Spatial and Temporal Analysis of Oil and Gas Development, Mitigation, and Sage Grouse Lek Attendance in the Pinedale Planning Area, Wyoming: 1990-2012.

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Abstract

The Pinedale Planning Area of Wyoming was chosen as the focus of this study because it is essentially "ground zero" for study of the effects of oil and gas development on sage grouse and has influenced many of the perceptions regarding impacts of oil and gas development on greater sage grouse.

For this study, 100 years of data on oil and gas development in the Pinedale Planning Area was compiled and analyzed. Also included was data on recent mitigation efforts to benefit sage grouse, spatial and temporal changes in oil and gas development, restoration, and greater sage grouse responses based on 22 years of male greater sage grouse lek attendance data. These data and analyses were used to test hypotheses regarding the effect of oil and gas development on patterns of sage grouse lek attendance, as well as predictions and conclusions made by previous authors. Finally, the effect of several recently recommended conservation measures for greater sage grouse were also tested. These include the 3% disturbance cap and the 4-mile no surface occupancy (NSO) buffers recommended by the Bureau of Land Management's (BLM) Sage Grouse National Technical Team Report (NTT 2011) and cited in more recent draft land use plan revisions proposed by BLM and the U.S. Forest Service (USFS).

Despite predictions and conclusions from earlier studies, data from 1990 to 2012 do not indicate a sage grouse population decline or widespread lek abandonment near oil and gas operations in the Pinedale Planning Area. Lek attendance in this population has been consistently above statewide averages and other populations since 1990. Overall lek attendance in areas that exceed 3% disturbance within 4-miles of a lek has not declined.

Key regulatory decisions in 2008, mitigation efforts, and concurrent advances in oil and gas technology and efficiency are all factors that distinguish past from current oil and gas practices in the Pinedale Planning Area. The Pinedale studies that are currently being utilized in regulatory decisions on sage grouse include data that were collected before these key changes took place and, therefore, are outdated and inappropriate as regulatory justifications. The more current data and analyses presented here provide a more accurate picture of sage grouse responses to oil and gas activity in the Pinedale Planning Area.

Introduction

Over the past two decades, conservation efforts have been ramped up on private, state, and public lands across the western United States and southern Canada to benefit the greater sage grouse. These efforts have resulted in an unprecedented level of conservation and preservation for the species and its habitat. Efforts were increased in number and scope after studies reported declines in available habitat, increased lek abandonment, and declining trends in lek attendance in areas of development and disturbance. Repeated attempts were made to list the greater sage grouse as threatened under the Endangered Species Act. Conservation efforts were markedly accelerated in 2010 following a decision by the U.S. Fish and Wildlife Service (USFWS) to list the species as “threatened” under the U.S. Endangered Species Act (ESA), but precluded at the time by higher ESA listing priorities (USFWS 2010).

The threats to sage grouse identified in the 2010 ESA listing decision were numerous, and while these included sagebrush habitat loss and fragmentation, disease, predation, grazing, agriculture, and residential development, oil and gas development was singled out as one of the primary threats to this species. Several of the key studies cited in that decision were conducted in the intensively developed Jonah and Pinedale Anticline gas fields of BLM's Pinedale Planning Area (PPA) of southwestern Wyoming (Lyon 2000; Lyon and Anderson 2003; Holloran 2005; and Holloran 2010). These studies, conducted prior to extensive mitigation efforts and advent of less invasive technologies, reported decreased male lek attendance, avoidance, lower nest initiation rates and increased sage grouse mortalities from predation adjacent to development. One frequently cited study (Holloran 2005), predicted future sage grouse population declines of 8.7 to 24.4% annually in the Pinedale population.

Development of oil and gas fields near Pinedale began with the first well drilled in the La Barge field in 1912. While production began there in 1924 and increased during World War II, intense development of the La Barge field took off during the 1960s, and subsequently at Jonah and Pinedale Anticline fields in the 1990s and early 2000s (Animation 1).

Although oil and gas development continues in these three fields, more efficient and less impactful methods of drilling and production and methods to reduce surface disturbance are now used regularly compared to previous years. Early development of the La Barge and Jonah fields, and similar intensive developments elsewhere, were permitted decades ago, prior to concerns over sage grouse conservation, and were developed using less sophisticated and more invasive technologies and methods. For example, the density of wells in the La Barge and Jonah fields is higher than would typically be necessary or permitted today, as development of these fields relied on the now largely outdated practice of drilling many vertical wells to tap the subsurface resource. This practice predates the more current and widespread use of directional and horizontal drilling in the PPA (Kneller et al. 2006; Han et al. 2013). These newer technologies (and others, discussed below) allow multiple wells to be drilled from a single well pad, thus reducing overall surface disturbance (BLM 2006a,b; Kreckel 2011; Ramey, Brown, and Blackgoat 2011; Applegate and Owens 2014).

Another difference between past and current oil and gas development in the PPA has been the implementation of extensive mitigation measures designed to reduce overall impacts to sage grouse and enhance their habitat. On BLM lands, these efforts became notable in 2000 with stipulations and required mitigation measures associated with the Record of Decision for the Pinedale Anticline Oil & Gas Exploration and Development Project (BLM 2000). Subsequent BLM decisions substantially stepped-up required mitigation efforts to benefit sage grouse and other species. Those include the 2006 approval of the Jonah Drilling Infill Project (BLM 2006c), Pinedale Anticline Project Area Supplemental Environmental Impact Statement (BLM 2008a) and, most significantly, the Pinedale Resource Management Plan Record of Decision (BLM 2008b). On a broader scale, Executive Orders issued by the Governors of Wyoming, beginning with Core Population Area designation and protection in 2008, and subsequently updated (State of Wyoming. 2014), have laid out similar stipulations that apply to state, federal, and private lands.

These efforts, along with voluntary conservation efforts, resulted in extensive areas of sage grouse habitat being set aside and declared as "unavailable" to oil and gas development (BLM 2008b). These efforts also led to the establishment of the Jonah Interagency Mitigation and Reclamation Office, and Pinedale Anticline Project Offices, whose purpose is to coordinate and fund species monitoring, scientific research, offsite mitigation, purchase of conservation easements, and funding habitat improvement projects. The 2008 Pinedale RMP also required 301,780 acres (122,126 ha) of seasonal restrictions to safeguard sage grouse winter concentration areas and nesting habitat, and no surface occupancy stipulations to protect habitat. It also required telemetry systems to be installed at gathering systems, wells, and condensate tanks that could be monitored remotely in order to reduce truck traffic. Although there has been a substantial investment in these efforts, there has not been a concomitant systematic effort to quantify the response of the sage grouse population to these efforts. This is a significant data gap because each study from this area spanned a narrow window of time (2-5 years, between 1997 and 2006), and all but one year of a single study predated implementation of most of the mitigation and conservation efforts. These studies were also conducted at a time when more impactful and less efficient technology was in use.

In order to fill this information gap, data on oil and gas development, mitigation to offset its negative effects on sage grouse, and sage grouse lek attendance data from the PPA were compiled. This allowed a quantification of long-term spatial and temporal patterns of oil and gas development, mitigation efforts, and sage grouse responses to these activities.

Methods

Sources of data

Well location and production data were obtained from the Wyoming Oil and Gas Conservation Commission (WOGCC) and rectified with field-verified data from IHS (IHS.com). Well pad disturbance and reclamation spatial-temporal data was obtained from the Jonah Infill Data Management System (JIDMS) and Pinedale Anticline Data Management System (PADMS) databases, the Pinedale BLM Field Office, and individual operators. In some cases, such as the older La Barge field, pad disturbance and reclamation over the lifetime of a well was modeled, based on a subsampling of pads from aerial imagery with known dates of activity. Spatial and temporal data on primary and secondary roads were obtained from the BLM and operators. In cases where data were not available for the year that access roads were connected to individual well roads (or their precise location), we modeled the pattern of development, based on the assumption that the access road construction and pad construction was contemporaneous with the year a well was spudded, and utilized a least cost path to model connection between wells and roads. Similarly, data on pipeline locations and construction dates was based on data available from the Wyoming Pipeline authority, IHS, and satellite imagery (USGS, USDA, ESRI), and from pipeline operators. In the case of feeder lines from wells, it was assumed that these were constructed in the same year that the well was drilled and ran parallel and adjacent to well access roads. In cases where pipeline location was not available, a least cost path analysis was used to link wells to associated trunk lines.

Individual well activity was classified on an annual basis as either “under development”, “producing,” "injecting," or “inactive” based on dates in IHS well database. Wells in the development phase included the period from being spudded until the year of production. This is when the greatest level of activity and traffic occurs at a well. The producing well phase started the year a well was producing oil or gas. This is a period with a substantially lower level of activity, although periodic maintenance may occur. Inactive wells are those that are plugged, abandoned, or suspended.

The majority of oil and gas pads in the study area that were drilled in the past decade contain multiple wells. In the Jonah (JIO) and Pinedale Anticline (PAPO) fields, geospatial data was provided by PADMS and JDMS in the form of polygons associated with well pad, road, and pipeline disturbance and reclamation. This provided a snapshot of recent pads, but gave little insight into pad disturbance in the past. To estimate historic disturbance, historic aerial imagery was downloaded from the USGS EarthExplorer website and orthocorrected (using spline transformations) to align with recent imagery and project-related GIS data. Then 103 pads were digitized for pre-1953 time periods until a representative sample was obtained for each decade from 1912-1953. The spud date from the well point data ensured that each digitized pad corresponded with only one disturbance time in history, as opposed to digitizing pads that have been drilled multiple times. The area was calculated for the pads and each pad was tagged with its respective disturbance decade. The pad size and spud decade were graphed in Excel and polynomial trend was extracted from the bivariate relationship. This polynomial equation ($y = -0.0000115895x^4 + 0.0019003170x^3 - 0.0755722180x^2 + 2.0572264991x + 44.0116000000$; $R^2 = 0.9703629150$) was then used to model pad size from 1912-2012 for the entire PPA, using the ArcGIS buffer tool. The resulting model was tested against the digitized pads and was within 3% in terms of aerial accuracy.

Oil and gas-related disturbance from roads was modeled using the modeled pads and the existing road network (BLM) using the least cost path tool in ArcGIS.
Major pipeline locations and configurations were obtained from various sources including operators, IHS, Wyoming Pipeline Authority and ortho-imagery (USGS, USDA, ESRI). Estimates of pipeline installation dates were modeled using production start dates associated with nearby well point data and the least cost path tool (ArcGIS).

We plotted and quantified spatial changes in oil and gas related road, well pad, and pipeline development over time to examine development in the PPA in terms of cumulative area of surface disturbance; number of developing, producing, and inactive wells; and surface disturbance in excess of 3% within four miles of a lek. Quantifiable mitigation efforts included: acreage in the process of reclamation, conservation easements, and BLM "unavailable areas" (designated in 2008 as unavailable to oil and gas development). Mitigation efforts such as: installation of telemetry at wells and condensate tanks, field electrification (i.e. conversion from diesel and gas powered compressors to electric), and liquid gathering systems (to reduce truck traffic); anti-perch device installation; fence marking; and powerline burial; were quantified separately in terms of dates of completion across a field, and in the case of liquid gathering systems, the number of truck trips eliminated. Lek location and attendance data were obtained from the Wyoming Game and Fish Department for the PPA. The PPA is a semi-isolated segment of the greater Wyoming Basin Population which encompasses most of the upper Green River Basin of Wyoming.

To test the effectiveness of disturbance thresholds recommended by the NTT Report (NTT 2011), we used a criterion that there must be greater than 3% surface disturbance within 4-miles of a lek for it to be classified as "disturbed" in our analysis. Land in excess of this threshold was calculated as a "moving window," which allowed us to objectively test potential effects of cumulative surface disturbance on lek attendance. Lek location and male lek attendance data were obtained from the State of Wyoming.

We also conducted a preliminary investigation into the potential effects of localized oil and gas activity on sage grouse lek attendance, using a radius of 0.6 mile around each well during its development, injection, and/or production phase. If a lek was within the 0.6 mile radius it was considered as potentially disrupted by the activity. Wells that have been plugged and abandoned are inactive and therefore were not considered in the analysis.

Hypotheses and predictions tested

Hypothesis 1a (*The universally negative and typically severe impact hypothesis*): The impact of oil and gas development has had a severe, negative effect on the sage grouse population in the PPA. This hypothesis is based upon an influential statement in the NTT Report (2011) that the effect of oil and gas development on sage grouse populations "*is universally negative and typically severe*".

- Prediction 1a.1: The sage grouse population across the PPA will show evidence of decline in terms of average number of males per lek, and the number of leks, as oil and gas surface disturbance and activity increase over time. Lek attendance will decline to zero in areas with the highest levels of oil and gas surface disturbance and activity.

- Prediction 1a.2: The sage grouse population in the PPA will go extinct 19 years after oil and gas field development has begun (based on the prediction by Holloran 2005).

Alternative hypothesis 1b (*The mitigated impacts hypothesis*): The impact of oil and gas development on sage grouse has moderated as a result of increased mitigation efforts and less-invasive technology.

- Prediction 1b.1: Sage grouse lek attendance and the number of leks will stabilize or increase in disturbed areas after implementation of intensive mitigation efforts.

Alternative hypothesis 1c (*the previously overestimated impacts hypothesis*): The impact of oil and gas development on sage grouse was previously overestimated.

- Prediction 1c.1): Lek attendance will not decline (relative to population fluctuations found across the state), and leks will not be lost across a large portion of the population, despite increasing oil and gas development, so long as there is adequate undeveloped habitat nearby and responsible measures taken to mitigate the development.

Hypothesis 2 (*the 3% disturbance cap and 4-mile NSO hypothesis*): A 3% surface disturbance cap and/or a 4-mile NSO buffer surrounding each lek is required to maintain or increase sage-grouse distribution in the affected area. This hypothesis is based upon a statement in the NTT Report (2011) that these disturbance thresholds are *"required to maintain or increase sage-grouse distribution."*

- Prediction 2.1): Sage grouse lek attendance will decline as surface disturbance exceeds the threshold of 3% within 4-miles of a lek and will result in an overall decline in the average number of males per lek across the population (indicative of a population decline).

- Prediction 2.2): Leks will not persist or be recolonized in areas that exceed a 3% surface disturbance within 4-miles of a lek, or in areas where well development or injection occurs within 4 miles of a lek.

Results

Spatial and temporal patterns of 100 years of oil and gas development

The pattern of development in the PPA over the past 100 years has been one of concentrated development in the La Barge, Jonah, and Pinedale Anticline fields, with limited to no oil and gas development in surrounding areas **(Animation 1**). The majority of wells drilled in the center of the PPA, between the Pinedale Anticline and Jonah fields on the east and the main La Barge Field on the west were wildcat (exploratory) wells drilled between 1945 and 2000. Those wells were essentially probes into the earth, drilled prior to the widespread use of high-resolution 3D and 4D seismic reservoir mapping, which allows for more precise drilling in order to achieve more efficient extraction of the resource (Cartwright and Huuse 2005; Castro 2007). By the end of 2012, the majority of those wildcat wells were either suspended, or plugged and abandoned. While there may be remaining surface disturbance at these well sites until reclaimed, the wellheads of inactive wells (if they are visible at all) are inanimate objects in the environment, typically denoted by a stake in the ground above the former wellhead, and cause no further disturbance to sage grouse from human activity. The cumulative total of wells drilled in the PPA at the end of 2012 was 8,029. There were 300 wells being developed, 5,316 producing wells, 64 injection wells, and 2,349 suspended/plugged and abandoned wells.

Oil and gas development, Unavailable Areas, and Core Habitat

The concentrated surface development observed in PPA is in part due to BLM land use planning to minimize impacts to surrounding areas. For example, the 2008 Pinedale RMP Record of Decision designated 175,040.5 acres (70,836.6ha) as intensively developed oil and gas fields, and 453,702.5 acres (183,607.6ha) as "Unavailable Areas" to oil and gas development (subject to valid existing rights). Our analyses estimate that by the end of 2012, the surface disturbance from oil and gas development (well pads, roads, and pipelines, including areas which are in "interim" reclamation status) in the PPA was approximately 39,013.3 acres (15,788ha) or 2.4% of the Planning area, consistent with in BLM planning documents.

The PPA also contains 717,728 acres (290,454.2 ha) of core sage grouse habitat (State of Wyoming 2014). We estimate that the total surface disturbance in core habitat as a result of oil and gas development has been approximately 4,173 acres (or 0.58% of core habitat).

The 2008 Pinedale RMP Record of Decision designated 453,702.5 acres (183,607.6 ha) as "Unavailable Areas" to oil and gas development. Those acres, in combination with private land enrolled in conservation easements, provide protection to 51.6% of the core habitat (370,237 acres) in the PPA (**Figure 1**). Additionally, sage grouse nesting habitat in traditional leasing and unavailable areas (301,780 acres, 122,126.03 ha.) is further protected under seasonal restrictions to protect breeding and nesting sage grouse (BLM 2008b).

Directional drilling technology and operational efficiencies

Until 2004, the majority of wells drilled in the PPA were vertical wells. Directional wells eclipsed vertical wells from 2004 onward, and by 2010 made up virtually all of the wells drilled in the PPA **(Figure 2)**. As a direct result of directional drilling, the average number of wells per pad in the PPA has increased. By the end of 2012, there were an average of 4.74 wells per pad (range: 1 to 50) and the average horizontal distance drilled from a wellhead was 1,323 feet (range: 801 to 2,995 feet) **(Figures 3 and 4)**. The maximum horizontal distance for a directional well drilled in the PPA was 6,463 feet, drilled in 2011. The average time from the spudding of a well to its completion on the Pinedale Anticline was 44 weeks in 1998. This declined to 27.5 weeks by 2012.

Sage grouse lek attendance from 1990 to 2012

The average number of males per lek has been consistently above statewide averages in the PPA from 1990 through 2012. Annual trends in male lek attendance fluctuated in synchrony with the statewide average for male lek attendance **(Figure 5)**. The number of active leks sampled, has increased over time, primarily due to an increase in sampling efforts by the Wyoming Game and Fish Department **(Figure 6)**.

Although the average number of males per lek was higher in undisturbed areas compared to those that were disturbed, a similar net change overtime in lek attendance was apparent in both disturbed and undisturbed leks. We found no evidence of a population decline or population extirpation in the PPA, as predicted by Holloran (2005) **(Figure 1; Animation 2)**.

Several sage grouse leks had male attendance decline to zero during intensive field development (Holloran 2005), however, there has not been a consequent extirpation of sage grouse from the Pinedale Anticline or La Barge fields. In the Pinedale Anticline, the number of leks in disturbed areas fluctuated between 9 and 11 between 2005 and 2012. In the older La Barge field, the number of leks increased during the same period (from 7 in 2005 to 11 in 2012). In the Jonah field, lek attendance declined to zero at three leks by 2008, although lek use continued around its periphery **(Animations 3 and 4)**. A comparison of long-term patterns of lek attendance in the Jonah and La Barge fields, with increasing levels of surface disturbance, reveals that leks may persist in areas with surface disturbance thresholds of even 10% or higher **(Figures 6 and 7; Animation 5)**.

Lek attendance across the PPA has fluctuated in both disturbed and undisturbed areas, and the fluctuations appear to be independent of development status. Also, lek use fluctuates in both developed and undeveloped areas (**Animation 2**), which is consistent with observations and data that male sage grouse are not tied to specific leks (Bush et al. 2010).

Hypothesis testing results

The data are inconsistent with predictions 1a.1 and 1a.2, leading to the rejection of Hypothesis 1a (*the universally negative and typically severe impact* hypothesis). The impact of oil and gas development has NOT resulted in a severe, negative effect on the sage grouse population in the PPA.

The data are consistent with Prediction 1b.1, although not enough time may have elapsed to quantify its full effects because the primary mitigation efforts were implemented in 2008. Therefore, while Alternative Hypothesis 1b (*the mitigated impacts hypothesis*) cannot be rejected, it must be acknowledged that more time may be need for it to be fully tested.

The data are consistent with Prediction 1c, as lek attendance did not decline relative to population fluctuations found across the state. Therefore, Alternative hypothesis 1c (*the previously overestimated impacts hypothesis*) could not be rejected.

The data are inconsistent with Predictions 2.1 and 2.2. Sage grouse persist and in some cases, increase in number in areas where surface disturbance exceeds a threshold of 3% within 4-miles of leks. Therefore, Hypothesis 2 (*the 3% disturbance cap and 4-mile NSO hypothesis*) is rejected.

Our preliminary analysis of sage grouse lek attendance in areas with high levels of human activity (i.e. within 0.6 miles for wells being developed, injected, or producing) indicate that this is a rare occurrence (potentially due to regulations requiring avoidance), with just 2 to 7 leks in that proximity from 1990 to 2012 (out of 99 total active leks). However, leks do persist in that category of disturbance, including at least two leks with long-term, periodic use in the La Barge field.

Discussion

We found no evidence of a sage grouse population decline in the PPA as a result of oil and gas development. The average male lek attendance in this population was consistently above statewide averages, including averages during natural, regional population fluctuations. Our observations are consistent with those of the State of Wyoming, that this population has one of the highest sage grouse densities in the State (Wyoming Game and Fish 2012).

The overall increase in the number of leks and total number of males may be attributed to an increase in sampling effort since 1990, rather than a dramatic population increase.

Although the average number of males per lek was higher in undisturbed areas compared to those that were disturbed, both showed the same pattern of fluctuations and tracked statewide trends. These results and the lack of decline to extirpation in disturbed leks suggests that the male sage grouse are more tolerant of this level of surface disturbance than expected. These results are significant because the NTT (2011) recommended a 3% disturbance threshold and 4-mile seasonal NSO based upon opinion rather than tests of their effectiveness, as performed in this study.

We found no evidence of a population decline or population extirpation in the PPA or Pinedale Anticline, as was predicted by Holloran (2005).

Although we found that some leks declined to zero during full-field development, such as within the Jonah field, we point out that the most discussed case in the Pinedale Anticline (Holloran 2005), can be attributed to the fact that stipulations designed to protect sage grouse from disturbance were purposefully waived at those affected leks for the purpose of research (i.e. to experimentally expose the leks to abandonment). This fact was not reported by Holloran (2005).

We rejected Hypothesis 1a (*The universally negative and typically severe impact* hypothesis), that was based on opinions expressed in the 2011 NTT Report that the effects of oil and gas development on sage grouse populations "*is universally negative and typically severe.*" There was no evidence of a population decline in the PPA despite 100 years of oil and gas development, (as well as agriculture, grazing, highways, and human habitation).

We were unable to reject Alternative Hypotheses 1b and 1c, although we acknowledge that more time may be needed to quantify the full effects of mitigation and less impactful technology tested by predictions of Hypothesis 1b (*The mitigated impacts hypothesis*). On the other hand, Alternative Hypothesis 1c (*The previously overestimated impacts hypothesis*) could not be rejected. It is apparent that sage grouse are more tolerant of these activities than previously thought.

And finally, we rejected Hypothesis 2 (*The 3% disturbance cap and 4-mile NSO hypothesis*). Sage grouse persisted and in some cases, increased in number in areas where surface disturbance exceeds a threshold of 3% within 4-miles of leks. The necessity of the 3% surface disturbance cap and 4-mile NSO restriction, which were based upon the opinion of NTT members, can now be retired from service and should not be relied upon in future state and federal regulations. In their place, it makes more sense to focus on local conditions and mitigating specific threats to sage grouse.

Limitations to the use and interpretation of male lek attendance data

Although male lek count data can provide an index of population trends, there are limitations to the inferences that can be drawn from those data. Statistical inference using these data is problematic because lek counts typically involve changes in sampling effort over time, a non-random sampling of leks, and females and juveniles are not counted (Walsh et al. 2004; WAFWA 2008; Ramey et al., in press). However, comparisons of changes in the average number of males per lek, and the distribution of leks sampled across the population, can provide a useful (albeit imperfect) index of population status over time. If these trends are compared to the synchronous trends found in other populations in the region, the potentially confounding influence of abiotic factors on estimated trends of short duration may be avoided (Fedy and Doherty 2010).

In addition to these issues, there are issues with how male lek count data have been interpreted in the past, when used to investigate human disturbance on sage grouse (and in particular, the effects of oil and gas development on sage grouse). For example, several previous studies of the effects of oil and gas development on sage grouse have relied upon comparisons of male lek attendance or lek persistence at disturbed versus undisturbed leks. If the number of males observed in disturbed leks was lower than the number in undisturbed leks, then it was assumed this would inevitably lead to a population decline. However, that approach ignores the fact that sage grouse can move between leks, and thus the measured difference in attendance may be simply due to avoidance behavior that is of no demographic consequence to the population. The only situation where this could be of demographic consequence would be if density-dependent effects were present (i.e. if habitat in the undisturbed areas was limited and overcrowding caused a reduction in survivorship and/or recruitment that was then detectable as a population-level decline). To date, no examples of density dependent effects resulting from human disturbance have been reported in the literature.

A similar issue to that above can occur if researchers track the fate of selected leks without taking into account trends in lek attendance and distribution across the population as a whole. In this situation, a decline in lek attendance or the "disappearance" of one or more leks is sometimes interpreted as evidence of a population decline, when the alternative hypothesis, that the birds simply shifted their use to other leks in the population, was not considered. As noted earlier, lek use can shift over time in response to changes in human activity and development, or due to natural factors such as changes in vegetation or patterns of predation. However, if there was no corresponding decline in overall numbers across the population, then there is no basis for concluding that a population decline had in fact occurred.

One of the most difficult misconceptions to overcome in the study of sage grouse is the belief that sage grouse are tied to specific leks, and therefore, a change in attendance at an individual lek indicates a loss or gain of individuals to the population as a whole. While research has shown that sage grouse may have an affinity for particular lek(s), this is by no means absolute. Simply put, sage grouse are not sessile animals, like barnacles on a reef. They can easily move among leks (Bush et al. 2010) and among populations and use non-traditional habitat to make these movements (Harju et al. 2013). It is because of their efficient flight (Drovetski 1996) that sage grouse are capable of dispersal among populations, including movements of over 75 miles (120 km) for females and 186 miles (300 km) for males (Bush 2009; Bush et al. 2011; Tack et al. 2012). These and other studies have also documented sage grouse dispersal and migration over or around developed areas such as: roads, transmission lines, agricultural areas, and oil and gas development (Lyon 2000; Bush 2009; Bush et al. 2011; Tack et al. 2012; Thompson 2012; Harju et al. 2013).

The examples above illustrate how focusing on comparative lek counts, without taking in the bigger picture of what is occurring in trends across the population, can lead to erroneous conclusions. In addition, rules and regulations that are based on those conclusions may be specious and result in operational constraints that may not actually benefit sage grouse. These are pitfalls that we assiduously sought to avoid.

The most substantial mitigation efforts have been recent

As noted in the introduction, intensive mitigation efforts for sage grouse in the PPA accelerated in approximately 2005 with the Jonah Infill Project ROD, and accelerated in 2008 with implementation of the Pinedale RMP and Wyoming Governor's Executive Orders (State of Wyoming 2014). The most significant aspects of these efforts to sage grouse conservation (and the most easily quantified) was the designation of Core Population Areas by the State of Wyoming and Unavailable Areas (to oil and gas development) by the BLM, followed by voluntary enrollment in conservation easements (funded in large measure by the Jonah Interagency Mitigation and Reclamation Office's compensatory mitigation fund). Although these have been significant events in sage grouse conservation in Pinedale, in terms of acreage and protections implemented, there is no mention of them in primary publications regarding the impact of oil and gas development on sage grouse in the Pinedale area. This may be explained by the fact that three of the four primary studies conducted on the impact of oil and gas development on sage grouse in Pinedale concluded before these measures were implemented (Lyon 2000; Lyon and Anderson 2003; Holloran 2005). The fourth study (Holloran et al. 2010) only overlapped with implementation of the Jonah ROD by one field season (2006), and therefore, could not reasonably be expected to document its effect.

The life cycle of oil and gas wells is misunderstood

Many publications regarding the impact of oil and gas development on sage grouse rely on inaccurate assumptions about the tenure of disturbing activities associated with the life of an oil and gas well. In terms of potentially disturbing sage grouse, wells under development have the largest number of personnel on site, and the highest noise generated (from drilling, hydraulic fracturing, interim reclamation, and completion operations). Injection and producing wells have low levels of intermittent activity (for maintenance and monitoring), and inactive wells have zero, or near zero, levels of activity (except for one time plugging and reclamation activities). Therefore, oil and gas wells are not permanently disturbing features on the landscape as assumed in some analyses (i.e. Copeland et al. 2009, 2013). Wells have a life cycle, and the duration of oil and gas production is finite and generally assumed to be approximately 30 years. Therefore, their impacts as a source of disturbance to sage grouse cannot be expected to be permanent. After wells are plugged and abandoned, if reasonable and prudent restoration efforts are undertaken, surface disturbance impacts will be minimal and temporary.

Conclusion

In conclusion, it is worthwhile asking the question, *why has the impact of oil and gas development on sage grouse, based on the early Pinedale studies, been overestimated?*

We propose that there are four underlying causes. First, the majority of the one hundred year history of oil and gas development in the PPA was concentrated in three intensively developed fields, with extensive undeveloped areas of suitable habitat surrounding these fields. This has afforded refugia for sage grouse, if needed, during intense periods of development, including full-field development. Secondly, mitigation efforts have had a net positive effect on the sage grouse population by reducing the overall impact of oil and gas through reclamation, habitat improvement projects, strategically targeted conservation easements, and land set-asides (thus avoiding density dependent effects). They have also addressed specific threats and minimized activities that sage grouse avoid. Thirdly, there have been nearly simultaneous technological advances in oil and gas development and operations that have reduced or eliminated impacts to sage grouse, beginning with the widespread adoption of directional drilling around 2004. Because many of these technologies are not well known outside of the oil and gas industry (refer to Appendix A for a more detailed discussion), there is a tendency for some outdated perceptions to persist in scientific literature and resulting policy decisions . And finally, the primary studies from Pinedale, cited as the basis for many impacts, all predated the above-mentioned advances in mitigation, regulatory actions, and more efficient technology. While those studies may have been pertinent at the time they were conducted, they are now outdated and superseded by new information.

Literature cited

AECOM. 2013. Base Case 2015 Emission Inventory Report for the Pinedale Anticline Record of Decision Milestone #3 Visibility Goal. AECOM, Fort Collins, Colorado. 98 pages.

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

Arthur, D. and D. Cornue. 2010. Technologies Reduce Pad Size, Waste. *The American Oil & Gas Reporter*. August 2010. 4pp.

BLM. 2000. Record of Decision for the Pinedale Anticline Oil & Gas Exploration and Development Project. Available at http://www.blm.gov/wy/st/en/info/NEPA/documents/pfo/anticline.htmlAccessed 24 January 2014.

BLM. 2005. Finding of No Significant Impact (FONSI) and Decision Record (DR) for Questar year-round drilling proposal – condensate pipeline modification (QYDP-CPM) EA #WY-100-EA05-283. Available at http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/qypd.Par.6340.File.dat/01dr_fonsi.pdf. Accessed 21 January 2014.

BLM. 2006a. Review of exploratory and production activity and operations. Wyoming State Office Reservoir Management Group. 85pp. Available at: http://www.blm.gov/pgdata/etc/medialib/blm/wy/programs/planning/rmps/pinedale/rfd.Par.68069.File.dat/02_Report.pdf Accessed 21 January 2014.

BLM. 2006b. Best management practices for fluid minerals. 28 pages. Available at http://www.blm.gov/bmp/technical info_pdfs_ppt_text/WO1_WildlifeMgmt_BMPs_Slideshow.pdf Accessed 4 February 2014.

BLM. 2006c. Jonah Drilling Infill Project. Available at http://www.blm.gov/wy/st/en/info/NEPA/documents/pfo/jonah.html Accessed 21 January 2014.

BLM 2008a. Pinedale Anticline Project Area Supplemental Environmental Impact Statement. Available at http://www.blm.gov/wy/st/en/field_offices/Pinedale/anticline.html Accessed 21 January 2014.

BLM 2008b. Pinedale Resource Management Plan Record of Decision. Available at http://www.blm.gov/wy/st/en/programs/Planning/rmps/pinedale/rod_armp.htmlAccessed 21 January 2014.

BLM. 2012. Anticline Electrification Project Phase I. Environmental Assessment, Finding of No Significant Impact (FONSI) and Decision Record (DR) Available att. Environmental Assessment DOI-BLM-WY-100-2012-86-EA. Available at http://www.blm.gov/wy/st/en/info/news_room/2012/september/04pfo-papaelec.html Accessed 21 January 2014.

Blomberg, E.J. 2012. Population Ecology of Sage-grouse in the Great Basin: Predictable Patterns in a Variable Environment. Doctoral Dissertation, university of Nevada, Reno.

Bush, K. 2009. Genetic diversity and paternity analysis of endangered Canadian Greater Sage-Grouse (*Centrocercus urophasianus*). Ph.D. dissertation, University of Alberta, Edmonton, Alberta, Canada.

Bush, K.L., C.L. Aldridge, and J.E. Carpenter, et al. 2010. Birds of a feather do not always lek together: genetic diversity and kinship structure of greater sage-grouse (*Centrocercus urophasianus*) in Alberta. *The Auk* 127(2):343−353.

Bush, K.L., C.K. Dyte, B.J. Moynahan, C.L. Aldridge, H.S. Sauls, A.M. Battazzo, B.L. Walker, K.E. Doherty, J. Tack, J. Carlson, D. Eslinger, J. Nicholson, M.S. Boyce, D.E. Naugle, C.A. Paszkowski, and D.W. Coltman. 2011. Population structure and genetic diversity of greater sage-grouse (*Centrocercus urophasianus*) in fragmented landscapes at the northern edge of their range. *Conservation Genetics* 12:527–542.

Cartwright, J. and M. Huuse. 2005. 3D seismic technology: the geological 'Hubble'. *Basin Research* 17:1-20. Available at http://www.basins.utah.edu/Classes/SSS/pdfs/Cartwright and Huuse.pdf Accessed 27 January 2014.

Castro, S.A. 2007. A probabilistic approach to jointly integrate 3d/4d seismic, production data and geological information for building reservoir models. Unpublished doctoral dissertation. Stanford University. https://pangea.stanford.edu/ERE/pdf/pereports/PhD/Castro07.pdf Accessed 2 February 2014.

Copeland, H.E., K.E. Doherty, D.E. Naugle, A. Pocewicz, 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

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(6): e67261. doi:10.1371/journal.pone.0067261

Davis, C. 2013. Ultra Turns on Mojo, Reduces Pinedale Well Costs 14%. Shale Daily. November 6, 2013. Available at http://www.naturalgasintel.com/articles/96327-ultra-turns-on-mojo-reduces-pinedale-well-costs-14 Accessed February 2, 2014.

Drovetski, S.V. 1996. Influence of the trailing-edge notch on flight performance of Galliforms. *The Auk* 113(4):802-810.

DTC Energy Group. 2013. Bakken 5-year drilling and completion trends. DTC Energy Group, October 10, 2013. Available at http://dtcenergygroup.com/bakken-5-year-drilling-completion-trends/ Accessed 2 February 2014.

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* DOI 10.1007/s00442-010-1768-0.

Guttery, M.R., D.K. Dahlgren, T.A. Messmer, J.W. Connelly, K.P. Reese, et al. (2013) Effects of landscape-scale environmental variation on greater sage-grouse chick survival. PLoS ONE 8(6): e65582. doi:10.1371/journal.pone.0065582

Han, G., L. Lemesany, F. DeLeon, and A.A. Azizov. 2013. Practical directional drilling techniques in Pinedale field, Wyoming to improve drilling performance. Conference Paper. SPE Unconventional Resources Conference Canada, 5-7 November, Calgary, Alberta, Canada. Society of Petroleum Engineers. ISBN 978-1-61399-293-7. Available at https://www.onepetro.org/conference-paper/SPE-167141-MSAccessed 21 January 2014.

Harju, S.M., C.V. Olson, M.R. Dzialak, J.P. Mudd, and 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

Hess, J.E. and J.L. Beck. 2012. Disturbance Factors Influencing Greater Sage-Grouse Lek Abandonment in North-Central Wyoming. *The Journal of Wildlife Management* 76(8):1625–1634; 2012; DOI: 10.1002/jwmg.417

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.

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.

Kneller, S.R., S.G. Zinke, R.W. McDermott, T.G. Graham, S.E. Shearer. 2006. Unlocking the potential of a tight gas sand giant: Pinedale Field, Wyoming. *The Mountain Geologist* 43(3):181-186.

Kreckel, K. 2011. Directional Drilling: The Key to the Smart Growth of Oil and Gas Development in the Rocky Mountain Region. Unpublished report prepared for the Wilderness Society. 56 pages.

Lyon, A.G. 2000. *The potential effects of natural gas development on sage grouse (Centrocercus urophasianus) near Pinedale, Wyoming.* M. S. Thesis, Laramie, Wyoming: Department of Zoology and Physiology, University of Wyoming.

Lyon, A.G. and S.H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. *Wildlife Society Bulletin* 31(2):486-491.

Lyon, A.G. and S.H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. *Wildlife Society Bulletin* 31(2):486-491

NTT (Sage-grouse National Technical Team). 2011. Report on National Greater Sage-Grouse Conservation Measures. Available at http://www.blm.gov/pgdata/etc/medialib/blm/co/programs/wildlifePar.73607.File.dat/GrSG Tech Team Report.pdf Accessed 21 January 2014

OGJ. 2007. Various technologies unlock Pinedale Anticline tight gas. *Oil & Gas Journal*. June 25, 2007. Available at http://www.ogj.com/articles/print/volume-105/issue-24/drilling-production/various-technologies-unlock-pinedale-anticline-tight-gas.html Accessed 30 January 2014.

Okafor, Z., R. Auflick, D. Parker, and S. Faulkner. 2009. Drilling performance improvements in the Pinedale Anticline: A case study of the applications of rotary steerable systems. American Association of Drilling Engineers, 2009 National Technical Conference & Exhibition, New Orleans, Louisiana. Manuscript no. AADE 2009NTCE-14-01. Available at http://www.slb.com/~/media/files/technical_papers/2009/09ntce1401.pdf Accessed 21 January 2014.

QEP. 2013. QEP Resources Reports First Quarter 2011 Production; Updates 2011 Production Guidance and Provides an Operations Update. QEP News Release. Available at http://ir.qepres.com/phoenix.zhtml?c=237732&p=irol-newsArticle_print&ID=1554110&highlight= Accessed 21 January 2014.

Ramey, R.R., L.M. Brown, and F. Blackgoat. 2011. Oil and gas development and greater sage grouse (*Centrocercus urophasianus*): a review of threats and mitigation measures. *The Journal of Energy and Development* 35(1):49-78.

Ramey, R.R., J.D. Wehausen, and L.M. Brown (in press) Peer review and information quality breakdown in an Endangered Species Act decision: the case of the greater sage grouse.

Seto, C. 2011. The Future of Natural Gas, Supplementary Paper SP 2.3, Role of Technology in Unconventional Gas Resources. Massachusetts Institute of Technology. ISBN (978-0-9828008-5-0). Available from: http://mitei.mit.edu/system/files/Supplementary_Paper_SP_2_3_Unconventional_Technology.pdf Accessed January 24, 2014.

Tack, J.D., D.E . Naugle, J.C. Carlson and P.J . Fargey. 2012. Greater sage-grouse *Centrocercus urophasianus* migration links the USA and Canada: a biological basis for international prairie conservation. *Oryx* 46(1):64-68.

Thompson, T.R. 2012. Dispersal ecology of greater sage-grouse in northwestern Colorado: evidence from demographic and genetic methods. Doctoral dissertation, University of Idaho.

USFWS (U.S. Fish and Wildlife Service). 2010. Endangered and Threatened Wildlife and Plants; 12-Month Findings for Petitions to List the Greater Sage-Grouse (*Centrocercus urophasianus*) as Threatened or Endangered. *The Federal Register* 75(55):13909-14014.

WAFWA (Western Association of Fish and Wildlife Agencies). 2008. Greater sage-grouse population trends: an analysis of lek count databases 1965-2007. Unpublished report by the Western Association of Fish and Wildlife Agencies, Sage- and Columbian Sharp-tailed Grouse Technical Committee, provided to K. E. Mayer, Chair, Bird Committee, Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

Walsh, D.P., G.C. White, T.E. Remington, and D.C. Bowden. 2004. Evaluation of the lek-count index for greater sage-grouse. *Wildlife Society Bulletin* 32(1):56-68.

Wyoming Game and Fish. 2012. Wyoming Sage-Grouse Population Trends 1995-2012. Unpublished presentation of analyses by Tom Christiansen, Wyoming Game and Fish, Sage-Grouse Program Coordinator, Cheyenne, Wyoming. 14pp.

State of Wyoming. 2014. Wyoming State Executive Orders. Available at: http://will.state.wy.us/sis/wydocs/execorders.html and http://wgfd.wyo.gov/web2011/wildlife-1000382.aspx. Accessed 1 December 2014.

Appendix 1.

Improvements in technology that reduce impacts to sage grouse

Improvements in drilling, completion, and production technologies have lessened potential impacts to sage grouse, and other species, by reducing the duration of potentially disruptive activities, surface disturbance, and noise. The most significant of these technologies has been directional drilling (directional wells that turn 90 degrees are also known as horizontal wells). This technology allows operators to access subsurface resources over a broad area (over a mile in some cases) using multiple wells per pad (up to 50), thereby reducing surface disturbance compared to multiple vertical wells drilled from separate pads (Arthur and Cornue 2010; BLM 2011; Ramey, Brown, and Blackgoat 2011; Seto 2011; Applegate and Owens 2014). This is a more efficient way to access the resource because most oil and gas fields are in horizontal strata that used to require many vertical wells to tap. The transition in 2004 from drilling predominantly vertical wells to directional wells represented a major shift in drilling efficiency and consequently less surface disturbance (i.e. more wells from fewer pads). Directional wells now account for virtually all of the wells drilled in the PPA.

More efficient technology has also resulted in shorter drilling and well completion times. While the averages we report show marked improvement (from spudding to completion), it should be noted that these completion times also include periods of inactivity at a well site due to interruptions from logistical and seasonal constraints. Therefore, actual drill and completion times (not including inactive periods), may provide a more accurate portrayal of the duration of potentially disturbing activities to sage grouse. For example, companies reported that drilling a well on the Pinedale Anticline (with an average depth of 13,000 feet) took an average of 65 days in 2002 and this decreased to 35 days by 2006 (OGJ 2007). By 2011 this had improved further, to an average of 14 days of drilling to depth, and in 2013, QEP Resources reported that they had achieved a well to depth time of 9.3 days, a new record (QEP 2013). Similar improvements in drilling and completion efficiency have been reported elsewhere (DTC Energy Group 2013). Overall, uninterrupted completion times have dropped from six months to as few as 2 to 3 days in 2013 (AECOM 2013).

Directional drilling of multiple wells from the same well pad has also led to a new type of operational efficiency, one that was not possible during the single-well-per-pad-era: the co-location of facilities and simultaneous operations on a single well pad. This means that site preparation, drilling, hydraulic fracturing, completion, and production can be simultaneously carried out on different wells drilled from the same well pad. This translates into less equipment moving on and off site, and less manpower required. Rig moves, that used to take 150 or more truck trips to move between pads, and are accomplished by skidding the rig to a nearby location on the same pad (Kreckel, 2011).

Other advancements in operational efficiency, with secondary benefits to sage grouse, have also been implemented in the PPA, both as voluntary and regulatory efforts. The most significant of these to sage grouse have included:

- Installation of a liquid gathering system designed to eliminate 165,000 truck trips per year (initiated in 2005 and completed in 2012; BLM 2005).

-Installation of remote telemetry systems to monitor wells and condensate tanks (initiated in 2008 and completed in 2012; BLM 2008b).

- Electrification of the Pinedale Anticline (BLM 2012), allowing equipment to be powered with electricity rather than internal combustion generators and motors. While this change was originally intended to reduce high levels of ozone accumulation in the PPA, it has the secondary benefit of reducing engine noise and truck traffic (needed to refuel and maintain internal combustion engines).

- Introduction of rotary steerable systems (RSS). These are a "steerable" downhole drilling apparatus that was introduced on the Pinedale Anticline in 2008 and its widespread adoption has led to dramatic decreases in drilling time (Okafor et al. 2009).

- Required use of EPA compliant Tier II diesel engines on drill rigs, with phase out into more efficient and Tier III and IV designs, all of which reduce noise (and pollutants) compared to non-compliant engines in use prior to 2006.

Collectively, these improvements in efficiency translate into reduced drilling time and completion times, and therefore, reduced disturbance to sage grouse and other species. Virtually all of the innovations above came *after* the primary studies were conducted at Pinedale (from 1997 to 2006).

Although the development of more efficient oil and gas development and production technology is mainly driven by economic considerations, the benefits to the environment are obvious: reduced drilling and completion time, which translates into less noise, less traffic, and less overall disturbance to wildlife.

Figure 1. Surface disturbance from oil and gas development, sage grouse lek attendance, and land use protections in the Pinedale Planning Area in 2012. Black lines indicate surface disturbance from roads, pads, and pipelines. Lek locations and male lek attendance are represented by red or green circles indicating whether the lek is in a disturbed (red) or undisturbed (green) area. The diameter of the circle represents male lek attendance (number of males) at each lek. "Disturbed" leks were defined as those exposed to 3% or more surface disturbance within a 4-mile radius of the lek. Areas exceeding this disturbance threshold are indicated in yellow. The upper right chart compares two different measures of oil and gas related disturbance: the yellow line indicates the cumulative area surrounding "disturbed" leks (that exceeds the 3% surface disturbance threshold within a 4-mile radius of a lek) and the actual measured surface disturbance (black line). The lower right chart compares changes in the average number of males in disturbed leks (red line) and undisturbed leks (green line), compared to the Pinedale population average (black line) and the Statewide average (dashed line). Land status as follows: conservation easements (pink) include private (as well as some local government, state, and federal lands having protected status, as per the National Conservation Easement Database), BLM "Unavailable Areas" (light blue), and Core Habitat (hatched area).

Results and significance: As surface disturbance has increased, male lek attendance has not decreased and has remained above statewide averages in the Pinedale Planning Area, contrary to predictions of population decline made by several previous authors (i.e. Lyon 2000; Lyon and Anderson 2003; Holloran 2005; Holloran et al. 2010) and the NTT Report. Male lek attendance at Pinedale has been consistently above the statewide average for the past 22 years. The fluctuations in male lek attendance are synchronous with other populations in Wyoming and appear to be independent of patterns of surface disturbance. These results are not consistent with the BLM NTT Report's assertion that oil and gas, *"impacts are universally negative and typically severe"* on sage grouse populations. Nor do these results indicate a necessity for a 3% disturbance cap or 4-mile NSO in order to prevent a population decline (NTT 2011). A total of 51.6% of Core Habitat is covered by additional protections from conservation easements and BLM areas unavailable to oil and gas development that overlap with it.

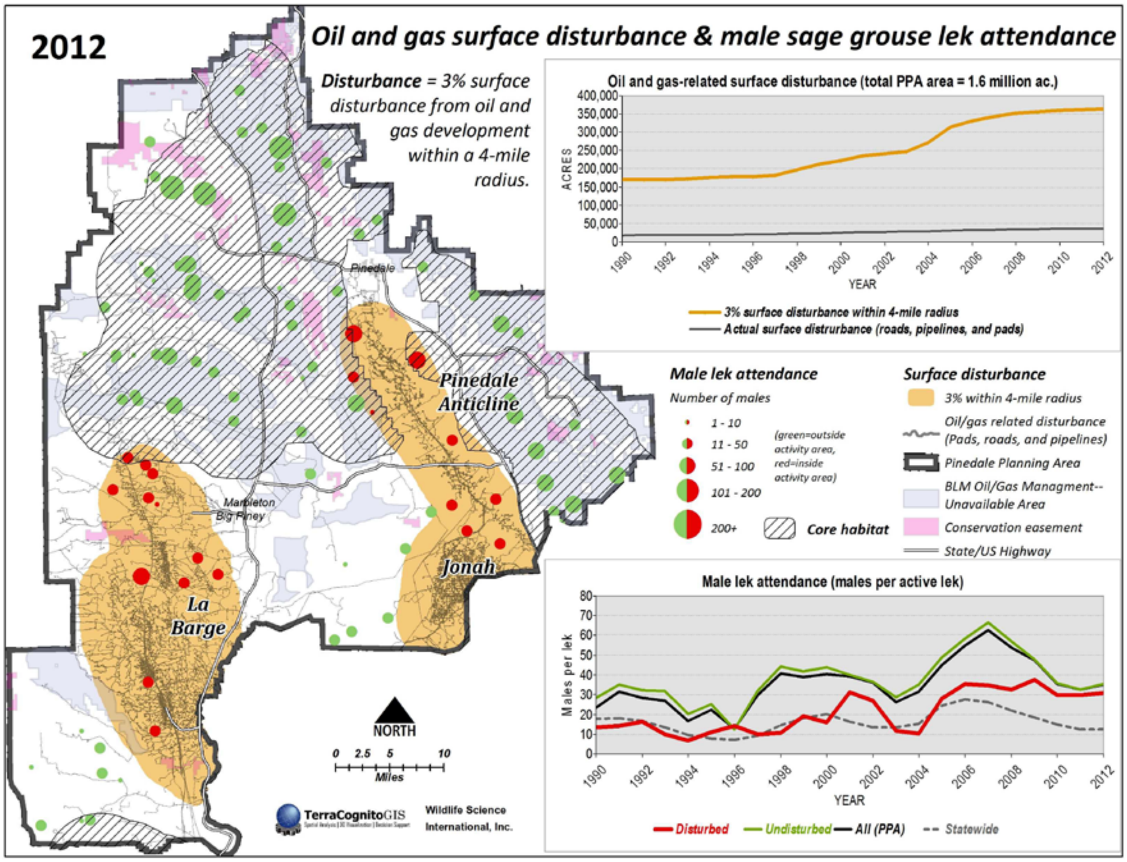

2012
Oil and gas surface disturbance & male sage grouse lek attendance
Disturbance = 3% surface disturbance from oil and gas development within a 4-mile radius.
Oil and gas-related surface disturbance (total PPA area = 1.6 million ac.)
ACRES
YEAR
3% surface disturbance within 4-mile radius
Actual surface distrurbance (roads, pipelines, and pads)
Pinedale
Pinedale Anticline
Marbleton
Big Piney
La Barge
Jonah
Male lek attendance
Number of males
1 - 10
11 - 50
51 - 100
101 - 200
200+
(green=outside activity area, red=inside activity area)
Core habitat
Surface disturbance
3% within 4-mile radius
Oil/gas related disturbance (Pads, roads, and pipelines)
Pinedale Planning Area
BLM Oil/Gas Managment--Unavailable Area
Conservation easement
State/US Highway
NORTH
0 2.5 5 10
Miles
TerraCognitoGIS
Wildlife Science International, Inc.
Male lek attendance (males per active lek)
Males per lek
YEAR
Disturbed
Undisturbed
All (PPA)
Statewide

Figure 2. Annual number of vertical and directional wells drilled by the oil and gas industry in the Pinedale Planning Area from 1973 to 2012. The annual number of traditional, vertical bore wells is indicated in red, and directional wells (including horizontal wells) are indicated in blue. The transition from predominantly vertical wells to directional wells took place in 2004. As of 2010, virtually all new wells drilled in the Pinedale Planning Area are directional wells.

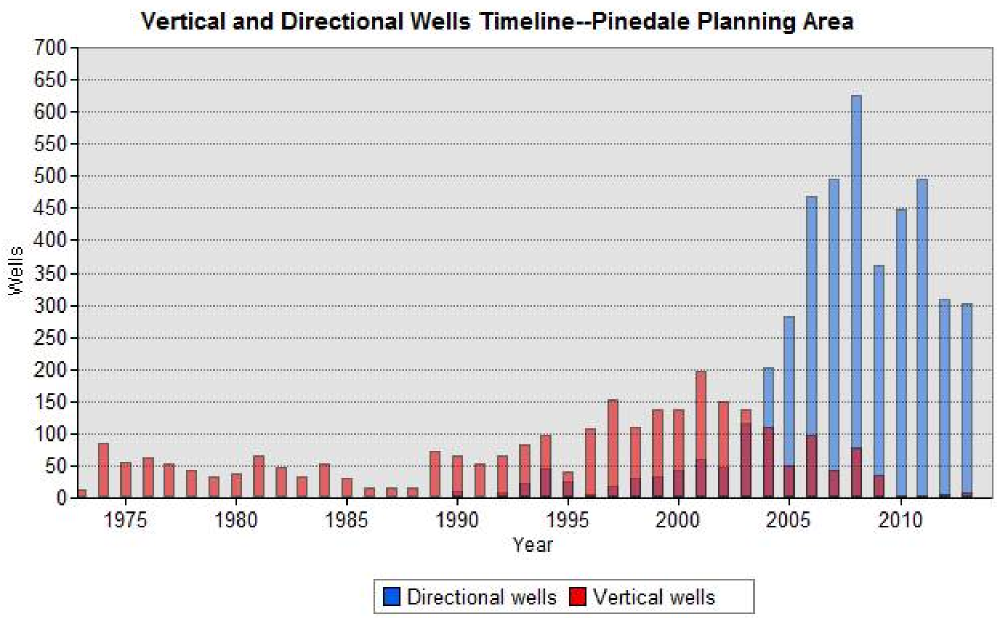


Figure 3. Increase in number of directional wells per pad in the Pinedale Planning Area, 1990 to 2012. The widespread adoption of directional drilling technology since 2004 has allowed for the proliferation of multiple wells per pad and therefore more efficient extraction of subsurface resources and elimination of the need for additional surface infrastructure, roads, pipeline, powerlines, and vehicle traffic. Currently the maximum number of wells drilled per one pad in the Pinedale Anticline is 50.

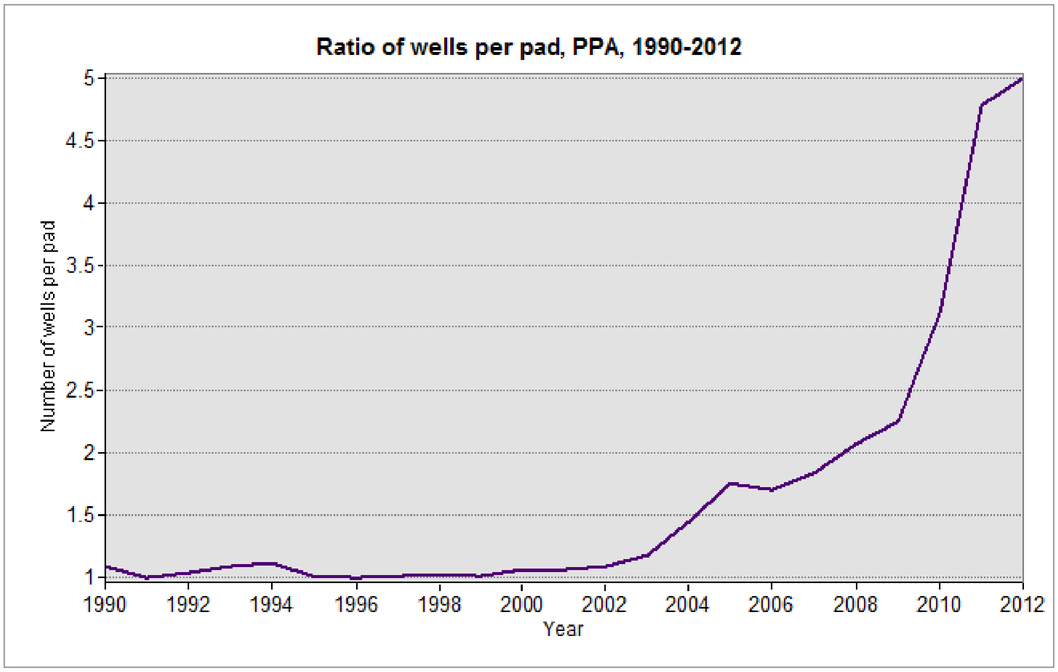


Figure 4. Satellite image with overlay of subsurface directional well bores in a portion of the Pinedale Anticline in 2012. Directional and horizontal wells are indicated in red. At the center of each cluster of well bores is the well pad. By comparison, if traditional vertical drilling was used to reach the same resources, the end point of each well bore would have required a separate pad (with a well spacing of 10 acres or less). That would have resulted is substantially greater surface impacts, similar to that to the early development of the Jonah field. The well spacing in this image is approximately one-pad per 160 acres.

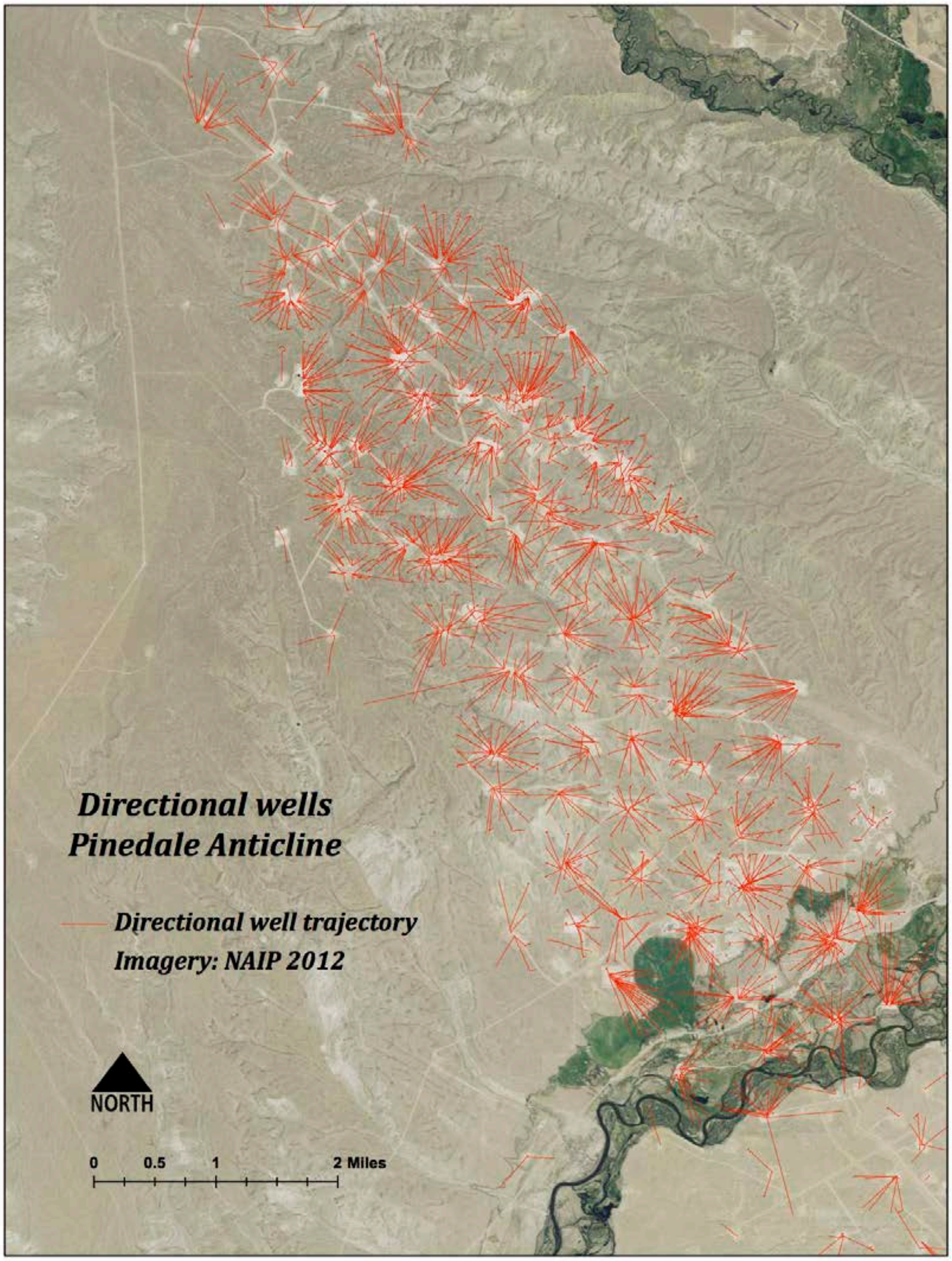


Figure 5. Male lek attendance expressed as the average maximum number of males per active lek in the Pinedale Planning Area from 1990 to 2012. "Disturbed" leks were those in areas that exceeded a 3% surface disturbance threshold within in a 4-mile moving window that encompassed the lek. A higher net gain in males per lek was found in disturbed leks (+17) versus undisturbed leks (+8). Fluctuations observed in the number of males attending leks are consistent with statewide and regional patterns, however, the magnitude of fluctuations are not as large in the disturbed leks. Recent authors have reported that periodic sage grouse population fluctuations are driven by variation in abiotic factors including precipitation and temperature (Fedy and Doherty 2010; Blomberg 2012; Guttery et al. 2013).

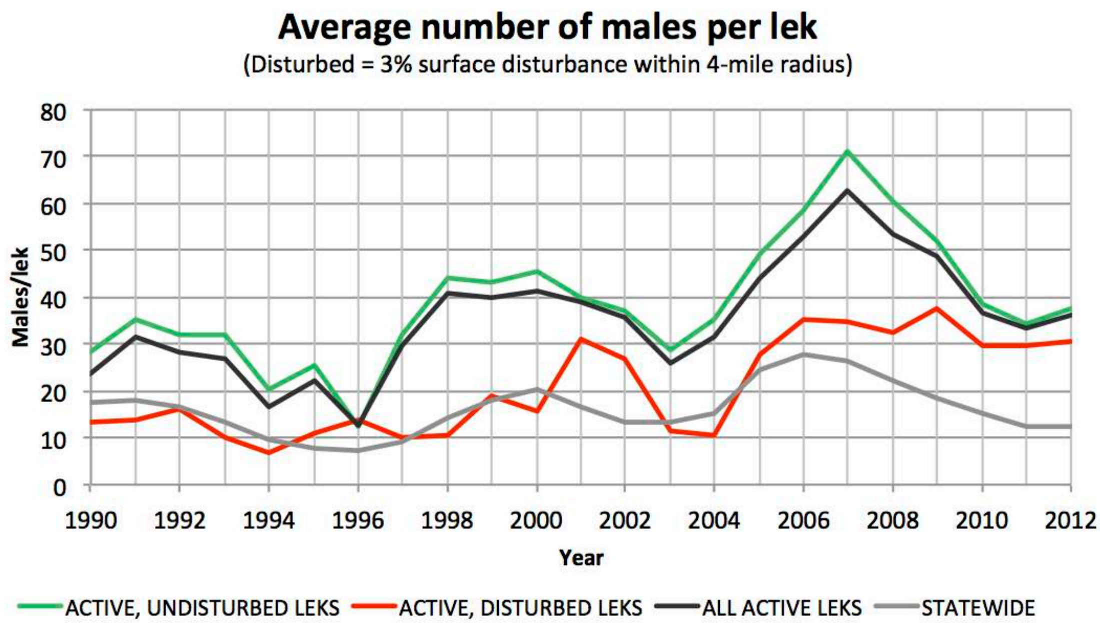


Figure 6. Number of active sage grouse leks counted by the State of Wyoming in "disturbed" and undisturbed areas of the Pinedale Planning Area from 1990 to 2012.

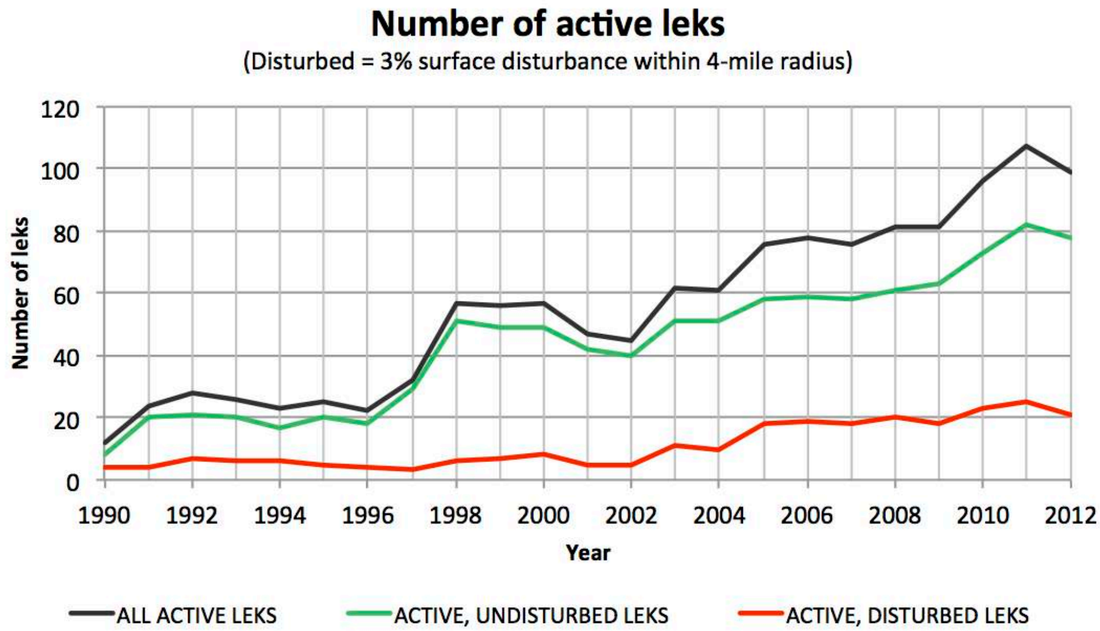
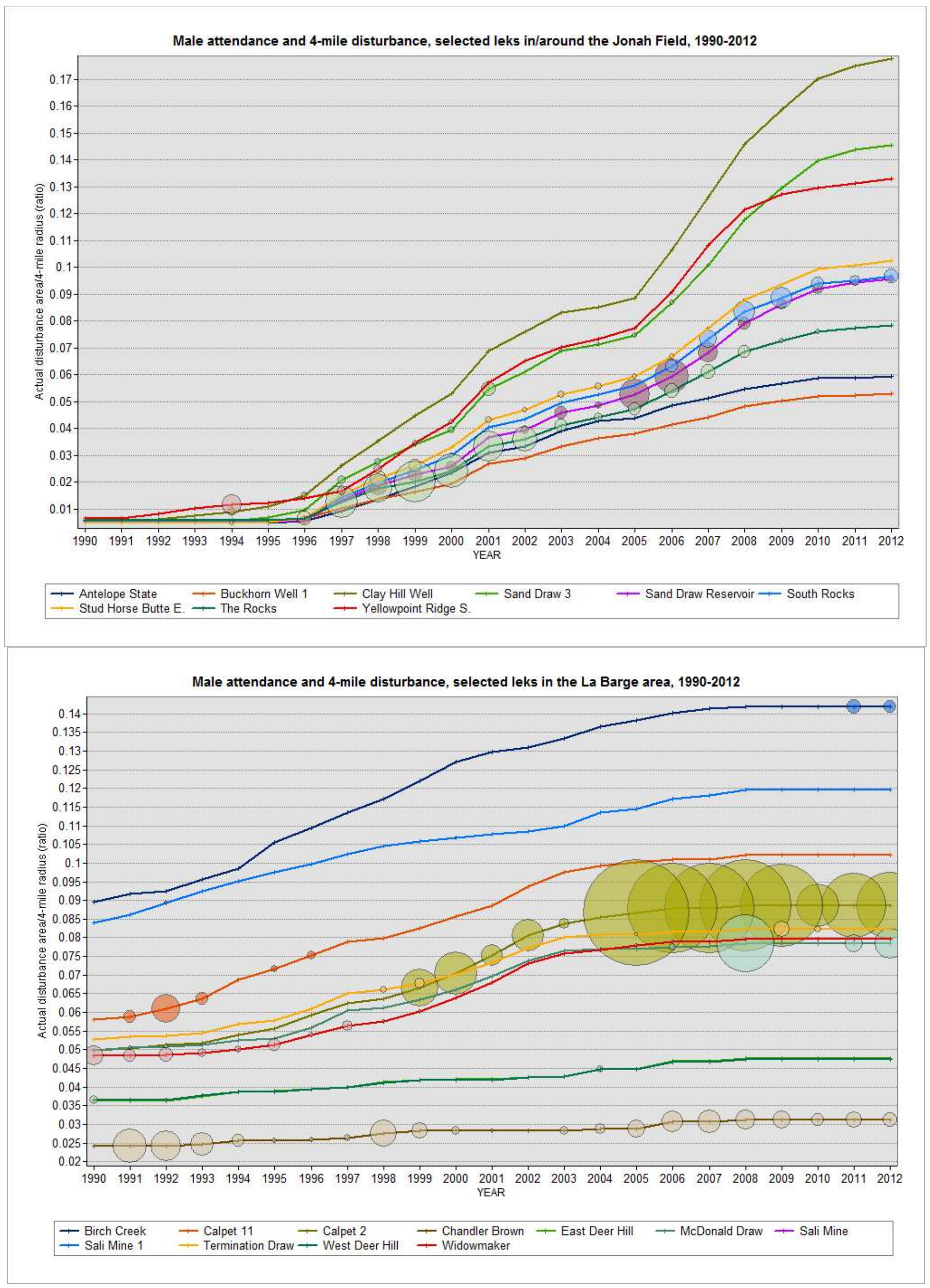


Figure 7. Trends male sage grouse lek attendance at selected leks in the Jonah (7a) and La Barge fields (7b) in response to increasing surface disturbance. The annual number of attending males at each lek is indicated by size of the circle and the fate of individual leks may be traced over time by following the colored lines. The vertical axis is the ratio of actual surface disturbance (including land in interim reclamation) to the area within a 4-mile radius (multiply by 100 to obtain percent surface disturbance). In both charts, there appears to a threshold of approximately 10% surface disturbance, although one lek in La barge became occupied after surface disturbance exceeded 14%. These results underscore the arbitrary nature of currently recommended surface disturbance thresholds.



Animation Captions

Animation 1. One hundred years of oil and gas well development activity in the Pinedale Planning area (1912 to 2012).

Description: Oil and gas development in the Pinedale Planning Area is concentrated over areas of oil and gas resources in three fields: La Barge, Jonah, and Pinedale. The phase of well activity for each year is indicated for developing (red), injecting (blue), producing (green), and suspended or abandoned (black) wells.

Results and significance: This concentrated pattern of development over 100 years, contrasts sharply with hypothetical build-out scenarios of Copeland et al. (2009, 2013). Those studies relied on the computer program "Random Forests" to project a hypothetical, random distribution of wells over potential oil and gas resources, whether or not access to those resources would be precluded by land use restrictions (i.e. BLM Unavailable Areas), mineral rights, or economic feasibility, thus overestimating impacts to sage grouse. The authors of these studies also assumed that the impacts of inactive wells (i.e. suspended, or plugged and abandoned) in their models were equivalent to impacts of active wells (i.e. that the impacts are permanent regardless of the life of the well). These two assumptions overestimate impacts to sage grouse because: 1) inactive wells are inanimate objects on the landscape, therefore, are an unlikely threat to sage grouse, 2) many of the early wildcat well pads have been naturally reclaimed and are now virtually indistinguishable from the surrounding landscape, and 3) the reclamation of well pads became a requirement across the Pinedale Planning Area since 2008, thus surface disturbance is not permanent.

Animation 2. Changes in surface disturbance from oil and gas development and sage grouse lek attendance in the Pinedale Planning Area from 1990 to 2012.

Description: In this animation, black lines indicate surface disturbance from roads, pads, and pipelines. Lek locations and male lek attendance are represented by red or green circles indicating whether the lek is in a disturbed (red) or undisturbed (green) area. The diameter of the circle represents male lek attendance (number of males) at each lek. "Disturbed" leks were defined as those exposed to 3% or more surface disturbance within a 4-mile radius of the lek. Land area exceeding this disturbance threshold is indicated in yellow. The upper right chart compares two different measures of oil and gas related disturbance: the yellow line indicates the cumulative area surrounding "disturbed" leks (that exceeds the 3% surface disturbance threshold within a 4-mile radius of a lek) and the actual measured surface disturbance (black line). The lower right chart compares changes in the average number of males in disturbed leks (red line) and undisturbed leks (green line), compared to the Pinedale population average (black line) and the Statewide average (purple line). Conservation easements (pink) include private land (as well as local government, state, and federal lands under special conservation status) as per the National Conservation Easement Database. Core habitat is indicated as areas with diagonal lines.

Results and significance: As surface disturbance has increased, male lek attendance has also increased in the Pinedale Planning Area, contrary to predictions of population decline made by several previous authors (i.e. Lyon 2000; Lyon and Anderson 2003; Holloran 2005; Holloran et al. 2010) and the NTT Report. Male lek attendance at Pinedale has been consistently above the statewide average for the past 22 years. The fluctuations in male lek attendance are synchronous with other populations in Wyoming and appear to be independent of patterns of surface disturbance. These results are not consistent with the BLM NTT Report's assertion that oil and gas, *"impacts are universally negative and typically severe"* on sage grouse populations. Nor do these results indicate a necessity for a 3% disturbance cap or 4-mile NSO in order to prevent a population decline (NTT 2011).

Animation 3. Changes in surface disturbance from oil and gas development and sage grouse lek attendance in the La barge/Big Piney area from 1990 to 2012.

Description: Legend is the same as in previous animations, except that a colored (blue-red) surface topography indicates the magnitude of annual changes in male lek attendance in clusters of nearby leks (red = increasing, blue = decreasing).

Results and significance: Note that lek attendance fluctuates on an annual basis among clusters of leks, even in undisturbed areas. This is consistent with observations that males are not tied to specific leks but shift use among lek locations. Sage grouse males continue to attend leks in the La barge field in significant numbers despite the area exceeding the 3% surface disturbance threshold.

Animation 4. Changes in surface disturbance from oil and gas development and sage grouse lek attendance in the Pinedale Anticline/Jonah area from 1990 to 2012.

Description: The legend is the same as in previous animations, except that a colored (blue-red) surface topography indicates the magnitude of annual changes in male lek attendance in clusters of nearby leks (red=increasing, blue=decreasing).

Results and significance: Note that lek attendance fluctuates on an annual basis among clusters of leks, even in undisturbed areas. This is consistent with observations that males are not tied to specific leks but shift use among lek locations. Sage grouse males continue to attend leks in the Pinedale Anticline field in significant numbers despite the area exceeding the 3% surface disturbance threshold. Sage grouse no longer attend leks within the Jonah field however use continues on its periphery and over a broad area outside the field.

Animation 5. Surface disturbance and reclamation in the Jonah field from 1990 to 2013.

Description: In this satellite image overlay, areas of surface disturbance are indicated in red (i.e. well pads), and areas undergoing reclamation are indicated in green. Charts on the right show the cumulative acreage of actual surface disturbance, reclamation, and net disturbance.

Results and significance: The Jonah Infill ROD required operators to mitigate surface disturbance and associated environmental impacts as quickly as possible, and awards credit on an acre-for-acre basis once the BLM determines areas have been successfully been reclaimed (i.e. rollover status). As of June 2013, none of the Jonah field reclamation had achieved rollover status. Data from the Jonah Infill Data Management System.