GREATER SAGE-GROUSE POPULATION TRENDS: AN ANALYSIS OF LEK COUNT DATABASES 1965-2015

Western Association of Fish and Wildlife Agencies, Cheyenne, WY

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Executive Summary - Counts of males attending leks in the spring have been the primary means employed by states to monitor status of greater sage-grouse (*Centrocercus urophansianus*) populations for over 75 years. Despite limitations and potential biases, lek count data remain the only long-term, range-wide dataset available for evaluating trends in sage-grouse populations. Using lek data provided by each state, we calculated the number of active leks, the average number of males per active lek each year, and modeled trends in male counts using a set of mixed-effects, Bayesian hierarchical models at range-wide, management zone, and state spatial scales for the 1965-2015 period. Trends within high population density core areas were compared to peripheral areas at range-wide and management zone scales. Trend estimates were also modeled at range-wide scales for the most recent 10-year period (2005-2015). Summary statistics on average males per lek indicate large variability in sage-grouse population size over time at all spatial and temporal scales. Our results support previous findings that have documented a long-term (1965-2015) decline of greater sage-grouse range-wide. The long-term (1965-2015) decline in average males per lek was estimated at 0.83% per year range-wide, and 2.7% and 0.5% for Management Zones I and II, and 0.70, 1.38, and 0.06% per year for Management Zones IV, V, and VI, respectively. Management Zone III showed an increasing trend in average males per lek of 0.19% per year. In 5 of 6 management zones, annual decreases were greatest in the periphery, and lower in core areas. This suggests that denser sage-grouse populations located within the core appear to be insulated more readily from population decline than those on the periphery. Modeling indicated positive trends in average males per lek since 1965 in Wyoming, Utah and Idaho, with negative trends in the 8 other sage-grouse states and declines greater than 1% per year in North Dakota, South Dakota, and Montana. The number of males counted on leks range-wide in 2015 (80,284) increased by 63% compared to the number counted in 2013 (43,397), the most recent trough. A minimum breeding population of 424,645 was estimated for 2015, which does not include grouse on unknown leks.

Introduction

The decline of greater sage-grouse (*Centrocercus urophansianus*) populations concerned naturalists at the turn of the century (Hornaday 1916) and has been a concern for biologists for nearly 30 years (Braun 1995, Connelly and Braun 1997, Aldridge and Brigham 2003, Schroeder et al. 2004). Some of the early concern has been reactive but most of the concern has been observed and documented through the loss of habitat and declines in abundance (Connelly and Braun 1997, Connelly et al. 2004). The primary approach to estimating abundance of greater sage-grouse has been by counting males when they attend strutting grounds (leks) in the spring (Connelly et al. 2003). Although this approach has been questioned because of the biased nature of data collection and the inference to population trends (Jenni and Hartzler 1978, Beck and Braun 1980, Walsh 2002) this is the primary data source available to monitor long-term trends of greater sage-grouse populations (Connelly et al. 2000, Connelly et al. 2003, Connelly et al. 2004). Standardized techniques for data collection were recommended by the Western Sage and Columbian Sharp-tailed Grouse Technical Committee (Technical Committee) under the auspices of their parent organization the Western Association of Fish and Wildlife Agencies (WAFWA). The WAFWA has signed at least 2 Memorandums of Understanding agreeing to collect trend data in a format that was recommended by the Technical Committee (Connelly et al. 2004, Stiver et al. 2006).

The United States Fish and Wildlife Service (USFWS) found greater sage-grouse warranted for protection under the Endangered Species Act in 2010, but that listing at that time was precluded by higher priorities (U.S. Fish and Wildlife Service 2010). A coalition of environmental groups sued the USFWS for failing to list greater sage-grouse and many other species. A settlement agreement was reached in 2011, under which the USFWS agreed to make a listing determination for greater sage-grouse by 30 September, 2015. As a result, the USFWS issued a data call (U.S. Fish and Wildlife Service 2014) for the most recent information on greater sage-grouse populations and habitat to assist in their listing decision. Although each state is providing information on populations and habitat, WAFWA agreed to update its prior analysis of trends based on lek counts at range-wide, management zone, and state scales. To date, three separate analyses of male-count trends have occurred through WAFWA. The first was provided by Connelly et al. 2004, the second by the Technical Committee in 2008, and this report represents the most recent analysis of male-count data from 1965–2015 for the aforementioned grouse population designations.

Methods

Because sage-grouse gather on traditional display areas (leks) each spring, biologists typically use counts of displaying males as an index to track changes in breeding populations (Connelly et al. 2003). A large number of leks are regularly monitored each year throughout North America, many state databases have >50 years of information, and most states have conducted extensive searches for new leks. All state wildlife agencies monitor sage-grouse breeding populations using data from leks, but methods for gathering these data vary somewhat among agencies and sometimes within agencies among years (Connelly et al. 2004). Lek databases were obtained from each state containing data on number of males counted through 2015. See Appendix I for a discussion on limitations of lek data and pertinent assumptions.

Lek data filtering

For the purposes of this analysis, we defined a lek as a display site at a specific geographic location at which 2 or more males were counted in 2 or more years during the assessment period (1965-2015). We assumed that if a state reported count data for a specific lek that those data were spatially associated with the location reported for that lek. However, in practice, the definition of a lek is more complicated. For example, a lek location can shift over time so that what is in effect the same lek can have 2 or more coordinates. Satellite leks can form near large leks during years with relatively high populations, and/or birds may use alternate display areas near leks, particularly if disturbance is common on the primary lek. Satellite and alternate lek locations may be considered independently in state databases, or may be combined under the primary lek count. In addition, observers may have considered multiple activity centers within a large lek as separate leks, all of which can affect count data reported for a specific lek location. To deal with these issues, we grouped spatially proximate leks using hierarchical clustering analysis (hclust function with complete method) in R (R Development Core Team 2015). Each lek was assigned to its own cluster and then the algorithm proceeds iteratively. At each stage, the two closest clusters are joined and the algorithm proceeds until there is just a single cluster. The distances between clusters were recomputed after each join by the Lance–Williams dissimilarity formula. Finally, we used cutree to separate clusters separated by greater than 1.2 km. Counts within these 1.2-km lek clusters were combined, and summed if they were counted in the same years.

State lek count databases are used to retain a variety of information about leks, and were not necessarily designed for this type of analysis so extensive filtering was necessary. Nevada, Oregon and Wyoming provided individual replicate count data for each year, other states provided peak count by year only. For Nevada, Oregon, and Wyoming datasets we attempted to standardize the data as much as possible by excluding data from: (1) counts conducted prior to 15 March or after 15 May; (2) counts conducted earlier than 0.5 hours before sunrise or later than

1.5 hours after sunrise (for Wyoming and Oregon only) (Braun 1995, Beck et al. 2003, Walsh et al. 2004); (3) entries without count data (e.g., “active”, “sign present”, “no count”, etc.) or entries with ambiguous data (counts where no attempt was made to separate males from females, counts with some males identified and others unknown were retained); (4) duplicate records (i.e., those with the same observer, date, time, and count); and (5) aerial counts, which are likely to have different detection probabilities than ground-based counts. Peak counts were then calculated by taking the maximum of individual counts by lek and year. We did not exclude data from leks counted only once in a season, as most state databases do not contain information as to the number of counts, and Fedy and Aldrich (2011) found that at large spatial scales including >50 leks the absence of repeated counts within a year did not significantly alter population trend estimates or interpretation.

Data excluded from peak-count lek databases included: (1) lek counts prior to 1965, (2) entries for leks with fewer than 2 males for 2 or more years; (3) aerial counts, and (4) some zero counts. Many states continue to count leks that are no longer active which creates long strings of zero counts that don’t contribute trend information. Consequently we excluded zero counts before calculating average males per active lek, and for the modeling effort we retained the first zero in any consecutive string of zeroes (to capture declining trends as counts go to zero and increasing trends from zero).

Duplicate entries of several types were encountered and resolved. Duplicates where all the same information was entered multiple times were identified and removed using the Excel remove duplicates feature. Some states group satellite and adjacent or nearby leks into lek complexes, and occasionally identical count information over a period of years was entered into 2 leks within a complex. These were identified by examining peak count data within complexes, and removed after confirming with state biologists that these were duplicate entries. Finally, count information for some leks near state borders is maintained in both state databases although usually with different lek names and slightly different locations. To identify these, we examined all 1.2-km lek clusters containing leks from more than one state, and looked for substantially similar count information over time. Because state databases differed in the amount of count information on these shared leks, they were combined by giving them a common lek ID and then taking the maximum count by year. Although several states had duplicate information on shared leks with different IDs (CO/WY – 1, MT/WY – 5, MT/ND - 2), this was most common between California and Nevada where 133 leks occurred in both state databases.

Leks with different names but the same reported location were resolved prior to analysis. We also attempted to obtain any missing lek locations, but deleted several leks for which this information could not be obtained. Blank values in the field containing number of males counted were assumed to be dates or years in which no count was conducted (and not zeroes). There were some cases where this field was blank, and other information such as date, time, and observer name indicated a count was likely conducted. State biologists were able to confirm these should have been zeroes. In some cases, counts were made over a relatively short time frame or not made in consecutive years. For instance, North Dakota conducted all lek counts only during the third week of April, but has used this approach for well over 30 years.

Analysis Methods

We evaluated population status of sage-grouse in two ways. First we provide summary statistics on number of active (with one or more males) leks counted over time at range-wide, management zone, and state spatial scales, and calculated the average number of males counted per lek over time at each scale. The premise behind these summary statistics is this; recent levels/trends should be considered in the context of historical trends; are “cyclic” lows and highs decreasing over time? Has the number of active leks decreased over time? Loss or degradation of existing habitat (decreased carrying capacity) should be reflected in a decline in average males per lek and a decrease in the number of active leks. In an attempt to deduce patterns in rate of population change from long-term lek counts, we developed models, described below and in Appendix II. Modeling was performed independently by Western Ecosystems Technology (WEST), an Environmental and Statistical Consulting firm based in Cheyenne, Wyoming.

Modeled Trend Analysis

Long-term trends in sage-grouse populations were estimated within the core area occupied by greater sage-grouse during the lekking season, the periphery (i.e., outside the core area), as well as the combined area (core + periphery; Fig. 1) within each management zone (Fig. 1). Core areas used were high population density areas that contained 75% of the average peak count from leks between 2010 and 2014. Leks were assigned to core or periphery based on information provided by the USFWS (Doherty, personal communication). Doherty et al. (2010) described the rationale behind the 75% core areas. Although methodology to define 75% cores has been refined, original cores depicted contained 75% of the population on just 27% of the overall range (Doherty et al. 2010).

Hierarchical models allow for modeling of trends specific to various geographic extents simultaneously. We developed a hierarchical model that followed individual leks through time and allowed trends at individual leks to inform estimates of trends within individual management zones and states. This approach reduced the potential bias that could result if larger leks tended to be monitored earlier (e.g., 1965–1980; larger lek = more males) and many smaller leks were only recently included in the monitoring efforts. This hierarchical modeling approach included both fixed and random effects and was similar to approaches used to estimate trends in Breeding Bird Survey data (Sauer and Link 2002, 2011; Thogmartin et al. 2004; Nielson et al. 2008) and data from large-scale monitoring efforts like the west-wide golden eagle survey (Millsap et al. 2013, Nielson et al. 2014). A complete description of this modeling approach and assumptions made is included in Appendix II.

Ninety percent credible intervals (CRIs) – essentially the Bayesian form of a confidence interval – were calculated for all estimates of trend. If a 90% CRI included 0.0, then we concluded there was no evidence of trend in the data.

Finally, we used the results from Bayesian hierarchical model (equation [1]) and equation (6) [see Appendix II] to estimate all possible 10-year trends (e.g., 1965 – 1975, 1966 – 1976, …, 2005 – 2015) for the core, periphery, and combined areas range-wide.

It should be noted that a true understanding of the trend in sage-grouse populations over time would require modeling both the change in the number of leks and the change in the average number of males on each lek. We have no information to model change in the number of leks. There are inherent potential biases associated with a model based on average males per lek; if the small sample of leks in early years were larger than average, trends based on following those leks through time could be higher (more positive) than if trends were based on a representative sample of small and large leks. If smaller leks drop out over time, the average males per lek will be based on the larger leks that persist and may lead to inflated trends. In addition, excluding some zero counts in the modeling could result in optimistic estimates of trends, but that potential effect has not been investigated. We view average males per lek as a strong indicator of the health of a sage-grouse population, which is likely highly related to, but not directly equivalent to, population performance. Consequently we urge caution when interpreting modeled trends; they may be more useful for relative comparisons across spatial scales and temporal periods than as absolute indicators of population status.

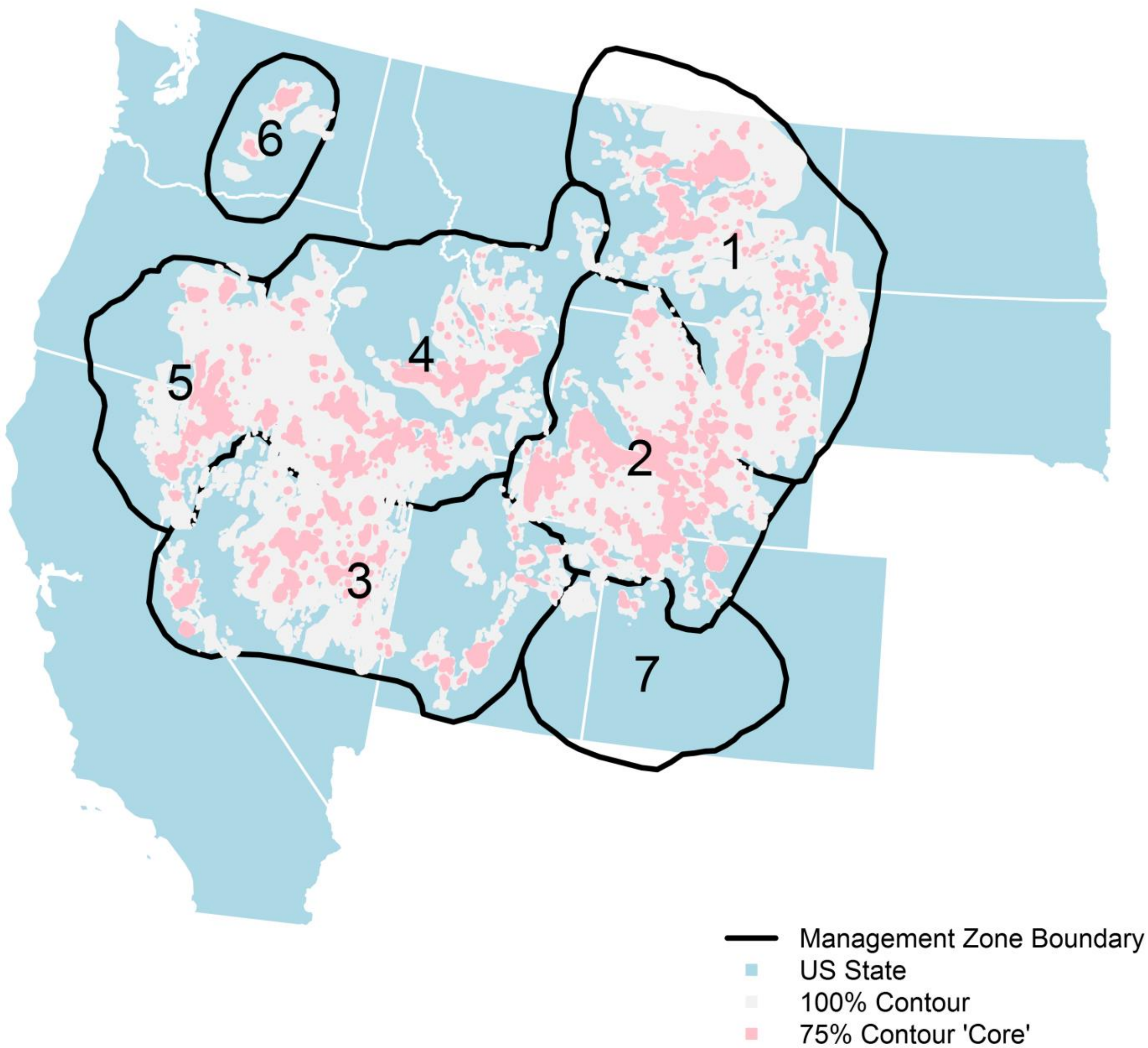


Figure 1. WAFWA sage-grouse management zones I (Great Plains), II (Wyoming Basins), III (Southern Great Basin), IV (Snake River Plain), V (Northern Great Basin), VI (Columbia Basin) and VII (Colorado Plateau) and 75% core areas around leks.

Results

Range-wide

Monitoring effort. The number of leks counted that met criteria for inclusion in the trend analysis increased markedly over the assessment period, from 267 in 1965 to 3,154 in 2015 (Fig. 1). This dramatic increase over time reflects increased efforts by state wildlife agencies and others in research, monitoring, and range-wide efforts to locate new leks as conservation concern over sage-grouse has grown.

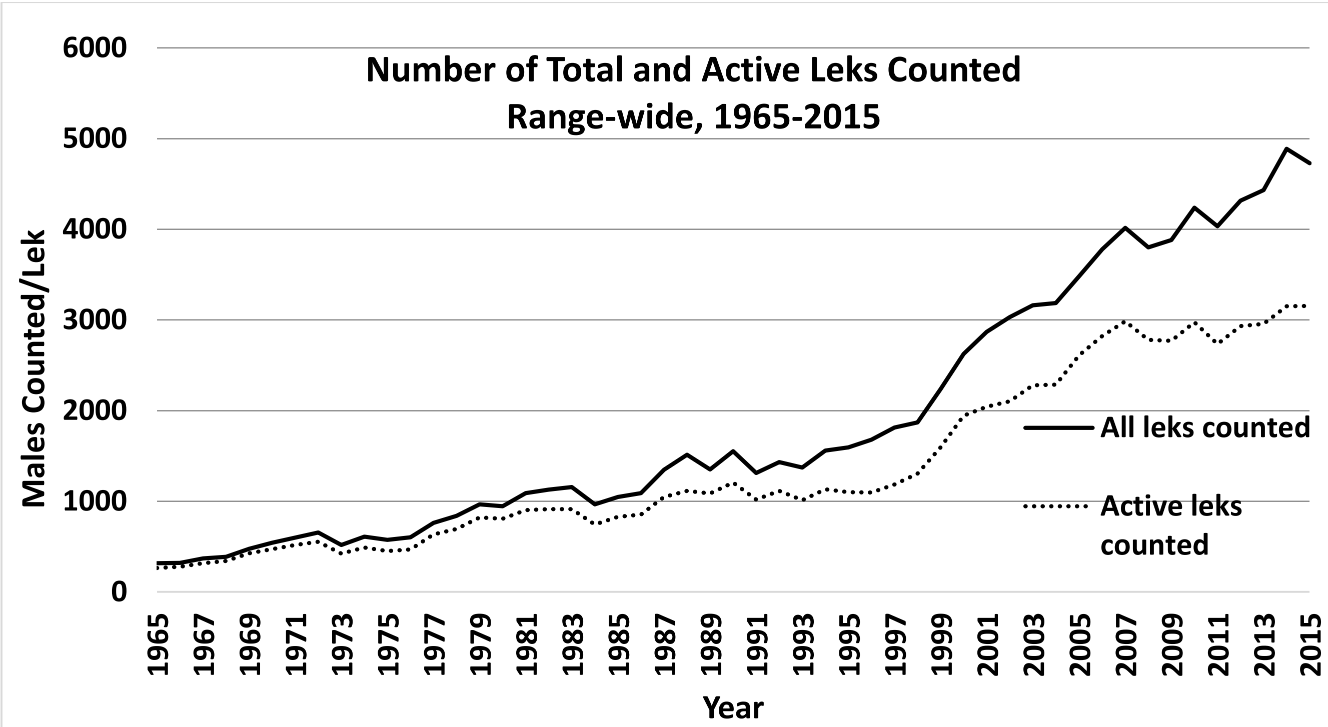
Lek-count trends. Average males per lek has varied over the 1965-2015 interval, reflecting both cyclic or cycle-like trends in roughly 6-11 year intervals as described by Fedy and Doherty (2011) for Wyoming, and a long term decline (Fig. 1). Confidence intervals around males per lek estimates are large in the early years, and have declined over time as sampling intensity has increased (Fig. 1). Consequently, confidence in average males per lek values in the early analysis period is low, particularly since confidence intervals would not reflect bias in sampling; if larger leks were chosen for the relatively few leks counted, the true value of average males per lek would fall below the 95% confidence interval.

The model for the long term trend analysis (1965-2015) indicated a decreasing trend in average males per lek range-wide of 0.83% per year (90% CI: –0.76 to –0.90, Fig. 3 and Table 1). Estimates of trend (percent change per year) in the peak number of males per lek in the core areas generally showed less of a decline from 1965–2015 compared to estimates for leks in the periphery (non-core) and thus all leks combined (Figure 3, Table 1). The estimated percent change per year in the average number of males per lek in the core areas was -0.09% (90% CRI from 0.02 to -0.20; Table 1) and not statistically different from 0. However, estimates of trends for leks in the periphery and all leks regardless of location were negative (Table 1). All combined 6,752 leks, regardless of core status, witnessed a significant average annual range-wide decline of -0.83% (-0.76% to -0.90%), with the 2,411 leks of the periphery driving much of that decline, with even greater annual declines of -1.23% (-1.09% to -1.39%).

The trend for the previous 10 years (2005-2015) was -0.07% per year (90% CRI from -0.29 to 0.15) for the core area (range-wide), -2.37% per year for the periphery (90% CRI from -2.89 to -1.87), and +0.78% per year for the combined area (90% CRI from 0.53 to 1.02). Estimates of all possible 10-year trends since 1965 for leks in the core areas ranged from -1.29 to 0.85. Estimates for leks in the periphery ranged widely from -8.23 to 7.74, and estimates for all leks regardless of location ranged from -4.36 to 2.64. These wide-ranges in trends indicate both variability in population trends and that short-term trends can be misleading.

Discussion. Although average males per lek declined significantly range-wide since peaking in 2006, the value they fell to at the lowest point in 2013 (16.7) was still above recent lows in 1995 (15.1) and 1996 (14.9), although below lows in 2002 (20.9) (Fig. 1). The peak in average males per lek in 2006 was the highest recorded since 1970, which was likely biased high. The number of active leks is a function of both sage-grouse population size and lek counting intensity. Although lek counting intensity (as measured by total number of leks counted, Fig. 1) continues to rise, an increasing portion of that effort appears directed at historic, inactive leks. There is no evidence that the number of active leks has declined recently (2,822 active leks in 2006 and 3,154 in 2015, Fig. 1).

At range-wide scales, core areas seem to be holding up well based on model results showing average males per lek trend estimates since 1965 that are not different than zero (stable). The most recent 10-year trend was increasing for all range-wide leks, stable for core leks, but negative for leks at the periphery.



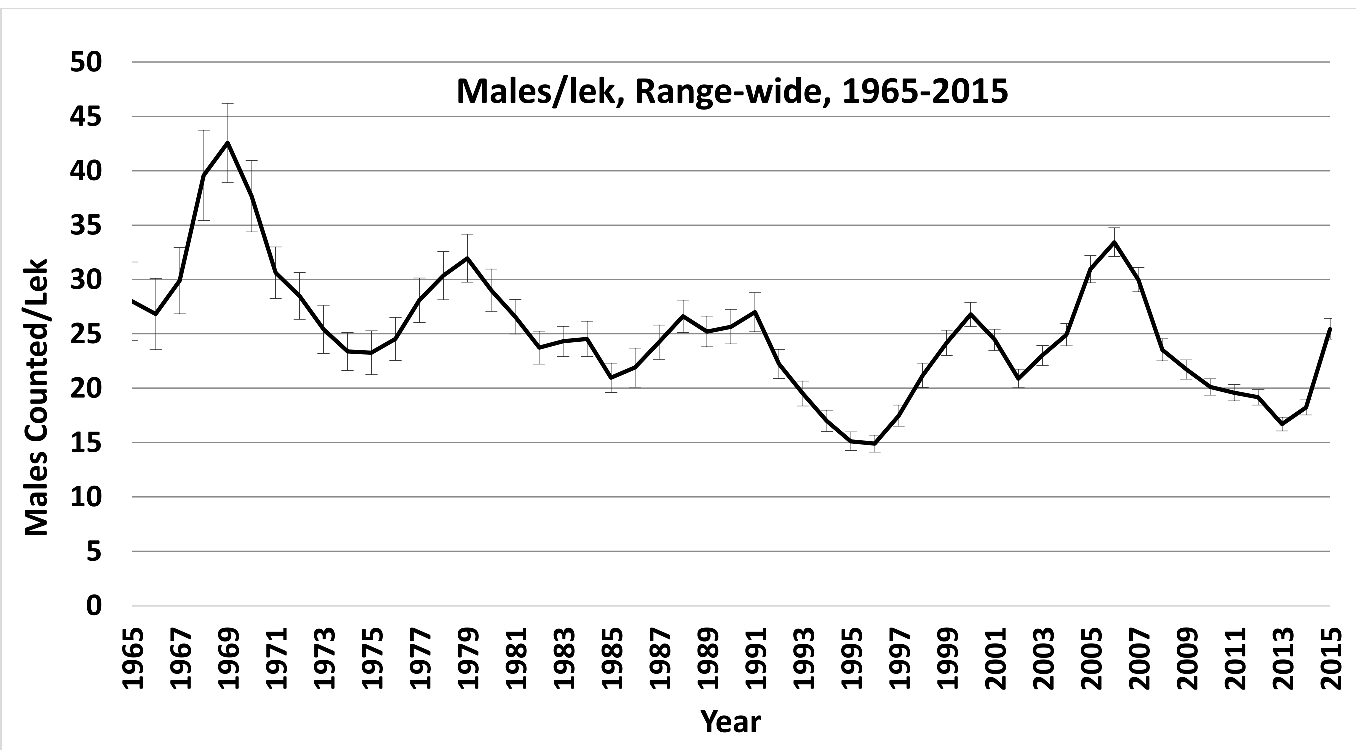


Figure 2. The number of total and active (1 or more males) leks counted, range-wide, 1965-2015 (top), and average number of males per lek, range-wide, 1965-2015 (bottom). Vertical bars represent 95% confidence intervals around the mean.

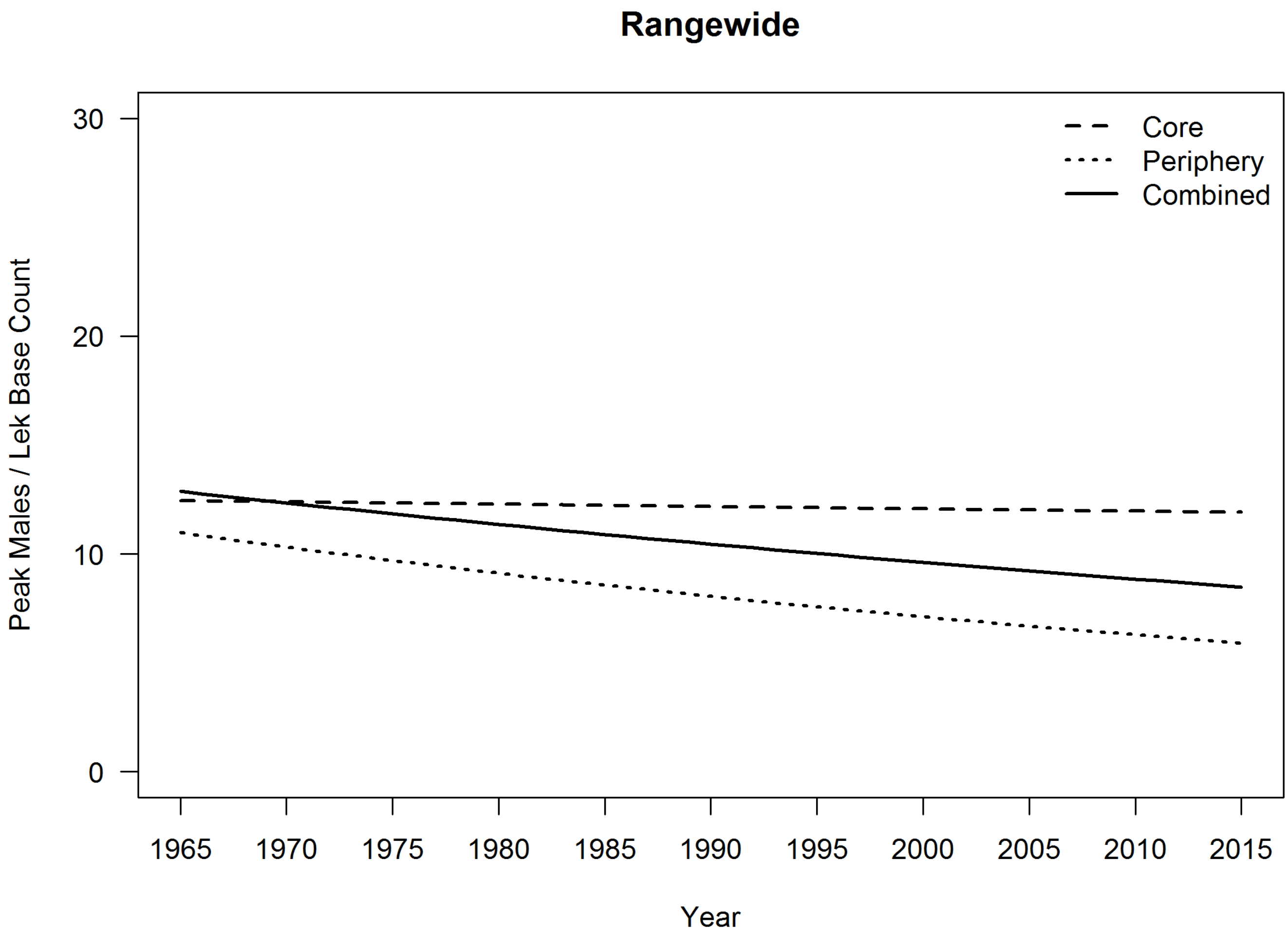


Figure 3. Trends in males per lek in core areas (containing 75% of males), peripheral areas, and combined areas, range-wide, 1965-2015.

Range-wide Population Estimate. There is considerable interest in estimating the current and historical population of sage-grouse at range-wide and other scales, and unsubstantiated estimates of 16 million historically have appeared in the popular media and even the Federal Register. The reality is, no scientifically defensible (estimates with defensible assumptions and bounded by confidence intervals) current or certainly historic estimate of population size is possible by extrapolation from lek counts, at least without marked individuals and a mark/resight

Table 1: Sample sizes (*N*; number of leks) and **e**stimates of trend (percent change per year) and 90% credible intervals for peak number of male sage-grouse on leks from 1965 to 2015 for individual WAFWA Management zones and U.S. States. Analyses based on Management zones focused on the all leks in the 75% core areas, periphery areas (non-core), and all leks, regardless of location within each zone. In addition, a weighted average of trends across management zones was calculated for an estimate of range-wide trends. Analyses based on state boundaries considered all leks identified in 1965 – 2015 within a state. Positive numbers indicate increases, while negative numbers indicate estimated declines. If a 90% credible interval does not contain 0.0, it is considered to be evidence of a statistically significant trend.

		Core		Periphery		All Combined	
Partition	Region	*N*	Estimated Annual % Change (90% Credible Interval)	*N*	Estimated Annual % Change (90% Credible Interval)	*N*	Estimated Annual % Change (90% Credible Interval)
Management Zone	1	877	-2.22 (-2.02 to -2.43)	657	-0.55 (-0.50 to -0.61)	1,534	-2.74 (-2.57 to -2.91)
	2 & 7	1,327	-0.40 (-0.25 to -0.54)	730	-1.09 (-0.95 to -1.22)	2,057	-0.53 (-0.45 to -0.60)
	3	464	+0.06 (0.00 to 0.10)	189	-1.90 (-1.55 to -2.25)	653	+0.19 (0.10 to 0.20)
	4	1,284	+0.98 (0.70 to 1.20)	668	-1.35 (-1.21 to -1.49)	1,952	-0.70 (-0.63 to -0.78)
	5	358	-0.91 (-0.54 to -1.28)	152	-1.69 (-1.22 to -2.17)	510	-1.38 (-1.05 to -1.72)
	6	31	+1.38 (0.50 to 2.30)	15	-2.82 (-0.95 to -4.46)	46	-0.06 (-0.04 to -0.09)
Range-wide		4,341	-0.09 (0.02 to -0.20)	2,411	-1.23 (-1.09 to -1.39)	6,752	-0.83 (-0.76 to -0.90)
State	CA					99	+0.08 (-0.06 to 0.20)
	CO					384	-0.51 (-0.34 to -0.68)
	ID					1,243	+0.91 (0.80 to 1.00)
	MT					1,126	-2.75 (-2.54 to -2.96)
	ND					39	-1.21 (-0.86 to -1.58)
	NV					946	-0.24 (-0.19 to -0.30)
	OR					490	-0.06 (-0.05 to -0.07)
	SD					43	-1.72 (-1.13 to -2.36)
	UT					395	+0.77 (0.60 to 1.00)
	WA					46	-0.06 (-0.03 to -0.09)
	WY					1,941	+0.30 (0.30 to 0.30)

approach (Walsh et al. 2010, Blomberg et al. 2013) or incorporation of demographic data from telemetry (Coates et al. 2014). It is possible to estimate minimum population size using assumptions that have measures of precision associated with them, and from that, and depending on one's comfort level, one can speculate about things that are not known (like proportion of unknown leks) and expand minimum population sizes to scenarios about total population size.

Range-wide, even 2 years from a "cyclic" low, states counted from the ground 80,254 males on 3,154 leks in 2015. An additional 5,390 males on 405 additional leks were either newly discovered in 2015 or counted from the air and excluded from this analysis, meaning a minimum of 85,674 males were counted in 2015 on 3,559 known leks. Few states (Colorado, Utah, North Dakota, South Dakota) attempt to count every known lek, and dual frame sampling approaches in Colorado suggest only 50-75% of leks are known. In states with large sage-grouse populations like Wyoming, Montana, Nevada, and Idaho, complete counts of known leks are not practical.

Walsh (2002) and Walsh et al. (2004, 2010) estimated the population of male sage-grouse in Middle Park, Colorado in 2001 using mark-resight approaches as 544 (370 adults and 174 yearlings), yet 14 counts throughout the season resulted in a maximum count of males of only 313 (57.5%). Using this correction factor, which is likely very conservative as they counted each lek 12-14 times and our database includes peak counts from leks typically counted 1-4 times per year, 148,998 males would be associated with known leks. Sex ratios of adult sage-grouse have been quantified from evaluation of wings obtained from hunters in the fall. Guttery et al. (2013) found 1.65 adult and yearling females per adult and yearling male from a single population in Utah, while Braun et al. (2015) found 1.65 and 2.10 breeding age females per breeding age male in 12 areas in Oregon and 10 in Colorado, respectively. Assuming that these fall ratios are reflective of sex ratios in the spring, using a weighted average of 1.85 females per male, extrapolating would yield 275,647 females, for a total of 424,645 breeding sage-grouse representing known leks in the spring of 2015. This is a reasonable deductive inference using assumptions that have been evaluated to some extent, but extrapolating from this minimum to adjust for known leks not counted or for unknown leks is perilous because we don't know what we don't know, and the proportion of unknown leks certainly varies widely from virtually zero in places like North and South Dakota to substantial in states with large sage-grouse populations over large areas like Wyoming, Montana, Idaho, and Nevada. Estimates of the number of unknown leks have not been published, and have been obtained only for 1 population in Colorado (49% of leks and 80% of males known; Lukacs pers. comm.).

Trends within Management Zones

WAFWA, in its 2006 Greater Sage-Grouse Comprehensive Conservation Strategy, established 7 sage-grouse management zones based on populations within floristic provinces (Fig. 1). This scale, below range-wide but larger than states, is the scale likely to be most useful to the Fish and Wildlife Service and is the scale where we focused our analyses. Management Zone VII was established primarily for Gunnison sage-grouse in southwest Colorado and adjoining portions of southeast Utah but included a small area of greater sage-grouse as well. Count data was available from 1-29 active leks in Management Zone VII since 1965, but sample sizes were not adequate for trend analysis so these data were combined into Management Zone II.

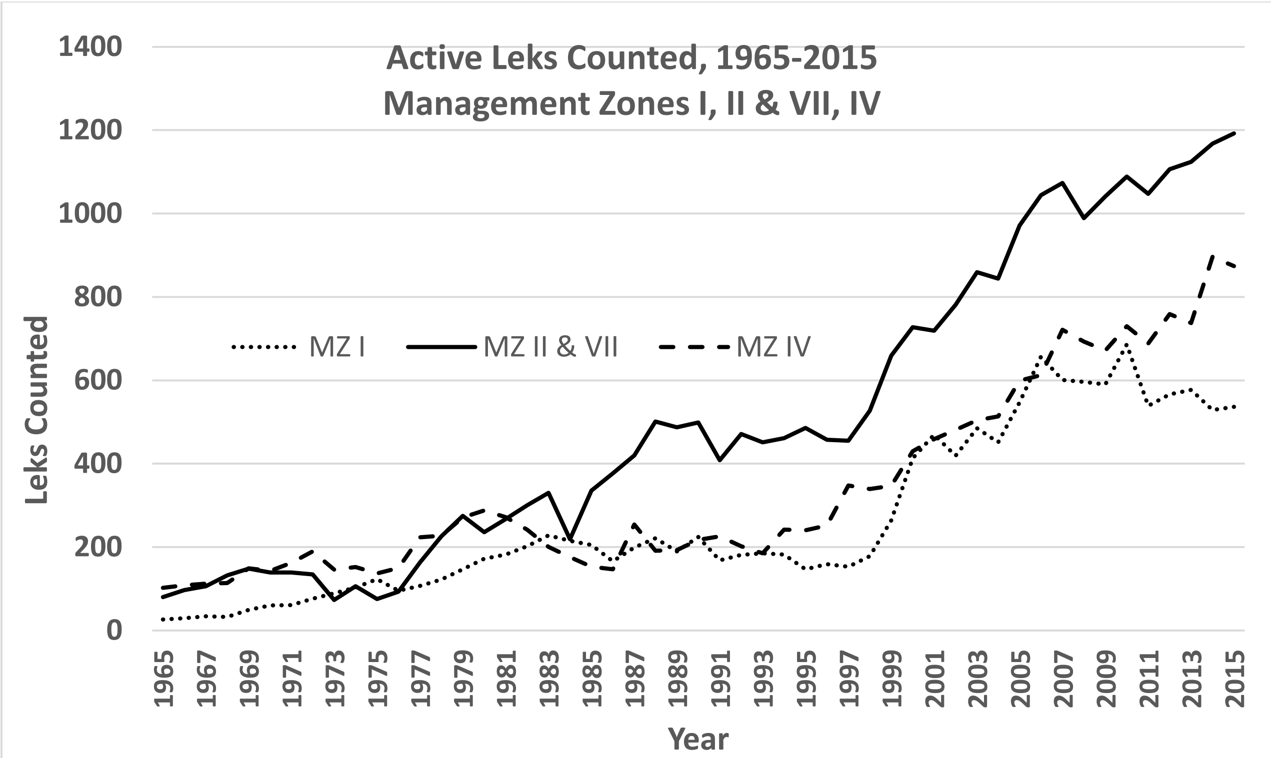
Management Zone I - Great Plains

Monitoring effort. Management Zone I accounted for 11.2% of all males counted from the ground in 2015. The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 26 in 1965 to a peak of 686 in 2010, then declined to 529 in 2014 and 536 in 2015 (Fig. 4).

Lek-count trends. Average males per lek in Management Zone I has varied over time, with peak counts averaging between 25 and 30 males per lek and troughs averaging about 14-20 males per lek (Fig. 5). A recent peak in 2006 of 26.6 males per lek was followed by a decline in subsequent years to a low in 2014 of 9.6 males per lek before rebounding sharply to 16.8 in 2015 (Fig. 5).

Modeled estimates of annual percent change in the average peak number of male sage-grouse in Management Zone I leks from 1965 to 2015 were -2.22% (90% CRI = -2.02 to -2.43) in the 75% core area, -0.55% in the periphery (non-core) (90% CRI = -0.50 to -0.61), and for all leks combined -2.74% (90% CRI = -2.57 to -2.91) (Fig. 6, Table 1).

Discussion. Declines in Management Zone I are concerning, for several reasons. The magnitude of the annual decrease (-2.74% overall, -2.22% core) is large, the rate of decline appears to be increasing in recent years (Fig. 5), "cyclic" lows and highs are below historical norms (Fig. 5), and there appears to be a declining trend in the number of active leks in recent years (Fig. 4). The 78% increase in number of males counted in 2015 compared to 2014 is encouraging, but the males per lek average of 16.8 is still well below 2015 levels in other Management Zones (II&VII - 33.9, III - 22.1, IV - 21.6, V - 20.9), and below the 1965-2015 average (19.2).



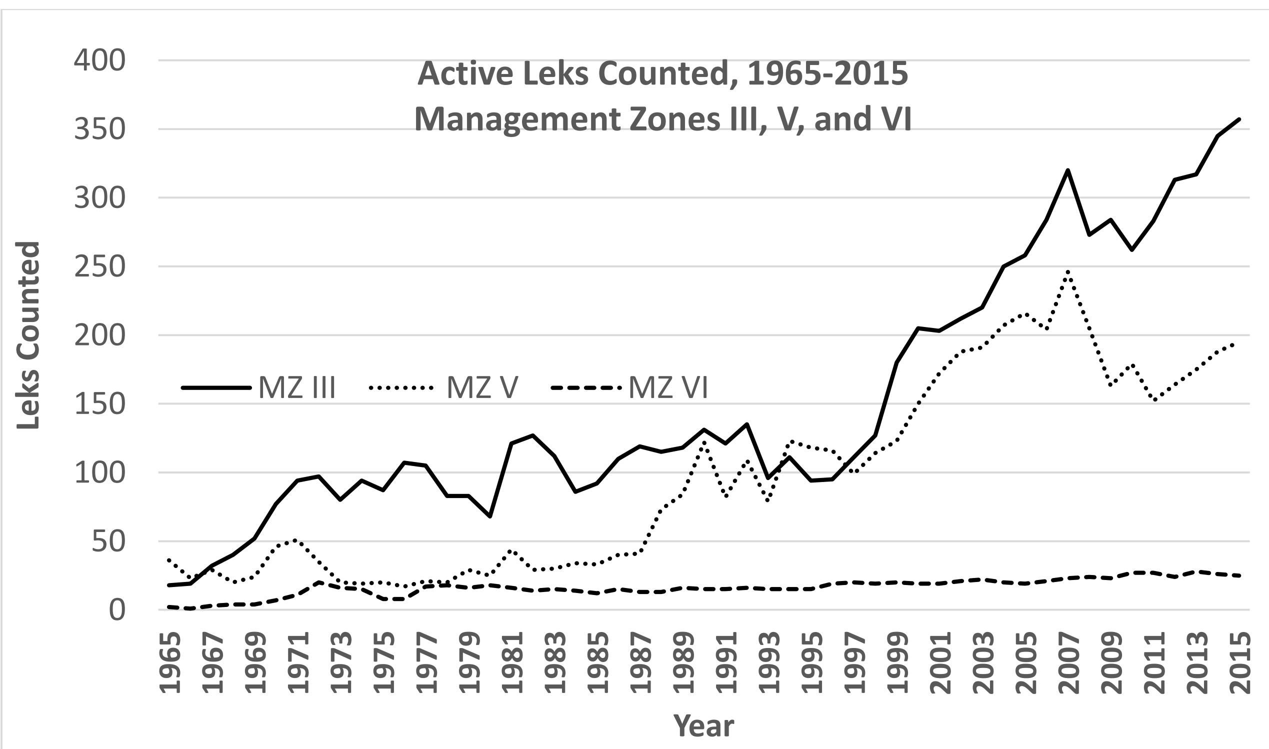


Figure 4. Number of active (1 or more males) leks counted in Management Zones I, II & VII, and IV (top), and Management Zones III, V, and VI (bottom), 1965-2015.

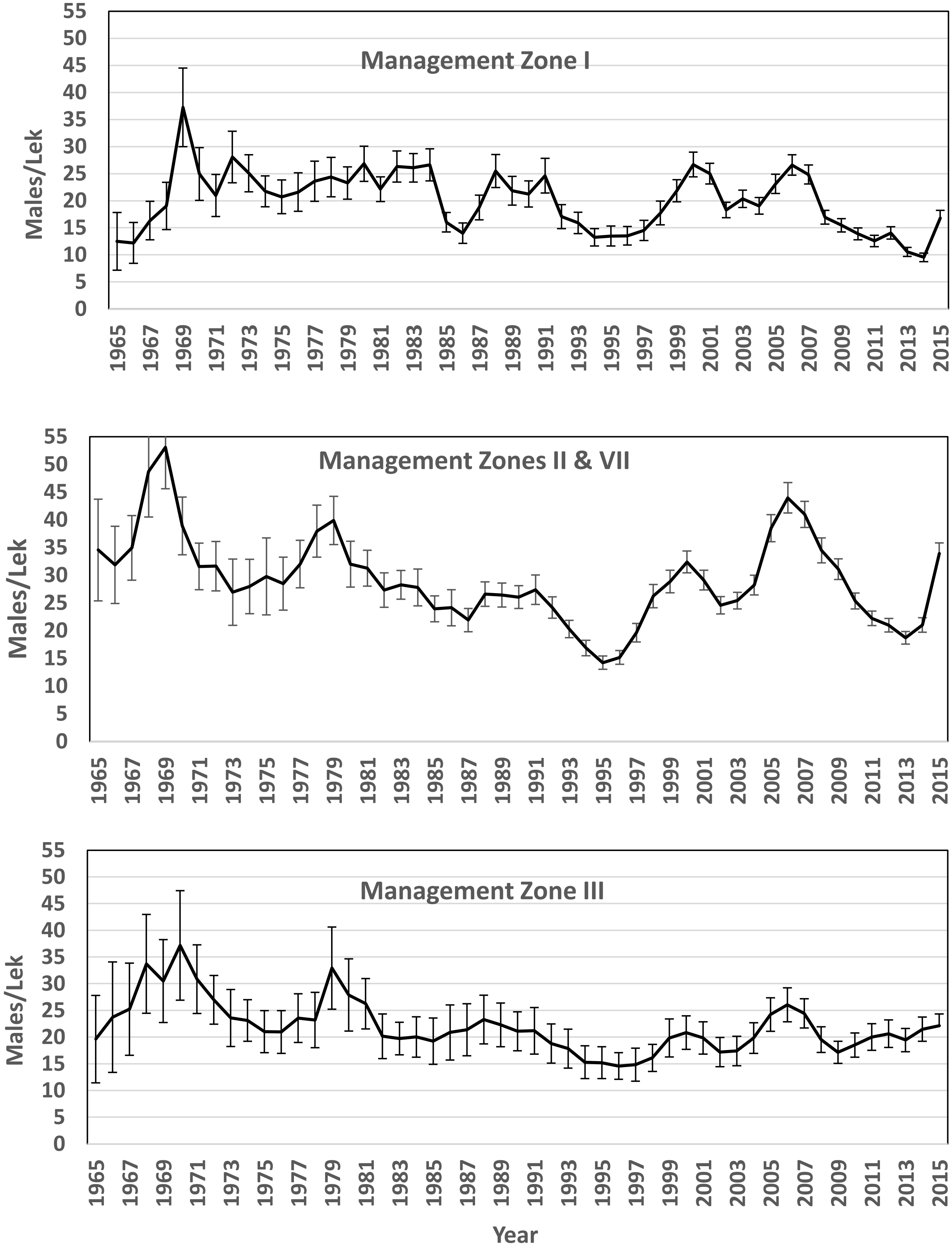


Figure 5. Mean number of males counted per active lek from 1965-2015 in Management Zones I, II & VII, and III. Vertical bars represent 95% confidence intervals around the mean.

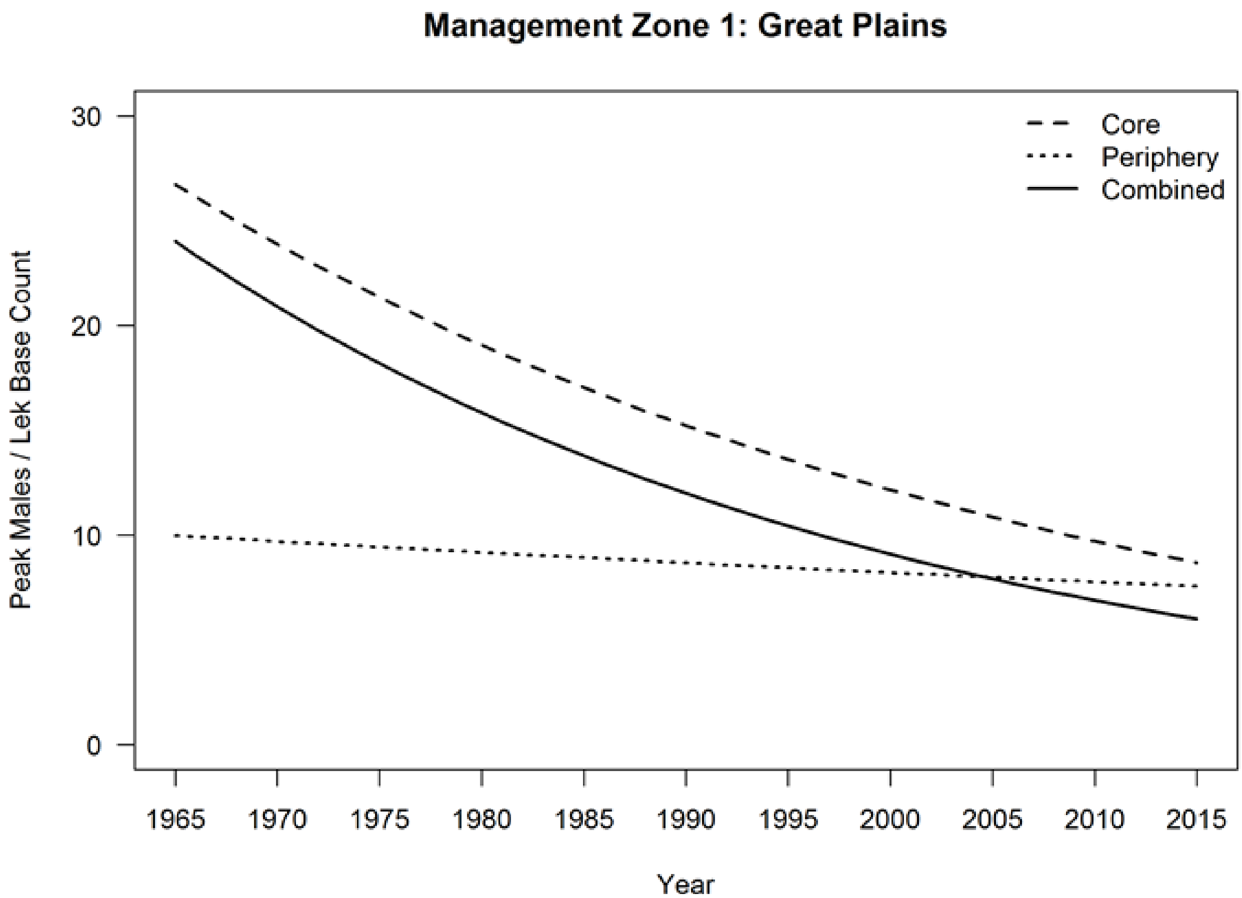


Figure 6. Estimated annual percent change in the average peak number of male sage-grouse on Management Zone I leks in the 75% core area (-2.22, 90% CRI=-2.02 to -2.43), periphery (non-core; -0.55%, 90% CRI=-0.50 to -0.61), and all leks combined (-2.74%, 90% CRI = -2.57 to -2.91).

Management Zone II and VII – Wyoming Basins and Colorado Plateau

Monitoring effort. Management Zone II and VII represented 50.4% (40,444/80,284) of males counted in 2015, virtually all of those in Management Zone II. The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period from 80 in 1965 to 1,192 in 2015 (Fig. 4).

Lek-count trends. Average males/lek in Management Zone II&VII experienced peaks in the late 1960s and late 1970s, with troughs in the mid-1970s and 1980s, before bottoming out in the mid-1990s (Fig. 5). Confidence intervals around the mean number of males are relatively large prior to the 1980s, and may not contain the true mean in earlier years. More recently, average males per lek had a peak of about 32 around 2000, a larger peak of 44 in 2006, followed by a steady decline to 18.7 in 2013 before increasing to 21.0 in 2014 and 33.9 in 2015 (Fig. 5).

Modeling of percent annual change in Management Zone II and VII indicated peripheral areas have declined from 1965 to 2015 at a rate of 1.1% per year, but that core areas have declined at less than half that rate (0.4%; Fig. 6, Table 1). Overall, average males per lek in Management Zones II and VII have declined at a rate of 0.53% since 1965.

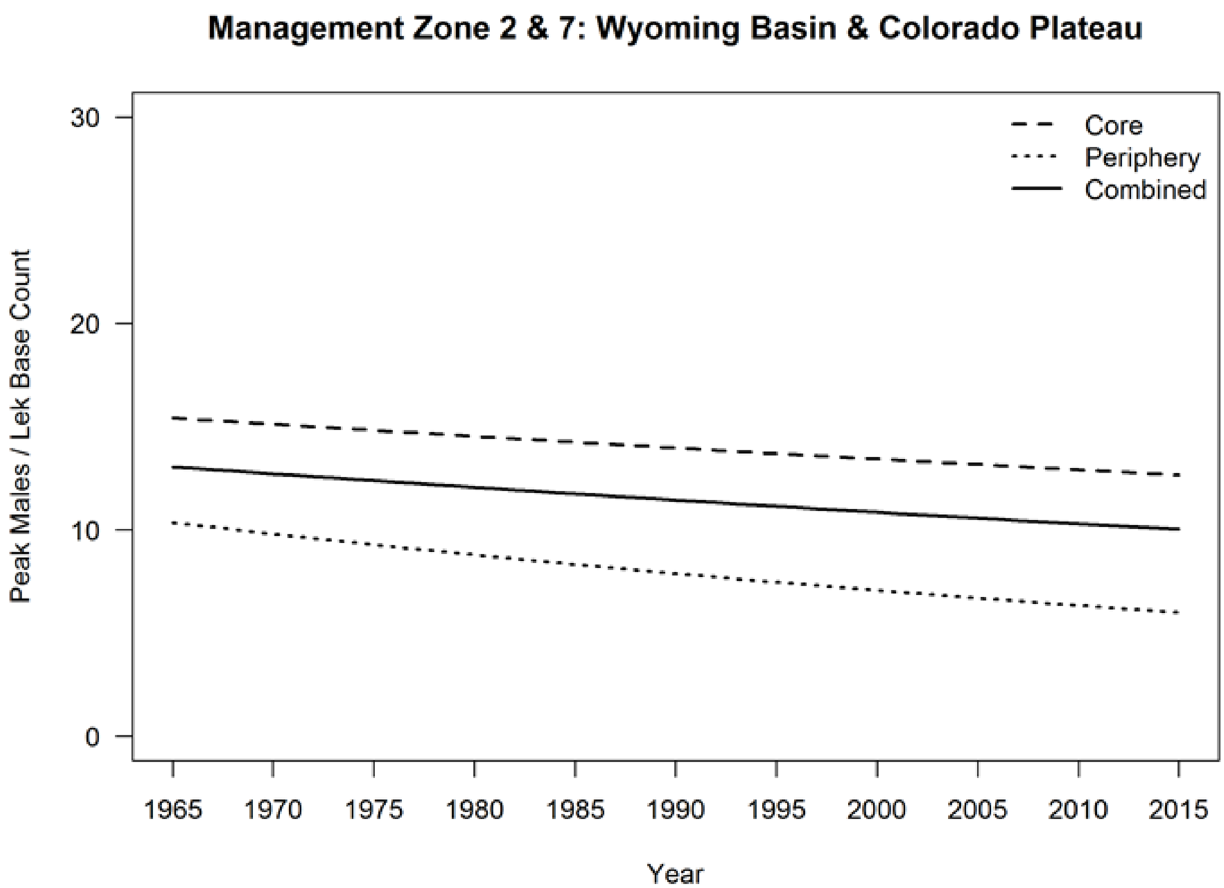


Figure 6. Estimated annual percent change in the average peak number of male sage-grouse on Management Zone II&VII leks in the 75% core area (-0.40, 90% CRI= - 0.25 to -0.54), periphery (non-core; -1.09, 90% CRI=-0.95 to -1.22), and all leks combined (-0.53, 90% CRI = - 0.45 to -0.60).

Discussion. Although average males per lek declined recently over a prolonged period (2006-2013), the bottom (19.1) was still above the lows experienced in 1995 (14.3) and 1996 (15.2) (Fig. 5). The 2006 peak (44.0 males/lek) was the highest since 1969. The number of active leks has been on an increasing trend since the peak in 2006 (Fig. 4).

Management Zone III - Southern Great Basin

Monitoring effort. Management Zone III accounted for 7,897 of 80,284 males counted in 2015 (9.8%). The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 18 in 1965 to 357 in 2015 (Fig. 4).

Lek-count trends. Average males per lek in Management Zone III showed large peaks around 1970 and 1979, and lower peaks between about 20 and 26 around 1988, 2000, and 2006 (Fig. 5). More recently, males per lek showed a trough of 17.1 in 2009, increased to about 20 in 2011-2013, before increasing to 21.5 in 2014 and 22.1 in 2015 (Fig. 5).

Modeling of percent annual change in Management Zone III indicated core and combined areas have increased from 1965 to 2015 at low levels (0.06%/year; 90% CRI 0.00 to 0.10 and 0.19%/year; 90% CRI 0.10 to 0.20, respectively), but peripheral areas have declined at a rate of 1.90%/year (90% CRI -1.55 to -2.25; Fig. 7, Table 1).

Discussion. Average males per lek declined after peaking in 2006, but the decline occurred earlier and to less of an extent than in other management zones. The bottom of 17.1 males per lek in 2009 was equal to the 2002 bottom, and above the 1996 low of 14.6. The peak in 2006 was the highest since 1979. Active leks declined from 2007 (320) to 2010 (262), but have increased steadily since to 357 in 2015. Models suggest stable to slightly increasing populations overall since 1965, with some decline in peripheral areas.

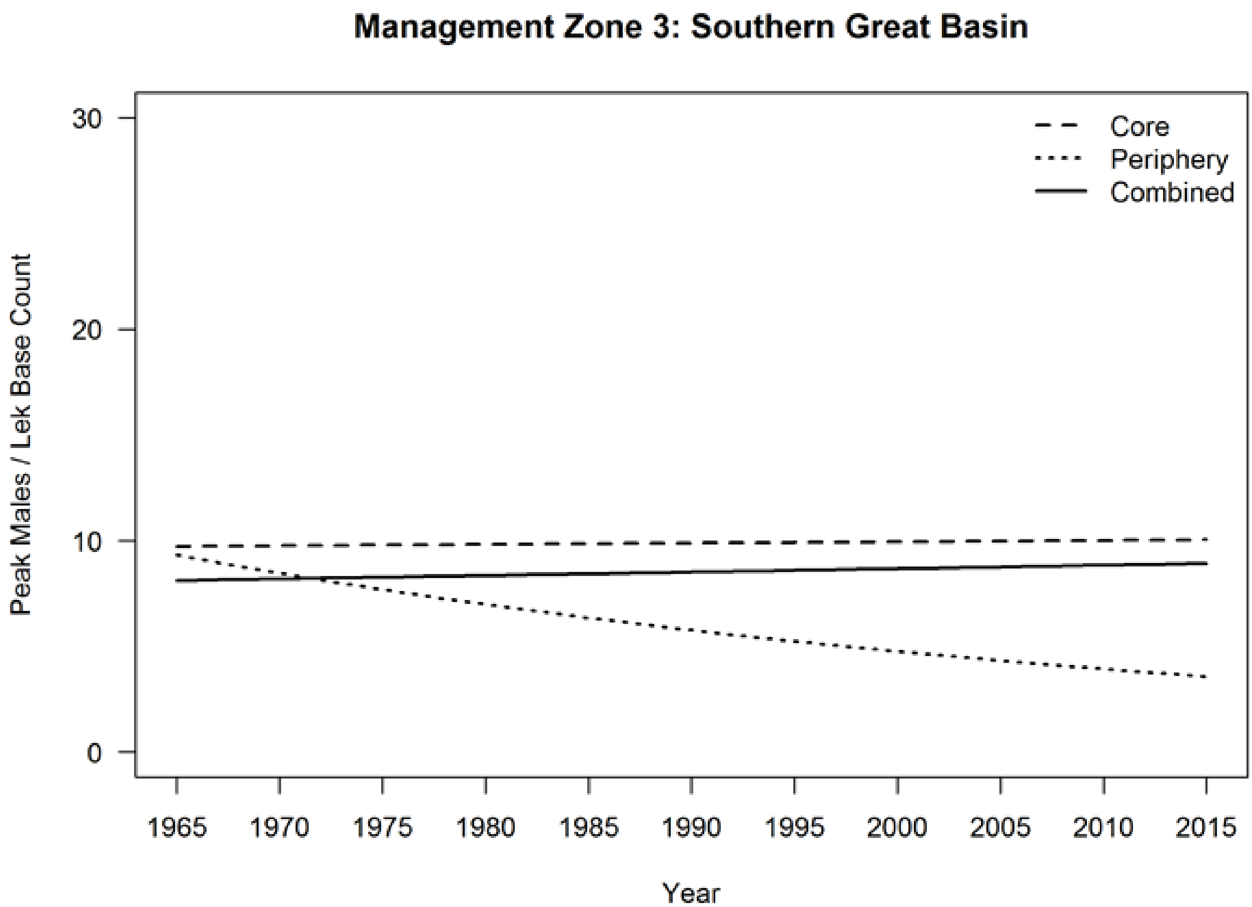


Figure 7. Estimated annual percent change in the average peak number of male sage-grouse on Management Zone III leks in the 75% core area (0.06; 90% CRI 0.00 to 0.10), periphery (non-core; -1.90 (90% CRI -1.55 to -2.25), and all leks combined (0.19; 90% CRI 0.10 to 0.20).

Management Zone IV - Snake River Plain

Monitoring effort. Management Zone IV represented 23.5% of males counted from the ground in 2015 (18,851/80,284). The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 102 in 1965 to a high of 896 in 2014 (Fig. 4).

Lek-count trends. Average males per lek in Management Zone IV increased from around 30 in 1965-1966 to a peak of 47.3 in 1970, then declined to a low of 23.2 in 1974 (Fig. 8). Since then, peaks of around 30 males per lek have followed in the late 1970s, and late 1980s, with a

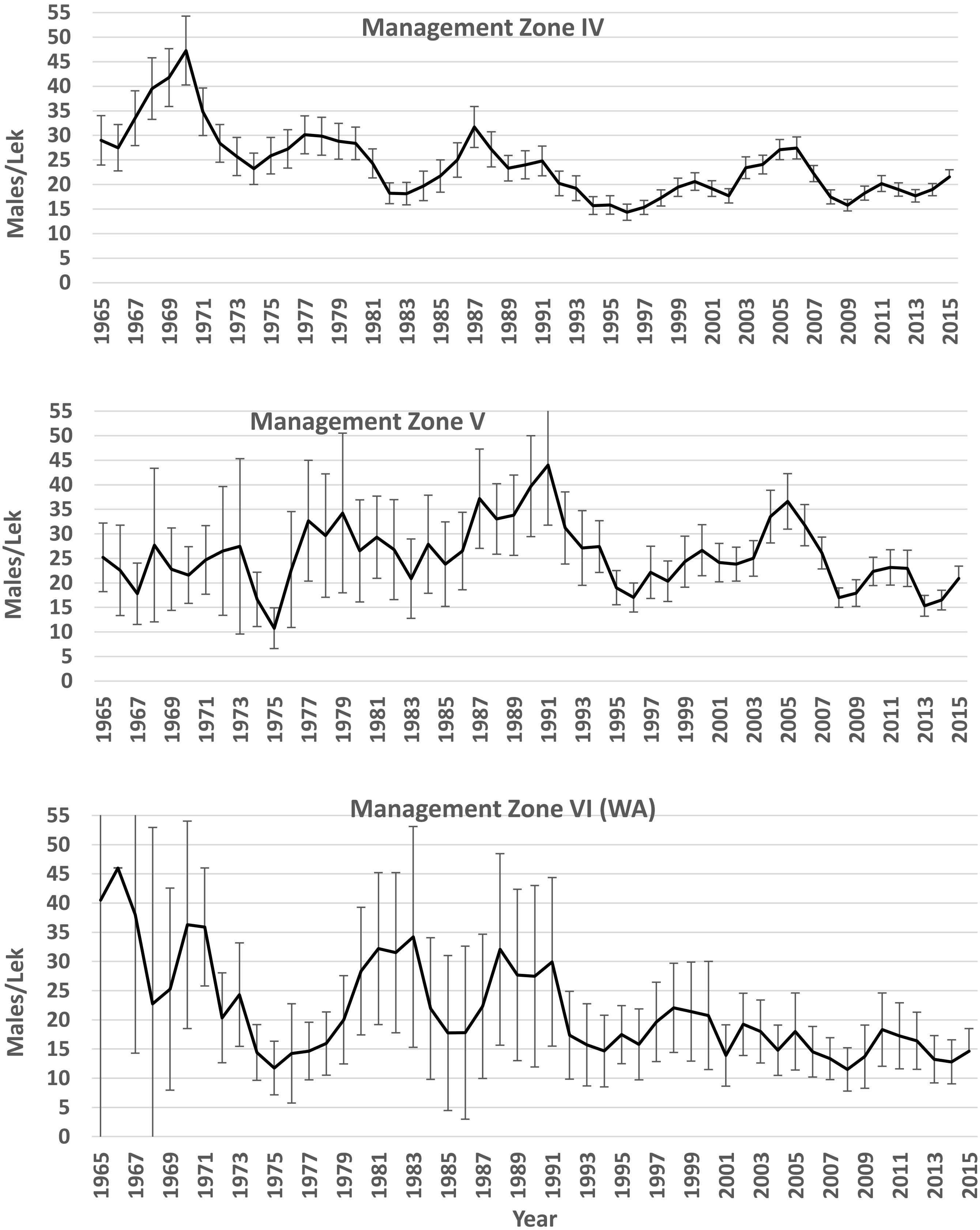


Figure 8. Mean number of males counted per active lek from 1965-2015 in Management Zones IV, V & VI. Vertical bars represent 95% confidence intervals around the mean.

lower peak of 27.4 in 2006. Troughs occurred in 1983 (18.1), 1996 (14.4), and 2009 (15.8) (Fig. 8). Average males per lek has varied between 18.2 and 21.6 since 2010 (Fig. 8).

The results of the modeling effort indicated average males per lek within core areas of Management Zone IV have been increasing since 1965 at about 1% per year (+0.98%, 90% CRI 0.70 to 1.20, Fig. 9, Table 1), but that peripheral areas have declined at a rate of -1.35% per year, resulting in an overall decrease of -0.7% per year (Fig. 9, Table 1).

Discussion. The 2006 peak in average males per lek in Management Zone IV (27.4) was the largest since 1987 (31.7), and comparable to the peak in the late 1970s (Fig. 8). The recent low in 2009 (15.8) was similar to lows in 2002 and in the late 1990s (Fig. 8). The number of active leks has varied somewhat since 2006, but on a generally increasing trend (Fig. 6). Core areas appear to be doing well, modeled declines since 1965 overall have been relatively low. Examining Figure 8 suggests most of this decline occurred from 1965 to the mid-1990s, and that populations have stabilized since then.

Management Zone V - Northern Great Basin

Monitoring effort. In 2015 biologists counted 4,080 male sage-grouse in Management Zone V, or 5.1% of the range-wide total. The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 37 in 1965 to a high of 246 in 2007, then declined to 152 in 2011 before increasing again to 195 in 2015 (Fig. 4).

Lek-count trends. Fewer than 50 leks were counted each year until 1988, when sampling intensity increased (Fig. 4). Consequently, confidence limits around average males per lek in Management Zone V are quite large (43-130% of the average) prior to 1994, both because relatively few (<100) leks were counted, and because of high variability in lek counts (Fig. 8).

Confidence limits since 1994 have tightened as the number of leks counted has increased to between 150 and 246 (Fig. 4). Inferring any trends in average males per lek in early years is problematic given the variability around these averages. That said, unlike other Management Zones, the overall trend in average males per lek appears to be increasing from 1965 to about 1991, with an overall declining trend since 1991 or at least since the 2006 peak (Fig. 8).

Modeling results indicated average males per lek within Management Zone V has declined at a rate of 1.38% per year since 1965 (90% CRI -1.05 to -1.72), with declines substantially greater in peripheral areas than core areas (-1.69 vs -0.91; Fig. 10, Table 1).

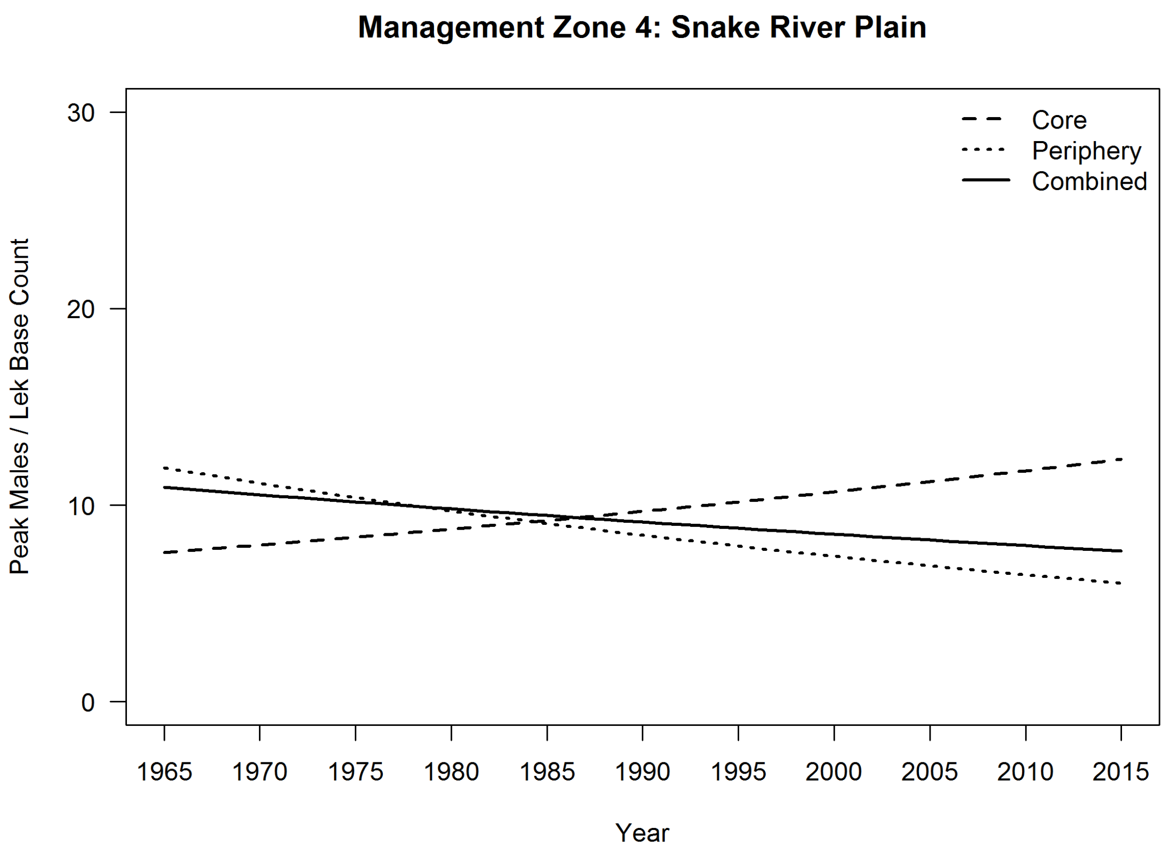
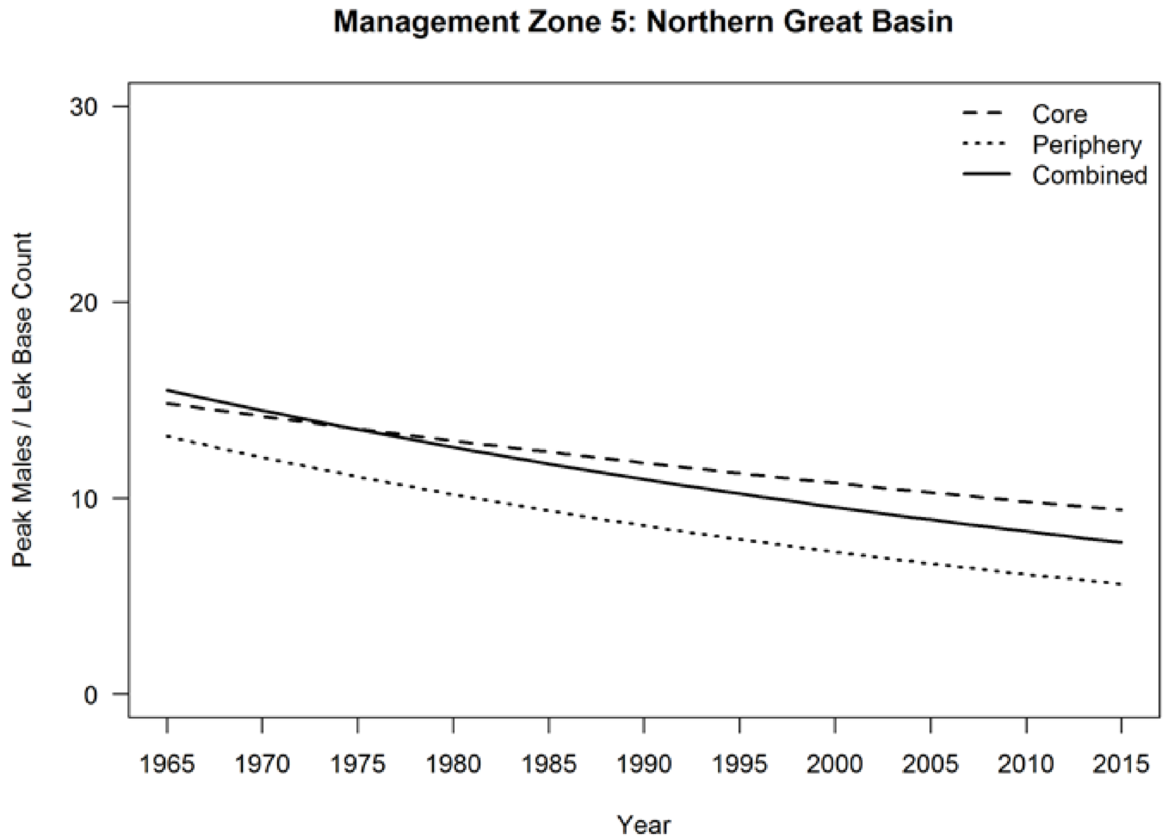


Figure 9. Estimated annual percent change in the average peak number of male sage-grouse on Management Zone IV leks in the 75% core area (0.98; 90% CRI 0.70 to 1.20), periphery (non-core; -1.35% (90% CRI -1.21 to -1.49), and all leks combined (-0.70; 90% CRI -0.63 to -0.78).



`Figure 10. Estimated annual percent change in the average peak number of male sage-grouse on Management Zone V leks in the 75% core area (-0.91; 90% CRI -0.54 to -1.28), periphery (non-core; -1.69% (90% CRI -1.22 to -2.17), and all leks combined (-1.38; 90% CRI -1.05 to -1.72).

Discussion. Declines in Management Zone V are concerning for several reasons. The magnitude of the modeled annual decrease (-1.38%) is significant, core and peripheral areas are both decreasing, and the rate of decline appears to be increasing in recent years (Fig. 8). In addition, "cyclic" lows and highs are somewhat below historic norms (Fig. 8), and there appears to be a declining trend in the number of active leks in recent years (Fig. 4). It is encouraging that the recovery from the recent trough in 2013 was significant, an increase of 52% in total males counted and an increase of 20 active leks (11%), which increased males per lek from 15.3 to 20.9 (Fig. 8).

Management Zone VI - Columbia Basin

Management Zone VI consists entirely of sage-grouse populations in the state of Washington. Average annual rates of change indicate that male counts in this management zone decreased an average of 0.06% per year from 1965-2015 (90% CI -0.04 to -0.09). See the section on Washington (below) for additional information.

State Level Analyses

Wyoming

Monitoring effort. Wyoming counted 34,518 males (excluding aerial counts) in 2015, which was 43% of the range-wide total. The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period from 28 in 1965 to a high of 1,052 in 2015 (Fig. 11). During the 1960s and 1970s about 24-54 leks were counted each year, increasing to over 200 per year after 1981, then increasing steadily until approximately 1,000 active leks were counted each year after 2006 (Fig. 11). Wyoming, like most states, maintains an inventory of historic lek locations which are checked for activity each spring, bringing the total number of leks counted to about 1,600 in recent years (Fig. 11). Counting over 1,500 sage-grouse leks each year is a monumental task, and Wyoming should be commended for their effort.

Lek-count trends. Confidence limits are relatively large around average males/lek until the 1980s when counting effort surpassed 200 leks annually (Fig. 11). A peak in 1968 of 58.8 males per lek was based on 68 leks counted. Subsequent peaks have been 40.1, 26.0, 33.3, and 44.9 males per lek in 1978, 1991, 2000, and 2006, respectively (Fig. 11). Troughs of 25.5, 20.2, 13.1, 23.0, and 17.4 males per lek occurred in 1971, 1987, 1996, 2002, and 2013, respectively (Fig. 11).

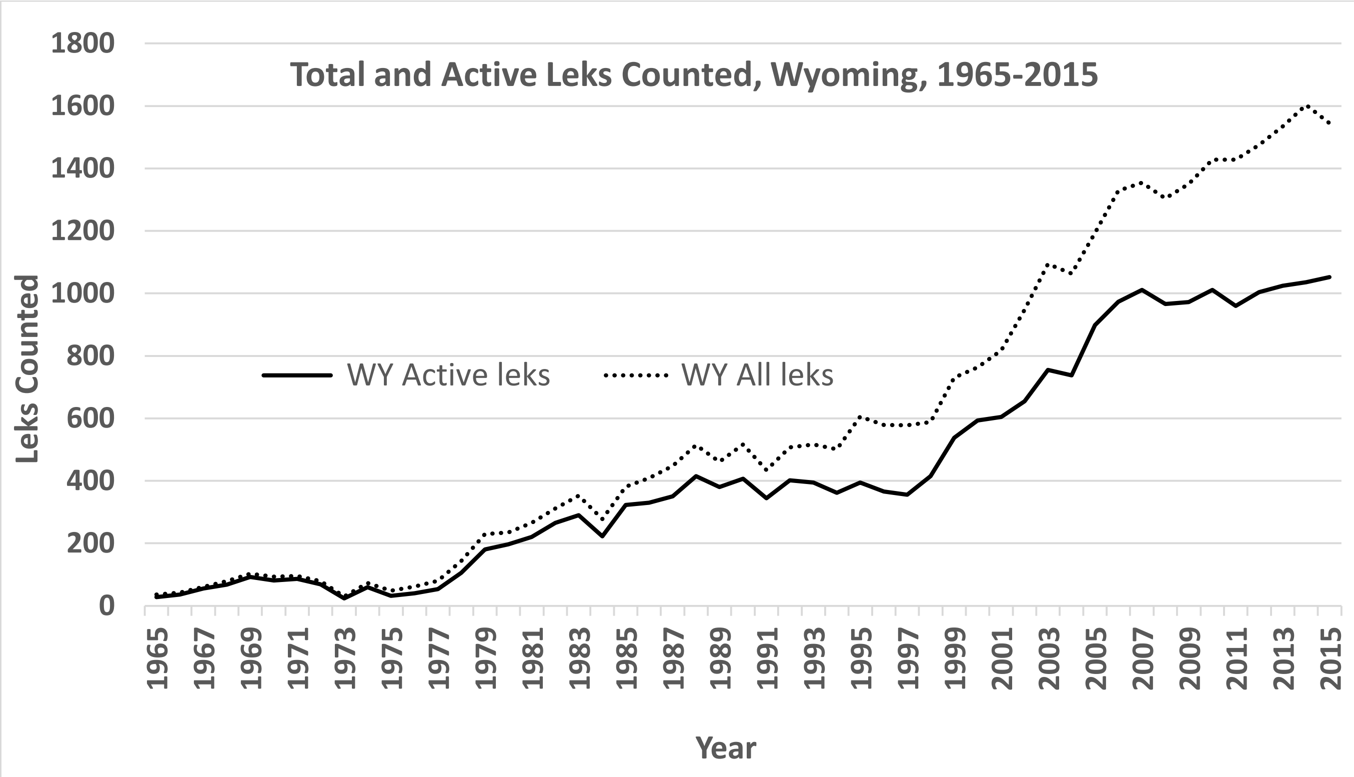
Modeling indicated average males per lek in Wyoming has increased over the 1965-2015 at a rate of 0.30% annually (Table 1).

Discussion. The 2006 peak was the highest average males per lek since 1968, which may have been biased high as relatively few leks were counted. This peak likely had a strong influence on the somewhat surprising modeling result that showed an annual increase since 1965 of 0.3%. Still, evidence suggests that Wyoming sage-grouse are doing well. Habitat supported a peak of 45 males per lek as recently as 2006. Recent lows in 2013, while below 2002 lows, were above mid-1990s lows and comparable to troughs in 1987 (Fig. 11). The number of active leks is stable to increasing in recent years (Fig. 11).

Idaho

Monitoring effort. Idaho counted 12,414 male sage-grouse in 2015, or 15.5% of the range-wide total. The number of leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 67 in 1965 and 1966 to a high of 623 in 2014 (Fig. 12). The number of leks counted in Idaho ranged generally between 100 and 200 until 1997 (245) when a steady increase in counting effort began that continued until over 600 active leks were counted in 2014.

Lek-count trends. Average males per lek has varied over time but increased from 1965 to a peak of 53.3 in 1970, before a long term decline to a low of 15.3 males in 1983 (Fig. 12). Males per lek then increased to a peak of 33.8 in 1987 before a decline, with other peaks of 27.7 in 1991 and 29.1 in 2006 (Fig. 12). Average males per lek then declined to a low of 17.3 in 2009, before increasing slightly to 18.3-19.1 males per lek between 2009 and 2014 (Fig. 12). This increased to 22.4 in 2015 (Fig. 12).



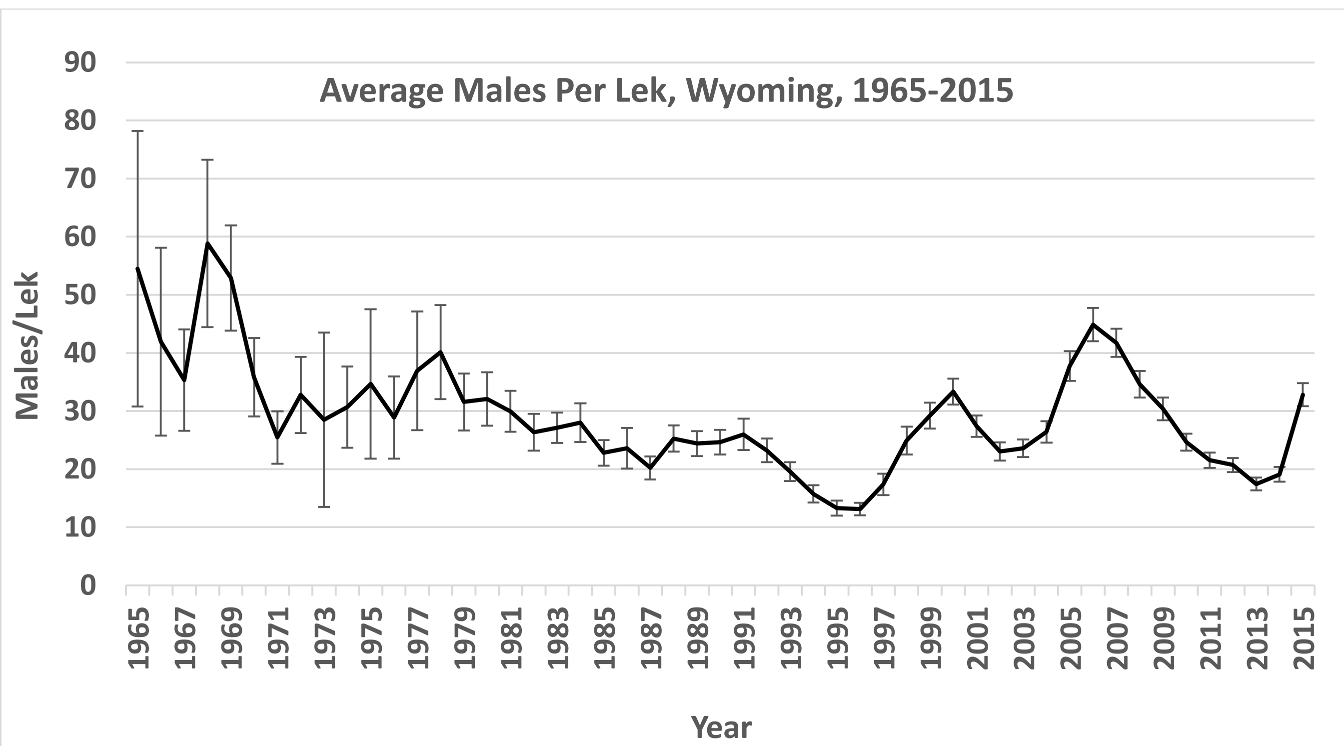


Figure 11. Number of total and active (1 or more males) leks counted from 1965-2015 in Wyoming (top), and mean number of males counted per active lek from 1965-2015 in Wyoming (bottom). Vertical bars represent 95% confidence intervals around the mean.

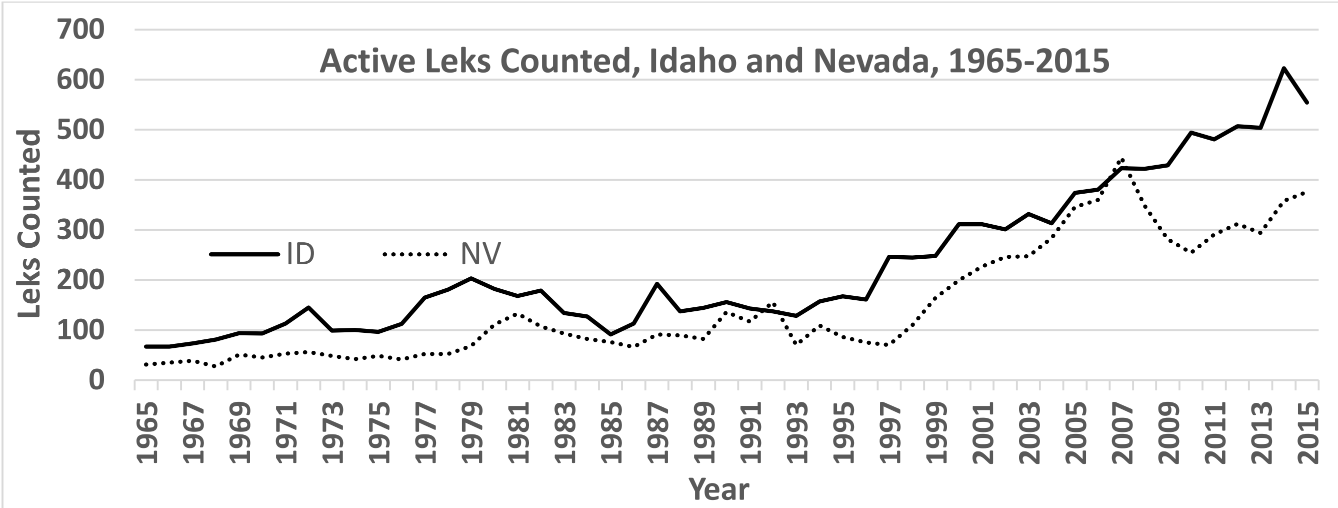
Since 1965, average males per lek in Idaho has increased at a rate of 0.91% per year according to modeling results (90% CRI 0.80 to 1.00, Table 1).

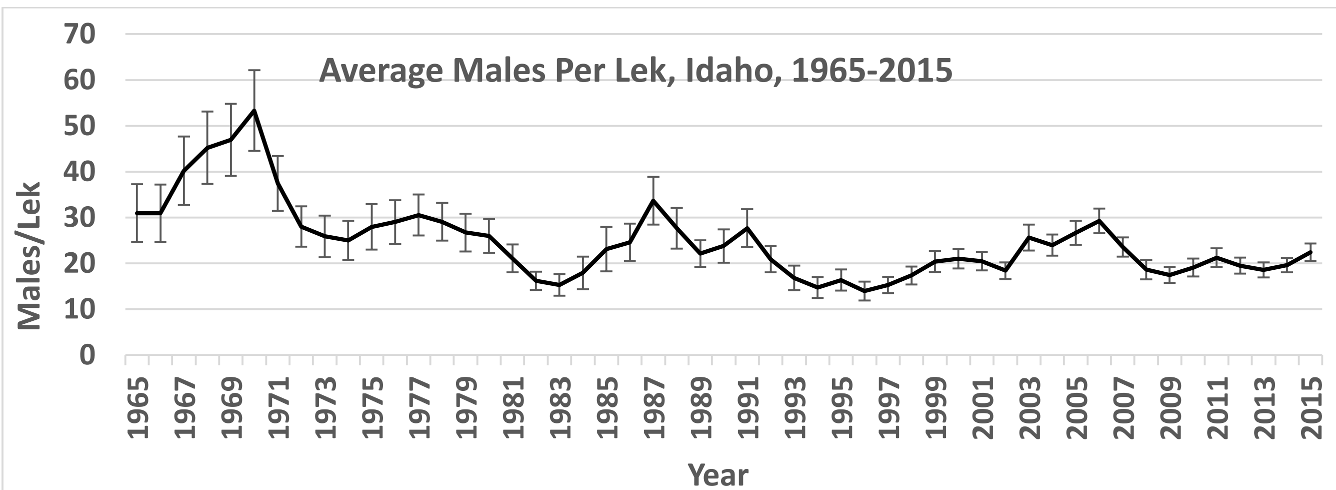
Discussion. Idaho sage-grouse populations have fluctuated less than those in many other states, particularly in recent years (Fig. 12). Recent peaks in 2006 in average males per lek were roughly comparable to earlier peaks, except for the 1969 peak which may have been biased high. Idaho did not experience the 2013 trough other states did. The last trough in 2009 was not as low as the mid-1990s trough, but comparable to other low periods.

Nevada

Monitoring effort. Nevada counted 8,994 male sage-grouse in ground counts in 2015 (11.2% of range-wide total), and an additional 2,822 males from aerial searches, or about 15% of all males counted by all means range-wide. The number of active leks counted that met criteria for inclusion in the trend analysis varied substantially over the assessment period, from 27-57 between 1965 and 1979, from 66 to approximately 150 until 1999, then increased to a high of 444 in 2007, and ranged from 284-376 between 2008 and 2015 (Fig. 12).

Lek-count trends. Confidence intervals around average males per lek are relatively large until the 1980s because of small sample sizes and variable count data, complicating interpretation of trends (Fig. 12). There were apparent pronounced peaks in 1970 of 45.4 and 1979 of 42.5, with troughs in 1975 of 16.6 and in 1982 of 19.9 (Fig. 12). Since then, average males per lek have fluctuated between about 16 and 27, with a smaller peak in 2004-2007 and a trough in 2008-2009 (Fig. 12).





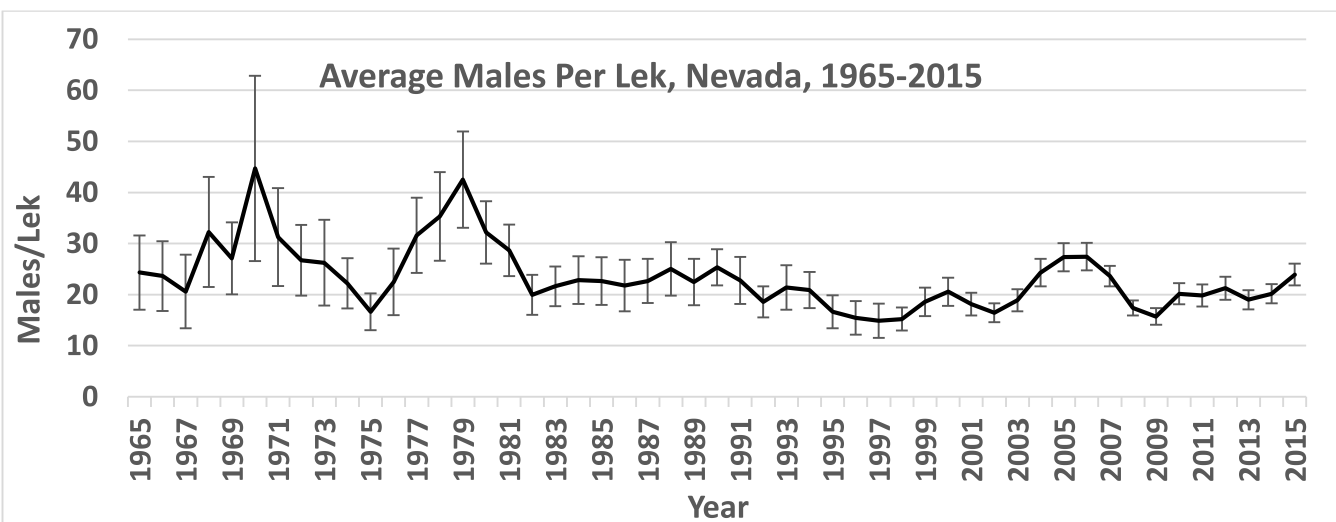


Figure 12. Number of active leks counted from 1965-2015 in Idaho (ID) and Nevada (NV) (top), and mean number of males counted per active lek from 1965-2015 in Idaho (middle) and Nevada (bottom). Vertical bars represent 95% confidence intervals around the mean.

Modeling results indicated a decline in average males per lek since 1965 of 0.24% per year (90% CRI -0.19 to -0.30; Table 1) in Nevada.

Discussion. Nevada, because many sage-grouse leks are located in remote, inaccessible locations, surveys many leks from the air (213 in 2015, vs. 462 leks counted from the ground). These aerial counts are excluded from our analysis because detectability of males is likely to differ in aerial and ground counts, and trends could be created as an artifact of changes in sampling intensity by air or ground. Still it complicates interpretation; did the number of active leks decline markedly from a peak in 2007 to 2010 because of a population decline, or because fewer leks were counted from the ground and more by air and thus not included in our sample? Similar to Idaho, average males per lek declined to a trough in 2009, and have generally increased since (Fig. 12). Figure 12 suggests most of the decline indicated by the model since 1965 likely occurred prior to the mid-1990s, and that population trends have been relatively flat since.

Oregon

Monitoring effort. Oregon accounted for 5.3% of males counted range-wide in 2015 (4,256/80,284). The number of active leks counted that met criteria for inclusion in the trend analysis increased significantly over the assessment period, ranging from 10-26 between 1965-1985, then increasing steadily to a high of 218 in 2010 (Fig. 13). Active leks counted declined to 163 in 2011. The number of active leks counted has increased markedly since 2011 to a high of 243 in 2015 (Fig. 13).

Lek-count trends. Confidence intervals around the average males per lek are very large until the 1990s when sample sizes increased, complicating interpretations of trends in the early interval. Generally there was a declining trend in average males per lek from 1965 until the mid-1970s, an increasing period until 1991, then a decline until the mid-1990s, an increase that culminated in a large peak of 35.4 in 2005, followed by a decline and trough in 2008-2009 to about 14 (Fig. 13). Average males per lek has fluctuated between 13 and 20 since 2010 (Fig. 13).

Modeling indicated average males per lek has declined slightly, 0.06% per year since 1965 (90% CRI -0.05 to -0.07).

Discussion. As recently as 2005, average males peaked at 35.3, the highest peak recorded in the 1965-2015 interval. Troughs in average males per lek in 2013 and 2008-2009 were similar to troughs in prior decades. Number of active leks has fluctuated, but has generally increased since about 1994, which is likely indicative of increased effort. There is no evidence of a decreasing trend in active leks over that period.

Montana

Monitoring effort. Montana counted 7,136 males in 2015, 8.9% of the range-wide total. The number of leks counted that met criteria for inclusion in the trend analysis increased substantially over the assessment period, from 12 in 1965 to approximately 100-200 leks per year from 1977-1999 before increasing to a high of 519 in 2010, then dropping to between 380 and 435 active leks counted from 2011-2015 (Fig. 13).

Lek-count trends. Confidence limits around the mean number of males counted per lek are large until the late 1970s because of small sample sizes and variability in count data, complicating interpretation of trends (Fig. 13). Average males per lek generally increased from the mid-1970s through 1984, then declined to a low of 15.8 in 1986 before increasing to peaks of

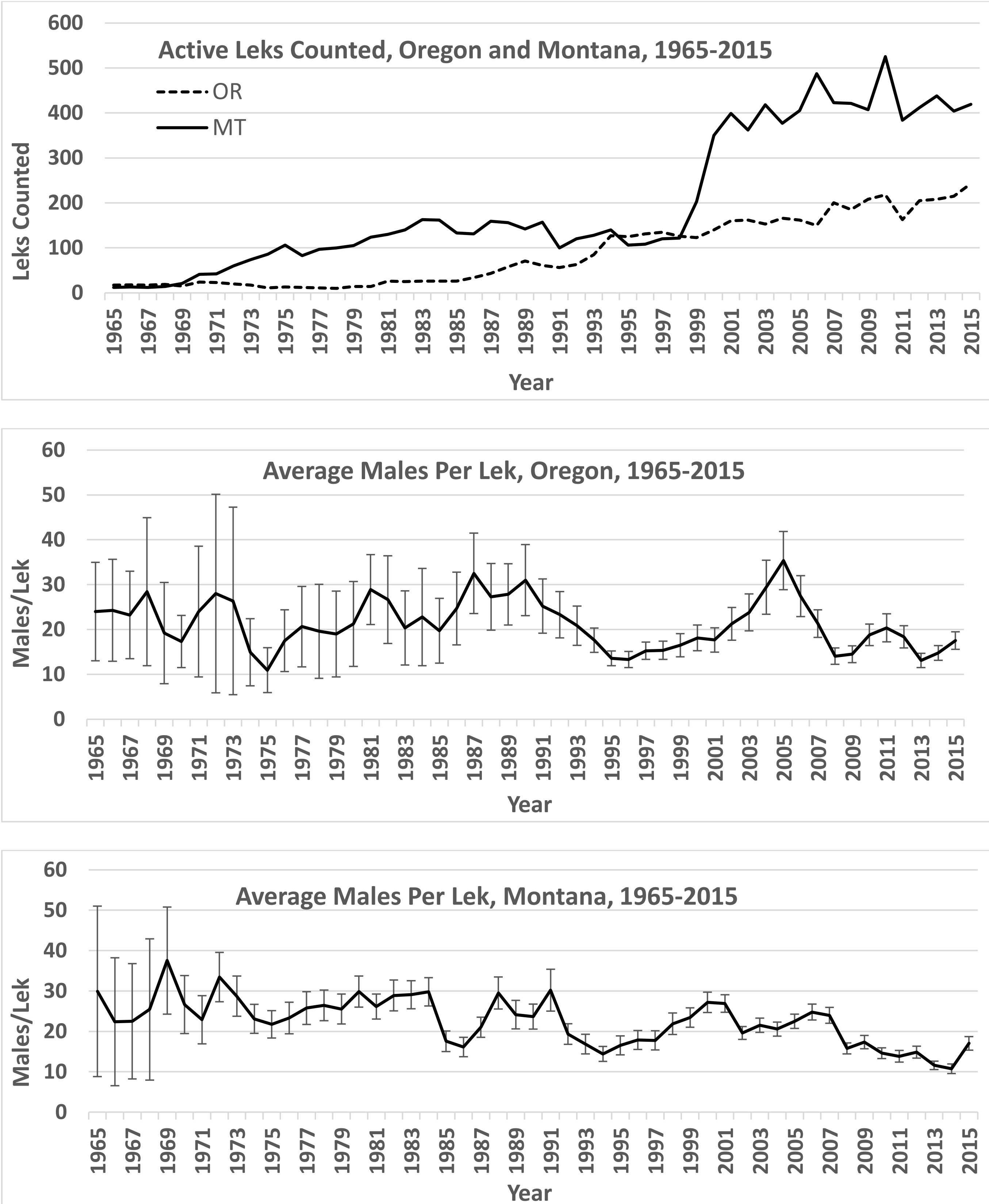


Figure 13. Number of active leks counted from 1965-2015 in Oregon (OR) and Montana (MT) (top), and mean number of males counted per active lek from 1965-2015 in Oregon (middle) and Montana (bottom). Vertical bars represent 95% confidence intervals around the mean.

29.3 in 1988 and 30.1 in 1991 (Fig. 13). Average males per lek then declined to a low of 14.3 in 1994, increased to 26.9 in 2000, ranged between about 20-25 from 2002-2007 before beginning a period of decline to a low of 10.7 in 2014 (Fig. 13). In 2015 average males per lek increased sharply to 17.0 (Fig. 13).

Modeling estimated that average males per lek has declined from 1965-2015 at a rate of 2.75% per year in Montana (Table 1, 90% CRI -2.54 to -2.96).

Discussion. It appears from examining Figure 13 that since the early 1990s, peaks in average males per lek in Montana have gotten lower and troughs deeper, which is consistent with modeled declines of 2.75% per year over the 1965-2015 interval.

Colorado

Monitoring effort. Colorado accounted for 7.7% of males counted in 2015 range-wide (6,199/80,284). The number of active leks counted that met criteria for inclusion in the trend analysis increased substantially over the assessment period, from a low of 24 active leks counted in 1975 to a high of 204 in 2015 (Fig. 14). There were several periods when the number of active leks declined, presumably because lek counting intensity dropped; from 1973-1976, from 1984-85, and from 1991-1994, so counts during these periods may not be representative of counts immediately before or after.

Lek-count trends. In the early analysis period there were pronounced peaks in average males per lek in 1969 (54.1) and 1979 (48.4), with troughs in between in 1974 (23.9) and 1984 (19.4) (Fig. 14). Both of these troughs coincided with declines in lek sampling intensity, particularly in Moffat County where some of the larger leks in CO occur, which may have exaggerated the extent of the decline. More recently peaks have averaged between 26 and 32 males per lek, with troughs around 16 or 17 males.

Modeling indicated a declining trend in average males per lek since 1965 of 0.51% per year (Table 1, 90% CRI -0.34 to -0.68).

Discussion. The average males per lek in Colorado has recovered to the point where the 2015 level of 30.4 is almost to the 2005 peak of 32.1, which was the highest peak since 1979. The number of active leks is on an increasing trend, with relatively similar effort across recent years.

Utah

Monitoring effort. Utah counted 5,451 males in 2015, which was 6.8% of the range-wide total. The number of active leks counted that met criteria for inclusion in the trend analysis increased significantly over the assessment period, from 15 in 1965 to a high of 245 in 2015 (Fig. 14).

Lek-count trends. Average males per lek in Utah exhibited peaks in 1969 (36.6), 1979 (31.7), 1989 (27.8) and 2006 (29.8), with troughs generally in the 15-20 males per lek range in the intervening years (Fig. 14). Average males per lek declined from the 2006 peak to 16.1 in 2012, then increased steadily to 22.2 in 2015 (Fig. 14).

Modeling indicated that average males per lek in Utah have increased at a rate of 0.77% per year since 1965 (Table 1, 90% CRI 0.60 to 1.00).

Discussion. The recent 2006 peak in average males per lek was very similar to or above previous peaks back to the 1979 level, and the recent trough in 2010-2011 was similar to the bottom in the mid-1990s, but somewhat below previous troughs. The number of active leks has increased since 2011.

California

Monitoring effort. California counted 1,158 males in 2015, or 1.4% of the range-wide total. The number of active leks counted that met criteria for inclusion in the trend analysis increased significantly over the assessment period, from a low of 6 in 1978 to a high of 52 in 2004, and has ranged between 41-52 since 2000 (Fig. 15).

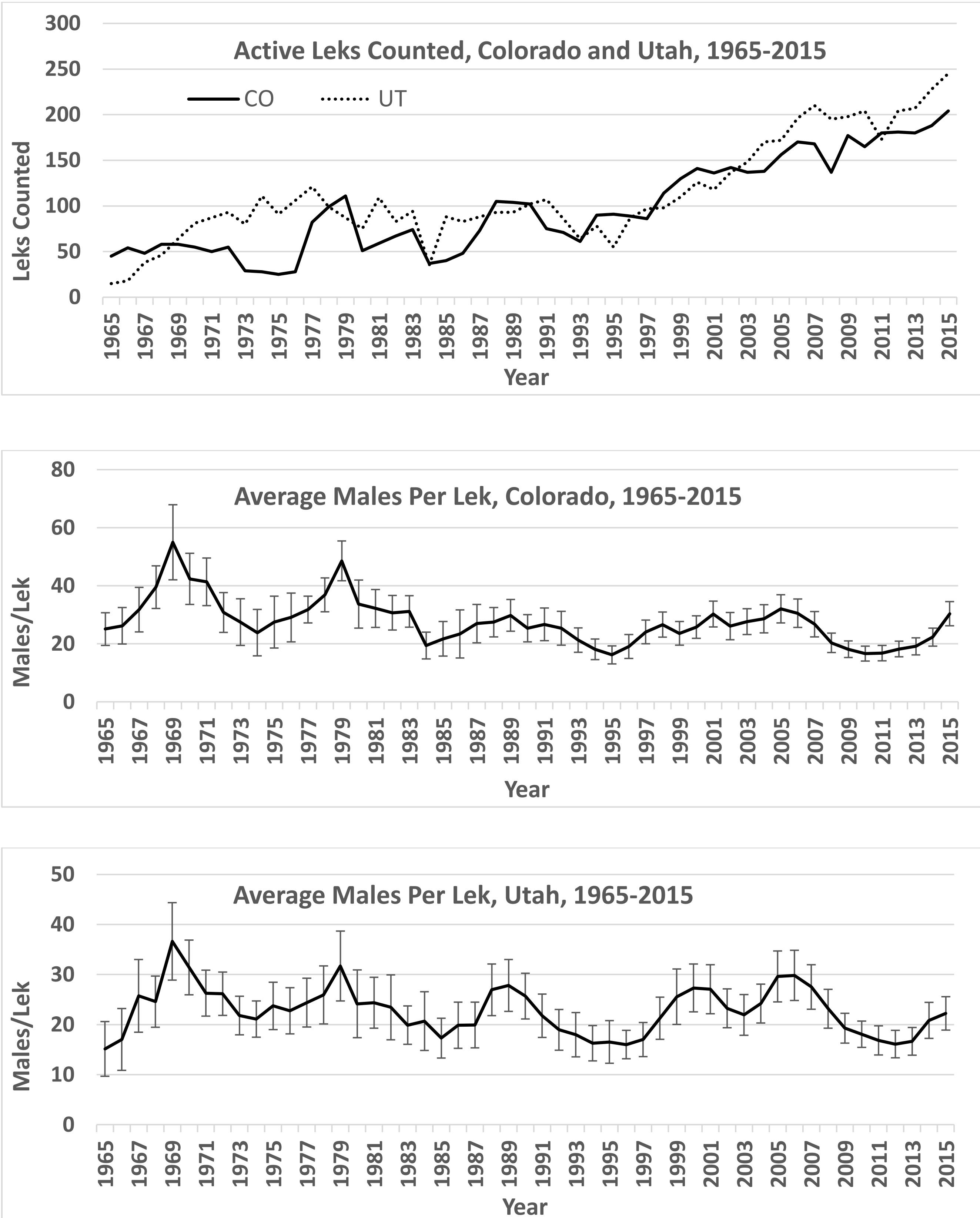


Figure 14. Number of active leks counted from 1965-2015 in Colorado (CO) and Utah (UT) (top), and mean number of males counted per active lek from 1965-2015 in Colorado (middle) and Utah (bottom). Vertical bars represent 95% confidence intervals around the mean.

Lek-count trends. Average males per lek in California has varied significantly over the 1965-2015 time period, although large confidence limits around the average complicates interpreting trends (Fig. 15). Average males per lek peaked in 1969 (29.7), 1980 (35.5), 1987 (45.3), 1991 (64.3), 2000 (40.5), 2005 (29.5) and 2012 (34.4) (Fig. 15). There were significant troughs in average males per lek in 1967, 1978, 1983, 1996, 2002, and 2008, with values ranging from 11.7-22.6 (Fig. 15).

Modeling results indicated average males per lek has been stable since 1965 (0.06% per year, but 90% CRI includes zero, Table 1).

Discussion. Average males per lek increased from the mid-1960s to a peak of 67.7 in 1991, but has generally decreased since. The 1991 peak is largely an artifact of several large leks in close proximity being clustered which formed two, 300-bird leks which raised the per lek average considerably. The recent trough in average males per lek in 2008 (18.2) was lower than troughs in 2002 and 1996 (23.7 & 24.2, respectively), but similar to the trough in 1983 (18.1). In the last 5 years average males per lek in California has fluctuated between 25 and 35 (Fig. 15).

Washington

Monitoring effort. Washington counted 366 males in 2015, which represented 0.5% of the range-wide total. The number of leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 2 in 1965 to a high of 28 in 2013 before declining to 26 in 2014 and 25 in 2015 (Fig. 15).

Lek-count trends. Confidence intervals around average males per lek are very large until lek counting effort increased to over 20 leks in the mid-1990s. Counts in the 1965-1970 interval included average males per lek as high as 36, 38, 40 and 46, (Fig. 15), but these were based on counts of only 1-7 leks (Fig. 15). Subsequent peak and trough counts ranged between 30-34 and 12-18, respectively through 1991, but counts since then have averaged between 10 and 21 males per lek (Fig. 15).

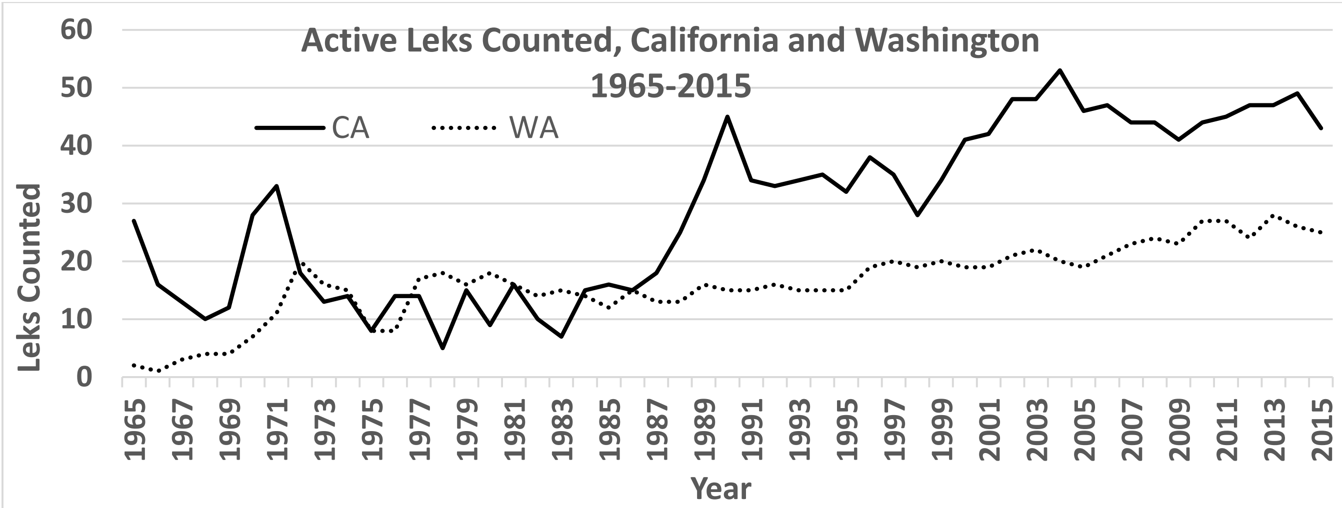
Washington had a declining trend in average males per lek since 1965 of 0.06% per year overall, but a decline of 2.8% per year in peripheral areas (see Management Zone 6, Table 1) based on modeling results (Table 1.)

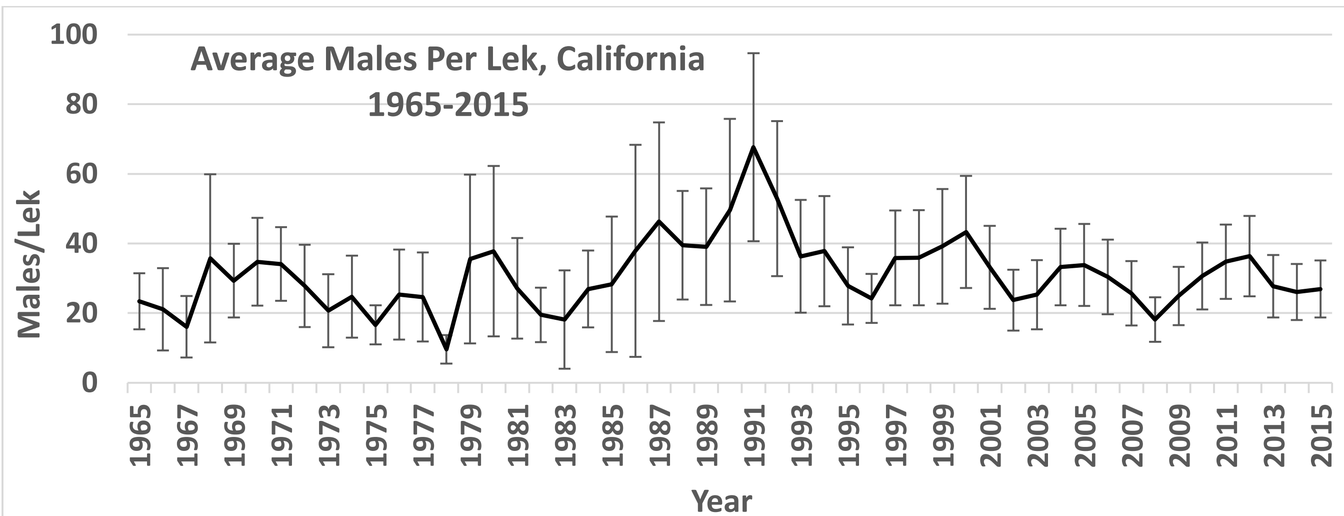
Discussion. While a small population, continuing decreases in peripheral areas within Washington (15 of 46 total leks) could lead to concerns about eventual sage-grouse extirpation in the near future.

South Dakota

Monitoring effort. South Dakota counted 146 males in 2015, or less than 0.2% of the range-wide total. Lek count data was not available from 1965-1970, or for 1972. The number of active leks counted that met criteria for inclusion in the trend analysis increased over the assessment period, from 4 in 1971 to a high of 28 in 2012 (Fig. 16). Active leks counted declined to 21 in 2013 and 2014, and 15 in 2015 (Fig. 16).

Lek-count trends. Confidence intervals around average males/lek were very high in the 1971-1989 interval because of small sample sizes and high variability in lek counts, complicating interpretation of trends (Fig. 16). Average males per lek declined from a high of about 30 in 1971 (average of only 4 leks) to a low of 1.2 males on 5 leks counted in 1988, before rebounding to between 15-21 males per lek in 1989-1994 as the number of leks counted increased (Fig. 16).





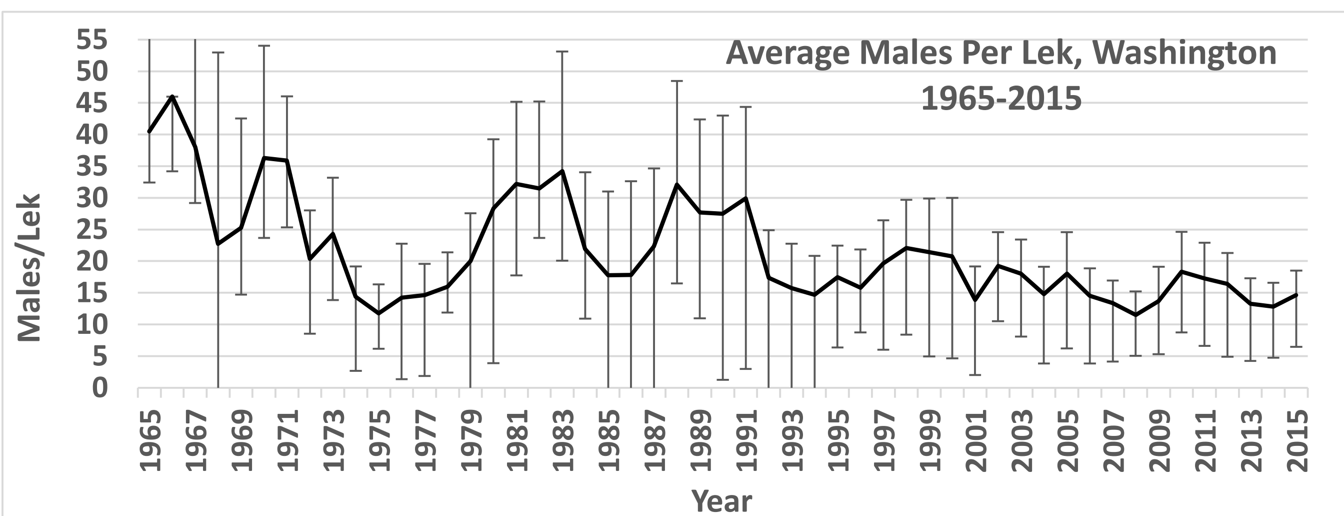


Figure 15. Number of active leks counted from 1965-2015 in California (CA) and Washington (WA) (top), Mean number of males counted per active lek from 1965-2015 in California (middle) and Washington (bottom). Vertical bars represent 95% confidence intervals around the mean.

Average males per lek declined in South Dakota in the mid- to late-1990s to between 5 and 10 males per lek before increasing to about 23 in 2006-2007 (Fig. 16). Average males per lek declined steadily after 2007 to 5.2 in 2014, but increased to 9.7 in 2015 (Fig. 16).

In the trend analysis, the model showed a declining trend in average males per lek of 1.72% per year (90% CRI -1.13 to -2.36, Table 1).

Discussion. South Dakota, at the eastern edge of the range, has seen a decline in the number of active leks, and a decrease since 2006 in the average number of males before increasing last year. With only 15 active leks, average males per lek below 10 in recent years, and a long term declining trend this population must be considered at risk of extirpation.

North Dakota

Monitoring effort. North Dakota counted 30 males on 6 active leks in 2015 (<0.1% of range-wide total). The number of active leks counted that met criteria for inclusion in the trend analysis declined significantly over the assessment period, peaking at 22 leks in 1980 and 1982, then declining to a low of 6 leks in 2014 and 2015 (Fig. 16).

Lek-count trends. Confidence intervals around average males per lek are large because of relatively small sample sizes and variable counts. Average males per lek in North Dakota has fluctuated over time at relatively low levels; between about 10 and 20 males per lek from 1965 to 2007, but has ranged from 4 to 6 males per lek since (Fig. 16).

The model for the long term trend analysis (1965-2015) showed a declining trend of 1.21% per year in North Dakota (90% CI: –0.086 to –1.58, Table 1).

Discussion. The number of active leks has declined significantly since 2002, as has average males per lek since 2000. With only 6 active leks averaging 5 males, this population is at a very high risk of extirpation.

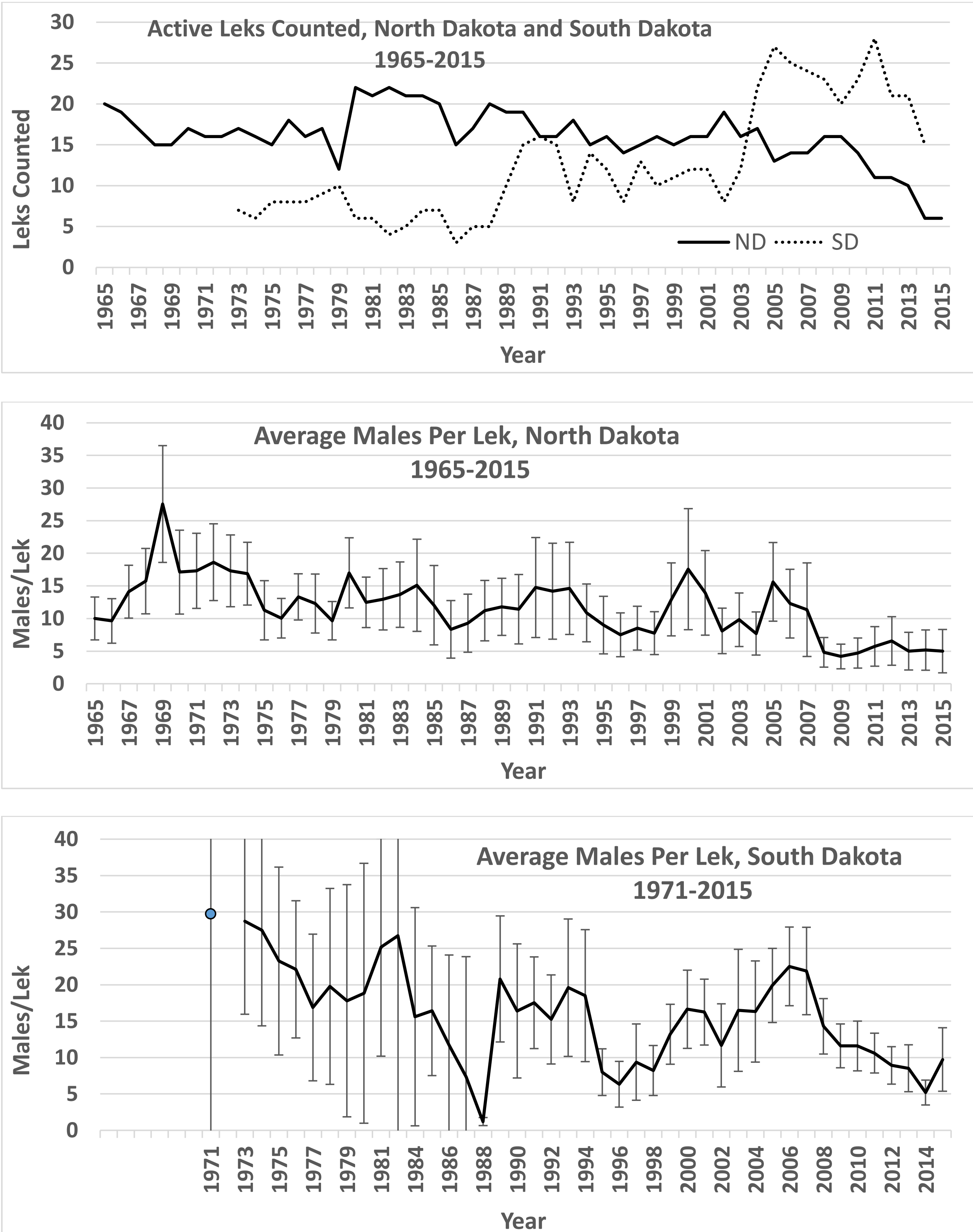


Figure 16. Number of active leks counted from 1965-2015 in North Dakota (ND) and South Dakota (SD) (top), and mean number of males counted per active lek from 1965-2015 in North Dakota (middle) and from 1971-2015 in South Dakota (bottom). Vertical bars represent 95% confidence intervals around the mean.

Appendix I - Limitations of Lek Data and Assumptions

Because sage-grouse gather on traditional display areas (leks) each spring, biologists typically use counts of displaying males as an index to track changes in breeding populations (Connelly et al. 2003). A large number of leks are regularly monitored each year throughout North America, many state databases have >50 years of information, and most states have conducted extensive searches for new leks. All state wildlife agencies monitor sage-grouse breeding populations using data from leks, but methods for gathering these data vary somewhat among agencies and sometimes within agencies among years (Connelly et al. 2004).

Although information on number of females observed during lek counts is often recorded, female attendance is so variable that only male peak counts are used as an index to population trends. Attendance by yearling males is lower than for adult males, and highly variable (Walsh et al. 2004). The implicit assumption is that peak counts of males are representative of trends in the population as a whole, which may not be accurate given that females represent about 60-66% of the population (Guttery et al. 2013, Braun et al. 2015).

For the lek count index to be representative of trends in male populations over time the leks chosen for counting must be representative of the total universe of leks. Ideally, a random sample would be selected for counting from the total population of leks in each state, but many lek locations are not known. The assumption that the size and trends of counted leks is representative of all leks may be reasonable in recent years when 2-3,000 leks have been counted across the range each year, but is highly suspect in the early years of the analysis period when individual states counted a handful of leks. For instance, California counted 10-32 leks until 1989, Colorado counted 20-60 leks until 1977, Idaho counted less than 100 until 1970, Montana counted less than 50 leks until 1972, Nevada counted approximately 50 leks until 1979, Oregon counted less than 25 until 1988, Washington counted less than 10 leks until 1971. Wyoming, which has counted around 1,000 leks in recent years, counted as few as 24 in 1973 and 36 in 1966, and did not count more than 100 leks until 1978. Lek sizes can vary from as few as 2 males to as many as 300. If larger leks were chosen for sampling in the relatively limited counting done in the earlier years of the analysis period, then the average males per lek would be inflated and a negative bias introduced in trend analysis over time. Smaller leks are also less likely to be detected so that they can be counted. When systematic, area-based sampling was done to search for previously unknown leks in Colorado and Montana, newly discovered leks had significantly fewer males than previously known leks (Lukacs personal communication), which indicates summary statistics like males per lek will decline as lek counting intensity increases independent of other population influences.

Another implicit assumption when inferring population trends from male lek counts is that detectability of males does not change over time. Detectability of males does vary from year to year, because observers change and weather conditions may influence strutting behavior and the ability of observers to get to leks during periods of peak attendance. The proportion of males detected at leks likely also varies as a function of the proportion of yearlings in the male population. Blomberg et al. (2013) evaluated the extent to which variation in annual lek attendance by males influenced estimated population trends, and concluded that such variance made inferences on trends between years unreliable, but longer term (8 years in their study) trend inferences were not affected. Variation in apparent detectability is likely greater in this analysis where most leks were counted 1-4 times per year as opposed to their study where each lek was counted an average of 9 times per year and weather was not mentioned as a factor.

The lek count data contain many missing values (years in which no count was conducted at a given lek). Given limited information available as why a lek was not counted in a particular year and the short time-frame for this analysis, we must assume the data are missing completely at random (Rubin 1976, Gelman et al. 2003). This assumption requires that the probability of all possible patterns of missing data are the same for all values of the missing data and the probability of all possible patterns of observed data are the same for all values of the missing data (Rubin 1976). No missing values were imputed.

One missing value problem should be particularly noted with this data set. Surveying a particular lek typically only occurs after it is found with grouse on it. Therefore, very few leks are included in the data set starting with a zero. As a result, the initial establishment of a lek with a small number of male grouse and its concurrent increase from zero to a positive number of grouse is generally missing from these data. This could lead to negatively biased estimates of trend in male count.

Measurement error is known to exist in the count data. Measurement error arises from several sources including variation in detectability, observer acuity, and number of counts conducted for a given lek in a year. The number of counts within a given year is important because increasing the number of counts within a year increases the chance of getting a higher male count. Therefore, if the number of counts of a lek within a year has increased over time, then the trend could be positively biased.

Appendix II – Methodology used in Modeled Trend Analysis

Trends in the true peak number of males at a lek may vary over time and space. For example, localized areas may support stable greater sage-grouse populations, while a larger geographic extent of sage-grouse may be experiencing population declines or increases. Hierarchical models allow for modeling of trends specific to various geographic extents simultaneously. We developed a hierarchical model that followed individual leks through time and allowed trends at individual leks to inform estimates of trends within individual Management zones and states. This approach reduced the potential bias that could result if larger leks tended to be monitored earlier (e.g., 1965 – 1980; larger lek = more males) and many smaller leks were only recently included in the monitoring efforts. This hierarchical modeling approach included both fixed and random effects and was similar to approaches used to estimated trends in Breeding Bird Survey data (Sauer and Link 2002, 2011; Thogmartin et al. 2004; Nielson et al. 2008) and data from large-scale monitoring efforts like the west-wide golden eagle survey (Millsap et al. 2013, Nielson et al. 2014).

We fit overdispersed Poisson regression models to peak male attendance data for each individual lek, within each management zone and state. Within a Management zone or state (*i*), counts $Y_{i,j,t}$ (*i* for Management zone/state, *j* for lek, and *t* for year) were assumed to be independent Poisson random variables with means $\lambda_{i,j,t}$. The means were log-linear with respect to explanatory variables, i.e.,

$$\ln(\lambda_{i,j,t}) = \mu_i + a_j + (\beta_i + b_j)(t - t^*) + \varepsilon_{i,j,t}. \qquad (1)$$

Explanatory variables included in equation (1) include a_j and b_j, a random intercepts and slopes for individual leks, respectively, while parameters μ_i and β_i represent fixed effects for the overall intercept (centered on the median year 1990) and slope for the individual Management zone or state. Additionally, *t* represents year, while t^* represents the baseline year of 1990; the difference $t - t^*$ centered the model at the median year 1990. Finally, $\varepsilon_{i,j,t}$ represents overdispersed error terms specific to the lek, Management zone/state, and year.

We fit the overdispersed Poisson models using Bayesian hierarchical framework and Markov-chain Monte Carlo (MCMC) methods (Gelman et al. 2007, Gelman and Hill 2007). MCMC methods require specification of random effects and priors, respectively. We set μ_i and β_i, to originate from a multivariate normal:

$$\begin{bmatrix}\mu_i\\ \beta_i\end{bmatrix} \sim MVN\begin{bmatrix}\sigma_\mu & \rho\sigma_\mu\sigma_\beta\\ \rho\sigma_\mu\sigma_\beta & \sigma_\beta\end{bmatrix}, \tag{2}$$

with intercept and slope standard-deviation priors, σ_μ and σ_β , respectively, set to a Uniform(0, 100), and their correlation (ρ) prior set to a Uniform(-1, 1). The overdispersed error term $(\varepsilon_{i,j,t})$ was sampled from a mean-zero normal distribution with a tolerance prior of Gamma(0:001, 0:001), where tolerance equaled the 1/variance.

Estimation of grouse count indices $(n_{i,t})$ in the *i*th management zone or state, at time *t*, were calculated using

$$n_{i,t} = e^{\mu_i+\beta_i(t- t^*)+\frac{1}{2}\sigma_\varepsilon^2} , \tag{3}$$

where σ_ε^2 was the variance of the overdispersed error term, μ_i was the overall intercept, and β_i was the overall slope estimated for the *i*th Management zone or state.

The individual Management zone trend parameters, as estimated with the Bayesian hierarchical model described above, describe the average trend effect, on a per-year basis, for the entire fifty-one-year study period. While informative, analysis of data with a cyclical nature benefits from a more nuanced statistic that emphasizes temporally local trends, pertaining to a subset of years, rather than a global trend that encompasses all years. The estimated trend, for Management zone / state *i* across a time period (t_a to t_b; e.g., 1965 – 2015), was calculated as (Sauer and Link 2011)

$$B_i = \frac{n_{i,t_b}}{n_{i,t_a}}^{\frac{1}{t_b-t_a}} . \tag{4}$$

Equation (4) represents a geometric mean of the count indices n_{i,t_a} and n_{i,t_b}, calculated over the difference in the number of years $t_b - t_a$.

Equation (3) allowed for the estimation of counts of peak males over individual Management zones or states for individual years. We estimated range-wide (across Management zones) trends by calculating weighted means of the estimated peak male attendance within each Management zone *i* within year *t* $(n_{i,t})$ using

$$n_t = \frac{\sum_{i=1}^{6} n_{i,t} w_{i,t}}{\sum_{i=1}^{6} w_{i,t}} \ , \quad (5)$$

where the weights $(w_{i,t})$ were based on the number of leks within each Management zone during year *t*. The estimated range-wide trend between years t_a to t_b was calculated using

$$B = \frac{n_{t_b}}{n_{t_a}}^{\frac{1}{t_b - t_a}} \ , \quad (6)$$

which is similar to equation (4).

Estimation of posterior distributions via the MCMC methodology utilized WinBUGS (Kéry 2010) for all models. We used a burn-in of 76,000 initial samples, after which another 4,000 samples formed the simulation sample from which posterior distributions were obtained. We did not thin (i.e., discard) any of the 4,000 follow-up samples; in this way, all replicates following burn-in contributed to estimation of posterior distributions. Ninety percent credible intervals (CRIs) – essentially the Bayesian form of a confidence interval – were calculated for all estimates of trend. If a 90% CRI included 0.0, then we concluded there was no evidence of trend in the data.

Finally, we investigated how analysis of data from different time periods could effect estimates of trends using the results from Bayesian hierarchical model (equation [1]) and equation (6) to estimate all possible 10-year trends (e.g., 1965 – 1975, 1966 – 1976, …, 2005 – 2015) for the core areas, periphery, and the combined areas data across the entire range of greater sage-grouse.

Appendix III - Literature Cited

Aldridge, C. L., and R. M. Brigham. 2003. Distribution, status and abundance of Greater Sage-Grouse, *Centrocercus urophansianus*, in Canada. Canadian Field Naturalist 117:25-34.

Beck, T. D. I., and C. E. Braun. 1980. The strutting ground count: variation, traditionalism, management needs. Proceedings of the Western Association of Fish and Wildlife Agencies 60:558-566.

Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. Western North American Naturalist 63:203-214.

Blomberg, E. J., J. S. Sedinger, D. V. Nonne, and M. T. Atamian. 2013. Annual male lek attendance influences count-based population indices of greater sage-grouse. Journal of Wildlife Management 77:1583-1592.

Braun, C. E. 1995. Distribution and status of Sage Grouse in Colorado. Prairie Naturalist 27:1-9.

Braun, C. E., D. A. Budeau, and M. A. Schroeder. 2015. Fall population structure of sage-grouse in Colorado and Oregon. Wildlife Technical Report 005-2015. Oregon Department of Fish and Wildlife. Salem.

Coates, P. S., B. J. Halstead, E. J. Blomberg, B. Brussee, K. B. Howe, L. Wiechman, J. Tebbenkamp, K. P. Reese, S. C. Gardner, and M. L. Casazza. 2014. A hierarchical integrated population model for greater sage-grouse (*Centrocercus urophasianus*) in the Bi-State Distinct Population Segment, California and Nevada. U.S. Geological Survey Open-File Report 2014-1165, 34 p.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:229-234.

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, Cheyenne, WY.

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

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:967-985.

Doherty, K. E., J. D. Tack, J. S. Evans, and D. E. Naugle. 2010. Mapping breeding densities of greater sage-grouse: A tool for range-wide conservation planning. BLM Completion Report: Inter Agency Agreement # L10PG0911. Bureau of Land Management, Washington, D.C. 29 pp.

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. The Journal of Wildlife Management 75: 1022–1033.

Fedy, B. C. and K. E. Doherty. 2011. 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.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2003. Bayesian data analysis, second edition. Chapman & Hall/CRC, New York.

Gelman, A., J. B. Carlin, H. S. Stern, D. B. Dunson, A. Vehtari, and D. B. Rubin. 2007. Bayesian Data Analysis. CRC Press, New York, NY, third edition.

Gelman, A., and J. Hill. 2007. Data Analysis Using Regression and Multi-level/Hierarchical Models. Cambridge, New York, NY.

Guttery, M. R., T. A. Messmer, E. T. Thacker, N. Gruber, and C. M. Culumber. 2013. Greater sage-grouse sex ratios in Utah: Implications for reporting population trends. The Journal of Wildlife Management, 77: 1593–1597.

Hornaday, W. T. 1916. Save the sage grouse from extinction, a demand from civilization to the western states. New York Zoological Park Bulletin 5:179-219.

Jenni, D. A., and J. E. Hartzler. 1978. Attendance at a sage grouse lek: implications for spring census. Journal of Wildlife Management 42:46-52.

Kéry, M. 2010. Introduction to WinBUGS for Ecologists. Academic Press, Burlington, MA.

Millsap, B. A., G. S. Zimmerman, J. R. Sauer, R. M. Nielson, M. Otto, E. Bjerre, and R. Murphy. 2013. Golden eagle population trends in the western United States: 1968–2010. Journal of Wildlife Management 77:1436–1448.

Nielson, R. M., L. L. Mcdonald, J. P. Sullivan, C. Burgess, D. S. Johnson, D. H. Johnson, S. Bucholtz, S. Hyberg, and S. Howlin. 2008. Estimating the response of Ring-necked pheasants (*Phasianus colchicus*) to the conservation reserve program. The Auk 125:434–444.

Nielson, R. M., L. McManus, T. Rintz, L. L. McDonald, R. K. Murphy, W. H. Howe, and R. E. Good. 2014. Monitoring abundance of golden eagles in the western United States. Journal of Wildlife Management, 78:721-730.

R Development Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rubin, D. B. 1976. Inference and missing data. Biometrika 63: 581–592.

Sauer, J. R. and W. A. Link. 2002. Hierarchical modeling of population stability and species group attributes from survey data. Ecology, 86:1743-1751.

Sauer, J. R. and W. A. Link. 2011. Analysis of the North American Breeding Bird Survey using hierarchical models. The Auk 128:87-98.

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, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Sitver. 2004. Distribution of sage-grouse in North America. Condor 106:363-373.

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.

Thogmartin, W. E., J. R. Sauer, and M. G. Knutson. 2004. A Hierarchical spatial model of avian abundance with application to Cerulean warblers. Ecological Applications 14:1766–1779.

U.S. Fish and Wildlife Service. 2005. Endangered and threatened wildlife and plants; 2-month finding for petitions to list the greater sage-grouse as threatened or endangered. Federal Register 70:2244-2282.

U.S. Fish and Wildlife Service. 2008. Endangered and threatened wildlife and plants; initiation of status review for the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. Federal Register 73:10218-10219.

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. Federal Register 75:13910-13958.

Walsh, D. P. 2002. Population estimation techniques for Greater Sage-Grouse. M. S. Thesis, Colorado State University, Fort Collins, CO.

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 32:56-68.

Walsh, D. P., J. R. Stiver, G. C. White, T. E. Remington, and A. D. Apa. 2010. Population estimation techniques for lekking species. Journal of Wildlife Management 74:1607-1613.