.123)	0.216 (-0.164, 0.596)	-0.176 (-0.521, 0.170)	2.314* (0.946, 3.683)	-2.083* (-3.412, -0.754)
RAP06	-0.261* (-0.433, -0.089)	-0.338* (-0.518, -0.159)	0.489 (-0.313, 1.292)	-0.516 (-1.301, 0.268)	-1.761* (-3.360, -0.161)	1.699* (0.116, 3.283)
RAP09	0.062 (-0.100, 0.224)	-0.071 (-0.210, 0.067)	0.796* (0.194, 1.397)	-0.840* (-1.425, -0.256)	-0.152 (-1.615, 1.310)	0.100 (-1.337, 1.538)
High-exposure hens						
HAR06	-0.047 (-0.212, 0.117)	0.032 (-0.085, 0.150)	0.682* (-0.032, 1.397)	-0.646* (-1.277, -0.015)	0.269 (-1.495, 2.032)	-0.181 (-1.898, 1.535)
HAR12	-0.314* (-0.475, -0.152)	-0.077 (-0.216, 0.063)	0.498 (-0.065, 1.061)	-0.309 (-0.181, 0.200)	0.186 (-1.802, 2.174)	-0.256 (-2.222, 1.710)
HAR17	0.017 (-0.160, 0.194)	-0.044 (-0.197, 0.109)	0.767 (0.133, 1.402)	-0.149 -0.667, 0.370)	-2.571* (-4.374, -0.768)	2.328* (0.607, 4.049)

PAR09	-0.004 (-0.137, 0.130)	-0.224* (-0.351, -0.097)	0.220 (-0.160, 0.601)	-0.175 (-0.537, 0.188)	0.774 (-0.857, 2.404)	-1.026 (-2.665, 0.612)
RAH08	-0.090 (-0.224, 0.044)	-0.014 (-0.117, 0.089)	0.127 (-0.209, 0.464)	-0.246 (-0.579, 0.088)	2.366* (0.900, 3.832)	-2.467* (-3.945, -0.989)
RAP19	-0.047 (-0.191, 0.098)	-0.310* (-0.466, -0.153)	1.537* (0.870, 2.205)	-1.144* (-1.705, -0.584)	-2.606* (-3.971, -1.241)	2.559* (1.267, 3.851)
RAP25	-0.216* (-0.393, -0.038)	0.053 (-0.088, 0.194)	0.518 (-0.009, 1.045)	-0.314 (-0.777, 0.149)	-0.872 (-2.513, 0.769)	0.722 (-0.879, 2.324)
RAP27	-0.089 (-0.223, 0.045)	-0.026 (-0.130, 0.077)	0.029 (-0.310, 0.368)	-0.197 (-0.531, 0.137)	3.852* (1.986, 5.719)	-3.902* (-5.781, -2.023)

Table 5.2: Beta coefficients for environmental and movement-related covariates that were significant (85% confidence interval [CI]) in our individual base models for brood-rearing female sage-grouse. Cos_ta explains the directional persistence of movements and was the only movement-related covariate that was significant in any of our individual models. Vector roughness measure (VRM) is a measure of terrain roughness. Sage + $Sage^2$ is the quadratic form of sagebrush cover. Normalized difference vegetation index (NDVI) is a measure of “greenness” or live green vegetation. NDVI + $NDVI^2$ is the quadratic form of NDVI. All covariates were modeled at a 30 x 30 m resolution. Cells shaded grey with an asterisk (*) by the coefficient indicate that the covariate was statistically supported (85% CI did not include zero).

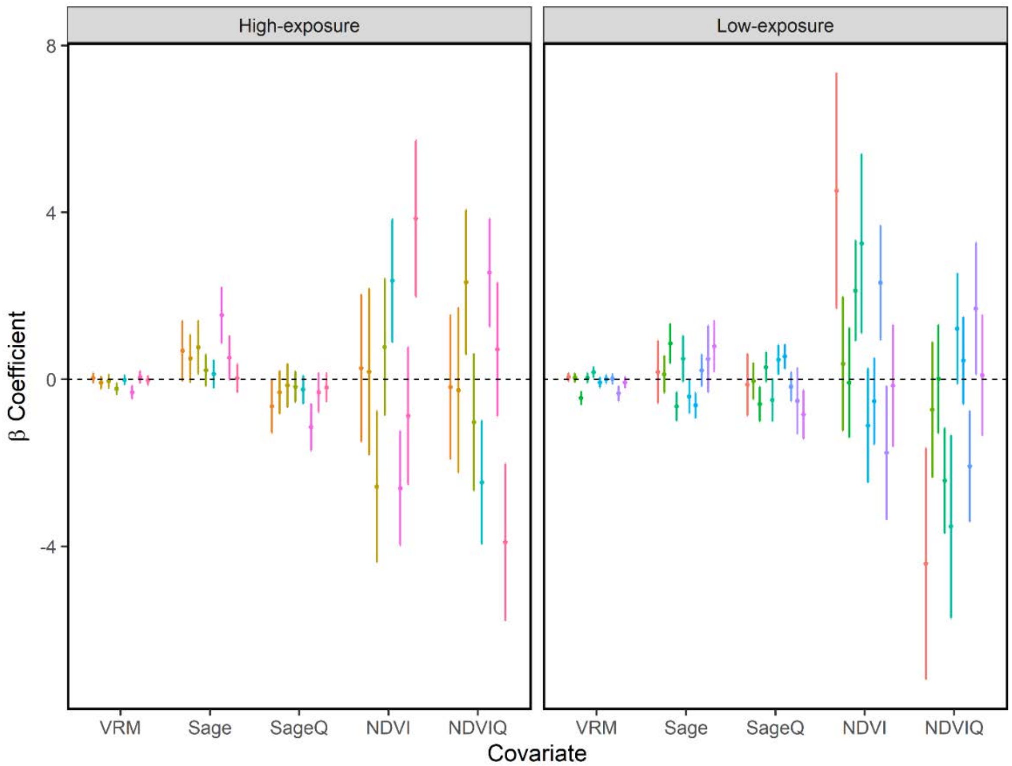


Figure 5.4: Beta coefficients and 85% confidence intervals (CI) for environmental covariates included in all individual models. Each color represents an individual (*n* = 18). The terms Sage + SageQ is the quadratic form of sagebrush cover and NDVI + NDVIQ is the quadratic form of NDVI. Covariates plotted for high- and low-exposure brood-rearing greater sage-grouse in northeastern Wyoming, USA.

Anthropogenic covariates were not explanatory and did not improve model fit in 28% of these individual models (Table 5.3 and 5.4). Eighty-three percent (*n* = 15) of the brood-rearing females were exposed to a surface disturbance covariate (Active disturbance, Reclamation or Landcover factor) within their availability domain (Table 5.3). Selection for natural landcover and against disturbed surfaces (active disturbance and reclamation) was the most commonly supported anthropogenic covariate in our individual models. Of the females exposed to anthropogenic disturbance, the Landcover factor was predictive in 33% of the individual models (Table 5.3). No individual models indicated a selection preference for disturbed surfaces (Table 5.3). Support for Landcover factor differed minimally between high-exposure (38%) and low-exposure females (29%) models (Figure 5.5). Continuous forms of active disturbance and reclamation covariates were supported in four models. The coefficient was generally negative suggesting that as active disturbance or reclamation increased within an area the likelihood of use decreased (Table 5.3). Only 39% of the brood-rearing females were exposed to reclamation, while 78% were exposed to active disturbance.

The majority (n = 16) of brood-rearing individuals were exposed to an anthropogenic feature covariate (Power line viewshed, Structure viewshed or Reservoir) within their availability domain (Table 5.4). Sixty-three percent of these individuals were exposed to power lines, either within their home range or adjacent to their home range, but within a 1.0 km viewshed distance (i.e., availability domain). A negative relationship between power line visibility and habitat use was detected in 30% (n = 3) of these models suggesting that areas with a greater number of visible power line poles were less likely to be used. Support for a negative relationship between power line visibility and habitat preference differed some between high (17%) and low exposure females (50%; Table 5.4).

We did not detect a consistent relationship between visible CBNG structures and habitat use (Table 5.4). Seventy-two percent of individuals were exposed to CBNG structures. All of these individuals, with the exception of one (n = 12), were only exposed to 3 m tall CBNG wells within their availability domain. A positive coefficient for the structure visibility covariates in two of the individual models suggested that these females were using areas with higher structure visibility values. One of these individuals (RAH06) had a positive coefficient for structure visibility but also showed strong avoidance of areas with more power line visibility (Table 5.4).

Experienced females were less likely than inexperienced females to establish home ranges in areas with anthropogenic disturbance or infrastructure features. Within their availability domain, 64% of experienced females were exposed to active disturbance, 45% were exposed to power lines (1.0 km viewshed distance of power lines) and 64% were exposed to CBNG structures (1.0 km viewshed distance of structures). In contrast, 100% of inexperienced females were exposed to active disturbance, 71% were exposed to power lines and 85% were exposed to CBNG structures (Figure 5.6). Experienced females were also more likely to demonstrate avoidance of areas with more power line visibility and higher percentages of active disturbance and no experienced females indicated a positive relationship with these covariates while two inexperienced females did (Figure 5.7).

Thirty-nine percent of brood-rearing females were exposed to reservoirs in their availability domain. Of these individuals, decay distance to reservoir edge was only supported in two models. In both cases, a negative coefficient suggested that as the distance from reservoir edge increased the likelihood of use also increased (Table 5.4). No individuals demonstrated a selection preference for areas adjacent to reservoirs.

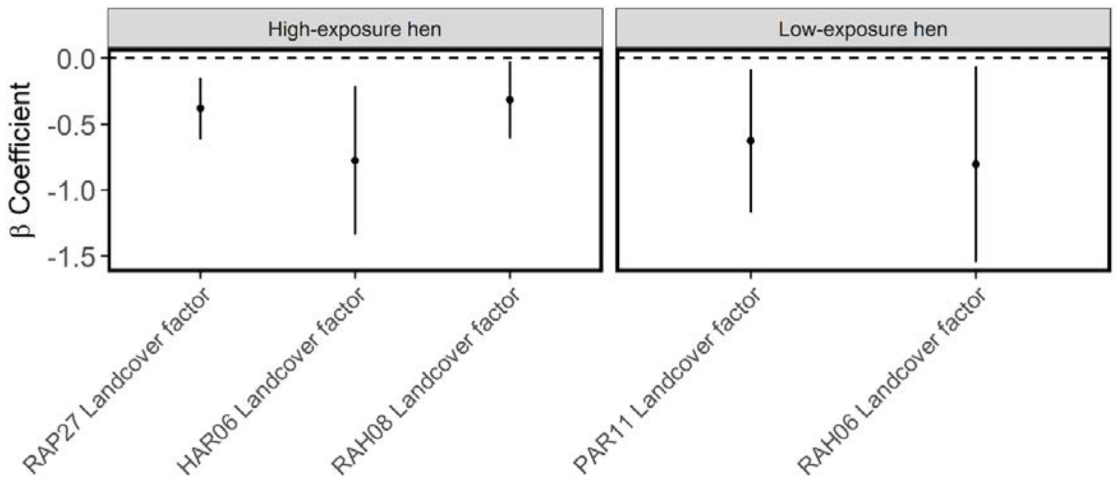


Figure 5.5: Beta coefficients and 85% confidence intervals (CI) for all individual models in which Landcover factor was supported. A negative coefficient for Landcover factor indicates selection for undisturbed natural vegetation (coded as 0) and against disturbed areas (coded as 1). Covariates plotted for high- and low-exposure brood-rearing greater sage-grouse in northeastern Wyoming, USA.

Table 5.3: Beta coefficients and 85% confidence intervals (CI) for anthropogenic surface disturbance covariates that were the most informative in our individual models for brood-rearing female sage-grouse. Active disturbances were areas stripped of natural vegetation (e.g., sagebrush shrubs) that remain devegetated or are partially vegetated with interim reclamation seed mixes. Reclamation were areas revegetated with reclamation seed mixes but largely devoid of sagebrush land cover. Active disturbance and reclamation covariates were quantified as the percent of disturbance per landscape pixel (0-100% active disturbance or reclamation). The Landcover factor covariate represented areas categorized into discrete classes of undisturbed natural vegetation or disturbed (active disturbance + reclamation). A negative coefficient for Landcover factor indicates selection for undisturbed natural vegetation (coded as 0) and against disturbed areas (coded as 1). All covariates were modeled at a 30 x 30 m resolution. An NA indicates that the individual was not exposed to that covariate. A dash (—) indicates that the individual was exposed to that covariate but the covariate was not statistically supported.

Grouse Id	**Active disturbance (%)**	**Reclamation (%)**	**Landcover factor (categorical)**
Low-exposure hens	***β* (85% CI)**	***β* (85% CI)**	***β* (85% CI)**
HAR03	NA	NA	NA
PAR11	—	NA	-0.626 (-1.169, -0.083)
PAR17	—	NA	—
PAR20	-0.254 (-0.401, -0.107)	NA	—
RAH06	—	NA	-0.803 (-1.546, -0.059)
RAH15	—	NA	—
RAH24	—	-0.187 (-0.354, -0.021)	—
RAP03	—	—	—
RAP06	NA	NA	NA
RAP09	NA	NA	NA
High-exposure hens			
HAR06	—	NA	-0.775 (-1.338, -0.211)
HAR12	—	NA	—
HAR17	—	—	—
PAR09	NA	—	—
RAH08	—	NA	-0.314 (-0.608, -0.020)
RAP19	—	—	—

RAP25	-0.285 (-0.521, -0.049)	–	–
RAP27	0.181 (0.080, 0.281)	–	-0.379 (-0.614, -0.144)

Table 5.4: Beta coefficients and 85% confidence intervals (CI) for anthropogenic infrastructure covariates that were the most informative in our individual models for brood-rearing female sage-grouse. Power line viewshed represented the number of power poles that were visible from any given pixel on the landscape. Structure viewshed represented the number of infrastructure features, such as coal-bed natural gas (CBNG) wells and compressor stations, that were visible from any given pixel on the landscape. We calculated how many power poles or structures were visible within a 1.0 km viewshed distance. These covariates were modeled at a 30 x 30 m resolution. Reservoir distance represents linear distances to man-made reservoirs transformed using a decay function ($e^{-d/\alpha}$) where 100 was a decay constant (α) and d was the distance in meters from each pixel to the reservoir edge which allowed the effect to decay as distance to the reservoir increased. An NA indicates that the individual was not exposed to that covariate. A dash (—) indicates that the individual was exposed to that covariate but the covariate was not statistically supported.

Grouse Id	**Power line viewshed (count)**	**Structure viewshed (count)**	**Reservoir distance (decay)**
Low-exposure hens	**β (85% CI)**	**β (85% CI)**	**β (85% CI)**
HAR03	NA	NA	NA
PAR11	NA	—	NA
PAR17	-0.338 (-0.538, -0.138)	—	—
PAR20	0.206 (0.097, 0.316)	NA	NA
RAH06	-0.661 (-1.128, -0.194)	0.364 (0.220, 0.509)	NA
RAH15	NA	—	NA
RAH24	NA	—	NA
RAP03	NA	0.188 (0.062, 0.315)	NA
RAP06	NA	NA	—
RAP09	—	NA	—
High-exposure hens			
HAR06	NA	—	NA
HAR12	—	—	-14.220 (-24.639, -3.809)
HAR17	—	—	—
PAR09	NA	NA	NA
RAH08	—	-0.202 (-0.321, -0.083)	NA
RAP19	-0.338 (-0.476, -0.199)	—	—

RAP25	–	–	-2.331 (-4.496, -0.165)
RAP27	–	–	NA

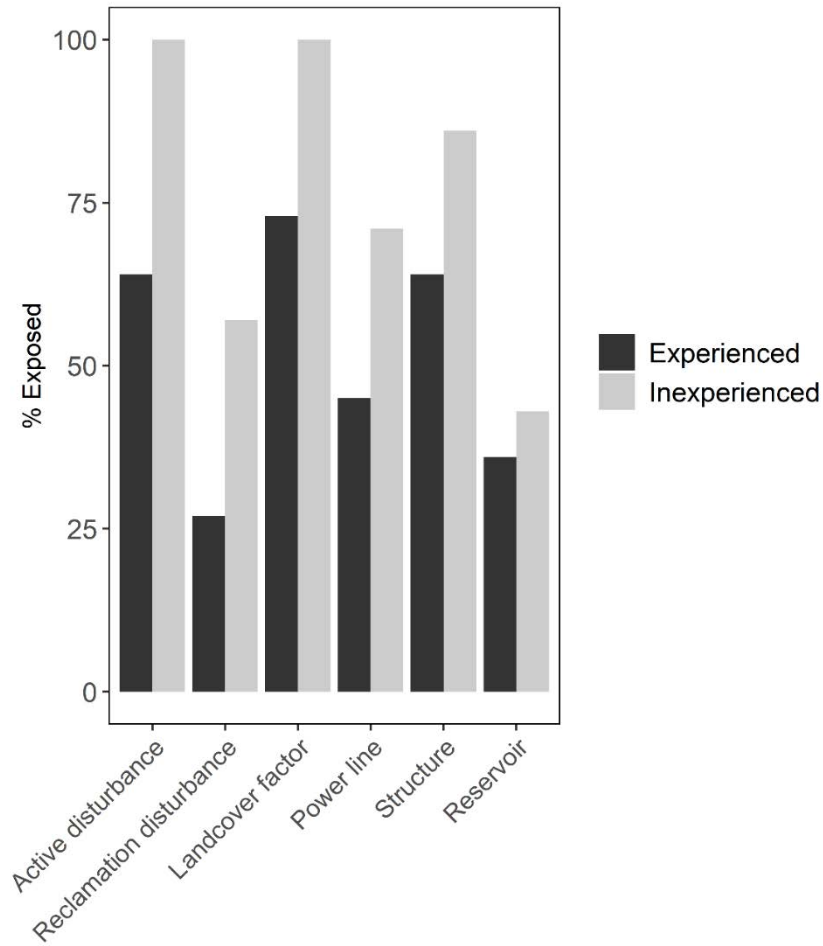


Figure 5.6: Comparison between the percent exposure of experienced (adult) and inexperienced (first year) brood-rearing greater sage-grouse to anthropogenic covariates within their availability domain in northeastern Wyoming, USA.

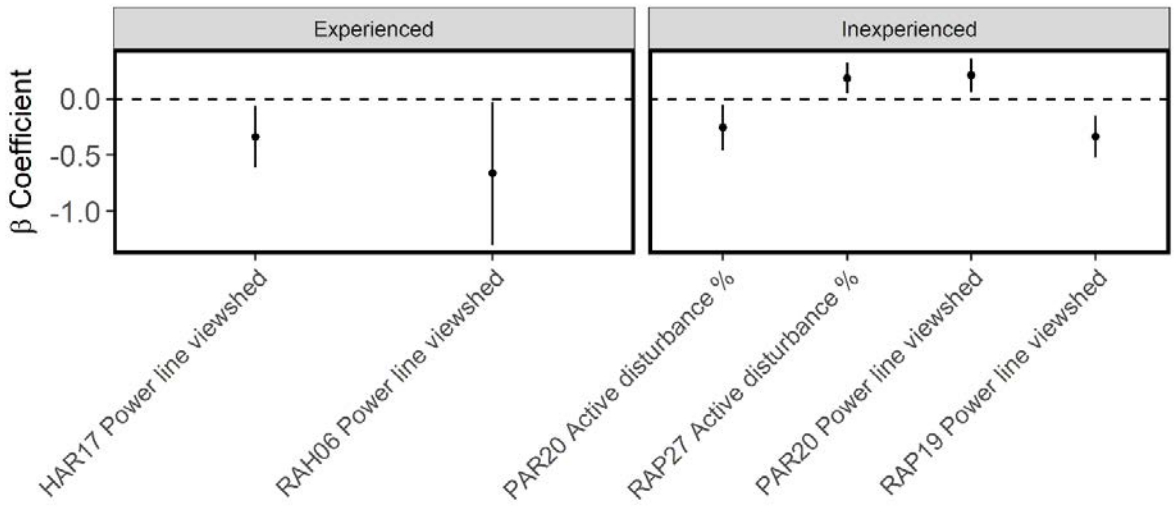


Figure 5.7: Beta coefficients and 85% confidence intervals (CI) for all individual models in which the covariates power line visibility and active disturbance were supported. Covariates plotted for experienced and inexperienced hens. Brood-rearing greater sage-grouse in northeastern Wyoming, USA.

5.5 Discussion

We evaluated several interrelated research questions using high-frequency relocation data from brood-rearing female sage-grouse in an energy development landscape. There was broad overlap between optimal brood-rearing habitat and CBNG development in our study area. Our findings reiterate the importance of contiguous sage-grouse habitat for brood-rearing females even if that habitat has been degraded by development. We did not find that individual differences in movements or home range sizes were explained by the amount of CBNG disturbance that brood-rearing females were exposed to at the level of the home range (high- and low-exposure females). Third-order habitat selection modeled at an individual-level reveled individual variability, but also consistent patterns of habitat selection and avoidance behaviors. Females consistently selected for natural landcover and avoided disturbed surfaces. Visible structures elicited different habitat selection responses. Power line visibility was generally negatively related to habitat selection, but visibility of shorter CBNG well structures did not seem to influence habitat selection. Our findings suggest that the age (adult or first year) of brood-rearing females explained some of the variability in home range (second-order) characteristics and third-order responses to development covariates.

5.5.1 Brood-rearing life stage

We assessed if the brood-rearing females in our study demonstrated distinct shifts in space-use patterns that would indicate two brood stages, early and late, between hatch and 40 days post-hatch. This step was necessary to accurately estimate home ranges and model third-order selection because others have suggested that hatch to about six weeks post-hatch could represent two distinct life stages (early and late brood-rearing; Atamian et al. 2010, Connelly et al. 2011*b*). Connelly et al. (2011*b*) suggested that early brood-rearing habitat is the habitat within the vicinity of the nest that is used by the brood-rearing females up to three weeks after hatching. We found no evidence supporting a two stage brood-rearing period or shifts in habitat use between 0-6 weeks after hatching. However, the majority of our brood-rearing home ranges were in close proximity or included the individual's nest site as described by Connelly et al. (2011*b*). This supports the hierarchical nature of the selection process by which female sage-grouse select nest sites (fourth-order) within larger areas (third- and second-order) that also provide resources needed to successfully raise chicks (Gibson et al. 2016). Our findings align with Hagen et al. (2007) that suggested female sage-grouse generally do not move from early to late brood-rearing habitats until after 6 weeks post-hatch; however, we did not evaluate brood-rearing female movements and space use after 6 weeks in this study. Furthermore, because our study population has been under energy development pressure for over a decade and is in a highly fragmented sagebrush landscape, we cannot rule out the possibility that the space-use patterns we observed were different from those that may have historically occurred in this population. Our results provide evidence that a temporally consistent pattern of early and late brood-rearing space use may not be uniform across the sage-grouse range and that a one-size-fits-all definition may not be prudent.

5.5.2 Home range, space use and movements

Contiguous sagebrush landcover is key to sage-grouse occupancy and survival at broad and fine spatial scales (Johnson et al. 2011*b*, Dinkins et al. 2014*b*, Fedy et al. 2014) and many studies have demonstrated that sage-grouse select for the flattest areas of sagebrush landcover available for nesting and brood-rearing (Fedy et al. 2015, Kirol et al. 2015*a*, Walker et al. 2016, Smith et al. 2018). Several of our brood-rearing home ranges were concentrated in the central portion of the study area. This area had more contiguous sagebrush landcover and gentler topography than the surrounding landscape (Figure 5.1). The central portion of our study area also contained the highest density of CBNG infrastructure. Energy development often targets areas of flatter terrain because development costs increase with topographic ruggedness (Walker et al. 2020). Walker et al. (2020) observed a similar energy development pattern in Colorado, USA where areas of sagebrush landcover with gentler topography, that also had disproportionately high sage-grouse use, were the areas experiencing the most development pressure (Walker et al. 2020). The overlap between energy disturbances and optimal nesting and brood-rearing habitat may be even more pronounced in our study area because it is characterized by rugged terrain and a patchy distribution of sagebrush landcover compared to much of the sage-grouse range (Fedy et al. 2014, 2015).

As expected, females in our study established brood-rearing home ranges in areas that were dominated by sagebrush landcover. The proportion of sagebrush landcover within individual home ranges averaged 77% and no individuals established home ranges in areas with less than 40% sagebrush landcover. The proportion of sagebrush landcover in our brood-rearing home ranges reiterates that, while access to food resources like insects and forbs are critical to chick production (Blomberg et al. 2013*a*), these resources need to be available in conjunction with adequate sagebrush cover (Cassaza et al. 2011, Connelly et al. 2011*b*, Smith et al. 2018).

Brood-rearing sage-grouse in our study established home ranges in areas that had 3.5% anthropogenic surface disturbance on average. This estimate included both active disturbance and reclamation. Kirol et al. (2020*a*) showed that during the reproductive life stages female sage-grouse, from multiple regions in Wyoming, USA, consistently occupied areas with less surface disturbance relative to what was available to them. Ninety percent of nesting and brood-rearing locations were in areas with < 3% disturbance within a ~3-km^2 area (Kirol et al. 2020*a*). Researchers have pointed to similar percentages of surface disturbance when studying impacts of energy disturbance on other sagebrush associated species. For instance, the presence and abundance of the pygmy rabbit (*Brachylagus idahoensis*) declined sharply once oil and gas surface disturbance reached 2% and mule deer (*Odocoileus hemionus*) rarely used areas with greater than 3% oil and gas disturbance during migration (Germaine et al. 2017, Sawyer et al. 2020).

We tested the hypothesis that brood-rearing females exposed to higher percentages of anthropogenic surface disturbance (high-exposure females) would demonstrate different movement and space-use patterns than those exposed to less disturbance (low-exposure females). Because sage-grouse with chicks are particularly sensitive to energy development (Aldridge and Boyce 2007, Kirol et al. 2015*a*), we suspected that females in areas with more disturbance would restrict their movements to avoid anthropogenic edge, such as graveled CBNG access roads and structures, such as power lines. For instance, research has demonstrated that power line corridors constrain movements of prairie-chickens (*Tympanuchus* spp. Pruett et al. 2009). We expected that restricted movements in highly disturbed areas would lead to smaller home ranges. However, we did not detect a difference in movements or home range sizes between low-exposure and high-exposure females. However, the distribution of energy development covariates were limited in two important ways in our study. First, almost all of our birds were exposed to energy development and therefore we did not have birds that raised their broods in a 'control' or unimpacted area. Ideally, to maximize our potential to detect a biological difference, we would compare brood-rearing females that were not exposed to any disturbance to females exposed to high percentages of disturbance.

5.5.3 Movement linked habitat selection

The movement related covariate (cos_ta) was supported in about 39% of our iSSA individual models. In all but one of these models a negative coefficient indicted that the female was generally turning back rather than moving forward. This is consistent with home range behavior in that females in our study had core areas within their home ranges and were generally turning back towards those core areas. When animals are migrating or dispersing this movement covariate (cos_ta) is consistently positive suggesting a forward-directional persistence (Prokopenko et al. 2017).

Many studies have documented the importance of sagebrush cover for brood-rearing sage-grouse (Cassaza et al. 2011); yet, sagebrush cover was only informative in one third of individual models. In the context of a hierarchal selection process, the minimal support for the sagebrush cover covariate in our third-order models was not surprising because iSSA models bound availability to what is available to that individual at that time. Since females in our study established home ranges (second-order) in areas that were dominated by sagebrush landcover the availability domains for the iSSA models were constrained to within areas of sagebrush cover. In the cases when sagebrush cover was informative, females were selecting for patches (900-m^2 area) of intermediate levels of sagebrush canopy cover. This selection for intermediate levels of sagebrush cover and not for the high and low cover extremes is consistent with previous research (Aldridge and Boyce 2007, Doherty et al. 2010, Kirol et al. 2015*a*).

Third-order selection for natural landcover (Landcover factor) and against disturbed surfaces (i.e., active or reclamation surfaces) was consistent across 33% percent of the females and no females showed a preference for disturbed surfaces. This finding concurs with much research demonstrating that females with chicks are highly reliant on natural sagebrush vegetation communities (Connelly et al. 2011*b*) and at local scales (third- and fourth-order), brood-rearing females select for structure, cover and food (Smith et al. 2018). In response to perceived risks related to human activity (e.g., vehicle traffic or industrial noise; Frid and Dill 2002, Blickley et al. 2011), we predicted that natural vegetation in combination with sagebrush cover might be more important to high-exposure than low-exposure females because these vegetation attributes provide refuge habitat for females and chicks and were generally more limited in areas with more surface disturbance. However, our results suggested there was similar support for sagebrush cover and natural vegetation covariates in our high-exposure and low-exposure female models.

Our findings did not provide evidence that brood-rearing females were treating reclamation surfaces differently than active surfaces. However, only 39% of brood-rearing females in our study were exposed to reclaimed surfaces so our sample size was limited. The proportion of reclamation per area was only informative in one individual model and this female was selecting against areas (900 m^2) with more reclamation surface. It can take big sagebrush >80 years to naturally reestablish on disturbed surfaces (Avirmed et al. 2015). Therefore, the reclaimed surfaces in our study represent early-stage reclamation (≤10 years since the surface was reclaimed). Pipeline corridors were the primary reclamation surface within our brood-rearing home ranges and these reclaimed surfaces were often in close proximity to active development making it difficult to tease out effects of reclamation on habitat-selection patterns of female sage-grouse. More research is needed to better understand the relationship between reclaimed surfaces and sage-grouse habitat selection, especially in areas where entire landscapes have been reclaimed and the human activity component of energy disturbance has subsided (sensu Barlow et al. 2020).

Visible structures were not universally related to avoidance behavior in our study. We found greater power line visibility often elicited an avoidance response in brood-rearing females, but visible CBNG well structures generally did not. Thirty percent of the individuals exposed to power lines were less likely to use areas with greater power line visibility and as the amount of power lines visible from an area increased the probability of selection of that area decreased. Dinkins et al. (2014*b*) found the density of power lines within a 1-km^2 area was negatively related to female sage-grouse survival. They concluded that reduced survival was likely a consequence of power lines acting as perching structures for raptors (Dinkins et al. 2014*b*). Others have shown that power lines also provide perching structures for common ravens (*Corvus corax*) that depredate sage-grouse nests and chicks (Hagen 2011, Coates et al. 2014, Gibson et al. 2018). Several species of raptors were common in our study area (sensu Tack and Fedy 2015). Common ravens were uncommon during our study but ravens are currently expanding into this region (Kirol et al. 2015*b*, *unpublished data*). Brood-rearing females in our study may have recognized the increased risk of using habitats near power lines. In our study we demonstrated that brood-rearing sage-grouse avoid areas ≤1 km from power line corridors. Therefore, the ecological footprint was much larger than the actual disturbance footprint of power lines because of the functional habitat loss due to avoidance behavior. Previous studies have shown sage-grouse avoid otherwise suitable habitat when power lines are introduced and this avoidance can sometimes extend 4 km from power line corridors

(Dinkins et al. 2014*b*, Lebeau et al. 2019). The avoidance of power lines may be common in prairie grouse (Pruett et al. 2009, Hovick et al. 2014).

CBNG wells in our study area were generally small buildings (~2x2 m structure) and approximately two meters tall with instruments that rose another one meter above the building. Thus, they were much shorter than power lines (~24 m) and provided limited perching opportunities. Our inference about taller CBNG infrastructure, such as compressor or pumping stations (5-8 m tall), was limited because female home ranges were rarely within 1 km (viewshed distance) of these structures and only one female had a compressor or pumping station within her home range and it was only slightly within her home range (i.e., outside the 98% isopleth). While 72% of our brood-rearing females were within a 1 km viewshed distance of CBNG wells, our results suggested there was no relationship between well visibility and habitat selection for the majority of the individual models and two individuals showed a positive relationship between CBNG well visibility and habitat selection. Collectively, these results suggest that visibility of CBNG wells were not predictive of third-order selection of brood-rearing females. This finding is in contrast to Kirol et al. (2015*a*) that found the likelihood of an area being used by brood-rearing females declined as the number of visible CBNG wells increased.

An important consideration is the stage of energy development in our study (production phase). When we began putting transmitters on birds, the CBNG infrastructure had been in place for >10 years. Because of a reduction in traffic, heavy machinery (e.g., drilling rigs), industrial noise and human presence, the environment experienced by the animals is much different during the production phase than during the development phase (Ingelfinger and Anderson 2004, Sawyer et al. 2009, Holloran et al. 2015). Like the majority of wildlife impact studies, the Kirol et al. (2015*a*) study was conducted when an area was first being developed for CBNG reserves (development phase). We suspect that the avoidance of visible CBNG wells identified by Kirol et al. (2015*a*) may have more to do with the human activity associated with those wells than the ~3 m tall structure. Therefore, the different phase of development between this study and our current study may partially explain the differences observed in avoidance behavior of brood-rearing females. Prey have evolved antipredator behavioral responses to perceived threats, such as loud noises and rapidly approaching objects (Frid and Dill. 2002). Vehicles can lead to antipredator responses in many animals and avoidance behavior is an example of an antipredator response (Frid and Dill 2002, Lyon and Anderson 2003). Studies have demonstrated that sage-grouse and other bird species respond negatively to vehicle traffic in energy development landscapes; however, these negative responses may be reduced with lower traffic volumes (Lyon and Anderson 2003, Ingelfinger and Anderson 2004, Holloran 2005). During the production phase of energy development vehicle traffic can be as high as 75 vehicles per hour (Ingelfinger and Anderson 2004). Sawyer et al. (2009) recorded 112 vehicles passing per day accessing well pads that were being drilled in a natural gas field in southern, Wyoming, USA. During our study, vehicle traffic recorded on a main haul road ─ main road that branched off into multiple well access roads ─ that bisected one of our brood-rearing home ranges averaged 21 vehicles passing per day during the brood-rearing period (*unpublished data*).

We were able to quantify patterns of variability across age classes in the response of female sage-grouse to energy development that would not have been apparent if we were pooling all individuals in population-level models. For instance, while selecting brood-rearing habitat the only females that did not avoid areas with greater power line visibility or higher percentages of active disturbance were first year females. At the level of the home range (second-order), first year females were also more likely than adult females to be exposed to CBNG features including power lines, well structures and man-made reservoirs, because they were more likely to establish home ranges in areas with anthropogenic disturbance. Other research has shown that an animals age and experience can influence habitat selection and space use. Cresswell (1994) showed that juvenile redshank (*Tringa tetanus*) primarily feed on saltmarshes while adults primarily feed on mussel beds. The saltmarshes were riskier habitats and; consequently, juvenile redshanks experienced more predation than the adults. Based on previous experiences, birds will modify their habitat-selection patterns to avoid predation of themselves, nests, or dependent young (Lima 2009). Therefore, it is possible that inexperienced female sage-grouse do not recognize the risk associated with brood-rearing in areas with more power lines and more anthropogenic habitat fragmentation, while experienced females have learned that these areas are riskier.

5.5.4 Conclusions

Optimal brood-rearing habitat is limited for female sage-grouse in our study area and the optimal habitats contained a high density of energy disturbance. Within these development landscapes females established home ranges in areas that contain more contiguous sagebrush landcover and fewer CBNG features.

Individual-level selection analyses conducted at the third-order helped us uncouple some aspects of energy development that influence habitat selection that likely would not have been detected at broad spatial scales (e.g., second-order). For instance, female brood-rearing sage-grouse did not respond the same to all structures. Power lines generally lead to avoidance behavior; however, 3 m tall CBNG wells did not. Even though most of the brood-rearing females were in close proximity to active and reclamation surface disturbance within their home ranges, they selected for natural vegetation and avoided disturbed surfaces at fine spatial scales. As a whole there was more individual variability in our third-order habitat selection models than expected. Therefore, our results do not support individual uniformity in brood-rearing sage-grouse. We found that first year females were more likely than adults to not demonstrate avoidance at the third-order of selection and were also more likely to establish home ranges in areas with CBNG features. We suggest that individual variation between adults and first year females may be explained by the previous experience of the landscape by the adults leading to selection for less risky habitats. However, more research is needed to better understand drivers of individual variation in female sage-grouse. It is not feasible for management and conservation to occur at an individual level; however, we demonstrate that it is important to understand there is variation in individual sage-grouse within populations. Furthermore, these findings reiterate the importance of accounting for, or at least recognizing, individual variability in population-level modeling efforts (Duchesne et al. 2010).

Chapter 6
Discussion

Our research represented management-oriented science related to the conservation of sagebrush associated species. We used a sagebrush-obligate songbird, the Brewer's sparrow (*Spizella breweri breweri*), and the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) to address question related to habitat selection, space use, reproductive rates and movements in an established coal-bed natural gas (CBNG) field. This CBNG field was developed over a decade ago and during our study some wells were at the end of their production life and undergoing site reclamation. Most studies of wildlife and energy development impacts are conducted when the development is first occurring and, thus is novel to the co-occurring species. However, the birds in our study represented multiple generations that have been exposed to CBNG development. We uncoupled the components of CBNG development into specific infrastructure features and surface disturbance covariates, such as active disturbance and reclamation, to gain a better understanding of responses of these species to the different components of energy development (e.g., power lines or CBNG well structures) and site reclamation. The individual-based models we used in our sage-grouse analysis helped us better understand individual variability in responses to CBNG features. We suggested that individual variability we observed was partially explained by the age and experience of the female sage-grouse. We hope this information will help focus mitigation efforts on the components of energy development that have the greatest negative impacts on sagebrush-obligate birds.

6.1 Sage-grouse tracking and capturing advances

Our research objective required capturing female sage-grouse to attach GPS transmitters (i.e., tags). In Chapter 2, we describe a method of capturing sage-grouse that proved to be effective in our study area, that contains a low density of sage-grouse, and minimized capturing impacts when compared to other commonly used capturing techniques.

The sage-grouse tag (hybrid tag) and harness we describe in Chapter 3 was designed to be cost-effective and to reduce impacts of fitting rump-mounted tags on sage-grouse while also providing the high-resolution GPS location data that we needed to address our research questions. Research that requires tracking animals, needs to be able to securely attach tags in a way that does not harm the animal or affect the animal's behavior (Barron et al. 2010). Fitting tags on birds may have deleterious effects depending on a variety of factors such as the attachment method and the proportionate mass of the tag (Barron et al. 2010, Fair et al. 2010). However, there is a general consensus that potential detrimental effects of tags fitted on birds are reduced with proportionally lighter tags (Fair et al. 2010, Vandenabeele et al. 2012). Necklace-style (hereafter necklace) very-high frequency (VHF) tags have been used on sage-grouse and other Galliformes for decades and there is abundant information on possible effects of these tags on behavior and survival. Of note, early research suggested not using necklace tags on male sage-grouse because of interference with the air sacs used in lekking displays (Amstrup 1980); therefore, my comparisons below only reference research of female sage-grouse fitted with necklace tags. Rump-mounted solar tags are a fairly new tracking method used in sage-grouse research (Bedrosian and Craighead 2010) and there is little information available on how these type of tags may affect sage-grouse behavior and survival.

Like all species of Galliformes, sage-grouse are targeted by a variety of raptor and mammalian predators and predation is the leading cause of adult mortality usually accounting for greater than 90% of deaths (Blomberg et al. 2013*b*). Therefore, research focused on potential impacts of tags on sage-grouse survival are really trying to understand if individuals fitted with tags are at higher predation risk than those that are not fitted with tags (Frye et al. 2014). It is difficult to uncouple 'natural' survival rates in sage-grouse from survival rates of tagged sage-grouse because of the challenges in collecting the data necessary to estimate survival rates when birds are not tagged. However, there is some research available on annual survival that used leg band recovery data (Zablan et al. 2003). The annual survival rates they report are very similar to survival estimates reported by numerous studies that used necklace tags on female sage-grouse (Schroeder et al. 1999, Zablan et al. 2003, Connelly et al. 2011*a*). Hagen et al. (2006) studied another gallinaceous bird, the lesser prairie-chickens (*Tympanuchus pallidicinctus*), found that survival estimates of birds fitted with necklace tags were not different than non-tagged birds that were banded. Research on flushing behavior in sage-grouse found no difference in flushing order (flushing earlier or later than flock mates) between necklace tagged and non-tagged birds (Frye et al. 2014). The large amount of information available on necklace tags used in sage-grouse research suggests that these type of tags do not contribute to increase predation risk or significantly alter sage-grouse behavior.

However, there is much less information available on potential effects of rump-mounted tags on survival and behavior of sage-grouse and other Galliformes. This can be attributed to the fact that solar GPS units light enough to attach to gallinaceous birds are a recently developed technology (Bridge et al. 2011). Studies that we are aware of that have evaluated potential impacts of rump-mounted tags on sage-grouse were all using Argos satellite relay tags (hereafter Argos tags). The hybrid tags we attached to female sage-grouse in our research were similar to the Argos tags in many ways and both are attached to birds using a rump-mounted harness system. However, the hybrid tag we developed was slightly lighter

(≤4 g; lower tag-to-body mass ratio) than Argos tags, commonly used in female sage-grouse studies, and the hybrid tag did not have a ridged antenna protruding from the back of the unit as do Argos tags (Severson et al. 2019).

Some of the earliest research that used rump-mounted Argos tags on sage-grouse found that sage-grouse fitted with rump-mounted tags did not experience increased mortality when compared to sage-grouse fitted with conventional necklace tags (Bedrosian and Craighead 2010). Bedrosian and Craighead (2010) concluded that rump-mounted tags had minimal impacts on sage-grouse in their study. Foster et al. (2018) suggest that sage-grouse with rump-mounted tags may have had slightly reduced survival (~5%) compared to those with necklace tags but the results were inconclusive because of marginal statistical support. A recent study conducted by Severson et al. (2019) found that female sage-grouse fitted with necklace tags had median survival estimates that were 1.08 to 1.19 times greater than those fitted with rump-mounted Argos tags. Their results also suggested that proportionally heavier (tag-to-body mass ratio) rump-mounted tags lead to lower survival (Severson et al. 2019).

Further studies are needed to gain a better understanding of potential effects of attaching rump-mounted tags to sage-grouse. This information is critical to help researchers weigh the cost and benefits of fitting sage-grouse with rump-mounted tags, especially in areas where sage-grouse numbers are low.

6.2 Brewer's sparrow

6.2.1 Caveats, research considerations and future research

Survival analyses are particularly sensitive to sample sizes and, more importantly, the numbers of events of interest), such as nest failure in our study (Concato et al. 1995, Hosmer and Lemshow 2008). More events per explanatory covariate increase the power of the analysis to detect influential covariates and improve the precision of estimates and error terms (Concato et al. 1995, Hosmer and Lemshow 2008). Our Brewer's sparrow nest survival analysis (Chapter 4) had a robust sample size broadly (n = 107 nests, n = 50 events [nest failures]) but sample sizes and corresponding events were more limited when we modeled specific anthropogenic covariates of interest, like the proportion of active disturbance per scale. For instance, we found a relationship between the proportion of active disturbance within 50 m radius of a Brewer's sparrow nest site and nest survival. Yet, this relationship was only informed by ten events (n = 23 nests). Therefore, a larger sample size of nests that were associated with the anthropogenic covariates of interest in this research (e.g., active disturbance, reclamation and power lines) would have benefited our survival modeling and resulted in greater precision in our estimates and error terms (i.e., tighter confidence intervals). The distribution of nest sites in our study suggest that Brewer's sparrows were, on average, avoiding placing nests in areas with higher proportion of habitat disturbance which acted to limit our sample sizes in regards to the anthropogenic covariates of interest. However, we may have been able to increase sample size of nests relative to disturbance covariates if we targeted additional areas that were proximate to active disturbance, reclamation and power lines when nest searching.

Nest productivity is a critical component of population persistence in birds and nest predation is the primary cause of nest failure (Saether and Bakke 2000, Chalfoun et al. 2002, Ibáñez-Álamo et al. 2015). Our work in Chapter 4 and other research demonstrate that anthropogenic development and habitat fragmentation may lead to co-occurring songbird nests being at increased risk of predation (Winter et al. 2000, DeGregorio et al. 2014, Hethcoat and Chalfoun 2015*b*, Bernath-Plaisted and Koper 2016). In disturbed sagebrush habitats, there is limited information on the nest predator component that are responsible for these lower nest survival rates (Sanders and Chalfoun 2019). More research is needed that focuses on nest predators in sagebrush habitats to gain a more mechanistic understanding of why nest predators are more likely to locate and depredate bird nests in association with anthropogenic disturbance. Changes in nest survival might be explained by different predator communities and predator abundance in disturbed habitats (Hethcoat and Chalfoun 2015*b*) or the expansion of novel predators that may be benefiting from human subsidies (Howe et al. 2014, Kirol et al. 2018). Reduced nest survival could also be explained by native predators gaining a competitive advantage in sagebrush habitats that have been fragmented by anthropogenic development which has been demonstrated in forest and grassland ecosystems (Winter et al. 2000, Chalfoun et al. 2002, Vander Haegen 2007).

Reclamation surfaces in our study, represented early-stage reclamation; therefore, the primary difference between disturbances that had been reclaimed and those that had not been reclaimed was that reclaimed surfaces no longer had the CBNG infrastructure and, instead of gravel roads or compacted surface well pads, contained seeded grass and forb ground cover. Our findings in Chapter 4 suggest that Brewer's sparrow nest survival is lower when nests are exposed to higher levels of active disturbance but when nests are exposed to comparable proportions of reclamation there was no effect on nest survival. This finding suggests that the removal of infrastructure and the human activity component (e.g., vehicle traffic to monitor wells) changed the relationship to nest survival. Therefore, another important avenue of research is how nest predator communities respond to reclamation and infrastructure removal. Specifically addressing the question, if some nest predators are benefiting from human subsidies, such as perching structures, do they lose their competitive advantage if these structures are removed?

Sage-grouse are often considered an umbrella species for other sagebrush dependent wildlife (Rowland et al. 2006, Hanser and Knick 2011). The umbrella species concept assumes that protection of one species provides benefits to other naturally co-occurring species (Roberge and Angelstam 2004). With sage-grouse, the assumption is that by conserving sage-grouse habitat you are also benefiting other sagebrush associated species under its umbrella (Hanser and Knick 2011). For the umbrella species concept to be effectively applied, habitat requirement of species under the sage-grouse umbrella need to be well understood (Hanser and Knick 2011, Barlow et al. 2019). The umbrella species concept, like habitat selection, is scale dependent. For instance, the sage-grouse has been shown to be an effective umbrella for sagebrush associated songbirds at broad spatial scales (first- and second-order selection; Hanser and Knick 2011, Carlisle et al. 2018*b*) but much less is known about its effectiveness local scales (third- and fourth-order; Barlow et al. 2019). Barlow et al. (2019) found that Brewer's sparrows and sage-grouse select for some similar habitat attributes at the nest site but also some different attributes. They conclude that, fine-scale habitat management for sage-grouse as a proxy for conservation of other species may be justified if the microhabitat preferences of the species under the umbrella are understood to avoid unintentional negative effects (Barlow et al. 2019). More research is needed to understand fine-scale habitat preferences and habitat partitioning of bird species that nest in sagebrush habitats and that fall under the sage-grouse umbrella. For example, we observed a large diversity of nesting birds within relatively small sagebrush patches in our study area. In our 0.25 km^2 nest searching plots (Chapter 4) across the three years of our study (2016-2018), we discovered nest of Brewer's sparrow, Brewer's blackbird (*Euphagus cyanocephalus*), common nighthawk (*Chordeiles minor*), sage-grouse, short-eared owl (*Asio flammeus*), lark bunting (*Calamospiza melanocorys*), lark sparrow (*Chondestes grammacus*), loggerhead shrike (*Lanius ludovicianus*), mallard (*Anas platyrhynchos*), mourning dove (*Zenaida macroura*), sage thrasher (*Calamospiza melanocorys*), spotted towhee (*Pipilo maculatus*), vesper sparrow (*Anas platyrhynchos*) and western meadowlark (*Sturnella neglecta*; *unpublished data*).

6.3 Sage-grouse

6.3.1 Caveats, research considerations and future research

In Chapter 5, we modeled third-order selection of female sage-grouse during the brood-rearing life stage because the ability of females to successfully raise chicks to independence is critical to sage-grouse population persistence and research has demonstrated that brood-rearing females are particularly sensitive to energy development (Aldridge and Boyce 2007, Kirol et al. 2015*a*). By using the integrated step selection analysis (iSSA) we were able to assess third-order selection of individuals while simultaneously accounting for the movement process. However, because the majority of females in our study were fairly localized during the brood-rearing period and, on average, not moving far (e.g., short step lengths) the iSSA analysis had less power to identify movement relationships relative to environmental and anthropogenic covariates. When animals are moving they are more likely to move through a greater diversity of landcover types and encounter a variety of anthropogenic features and disturbances. The ideal application of iSSA is when animals are moving or dispersing because one is able to learn more about the environmental and anthropogenic factors that are affecting the movement process. For example, Scrafford et al. (2018), using iSSA, found that wolverines (*Gulo gulo luscus*) increased their movements near roads and their movements increased even more when they encountered higher traffic roads. Dickie et al. (2019) found that moose (*Alces alces*), black bear (*Ursus americanus*) and wolf (*Canus lupus*) exhibited the slowest movements when they were traveling through undisturbed habitats and fastest movements when traveling in areas with anthropogenic linear features such as seismic lines and roads. Applying the iSSA model to a life stage when sage-grouse are dispersing like when they are transitioning to winter range (Fedy et al. 2012) would likely allow for more insight into anthropogenic and environmental factors that are affecting the movement process in sage-grouse.

Comparisons to previous studies of impacts of energy development on sage-grouse suggest that brood-rearing sage-grouse in this population may be exhibiting less avoidance behavior towards infrastructure features, notably well structures (Holloran et al. 2010, Kirol et al. 2015*a*). In Chapter 5, we hypothesize that the phase of development (e.g., development or production phase) may partially explain the reduced avoidance of visible CBNG well structures we observed when compared to other studies that were conducted when the development was first occurring (i.e., more human activity and greater traffic volumes during the development phase). However, there may be more than one factor at work here. For instance, there could be less avoidance due to lower levels of human activity during the production phase as well as a degree of habituation that might be occurring in our study population.

The sage-grouse population we studied had been exposed to energy development for >10 years when this study was initiated. Therefore, female sage-grouse in our study represent multiple generations that have nested or raised chicks in this development landscape. Therefore, the idea that there may be a level of habituation occurring is a possibility that warrants further research. In the context of anthropogenic development, habituation assumes that negative behavioral responses exhibited by animals (e.g., avoidance behavior) towards novel features, such as oil and gas wells, may gradually dissipate over time (Blumstein 2016, Sawyer et al. 2017). It is important to note, however, that habituation does not imply population fitness because human-altered landscapes can lead to lower reproductive rates and may act as ecological traps for many animals including sage-grouse (Robertson and Hutto 2006, Aldridge and Boyce 2007, Kirol et al. 2020*a*).

In Chapter 5, we quantified landcover and surface disturbance (i.e., active and reclaimed disturbances that quantified the direct loss of natural vegetation) within brood-rearing home ranges. The distribution of the home ranges in our study and our findings related to landcover and surface disturbance within these home ranges lead to questions about selection occurring at broader spatial scales. The logical next step in our research is to evaluate selection at the home range level (i.e., second-order selection) during the brood-rearing life stage to better understand brood-rearing female tolerance related to surface disturbance and infrastructure features at a higher order of selection (Holbrook et al. 2017). For instance, even though there were compressor stations distributed throughout the study area we only had one brood-rearing female that had a compressor station within her home range and the compressor station was only slightly within her home range (i.e., outside the 98% isopleth). A second-order analysis should help us understand if this was random or if brood-rearing females were actively avoiding compressor stations when establishing home ranges.

Federal and state management agencies are increasingly focusing on surface disturbance caps to regulate disturbance within the sagebrush ecosystem and to mitigate impacts on sage-grouse and other sagebrush associated wildlife. For example, the Wyoming Core Area policy caps surface disturbance to 5% when development projects occur within Core Areas. Core Areas are areas previously identified as containing high sage-grouse breeding population densities (Doherty et al. 2011). However, not all areas identified as sage-grouse core population areas by Doherty et al. (2011) were included as Core Areas in the state and federal management plans (BLM 2015, State of Wyoming 2019, Kirol et al. 2020*a*). The south central portion of our study area contained the majority of brood-rearing home ranges. This area is an example of an area identified through science as a sage-grouse population core area that was not included as a Core Area in the Core Area policy (Doherty et al. 2011, BLM 2015, State of Wyoming 2019). Therefore, this area provides a unique opportunity to evaluate possible thresholds of tolerance of brood-rearing females to varying levels of surface disturbance. In Chapter 5, we found that the proportion of surface disturbance averaged 3.59% across individual home ranges. Research using peak male sage-grouse lek counts as a population index, demonstrated that surface disturbance >3% led to local sage-grouse population declines (Knick et al. 2013). Through previous research that occurred in this same region we know that of surface disturbance levels exceed 3.59% in much of our study area (Kirol et al. 2020*a*); therefore, female sage-grouse with chicks may, on average, be selecting home ranges in patches of sagebrush with lower levels of disturbance relative to what is available to them. A second-order selection analysis would help us understand if selection for home ranges with lower proportions of disturbance is occurring and identify the remaining lower disturbance sagebrush areas that are suitable brood-rearing habitats.

In our analysis we separated disturbance into active disturbances and reclamation. Active disturbances were areas stripped of vegetation that remain devegetated or are partially vegetated with interim reclamation seed mixes such as graveled access roads and well pads (Figure A3). Reclamation included areas without above ground infrastructure that had been revegetated with reclamation seed mixes but were largely devoid of sagebrush (Figure A4). One brood-rearing female in our study established a home range in an area that had a level of surface disturbance (14.65%) that was almost four times as high as the average surface disturbance across all individuals (3.59%). A large portion of surface disturbance within this individual's home range was reclamation (5.33%). This female was an outlier but raises questions about tolerance levels related to different types of surface disturbance. That is, would this female have established a home range in this area if all of this disturbance was active disturbance? A second-order selection analysis would allow for greater inference into possible differences in responses to reclaimed versus active disturbances (Holbrook et al. 2017). In our third-order selection analysis (Chapter 5), we did not find evidence that female sage-grouse were responding differently to active disturbances and reclamation surfaces during the brood-rearing period. However, at broader spatial scales (i.e., second-order) we may observe different responses to reclamation and active disturbance.

Animal occurrence considered alone can be a misleading indicator of population fitness in human-altered landscapes (Van Horne 1983, Robertson and Hutto 2006). Research is needed in northeastern Wyoming that seeks to identify source habitats that are creating a surplus of individuals before these areas are degraded further by energy development or other anthropogenic disturbances (Pulliam and Danielson 1991, Kirol et al. 2015*a*). This information is need to focus conservation efforts on these sage-grouse nurseries that are critical to the persistence of sage-grouse in this region.

6.1 Final remarks

Given the continued energy development pressures on the sagebrush ecosystem, developing best management practices and using adaptive management approaches that are based on science will be essential to maintain wildlife species that are dependent on sagebrush habitat (Boyce et al. 2011, Naugle et al. 2011, Nichols et al. 2015). Our study helped advance capturing and tracking technologies that are transferable to a variety of other bird species and research. Our study filled in knowledge gaps related to the response of sagebrush nesting birds to post-development reclamation and active energy development.

Our individual-level models helped us better understand sage-grouse habitat selection, space use, movements in an established natural gas field and during a critical reproductive life stage for sage-grouse.

References

Aldridge C. L., and R. M. Brigham. 2002. Sage-grouse nesting and brood habitat use in southern Canada. Journal of Wildlife Management 66:433–444.

Aldridge, C. L., and M. S. Boyce. 2007. Linking occurrence and fitness to persistence: Habitat-based approach for endangered greater sage-grouse. Ecological Applications 17:508–526.

Aldridge, C. L., D. J. Saher, T. M. Childers, K. E. Stahlnecker, and Z. H. Bowen. 2012. Crucial nesting habitat for Gunnison sage-grouse: a spatially explicit hierarchical approach. Journal of Wildlife Management 76:391–406.

Aldridge, H. D. J. N., and R. M. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% "rule" of radio-telemetry. Journal of Mammalogy 69:379–382.

Allred, B. W., K. W. Smith, D. Twidwell, J. H. Haggerty, S. W. Running, D. E. Naugle, and S. D. Fuhlendorf. 2015. Ecosystem services lost to oil and gas in North America: net primary production reduced in crop and rangelands. Science 348:401–402.

Amstrup, S. C. 1980. A radio-collar for game birds. Journal of Wildlife Management 44:214–217

Andersen, M. A., R. H. Coupal, and B. White. 2009. Reclamation costs and regulation of oil and gas development with application to Wyoming. Western Economics Forum 8:40–48.

Anderson, J. E., and R. S. Inouye. 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. Ecological Monographs 71:531–556.

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355–366.

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's information criterion. Journal of Wildlife Management 74:1175–1178.

Atamian, M. T., J. S. Sedinger, J. S. Heaton, and E. J. Blomberg. 2010. Landscape-level assessment of brood rearing habitat for greater sage-grouse in Nevada. Journal of Wildlife Management 74:1533–1543.

Avgar, T., J. R. Potts, M. A. Lewis, and M. S. Boyce. 2016. Integrated step selection analysis: Bridging the gap between resource selection and animal movement. Methods in Ecology and Evolution 7:619–630.

Avirmed, O., W. K. Lauenroth, I. C. Burke, and M. L. Mobley. 2015. Sagebrush steppe recovery on 30–90-year-old abandoned oil and gas wells. Ecosphere 6:art115.

Back, G. N., M. R. Barrington, and J. K. McAdoo. 1987. Sage grouse use of snow burrows in northeastern Nevada. Wilson Bulletin 99:488–490.

Baker, M. F., R. L. Eng, J. S. Gashwiler, M. H. Schroeder, and C. E. Braun. 1976. Conservation committee report on effects of alteration of sagebrush communities on the associated avifauna. The Wilson Bulletin 88:165–171.

Baker, W. L. 2011. Pre-euro-american and recent fire in sagebrush ecosystems. Studies in Avian Biology 38:185–201.

Barlow, N. L., C. P. Kirol, K. E. Doherty, and B. C. Fedy. 2019. Evaluation of the umbrella species concept at fine spatial scales. The Journal of Wildlife Management 84:237–248.

Barlow, N. L., C. P. Kirol, and B. C. Fedy. 2020. Avian community response to landscape-scale habitat reclamation. Biological Conservation 252:108850.

Barron, D. G., J. D. Brawn, and P. J. Weatherhead. 2010. Meta-analysis of transmitter effects on avian behaviour and ecology. Methods in Ecology and Evolution 1:180–187.

Bayne, E. M. and B. C. Dale. 2011. Effects of energy development on songbirds. Pages 95–114 *in* D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington D.C., USA.

Beck, T. D. I., and C. E. Braun. 1978. Weights of Colorado sage grouse. American Ornithological Society 80:241–243.

Bedrosian, B., and D. Craighead. 2010. Solar powered GPS transmitter use on sage-grouse: methods of attachment, influences on survival, and success rate of the transmitters. Unpublished report. <https://www.fs.fed.us/t-d/programs/im/satellite_gps_telemetry/_assets/Grouse%20GPS%20Attachment_Craighead%20Beringia%20South.pdf>. Accessed 3 Sept. 2018.

Bedrosian, B., D. Craighead, and K. A. Engel. 2007. Evaluation of techniques for attaching transmitters to common raven nestlings. Northwestern Naturalist 88:1–6.

Bernath-Plaisted, J., and N. Koper. 2016. Physical footprint of oil and gas infrastructure, not anthropogenic noise, reduces nesting success of some grassland songbirds. Biological Conservation 204:434–441.

Blakey, R. V., R. B. Siegel, E. B. Webb, C. P. Dillingham, M. J. Johnson, and D. C. Kesler. 2020. Multi-scale habitat selection and movements by northern goshawks (*Accipiter gentilis*) in a fire-prone forest. Biological Conservation 241:108348.

Blickley, J. L., D. Blackwood, and G. L. Patricelli. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. Conservation Biology 26:461–471.

Blickley, J. L., K. R. Word, A. H. Krakauer, J. L. Phillips, S. N. Sells, C. C. Taff, J. C. Wingfield, and G. L. Patricelli. 2012. Experimental chronic noise is related to elevated fecal corticosteroid metabolites in lekking male greater sage-grouse (*Centrocercus urophasianus*). PLoS ONE 7:e50462.

Blomberg, E. J., J. S. Sedinger, M. T. Atamian, and D. V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. Ecosphere 3(6):e00304.

Blomberg, E. J., D. Gibson, J. S., Sedinger, M. L. Casazza and P. S. Coates. 2013b. Intraseasonal variation in survival and probable causes of mortality in greater sage-grouse (*Centrocercus urophasianus*). Wildlife Biology 19:347–357.

Blomberg, E. J., S. R. Poulson, J. S. Sedinger, and D. Gibson. 2013a. Prefledging diet is correlated with individual growth in greater sage-grouse (*Centrocercus urophasianus*). Auk 130:715–724.

Blumstein, D. T. 2016. Habituation and sensitization: new thoughts about old ideas. Animal Behaviour 120:255–262.

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. H. Stevens and J. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24:127–135.

Börger, L., B. D. Dalziel, and J. M. Fryxell. 2008. Are there general mechanisms of animal home range behaviour? A review and prospects for future research. Ecology Letters 11:637–650.

Boyce, M. S. 2011. Forward. Pages ix–xi *in* D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington D.C., USA.

Bridge, E. S., K. Thorup, M. S. Bowlin, P. B. Chilson, R. H. Diehl, R. W. Fléron, P. Hartl, R. Kays, J. F. Kelly, W. D. Robinson, and M. Wikelski. 2011. Technology on the move: recent and forthcoming innovations for tracking migratory birds. BioScience 61:689–698.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, USA.

Bush, K. L. 2008. A pressure-operated drop net for capturing greater sage-grouse. Journal of Field Ornithology 79:64–70.

Caccamise, D. F., and R. S. Hedin. 1985. An aerodynamic basis for selecting transmitter loads in birds. Wildlife Society Bulletin 97:306–318.

Calabrese, J. M., C. H. Fleming, and E. Gurarie. 2016. ctmm: an R package for analyzing animal relocation data as a continuous-time stochastic process. Methods in Ecology and Evolution 7:1124–1132.

Carlisle, J. D., A. D. Chalfoun, K. T. Smith, and J. L. Beck. 2018*a*. Nontarget effects on songbirds from habitat manipulation for Greater Sage-Grouse: Implications for the umbrella species concept. Condor 120:439–455.

Carlisle, J. D., D. A. Keinath, S. E. Albeke, and A. D. Chalfoun. 2018*b*. Identifying holes in the greater sage-grouse conservation umbrella. Journal of Wildlife Management 82:948–957.

Cassaza M. L., P. S. Coates, and C. T. Overton. 2011. Linking habitat selection to brood success in greater sage-grouse. Studies in Avian Biology 38:151–167.

Chalfoun, A. D., F. R. Thompson III, and M. J. Ratnaswamy. 2002. Nest predators and fragmentation: a review and meta-analysis. Conservation Biology 16:306–318.

Chalfoun, A. D., and T. E. Martin. 2007. Assessments of habitat preferences and quality depend on spatial scale and metrics of fitness. Journal of Applied Ecology 44:983–992.

Chalfoun, A. D., and K. A. Schmidt. 2012. Adaptive breeding-habitat selection: Is it for the birds? Auk 129:589–599.

Clement, J. P., A. d´A Belin, M. J. Bean, T. A. Boling and J. R. Lyons. 2014. A strategy for improving the mitigation policies and practices of the Department of the Interior. A report to the Secretary of the Interior from the Energy and Climate Change Task Force. Washington, D.C. USA.

Coates, P. S., and D. J. Delehanty. 2010. Nest predation of greater sage-grouse in relation to microhabitat factors and predators. Journal of Wildlife Management 74:240–248.

Coates, P. S., K. B. Howe, M. L. Casazza, and D. J. Delehanty. 2014. Landscape alterations influence differential habitat use of nesting buteos and ravens within sagebrush ecosystem: Implications for transmission line development. Condor 116:341–356.

Coates, P. S., M. A. Ricca, B. G. Prochazka, M. L. Brooks, K. E. Doherty, T. Kroger, E. J. Blomberg, C. A. Hagen, and M. L. Casazza. 2016. Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems. Proceedings of the National Academy of Sciences of the United States of America 113:12747–12750.

Cochran, W. W. 1987. Orientation and other migratory behaviors of a Swainson's thrush followed for 1500 km. Animal Behaviour 35:927–929.

Concato, J., P. Peduzzi, T. R. Holford, and A. R. Feinstein. 1995. Importance of events per independent variable in proportional hazards regression analysis I. Background, goals, and general strategy. Journal of Clinical Epidemiology 48:1495–1501.

Connelly, J. W., K. P Reese, and M. A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. College of Natural Resources Experiment Station Bulletin 80, University of Idaho, Moscow, ID, USA.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming, USA.

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011*a*. Characteristics and dynamics of greater sage-grouse populations. Studies in Avian Biology 38:53–67.

Connelly, J. W., T. E. Rinkes, and C. E. Braun. 2011*b*. Characteristics of greater sage-grouse habitats: A landscape species at micro- and macroscales. Studies in Avian Biology 38:69–83.

Copeland, H. E., A. Pocewicz, and J. M. Kiesecker. 2011. Geography of energy development in western North America: potential impacts on terrestrial ecosystems. Pages 7–22 *in* D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington, D.C., USA.

Copeland, H. E., A. Pocewicz, D. E. Naugle, T. Griffiths, D. Keinath, J. Evans, and J. Platt. 2013. Measuring the effectiveness of conservation: A novel framework to quantify the benefits of sage-grouse conservation policy and easements in Wyoming. PLoS ONE 8:e67261.

Cresswell, W. 1994. Age-dependent choice of redshank (Tringa totanus) feeding location: Profitability or risk? Journal of Animal Ecology 63:589–600.

Cross, T. B., M. K. Schwartz, D. E. Naugle, B. C. Fedy, J. R. Row, and S. J. Oyler-McCance. 2018. The genetic network of greater sage-grouse: Range-wide identification of keystone hubs of connectivity. Ecology and Evolution 1–19.

Dahlgren, D. K., T. A. Messmer, and D. N. Koons. 2010. Achieving better estimates of greater sage-grouse chick survival in Utah. Journal of Wildlife Management 74:1286–1294.

Dahlgren, D. K., T. A. Messmer, E. T. Thacker, and M. R. Guttery. 2010. Evaluation of brood detection techniques: recommendations for estimating greater sage-grouse productivity. Western North American Naturalist 70:233–237.

Dalke, P. D., D. B. Pyrah, D. C. Stanton, J. E. Crawford, and E. F. Schlatterer. 1963. Ecology, productivity, and management of sage grouse in Idaho. Journal of Wildlife Management 27:811–841.

Davies K. W., C. S. Boyd, J. L. Beck, J. D. Bates, T. J. Svejcar, M. A. Gregg. 2011. Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities. Biological Conservation 144:2573–2584

Davies, K. W., C. S. Boyd, and A. M. Nafus. 2013. Restoring the sagebrush component in crested wheatgrass-dominated communities. Rangeland Ecology and Management 66:472–478.

DeGregorio, B. A., P. J. Weatherhead, and J. H. Sperry. 2014. Power lines, roads, and avian nest survival: Effects on predator identity and predation intensity. Ecology and Evolution 4:1589–1600.

Dickie, M., S. R. McNay, G. D. Sutherland, M. Cody, and T. Avgar. 2020. Corridors or risk? Movement along, and use of, linear features varies predictably among large mammal predator and prey species. Journal of Animal Ecology 89:623–634.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2014*a*. Greater sage-grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. The Condor 116:629–642.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2014*b*. Greater sage-grouse (*Centrocercus urophasianus*) hen survival: Effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology 92:319–330.

Dinkins, J. B., K. T. Smith, J. L. Beck, C. P. Kirol, A. C. Pratt, and M. R. Conover. 2016. Microhabitat conditions in Wyoming's sage-grouse core areas: effects on nest site selection and success. PLoS ONE 11:e0150798.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476–3488.

Doherty, K. E. 2008. Sage-grouse and energy development: Integrating science with conservation planning to reduce impacts. Dissertation, University of Montana, Missoula, USA.

Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. Journal of Wildlife Management 74:1544–1553.

Doherty, K. E., D. E. Naugle, H. E. Copeland, A. Pocewicz, and J. M. Kiesecker. 2011. Energy Development and Conservation Tradeoffs: Systematic planning for greater sage-grouse in their eastern range. Studies in Avian Biology 38:505–516

Duchesne, T., D. Fortin, and N. Courbin. 2010. Mixed conditional logistic regression for habitat selection studies. Journal of Animal Ecology 79:548–555.

Durell, S. E. A. 2000. Individual feeding specialisation in shorebirds: Population consequences and conservation implications. Biological Reviews 75:503–518.

Dzialak, M. R., C. V. Olson, S. M. Harju, S. L. Webb, J. P. Mudd, J. B. Winstead, and L. D. Hayden-Wing. 2011. Identifying and prioritizing greater sage-grouse nesting and brood-rearing habitat for conservation in human-modified landscapes. PLoS ONE 6:e26273.

Edelhoff, H., J. Signer, and N. Balkenhol. 2016. Path segmentation for beginners: An overview of current methods for detecting changes in animal movement patterns. Movement Ecology 4:1–21.

Ehrlich, P. R., D. S. Dobkin, and D. Wheye. 1988. The birder's hand-book: a field guide to the natural history of North American birds. Simon & Schuster, New York, USA.

Eng, R. L. 1955. A method for obtaining sage grouse age and sex ratios from wings. Journal Wildlife Management 19:267–272.

Eng, R. L., and P. Shladweiler. 1972. Sage grouse winter movements and habitat use in central Montana. Journal of Wildlife Management 36:141–146.

Evangelista, P. H., A. W. Crall, and E. Bergquist. 2011. Invasive plants and their response to energy development. Pages 115–130 *in* D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington D.C., USA.

Evans, J. S., J. Oakleaf, S. A. Cushman, and D. Theobald. 2014. An ArcGIS toolbox for surface gradient and geomorphometric modeling, version 2.0-0. <http://evansmurphy.wix.com/evansspatial>. Accessed 1 May 2019.

Fair, J. M., E. Paul, and J. Jones. 2010. Guidelines to the use of wild birds in research. Third edition. Ornithological Council, Washington, D.C., USA.

Fedy, B. C. and Martin, K. 2011. The influence of fine-scale habitat features on regional variation in population performance of alpine white-tailed ptarmigan. Condor 113:306–315.

Fedy, B. C., C. L. Aldridge, K. E. Doherty, M. O'Donnell, J. L. Beck, B. Bedrosian, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, G. McKee, C. Olson, C. C. Swanson, and B. L. Walker. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. Journal of Wildlife Management 76:1062–1071.

Fedy, B. C., K. E. Doherty, C. L. Aldridge, M. O'Donnell, J. L. Beck, B. Bedrosian, D. Gummer, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, G. McKee, C. Olson, A. C. Pratt, C. C. Swanson, and B. L. Walker. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: An example using greater sage-grouse in Wyoming. Wildlife Monographs 190:1–39.

Fedy, B. C., C. P. Kirol, A. L. Sutphin, and T. L. Maechtle. 2015. The influence of mitigation on sage-grouse habitat selection within an energy development field. PLoS ONE 10:e0121603.

Fedy, B. C., J. R. Row, and S. J. Oyler-McCance. 2017. Integration of genetic and demographic data to assess population risk in a continuously distributed species. Conservation Genetics 18:89–104.

Finn, S. P. and S. T. Knick. 2011. Changes to the Wyoming Basins landscape from oil and natural gas development. Pages 69–87 *in* S. E. Hanser, M. Leu, S. T. Knick and C. L. Aldridge, editors. Sagebrush ecosystem conservation and management-Ecoregional assessment tools and models for the Wyoming Basins. Allen Press, Lawrence, Kansas, USA.

Forester, J. D., H. K. Im, and P. J. Rathouz. 2009. Accounting for animal movement in estimation of resource selection functions: Sampling and data analysis. Ecology 90:3554–3565.

Foster, L., K. M. Dugger, C. A. Hagen, and D. A. Budeau. 2018. Potential effects of GPS transmitters on greater sage-grouse survival in a post-fire landscape. Wildlife Biology wlb.00479.

Francis, C. D., C. P. Ortega, and A. Cruz. 2009. Noise Pollution Changes Avian Communities and Species Interactions. Current Biology 19:1415–1419.

Frid, A., and L. Dill. 2002. Human-caused disturbance as a form of predation risk. Conservation Ecology 6:11.

Frye, G. G., J. W. Connelly, D. D. Musil, R. Berkley, M. C. Kemner, C. Cardinal, L. Cross, and J. S. Forbey. 2014. Do necklace-style radiotransmitters influence flushing behavior of greater sage-grouse? Wildlife Society Bulletin 38:433–438.

Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser and M. A. Schroeder. 2011. Greater sage-grouse population dynamics and probability of persistence. Studies in Avian Biology 38:293–374.

Gasch, C. K., S. V. Huzurbazar, and P. D. Stahl. 2016. Description of vegetation and soil properties in sagebrush steppe following pipeline burial, reclamation, and recovery time. Geoderma 265:19–26.

Gerber, B. D., M. B. Hooten, C. P. Peck, M. B. Rice, J. H. Gammonley, A. D. Apa, and A. J. Davis. 2018. Accounting for location uncertainty in azimuthal telemetry data improves ecological inference. Movement Ecology 6:1–14.

Germaine, S. S., S. K. Carter, D. A. Ignizio, and A. T. Freeman. 2017. Relationships between gas field development and the presence and abundance of pygmy rabbits in southwestern Wyoming. Ecosphere 8(5):e01817.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. LoCoH: Nonparameteric Kernel methods for constructing home ranges and utilization distributions. PLoS ONE 2(2):e207.

Gibson, D., E. J. Blomberg, M. T. Atamian, and J. S. Sedinger. 2016. Nesting habitat selection influences nest and early offspring survival in greater sage-grouse. Condor 118:689–702.

Gibson, D., E. J. Blomberg, M. T. Atamian, S. P. Espinosa, and J. S. Sedinger. 2018. Effects of power lines on habitat use and demography of greater sage-grouse (*Centrocercus urophasianus*). Wildlife Monographs 200:1–41.

Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. Wildlife Society Bulletin 10:224–231.

Giesen, K. M., and J. W. Connelly. 1993. Guidelines for management of Columbian sharp-tailed grouse habitats. Wildlife Society Bulletin 21:325–333.

Gilbert, M. M., and A. D. Chalfoun. 2011. Energy development affects populations of sagebrush songbirds in Wyoming. Journal of Wildlife Management 75:816–824.

Goss-Custard, J. D., and S. E. A. Durell. 1983. Individual and age differences in the feeding ecology of Oystercatchers *Haematopus ostralegus* wintering on the Exe Estuary, Devon. Ibis 125:155–171.

Gregg, M. A., M. R. Dunbar, and J. A. Crawford. 2007. Use of implanted radiotransmitters to estimate survival of greater sage-grouse chicks. Journal of Wildlife Management 71:646–651.

Hagen, C. A., and K. M. Giesen. 2005. Lesser prairie-chicken (*Tympanuchus pallidicinctus*). Account 364 *in* A. F. Poole, editor. The birds of North America. Version 2. Cornell Lab of Ornithology, Ithaca, New York, USA.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007. A meta-analysis of greater sage-grouse Centrocercus urophasianus nesting and brood-rearing habitats. Wildlife Biology 13:42–50.

Hagen, C. A., B. K. Sandercock, J. C. Pitman, R. J. Robel, and R. D. Applegate. 2006. Radiotelemetry survival estimates of lesser prairie- chickens in Kansas: Are there transmitter biases? Wildlife Society Bulletin 34:1064–1069.

Hagen, C. A. 2011. Predation on greater sage-grouse: facts, process, and effects. Studies in Avian Biology 38:95–100.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25:173–182.

Hansen, C. P., M. A. Rumble, S. R. Gamo, and J. J. Millspaugh. 2014. Auxiliary VHF transmitter to aid recovery of solar Argos/GPS PTTs. USDA Forest Service─Research Note RMRS-RN 72:1–13.

Hanser, S. E., M. Leu, C. L. Aldridge, S. E. Nielsen, and S. T. Knick. 2011. Occurrence of small mammals: Deer mice and the challenge of trapping across large spatial extents. Pages 337–356 *in* S. E. Hanser, M. Leu, S. T. Knick, and C. L. Aldridge, editors. Sagebrush ecosystem conservation and management: ecoregional assessment tools and models for the Wyoming Basins. Allen Press, Lawrence, Kansas, USA.

Hanser, S. E., and S. T. Knick. 2011. Greater sage-grouse as an umbrella species for shrubland passerine birds: A multiscale assessment. Studies in Avian Biology 38:475–487.

Hansley, P. L., and G. P. Beauvais. 2004. Species assessment for Brewer's sparrow (*Spizella breweri*) in Wyoming. Department of the Interior, Bureau of Land Management, Wyoming State Office, Cheyenne, Wyoming, USA.

Harrison, M. L., D. J. Green, and P. G. Krannitz. 2009. Conspecifics influence the settlement decisions of male Brewer's Sparrows at the northern edge of their range. Condor 111:722–729.

Harrison, M. L., and D. J. Green. 2010. Vegetation influences patch occupancy but not settlement and dispersal decisions in a declining migratory songbird. Canadian Journal of Zoology 88:148–160.

Haukos, D. A., L.M. Smith, and G.S. Broda. 1990. Spring trapping of lesser prairie-chickens. Journal of Field Ornithology 61:20–25.

Hausleitner, D. 2003. Population dynamics, habitat use and movements of greater sage-grouse in Moffat County, Colorado. Thesis, University of Idaho, Moscow, USA.

Hebblewhite, M., and D. T. Haydon. 2010. Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2303–2312.

Hebblewhite M. 2011. Effects of energy development on ungulates. Pages 71–94 *in* D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington D.C., USA.

Hebblewhite M. 2017. Energy sprawl and wildlife conservation. Pages 39–50 *in* J. M. Kiesecker J. M. and D. E. Naugle, editors. Energy Sprawl Solutions. Island Press, Washington, DC, USA.

Hertel, A. G., P. T. Niemelä, N. J. Dingemanse, and T. Mueller. 2020. A guide for studying among-individual behavioral variation from movement data in the wild. Movement Ecology 8:1–18.

Hethcoat, M. G., and A. D. Chalfoun. 2015*a*. Energy development and avian nest survival in Wyoming, USA: A test of a common disturbance index. Biological Conservation 184:327–334.

Hethcoat, M. G., and A. D. Chalfoun. 2015*b*. Towards a mechanistic understanding of human-induced rapid environmental change: A case study linking energy development, nest predation and predators. Journal of Applied Ecology 52:1492–1499.

Holbrook, J. D., J. R. Squires, L. E. Olson, N. J. Decesare, and R. L. Lawrence. 2017. Understanding and predicting habitat for wildlife conservation: The case of Canada lynx at the range periphery. Ecosphere 8:e01939.

Holloran, M. J. 2005. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. Dissertation, Department of Zoology and Physiology, University of Wyoming, Laramie, USA.

Holloran, M. J., B. J. Heath, A. G. Lyon, S. J. Slater, J. L. Kuipers, and S. H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. Journal of Wildlife Management 69:638–649.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2010. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65–72.

Holloran, M. J., B. C. Fedy, and J. Dahlke. 2015. Winter habitat use of greater sage-grouse relative to activity levels at natural gas well pads. Journal of Wildlife Management 79:630–640.

Homer, C. G., C. L. Aldridge, D. K. Meyer, and S. J. Schell. 2012. Multi-scale remote sensing sagebrush characterization with regression trees over Wyoming, USA: Laying a foundation for monitoring. International Journal of Applied Earth Observation and Geoinformation 14:233–244.

Hosmer, D. W., and S. Lemeshow. 2008. Applied survival analysis: regression modeling of time to event data. Second edition. John Wiley and Sons, New York, USA.

Hovick, T. J., R. D. Elmore, D. K. Dahlgren, S. D. Fuhlendorf, and D. M. Engle. 2014. Evidence of negative effects of anthropogenic structures on wildlife: A review of grouse survival and behaviour. Journal of Applied Ecology 51:1680–1689.

Howe, K. B., P. S. Coates, and D. J. Delehanty. 2014. Selection of anthropogenic features and vegetation characteristics by nesting Common Ravens in the sagebrush ecosystem. Condor 116:35–49.

Ibáñez-Álamo, J. D., R. D. Magrath, J. C. Oteyza, A. D. Chalfoun, T. M. Haff, K. A. Schmidt, R. L. Thomson, and T. E. Martin. 2015. Nest predation research: recent findings and future perspectives. Journal of Ornithology 156:247–262.

Ingelfinger, F. M., and S. H. Anderson. 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist 64:385–395.

Ingelfinger, F., and S. Anderson. 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist 64:385–395.

Johnsgard, P. A. 1983. The grouse of the world. University of Nebraska, Lincoln, USA.

Johnson, D. H. 1980. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology 61:65–71.

Johnson, D. H., M. J. Holloran, J. W. Connelly, S. E. Hanser, C. L. Amundson, and S. T. Knick. 2011b. Influences of environmental and anthropogenic features on greater sage-grouse populations, 1997-2007. Studies in Avian Biology 38:407–450.

Johnson, J. A., M. A. Schroeder, and L. A. Robb. 2011a. Greater prairie-chicken (*Tympanuchus cupido*). A. F. Poole, editor. The birds of North America online. Version 2. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.grpchi.01. Accessed 8 April 2020.

Jones, J. 2001. Habitat selection studies in avian ecology: a critical review. The Auk 118:557–562.

Jones, M. O., B. W. Allred, D. E. Naugle, J. D. Maestas, P. Donnelly, L. J. Metz, J. Karl, R. Smith, B. Bestelmeyer, C. Boyd, J. D. Kerby, and J. D. McIver. 2018. Innovation in rangeland monitoring: annual, 30 m, plant functional type percent cover maps for U.S. rangelands, 1984-2017. Ecosphere 9:e02430.

Jongsomjit, D., S. L. Jones, T. Gardali, G. R. Geupel, and P. J. Gouse. 2007. A guide to nestling development and aging in altricial passerines. Biological Technical Publication BTP- R6008-2007. U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C., USA.

Kalyn Bogard, H. J., and S. K. Davis. 2014. Grassland songbirds exhibit variable responses to the proximity and density of natural gas wells. Journal of Wildlife Management 78:471–482.

Kays, R., M. C. Crofoot, W. Jetz, and M. Wikelski. 2015. Terrestrial animal tracking as an eye on life and planet. Science 348:aaa2478.

Kenward, R. E. 2001. Historical and practical perspectives. Pages 3–12 *in* J. J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

Kernohan, B. J., R. A. Gitzen, and J. J. Millspaugh. 2001. Analysis of survival data from radiotelemetry studies. Pages 125–166 *in* J. J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

Kéry, M, and J. A. Royle. 2016. Applied hierarchical modeling in ecology: analysis of distribution, abundance and species richness in R and BUGS. Vol. 1, prelude and static models. Academic Press, London, UK.

Kirol, C. P., J. L. Beck, J. B. Dinkins, and M. R. Conover. 2012. Microhabitat selection for nesting and brood-rearing by the greater sage-grouse in xeric big sagebrush. Condor 114:75–89.

Kirol, C. P., J. L. Beck, S. V. Huzurbazar, M. J. Holloran, and S. N. Miller. 2015*a*. Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape. Ecological Applications 25:968–990.

Kirol, C. P., A. L. Sutphin, L. Bond, M. R. Fuller, and T. L. Maechtle. 2015*b*. Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development. Wildlife Biology 21:98–109.

Kirol, C. P., K. L. Pilgrim, A. L. Sutphin, and T. L. Maechtle. 2018. Using DNA from hairs left at depredated greater sage-grouse nests to detect mammalian nest predators. Wildlife Society Bulletin 42:160–165.

Kirol, C. P., D. C. Kesler, B. L. Walker, and B. C. Fedy. 2020*b*. Coupling Tracking Technologies to Maximize Efficiency in Avian Research. Wildlife Society Bulletin 44:406–415.

Kirol, C. P., K. T. Smith, N. E. Graf, J. B. Dinkins, C. W. Lebeau, T. L. Maechtle, A. L. Sutphin, and J. L. Beck. 2020*a*. Greater sage-grouse response to the physical footprint of energy development. Journal of Wildlife Management 84:989–1001.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. Van Riper, III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. The Condor 105:611–634.

Knick, S. E., S. E. Hanser, R. F. Miller, D. A. Pyke, M. J. Wisdom, S. P. Finn, E. T. Rinkes, and C. J. Henry. 2011. Ecological influence and pathways of land use in sagebrush. Studies in Avian Biology 38:203–251.

Knick, S. T., S. E. Hanser, and K. L. Preston. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: Implications for population connectivity across their western range, U.S.A. Ecology and Evolution 3:1539–1551.

Kranstauber, B., M. Smolla, A. K. Scharf. 2020. Move: Visualizing and analyzing animal track data. R package version 4.0.4 <https://cran.r-project.org/web/packages/move/index.html>. Accessed 21 September 2020.

Lacher, J. R., and Lacher, D. D. 1964. A mobile cannon net trap. Journal of Wildlife Management 28:595–597.

Latif, Q. S., S. K. Heath, and J. T. Rotenberry. 2012. How avian nest site selection responds to predation risk: Testing an “adaptive peak hypothesis.” Journal of Animal Ecology 81:127–138.

LeBeau, C. W., G. D. Johnson, M. J. Holloran, J. L. Beck, R. M. Nielson, M. E. Kauffman, E. J. Rodemaker, and T. L. McDonald. 2017. Greater sage-grouse habitat selection, survival, and wind energy infrastructure. Journal of Wildlife Management 81:690–711.

Lebeau, C. W., K. T. Smith, M. J. Holloran, J. L. Beck, M. E. Kauffman, and G. D. Johnson. 2019. Greater sage-grouse habitat function relative to 230-kV transmission lines. Journal of Wildlife Management 83:1773–1786.

Leclerc, M., E. Vander Wal, A. Zedrosser, J. E. Swenson, J. Kindberg, and F. Pelletier. 2016. Quantifying consistent individual differences in habitat selection. Oecologia 180:697–705.

LeMunyan, C. D., W. White, E. Nyberg, and J. J. Christian. 1959. Design of a miniature radio transmitter for use in animal studies. Journal of Wildlife Management 23:107–110.

Leonard, K.M., K.P. Reese, and J.W. Connelly. 2000. Distribution, movements and habitats of sage grouse Centrocercus urophasianus on the Upper Snake River Plain of Idaho: changes from the 1950s to the 1990s. Wildlife Biology 6:265–270.

Leu M., and S. E. Hanser. 2011. Influences of the human footprint on sagebrush landscape patterns. Studies in Avian Biology 38:253–257.

Liebezeit, J. R., S. J. Kendall, S. Brown, C. B. Johnson, P. Martin, T. L. McDonald, D. C. Payer, C. L. Rea, B. Streever, A. M. Wildman, and S. Zack. 2009. Influence of human development and predators on nest survival of tundra birds, Arctic Coastal Plain, Alaska. Ecological Applications 19:1628–1644.

Lima, S. L. 2009. Predators and the breeding bird: Behavioral and reproductive flexibility under the risk of predation. Biological Reviews 84:485–513.

Lloyd, P., T. E. Martin, U. Langner, and M. M. Hart. 2005. Linking demographic effects of habitat fragmentation across landscapes to continental source-sink dynamics. Ecological Applications 15:1504–1514.

Ludlow, S. M., R. M. Brigham, and S. K. Davis. 2015. Oil and natural gas development has mixed effects on the density and reproductive success of grassland songbirds. Condor 117:64–75.

Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. Wildlife Society Bulletin 31:486–491.

Mahony, N. A., W. M. Vander Haegen, B. L. Walker, and P. G. Krannitz. 2001. Male incubation and multiple brooding in sagebrush Brewer's sparrows. The Wilson Bulletin 113:441–444.

Maresh Nelson, S. B., J. J. Coon, C. J. Duchardt, J. R. Miller, D. M. Debinski, and W. H. Schacht. 2018. Contrasting impacts of invasive plants and human-altered landscape context on nest survival and brood parasitism of a grassland bird. Landscape Ecology 33:1799–1813.

Martin, T. E. 1993. Nest predation and nest sites. BioScience 43:523–532.

Martin, T. E., and G. R. Geupel. 1993. Nest-monitoring plots: Methods for locating nests and monitoring success. Journal of Field Ornithology 64:507–519.

Martin, T. E. 1998. Are microhabitat preferences of coexisting species under selection and adaptive? Ecology 79:656–670.

Meyer, C. B., and W. Thuiller. 2006. Accuracy of resource selection functions across spatial scales. Diversity and Distributions 12:288–297.

Miller, R. F., Knick, S. T., Pyke, D. A., Meinke, C. W., Hanser, S. E., Wisdom, M. J. and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Studies in Avian Biology 38:145–184.

Moynahan, B. J., M. S. Lindberg, and J. W. Thomas. 2006. Factors contributing to process variance in annual survival of female greater sage-grouse in Montana. Ecological Applications 16:1529–1538.

Muff, S., J. Signer, and J. Fieberg. 2020. Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation. Journal of Animal Ecology 89:80–92.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10:58–62.

Naugle, D. E., K. E. Doherty, B. L. Walker, M. J. Holloran, and J. D. Tack. 2011. Sage-grouse and cumulative impacts of energy development. Pages 55–70 *in* D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington D.C., USA.

Nichols, J. D., F. A. Johnson, B. K. Williams, and G. S. Boomer. 2015. On formally integrating science and policy: Walking the walk. Journal of Applied Ecology 52:539–543.

Niemi, G. J., and M. E. McDonald. 2004. Application of ecological indicators. Annual Review of Ecology, Evolution, and Systematics 35:89–111.

Northrup, J. M., and G. Wittemyer. 2012. Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecology Letters 16:112–125.

Nur, N., A. L. Holmes, and G. R. Geupel. 2004. Use of survival time analysis to analyze nesting success in birds: an example using loggerhead shrikes. Condor 106:457–471

Peluc, S. I., T. S. Sillett, J. T. Rotenberry, and C. K. Ghalambor. 2008. Adaptive phenotypic plasticity in an island songbird exposed to a novel predation risk. Behavioral Ecology 19:830–835.

Perring, M. P., R. J. Standish, J. N. Price, M. D. Craig, T. E. Erickson, K. X. Ruthrof, A. S. Whiteley, L. E. Valentine, and R. J. Hobbs. 2015. Advances in restoration ecology: Rising to the challenges of the coming decades. Ecosphere 6:art131.

Petersen, K. L., L. B. Best, and B. M. Winter. 1986. Growth of nestling Sage Sparrows and Brewer's Sparrows. The Wilson Bulletin 98:535–546.

Pratt, A. C., K. T. Smith, and J. L. Beck. 2017. Environmental cues used by greater sage-grouse to initiate altitudinal migration. Auk 134:628–643.

Prokopenko, C. M., M. S. Boyce, and T. Avgar. 2017. Characterizing wildlife behavioural responses to roads using integrated step selection analysis. Journal of Applied Ecology 54:470–479.

Pruett, C. L., M. A. Patten, and D. H. Wolfe. 2009. Avoidance behavior by prairie grouse: Implications for development of wind energy. Conservation Biology 23:1253–1259.

Pulliam, H. R., and B. J. Danielson. 1991. Sources, sinks, and habitat selection: a landscape perspective on population dynamics. American Naturalist 137:550–566.

Pyke, D. A. 2011. Restoring and rehabilitating sagebrush habitats. Studies in Avian Biology 38:531–548.

Pyke, D. A., J. C. Chambers, M. Pellant, S. T. Knick, R. F. Miller, J. L. Beck, P. S. Doescher, E. W. Schupp, B. A. Roundy, M. Brunson and J. D. McIver. 2015. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 1. Concepts for understanding and applying restoration: U.S. Geological Survey Circular 1416:1–44.

R Core Team, 2020. R: a language and environment for statistical computing.

Reisner, M. D., J. B. Grace, D. A. Pyke, and P. S. Doescher. 2013. Conditions favouring *Bromus tectorum* dominance of endangered sagebrush steppe ecosystems. Journal of Applied Ecology 50:1039–1049.

Ricklefs, R. E. 1969. An analysis of nesting mortality in birds. Smithsonian Contributions to Zoology 9:1–48.

Roberge, J. M., and P. Angelstam. 2004. Usefulness of the umbrella species concepts as a conservation tool. Conservation Biology 18:76–85.

Robertson, B. A., and R. L. Hutto. 2006. A framework for understanding ecological traps and an evaluation of existing evidence. Ecology 87:1075–1085.

Robinson, N. P., B. W. Allred, M. O. Jones, A. Moreno, J. S. Kimball, D. E. Naugle, T. A. Erickson, and A. D. Richardson. 2017. A dynamic landsat derived normalized difference vegetation index (NDVI) product for the conterminous United States. Remote Sensing 9:1–14.

Robinson, S. K., F. R. Thompson III, T. M. Donovan, D. R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987–1990

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J. D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, et al. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee.

Rotenberry, J. T., M. A. Patten, and K. L. Preston. 1999. Brewer's sparrow (*Spizella breweri*). Account 390 *in* A. F. Poole and F. B. Gill, editors. The birds of North America. Cornell Lab of Ornithology, Ithaca, New York, USA.

Rottler, C. M., I. C. Burke, K. A. Palmquist, J. B. Bradford, and W. K. Lauenroth. 2018. Current reclamation practices after oil and gas development do not speed up succession or plant community recovery in big sagebrush ecosystems in Wyoming. Restoration Ecology 26:114–123.

Row, J. R., K. E. Doherty, T. B. Cross, M. K. Schwartz, S. J. Oyler-McCance, D. E. Naugle, S. T. Knick, and B. C. Fedy. 2018. Quantifying functional connectivity: The role of breeding habitat, abundance, and landscape features on range-wide gene flow in sage-grouse. Evolutionary Applications 1305–1321.

Rowland, M. M., M. J. Wisdom, L. H. Suring, and C. W. Meinke. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. Biological Conservation 129:323–335.

Rowland, M. M., L. H. Suring, M. Leu, S. T. Knick, and M. J. Wisdom. 2011. Sagebrush-associated species of conservation concern. Pages 46–68 *in* S. E. Hanser, M. Leu, S. T. Knick, and C. L. Aldridge, editors. Sagebrush ecosystem conservation and management: Ecoregional assessment tools and models for the Wyoming Basins. Allen Press, Lawrence, Kansas, USA.

Ruehmann, M. B., M. J. Desmond, and W. R. Gould. 2011. Effects of smooth brome on Brewer's sparrow nest survival in sagebrush steppe. Condor 113:419–428.

Saether, B. E., and O. Bakke. 2000. Avian life history variation and contribution of demographic traits to the population growth rate. Ecology 81:642−653.

Samuel, M. D., and M. R. Fuller. 1994. Wildlife radiotelemetry. Pages 370–418 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. The Wildlife Society, Bethesda, Maryland, USA.

Sanders, L. E., and A. D. Chalfoun. 2018. Novel landscape elements within natural gas fields increase densities but not fitness of an important songbird nest predator. Biological Conservation 228:132–141.

Sanders, L. E., and A. D. Chalfoun. 2019. Mechanisms underlying increased nest predation in natural gas fields: a test of the mesopredator release hypothesis. Ecosphere 10:e02738.

Sappington, M. J., K. M. Longshore, and D. B. Thompson. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. Journal of Wildlife Management 71:1419–1426.

Sauer, J. R., W. A. Link, J. E. Fallon, K. L. Pardieck, and D. J. Ziolkowski, Jr. 2013. The North American Breeding Bird Survey 1966-2011: summary analysis and species accounts. North American Fauna 79:1–32.

Sawyer, H., M. J. Kauffman, and R. M. Nielson. 2009. Influence of well pad activity on winter habitat selection patterns of mule deer. Journal of Wildlife Management 73:1052–1061.

Sawyer, H., N. M. Korfanta, R. M. Nielson, K. L. Monteith, and D. Strickland. 2017. Mule deer and energy development—Long-term trends of habituation and abundance. Global Change Biology 23:4521–4529.

Sawyer, H., M. S. Lambert, and J. A. Merkle. 2020. Migratory disturbance thresholds with mule deer and energy development. Journal of Wildlife Management 1–8.

Schaid, T. A., D. W. Uresk, W. L. Tucker, and R. L. Linder. 1983. Effects of surface mining on the vesper sparrow in the northern Great Plains. Journal of Range Management 36:500–503.

Schroeder, M. A., and C. E. Braun. 1991. Walk-in traps for capturing greater prairie-chickens on leks. Journal of Field Ornithology 62:378–385.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Account 425 *in* A. Poole and F. Gill, editors. The birds of North America. The Academy of

Natural Sciences, Philadelphia, Pennsylvania, USA; and American Ornithologists' Union, Washington, D.C., USA.

Scrafford, M. A., T. Avgar, R. Heeres, and M. S. Boyce. 2018. Roads elicit negative movement and habitat-selection responses by wolverines (*Gulo gulo luscus*). Behavioral Ecology 29:534–542.

Severson, J. P., P. S. Coates, B. G. Prochazka, M. A. Ricca, M. L. Casazza, and D. J. Delehanty. 2019. Global positioning system tracking devices can decrease greater sage-grouse survival. The Condor 121:1–15.

Shaffer, T. L. 2004. A unified approach to analyzing nest success. The Auk 121:526–540.

Shipley, A. A., J. Cruz, and B. Zuckerberg. 2020. Personality differences in the selection of dynamic refugia have demographic consequences for a winter-adapted bird: Personality and dynamic refugia. Proceedings of the Royal Society B: Biological Sciences 287.

Shyvers, J. E., B. L. Walker, S. J. Oyler-McCance, J. A. Fike, and B. R. Noon. 2019. Genetic mark–recapture analysis of winter fecal pellets allows estimation of population size in sage grouse Centrocercus urophasianus. Ibis. https://doi.org/10.1111/ibi.12768

Signer, J., J. Fieberg, and T. Avgar. 2019. Animal movement tools (amt): R package for managing tracking data and conducting habitat selection analyses. Ecology and Evolution 9:880–890.

Silvy, N. J., M. E. Morrow, E. Shanley, and R. A. Fischer. 1990. An improved drop net for capturing wildlife. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 44:374–378.

Smith, K. T., J. L. Beck, and A. C. Pratt. 2016. Does Wyoming's Core Area Policy protect winter habitats for greater sage-grouse? Environmental Management 58:585–596.

Smith, K. T., J. L. Beck, and C. P. Kirol. 2018. Reproductive state leads to intraspecific habitat partitioning and survival differences in greater sage-grouse: implications for conservation. Wildlife Research 45:119–131.

Smith, R. E. 2010. Conserving Montana's sagebrush highway: long distance migration in sage-grouse. Thesis, University of Montana, Missoula, USA.

State of Wyoming. 2019. Greater sage-grouse Core Area protection. Office of the Governor, Executive Order Number 2019-3. State of Wyoming, Cheyenne, USA. <https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management/Sage-Grouse-Executive-Order>. Accessed 20 December 2020.

Stephens, S. E., D. N. Koons, J. J. Rotella, and D. W. Willey. 2004. Effects of habitat fragmentation on avian nesting success: A review of the evidence at multiple spatial scales. Biological Conservation 115:101–110.

Sutphin, A. L., T. L. Maechtle, C. P. Kirol, and B. C. Fedy. 2018. A mobile tool for capturing greater sage-grouse. Wildlife Society Bulletin 42:504–509.

Tack, J. D., and B. C. Fedy. 2015. Landscapes for energy and wildlife: Conservation prioritization for golden eagles across large spatial scales. PLoS ONE 10(8):e0134781.

Taylor, R. L., B. L. Walker, D. E. Naugle, and L. S. Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76:336–347.

Taylor, R. L., J. D. Tack, D. E. Naugle, and S. L. Mills. 2013. Combined Effects of Energy Development and Disease on Greater Sage-Grouse. PLoS ONE 8:e71256.

Taylor, P. D., T. L. Crewe, S. A. Mackenzie, D. Lepage, Y. Aubry, Z. Crysler, G. Finney, C. M. Francis, C. Guglielmo, D. J. Hamilton, R. L. Holberton, P. H. Loring, G. W. Mitchell, D. Norris, J. Paquet, R. A. Ronconi, J. Smetzer, P. A. Smith, L. J. Welch, and B. K. Woodworth. 2017. The Motus Wildlife Tracking System: a collaborative research network. Avian Conservation and Ecology 12:8.

Therneau, T. 2019. Package ‘survival’. R package version 3.1-8. <https://cran.r-project.org/web/packages/survival/index.html>. Accessed 2 December 2019.

Therneau, T. 2020. coxme: Mixed Effects Cox Models. R package version 2.2-16. <https://cran.r-project.org/web/packages/coxme/index.html>. Accessed 2 December 2019.

Therneau, T. 2020. Package ‘survival’. R package version 3.1-8. <https://cran.r-project.org/web/packages/survival/survival.pdf>. Accessed 2 October 2020.

Thomas, B., J. D. Holland, and E. O. Minot. 2011. Wildlife tracking technology options and cost considerations. Wildlife Research 38:653–663.

Thompson, S. J., D. H. Johnson, N. D. Niemuth, and C. A. Ribic. 2015. Avoidance of unconventional oil wells and roads exacerbates habitat loss for grassland birds in the North American great plains. Biological Conservation 192:82–90.

Thurfjell, H., S. Ciuti, and M. S. Boyce. 2014. Applications of step-selection functions in ecology and conservation. Movement Ecology 2:1–12.

U. S. Bureau of Land Management [BLM]. 2003. Record of decision and resource management plan amendments for the Powder River Basin oil and gas project. WY-070-02-065. Bureau of Land Management-Wyoming State Office, USA.

U. S. Bureau of Land Management [BLM]. 2004. National Sage-Grouse Habitat Conservation Strategy. Guidance for the management of sagebrush plant communities for sage-grouse conservation. Washington, D.C., USA. <https://www.blm.gov/documents/national-office/blm-library/report/blm-national-sage-grouse-habitat-conservation-strategy>. Accessed 20 December 2020.

U. S. Bureau of Land Management [BLM]. 2015. BLM, USFS greater sage-grouse conservation effort. Fact sheet. <https://www. blm.gov/sites/blm.gov/files/BLM-USFS%20Sage-grouse%20Plans% 20Fact%20Sheet%20Final915.pdf>. Accessed 7 December 2020.

U. S. Fish and Wildlife Service [USFWS]. 2010. Endangered and threatened wildlife and plants: 12-month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. Federal Register 75:13909–14014.

U. S Fish and Wildlife Service [USFWS]. 2013. Greater Sage-grouse (*Centrocercus urophasianus*) conservation objectives: Final report. U.S. Fish and Wildlife Service, Denver, Colorado, USA.

U. S. Fish and Wildlife Service [USFWS]. 2015. Endangered and threatened wildlife and plants; 12-month finding on a petition to list greater sage-grouse (*Centrocercus urophasianus*) as an endangered or threatened Species. Federal Register 80:59857–59942.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893–901.

Vandenabeele, S. P., E. L. Shepard, A. Grogan, and R. P. Wilson. 2012. When three per cent may not be three per cent; device-equipped seabirds experience variable flight constraints. Marine Biology 159:1–14.

Vander Haegen, W. M., M. A. Schroeder, and R. M. DeGraaf. 2002. Predation on real and artificial nests in shrubsteppe landscapes fragmented by agriculture. Condor 104:496–506.

Vander Haegen, W. M. 2007. Fragmention by agriculture influences reproductive success of birds in a shrubsteppe landscape. Ecological Applications 17:934–947.

Vogt, C. 1999. Creating Long Documents using Microsoft Word. Published on the Web at the University of Waterloo.

Wakkinen, W. L., K. P. Reese, J. W. Connelly, and R. A. Fischer. 1992. An improved spotlighting technique for capturing sage grouse. Wildlife Society Bulletin 20:425–426.

Walker, B. L. 2004. Effects of management practices on grassland birds: Brewer's sparrow. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Walker, B. L., K. E. Doherty, and D. E. Naugle. 2006. Spotlight counts: a new method for assessing chick survival in greater sage-grouse. Proceedings of the 25th Meeting of the Western Agencies Sage and Columbian Sharp-tailed Grouse Technical Committee, Spearfish, South Dakota, USA.

Walker, B. L., D. E. Naugle, and K. E. Doherty. 2007. Greater Sage-Grouse Population Response to Energy Development and Habitat Loss. Journal of Wildlife Management 71:2644–2654.

Walker, B. L. 2008. Greater sage-grouse response to coal-bed natural gas development and West Nile virus in the Powder River Basin, Montana and Wyoming. Dissertation, University of Montana, Missoula, USA.

Walker, B. L., A. D. Apa, and K. Eichhoff. 2016. Mapping and prioritizing seasonal habitats for greater sage-grouse in northwestern Colorado. Journal of Wildlife Management 80:63–77.

Walker, B. L., M. A. Neubaum, S. R. Goforth, and M. M. Flenner. 2020. Quantifying habitat loss and modification from recent expansion of energy infrastructure in an isolated, peripheral greater sage-grouse population. Journal of Environmental Management 255:109819.

Wallestad, R., and D. B. Pyrah. 1974. Movement and nesting of sage grouse hens in central Montana. Journal of Wildlife Management 38:630–633.

Webb, S. L., C. V. Olson, M. R. Dzialak, S. M. Harju, J. B. Winstead, and D. Lockman. 2012. Landscape features and weather influence nest survival of a ground-nesting bird of conservation concern, the greater sage-grouse, in human-altered environments. Ecological Processes 1:1–15.

Williams, M. I., G. B. Paige, T. L. Thurow, A. L. Hild, and K. G. Gerow. 2011. Songbird relationships to shrub-steppe ecological site characteristics. Rangeland Ecology & Management 64:109–118.

Winter, M., N. H. Johnson, J. Faaborg. 2000. Evidence of edge effects on multiple levels in tallgrass prairie. Condor 102: 256–266.

Withey, J. C., T. D. Bloxton, and J. M. Marzluff. 2001. Effects of tagging and location error in wildlife radiotelemetry studies. Pages 43–75 *in* J. J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

Xian, G., C. Homer, M. Rigge, H. Shi, and D. Meyer. 2015. Characterization of shrubland ecosystem components as continuous fields in the northwest United States. Remote Sensing of Environment 168:286–300.

Xu, J.-L., X.-H. Zhang, Q.-H. Sun, G.-M. Zheng, Y. Wang, and Z.-W. Zhang. 2009. Home range, daily movements and site fidelity of male Reeves's pheasants *Syrmaticus reevesii* in the Dabie Mountains, Central China. Wildlife Biology 15:338–344.

Yang, L., S. Jin, P. Danielson, C. Homer, L. Gass, S. M. Bender, A. Case, C. Costello, J. Dewitz, J. Fry, M. Funk, B. Granneman, G. C. Liknes, M. Rigge, and G. Xian. 2018. A new generation of the United States National Land Cover Database: Requirements, research priorities, design, and implementation strategies. ISPRS Journal of Photogrammetry and Remote Sensing 146:108–123.

Yoo, J. G. 2014. Effects of natural gas well development on songbird reproductive success in mixed-grass prairies of southeastern Alberta. Thesis. University of Manitoba, Winnipeg, Canada.

Zablan, M. A., C. E. Braun, and G. C. White. 2003. Estimation of greater sage-grouse survival in North Park, Colorado. Journal of Wildlife Management 67:144–154.

Appendix A
Photographs of coal-bed natural gas (CBNG) disturbance in northeastern Wyoming, USA

Figure A1. Reclaimed access road.

Figure A2. Reclaimed well pad.

Figure A3. CBNG infrastructure with a well and access road in foreground and a compressor station in the background.

Figure A4. Reclaimed surface, pipeline corridor.

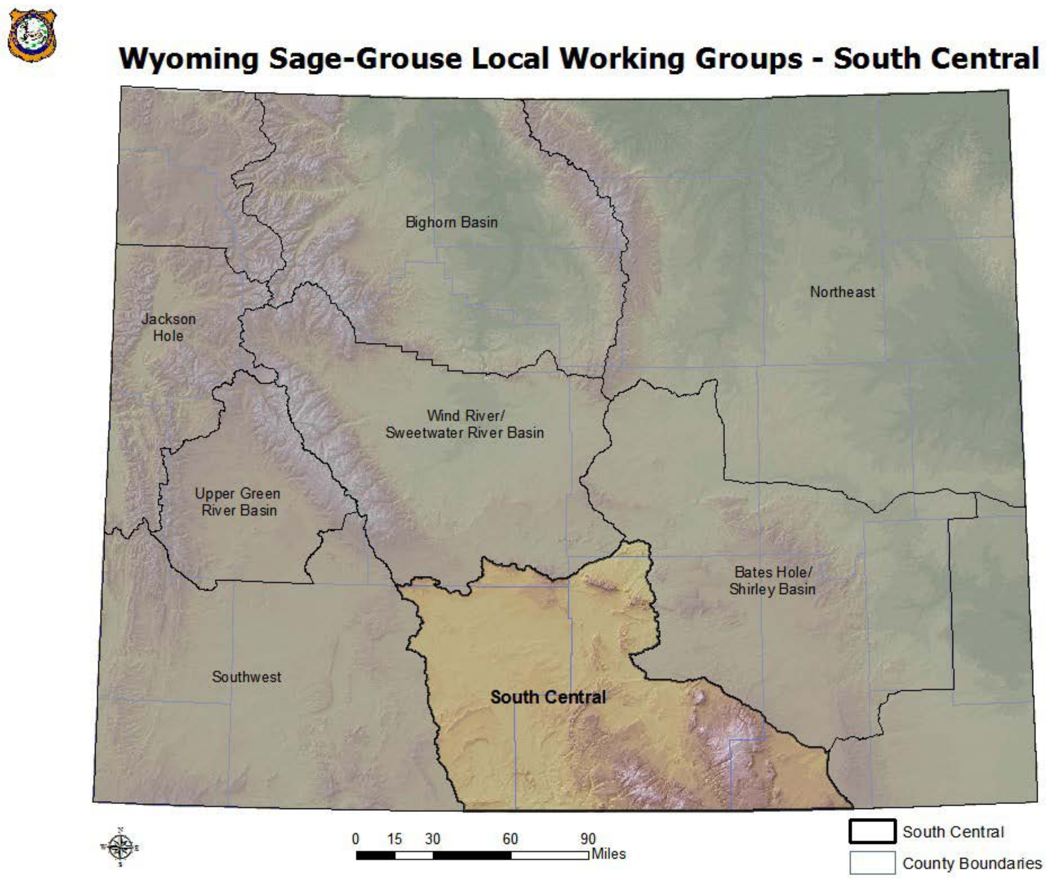
Figure A5. CBNG well and pad.

Figure A6. Compressor station.

Figure A7. Power lines.

South-Central Conservation Area
Job Completion Report

Species: Greater Sage-grouse
Mgmt. Areas: H
Period Covered: June 1, 2020- May 31, 2021
Prepared by: Teal Cufaude, Saratoga Wildlife Biologist



Sage Grouse Lek Characteristics

Management Area: H, Working Group: South Central

Region	Number	Percent
Green River	139	34.1
Lander	210	51.5
Laramie	59	14.5

Working Group	Number	Percent
South Central	408	100.0

Classification	Number	Percent
Occupied	259	63.5
Undetermined	51	12.5
Unoccupied	98	24.0

BLM Office	Number	Percent
Casper	2	0.5
Lander	26	6.4
Rawlins	363	89.0
Rock Springs	17	4.2

Biologist	Number	Percent
Baggs	126	30.9
Green River	14	3.4
Laramie	5	1.2
Saratoga	54	13.2
Sinclair	194	47.5
South Lander	15	3.7

Warden	Number	Percent
Baggs	125	30.6
East Rawlins	105	25.7
Elk Mountain	6	1.5
Lander	2	0.5
Rock Springs	14	3.4
Saratoga	48	11.8
South Laramie	5	1.2
West Rawlins	103	25.2

County	Number	Percent
Albany	5	1.2
Carbon	270	66.2
Fremont	13	3.2
Natrona	2	0.5
Sweetwater	118	28.9

Land Status	Number	Percent
BLM	228	55.9
LocalGov	1	0.2
Private	148	36.3
State	30	7.4
USFWS	1	0.2

Management Area	Number	Percent
H	408	100.0

Lek Status	Number	Percent
Active	181	44.4
Inactive	187	45.8
Unknown	40	9.8

Sage Grouse Job Completion Report

Year: 2012 - 2021, Management Area: H, Working Group: South Central

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	273	56	21	1490	28.1
2013	278	94	34	1662	21.9
2014	281	101	36	1607	21.4
2015	282	90	32	1915	32.5
2016	286	73	26	2381	39.0
2017	286	96	34	2176	29.4
2018	285	113	40	2210	24.6
2019	278	131	47	2419	22.0
2020	272	146	54	2584	22.7
2021	272	91	33	1604	21.7

b. Leks Surveyed

Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	273	178	65	2176	19.1
2013	278	159	57	1564	14.9
2014	281	175	62	2016	17.8
2015	282	170	60	3224	27.8
2016	286	192	67	3707	28.1
2017	286	162	57	2465	22.6
2018	285	153	54	2005	21.3
2019	278	126	45	1078	16.8
2020	272	101	37	875	18.6
2021	272	160	59	1285	15.7

1) Occupied - Active during previous 10 years (see official definitions)

2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

3) Inactive - Confirmed no birds/sign present (see official definitions)

Sage Grouse Job Completion Report

Year: 2012 - 2021, Management Area: H, Working Group: South Central

1. Lek Attendance Summary (Occupied Leks) (1) — Continued

c. Leks Checked

Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	273	234	86	3666	22.0
2013	278	253	91	3226	17.8
2014	281	276	98	3623	19.3
2015	282	260	92	5139	29.4
2016	286	265	93	6088	31.5
2017	286	258	90	4641	25.4
2018	285	266	93	4215	22.9
2019	278	257	92	3497	20.1
2020	272	247	91	3459	21.5
2021	272	251	92	2889	18.5

d. Lek Status

Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	176	32	26	208	84.6	15.4
2013	192	45	16	237	81.0	19.0
2014	198	71	7	269	73.6	26.4
2015	185	54	21	239	77.4	22.6
2016	198	54	13	252	78.6	21.4
2017	188	55	15	243	77.4	22.6
2018	192	53	21	245	78.4	21.6
2019	189	48	20	237	79.7	20.3
2020	172	68	7	240	71.7	28.3
2021	173	63	15	236	73.3	26.7

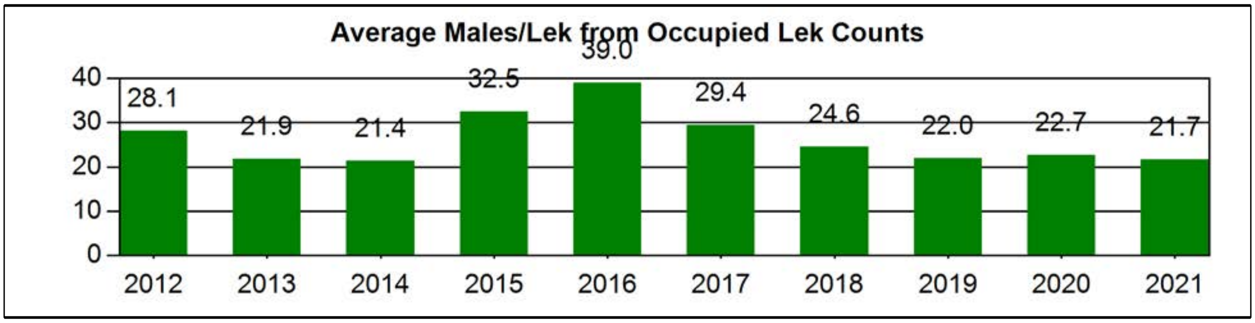
1) Occupied - Active during previous 10 years (see official definitions)

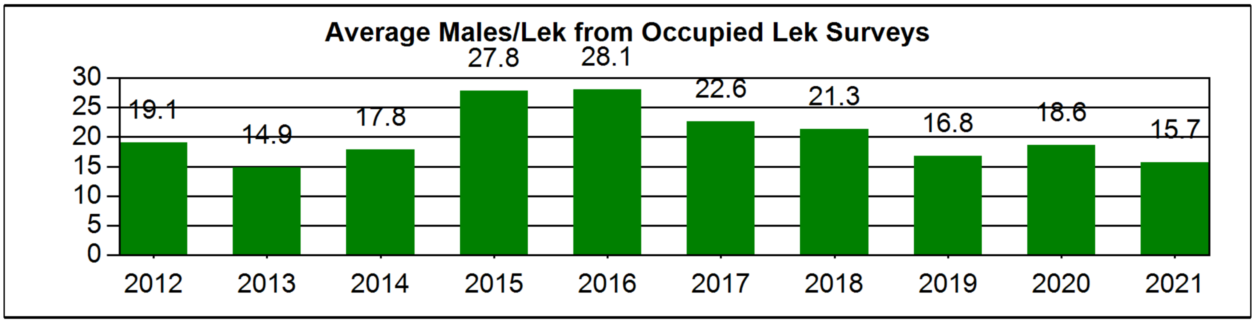
2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

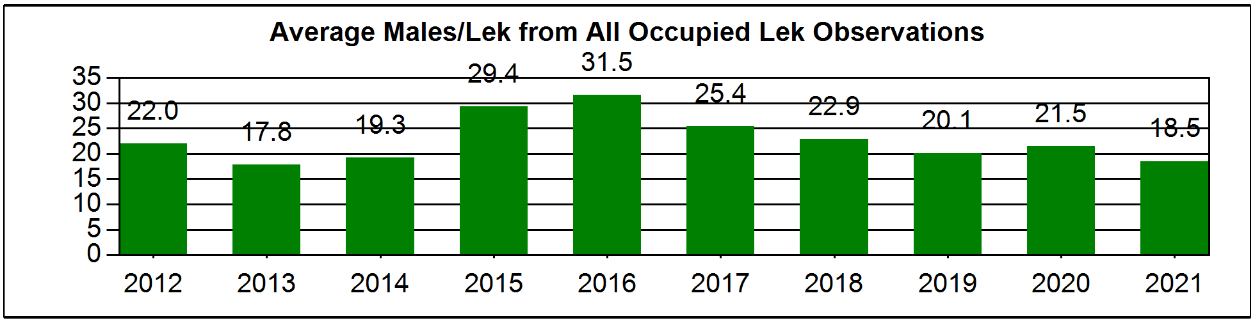
3) Inactive - Confirmed no birds/sign present (see official definitions)

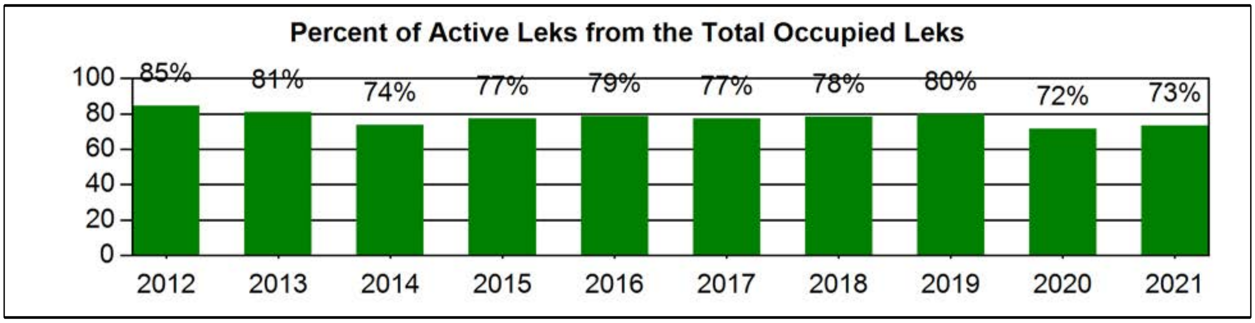
Sage Grouse Occupied Lek Attendance Summary

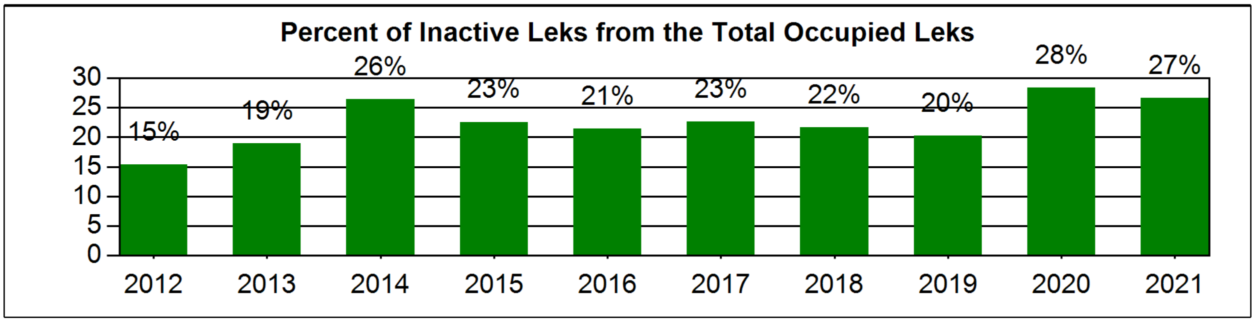
Year: 2012 - 2021, Management Area: H, Working Group: South Central











Sage Grouse Job Completion Report

Year: 2011 - 2020, Management Area: H, Working Group: South Central

3. Sage Grouse Hunting Seasons and Harvest Data

a. Season

Year	Season Start	Season End	Length	Bag/Possesion Limit
2011	Sep-17	Sep-30	14	2/4
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

b. Harvest

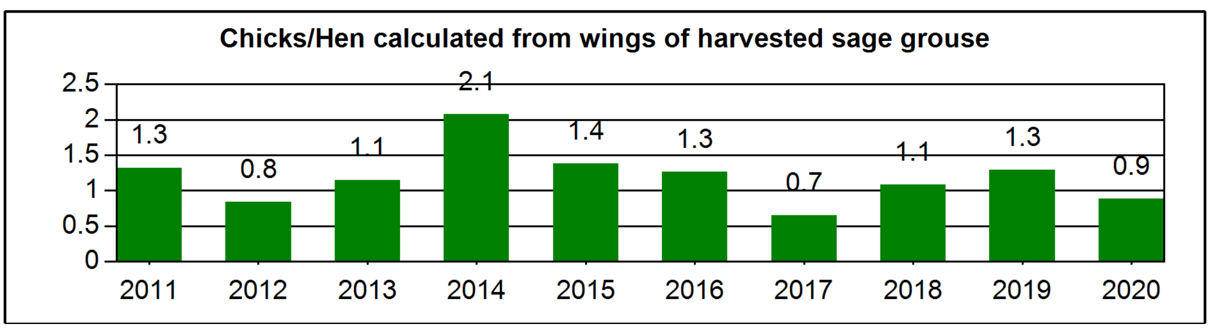
Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2011	1261	591	1483	0.9	2.1	2.5
2012	1194	636	1382	0.9	1.9	2.2
2013	624	437	928	0.7	1.4	2.1
2014	612	391	934	0.7	1.6	2.4
2015	776	457	963	0.8	1.7	2.1
2016	911	477	1162	0.8	1.9	2.4
2017	501	363	846	0.6	1.4	2.3
2018	903	500	1245	0.7	1.8	2.5
2019	1052	584	1186	0.9	1.8	2.0
2020	1023	465	1250	0.8	2.2	2.7
Avg	886	490	1,138	0.8	1.8	2.3

Sage Grouse Job Completion Report

Year: 2011 - 2020, Management Area: H, Working Group: South Central

4. Composition of Harvest by Wing Analysis

Year	Sample	Percent Adult		Percent Yearling		Percent Young		Chicks/
	Size	Male	Female	Male	Female	Male	Female	Hens
2011	271	11.8	29.2	3.0	7.4	20.7	27.7	1.3
2012	220	10.0	38.2	5.5	7.7	15.5	23.2	0.8
2013	107	14.0	36.4	1.9	1.9	15.9	27.1	1.1
2014	146	10.3	23.3	3.4	4.8	30.8	27.4	2.1
2015	192	10.4	30.7	2.6	5.7	24.5	26.0	1.4
2016	174	21.8	27.0	4.0	5.7	16.1	25.3	1.3
2017	123	13.8	39.8	5.7	8.9	16.3	15.4	0.7
2018	131	20.6	26.7	6.1	8.4	20.6	17.6	1.1
2019	196	13.8	25.0	6.6	9.7	13.8	31.1	1.3
2020	258	11.6	27.1	5.8	16.7	13.2	25.6	0.9



Report Date: December 20, 2021 Page: 1 of 1

Lek Monitoring

For biological year 2020, 408 sage-grouse leks were known to occur in the South-Central Conservation Area (SCCA). In the SCCA, the majority of known leks (56%) occur on Bureau of Land Management (BLM) managed lands and 36% occur on private land. There are likely other occupied leks in the SCCA that have not yet been documented (Fig. 1).

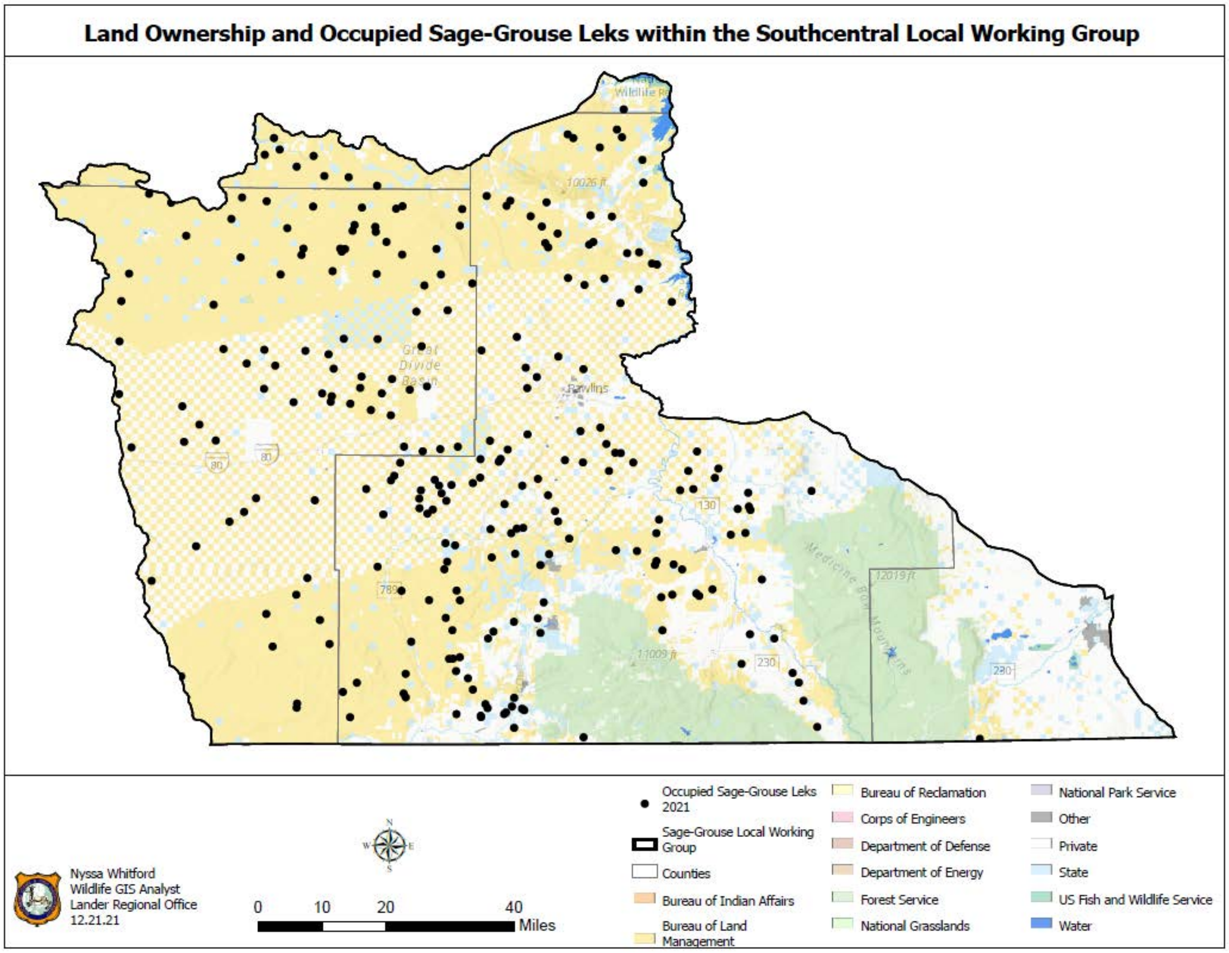


Figure 1. Landownership and sage-grouse lek locations within the SCCA, Wyoming.

Leks in the SCCA are monitored by Wyoming Game and Fish Department (WGFD), United States Forest Service (USFS) and BLM personnel, environmental consultants, and volunteers. Lek monitoring techniques are described in Christiansen (2012). During the 2021 lekking season, 251 leks were monitored. This represented checking 92% of the occupied status leks in the SCCA. This rate of effort was 1% greater than in 2020; and was the same as 10-year average rate of effort (Table 1c)[1].

A total of 91 leks were *counted* in the SCCA, resulting in an average of 21.7 males per lek. A total of 160 leks were *surveyed* resulting in an average of 15.7 males per lek. Across the SCCA, more leks were monitored with *survey* protocol and fewer were monitored with *count* protocol. In portions of the SCCA, COVID-19 restrictions on personnel may have resulted in more leks being *surveyed* rather than *counted*. To evaluate long-term population trends, average lek *survey* and

[1] Table 1c does not include “Unknown” lek observations.

count data are combined, because the more stringent count protocol was not used during the late 1980s and early 1990s. Fortunately, long-term data sets from Wyoming and neighboring states indicate similar trends from both *counts* and *surveys* (Fedy and Aldridge 2011). In 2021, the peak male lek attendance with the SCCA totaled 2,889 males. This was a 16% decrease from 2020. The average number of male sage-grouse on both *counted* and *surveyed* leks decreased from 21.5 and 28.3 in 2020 to 18.5 and 26.7 in 2021. Figure 2 illustrates the trends in average peak males per lek for all sage-grouse conservation areas in Wyoming, as well as the statewide average. Sage-grouse populations in Wyoming cycle on approximately 6 to 8-year intervals (Row and Fedy 2017). The proportion of occupied leks which were considered inactive decreased slightly from 28% in 2020 to 27% in 2021. During a downswing in the sage-grouse population, we would expect an increase in the number of inactive leks. In 2021, the management status for 15 leks (6%) was unknown because they were not monitored or monitoring protocol requirements were not met (Table 1a-d).

In spring 2021, biologists in Baggs and Saratoga conducted sage-grouse lek flights. One new sage-grouse lek was discovered near Muddy Mountain and active status was confirmed on two other leks in the Baggs area. Two new sage-grouse leks near and on Pennock Mountain Wildlife Habitat Management Area were discovered during the Saratoga area flight.

No reliable method for estimating the sage-grouse population for the SCCA exists at this time, however the number of male per lek provides a reasonable index of abundance of the population over time. The decrease in the male per lek average, decrease in peak male lek attendance, along with the observed chick per hen ratios in hunter submitted wings indicated a decreasing sage-grouse population across the SCCA during biological year 2020.

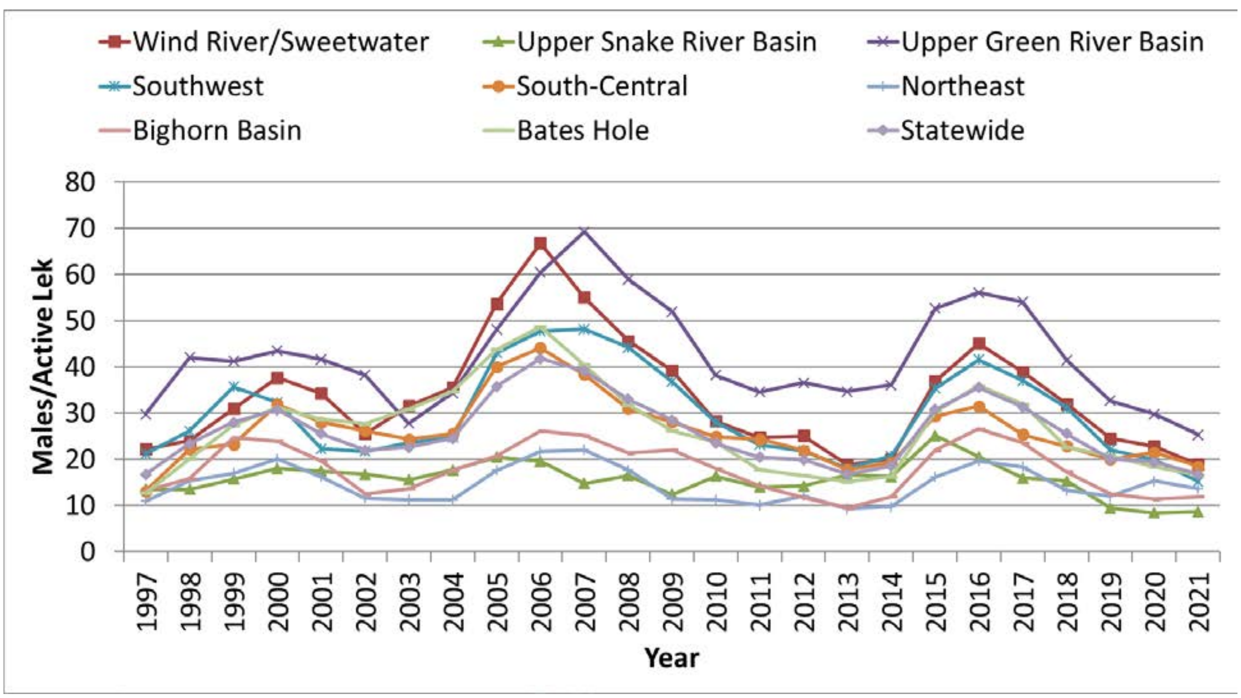


Figure 2. 1995-2021 Average peak male sage-grouse lek attendance, by Conservation Area and Statewide, Wyoming.

<u>Harvest</u>

The 2020 sage-grouse hunting season in the SCCA, was from 19 September to 30 September (12 days), and allowed for the harvest of 2 sage-grouse per day and 4 in possession (Table 3a). The 2020 upland harvest survey estimated 465 hunters spent 1,250 days to harvest 1,023 sage-grouse in the SCCA. Due to sampling errors, harvest data from 2020 should be interpreted with caution and may be unreliable. The average number of birds harvested per hunter day was 0.8. The average number of sage-grouse harvested per hunter was 2.2 and the average number of days hunted was 2.7 (Table3b). Compared to the 2019 season, when hunting regulations were similar with the exception of 2 fewer days in the 2019 season length; 2020 hunter numbers decreased by 20%, the birds/day decreased by 11%, and the days/hunter increased 35%, indicating hunters may have been less successful and harvesting required more hunter effort than previous years. Generally, during the past 10 years, overall harvest appeared to be correlated to both hunter numbers and sage-grouse abundance. Based on check station observations and hunter success appeared to vary across the SCCA, with lower success in the northern portions (Red Desert/ Ferris) and higher success in the southern portions (Saratoga, south Rawlins, Baggs).

Hunter-harvested sage-grouse wings have been collected annually and are used for estimating productivity. Wings were collected in barrels set out at major road junctions where hunters are most likely to pass, and can provide a relatively consistent source of productivity data. Wings are gathered and then aged/sexed by molt patterns, and numbers of chicks per hen are calculated and used as a measure of productivity. While there are biases associated with the hunter selectivity of different age/sex groups of sage-grouse, trends still provide yearly comparisons of relative chick production. During the 2020 hunting season, WGFD collected 258 wings from wing barrels within the SCCA, which was 25% of the estimated harvest of 1,023 birds. This was a 32% increase in the total number of wings when compared to the 196 wings collected in 2019. Age and sex composition of the wings indicated the proportion of chicks per hen decreased from 1.3 in 2019 to 0.9 in 2020 (Table 4). Statewide analyses of wing data from harvested sage-grouse have suggested chick per hen ratios of 1.4-1.7 typically results in relatively stable populations as determined by lek counts the following year.

Habitat

Sage-grouse habitat within the SCCA is comprised of relatively intact sagebrush communities. The health of these communities is predominately dependent on the type, amount, and timing of annual precipitation. Spring precipitation is an important factor in the quantity and quality of grass and forb production, which have been linked to sage-grouse nest success and chick survival. Much of the sagebrush habitat in the SSCA is trending towards older, decadent age classes. While mature sagebrush stands are important to sage-grouse for both forage and cover, a monoculture of older and decadent stands may lead to lower nutrient content of this key forage. We continue to see the proliferation of cheatgrass throughout sagebrush communities within the SCCA, reducing native plant density and diversity as well as increasing the risk of large fires that have the potential to devastate sage-grouse habitat.

Primary land use in the SCCA is livestock grazing and energy development. In the first half of the 20th century, much of the sage-grouse habitat in the SCCA provided winter grazing for hundreds of thousands of both domestic sheep and cattle. Sheep numbers have since declined and cattle have become the primary species of livestock grazing in the SCCA. Improved grazing management on both public and private lands during the last few decades has generally led to improved habitat for sage-grouse and other sagebrush obligate species. Feral horses continue inhabit the western and northern portions of the SCCA.

Energy development and mineral extraction continue to be a primary use of sage-grouse habitat within the SCCA, with a majority of the energy development focused on producing natural gas from both deep gas and coalbed methane sources. Large-scale wind farm developments have begun over the past few years in the northern part of the SCCA, introducing new challenges within sage-grouse habitat. Development for the Chokecherry/Sierra Madre Wind Energy Project, including access roads and turbine pads, continued through 2020 and 2021. Past and present uranium mining has also contributed to reducing sage-grouse habitat in the SCCA. Construction of the Energy Gateway West Aeolus-Jim Bridger powerline, which coincides with the EO 2019-3 Transmission Corridor, was completed in 2020. Energy development has directly and indirectly reduced the functionality of sage-grouse habitat in portions of the SCCA. The Interstate 80/Union Pacific Railroad transportation corridor bisects the SCCA east to west and is a major cause of habitat fragmentation. Continued urban/rural development within sagebrush communities also continues to fragment sage-grouse habitat.

The Mullen wildfire started in September 2020 and burned approximately 176,800 acres. While the Mullen fire was predominately on forested lands and no known sage-grouse leks were directly impacted, firefighting efforts resulted in back burning transitional shrub communities outside the forest. Controlling cheatgrass in the year following fire will be crucial to aid in the recovery of native, perennial vegetation. Planting sagebrush seedlings into these burn areas to aid in sagebrush recovery will need to be considered.

The 2020 growing season precipitation (April – July) within the SCCA was notably low and below the 30-year average. Annual vegetation monitoring in the area showed low grass and forb production, correlating with the low growing season precipitation. Forbs are an extremely important part of the sage-grouse diet in the spring and throughout the summer, especially for juveniles. Although grasses don’t make up a significant part of the sage-grouse diet, good grass production provides better hiding cover from predators. As such, low vegetation production in 2020 could have impacts to sage-grouse nutrition and survival.

In an effort to mitigate habitat issues related to cheatgrass in sage grouse habitats extensive large-scale, aerial herbicide treatments continue to be conducted throughout the SCCA. In the fall of 2020, approximately 2,196 acres of aerial cheatgrass herbicide treatments were completed. Cheatgrass was treated last year on Battle Mountain, Cottonwood Rim, and eastside tributary drainages to Savery Creek along the Forest boundary through existing collaborations. We also completed projects to remove encroaching juniper within the SCCA to improve sage-grouse habitat.

Plans for developing water wells to supplement flows in Stewart Creek to benefit sage grouse as mitigation for the Lost Creek Uranium did not occur in 2021. Soils were determined to be too sandy and porous to make these developments successful.

In the northwest portion of the SCCA, the BLM removed 1,763 wild horses in fall, 2020. Wild horse removals in the desert and prime sage-grouse habitats were successfully near target levels.

<u>Disease</u>

There were no cases of West Nile Virus in sage-grouse, or other diseases detrimental to sage-grouse documented within the SCCA in biological year 2020.

<u>Conservation Planning</u>

The South Central Local Working Group (SCLWG) was established in September of 2004 and they completed their Sage-grouse Conservation Plan (Plan) in 2007. In 2014, the SCLWG adopted an addendum to their Plan which is available at https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management/Sage-Grouse-Local-Working-Groups. This addendum documented conservation action such as research and habitat projects the SCLWG had supported since their Plan was completed, as well as how these projects addressed the goals and action items identified in the Plan.

The SCLWG held one meeting during this reporting period. During this meeting, the SCLWG allocated their $75,000 FY2021 funds. Projects that received support from SCLWG during this reporting period included:

1. Response of Greater Sage-Grouse to Treatments in Wyoming Big Sagebrush
2. Wind Energy Infrastructure and Greater Sage-grouse Population Viability and Connectivity
3. West Slope of Sierra Madre Large-Scale Cheatgrass Treatments
4. Pennock Wildlife Habitat Management Area Big Game/Sage-Grouse Water Development
5. Red Rim - Grizzly Wildlife Habitat Management Area Water Development

Local Working Group Adaptive Management Trigger Identification

Executive Order 2019-3 Appendix I called for sage-grouse local working groups to evaluate sage-grouse lek data annually to determine if anything unexpected is happening which may be cause for a suspected soft or hard trigger. In 2021, the SCLWG met to evaluate sage-grouse core areas within the SCCA using several tools to identify possible triggers. SCLWG identified a soft trigger had been tripped during biological year 2020 in the SCCA portion of Hanna Core Area. The SCLWG deferred to the Bates Hole/Shirley Basin Local Working Group to evaluate a possible trigger from the 2020 316 Fire. The SCLWG determined that South Rawlins Core needed to be watched, but did not meet the group's criteria for a trigger during this evaluation period. This decision was based on Executive Order calculations not indicating a soft or hard trigger, borderline habitat triggers that needed further investigation, and the USGS clusters only being representative of 2019 lek data. The Greater South Pass Core Area did not meet the SCLWG's criteria for tripping a trigger based on the Executive Order calculations not indicating a trigger. The SCLWG agreed that both the South Rawlins and Greater South Pass Core Areas should be evaluated closely next year. The Statewide Adaptive Management Working Group (SAMWG) met multiple times to consider the suspected triggers identified by all the local working groups. The SAMWG group will work on drafting a new Appendix I that will focus on the process, clarifying roles and responsibilities, and defining triggers. The SAMWG did not declare any triggers during this reporting period.

Special Projects

The North Dakota Greater Sage-Grouse Translocation Project was completed in June 2020. This translocation effort was done in an effort to supplement North Dakota's remnant sage-grouse population. Translocation success and the impacts to the Stewart Creek source population are being studied by Utah State University and U.S. Geological Survey researchers.

Management Recommendations for the SCCA

1. Continue to monitor a minimum of 80% of the occupied leks in the SCCA.

2. Update all lek observers on WGFD survey protocols, and familiarize them with standardized datasheets.
3. Expand lek searches to ensure all active leks within the SCCA have been identified.
4. Seek out opportunities to increase flight money for lek searches and surveys in hard to access portions of the SCCA.
5. Support WGFD and BLM efforts to address mitigation and reclamation issues.
6. Support research efforts to identify seasonal habitats, especially winter concentration habitat.
7. Coordinate with BLM and USFS to ensure development and habitat treatments in Sage-Grouse Core Area comply with WY-EO-2019-3.
8. Continue to build partnerships with private landowners to maintain or improve sage-grouse habitat on private lands through mutually beneficial habitat projects.

Research

The UW sage grouse-feral horse study examining the potential impacts of feral horses on sage grouse was in its 4th year. The objectives of this research included evaluating: 1) the potential impact of free-roaming horses on greater sage-grouse nest and brood-rearing site selection, as well as nest and brood survival measured from marked female sage-grouse, and 2) the relative degree in which horse utilization, modeled from horse fecal transects, compared to free-roaming horse resource selection modeled from locations acquired from GPS-equipped free-roaming mares.

In April 2020, the University of Wyoming, began the first of two consecutive field seasons to re-evaluate source and sink dynamics for greater sage-grouse in the Atlantic Rim Project Area (ARPA). The objectives of this study are to: 1) collect appropriate habitat and population data in spring and summer to develop new source and sink models and in winter to develop new winter occurrence and survival risk models and maps for the ARPA, 2) compare and contrast new models based on 2020–2022 data with those generated from 2008 and 2009 for breeding habitat and winters 2007–2008, 2008–2009, and 2009–2010 for wintering habitat within the ARPA and surrounding public lands, and 3) determine juvenile survival from the end of summer throughout the winter months.

The following publications have been authored relative to research conducted in the SCCA or have received funding from the SCLWG.

Dinkins, J.B. 2013. Common raven density and greater sage-grouse nesting success in southern Wyoming: potential conservation and management implications. Dissertation. Utah State Univ., Logan.

Dinkins, J. B., M. R. Conover, C. P. Kirol, and J. L. Beck. 2012. Greater sage-grouse (Centrocercus urophasianus) select nest-sites and brood-sites away from avian predators. The Auk 129:600–610.

Dinkins, J.B., M.R. Conover and S.T. Mabray. 2013. Do artificial nests simulate nest success of greater sage-grouse? Human–Wildlife Interactions 7(2):299–312.

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck, and S.N. Frey. 2014. Greater sage-grouse (Centrocercus urophasianus) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology 92:319-330

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck and S.N. Frey. 2014. Greater Sage-Grouse (Centrocercus urophasianus) select habitat based on avian predators, landscape composition, and anthropogenic features. The Condor 116 (4), 629-642.

Dinkins, J. B., K. T. Smith, J. L. Beck, C. P. Kirol, A. C. Pratt, and M. R. Conover. 2016. Microhabitat conditions in Wyoming sage-grouse core areas: effects on selection and nest success. PLoS ONE 11:e0150798.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2016. Effects of common raven and coyote removal and temporal variation in climate on greater sage-grouse nesting success. Biological Conservation 202:50–58.

Dzialak, M. R., S. L. Webb, S. M. Harju, C. V. Olson, J. B. Winstead, and L. D. Hayden-Wing. 2013. Greater sage-grouse and severe winter conditions: identifying habitat for conservation. Rangeland Ecology and Management 66:10-18. Fremgen, A.L., Hansen, C.P., Rumble, M.A., Gamo, R.S., and Millspaugh, J.J., 2016, Male greater sage-grouse detectability on leks: Journal of Wildlife Management, v. 80, no. 2, p. 266-274.

Erickson, H. J. 2011. Herbaceous and avifauna responses to prescribed fire and grazing timing in a high-elevation sagebrush ecosystem. Thesis. Colorado State Univ., Ft. Collins.

Fremgen, A. L., C. P. Hansen, M. A. Rumble, R. S. Gamo, and J. J. Millspaugh. 2016. Male greater sage-grouse detectability on leks. Journal of Wildlife Management 80:266–274.

Heath, B. J., R. Straw, S. H. Anderson, J. Lawson, M. Holloran. 1998. Sage-grouse productivity, survival, and seasonal habitat use among three ranches with different livestock grazing, predator control, and harvest management practices. Research Completion Report. Wyoming Game & Fish Dept., Cheyenne.

Kirol, C. P. 2012. Quantifying habitat importance for greater sage-grouse (Centrocercus urophasianus) population persistence in an energy development landscape. Thesis. Univ. of Wyoming, Laramie.

Kirol, C. P., Beck, J. L., J. B. Dinkins, and M. R. Conover. 2012. Microhabitat selection for nesting and brood-rearing by the greater sage-grouse in xeric big sagebrush. The Condor 114:75-89.

Kirol, C. P., Beck, J. L., Huzurbazar, S. V., Holloran, M. J., Miller, S. N. 2015. Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape. Ecol Apps 25:968–990.

Klott, J. H. 1987. Use of habitat by sympatrically occurring sage-grouse and sharptailed grouse with broods. Thesis. Univ. of Wyoming, Laramie.

Klott, J. H., and F. G. Lindzey. 1989. Comparison of Sage and Sharp-tailed Grouse leks in south central Wyoming. Great Basin Naturalist 49:275-278.

Klott, J. H. and F. G. Lindzey. 1990. Brood habitats of sympatric sage grouse and Columbian sharptailed grouse in Wyoming. Journal of Wildlife Management 54:84-88.

LeBeau, C.W. 2012. Evaluation of Greater sage-grouse reproductive habitat and response to wind energy development in south-central Wyoming. Thesis, Univ. of Wyoming, Laramie.

LeBeau. C. W., J. L. Beck, G. D. Johnson, M. J. Holloran. 2014. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management 78:522-530.

LeBeau, C.W., Beck, J.L., Johnson, G.D., Nielson, R.M., Holloran, M.J., Gerow, K.G., and McDonald, T.L., 2017a, Greater sage-grouse male lek counts relative to a wind energy development: Wildlife Society Bulletin, v. 41, no. 1, p. 17-26.

LeBeau, C.W., Johnson, G.D., Holloran, M.J., Beck, J.L., Nielson, R.M., Kauffman, M.E., Rodemaker, E.J., and McDonald, T.L., 2017b, Greater sage-grouse habitat selection, survival, and wind energy infrastructure: Journal of Wildlife Management, v. 81, no. 4, p. 690-711.

LeBeau, C., G. Johnson, M. Holloran, J. Beck, R. Nielson, M. Kauffman, E. Rodemaker, and T. McDonald. 2016. Effects of a Wind Energy Development on Greater Sage-Grouse Habitat Selection and Population Demographics in Southeastern Wyoming. Unpublished report. Prepared for: National Wind Coordination Collaborative, Washington, DC. Prepared by: Western EcoSystems Technology, Inc., Cheyenne, WY.

Peebles, L. W. 2015. Winter ecology of common ravens in southern Wyoming and the effects of raven removal on greater sage-grouse populations. Paper 4617. Thesis. Utah State Univ., Logan.

Revekant, C. L. 2021. Comparison of common ravens in sage-grouse core and non-core areas: assessing predator densities related to anthropogenic features. Thesis. Oregon State Univ., Corvallis.

Schreiber, L. A. 2013. Greater sage-grouse nest site selection, brood-rearing site selection and chick survival in Wyoming. Thesis. Univ. of Missouri, Columbia.

Schreiber, L.A., Hansen, C.P., Rumble, M.A., Millspaugh, J.J., Gamo, R.S., Kehmeier, J.W., and Wojcik, N., 2015a. Microhabitat selection of brood-rearing sites by greater sage-grouse in Carbon County, Wyoming: Western North American Naturalist, v. 75, no. 3, p. 348-363.

Schreiber, L.A., C.P. Hansen, M.A. Rumble, J.J. Millspaugh, S. Gamo, J. Kehmeier, and N. Wojcik. 2015.. Greater sage-grouse apparent nest productivity and chick survival in Carbon County, Wyoming. Wildlife Biology 22:37-44. Smith, K. T., C. P. Kirol, J. L. Beck, and F. C. Blomquist. 2014. Prioritizing winter habitat quality for greater sage-grouse in a landscape influenced by energy development. Ecosphere 5(2):15

Smith, K. T., J. B. Dinkins, and J. L. Beck. 2019. Approaches to delineate greater sage-grouse winter concentration areas. Journal of Wildlife Management 83:1495–1507.

<u>Literature Cited</u>

Christiansen, T. 2012. Chapter 12: Sage Grouse (Centrocercus urophasianus). Pages 12-1 to 12-55 in S.A. Tessmann and J. R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne.

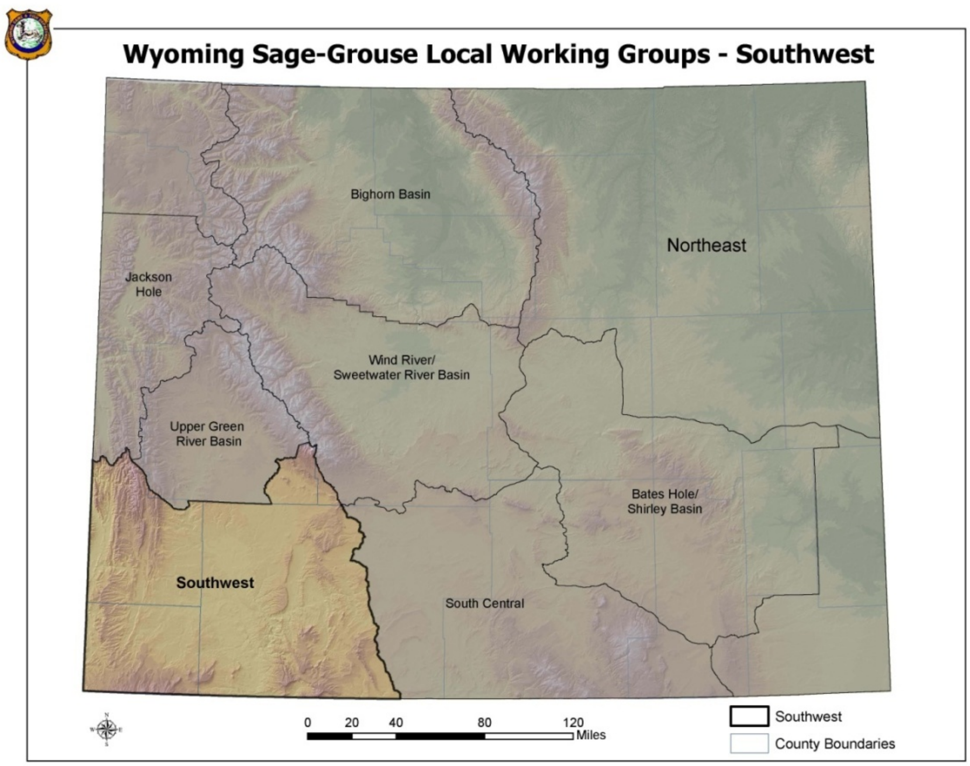
Fedy, B.C. and C.L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Row, J. R. and B. C. Fedy. 2017. Spatial and temporal variation in the range-wide cyclic dynamics of greater sage-grouse. Oecologia doi: 10.1007/s00442-017-3970-9.

Wyoming Game and Fish Department (WGFD). 2007. South Central Sage-Grouse Conservation Plan. 74pp.

Southwest Conservation Area
Job Completion Report

Species: Greater Sage-grouse
Management Areas: G, Green River & Pinedale Regions
Biological Year: June 1, 2020 – May 31, 2021
Prepared By: Patrick Burke, Green River Wildlife Biologist



Sage Grouse Lek Characteristics

Working Group: Southwest

Region	Number	Percent
Green River	400	88.1
Pinedale	54	11.9

Working Group	Number	Percent
Southwest	454	100.0

Classification	Number	Percent
Occupied	331	72.9
Undetermined	9	2.0
Unoccupied	114	25.1

BLM Office	Number	Percent
Kemmerer	198	43.6
Pinedale	14	3.1
Rawlins	4	0.9
Rock Springs	238	52.4

Biologist	Number	Percent
Green River	168	37.0
Mountain View	231	50.9
Pinedale	54	11.9
South Lander	1	0.2

Warden	Number	Percent
Cokeville	55	12.1
Evanston	36	7.9
Green River	75	16.5
Kemmerer	71	15.6
Mountain View	51	11.2
Rock Springs	112	24.7
South Pinedale	54	11.9

County	Number	Percent
Fremont	4	0.9
Lincoln	136	30.0
Sublette	35	7.7
Sweetwater	212	46.7
Uinta	67	14.8

Land Status	Number	Percent
BOR	15	3.3
National Park	2	0.4
State	15	3.3
USFS	1	0.2
Private	106	23.3
BLM	315	69.4

Management Area	Number	Percent
G	454	100.0

Lek Status	Number	Percent
Active	264	58.1
Inactive	82	18.1
Unknown	108	23.8

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Southwest

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

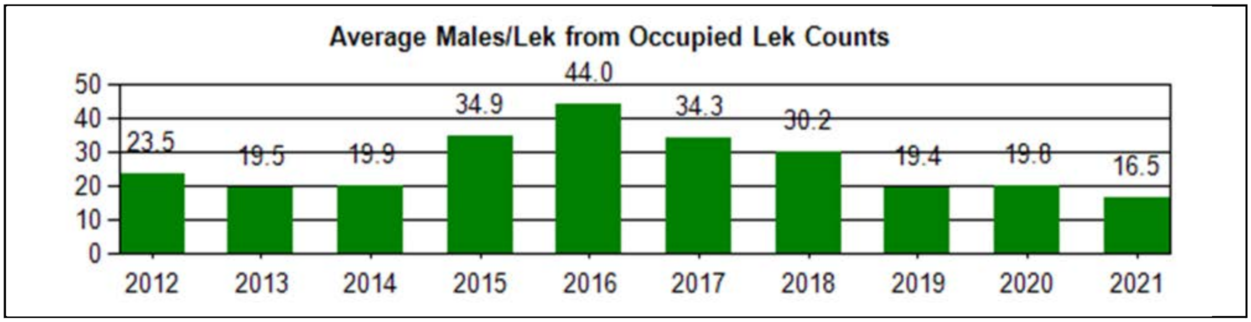
Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	301	81	27	1719	23.5
2013	308	116	38	1966	19.5
2014	310	96	31	1613	19.9
2015	316	70	22	2197	34.9
2016	325	94	29	3744	44
2017	334	97	29	2950	34.3
2018	338	102	30	2654	30.2
2019	337	87	26	1433	19.4
2020	336	68	20	1090	19.8
2021	335	84	25	1053	16.5

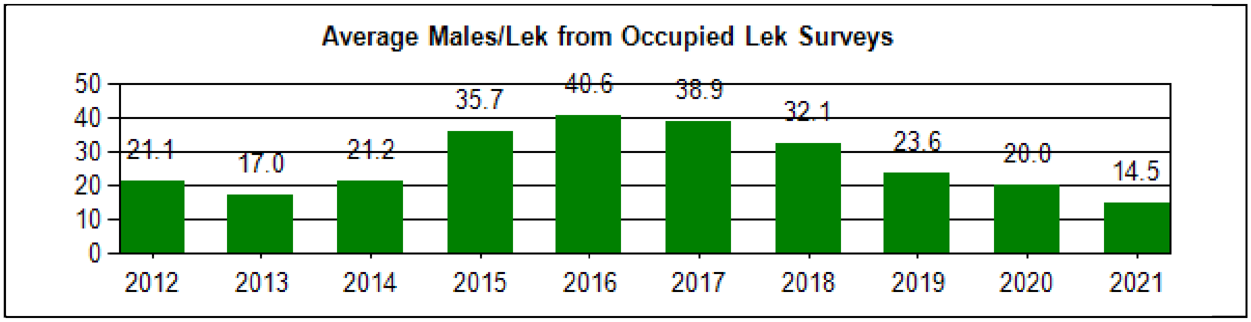
b. Leks Surveyed

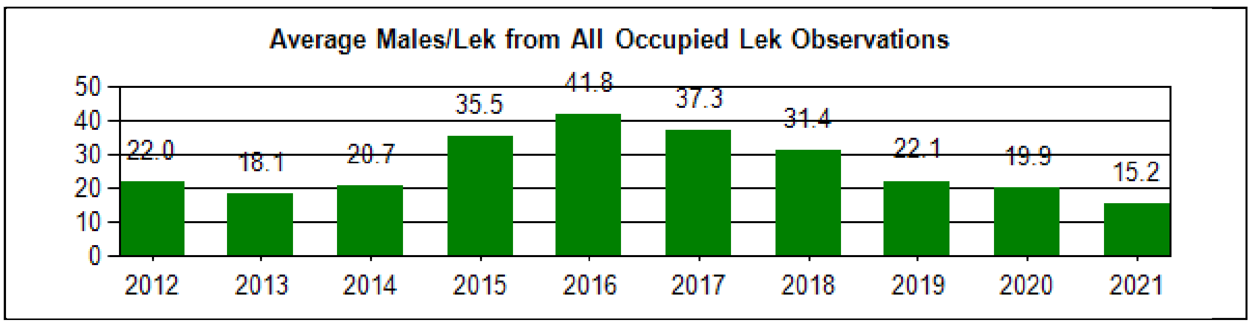
Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	301	181	60	2871	21.1
2013	308	175	57	2243	17
2014	310	190	61	3177	21.2
2015	316	222	70	6256	35.7
2016	325	211	65	6488	40.6
2017	334	203	61	5991	38.9
2018	338	210	62	5357	32.1
2019	337	201	60	3068	23.6
2020	336	192	57	2778	20
2021	335	161	48	1714	14.5

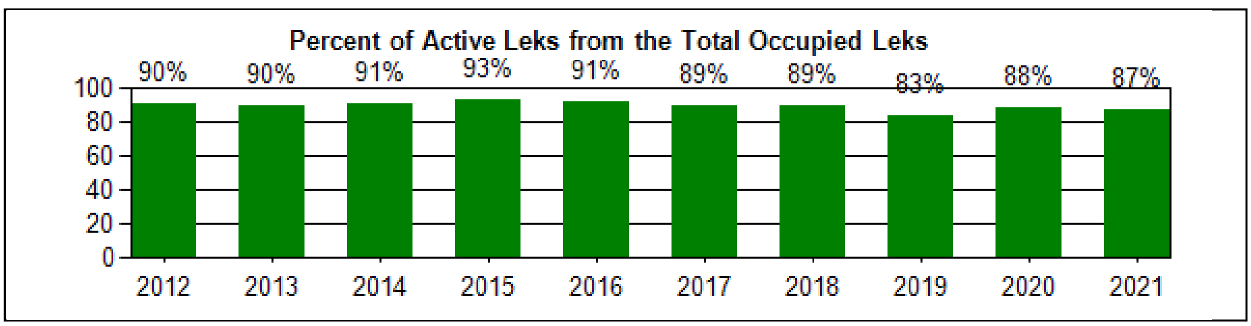
Sage Grouse Occupied Lek Attendance Summary

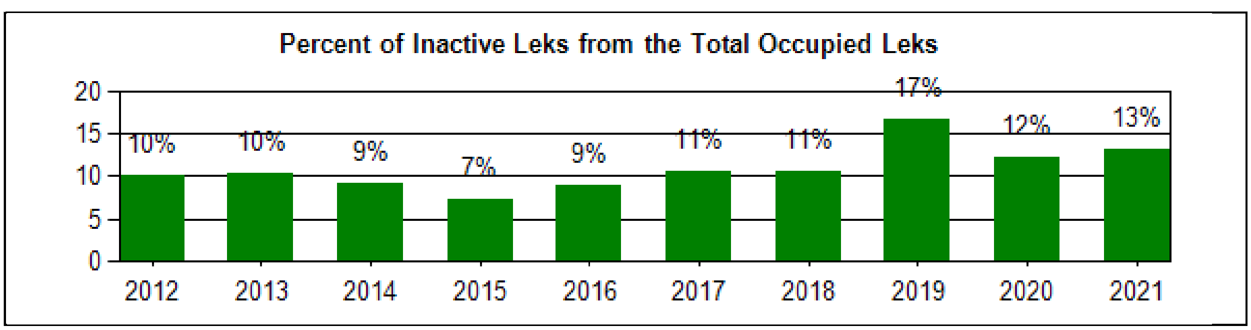
Year: 2012 - 2021, Working Group: Southwest











Sage Grouse Job Completion Report

Year: 2011 - 2020, Working Group: Southwest

3. Sage Grouse Hunting Seasons and Harvest Data

a. Season

Year	Season Start	Season End	Length	Bag/Possesion Limit
2011	Sep-17	Sep-30	14	2/4
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

b. Harvest

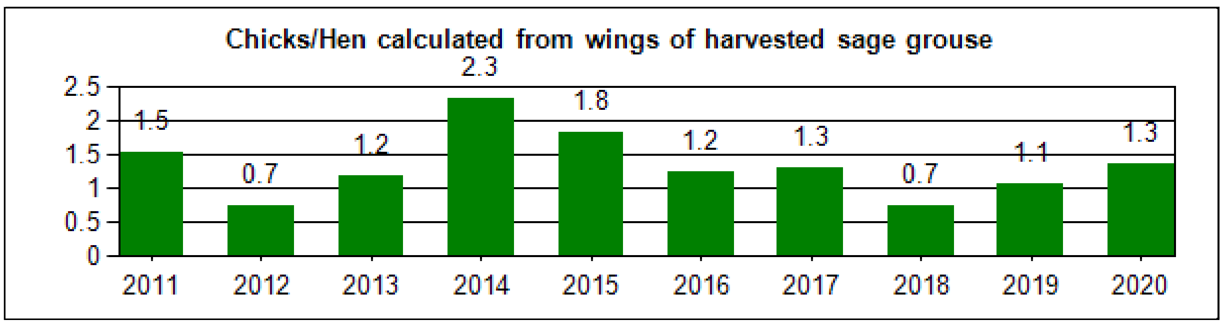
Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2011	3901	1709	4276	0.9	2.3	2.5
2012	3737	1775	4503	0.8	2.1	2.5
2013	2513	1307	3139	0.8	1.9	2.4
2014	2645	1165	2835	0.9	2.3	2.4
2015	4479	1586	4057	1.1	2.8	2.6
2016	4163	1672	4036	1.0	2.5	2.4
2017	3590	1421	3675	1.0	2.5	2.6
2018	3410	1630	3873	0.9	2.1	2.4
2019	2821	1514	3746	0.8	1.9	2.5
2020	1491	737	2336	0.6	2.0	3.2
Avg	3,275	1,452	3,648	0.9	2.2	2.5

Sage Grouse Job Completion Report

Year: 2011 - 2020, Working Group: Southwest

4. Composition of Harvest by Wing Analysis

Year	Sample Size	Percent Adult Male	Percent Adult Female	Percent Yearling Male	Percent Yearling Female	Percent Young Male	Percent Young Female	Chicks/ Hens
2011	998	6.1	31.9	2.9	4.3	23.9	30.9	1.5
2012	581	10.0	38.9	4.6	10.3	16.5	19.6	0.7
2013	390	9.2	38.5	1.5	2.3	20.5	27.9	1.2
2014	517	5.6	20.7	2.3	7.0	33.5	30.9	2.3
2015	860	13.5	25.1	3.1	4.3	27.4	26.5	1.8
2016	949	15.2	30.5	4.2	5.6	19.9	24.7	1.2
2017	813	9.5	31.0	2.8	7.0	22.6	27.1	1.3
2018	827	12.0	33.4	6.5	13.4	13.1	21.6	0.7
2019	570	7.9	37.5	2.1	6.3	14.4	31.8	1.1
2020	779	7.8	31.3	3.6	6.4	20.5	30.3	1.3



Lek Monitoring

A total of 335 occupied leks were known to exist in the SWSGCA during the 2021 lekking season. Of these 335 occupied leks, 245 of them were checked, with 84 of those checks being lek counts with three or more visits during the breeding season, with the remaining 161 checks consisting of lek surveys where less than three lek visits were made during the breeding season. In 2020, 74% of the known leks were checked at least once during the lekking season because of a decrease in the number of people that were available to checks leks due to the Covid-19 restrictions that were put in place in the spring of 2020; in 2021 however, that percentage increased to a more typical 84% of the known leks being checked.

Of the 454 known lek sites in the SWSGCA in 2021, 264 of them were documented as being active, 82 were classified as being inactive and 108 leks were of unknown or undetermined status. All lek monitoring data from 2021, along with data from the past ten years for comparison are summarized in Tables 1 a-d.

Because of the quantity of leks in the SWSGCA, data collection efforts have focused on lek surveys, which involved at least one visit to the lek during the breeding season over lek counts, which are more labor intensive and involve three or more visits during the breeding season. Fedy and Aldridge (2011) determined that population trends demonstrated by lek surveys are the same as those indicated by lek counts as long as the number of leks surveyed exceeds 50 leks in an area.

Since only “occupied” leks are being reported on Tables 1 a-d, it is important to consider trends in the numbers of active versus inactive leks in addition to the average size of active leks. During a period of population decline, the size of active leks typically declines and the number of inactive leks increases. The converse is typically true of an increasing population. Therefore the magnitude of both increases and decreases is usually greater than what is indicated by the average lek size alone. The proportion of known status leks that were active in the SWSGCA has remained relatively steady over the 10-year reporting period varying from 83-93% active. The proportion of active leks for the 2021 lekking season, was in line with typical values having 87% of the occupied leks being active.

Monitoring the total number of males on a lek is used as an index of trend, but these data should be viewed with caution for several reasons: 1) the survey effort and the number of leks surveyed/counted has varied over time, 2) it can be safely assumed that not all leks in the area have been located, 3) sage-grouse populations can exhibit cyclic patterns over approximately a decade long period, 4) the effects of un-located or un-monitored leks that have become inactive cannot be quantified or qualified, and 5) lek sites may shift over time. Both the number of leks and the number of males attending these leks must be quantified in order to estimate population trend.

The average number of males per active lek for all leks checked (both counted and surveyed) during the 2021 lekking season was 15.2 males per active lek. This is down from the high observations of 35 to 41 males per active lek observed from 2016 to 2018. The 2021 average number of males per active lek is also below the 10 year average of 24.9 males per active lek. The average number of males in attendance on the 84 count leks in 2021 was 14.5 males per lek. This number is below the 10 year average of 24.5 males per lek, and is the lowest number observed since the mid 1990’s. For the 161 leks that were surveyed in 2021, the average lek had 20.4 males in attendance, which is below the recent average of 25males per lek, and down substantially from 2016’s and 2017’s observed values of 40.3 and 38.7 males per survey lek.

It is important to note that data collection efforts have increased considerably since the early 2000's. In 2000, only 63% of known occupied leks were checked, but in recent years, the number annually checked is usually above 90% of the known occupied leks. In addition, efforts by WGFD personnel, volunteers, and other government and private industry biologists have led to increased numbers of known leks.

Currently, no method exists to estimate total sage-grouse population size in a statistically significant way. However, the recent male per lek averages along with the observed chick per hen ratios in hunter submitted wings indicate that the sage-grouse population in southwest Wyoming had been slightly decreasing during this reporting period.

Harvest

The 2020 hunting season for sage-grouse in the SWSGCA ran from September 19 to September 30 and allowed for a daily take of 2 birds with a limit of 4 grouse in possession (Table 3a). The 2020 season was consistent with how the season has been run since 2002 when the season opening date was moved to the third Saturday in September and the daily bag limit was reduced to 2 birds and a possession limit of 4 birds. The sage-grouse season had historically started as early as September first and ran for 30 days; during this time the daily limit was 3 grouse with a possession limit of up to 9 birds. Over time, the season was gradually shortened and the daily bag and possession limits reduced because of concern over declining sage-grouse populations. The opening date was moved back from the first of September to the third weekend because research suggested that hens with broods were concentrated near water sources earlier in the fall and therefore more susceptible to harvest. The later opening date allowed more time for those broods to disperse and therefore reduced hunting pressure on those hens that were successful breeders and on young of the year birds.

The data for grouse harvested in the SWSGCA are reported under Sage-Grouse Management Area G for the 2011 through 2020 hunting seasons in this report (Table 3b). Based on harvest survey estimates, 737 hunters harvested 1,491 sage-grouse during the 2020 hunting season. This is down slightly from the 3,590 birds reported harvested in 2017, and the 3,410 grouse harvested in 2018; and is the lowest number of grouse reported harvested since 2002 when 1,156 grouse were harvested. The trends in harvest statistics over the last 10 years are not well correlated with average male lek attendance due to changes in hunting season structure, weather conditions, and hunter participation levels over that period.*

Wings are collected each hunting season via voluntary hunter submission to allow for the determination of the sex and age of harvested birds. Successful hunters submitted 779 grouse wings from the 2020 hunting season (Table 4). This represents just over 50% of the estimated total harvest for 2020, which is well above the average submission rate of around 18%-19% of reported harvest.

The most important ratio obtained from the wing analysis is the chick to hen ratio; this ratio provides a general indication of chick recruitment. Assuming that hen and chick harvest is proportional to the actual makeup of the population, chick production for that year can be estimated. Even if the rate of harvest between age/sex groups is not random, the information can be used as a tool for looking at population trends as long as any biases are relatively consistent across years.

*The 2020 sage-grouse harvest estimates should be interpreted with caution, because that particular year's survey under-sampled potential sage-grouse hunters from certain license fee types, resulting in poor quality harvest estimates. Making comparisons between previous years' estimates and the 2020 estimates should be avoided, because the results from the voluntary survey were unreliable due to sampling issues.

In general it appears that chick:hen ratios of about 1.3:1 to 1.7:1 result in relatively stable grouse populations, while chick:hen ratios of 1.8:1 or greater result in increasing grouse numbers and ratios below 1.2:1 result in subsequent declines. The chick:hen ratio as determined from hunter submitted wings for the 2020 hunting season was 1.3 chicks/hen (Table 4). This ratio suggests a slightly decreasing grouse population. This observed chick:hen ratio corresponds well with the decreased male lek attendance seen in the spring of 2021.

Weather

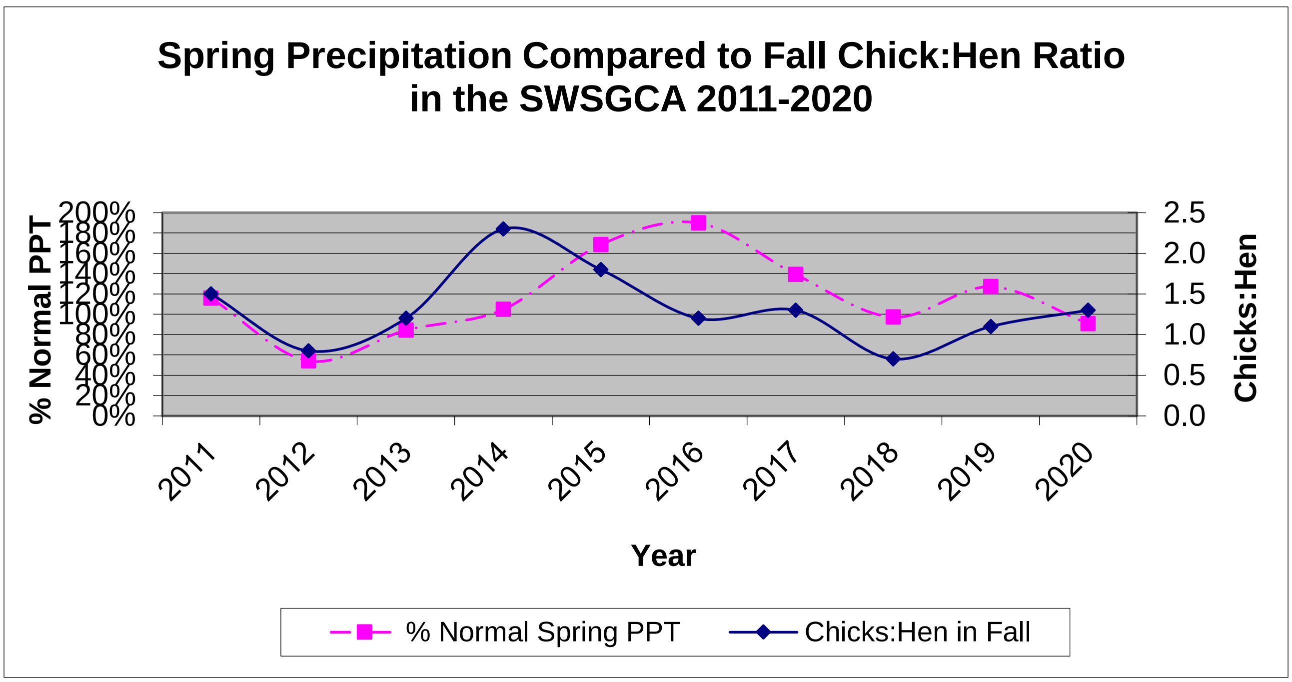
Spring habitat conditions are one of the most important factors in determining nesting success and chick survival for sage-grouse. Specifically, shrub height and cover, live and residual grass height and cover, and forb production, all have a large impact on sage-grouse nesting and brood rearing success. The shrubs and grasses provide screening cover from predators and weather, while the forbs provide forage and insects that reside in the forbs, which are an important food source for chicks. Spring precipitation is an important determinant of the quality and quantity of these vegetation characteristics. Residual grass height and cover depends on the previous year's growing conditions and grazing pressure while live grass and forb cover are largely dependent on the current year's precipitation.

Winter weather has not been shown to be a limiting factor to sage-grouse except in areas with persistent snow cover that is deep enough to limit sagebrush availability. This condition is rarely present in the SWSGCA even during severe winters.

The spring (March-June) precipitation and fall chick:hen ratios (as determined by hunter submitted wings) are given in Table 5 and Figure 4. Generally speaking, when spring precipitation is at or above 90% of average, chick to hen ratios are above average, but when spring precipitation is below average, chick:hen ratios also tend to be below average. However, periods of prolonged or poorly timed cold, wet weather may have adverse effects on hatching success, plant and insect phenology and production and chick survival.

Table 5. Spring precipitation compared to fall chick:hen ratios in the SWSGCA 2010-2019. Precipitation data from: http://www.wrcc.dri.edu/index.html (Click on Monitoring – under Monitoring click on Drought Monitoring then click on Monthly divisional precipitation or temperature – click on the map in the relevant portion of Wyoming, in this case division #3 Green and Bear Drainage Division – set up the plot as desired including "List the data for the points plotted?" Option – add the percentages listed under March through June of the year of interest and divide by four).

Year	% of Average March-June Precipitation	Chicks:Hen
2011	144%	1.5
2012	41%	0.7
2013	64%	1.2
2014	79%	2.3
2015	128%	1.8
2016	145%	1.2
2017	105%	1.3
2018	96%	0.7
2019	125%	1.1
2020	91%	1.3



HABITAT AND SEASONAL RANGE MAPPING

While new leks are still being located in the SWSGCA, we believe that the majority of the currently occupied leks have been documented, however important other seasonal habitats such as winter concentration areas and especially nesting/early brood-rearing areas have not yet been adequately identified.

PAST RESEARCH/STUDIES IN THE SWSGCA

Conover, M. R., J. S. Borgo, R. E. Dritz, J. B. Dinkins and D. K. Dahlgren. 2010. Greater sage-grouse select nest sites to avoid visual predators but not olfactory predators. The Condor 112(2):331-336.

Dinkins, J. B., M. R. Conover, C. P. Kirol, and J. L. Beck. 2012. Greater sage-grouse (*Centrocercus urophasianus*) select nest-sites and brood-sites away from avian predators. The Auk 129:600–610.

Dinkins, J.B., M.R. Conover and S.T. Mabray. 2013. Do artificial nests simulate nest success of greater sage-grouse? Human–Wildlife Interactions 7(2):299–312.

Dinkins, J.B. 2013. Common raven density and greater sage-grouse nesting success in southern Wyoming: potential conservation and management implications. Dissertation. Utah State Univeristy, Logan.

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck, and S.N. Frey. 2014a. Greater sage-grouse (Centrocercus urophasianus) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology 92:319-330.

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck and S.N. Frey. 2014b. Greater Sage-Grouse (Centrocercus urophasianus) select habitat based on avian predators, landscape composition, and anthropogenic features. The Condor 116 (4), 629-642.

Dinkins, J. B., K. T. Smith, J. L. Beck, C. P. Kirol, A. C. Pratt, and M. R. Conover. 2016. Microhabitat conditions in Wyoming sage-grouse core areas: effects on selection and nest success. PLoS ONE 11:e0150798.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2016. Effects of common raven and coyote removal and temporal variation in climate on greater sage-grouse nesting success. Biological Conservation 202:50–58.

Heath, B. J., R. Straw, S. H. Anderson and J. Lawson. 1997. Sage-grouse productivity, survival, and seasonal habitat use near Farson, Wyoming. Completion Report. Wyoming Game and Fish Department. Cheyenne.

Patterson, R. L. 1952. The sage-grouse in Wyoming. Wyoming Game and Fish Department. Sage Books.

Peebles, L. W. 2015. Winter ecology of common ravens in southern Wyoming and the effects of raven removal on greater sage-grouse populations. Paper 4617. Thesis. Utah State University, Logan.

Slater, S. J. 2003. Sage-grouse *(Centrocercus urophasianus)* use of different-aged burns and the effects of coyote control in southwestern Wyoming. M.S. Thesis. University of Wyoming, Department of Zoology and Physiology. Laramie.

Slater, S. J. and J. P. Smith. 2010 Effectiveness of raptor perch deterrents on an electrical transmission line in southwestern Wyoming. Journal of Wildlife Management 74:1080-1088.

LITERATURE CITED

Bui, T.D. 2009. The effects of nest and brood predation by common ravens (*Corvus corax*) on greater sage-grouse (*Centrocercus urophasianus*) in relation to land use in western Wyoming. M.S. Thesis. University of Washington, Seattle.

Christiansen, T. 2012. Chapter 12: Sage Grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S.A. Tessmann and J.R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne.

Christiansen, T. 2010. Hunting and sage-grouse: a technical review of harvest management on a species of concern in Wyoming. Wyoming Game and Fish Department, Cheyenne.

Conover, M. R., J. S. Borgo, R. E. Dritz, J. B. Dinkins and D. K. Dahlgren. 2010. Greater sage-grouse select nest sites to avoid visual predators but not olfactory predators. The Condor 112(2):331-336.

Dinkins, J. B., M. R. Conover, C. P. Kirol, and J. L. Beck. 2012. Greater sage-grouse (*Centrocercus urophasianus*) select nest-sites and brood-sites away from avian predators. The Auk 129:600–610.

Dinkins, J.B., M.R. Conover and S.T. Mabray. 2013. Do artificial nests simulate nest success of greater sage-grouse? Human–Wildlife Interactions 7(2):299–312.

Dinkins, J.B. 2013. Common raven density and greater sage-grouse nesting success in southern Wyoming: potential conservation and management implications. Dissertation. Utah State Univeristy, Logan.

Dinkins, J.B., M.R. Conover, C.P. Kirol, J.L. Beck, and S.N. Frey. 2014. Greater sage-grouse (Centrocercus urophasianus) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology 92:319-330.

Dinkins, J. B., K. T. Smith, J. L. Beck, C. P. Kirol, A. C. Pratt, and M. R. Conover. 2016a. Microhabitat conditions in Wyoming sage-grouse core areas: effects on selection and nest success. PLoS ONE 11:e0150798.

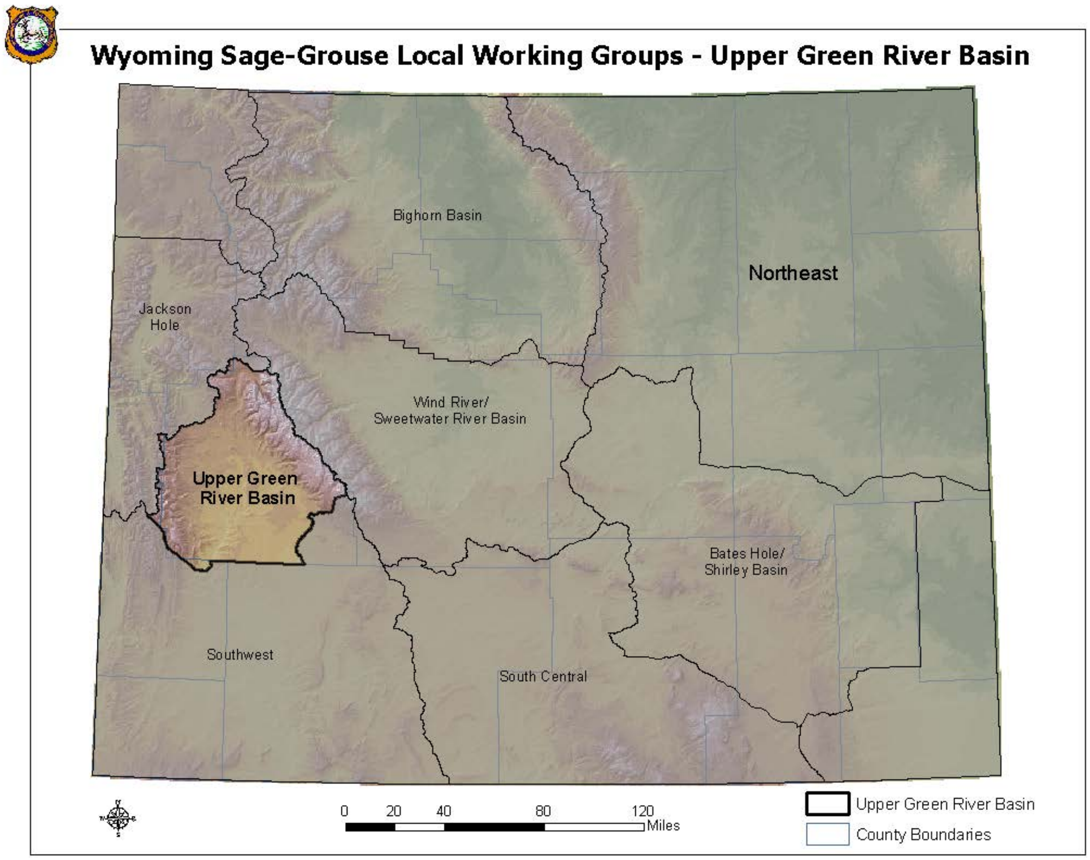
Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2016b. Effects of common raven and coyote removal and temporal variation in climate on greater sage-grouse nesting success. Biological Conservation 202:50–58.

Fedy, B.C. and C.L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Peebles, L. W. 2015. Winter ecology of common ravens in southern Wyoming and the effects of raven removal on greater sage-grouse populations. Paper 4617. Thesis. Utah State University, Logan.

Upper Green River Basin Working Group Area Job Completion Report

Species: **Greater Sage-grouse**
Conservation Plan Area: **Upper Green River Basin**
Period Covered: **6/1/2020 – 5/31/2021**
Prepared by: **Dean Clause, Pinedale Wildlife Biologist**



Region	Number	Percent
Pinedale	166	100.0

Working Group	Number	Percent
Upper Green River	166	100.0

Classification	Number	Percent
Occupied	129	77.7
Unoccupied	37	22.3

BLM Office	Number	Percent
Pinedale	153	92.2
Rock Springs	13	7.8

Biologist	Number	Percent
Pinedale	94	56.6
Thayne	72	43.4

Warden	Number	Percent
Big Piney	84	50.6
North Pinedale	24	14.5
South Pinedale	58	34.9

County	Number	Percent
Lincoln	2	1.2
Sublette	164	98.8

Land Status	Number	Percent
BLM	137	82.5
Private	20	12.0
State	9	5.4

Management Area	Number	Percent
D	166	100.0

Lek Status	Number	Percent
Active	104	62.7
Inactive	60	36.1
Unknown	2	1.2

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	132	117	89	3514	36.6
2013	130	116	89	3125	34.3
2014	130	111	85	3207	36.9
2015	134	109	81	4667	53.6
2016	138	117	85	5229	55.0
2017	137	97	71	4206	54.6
2018	140	116	83	4039	41.6
2019	138	69	50	2071	34.5
2020	135	100	74	2423	31.5
2021	130	115	88	2497	26.0

b. Leks Surveyed

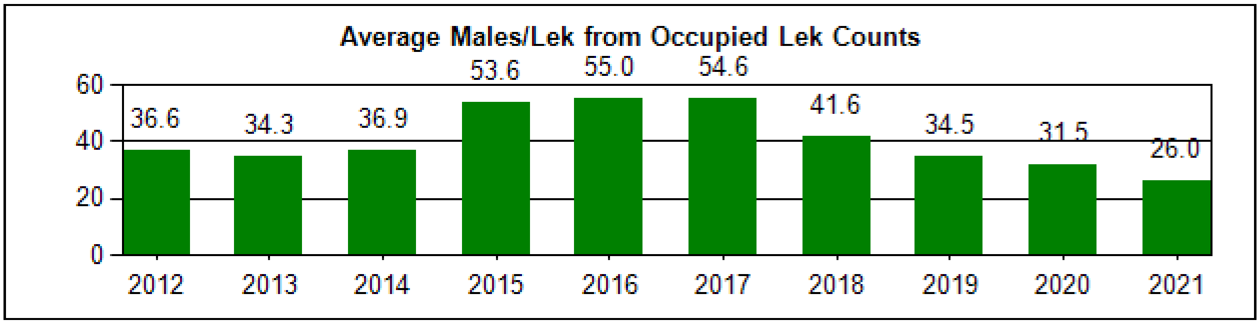
Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	132	6	5	149	37.3
2013	130	8	6	280	40.0
2014	130	14	11	290	29.0
2015	134	22	16	923	48.6
2016	138	19	14	886	63.3
2017	137	30	22	1091	52.0
2018	140	18	13	484	40.3
2019	138	62	45	1489	30.4
2020	135	29	21	498	23.7
2021	130	10	8	105	15.0

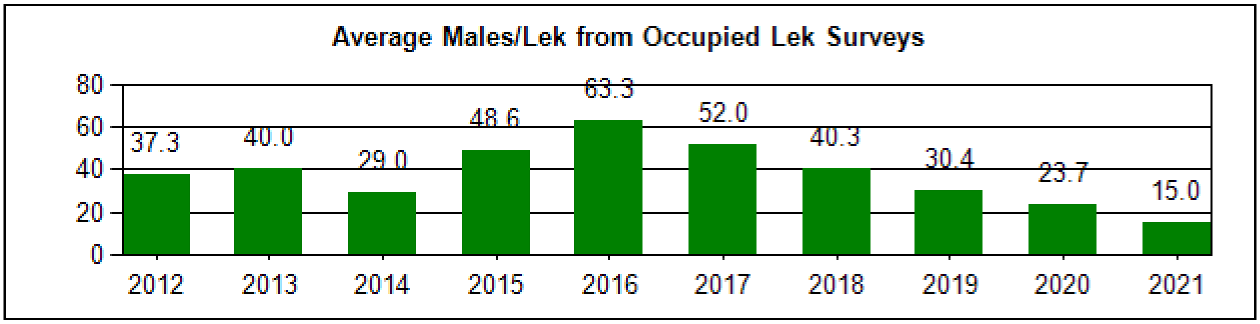
c. Leks Checked

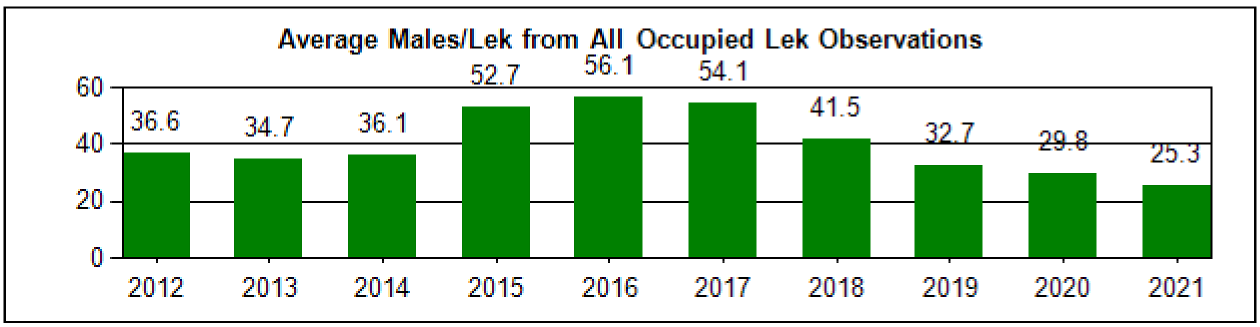
Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	132	123	93	3663	36.6
2013	130	124	95	3405	34.7
2014	130	125	96	3497	36.1
2015	134	131	98	5590	52.7
2016	138	136	99	6115	56.1
2017	137	127	93	5297	54.1
2018	140	134	96	4523	41.5
2019	138	131	95	3560	32.7
2020	135	129	96	2921	29.8
2021	130	125	96	2602	25.3

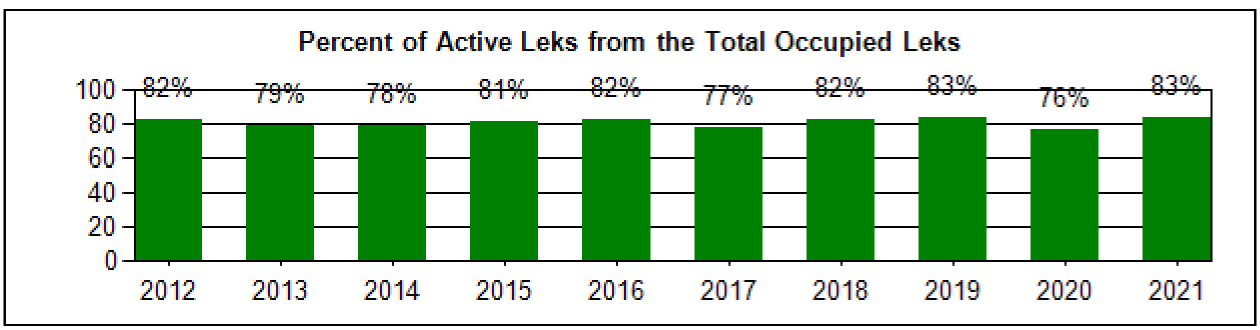
d. Lek Status

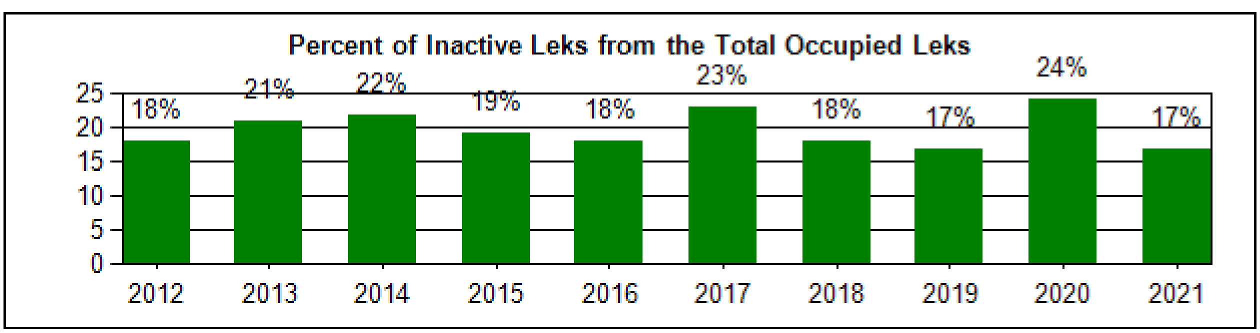
Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	101	22	0	123	82.1	17.9
2013	98	26	0	124	79.0	21.0
2014	98	27	0	125	78.4	21.6
2015	106	25	0	131	80.9	19.1
2016	109	24	3	133	82.0	18.0
2017	98	29	0	127	77.2	22.8
2018	109	24	1	133	82.0	18.0
2019	109	22	0	131	83.2	16.8
2020	98	31	0	129	76.0	24.0
2021	104	21	0	125	83.2	16.8


Average Males/Lek from Occupied Lek Counts
60
40
20
0
36.6
34.3
36.9
53.6
55.0
54.6
41.6
34.5
31.5
26.0
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021


Average Males/Lek from Occupied Lek Surveys
80
60
40
20
0
37.3
40.0
29.0
48.6
63.3
52.0
40.3
30.4
23.7
15.0
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021


Average Males/Lek from All Occupied Lek Observations
60
40
20
0
36.6
34.7
36.1
52.7
56.1
54.1
41.5
32.7
29.8
25.3
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021


Percent of Active Leks from the Total Occupied Leks
100
80
60
40
20
0
82%
79%
78%
81%
82%
77%
82%
83%
76%
83%
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021


Percent of Inactive Leks from the Total Occupied Leks
25
20
15
10
5
0
18%
21%
22%
19%
18%
23%
18%
17%
24%
17%
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

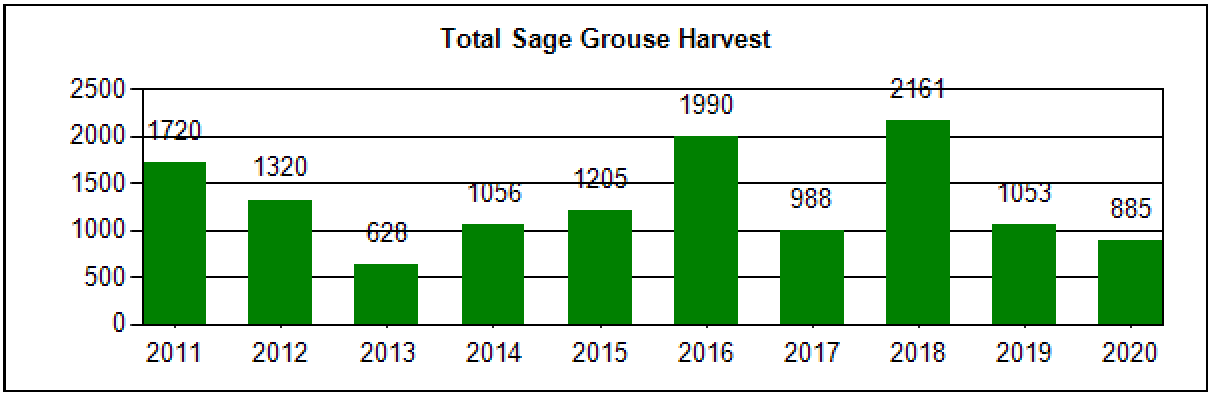
3. Sage Grouse Hunting Seasons and Harvest Data

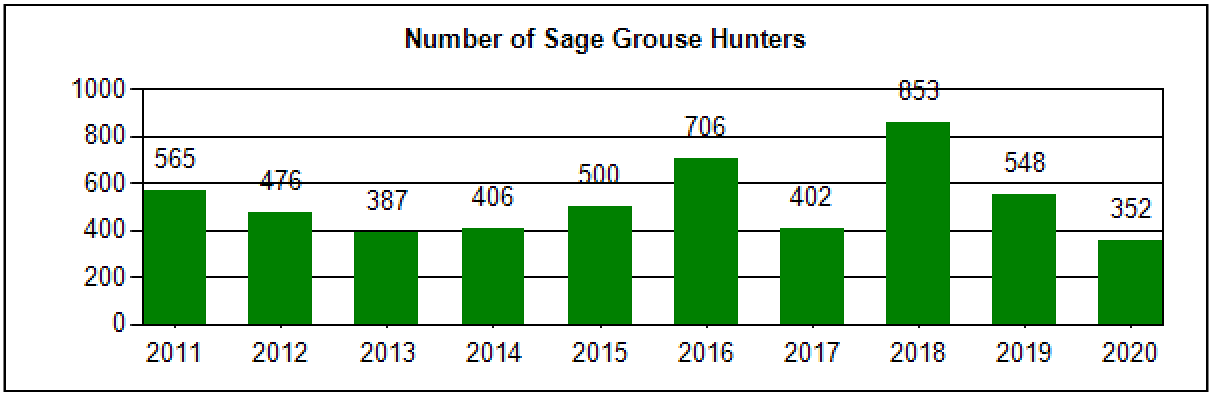
a. Season

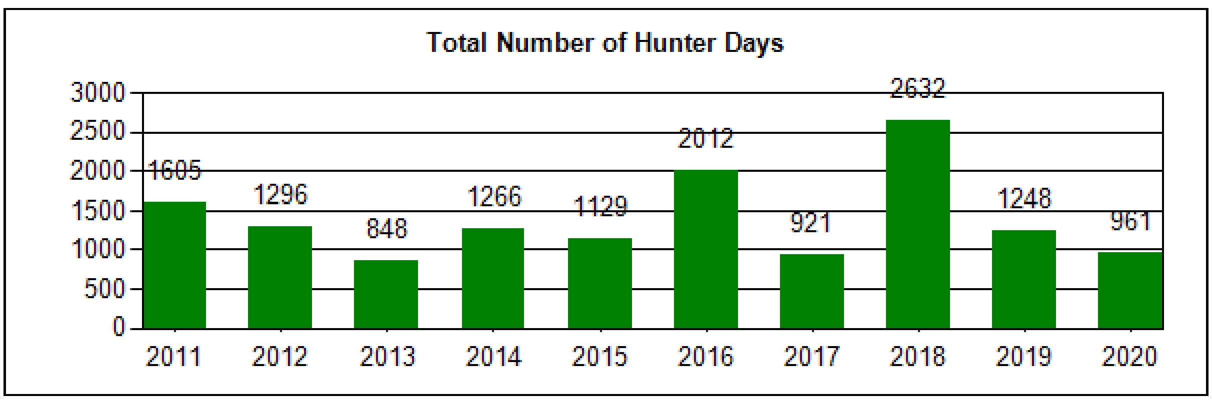
Year	Season Start	Season End	Length	Bag/Possesion Limit
2011	Sep-17	Sep-30	14	2/4
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

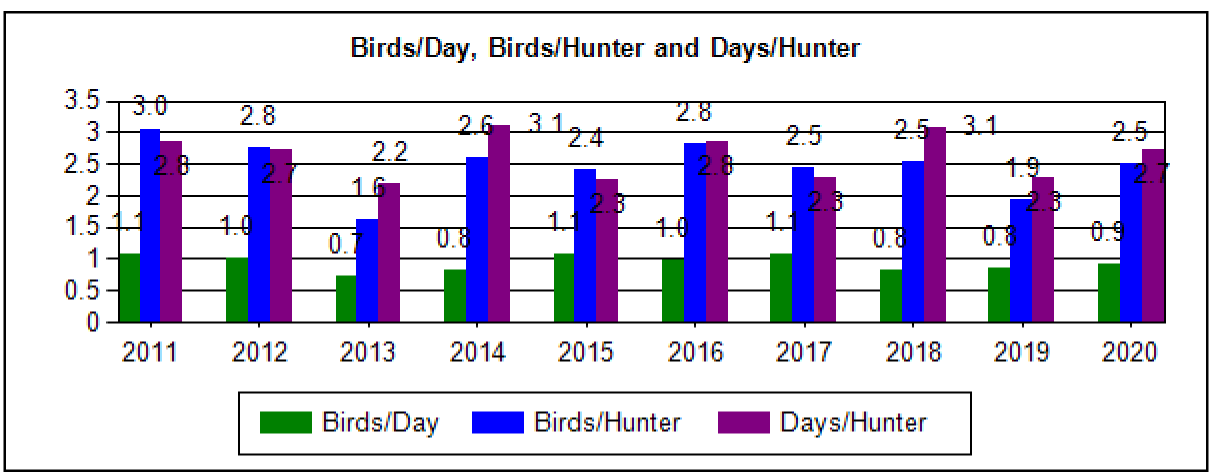
b. Harvest

Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2011	1720	565	1605	1.1	3.0	2.8
2012	1320	476	1296	1.0	2.8	2.7
2013	628	387	848	0.7	1.6	2.2
2014	1056	406	1266	0.8	2.6	3.1
2015	1205	500	1129	1.1	2.4	2.3
2016	1990	706	2012	1.0	2.8	2.8
2017	988	402	921	1.1	2.5	2.3
2018	2161	853	2632	0.8	2.5	3.1
2019	1053	548	1248	0.8	1.9	2.3
2020	885	352	961	0.9	2.5	2.7
Avg	1,301	520	1,392	0.9	2.5	2.6


Total Sage Grouse Harvest
2500
2000
1500
1000
500
0
1720
1320
628
1056
1205
1990
988
2161
1053
885
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

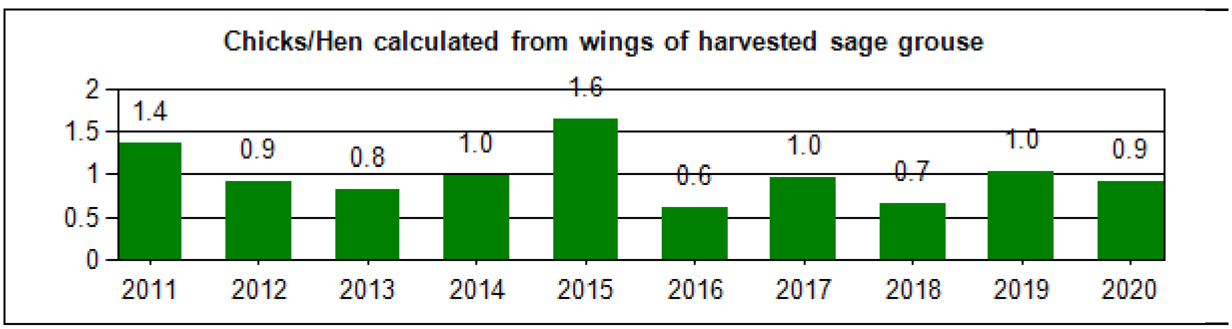

Number of Sage Grouse Hunters
1000
800
600
400
200
0
565
476
387
406
500
706
402
853
548
352
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020


Total Number of Hunter Days
3000
2500
2000
1500
1000
500
0
1605
1296
848
1266
1129
2012
921
2632
1248
961
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020


Birds/Day, Birds/Hunter and Days/Hunter
3.5
3
2.5
2
1.5
1
0.5
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Birds/Day
Birds/Hunter
Days/Hunter

4. Composition of Harvest by Wing Analysis

Year	Sample	Percent Adult		Percent Yearling		Percent Young		Chicks/
	Size	Male	Female	Male	Female	Male	Female	Hens
2011	547	8.6	32.5	4.0	4.4	24.1	26.3	1.4
2012	544	12.1	34.2	3.5	9.6	17.1	23.5	0.9
2013	372	12.1	40.9	3.2	5.6	17.2	21.0	0.8
2014	337	13.4	33.8	3.0	8.3	18.1	23.4	1.0
2015	482	12.4	27.0	2.1	5.4	24.7	28.4	1.6
2016	450	17.6	43.1	3.1	5.8	12.4	18.0	0.6
2017	573	15.0	35.1	3.3	6.3	18.8	21.5	1.0
2018	466	11.8	38.8	5.8	10.7	11.8	21.0	0.7
2019	342	7.3	32.5	1.8	12.0	14.3	32.2	1.0
2020	471	10.2	37.6	3.0	7.9	18.3	23.1	0.9



Lek Monitoring

A total of 166 leks are currently documented in the Upper Green River Basin Working Group Area (UGRBWGA). These leks are classified as follows; 125 occupied, 37 unoccupied, and 0 undetermined. During 2021, a total of 129 occupied leks (97%) were checked (survey or count). Lek monitoring efforts in 2021 resulted in a high proportion of counts (92%) verses surveys (8%), similar to most years. Results from lek monitoring in 2021 showed 83% were active and 17% inactive of those leks classified as occupied. The average number of males/lek for all active leks decreased to 25 in 2020, compared to the past three years of 30 in 2020, 33 in 2019, and 42 in 2018. This results in a 15 % decrease compared to 2020 and a 55% decrease since the last peak in 2016 (Figure 1).

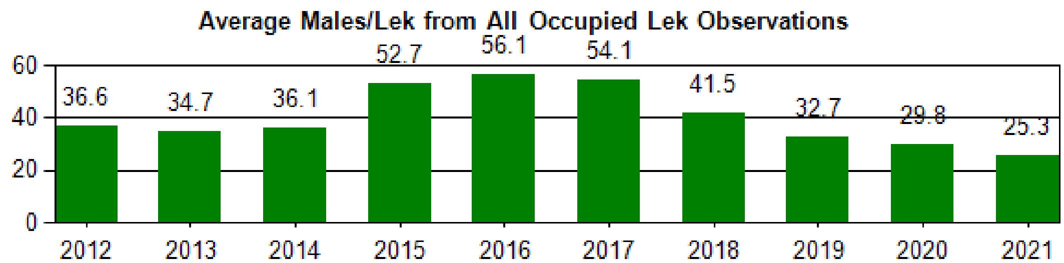


Figure 1. Average Peak Male Sage-grouse Lek Attendance 2012-2021, UGRBWG Area.

The highest documented average peak male attendance occurred in 2007 at 69 for this UGRBWGA. Since 2007, the observed average peak males has declined through 2010, stabilized from 2011-2014, and increased in 2015, stabilized in 2016-2017, and declined in 2018-2021 (Figure 3). The 2020 male lek attendance is 63% lower compared to the peak in 2007 using all occupied leks within the UGRBWGA. This trend is likely a combination of the cyclic nature of sage-grouse populations (Fedy and Doherty 2010), drought, and influences from habitat fragmentation in the Upper Green River Basin. Caution is warranted when analyzing long-range data sets (20+ years) within the UGRBWG area as the number of known (documented) leks have more than doubled during the past 19 years. Since many of these newly documented leks probably existed but were not monitored, there is some speculation in regards to what the average number of males/lek actually was prior to the mid 1990's.

The proportion of leks checked that are confirmed "active" has stayed relatively stable during the past 10 years, ranging from 76% to 83%. Although, there has been increased lek inactivity and abandonment in areas associated with gas development activity. Additional lek monitoring efforts and searches have resulted in locating new or undiscovered leks (65 new leks since 2004) mathematically negating the downward trend in the proportion of active leks in the UGRBWGA.

Peak male lek attendance from 1997-2021, using only leks known in 1997, reveals a trend similar to all known leks within the UGRBWGA (Figures 2 & 3). Since 1997, the discovery and monitoring of leks has more than doubled, explaining the variation in the average number peak males between the two data trends (known leks from 1997 verses all known leks).

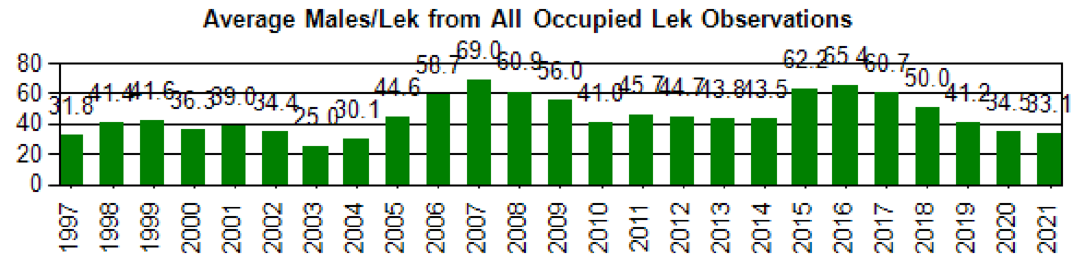


Figure 2. Average Peak Male Sage-grouse Lek Attendance 1997-2021 using only leks known in 1997, UGRBWG Area.

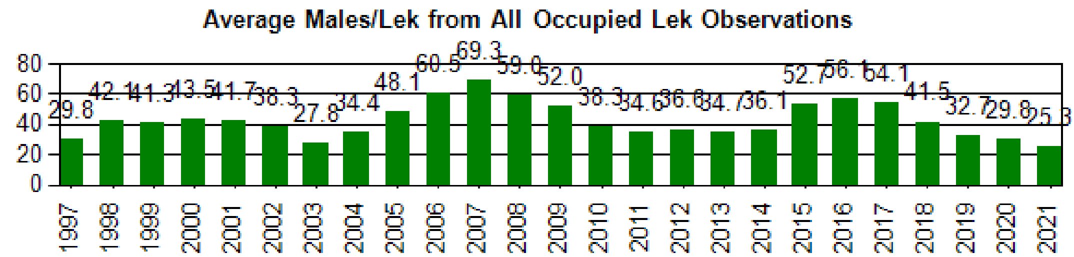


Figure 3. Average Peak Male Sage-grouse Lek Attendance 1997-2021 using all known leks, UGRBWG Area.

An analysis to assess natural gas development impacts to sage grouse leks in the Pinedale area shows lower male attendance, reduced occupancy and reduced activity on those leks within or near gas field development. The most recent analysis can be found in the 2019 (6/1/2019-5/31/2020) UGRBWGA Job Completion Report found on the WGFD website at https://wgfd.wyo.gov/ , with an updated analysis to be reported in the 2021 JCR.

Harvest

The 2020 sage-grouse season was September 19 through September 30, a 12-day hunting season, similar seasons since 2004. Hunting seasons since 2002 have allowed the season to remain open through two consecutive weekends. From 1995 – 2001 hunting seasons were shortened to a 15-16 day season that typically opened during the third week of September and closed in early October. Prior to 1995, the sage-grouse seasons opened on September 1 with a 30 day season. Seasons have been shortened with later opening dates to increase survival of successful nesting hens (as they are usually more dispersed later in the fall) and to reduce overall harvest.

Bag limits from 2003 to 2020 have been 2 per day and 4 in possession. 2003 was the first year that bag/possession limits had been this conservative. Bag limits traditionally (prior to 2003) were 3 birds/day with a possession limit 9 (changed to 6 birds from 1994-2002). Prior to 2010, harvest estimates in the UGRBWGA were only reported from UGBMA 3 and not in that portion of UGBMA 7 that lies within the UGRBWGA. New Sage-grouse Management Areas (SGMA) were developed in 2010, where SGMA D covers all of the UGRBWGA and has been reported that way since 2010.

The 2020 harvest survey* estimated that 352 hunters bagged 885 sage grouse and spent 961 days hunting, lower than most years, and a significant decrease from 2018 (the highest during the last 10-year period). The average number of birds per day was 0.9, the average number of birds per hunter was 2.5, and the number of days spent hunting

*The 2020 sage-grouse harvest estimates should be interpreted with caution, because that particular year's survey under-sampled potential sage-grouse hunters from certain license fee types, resulting in poor quality harvest estimates. Making comparisons between previous years' estimates and the 2020 estimates should be avoided, because the results from the voluntary survey were unreliable due to sampling issues.

per hunter was 2.7 during 2020. The increased hunter participation in 2018 can't be fully explained, except for the longer season length and favorable weather. Harvest rates (# birds/day, # birds/hunter, and # days/hunter) have remained somewhat similar since 2011, with the exception of lower harvest rates during 2013 and higher overall harvest and hunter participation in 2018 (Figure 4). From 1995 to 2002, overall harvest and harvest rates significantly declined following altered seasons (shortened and moved to a later date). Since 2011, hunter participation has varied from 352 to 853 hunters per year.

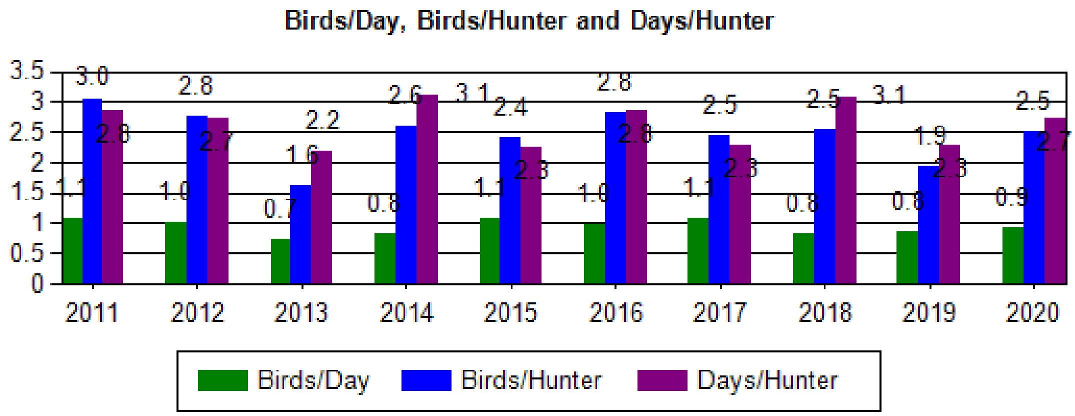


Figure 4. Sage grouse harvest rates 2011-2020 in SGMA D.

Wing Collections

Eighteen sage-grouse wing barrels were distributed throughout Sublette County in 2020 within SGMA D. Barrels were placed prior to the sage-grouse hunting season opener and were taken down following the closing date. Wing collections were typically made following each weekend of the hunting season. The wings are used to determine age and sex based on molting patterns and feather characteristics.

A total of 471 sage-grouse wings were collected from barrels in the UGRBWGA during 2020, compared to 342 in 2019 and 466 in 2018. The number of wings collected during the past 10-year period ranged from 337 to 547. Of the 471 wings collected in 2020, 41% were juvenile birds and 46% were adult and yearling hens. The overall composition of wings in 2020 indicated a ratio of 0.9 chicks/hen (adult and yearling females), which typically results in lower lek counts the following spring. The 2016 wing collections showed a 0.6 chicks/hen ratio, representing the lowest production during the past 10-year period. Conversely, wing collections during 2015 showed 1.6 chicks/hen, resulting in the highest production during the past 10-year period (Figure 5). The combination of low chick production during the past several years explains the recent declines male lek attendance. This chick/hen ratio derived from wing collections has been a relatively good indicator to predict future population trends, as male lek attendance trends have broadly correlated with chick production in the UGRBWGA.

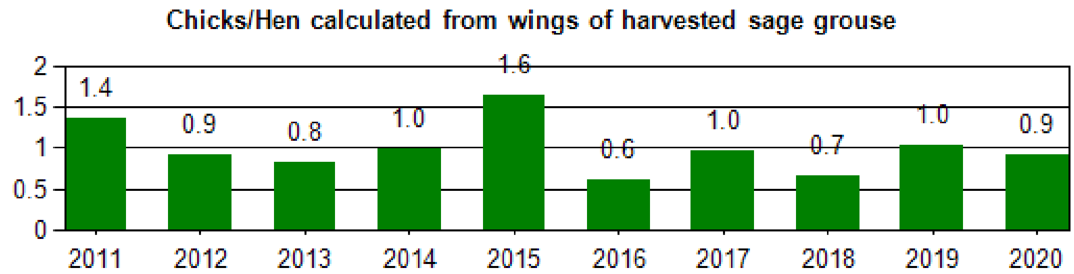


Figure 5. Sage grouse chick/hen ratios derived from wing collections 2011-2020, UGRBWGA.

Winter Distribution Surveys

No specific winter sage grouse surveys were conducted during the 2019-2020 winter within the UGRBWG Area. Winter surveys were initially conducted in 2004 and continued through 2013 within portions of the Upper Green River Basin. This winter data has been used to develop winter concentrations area maps (first map developed in 2008). Additional analysis methods such as Resource Selection Function (RSF) models have recently been utilized with winter survey data to help refine previously identified winter concentration areas (WCA). Although, WCA have been identified throughout the UGRBWG Area, the Sage Grouse Implementation Team has only recognized one area located in the Alkali Draw & Alkali Creek Area as of 2019. Efforts to re-delineate WCA's throughout the UGRBWGA are planned for completion in 2022.

Sage-grouse Research Projects

From 1998-2009 there were several research projects initiated and completed that have provided information on sage-grouse demographics and effects of natural gas development on sage-grouse populations. See UGRBWGA 2010 JCR for a summary of past sage-grouse research in the Pinedale area.

<u>Significance of Geophagy:</u>

There has been on-going study (initiated in 2013) looking into the significance of geophagy by sage grouse within the UGRBWGA. The field work was completed in the fall of 2021 with a summary report anticipated in 2022.

Sage-grouse geophagy, or intentional ingestion of soil, was documented in Sublette County Wyoming during the winter of 2012 – 2013. While it is well-known for a variety of other birds and mammals, it represents a behavior that has not been described for sage-grouse. The goal of this project is to assess the importance of "soil-eating" areas in describing winter habitat selection by sage-grouse. Currently, within the Upper Green River Basin researchers have identified 24 confirmed locations of geophagy behavior. An additional 20+ potential locations have also been identified. Past collaborators on the project have been the BLM, Teton Raptor Center, Wyoming Wildlife Consultants, and Sublette County Conservation District. Soil has been collected and tested at each confirmed location and compared to soil at random locations in order to identify the potential target mineral or compound responsible for the behavior. Soil tests indicate higher sodium, pH, and clay content at the documented geophagy sites.

A Utah State University graduate student is currently assessing habitat selection for wintering sage-grouse in the presence of geophagy sites. This resource selection analysis will not only help determine how geophagy sites influence winter habitat selection, but also help predict areas of importance to wintering sage-grouse in these areas. A second graduate student from Utah State University is continuing research and data collection efforts for this geophagy project specifically to evaluate how geophagy behavior may influence reproduction during the breeding season.

Ecology of Greater Sage-grouse in Alkali Creek and the Upper Green River Basin:
There are additional questions that would aid managers about the ecology of sage-grouse in the new 140,000 acre Normally Pressured Lance (NPL) Gas Field with a potential for up to 3,500 wells. Although there are large winter flocks and documentation of sage-grouse movement to the NPL in winter, it is unknown what proportion of birds survive while using the area. It is possible to have a great deal of human use or development of an area, without any impacts to survival. Instead, animals can be displaced or avoid an area, which might not result in any population-level impacts, but would reduce the carrying capacity. However, if survival is compromised, it becomes necessary to understand the timing and causes of bird mortality. Therefore, it is necessary to assess survival rates of sage-grouse in the region to better understand the utility of the area in sage-grouse conservation. In addition to the importance of movements, resource selection, and survival, it has been documented that sage-grouse in the area are geophagic. If geophagy plays an important role in winter resource selection, resulting in high use of the NPL site during winter, we might be missing a key parameter in RSF models and WCA delineations on the site, because we have not considered geophagy. Last, we know very little about the mobility of these flocks, their fidelity to certain areas, and the stability of group membership within Alkali Creek and Alkali Draw. The intensive aerial flights that were conducted on the site capture sage-grouse distributions in late January and February but key areas during November, December and March (i.e., current timing restriction for the WCA are in effect from November 15 to March 15), could go unknown if we rely solely on flight data. Because delineation of a WCA requires 50 birds, it becomes important to understand how flock numbers change over time.

Collectively, these issues require a comprehensive research project which will provide information to help manage sage-grouse populations in the NPL region. Specifically, this study will provide movements, resource selection, survival, and sites selected by sage-grouse for geophagic behavior. Because these questions require fine-scale observations of sage-grouse, global positioning systems transmitters combined with solar-powered Argos platform transmitter terminals (GPS-PTTs), along with infrared flights are being used which have been shown to effectively monitor activities of sage-grouse in other parts of Wyoming (J. Millspaugh, unpublished data). This study is focused within the Alkali Creek and Alkali Draw regions of the NPL that was initiated in 2019, put on hold in 2020 and 2021, except deployment of transmitter, due to lack of funding and will reengage during the 2021/2022 winter through the spring of 2026.

Sage-Grouse Working Group
The UGRBWG was formed in March of 2004. The group is comprised of representatives from agriculture, industry, sportsmen, public at large, conservation groups, and government agencies (federal and state). The purpose of the UGRBWG is to work towards maintaining or improving sage-grouse populations in the Upper Green River basin. The group is directed to formulate plans, recommend management actions, identify projects, and allocate available funding to support projects that will benefit sage-grouse. The Upper Green River Basin Sage-Grouse Conservation Plan was finalized in

May of 2007 and can be found on the WGFD website (https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management). This plan identified past, proposed, and ongoing projects; recommended management activities; funding sources; and other relevant sage-grouse information within the UGRBWGA intended to maintain and/or increase sage-grouse populations. The Working Group completed an addendum to this 2007 plan (Upper Green River Basin Sage-Grouse Conservation Plan Addendum – 2014) that provides updated information on activities, projects, and management strategies within the UGRBWGA. Appropriation of State monies approved for sage grouse projects during past years have been allocated to the UGRBWG for local conservation measures that benefit sage grouse. Raven control, water windmill to solar pump conversion, and cheatgrass inventory/control projects continue to account for the majority of allocated funds granted to the UGRBWG in recent years.

Management Summary

Data collected and reported in this 2020 Sage-Grouse Job Completion Report (June 2020 thru May 2021) gives insight to population trends. Analysis of lek trend data indicates that the sage-grouse populations steadily increased from 2003 to 2007, dropped slightly in 2008, continued to decline through 2011, stabilized through 2014, increased significantly in 2015, followed by a relatively stable population in 2016 and 2017, and population decline in 2018-2021. Lek trend data suggest grouse populations are currently at the lowest level in 2003 with the highest level in 2007.

Lek monitoring in the UGRBWGA showed a 146% increase in the peak number of males per lek from 2003 to 2007 as males increased from 28 males/lek to 69 males/lek. This trend reversed after 2007, as the number of males/lek declined by 48% dropping to 36 males/lek by spring of 2014. During 2015, lek counts showed a 47% (53 males/lek) increase followed by an 8% increase in 2016, 4% decrease in 2017, 23% decrease in 2018, 21% decrease in 2019 a decrease of 9% in 2020 (30 males/lek), and a continued decrease of 15% in 2021(25 males/lek). Sage-grouse leks within developing gas fields continue to show declines and lek abandonment regardless of lek trends outside of gas development, indicating negative impacts to sage grouse in and near natural gas fields. Existing leks within non-core habitats and within gas development fields will be subject to further impacts.

Sage-grouse hunting season dates, season length, and bag limits have remained similar since 2002, running from mid to late September for 9-15 days with a daily bag limit of 2 birds and a possession limit of 4 birds. Although season length and bag limits have remained similar since 2002, overall harvest and hunter participation has varied somewhat, while harvest rates (# birds taken/day, #birds taken/hunter, and # days/hunter) have remained similar on most years. With grouse numbers steadily increasing from 2003-2007, declining from 2007-2014, increasing in 2015-2016, and decreasing in 2017-2020, the progression of hunter participation was expected to show similar trends. Variation in hunter participation can be affected by hunting season structure, weather conditions (especially during the current short seasons), and hunter perceptions of sage-grouse populations.

Wing collection from barrels (drop locations) continues to provide good sample sizes to determine overall chick survival trends within the UGRBWGA. During 2008-2020 wing collections ranged from 22% to 58% of the reported harvest. The sample size of 471 wings in 2020 accounted for 53% of the reported harvest. These annual wing samples can vary significantly based on weather conditions affecting hunter participation, especially during the weekend days of hunting season. Overall, some correlation exists between trends in wing sample sizes and harvest, and provides managers the most reliable data for determining annual reproductive rates in the UGRBWGA.

Trends in chicks/hen derived from wing collections continue to show a correlation with following year lek trends. An increase (or decrease) in the number of chicks/hen in the harvest typically results in similar trends documented on leks the following year(s). In general, a chick/hen ratio below 1.1 has shown declines in overall male lek attendance the following spring, 1.1 to 1.3 chicks/hen has shown stable attendance, and a chick/hen ratio greater than 1.3 has shown increases in lek attendance in the UGRBWGA. During the past 5 years (2016-2020) the chicks/hen ratio has varied from 0.6 to 1.0 and averaging 0.8 chicks/hen, correlating to the significant decline in male lek attendance.

Above normal precipitation during 2004 and 2005 during key periods (specifically in the spring and early summer) contributed to increased sage-grouse numbers due to enhanced production and juvenile survival in the Upper Green River Basin. Declining chick survival was documented in 2006 and 2007 caused by spring and summer drought conditions in the Upper Green River Basin. Male sage-grouse lek numbers declined from 2007-2011 and remained stable from 2012-2014. Good to above average spring precipitation during 2008-2011 led to good herbaceous production, which should have helped turn around the recent declining trends in the UGRBWGA. It appears the cold temperatures during the spring of 2009 and 2010 impacted reproduction resulting in further declines in lek numbers in 2010. Spring moisture in 2011 resulted in very good habitat production, and most likely contributing to the slight increase in bird numbers documented during the spring of 2012. Drought conditions in 2012 and 2013 most likely attributed to poor chick survival as spring temperatures were near normal, resulting in little change on spring lek counts in 2014. In 2014, good forage production was the result of increased precipitation during the fall of 2013 and spring of 2014 which likely contributed to increased male lek counts in 2015. Although the winter of 2014-15 was mild with low precipitation, the spring of 2015 had above average precipitation, primarily attributed to a very wet May, apparently resulting in very good chick production. The 2015-2016 winter and 2016 spring conditions were very similar to the previous year with dry winter and wet spring conditions, but resulted in poor chick production and similar lek counts. The 2016-17 winter conditions were severe with heavy snow loads and cold temperatures followed by a dry spring, yet lek counts in 2017 were similar to those recorded in 2016. The 2017-18 winter was mild with low snow accumulations and above average temperatures followed by a relatively wet spring, and a decline in 2018 lek counts. The 2018-19 winter resulted in late persistent snow and cold temperatures through the spring of 2019, and a decline in 2019 lek counts. The 2019-20 winter had average snow and cold temperatures with a slight decline in 2020 lek counts. The 2020-2021 winter had very low snow and average temperatures with a decline in 2021 lek counts. The predictability of factors that determine nest success and chick survival remains complex and is likely more dynamic than just climate conditions such as precipitation and temperature trends.

The current amount and rate of natural gas development in the Upper Green River Basin has and will continue to impact sage-grouse habitat and localized populations. Lek monitoring data has shown lower male attendance and a high rate of lek abandonment within and adjacent to developing gas fields. Sage-grouse studies and research in the UGRBWGA has also documented impacts to grouse from gas development. Direct, indirect, and cumulative impacts to sage-grouse from gas and residential development will continue to challenge managers to maintain current grouse numbers.

Recommendations

1. Continue to monitor sage-grouse leks and look for new and previously undocumented ones.
2. Continue to monitor and provide input on natural gas development/sage-grouse projects being conducted.
3. Continue to place wing barrels in enough locations to obtain an adequate and representative sample to derive sex/age and harvest trend information.
4. Continue existing efforts and encourage new efforts to document and identify important sage-grouse areas (breeding, brood rearing, and winter).
5. Continue to work with GIS personnel and land managers to create and update seasonal range maps (breeding, summer/fall, and winter) to aid land managers in protecting and maintaining important sage-grouse habitats. Delineation of winter concentration areas will be a priority.
6. Continue to identify needed sage-grouse research, data collection efforts, project proposals, development mitigation, and funding.
7. Implement proposals and management recommendations identified in the Upper Green River Basin Sage-Grouse Working Group Conservation Plan and Plan Addendum where possible.

Literature Cited

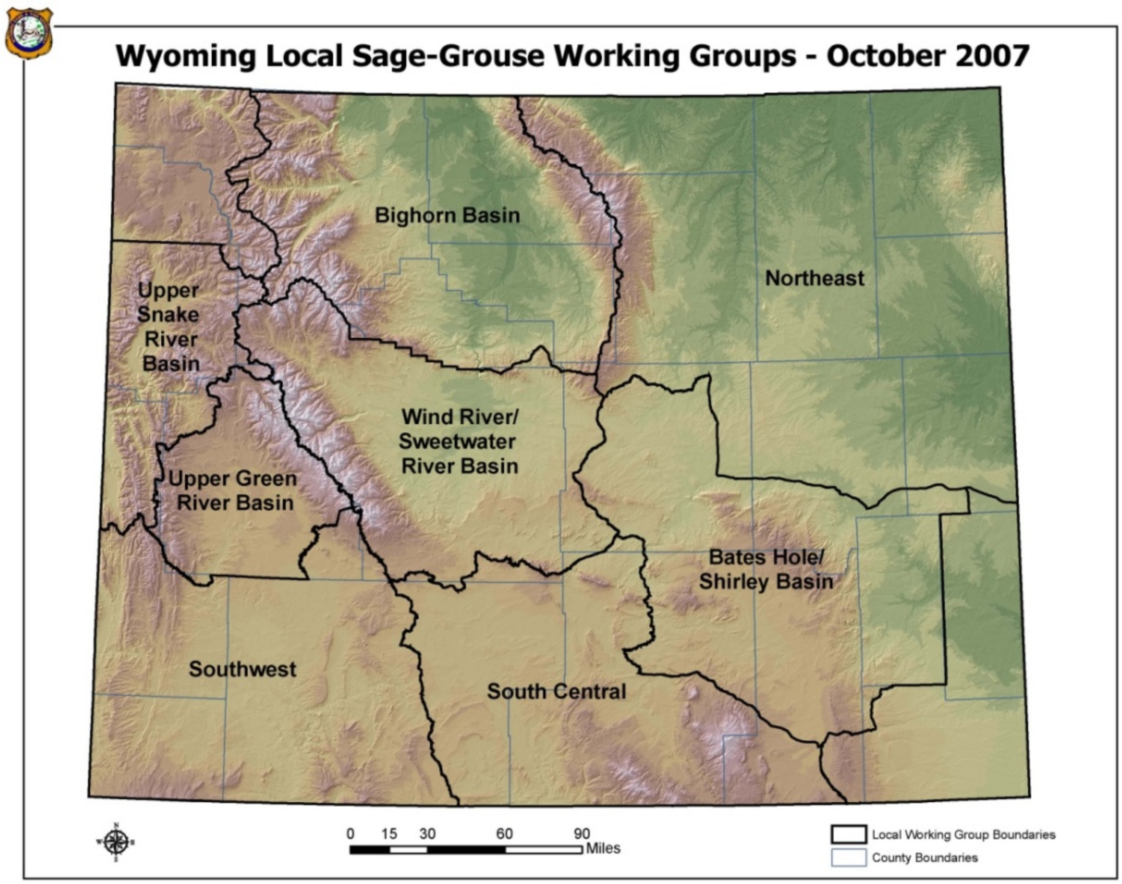
Christiansen, T. 2012. Chapter 12: Sage Grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S.A. Tessmann and J. R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne.

Fedy, B. C. and K. E. Doherty. 2010. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage-grouse and cottontail rabbits. Oecologia 165:915-924.

Fedy, B. C. and C. L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Upper Snake River Basin Conservation Area
Job Completion Report

Species: Greater Sage-Grouse
Period Covered: June 1, 2020 – May 31, 2021
Management Areas: A; Upper Snake River Basin
Prepared by: Alyson Courtemanch, North Jackson Wildlife Biologist



Sage Grouse Lek Characteristics

Working Group: Upper Snake River Basin

Region	Number	Percent
Jackson	17	89.5
Pinedale	2	10.5

Working Group	Number	Percent
Upper Snake River Basin	19	100.0

Classification	Number	Percent
Occupied	15	78.9
Undetermined	1	5.3
Unoccupied	3	15.8

BLM Office	Number	Percent
Pinedale	19	100.0

Biologist	Number	Percent
Jackson	17	89.5
Thayne	2	10.5

Warden	Number	Percent
Big Piney	2	10.5
North Jackson	15	78.9
South Jackson	2	10.5

County	Number	Percent
Sublette	2	10.5
Teton	17	89.5

Land Status	Number	Percent
National Park	12	63.2
USFS	4	21.1
USFWS	3	15.8

Management Area	Number	Percent
A	19	100.0

Lek Status	Number	Percent
Active	7	36.8
Inactive	8	42.1
Unknown	4	21.0

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Upper Snake River Basin

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	16	15	94	142	14.2
2013	16	13	81	149	16.6
2014	16	13	81	163	16.3
2015	16	14	88	227	25.2
2016	15	15	100	227	20.6
2017	15	15	100	176	16.0
2018	15	15	100	108	10.8
2019	15	15	100	62	5.6
2020	15	12	80	67	8.4
2021	15	14	93	61	8.7

b. Leks Surveyed

Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	16	0	0		#Error
2013	16	0	0		#Error
2014	16	0	0		#Error
2015	16	0	0		#Error
2016	15	0	0		#Error
2017	15	0	0		#Error
2018	15	0	0		#Error
2019	15	0	0		#Error
2020	15	0	0		#Error
2021	15	0	0		#Error

1) Occupied - Active during previous 10 years (see official definitions)

2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

3) Inactive - Confirmed no birds/sign present (see official definitions)

c. Leks Checked

Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	16	15	94	142	14.2
2013	16	13	81	149	16.6
2014	16	13	81	163	16.3
2015	16	14	88	227	25.2
2016	15	15	100	227	20.6
2017	15	15	100	176	16.0
2018	15	15	100	108	10.8
2019	15	15	100	62	5.6
2020	15	12	80	67	8.4
2021	15	15	100	61	8.7

d. Lek Status

Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	11	3	1	14	78.6	21.4
2013	9	4	0	13	69.2	30.8
2014	10	3	0	13	76.9	23.1
2015	9	5	0	14	64.3	35.7
2016	11	4	0	15	73.3	26.7
2017	11	4	0	15	73.3	26.7
2018	11	4	0	15	73.3	26.7
2019	11	4	0	15	73.3	26.7
2020	8	4	0	12	66.7	33.3
2021	7	8	4	15	46.7	53.3

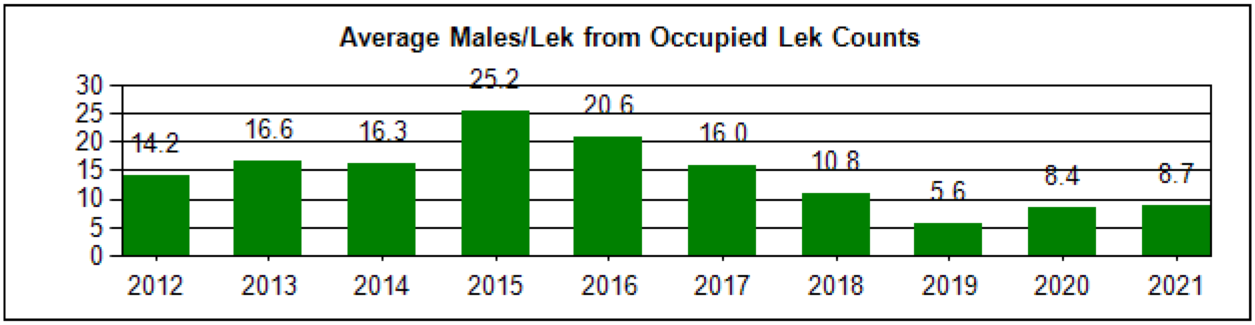
1) Occupied - Active during previous 10 years (see official definitions)

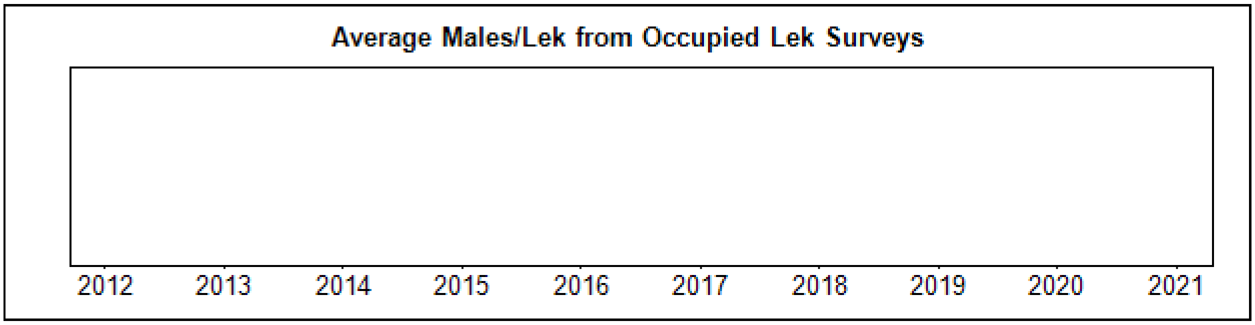
2) Avg Males/Active Lek - Includes only those leks where one or more strutting males were observed. Does not include "Active" leks where only sign was documented.

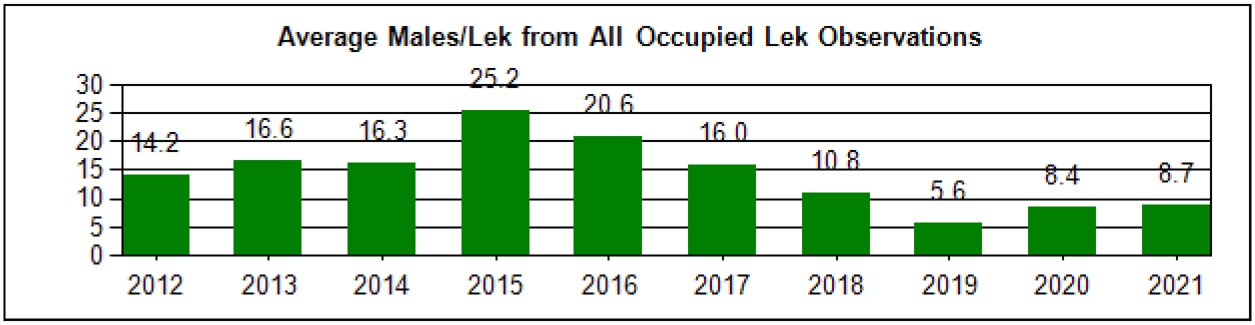
3) Inactive - Confirmed no birds/sign present (see official definitions)

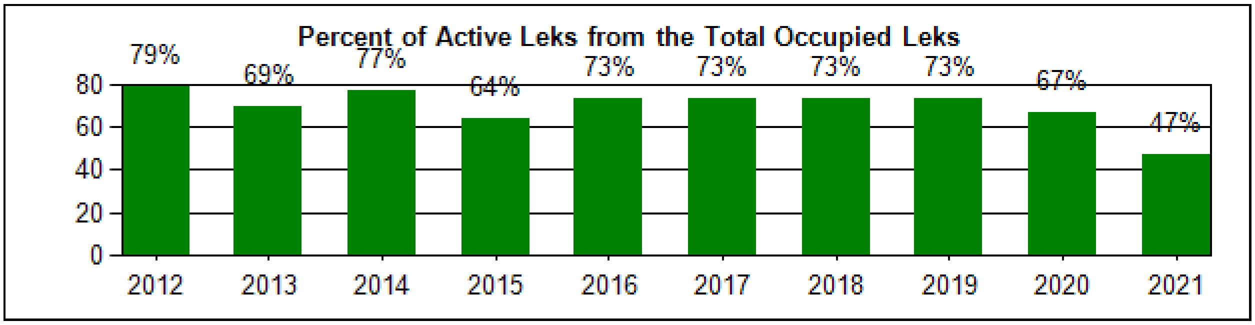
Sage Grouse Occupied Lek Attendance Summary

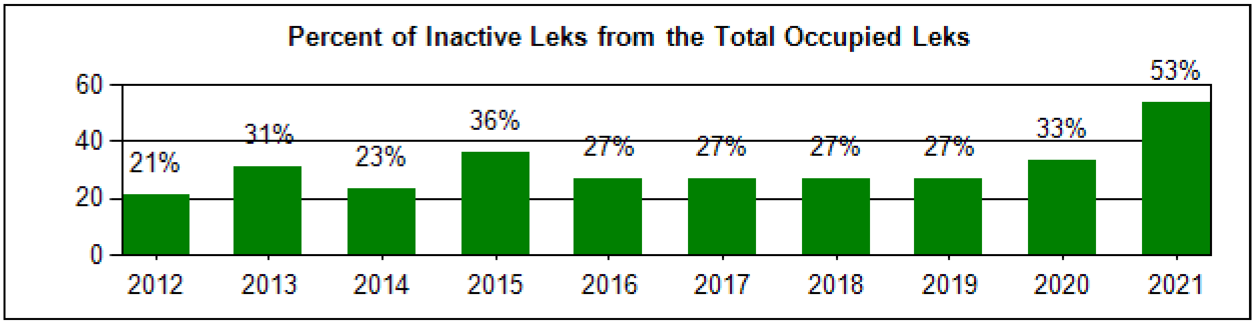
Year: 2012 - 2021, Working Group: Upper Snake River Basin











Lek Monitoring

Sage-grouse data collection within the Upper Snake River Basin Conservation Area (USRBCA) focuses on lek surveys. Prior to 1994, relatively few leks were monitored and since 2000, efforts have been made to increase data collection on leks and standardize data collection methods. Starting in 2005, lek counts in GTNP and to some extent on the NER, were coordinated to occur on the same days when it was logistically possible. This presumes that all leks in Jackson Hole constitute a sub-population and the leks in the Gros Ventre drainage constitute a second sub-population. No marked birds from the Gros Ventre leks have appeared on the Jackson Hole leks (Holloran and Anderson 2004, Bryan Bedrosian *pers. comm.*) and there is no evidence of genetic flow from the Gros Ventre to Jackson Hole (Schulwitz et al. 2014).

Lek counts and lek surveys have been conducted within the area since 1948; however, the most consistent data sets occur from 1989 to the present. Sage-grouse leks within the USRBCA are summarized in Table 1 from 2000 through 2021. There are a total of 19 leks in the USRBCA: 15 occupied (7 of these were active this year), 3 unoccupied, and 1 undetermined. Notably, the Spread Creek lek was inactive this year (the first time in the past 10 years) and the Bark Corral West was inactive (the first time in the past 7 years).

Gros Ventre

Lek counts at the two sites in the Gros Ventre drainage have been very low in recent years (Breakneck Flats and Dry Cottonwood leks). These leks are challenging to survey due to time-consuming and difficult access conditions as well as topography and sagebrush that birds often hide in. In order to improve lek counts, managers deployed several remote cameras at both sites and conducted two mornings of helicopter surveys in spring 2021. The remote cameras were programmed to automatically collect an image every 2 minutes for 2 hours after sunrise and 2 hours before sunset. Cameras were also programmed to collect an image at any time of day or night if the motion sensor was triggered. Wire spikes were also attached to the tops of the cameras to deter raptors from perching on them. We conducted helicopter surveys on the mornings of April 28 and 29, 2021, which coincides with the traditional time period of peak male counts at these leks. We flew for approximately 3 hours each morning and surveyed the two known leks as well as all other known sage grouse spring habitat in the Gros Ventre drainage.

The remote cameras captured a maximum of 4 males and 4 females at the Breakneck Flats lek and zero birds at the Dry Cottonwood lek. The helicopter survey found a total of 7 males at the Breakneck Flats lek on both mornings and zero birds at the Dry

Cottonwood lek. Ground surveys observed a maximum of 5 males and 9 females at the Breakneck Flats lek and zero birds at the Dry Cottonwood lek. We did not find any additional leks during the helicopter surveys. We observed one hen sage grouse on Bacon Ridge. Therefore, the cameras were the least successful method at detecting both male and female sage grouse, ground surveys detected the most females, and the helicopter survey detected the most males (7 males versus 5 males detected with ground surveys).

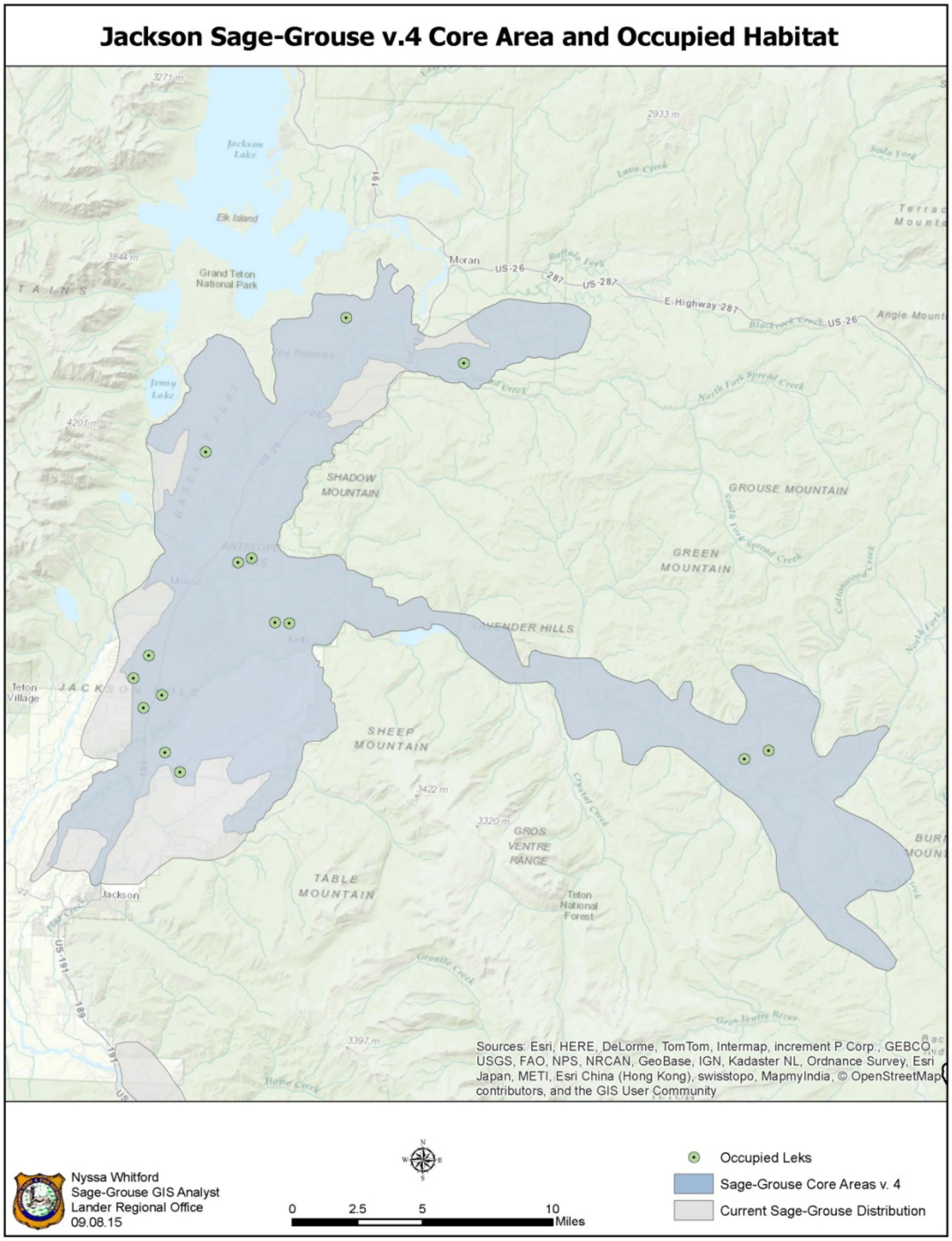


Figure 1. Sage-grouse core area, occupied habitat, and occupied leks in the Upper Snake River Basin Area (does not show Clark’s Draw and Ollie’s Draw leks).

Table 1. Maximum male counts at sage-grouse leks in the Upper Snake River Basin Conservation Area, 2000-2021. Blank cells denote years when the lek was inactive (zero birds seen) or it was not checked.

Year	3 Bar H Road	Airport	Airport Pit	Antelope Flats	Bark Corral East	Bark Corral West	Beacon	Breakneck Flats	Clark Draw	Dry Cottonwood	McBride	Moulton East	Moulton West	NER-North Gap	NER-Simpson	Ollie's Draw	RKO	Spread Creek	Timbered Island	Average # males/active lek
2000		18						21				28		5						18.0
2001		15						19				30		6						17.5
2002		19					24	9				28		4						16.8
2003		25						7				35		3					8	15.6
2004		17			2			14				54		4					15	17.7
2005		17						16		6		49		18					17	20.5
2006		23	6				4	21		9		44		30					20	19.6
2007		23			1			30		4	1	41		9				4	20	14.8
2008		16			2	8		22		13		38		23			12	5	26	16.5
2009		10	2		5			21		1		33		11			15	4	22	12.4
2010		10			24			24	13	4		40		13			13	5	18	16.4
2011		11				10		5	13			27		21			10	15		14.0
2012		17			3			14	14			44	14	18	3		8		7	14.2
2013		17						14	13	5		46		8			6	24	16	16.6
2014		11	3		10			18	7			61		21			8	8	16	16.3
2015		12				11		27	17			103		10			21	15	11	25.2
2016		7				13		34	12	8		21	53	7			48	6	18	20.6
2017		10				4		22	13			36	46	4		5	15	5	16	16.0
2018		13				7		8	5			28		6		8	16	5	12	10.8
2019		8				1		7	6			14	5	1		4	8	1	7	5.6
2020		7				6		3				24		12			4	4	7	8.4
2021		3						7	8			22		1			10		10	8.7
Max		63	6	10	24	13	24	34	17	13	27	103	63	30	54	8	48	24	26	

Population Trends and Estimates

The peak number of males and average number of males per lek are used as the main measures of population trend over time in the USRBCA. These provide a reasonable index of abundance of sage-grouse populations over time in response to environmental conditions. Average peak number of males per active lek declined in the early 1990's (Figure 2). Counts from 2009 - 2016 showed a generally increasing trend, however there has been a sharp decrease from 2017 – present (Figure 2). The average peak males per lek in 2015 and 2016 were the highest recorded since 1994 at 25.2 and 20.6, respectively. However, the average peak males per lek dropped to 5.6 in 2019, 8.4 in 2020, and 8.7 in 2021.

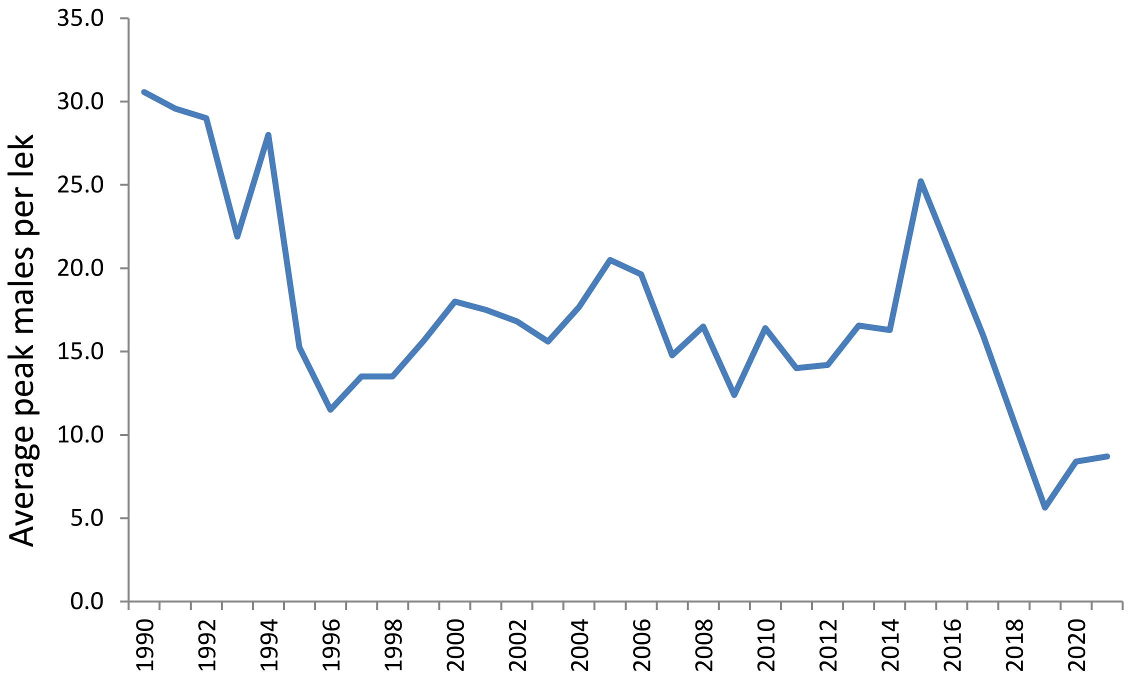


Figure 2. Average peak male counts for active leks in the Upper Snake River Basin Conservation Area, 1990-2021.

The population decline over the past 5 years is very concerning. The drop is largely driven by a significant reduction in counts at the Moulton East and Moulton West leks, which had a peak of 103 males in 2015 and only peaked at 19 males in 2019, 24 in 2020, and 22 in 2021. Declines at other leks such as Breakneck Flats in the Gros Ventre drainage (from 34 males in 2016 to 7 in 2019, 3 in 2020, and 7 in 2021) and RKO lek (48 in 2016 to 8 in 2019, 4 in 2020, and 10 in 2021) reflect this trend. The long term persistence of this population continues to be of paramount concern to the local working group and resource managers.

Productivity

No productivity data were collected on this population this year.

Harvest

Most of the USRBCA has been closed to hunting since the establishment of GTNP in 1929. No sage-grouse hunting has been allowed on lands under the jurisdiction of GTNP or the NER. In 2000, the hunting season was closed in the entire USRBCA and remains so today.

Habitat

The majority of sage-grouse habitat in the USRBCA is located within GTNP. There is also habitat in the Gros Ventre drainage on Bridger-Teton National Forest and the northern NER. Little habitat occurs on private lands. The majority of habitat on private lands is located on East and West Gros Ventre Buttes, the Spring Gulch area, and west of the Jackson Hole Airport.

No wildfires or prescribed burns occurred in significant areas of sagebrush habitat in sage-grouse core areas within the USRBCA during the reporting period. The Kelly Hayfields restoration project continued this year in GTNP, which is a project to remove smooth brome hayfields and reestablish a sagebrush community. There were no other significant human developments or surface disturbances in the core area during this reporting period.

Winter 2020/2021 conditions were average. Spring snowmelt arrived relatively early this year, especially compared to 2020.

Conservation Planning

The Upper Snake River Basin Sage-Grouse Conservation Plan was updated in March 2014 and can be found on the WGFD website at: https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Sage%20Grouse/SG_USR_CONSERVPLAN.pdf

The Upper Snake River Basin Sage-Grouse Working Group met several times during the reporting period to plan lek monitoring schedules, review lek survey data, discuss and fund special projects, and review other issues affecting sage-grouse in the area. The local working group is particularly concerned about the low lek counts from 2018-2021 and met several times to discuss potential courses of action to reverse this decline. Following Appendix I of the Executive Order, the working group prepared a document in 2019 notifying the Statewide Adaptive Management Working Group of this concern. In response, the Jackson Sage-Grouse Technical Team was assembled in 2019 to review the situation and make recommendations of ways to address the population decline. The Technical Team submitted a report outlining its findings and recommendations in April 2020.

Special Projects

Inventorying Fences in Sage-Grouse Habitat
Jackson Hole Wildlife Foundation

SUMMARY
The goal of this project is to determine where and how many problematic fences occur on the landscape in sage-grouse core habitat on Grand Teton National Park and the Gros Ventre drainage on Bridger-Teton National Forest lands. The objectives are to create maps and update shapefiles that are clear in definition of problematic fences for sage-grouse in core habitat so that they can be mitigated.
Jackson Hole Wildlife Foundation will use their records of fence removals and modifications from 2012 – present to compare with 1) an existing Grand Teton National Park fence shapefile, 2) shapefiles of allotment and pasture perimeters from the Bridger-Teton National Forest, and 3) shapefiles from the University of Wyoming (1992) and the Office of State Lands and Investment (2012). These shapefiles will be merged and updated to include information regarding past fence modifications that have occurred. If modifications have not occurred, then these fences will be targeted for manual inspection on the ground and the GIS layer updated. Fences that are deemed problematic in sage-grouse core habitat will be slated for future modifications or removals, as deemed appropriate and approved by the land managing agency.

Genetics Assessment of the Jackson Core Area Sage-grouse Population
Teton Raptor Center and U.S. Geological Survey

SUMMARY
The goal of this project is to assess the genetic health and genetic diversity of the Jackson Core Area sub-populations in relation to each other and other small, isolated sage-grouse populations. This builds on earlier genetic work conducted by Sarah Oyler-McCance from USGS on these populations. This project will collect and submit genetic samples (fecal and feathers) from the Jackson Hole and Gros Ventre sub-populations for genetic analysis. Knowledge of the degree of connectivity between populations and sub-populations is crucial for better management of small populations in this changing landscape.

Sage steppe plant community restoration in abandoned smooth brome dominated hayfields in Grand Teton National Park
Grand Teton National Park

SUMMARY
The sagebrush steppe vegetation within GTNP forms the core habitat for sage-grouse within the Upper Snake River Basin. While the Park contains 47,000 acres of big sagebrush, it has nearly 9,000 acres of abandoned hayfields that were once sagebrush. These hayfields are now dominated by a nearly shrubless monoculture of smooth brome (*Bromus inermis*). In the 30-50 years that these hayfields have been abandoned, sagebrush has re-established in only a limited area. However, where the sagebrush has returned, the native bunchgrass/forb understory hasn't always. Since 2006, Craighead Beringia South has been collecting GPS points from collared sage-grouse and has demonstrated that grouse do not utilize the hayfields

nearly frequently as the intact sagebrush nearby. These abandoned hayfields are within 4 miles of the Moulton lek. Clearly, for these hayfields to ever be prime habitat for sage-grouse and other sagebrush obligates, they must be restored to their former sagebrush-steppe vegetation.

For the benefit of sage-grouse and many other species, the park has begun to restore these hayfields to native sagebrush-steppe vegetation. This work has been initiated with funds from the Wyoming Sage-Grouse Conservation Fund and the National Park Service. During 2015 and 2016, Grand Teton National Park staff have treated additional acres for smooth brome removal, continued to monitor and conduct noxious weed treatments as necessary, collected native seeds, and seeded treated areas with native seeds. Fencing was also constructed on some treatment units to reduce native ungulate grazing pressure. In total, there are 1,263 acres in various stages of restoration treatment. The goal is to restore 4,500 acres to ecological function, which will require many more years of work.

<u>Invasive species control in occupied sage-grouse habitat</u>
Teton County Weed and Pest District

SUMMARY
This project is designed to address the issue of noxious weeds out-competing the natural habitat in such a way that sage-grouse suffer from lack of cover and inadequate forage. By employing Early Detection/Rapid Response tactics we will be more efficiently managing our resources. Over time this method can greatly conserve cost because it targets small problems while they are still manageable before they become too expensive and extensive to treat. Our project would benefit sage-grouse in preserving their natural habitat and keeping their habitat free of large noxious weed infestations. Well established noxious weed infestations will be controlled so they do not continue their spread.

Management Summary

It appears that following a population rebound in 2015 and 2016, the population has undergone a significant decline during the past 5 years. Lek counts in spring 2019 were the lowest on record for this population, and spring 2020 and 2021 only improved slightly. Data collection, monitoring, and discussions are continuing regarding which potential actions may or may not be implemented by the respective land management agencies and WGFD.

Limited winter habitat continues to be a primary issue for this population. Therefore, monitoring sagebrush habitats used by sage-grouse is a priority. Additional documentation of sage-grouse distribution and habitat condition would be helpful to confirm seasonal distribution, movements, and habitat use. Key areas on public lands used by sage-grouse should be protected from management actions which could have adverse impacts on that habitat, including recreation disturbance. Wildfire suppression should be considered in occupied sage-grouse habitat in Jackson Hole and the Gros Ventre drainage. Restoration of native sagebrush habitats on lands formerly hayed in GTNP and the Gros Ventre drainage appears to have the greatest potential to expand and enhance habitat used by sage-grouse in the USRBCA. Protecting sagebrush habitat on private lands from future residential development is also important. Sagebrush restoration on private lands may also be an option in the future.

Past and current sage-grouse research by local researchers provides essential information to manage this sage-grouse population and its habitat in Jackson Hole. Managers should continue to prioritize funding and in-kind support to these research efforts.

Recommendations

1**.** Continue to help coordinate lek surveys across jurisdictional boundaries using the lek survey protocols adopted by the WGFD.

2. Continue coordinating with other agencies to ensure periodic monitoring of historic, unoccupied or inactive leks. Continue to coordinate with other agencies to search for new leks.

3. Continue to document sage-grouse observations to improve occupied habitat mapping.

4. Support GTNP's sagebrush habitat restoration projects in the Mormon Row and Hayfields areas which could be used as winter, nesting, and brood-rearing habitats for sage-grouse.

5. Continue to work with land management agencies during the implementation of habitat improvement projects to minimize impacts to sage-grouse occupied habitats.

6. Implement the USRBWG Sage-Grouse Conservation Plan (2014). Work to implement the strategies and projects identified in the plan.

References

Bedrosian, B. and S. Walker. 2010. Sage-grouse baseline survey and inventory at the Jackson Hole Airport. Completion Report. Craighead Beringia South, P.O. Box 147, Kelly, WY 83011.

Bedrosian, B., R. Crandall, and D. Craighead. 2010. Jackson Hole Sage-grouse Project Completion Report: 2007-2009. Craighead Beringia South, P.O. Box 147, Kelly, WY 83011.

Bridger-Teton National Forest. 2007. DEIS Eagle Prospect and Noble Basin Master Development Plan. Plains Exploration and Development Company. Bridger Teton National Forest, Jackson WY 83001.

Courtemanch, A., Chong, G., and S. Kilpatrick. 2007. A remote sensing analysis of sage-grouse winter habitat in Grand Teton National Park and Bridger-Teton National Forest, Wyoming. Completion Report. Available in Appendix 3 in Upper Snake River Basin Sage-Grouse Working Group Plan: http://wgfd.wyo.gov/web2011/Departments/Wildlife/pdfs/SG_USR_CONSERVPLAN0005529.pdf

Garton, E.O., J.W. Connelly, J.S. Horne, C.A. Hagen, A. Moser, and M.A Schroeder. 2011. Pages 293-381 *in* S.T. Knick and J.W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. University of California Press, Berkeley, California.

Holloran, M. J. and S.H. Anderson. 2004. Greater sage-grouse seasonal habitat selection and survival in Jackson Hole, Wyoming. Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, USA.

Jackson Sage Grouse Technical Team. 2020. Status Review and Recommendations. Unpublished report submitted to Statewide Adaptive Management Working Group, April 22, 2020. 12 pp.

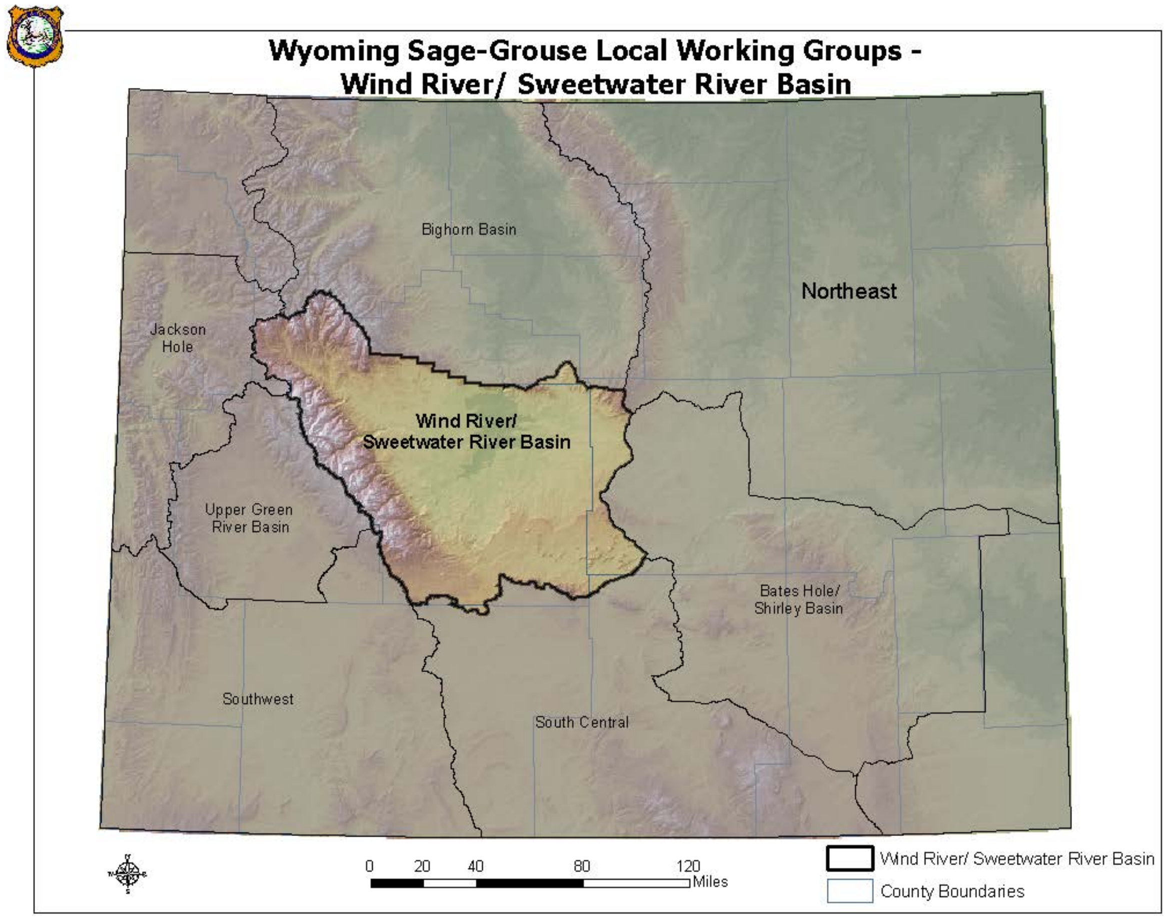
Patterson, R.L. 1952. The sage grouse in Wyoming. Sage Books, Denver, Colorado, USA.

Schulwitz, S., B. Bedrosian, and J.A. Johnson. 2014. Low neutral genetic diversity in isolated Greater Sage-Grouse (*Centrocercus urophasianus*) populations in northwest Wyoming. The Condor 116:560-573.

Upper Snake River Basin Sage-Grouse Working Group. 2014. Upper Snake River Basin Sage-Grouse Conservation Plan. 137 pp. Available at: https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Sage%20Grouse/SG_USR_CONSERVPLAN.pdf

Wind River/Sweetwater River Conservation Area
Job Completion Report

Species: **Greater Sage Grouse**
Mgmt. Areas: **E & WR, Lander Region**
Period Covered: **June 1, 2020 – May 31, 2021**
Prepared by: **Stan Harter, South Lander Wildlife Biologist**



Sage Grouse Lek Characteristics (2021)

Working Group: Wind River/Sweetwater River

Region	Number	Percent
Casper	2	0.8
Lander	196	75.7
WRIR	61	23.6

Working Group	Number	Percent
Wind River/Sweetwater River	259	100.0

Classification	Number	Percent
Occupied	195	75.3
Undetermined	18	6.9
Unoccupied	46	17.8

BLM Office	Number	Percent
Lander (WRR)	61	23.6
Casper	12	4.6
Lander	177	68.3
Rock Springs	7	2.7
Worland	2	0.8

Biologist	Number	Percent
WRR-USFWS	61	23.6
Casper	2	0.8
North Lander	69	26.6
Sinclair	1	0.4
South Lander	125	48.3
Worland	1	0.4

Warden	Number	Percent
Shoshone-Arapahoe Tribal	61	23.6
Dubois	1	0.4
Lander	73	28.2
North Riverton	27	10.4
South Riverton	62	23.9
West Casper	2	0.8
West Rawlins	33	12.7

County	Number	Percent
Carbon	1	0.4
Fremont	229	88.4
Hot Springs	4	1.5
Natrona	24	9.3
Sweetwater	1	0.4

Land Status	Number	Percent
BLM	149	57.5
BOR	4	1.5
Private	30	11.6
Reservation	60	23.2
State	16	6.2

Management Area	Number	Percent
E	198	76.4
WR	61	23.6

Lek Status	Number	Percent
Active	130	50.2
Inactive	39	15.1
Unknown	90	34.7

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Wind River/Sweetwater River

1. Lek Attendance Summary (Occupied Leks) (1)

a. Leks Counted

Year	Occupied	Counted	Percent Counted	Peak Males	Avg Males / Active Lek (2)
2012	193	78	40	1899	28.8
2013	196	81	41	1543	22.4
2014	199	101	51	1860	21.6
2015	215	116	54	4589	44.1
2016	212	95	45	4694	55.2
2017	207	87	42	3499	44.3
2018	209	110	53	3678	38.7
2019	206	97	47	2416	31.4
2020	204	104	51	2181	26.3
2021	202	85	42	1503	23.1

b. Leks Surveyed

Year	Occupied	Surveyed	Percent Surveyed	Peak Males	Avg Males / Active Lek (2)
2012	193	89	46	1358	21.2
2013	196	90	46	1056	15.3
2014	199	87	44	976	17.7
2015	215	85	40	1595	25.3
2016	212	104	49	2744	34.3
2017	207	103	50	2542	33.4
2018	209	87	42	1402	22.3
2019	206	100	49	1195	17.1
2020	204	68	33	605	15.1
2021	202	105	52	874	14.3

Sage Grouse Job Completion Report

Year: 2012 - 2021, Working Group: Wind River/Sweetwater River

1. Lek Attendance Summary (Occupied Leks) (1) Continued

c. Leks Checked

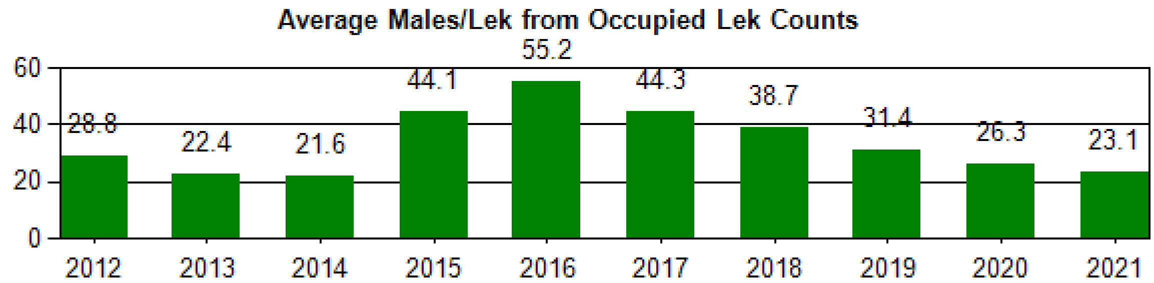
Year	Occupied	Checked	Percent Checked	Peak Males	Avg Males / Active Lek (2)
2012	193	167	87	3257	25.1
2013	196	171	87	2599	18.8
2014	199	188	94	2836	20.1
2015	215	201	93	6184	37.0
2016	212	199	94	7438	45.1
2017	207	190	92	6041	39.0
2018	209	197	94	5080	32.2
2019	206	197	96	3611	24.6
2020	204	172	84	2786	22.7
2021	202	190	94	2377	18.9

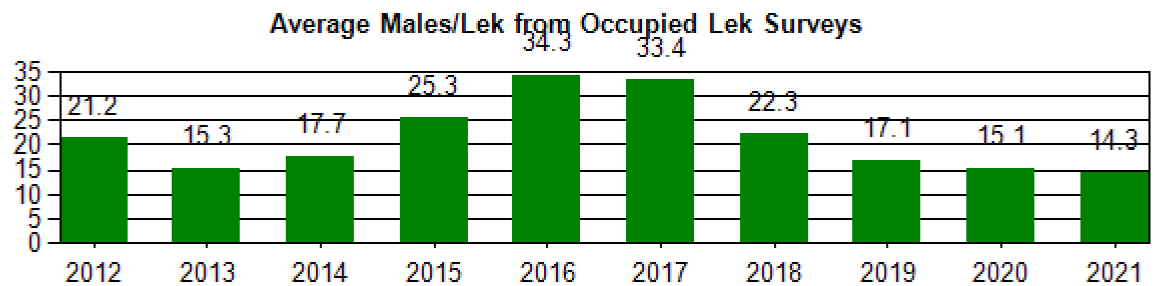
d. Lek Status

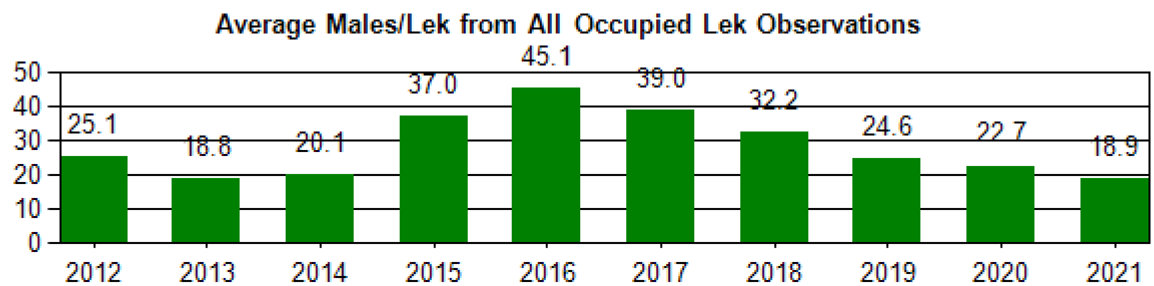
Year	Active	Inactive (3)	Unknown	Known Status	Percent Active	Percent Inactive
2012	131	16	20	147	89.1	10.9
2013	139	14	18	153	90.8	9.2
2014	142	22	24	164	86.6	13.4
2015	167	17	17	184	90.8	9.2
2016	167	11	21	178	93.8	6.2
2017	156	8	26	164	95.1	4.9
2018	158	14	25	172	91.9	8.1
2019	148	20	29	168	88.1	11.9
2020	126	21	25	147	85.7	14.3
2021	128	21	41	149	85.9	14.1

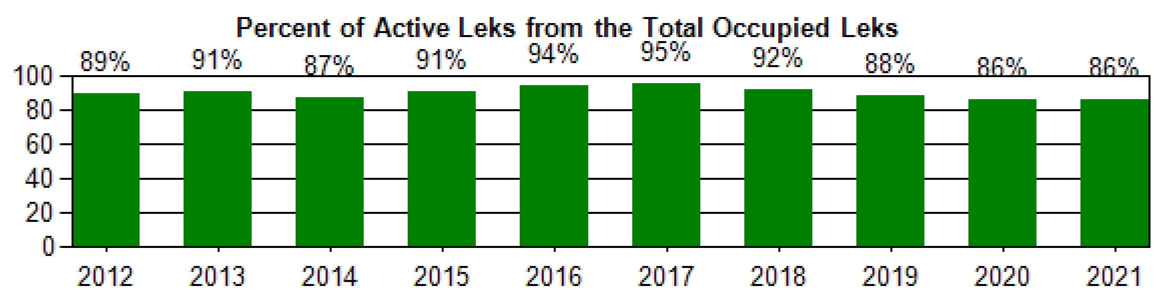
Sage Grouse Occupied Lek Attendance Summary

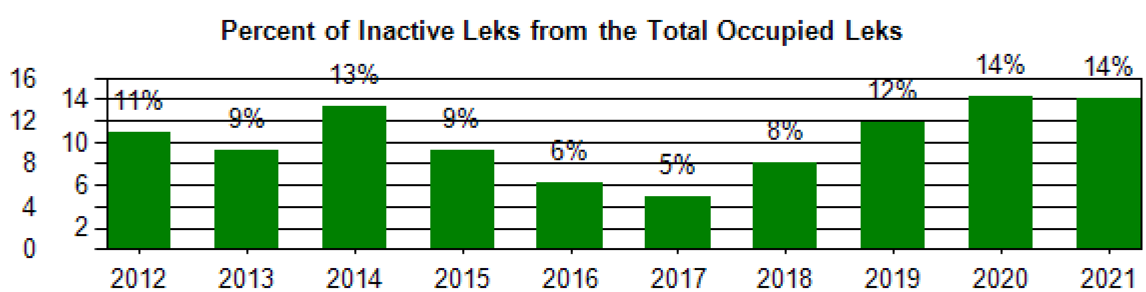
Year: 2012 - 2021, Working Group: Wind River/Sweetwater River











Sage Grouse Job Completion Report

Year: 2011 - 2020, Working Group: Wind River/Sweetwater River

3. Sage Grouse Hunting Seasons and Harvest Data

a. Season

Year	Season Start	Season End	Length	Bag/Possesion Limit
2011	Sep-17	Sep-30	14	2/4
2012	Sep-15	Sep-30	16	2/4
2013	Sep-21	Sep-30	10	2/4
2014	Sep-20	Sep-30	11	2/4
2015	Sep-19	Sep-30	12	2/4
2016	Sep-17	Sep-30	14	2/4
2017	Sep-16	Sep-30	15	2/4
2018	Sep-15	Sep-30	16	2/4
2019	Sep-21	Sep-30	10	2/4
2020	Sep-19	Sep-30	12	2/4

b. Harvest

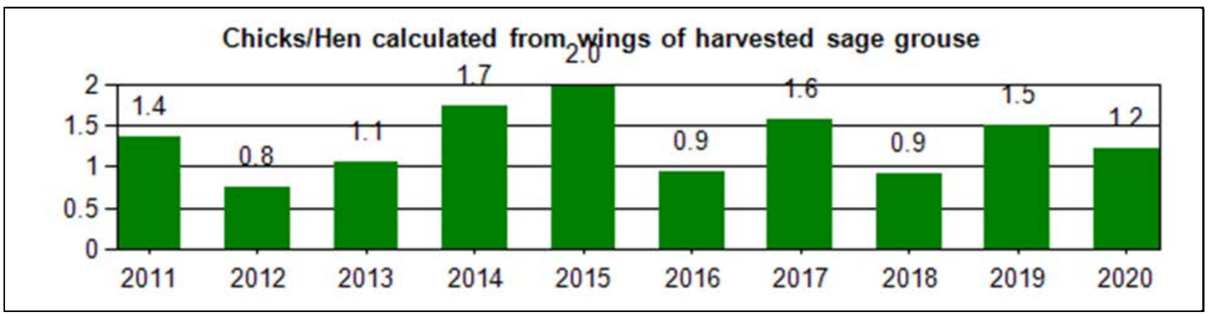
Year	Harvest	Hunters	Days	Birds/ Day	Birds/ Hunter	Days/ Hunter
2011	1779	771	1801	1.0	2.3	2.3
2012	2068	890	2296	0.9	2.3	2.6
2013	1240	565	1325	0.9	2.2	2.3
2014	1546	772	1853	0.8	2.0	2.4
2015	2158	737	1846	1.2	2.9	2.5
2016	1910	922	2264	0.8	2.1	2.5
2017	1364	630	1427	1.0	2.2	2.3
2018	2250	970	2519	0.9	2.3	2.6
2019	1525	814	1891	0.8	1.9	2.3
2020	1115	610	1767	0.6	1.8	2.9
Avg	1,696	768	1,899	0.9	2.2	2.5

Sage Grouse Job Completion Report

Year: 2011 - 2020, Working Group: Wind River/Sweetwater River

4. Composition of Harvest by Wing Analysis

Year	Sample Size	Percent Adult		Percent Yearling		Percent Young		Chicks/ Hens
		Male	Female	Male	Female	Male	Female	
2011	376	9.0	27.1	6.9	8.5	14.4	34.0	1.4
2012	443	18.5	36.1	6.3	6.8	11.1	21.2	0.8
2013	202	18.8	29.7	0.5	9.4	14.9	26.7	1.1
2014	343	10.5	23.3	2.3	8.5	30.3	25.1	1.7
2015	513	11.3	21.2	5.3	6.6	21.4	34.1	2.0
2016	307	16.9	29.6	3.9	11.1	16.9	21.5	0.9
2017	393	18.8	28.5	2.8	2.0	20.9	27.0	1.6
2018	520	17.9	29.0	6.5	10.4	13.7	22.5	0.9
2019	311	14.5	22.5	4.2	10.0	19.0	29.9	1.5
2020	390	12.8	27.9	5.1	9.0	17.4	27.7	1.2



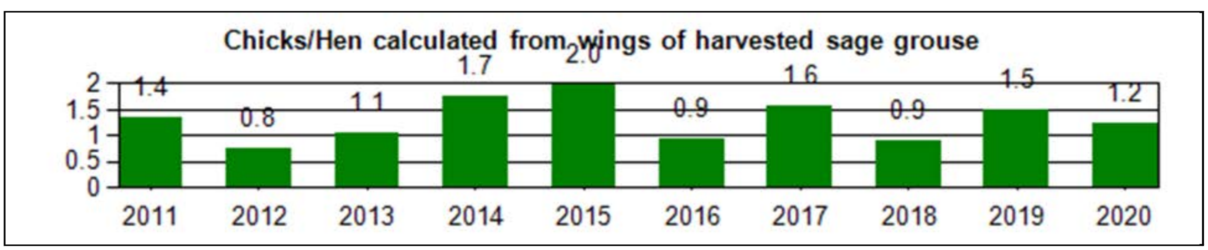
Sage Grouse Wing Analysis Summary

Year: 2020, Working Group: Wind River/Sweetwater River

Adult Males:	50	% of All Wings:	12.8
Adult Females:	109	% of All Wings:	27.9
Adult Unknown:	0	% of All Wings:	0.0
Total Adults:	159		
Yearling Males:	20	% of All Wings:	5.1
Yearling Females:	35	% of All Wings:	9.0
Yearling Unknown:	0	% of All Wings:	0.0
Total Yearlings:	55		
Chick Males:	68	% of All Wings:	17.4
Chick Females:	108	% of All Wings:	27.7
Chick Unknown:	0	% of All Wings:	0.0
Total Chicks:	176		
Unknown Sex/Age:	0		
Total for all Sex/Age Groups:	**390**		

Chick Males:	68	% of All Chicks	38.6
Yearling Males:	20	% of Adult and Yearling Males	28.6
Adult Males:	50	% of Adult and Yearling Males	71.4
Adult and Yearling Males:	70	% of Adults and Yearlings	32.7
Total Males:	138	% of All Sex/Age Groups	35.4
Chick Females:	108	% of All Chicks	61.4
Yearling Females:	35	% of Adult and Yearling Females	24.3
Adult Females:	109	% of Adult and Yearling Females	75.7
Adult and Yearling Females:	144	% of Adults and Yearlings	67.3
Total Females:	252	% of All Sex/Age Groups	64.6

Chicks:	176	% of All Wings:	45.1
Yearlings:	55	% of All Wings:	14.1
Adults:	159	% of All Wings:	40.8
Chicks/Hen	1.2		



Lek Monitoring

WGFD, federal agencies, and volunteers have conducted lek counts and surveys each spring within the WRSRCA for over 40 years, providing some of the best long-term abundance data currently available for sage-grouse. Known leks indicate sage-grouse distribution within the WRSRCA, as represented below in Figure 1.

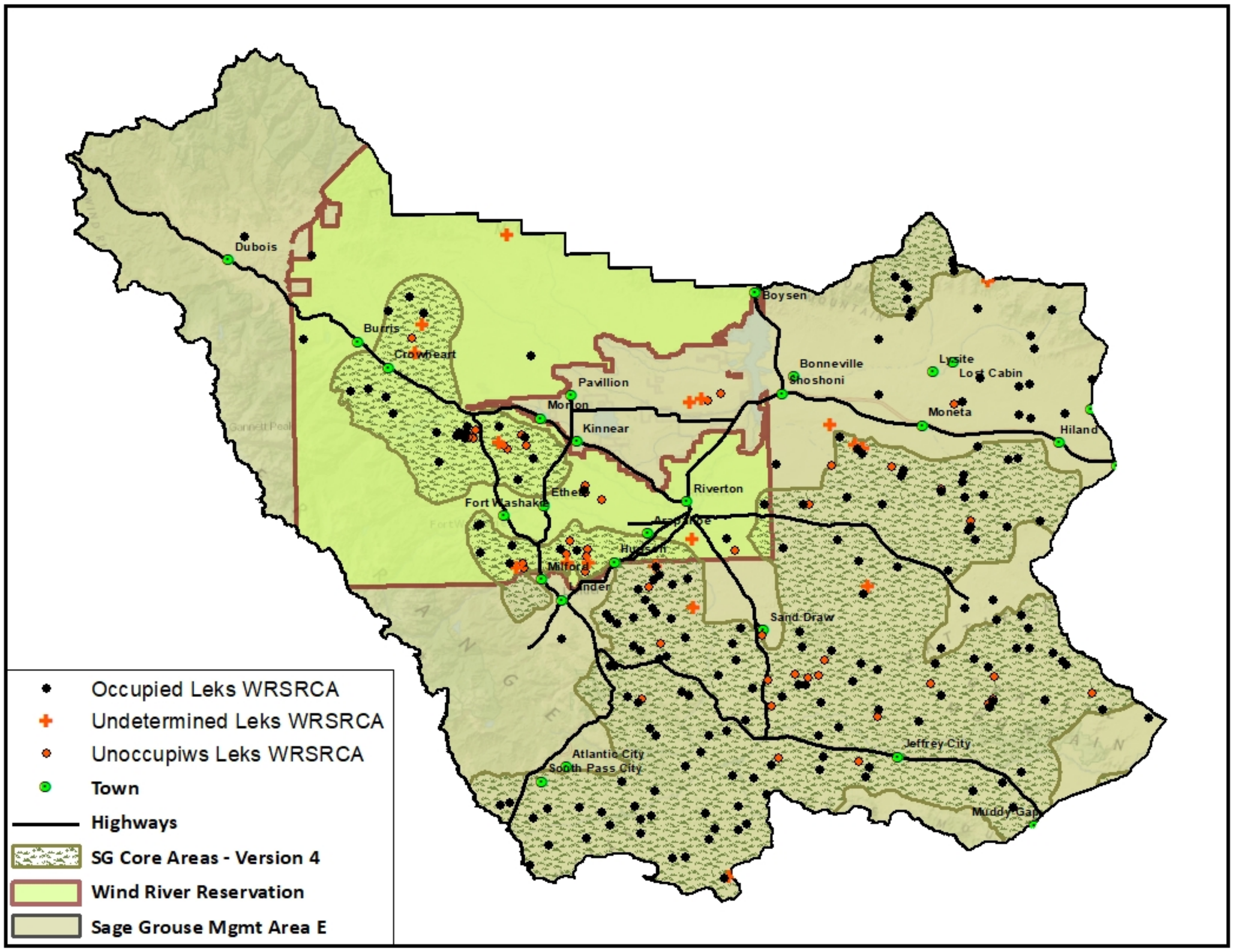


Figure 1. Known sage-grouse lek (2021) and core area distribution in the Wind River/Sweetwater River Conservation area.

Lek Attendance - 2021

Sage-grouse are generally found throughout the WRSRCA, except in heavily forested, agriculturally developed, or urbanized areas. Sage-grouse leks in the WRSRCA are located within the Lander WGFD Region, 4 BLM Resource Areas, 5 Wyoming counties, and the WRR. According to the lek characteristics report on page 2, there were 195 known occupied leks within the conservation area in 2021, along with 46 unoccupied and 18 undetermined leks. As seen above in Figure 1, a majority of leks of all 3 classification levels occur within the 3 core areas that are partially or entirely within the WRSRCA (Crowheart, Greater South Pass, and Washakie). It is highly probable there are leks within the WRSRCA that have not yet been documented, as evidenced by at least 133 (average 6 per year) new or newly discovered leks being documented in the WRSRCA through intensive monitoring and search efforts since 1995. Similarly, there are leks that have been abandoned or destroyed that are undocumented. Lek attendance generally increased between 1995 and 2006, declined until 2013, increased again for 3 years, only to decline in 2017 through 2021, mimicking Wyoming's statewide trends, but with generally higher numbers than the Wyoming average (Figures 2 and 3).

Personnel from WGFD, BLM, USFWS, and Shoshone-Arapahoe Tribal Fish and Game (SATFG), assisted by several researchers, consultants, and volunteers checked 190 of the 202 known occupied leks in the WRSRCA in 2021. This was an improvement over 172 leks checked in 2020. Of those leks checked, 85 were counted and 105 were surveyed. A lower percentage of leks counted was due to inclement weather and road conditions reducing the opportunity for multiple visits to many count leks. Of the 149 leks where status was confirmed, 128 (85.9%) were active and 21 (14.1%) were inactive, with a lower proportion in active status than the average since 2012.

Average male attendance for all leks checked dropped from 22.7 males per active lek checked in 2020 to 18.9 in 2021. Average maximum male attendance at count leks also dropped from 26.3 males per active lek in 2020 to 23.1 in 2021, remaining below the count lek average since 2012 (33.6), and 70% below the long-term peak in 2006 (76.0).

A subset of 16 leks in the Government Draw area east of Lander which have been counted since 1995 had an opposite lek attendance trend in 2021, with a 33% increase in male attendance from 21.9 males per active lek in 2020 to 29.2 males per active lek in 2021. Of concern though, the number of active leks in this subset has gone from 14 in 2018 to 9 in 2021 (perhaps a function of a much lower visitation rate since the last year of UC-Davis research in this area, which provided nearly daily visits to most of the leks to a much less rigorous rate of 3-4 visits per breeding season since?)

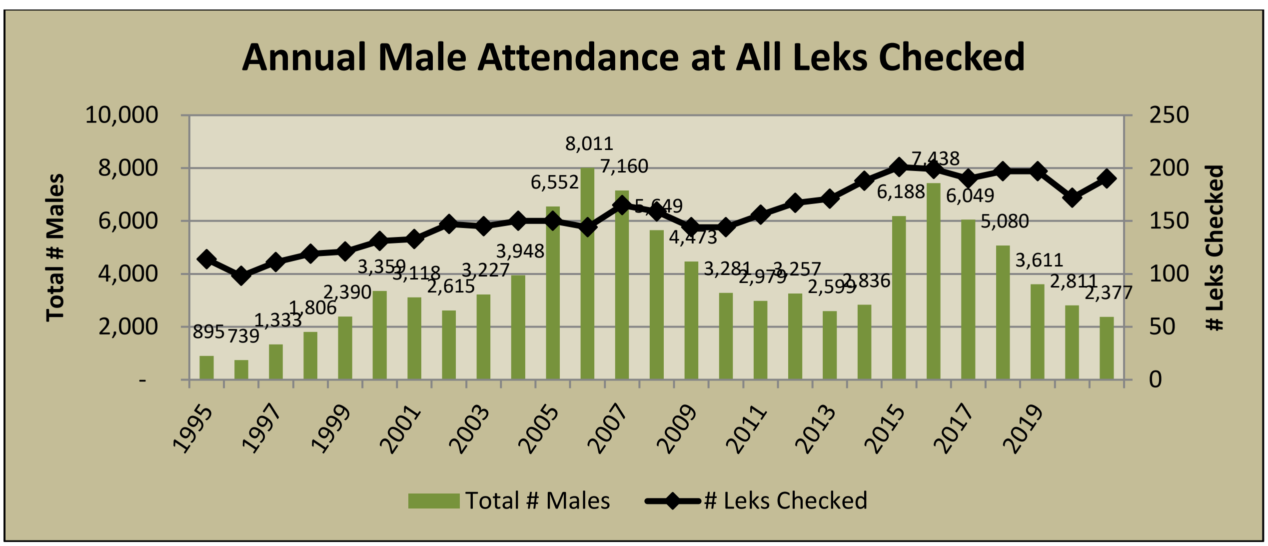


Figure 2. Total male attendance at all leks within the Wind River/Sweetwater River Conservation Area, 1995–2021.

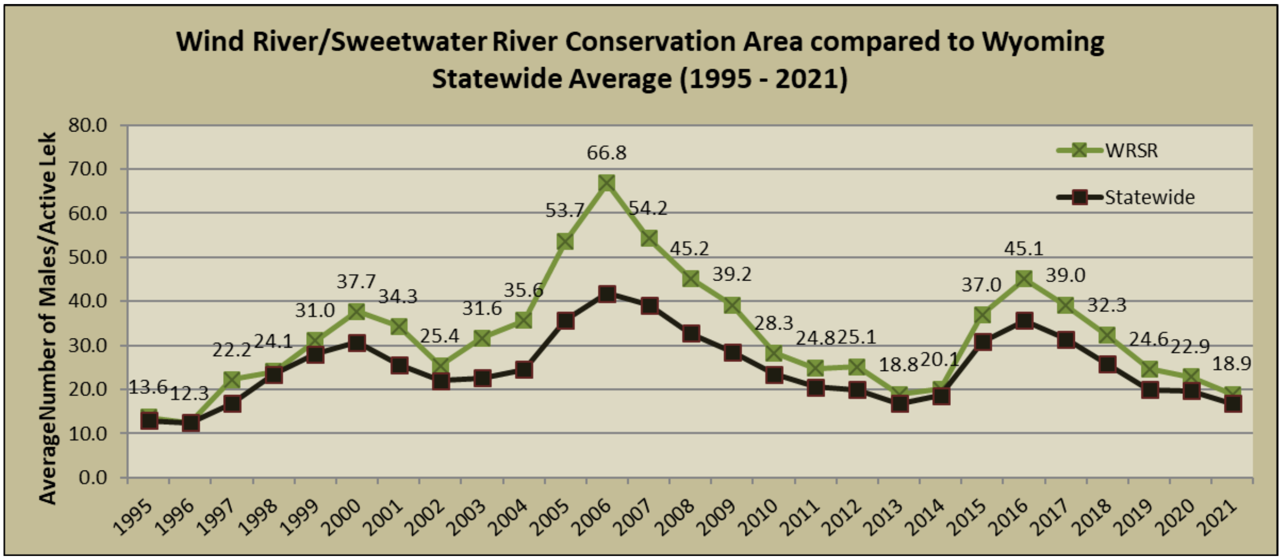


Figure 3. Average male lek attendance (all leks checked) in WRSRCA relative to Wyoming statewide trends, 1995 – 2021.

Lek Perimeter Mapping
As of 2021, nearly all leks in the WRSRCA have perimeters mapped.

Productivity
Since summer brood data are very limited in the WRSRCA, wing data collected from harvested sage grouse provide a more reliable indicator of recruitment than do brood survey data. Wings are collected from hunters at 7 wing barrels placed annually at exit roads from major hunting destinations in Sage Grouse Management Area E and at the Lander Game Check Station, and typically provide significant data, due to a relatively high number of sage-grouse hunters in the area. Wing data are summarized for the WRSRCA for hunting seasons 2011 – 2020, and reported in detail for 2020 (pages 7 and 8). Wings collected from harvested birds during the 2020 hunting season yielded an average brood size of 1.2 chicks per hen, just below the average of 1.3 chicks per hen observed over the last 10 years. Population growth typically requires 1.7 chicks/hen or more based on historic statewide averages. With chick survival in 2020 being below that threshold, male lek attendance in 2021 was 17% below that of 2020.

Hunting Season and Harvest
Sage-grouse hunting season in Management Area E lies entirely within Wyoming Hunt Area 1, which has been "standardized" since 2009, keeping opening day on the 3rd Saturday in September and ending on September 30. The 2020 sage-grouse hunting season was 12 days long (Sept. 19 – 30). In 2020, a total of 1,115 sage grouse were harvested in Management Area E, the lowest since 2020, with annual harvest levels generally following lek attendance trends. Hunter numbers were 25% lower and sage grouse harvest was 27% lower, compared with the 2019 hunting season. Hunter effort (days/hunter) was the highest and success (birds/hunter and birds/day) statistics were the lowest in the last 10-year period (Page 6).

Sage-grouse hunting on tribal lands within the Wind River Reservation is minimal and data are not included in this report.

Habitat (Current and Historic)

Long-term sage-grouse habitat conditions have been affected by long-term drought throughout the WRSRCA. Disturbance (i.e., localized energy development, season-long grazing by livestock and wildlife, etc.) combined with lengthy drought periods and sagebrush eradication programs in many areas have negatively impacted sage-grouse and their habitats. In an effort to improve conditions for sage-grouse, habitat improvement projects are being planned and/or implemented throughout the WRSRCA to address declining sage-grouse habitat condition. In addition, research projects in the WRSRCA are continuing to provide more insight to sage-grouse movements and habitat use. Habitat conditions vary greatly within the WRSRCA, due to climatic differences, soil types, land use, and elevation.

Habitat Monitoring/Inventory

Habitat monitoring is discussed in past WRSRCA JCRs, and in the 2007 WRSRCA Local Sage Grouse Conservation Plan and 2014 Addendum. No habitat monitoring transects were measured in 2020 specifically for sage grouse. However, implementation of Rapid Habitat Assessments (RHAs) continued as part of the South Wind River/Sweetwater Mule Deer Initiative, to develop a baseline from which to gauge overall habitat condition. Several RHAs covering shrub/rangeland habitats were completed within the WRSRCA in 2020, and offer insight as to the condition of sage-grouse habitats within the South Wind River and Sweetwater Mule Deer herd units that overlap a portion of the WRSRCA.

Winter Habitat Use Survey

Limited winter observations were collected in 2020-21, mostly as opportunistic observations during deer, elk, and moose classification flights or random ground surveys.

Habitat Treatments

Since adoption of the WRSR LWG plan in 2007, a number of vegetation treatments have been implemented with the intention of improving habitats for sage grouse, mule deer, and other wildlife. Summaries of these treatments are reported in past JCRs and in the 2007 WRSRCA Local Sage Grouse Conservation Plan and 2014 Addendum. No new treatments in sage grouse habitats occurred during 2020.

Conservation Easements

Within the WRSRCA, several privately owned properties have been placed under conservation easements with deed restrictions ranging from minimal to no new construction of houses, barns, or other buildings. Conservation easements are mostly located in the Lander Foothills, Sweetwater River, Twin Creek, Dubois, and Ervay Basin areas. Presently, over 32,000 acres of private lands are permanently protected by conservation easements within the WRSRCA, and provide protection of crucial wildlife habitat, water quality, maintain migration routes, and continue traditional agricultural land uses.

Research

A number of research projects have been conducted in the WRSRCA since 2000. Studies conducted prior to 2020 were reported in past JCRs and in the 2007 WRSRCA Local Sage Grouse Conservation Plan and 2014 Addendum, which contains the most complete bibliography of sage grouse research for the WRSRCA through March 2014. A collection of current sage-grouse research being conducted in Wyoming is compiled annually by Dr. Jeff Beck at the University of Wyoming and is included in the annual statewide sage-grouse JCR. Citations for ongoing research and published works from the WRSRCA are included at the end of this report.

Diseases
No new cases of West Nile Virus (WNv) or other avian diseases are known to have occurred in sage grouse in the WRSRCA in 2020.

Management Recommendations
1. Continue to collect age and sex composition of the harvest via wing collection and analyses.
2. Continue intensive lek counts in the Government Draw area south of Hudson.
3. Continue ground checks of all non-intensively monitored leks.
4. Continue to search for new or undiscovered leks in remote areas of WRSRCA.
5. Continue to cooperate with private landowners and Federal/State land managers to reduce negative impacts to crucial sage-grouse habitats.
6. Continue to coordinate research projects within or applicable to the WRSRCA.

Literature Cited

Recently Completed Research within the Wind River/Sweetwater River Sage-grouse Conservation Area

Response of Greater Sage-grouse to Treatments in Wyoming Big Sagebrush –
Smith, Beck, et al - University of Wyoming – Journal of Wildlife Management and Wildlife Monographs - Manuscript ID JWM-21-0126 *Submitted in April 2021*

Comparison of Avian and Mammalian Predators in Sage-Grouse Core and Non-Core Areas: Assessing Predator Abundance and Responses to Anthropogenic Features –
Claire L. Revekant[1] and Jonathan B. Dinkins[1] [1]Department of Animal and Rangeland Sciences, Oregon State University, Corvallis, OR 97331 – Master of Science Thesis June 2021

Published Works

Blomberg, E.J., D. Gibson, M. T. Atamian, and J.S. Sedinger. 2014a. Individual and environmental effects on egg allocations of female greater sage-grouse. Auk 131:507–523.

Blomberg, E.J., J.S. Sedinger, D. Gibson, P.S. Coates, and M.L. Casazza. 2014b. Carry-over effects and climatic conditions influence the post fledging survival of greater sage-grouse.
Ecology and Evolution doi: 10.1002/ece3.1139

Burkhalter, C., M. J. Holloran, B. C. Fedy, H. E. Copeland, R. L. Crabtree, N. L. Michel, S. C. Jay, B. A. Rutledge, and A. G. Holloran. *In Press*. Landscape-scale habitat assessment for an imperiled avian species. Animal Conservation.

Carlisle, J.D., A.D. Chalfoun, K.T. Smith, and J.L. Beck. 2018. Nontarget effects on songbirds from habitat manipulation for greater sage-grouse: implications for the umbrella species concept. The Condor: Ornithological Applications 120(2):439-455.

Carlisle, J.D., D.R. Stewart, and A.D. Chalfoun. 2017. An invertebrate ecosystem engineer under the umbrella of sage-grouse conservation. Western North American Naturalist 77(4):450–463.

Carlisle, J.D. 2017. The effect of sage-grouse conservation on wildlife species of concern: implications for the umbrella species concept. Dissertation. University of Wyoming, Laramie, WY.

Carlisle, J.D., G. Bedrosian, and T.L. McDonald. 2017. The influence of Greater Sage-Grouse management on risks faced by Golden Eagles in sagebrush ecosystems: a spatially explicit assessment of the umbrella species concept. Prepared for Western Golden Eagle Team, U.S. Fish and Wildlife Service. Final report, Western EcoSystems Technology, Inc., Laramie, WY.

Caudill, D., M. R. Guttery, B. Bibles, T.A. Messmer, G. Caudill, E. Leone, D. K. Dahlgren, and R. Chi. 2014. Effects of climatic variation and reproductive trade-offs vary by measure of reproductive effort in greater sage-grouse. Ecosphere 5(12):154. http://dx.doi.org/10.1890/ES14-00124.

Christiansen, T. 2012. Chapter 12: Sage Grouse (*Centrocercus urophasianus*). Pages 12-1 to 12-55 in S.A. Tessmann and J. R. Bohne (eds). Handbook of Biological Techniques: third edition. Wyoming Game and Fish Department. Cheyenne.

Dinkins, J. B., K. J. Lawson, K. T. Smith, J. L. Beck, C. P. Kirol, A. C. Pratt, M. R. Conover, and F. C. Blomquist. 2017. Quantifying overlap and fitness consequences of migration strategy with seasonal habitat use and a conservation policy. Ecosphere 8(11):e01991. 10.1002/ecs2.1991

Fedy, B.C. and C.L. Aldridge. 2011. The importance of within-year repeated counts and the influence of scale on long-term monitoring of sage-grouse. Journal of Wildlife Management 75(5): 1022-1033.

Forbey, J.S., G.L. Patricelli, D.M. Delparte, A.H. Krakauer, P.J. Olsoy, M.R. Fremgen, J.D. Nobler, L.P. Spaete, L.A. Shipley, J.L. Rachlow, A.K. Dirksen, A. Perry, B.A. Richardson, and N.F. Glenn. 2017. Emerging technology to measure habitat quality and behavior of grouse: examples from studies of greater sage-grouse. Wildlife Biology 2017(SP1)

Heath, B. J., R. Straw, S.H. Anderson, J. Lawson. 1997. Sage-grouse productivity, survival and seasonal habitat use near Farson, Wyoming. Research Completion Report. Wyoming Game & Fish Dept., Cheyenne.

Smith, K.T., J.S. Forbey, and J.L. Beck. 2018. Effects of mowing and tebuthiuron treatments on the nutritional quality of Wyoming big sagebrush. Rangeland Ecology & Management

Smith, K.T., and J.L. Beck. *In press*. Sagebrush treatments influence annual population change for greater sage-grouse. Restoration Ecology DOI: 10.1111/rec.12589

Wind River/Sweetwater River Local Working Group. August 2007. Wind River/Sweetwater River Local Sage-Grouse Conservation Plan. Wyoming Game and Fish Department, Cheyenne.

Wind River/Sweetwater River Local Working Group. March 2014. Addendum for the Wind River/Sweetwater River Local Sage-Grouse Conservation Plan. Wyoming Game and Fish Department, Cheyenne.