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Potential effects of GPS transmitters on greater sage-grouse survival in a post-fire landscape

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Rigorous monitoring and evaluation of wildlife population performance because of management or disturbance often relies upon the handling and marking of animals. Such studies must assume that marking animals does not affect their behavior or demography. We examined survival of greater sage-grouse *Centrocercus urophasianus* post wildfire in southeastern Oregon, USA. We observed extremely high mortality rates early in the study and questioned if our global positioning systems (GPS) transmitters were negatively affecting survival of adult greater sage-grouse. Thus, in situ we captured and randomly assigned additional grouse to either a GPS or VHF transmitter and examine patterns of mortality and estimated survival to evaluate if there were in fact transmitter effects on this important vital rate. Our results indicated that regardless of instrument type large wildfire had negative effects on monthly survival the first year after the fire. However, point estimates indicated that greater sage-grouse fitted with GPS transmitters had approximately 5% lower annual survival than VHF tagged birds, but although there was relatively large overlap in confidence limits, likely caused by small sample sizes. Further research is needed to disentangle potential confounding effects of GPS transmitters on survival impacts of grouse in association with large disturbance.

Keywords: Great Basin, Oregon, sagebrush, survival, transmitter effects, wildfire

Estimation of space use and vital rates resulting from large-scale perturbations is important to wildlife conservation. Often, such estimation is the result of capturing and marking individuals with visual marks for subsequent resighting (or recapture) or with telemetry devices for remote tracking of movement and mortality. In either case, estimation of vital rates from these types of data assume that the capture, handling and subsequent marks are neutral to the mortality risk, space use and behavior of individuals. Assessments of radio-marking effects have yielded mixed results on gallinaceous birds with early designs likely having negative demographic consequences (Withey et al. 2001). However, technological advances resulting in improved miniaturization of VHF devices yielded promising patterns of no measurable effect on survival (Thirgood et al. 1995, Hagen et al. 2006). Notwithstanding there is always the potential for other adverse effects (Peniche et al. 2011, Gibson et al. 2013, Fremgen et al. 2017, Blomberg et al. 2018).

Our recent study examining potential acute effects of wildfire on greater sage-grouse *Centrocercus urophasianus* (hereafter sage-grouse) survival and nest success observed some of the lowest estimates of adult female survival yet documented (Connelly et al. 2011, Foster et al. 2018). During the course of fieldwork in spring 2013, we observed very low monthly survival of female sage-grouse that had been tagged with 30-g rump-mounted global positioning system (GPS) platform-terminal transmitters (PTTs). At the time of our study relatively few researchers had utilized this technology for sage-grouse research, and we were thus concerned that our GPS devices may have negatively impacted survival of tagged individuals, as observed in studies of other avian taxa (Barron et al. 2010). Fortunately, we also had a small sample of female sage-grouse fitted with 18-g very-high-frequency (VHF) necklace-design transmitters with which to compare survival estimates. This sample was comprised of birds tagged immediately following the fire (October 2012), and those we tagged in situ during August 2013. Our objectives were to determine if survival of female sage-grouse fitted with GPS-PTTs was equivalent with VHF tagged birds in a post-wildfire landscape.

Study area

Our study occurred in the Trout Creek Mountains of southeastern Oregon (42°12′06.85″N, 118°16′86.11″W), which range in elevation from 1372 m to over 2438 m (Evenden

1989), and are characterized by mesas, buttes and fault blocks cut with deep stream canyons (Carlton 1968). The regional climate is semiarid with an average annual precipitation of 39.7 cm (range 19.7 to 76.5cm across the study area) with the majority of that falling between the months of November and May (1981–2010; PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>, accessed 14 May 2018). Annual precipitation during 2012, 2013 and 2014 was 32.1, 24.3 and 40.5 cm, respectively (PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>, accessed 14 May 2018). Average monthly temperature maximum and minimum were 28°C and –6°C occurring in July and December, respectively (1981–2010; PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>). Common predators of sage-grouse nests or adults in the area included badgers *Taxidea taxus*, common ravens *Corvus corax*, coyotes *Canis latrans*, bobcats *Lynx rufus* and golden eagles *Aquila chrysaetos*.

A lightning strike ignited the Holloway fire in the Trout Creek Mountains on 5 August 2012. The fire occurred approximately 40 km east of Denio, NV, and 210 km southeast of Burns, OR (Karges 2013), and was not fully contained until 25 August 2012. The Holloway fire burned 186 972 ha total, of which 99 352 ha were in southern Malheur and Harney counties, OR, and 87 227 ha were in northern Humboldt County, NV (Karges 2013). Fuel loads, wind speeds and topographic features conducive to fire spread caused the fire to burn intensely in some areas, consuming nearly all vegetation for square kilometers, and resulted in a variable mosaic of burned and intact vegetation in other areas. Within the fire boundary, 75.3% of the land area was burnt, while the remaining 24.7% was comprised of remnant intact habitat patches (Foster et al. 2018).

Methods

Capture and instrument attachment

We captured female sage-grouse during October 2012, and during both spring and summer of 2013 and 2014 using spotlights and long-handled nets (Wakkinen et al. 1992) near leks or roost sites within or near (≤ 2 km) the boundary of the Holloway fire. We used feather patterns and morphology to determine age of captured individuals (Braun and Schroeder 2015). Sage-grouse were classified as either adults (≥2 years of age) or yearlings (1 year of age), and no hatch year individuals were captured during the study. If yearlings survived more than 1 year of the study (the following May), they were reclassified as adults during their second year. We did not evaluate age in our comparison of monthly survival between transmitter types because a previous analysis showed that there were no age differences in survival within transmitter type (Foster 2016). In addition, the ratio of young to adults tagged in each transmitter group was approximately equal over the course of this study (46–61%).

Under the authority of project collaborators, Oregon Dept of Fish and Wildlife, we banded all captured individuals with an individually numbered aluminum leg band. All female sage-grouse captured in October 2012 (n = 12) received 18-g VHF radio-transmitters and a subsequent sample (n =14) was tagged with these units during August 2013 (A4000, ATS Inc., Isanti, MN 55040 USA). VHF transmitters were attached with a PVC covered cable neck collar, and contained a mortality switch which increased signal pulse rate if transmitters had not moved for 12 h. In March–April 2013 and we attached 30-g solar-powered GPS satellite transmitters (Argos/GPS PTT-100, Microwave Telemetry Inc., Columbia, MD 21045 USA; hereafter GPS-PTTs) to 33 females using a rump-mount attachment technique (Rappole and Tipton 1991). An additional 11 and 12 females were tagged with GPS-PTTs in August 2013 and April 2014, respectively. The GPS-PTTs were configured to record locations (± 20 m) six times daily from 1 March – 31 July, four times daily from 1 August – 31 October, and two times daily from 1 November – 29 February. All animal capture, handling and instrument attachment procedures were approved under Oregon State University's Institutional Animal Care and Use Committee.

Survival monitoring

We monitored VHF-tagged individuals monthly using aerial VHF telemetry from October 2012 – May 2013, and from October 2013 – May 2014. We monitored these individuals weekly using handheld VHF telemetry from June – September in 2013 and 2014. Mortality events were considered to have occurred on VHF-tagged birds when we detected the activation of mortality switches. Because detection of VHF-tagged birds varied, we estimated date of death as the midpoint from when the bird was last detected alive to recovery of the transmitter.

We used movement patterns interpreted from the GPS-PTT location data to identify mortality events of tagged females. If the GPS locations for a female remained stationary for >18 h outside of the nesting season we assumed that a mortality event had occurred. After the identification of a possible mortality event, we used the satellite location data to locate the general area of the event site. We located transmitters and specific mortality sites using either grid searches or a UHF receiver. We examined the mortality site and transmitter for signs of depredation or other signs of mortality, such as feathers and bone fragments, predator scat, a sage-grouse carcass, or damage to the transmitter or harness indicative of depredation (e.g. bite marks or scratches). Mortalities of GPS-PTT tagged individuals were only classified as such if we located a transmitter with conclusive signs of depredation or death (e.g. feather piles or bone fragments near transmitters, damage to transmitter or harness). In these cases, we recorded the date of mortality as the last known transmission of data consistent with live sage-grouse movement patterns (i.e. short between-location movement distances).

Analysis

We generated a combined known-fate capture history matrix for monthly survival of all birds carrying instruments from October 2012 – July 2014 (22 monthly intervals). We coded birds into different groups relative to their instrument type. No individuals were tagged with GPS-PTTs until March 2013, thus from November 2012 – February 2013 only

VHF-tagged individuals were available for monitoring. We analyzed survival separately for four periods of interest: the first 12 months (October 2012 – July 2013) following the fire which included the 10 months period of severely reduced survival (AFE; Foster et al. 2018); the five months following initiation of GPS-marking (March 2013 – July 2013), corresponding to the period of AFE during which sage-grouse were tagged with GPS-units; the first complete biological year following the fire (12 months; March 2013 – February 2014); and the final 12 months of monitoring both types of transmitters (August 2014 – July 2015). We used Program MARK to build models and calculate model selection results and parameter estimates (White and Burnham 1999). We used an information-theoretic approach (Burnham and Anderson 2002) and Akaike's information criterion corrected for small sample sizes (AIC_c) to determine the best model(s) supported by the data from a priori model sets generated to represent multiple hypotheses regarding survival of tagged birds. We selected the model with the lowest AIC_c value and highest Akaike weight (w_i) as our best model, but models within 4 AIC_c units of the top model ($\Delta AIC_c \leq 4.0$) were considered informative (Burnham and Anderson 2002, p. 63). When evaluating informative models, particularly those with $\Delta AIC_c \leq 4.0$, we also examined the deviance values to ensure that ΔAIC_c values were not solely a result of adding an additional, uninformative covariate (Arnold 2010). We evaluated the strength of evidence for specific effects in competing models based on the degree to which 95% confidence intervals (95% CI) for slope coefficients (β) overlapped 0 (Dugger et al. 2016). Covariates in competitive models with 95% CI that did not overlap zero were considered to have the strongest evidence of an effect. Covariates in competitive models with ≤10% of the 95% CI overlapping zero ('slightly' overlapping) were considered to have less evidence of an effect compared with covariates with 95% CI that did not overlap zero. Covariates with confidence limits with >10% of the interval above or below zero ('widely' overlapping) were considered to have no support for the importance of the effect. Given the relatively small sample sizes of VHF tagged birds (n < 30), there was the potential for relatively large uncertainty around our estimates. Thus, we used model averaging across the entire model set to estimate monthly survival and derive period survival for each group. Because model averaging uses w_i to generate parameter estimates, those models with little support contributed less to the overall estimates.

Covariates

We investigated the relationship between monthly survival (S) and instrument type (IT) , as well as time since the instrument was attached (time since attachment: TSA). We also investigated an acute effect of the fire (AFE) on monthly survival during the first growing season (October 2012 – July 2013) following Foster et al. (2018). A model with general time effects and an intercept-only model were included for comparison. Time since instrument attachment was coded as a time-varying individual covariate, starting at '1' when a bird was captured and the instrument was attached. This allowed us to investigate the potential acclimation of individuals to an instrument type over time, independent of when a bird was captured (month, season, year) within the time series. We examined interaction effects of temporal structures (i.e. AFE, t) with IT and TSA to account for the potential effect transmitter type over time. For example, it is possible there is a short period after attachment, where transmitters have a negative effect on survival, but after some adjustment period, that effect disappears.

Results

All the models with $\Delta AIC_c \leq 4.0$ contained the acute effects of the fire on monthly survival and these 6 models accounted for 99% of the model weight (Table 1). The top model included only AFE, consistent with a previous analysis where transmitter types were analyzed separately (Foster 2016). Models with additive and interaction effects of transmitter type were competitive, but 95% confidence limits on the beta parameter estimates for transmitter type widely overlapped zero, suggesting the transmitter effect was only weakly supported by the data (Table 1, 2).

For VHF-tagged birds, model-averaged monthly survival was ~9% lower during the 10 months (AFE) immediately following the fire (October–September: $\hat{S} = 0.84$, 95%CI: 0.77 to 0.90) relative to the rest of the time series ($\hat{S} = 0.94$, 95% CI: 0.90 to 0.95). The model averaged derived estimate of survival for VHF-tagged birds during the entire first 12 months post-fire was $\widehat{S_{12}} = 0.164$ (SE = 0.078). Model-averaged derived estimates during the five months post-fire (AFE; 6–10 months post-fire: March–July 2013), when we had data on birds wearing both types of instruments were similar between groups, but the point estimate for VHF-tagged birds ($\widehat{S_5} = 0.428$, SE = 0.102) was slightly higher

Table 1. Model selection results including delta Akaike information criteria corrected for small sample size (ΔAIC_c), AIC_c weights (w_i), number of parameters (k), and model deviance for known-fate models relating monthly survival of female sage-grouse in the Trout Creek Mountains, OR during October 2012 – August 2014, to the type of instrument (IT) they were equipped with (GPS versus VHF), time since instrument was attached (TSA) and acute fire effects (November 2012 – July 2013; AFE; Foster et al. 2018). A model with general time effects (t) and the intercept-only model [S(.)] were included for comparison.

Model	ΔAIC_c	w_i	k	Deviance
S(AFE)	0.00	0.38	2	285.82
S(IT + AFE)	1.14	0.21	3	284.93
S(TSA + AFE)	1.90	0.15	3	285.69
S(IT × AFE)	2.53	0.11	4	284.29
S(IT + TSA + AFE)	2.96	0.09	4	284.72
S(TSA × AFE)	3.71	0.06	4	285.46
S(TSA × t)	9.51	0.00	23	250.92
S(TSA)	10.38	0.00	2	296.19
S(.)	10.46	0.00	1	298.29
S(IT)	10.47	0.00	2	296.28
S(IT + TSA)	10.66	0.00	3	294.45
S(IE + TSA × t)	10.74	0.00	24	249.93
S(IT × TSA)	11.23	0.00	4	292.99
S(TSA + t)	12.91	0.00	23	254.32
S(IT + TSA + t)	13.55	0.00	24	252.75
S(t)	14.80	0.00	22	258.42
S(IT + t)	15.80	0.00	23	257.21
S(AFE + t)	17.01	0.00	23	258.42

Table 2. Model coefficients ($\hat{\beta}$), standard errors (SE), 95% confidence limits (lower: LCL; upper: UCL), and ΔAIC_c from competitive models evaluating the effect of instrument type (IT, where GPS was the reference), time since instrument attachment (TSA), and acute effects of the Holloway fire (October 2012 – July 2013: AFE) on female greater sage-grouse monthly survival in the Trout Creek Mountains, OR, October 2012 – August 2014. Bold denotes 95% confidence limits that do not overlap zero.

Model	$\hat{\beta}$	SE	LCL	UCL
S(AFE)				
Intercept	2.59	0.212	2.18	3.01
AFE	**–0.92**	**0.318**	**–1.54**	**–0.30**
S(IT+AFE)				
Intercept	2.44	0.240	1.97	2.92
IT	0.41	0.347	–0.27	1.09
AFE	**–0.89**	**0.320**	**–1.52**	**–0.26**
S(IT × AFE)				
Intercept	2.34	0.247	1.85	2.82
IT	0.78	0.485	–0.17	1.73
AFE	–0.64	0.382	–1.39	0.10
IT × AFE	–0.83	0.700	–2.21	0.54

than that of GPS-tagged birds ($\widehat{S_5}=0.394$, SE=0.102). This pattern of higher survival of VHF birds held true for the 12 months following the first breeding season (March 2013 – February 2014; VHF: $\widehat{S_{12}}=0.286$, SE=0.083; GPS: $\widehat{S_{12}}=0.246$, SE=0.059), and the final 12 months of monitoring (August 2014 – July 2015; VHF: $\widehat{S_{12}}=0.496$, SE=0.105; GPS: $\widehat{S_{12}}=0.441$, SE=0.095). The annual survival differences between the model-averaged estimates for the two transmitter types were 4% and 5.5% for the first biological year and final 12 months of monitoring, respectively.

Discussion

Our study found that the acute effects of fire on sage-grouse survival transcended any potential instrument affects. Although there was some uncertainty in model selection and parameter estimation, the markedly low survival estimates immediately following the fire for birds wearing both types of instruments were striking. Across the species' distribution, on average annual survival of females ranges between 0.54 and 0.69 (Taylor et al. 2012), which were primarily estimated with necklace style VHF transmitters. Thus, our survival estimates of VHF-tagged individuals during the first full year post-fire were 3.4–4.3 times lower than expected on average for the species and for contemporaneous studies in the Great Basin (Foster et al. 2018). While there was some improvement in survival from Mar 2013 to 2014, regardless of transmitter type it was 2.2–2.8 times lower than expected on average. However, as we examined survival in the final 12 months of our study, survival began to approach estimates within the range of natural variation. Our model averaged estimates indicated that survival of GPS-tagged birds was ~5% lower than VHF tagged birds overall, but the uncertainty around these estimates render these differences equivocal. If these point estimates are reflective of truth, a 5% change in female survival is of concern as this difference can measurably affect population growth rates (Taylor et al. 2012, Dahlgren et al. 2016).

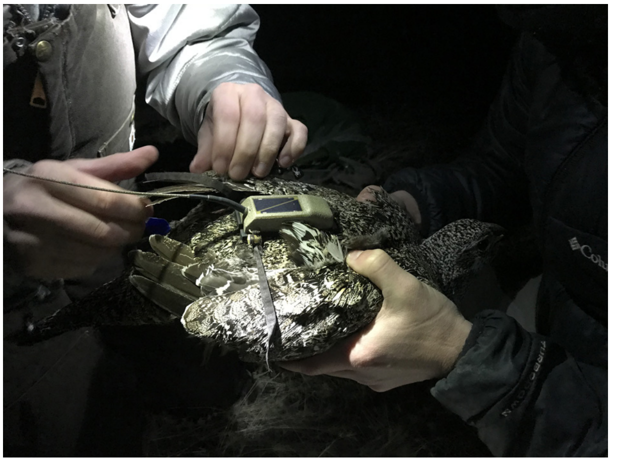

Figure 1. Female sage-grouse during attachment of GPS-PTT, Malheur County, OR, 2017.

Small sample sizes, exacerbated by the effect of the fire on survival for both instrument groups, did not allow us to disentangle these observed survival patterns relative to instrument type. However, we speculate that it is plausible the larger platform of the GPS-PTTs, or their dorsal solar panel may have increased the visibility of sage-grouse to predators (Fig. 1; Burger et al. 1991). This increased visibility could have been exacerbated in the highly disturbed landscape with little to no vegetative cover immediately following the fire, but we observed little support for an interaction between instrument type and the acute fire affect (AFE). We also cannot exclude the possibility that these devices may affect the mechanics of flight or other movement by birds (Gibson et al. 2013, Fremgen et al. 2017). The assumption that telemetry devices attached to animals do not influence their demographic rates or behavior is key to any study making use of these devices. However, this assumption has been called into question by ornithologists for almost the entire period that these devices have been used, and the type and magnitude of bias associated with telemetry devices varies according to both device type, and bird attributes (Barron et al. 2010). The effect of necklace style VHF radio-transmitters on survival and behavior of galliformes has been equivocal in the literature, with studies indicating no effect of VHF-transmitters (Thirgood et al. 1995, Hagen et al. 2006), and others indicating negative effects (Bro et al. 1999, Gibson et al. 2013, Fremgen et al. 2017). Given the increasing use of GPS-PTTs for the study of grouse demographic rates and behavior in recent years, it is critical to understand how this new technology influences the attributes it is used to study. If further studies also indicate potential negative effects of the technology further work should be conducted to understand the specific mechanisms underlying these effects, so that they can be mitigated through altered device design or attachment methods.

We were encouraged by our in situ sampling to identify only small potential effects of the GPS transmitters on survival, albeit there could be biological consequences on overall population growth rate. As this study has continued, we have observed annual survival of GPS tagged birds return to what one would expect on average (0.54–0.69) (Hagen and Dugger unpubl.). The goal of our paper was to provide insights on an important aspect of marking sage-grouse (or other galliformes) with these relatively large devices that have the potential to make a bird more conspicuous as they move through the landscape. Thus, more work is needed to disentangle potential effects of these marks on sage-grouse and other gallinaceous birds.

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