Greater Sage-Grouse Population Dynamics and Probability of Persistence

Executive Summary
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Approach: We updated an earlier comprehensive analysis of Greater Sage-Grouse (*Centrocercus urophasianus*) population dynamics and probability of persistence (Garton et al. 2011) throughout the species range by accumulating and analyzing additional counts of males from 2008 to 2013 in the 11 states occupied by the species. We 1) assess recent changes (2007-2013) in sage-grouse populations by population and sage-grouse management zone (SMZ); 2) reconstruct population abundance back to 1965; 3) identify the best models of annual population change from 2 trend and 24 density-dependent models; 4) evaluate the probability of persistence of sage-grouse populations; and 5) validate forecasts of future sage-grouse population abundance critical to estimating probability of persistence. We then examine these findings for evidence of stabilizing or increasing populations that could be attributed to recent conservation programs.

Methods: All 11 states occupied by sage-grouse except Colorado contributed data on lek surveys that were combined with earlier data (Garton, et al. 2011:293) to estimate minimum male numbers attending leks throughout the range. A total of 89,749 counts were conducted by biologists and volunteers at 10,060 leks from 1965 through 2013 in 11 states occupied by Greater Sage-Grouse. Leks surveyed in previous years (1965-2007) as well as leks added to the counts or discovered since 2007 were used to reconstruct an index of population abundance ($N(t)$) for each population and SMZ population based on the maximum count of males out of 3 or more surveys in a year at each lek. The population index was estimated from the total number of males counted and the associated standard error from mean counts in 2013, finite rates of change ($\lambda(t)$) and relative sizes of the previous years' populations ($\theta(t)$) in each pair of years using ratio estimators (Garton et al. 2011:301) to extend earlier estimates from 1965 to 2013. Only repeated counts of leks from consecutive years were included in the estimates to insure that they produce unbiased estimates of population size and rates of change. New leks added to the surveys or missed leks were included in estimation once they had been counted in successive years. New leks substantially increased the precision of the most recent estimates of minimum male abundance because of a 50% increase in the number of leks counted in most areas over the last 10 years of surveys. Confidence intervals for the reconstructed populations were calculated from the variance of mean lek counts in 2013 combined with the variances of successive ratios of previous year to current year abundance ($\theta(t)$) as in Garton et al. (2011:302). Thus we began at 2013 and reconstructed population sizes for each population and SMZ back to the earliest lek counts available to us, typically 1965. Finite rates of change ($\lambda(t)$) were transformed to instantaneous rates of change ($r(t)=\ln\lambda(t)$) to model population growth. These estimates provided an index of population abundance from 1965-2013 for modeling changes in population, population projections, and identifying the probability of the species persistence. We modeled sage-grouse population growth by fitting the same suite of 2 trend models and 24 stochastic population growth models as described by Garton et al. (2011:302) to the time series of reconstructed minimum male population indices for each SMZ and population using maximum likelihood methods. We combined the predictions of the best models using information theoretic methods to identify the true patterns of population growth and forecast future carrying capacities and probability of persistence for each population and SMZ.

Results: In spite of survey effort increasing substantially (12.6%) between 2007 and 2013, the reconstructed estimate for minimum number of breeding males in the population, using standard approximations for missing values from Colorado, fell by 56% from109,990 breeding males in 2007 to 48,641 breeding males in 2013. The *best model* of annual rates of change of populations estimated across the Sage-Grouse Management Zones was a stochastic density dependent Gompertz model with a 1-year time lag and a declining carrying capacity through time. This model forecasts *cyclic populations declining through time* exactly as we observed for both the range-wide population and each sage-grouse management zone. There is little support for simple trend models with this best model significantly better at $\alpha<0.001$. Weighted mean estimates of *carrying capacity* for the minimum number of males counted at leks for the entire range-wide distribution, excepting Colorado, were 40,505 (SE 6,444) in 2013 declining to 19,517 (SE 3,269) in 30 years and 8,154 (SE 1,704) in 2113. Starting with the estimated abundance of males counted at leks in 2007 a simple effort to evaluate the *validity* of future forecasts of abundance was conducted by forecasting abundance in 2013 from Gompertz density dependent models with 1-year time lag and declining carrying capacity models of 6 of the 7 management zone populations. Estimated mean abundance in 2013 predicted 95% of the variation in true abundance but overestimated true abundance by 22% suggesting that sage-grouse populations across the range are declining even faster than the best models forecast for this past 6 years. Parametric bootstraps *forecasting future abundance* of each population and SMZ population yielded higher probabilities of the minimum count of males attending leks falling below 20 or 200 compared to earlier projections based on models and parameters estimated in a previous analysis (Garton et al. 2011:293 ff.). Only the Great Plains and Columbia Basin SMZs showed high probability of declining below these levels of abundance but the likelihoods increase for effective population sizes of 50 and 500 for both of these SMZs and long-term (100 year) probability of abundance less than these levels are higher than 50% for the Wyoming Basin and Northern Great Basin in addition to the Great Plains and Columbia Basin SMZs.

Conservation Implications: Every management zone and almost all populations have declined substantially implying that current policies and programs across both public and private land ownerships that are intended to benefit sage-grouse show little current evidence of success, though optimistically we can hope that it is still too early to detect effects of habitat improvement. Clearly more effort will be required to stabilize these declining populations and ensure their continued persistence in the face of ongoing development and habitat modification in the broad sagebrush region of western North America. Application of classic adaptive management would move this process forward substantially but is nowhere in evidence at present.

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Literature Cited: Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2011. Greater sage-grouse population dynamics and probability of persistence. Studies in Avian Biology 38: 293-382.