Supplemental Material

Winter wolf minimum population and accumulated wolf pack range

To calculate the accumulated wolf pack area (km^2) we used the shape files of wolf pack territories for a given year provided by the Wisconsin Department of Natural Resources (WDNR) and summed their total area (Figure 1). To demonstrate the changes in wolf population over time we used the winter minimum wolf count from the WDNR (Figure 1). The WDNR uses aerial telemetry to monitor a proportion of the wolf packs in the state, and for the remaining wolves the WDNR uses track surveys and public reports of wolf activity to determine wolf pack territory boundaries and to determine the winter minimum wolf count (Wydeven et al. 2009).

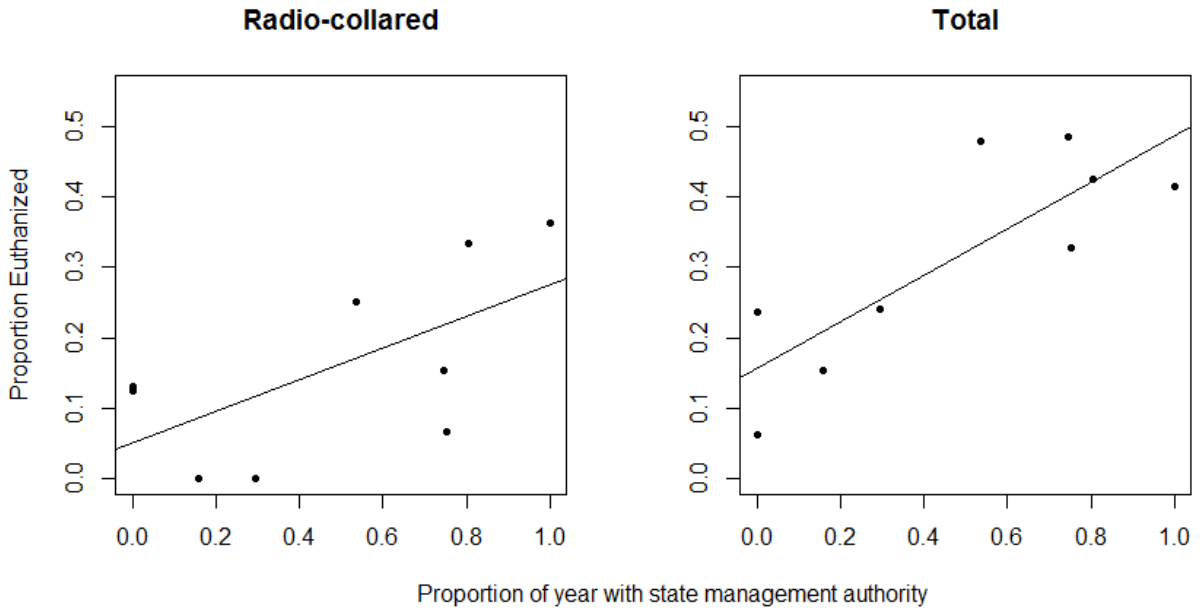
Negative interactions

In Wisconsin, the USDA APHIS WS received, investigated, and verified wolf-human conflict complaints since 1995 (*see* Ruid et al. 2009 for the verification process). Prior to 1995, the WDNR investigated and verified complaints of wolf-human conflict. Based on field investigations, agency personnel classified incidents as unverified, probable, or confirmed wolf conflicts (Ruid et al. 2009). We examined only verified (probable or confirmed) incidents of wolf conflict and we normalized the number of verified incidents in a given year by wolf range (i.e., accumulated area of wolf pack territories; Figure 2; see Olson 2013 for more details) and the minimum winter wolf count (Figure 2) for 1980-2011. Using R 3.0.1 we then fit both linear and quadratic lines to data. We tested for significance between the models using an analysis of variance. The quadratic fit was significantly better for both incidents per wolf range (P=0.035) and incidents per wolf (P=0.058).

Lethal control for depredating wolves

Throughout wolf recovery in Wisconsin, the State had management authority to control for wolves posing a human health and safety threat. However, the State's authority to control depredating wolves or issue landowner permits for proactive control was repeatedly gained and

lost throughout the sociopolitical conflict over wolves between 2003 and present. We examined the proportion of known annual mortality (all detected dead wolves) for radio-collared wolves and for all wolves for 2003 to 2012. The WDNR collars and tracks a proportion of the wolf population using aerial telemetry (*see* Wydeven et al. 2009).



Supplemental Material Figure 1. Proportion of known annual mortality (2003-2012) for radio-collared wolves (P=0.067, Adjusted R^2= 0.31) and all wolves (total; P<0.006, Adjusted R^2= 0.63) from euthanasia, by proportion of the year with state management authority to control depredating wolves, for Wisconsin, USA.

The radio collars (VHF) used by the WDNR send out a mortality signal that can then be used by field staff to locate, investigate, and collect the dead wolf. A proportion of wolf mortalities are then necropsied to determine the official cause of death, followed by further investigation if warranted. Detection of mortality signals from collars is less biased for certain mortality types (i.e., vehicle kill), but may be biased against euthanized wolves because most wolves are radio-collared on public lands where majority of the most favorable wolf habitat occurs (Mladenoff et al. 2009; Stenglein 2014). We examined the proportion of known annual mortality for both the

radio-collared wolves and all wolves from euthanasia by proportion of year (% of days) with state management authority to control for depredating wolves. The proportion of annual mortality for radio-collared wolves (P=0.067, Adjusted R^2= 0.31) and all wolves (P<0.006, Adjusted R^2= 0.63) from euthanasia was significantly correlated to the proportion of the year with state management authority (Supplemental Material Figure 1). *Note*: Some years the state had no management authority to control for depredating wolves, but did have authority to control for wolves that were considered a health and human safety threat. This explains why in some years with no management authority there was a proportion of mortality associated with euthanized wolves.

Illegal killing of wolves in relation to management authority

We examined the relationship between the proportion of the year with state management authority and the contribution of illegal killing to the radio-collared and total wolf mortality. We used known annual wolf mortality data from the WDNR (Wydeven et al. 2009, 2011, 2012) for 2003 to 2011, (n=9) which corresponds with the period of sociopolitical conflict. Because we expected that some cryptic poaching had occurred (Liberg et al. 2012) we assumed that the proportion of the known wolf mortality attributed to illegal kills for the total population could possibly be biased (Stenglein 2014). Therefore, we examined the proportion of the known wolf mortality attributed to illegal kills for both the radio-collared wolves and all wolves. We also knew that lethal control for depredating wolves, which was significantly correlated to the proportion of the year with state management authority (Supplemental Material Figure 1), would also bias findings by increasing the proportion of non-illegal kill mortality in each sample during years with state management authority. We therefore removed euthanized wolf mortalities from the mortality total for both populations, essentially correcting for this confounding effect, and we present the results of the corrected data. We used linear regression to test the correlation between

the proportion of the year with state management authority and the proportion of known wolf mortality attributed to illegal kills for radio-collared (i.e., illegally killed radio-collared wolves / [all recovered dead radio-collared wolves – lethally killed radio-collared wolves]) and all wolves (i.e., illegally killed wolves / [all recovered dead wolves – lethally killed wolves]), separately. Proportion of the annual mortality for radio-collared wolves ($P<0.009$, Adjusted $R^2=0.59$) and all wolves ($P<0.08$, Adjusted $R^2=0.28$) attributed to illegal killing had a significant inverse relationship to the proportion of the year with state management authority to control depredating wolves (Figure 3).

In addition, we examined the proportion of the radio-collared wolves illegally killed each year (i.e., illegally killed radio-collared wolves / number of wolves radio-collared) in relation to the proportion of the year with state management authority to use lethal control on depredating wolves. We chose to limit this analysis to radio-collared wolves only, because of the biases associated with detecting illegally killed non-collared wolves (Stenglein 2014). Furthermore, we knew the exact number of radio-collared wolves on the landscape throughout each year. The proportion of radio-collared wolves illegally killed was inversely related to the proportion of the year with state management authority ($P<0.01$, Adjusted $R^2=0.76$).

Further, we examined the probability of a radio-collared or non-collared dead wolf being illegally killed as it relates to the pendulum of lethal control action and no lethal control for depredating wolves. We used a logistic regression analysis to examine the probability of radio-collared and non-collared wolves being illegally killed using *season* (winter: Oct – Mar, summer: Apr – Sept), *region* (northern forest, central forest, the rest of Wisconsin), and a number of predictor variables representing various aspects of lethal control. Wolf carcasses were the response (0 as not illegally killed, and 1 as illegally killed) and potential covariates dealing with

lethal control management were, 1) the status of lethal control management at the time the wolf carcass was found (*lethal control*), 2) the cumulative number of lethally controlled wolves since the last change in management (*cumulative number*), 3) the number of times there had been a switch in management since 2003 (*switch number*), 4) defining the winter season as either having lethal control in the prior summer (April to September) or not (*prev.season*), and 5) whether the cumulative number of lethally controlled wolves since the last change in management was >10 (*count10*). We used Akaike Information Criteria (AIC) to evaluate and rank potential models.

For the radio-collared dataset, the models that distinguished winter seasons with and without lethal control the previous summer had lower AIC values than all other models that used *season* instead of *prev.season* (Supplemental Material Table 1). Overall, the best model was *prev.season + region*, but an ANOVA table showed that region was not significant (P=0.17). The model with just *prev.season* was just as good as the two variable model (Likelihood ratio test, P=0.51). Therefore, we used *prev.season* (P<0.01) as the only covariate for the radio-collared dataset. This model suggests that there is a significantly higher risk of dead radio-collared wolves being the result of illegal killing in winters following summers with no lethal control action (Supplemental Material Fig. 2). The predicted probability that a dead radio-collared wolf was illegally killed in a winter following no lethal control was double the probability in summer or winter following lethal control.

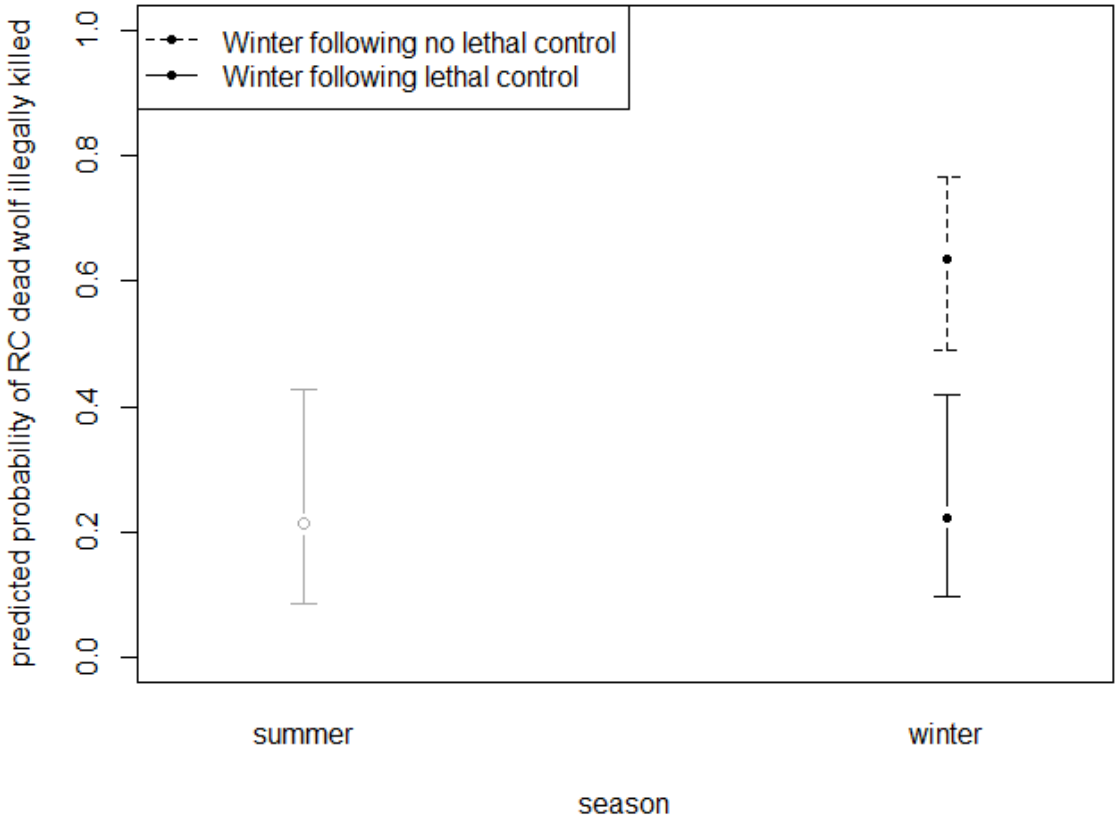
For the non-collared dataset, the models which included covariates *season + region* and *prev.season + region* were the ranked as the best models (Supplemental Material Table 1). We chose to use the model with *prev.season + region* because this was the best model based on AIC and we could compare the *prev.season* effect to the radio-collared dataset. In this model both

prev.season ($P<0.01$) and *region* were highly significant ($P<0.01$). The central forest and the rest of Wisconsin (non-northern forest) shared a higher predicted probability for a dead non-collared wolf being the result of illegal killing in summer and winter (Supplemental Material Fig. 3). Across all regions, the predicted probability that a dead non-collared wolf was illegally killed in a winter following no lethal control was 1.3 to 1.4 times that of when there was lethal control (Supplemental Material Fig. 3).

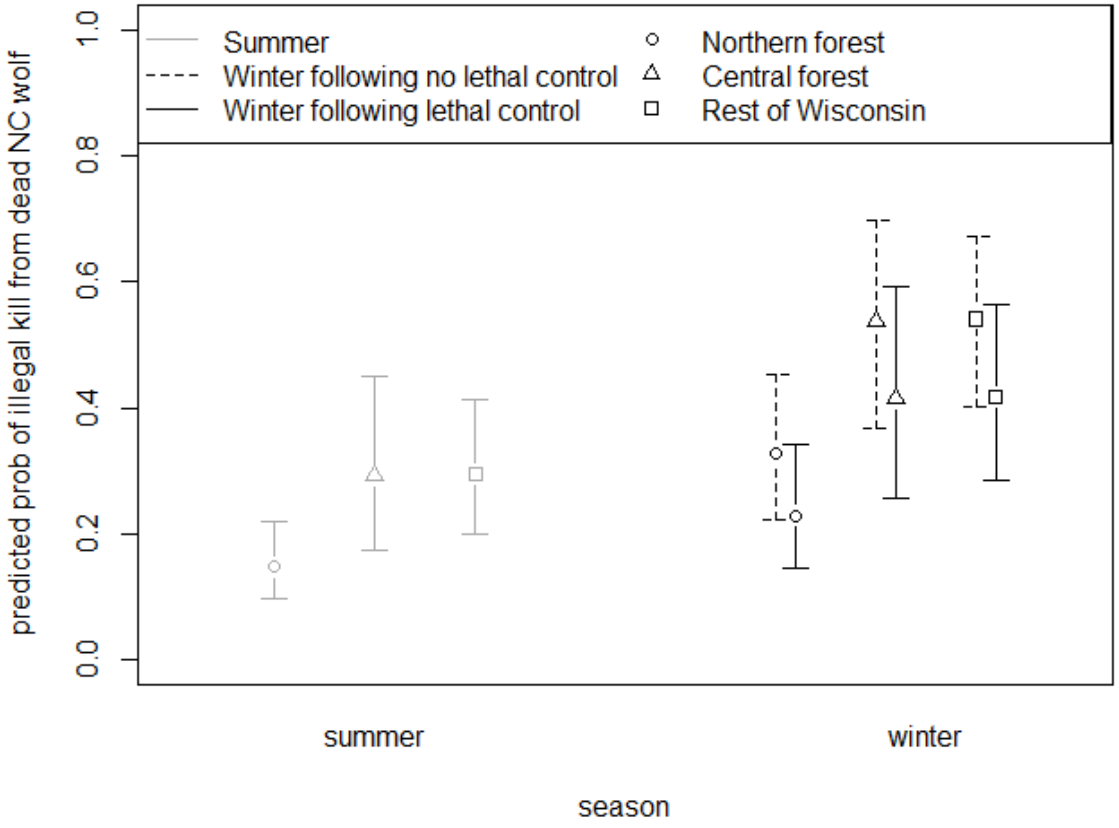
Supplemental Material Table 1. Akaike Information Criteria (AIC) values for ten logistic regression models run with the radio-collared (RC) dead wolf dataset and the non-collared (NC) dead wolf dataset as predicted by *season*, *region*, and some measure of lethal control (see text for a description of covariates).

Model covariates	**AIC - RC dataset**	**AIC - NC dataset**
season + region	140.8	361.7*
season + region + lethal control	138.9	363.6
season + region + cumulative number	141.1	363.5
season + region + switch number	140.7	363.7
season + region + count10	139.9	363.7
prev.season + region	137.5*	361.5*
prev.season + region + lethal control	138.6	363.2
prev.season + region + cumulative number	139.5	363.4
prev.season + region + switch number	139.3	363.0
prev.season + region + count10	138.6	369.9

***** indicates best models according to AIC.



Supplemental Material Figure 2. The predicted probability of a dead radio-collared (RC) wolf being the result of illegal killing in summer and in winters following no lethal control in summer (April to September) or following lethal control during that period, for Wisconsin, USA, from 2003 to 2011.



Supplemental Material Figure 3. The predicted probability of a dead non-collared (NC) wolf being the result of illegal killing in summer and in winters following no lethal control in summer (April to September) or following lethal control during that period for the northern forest, central forest, or all other parts of Wisconsin, USA, from 2003 to 2011.

Illegal killing versus lethal control

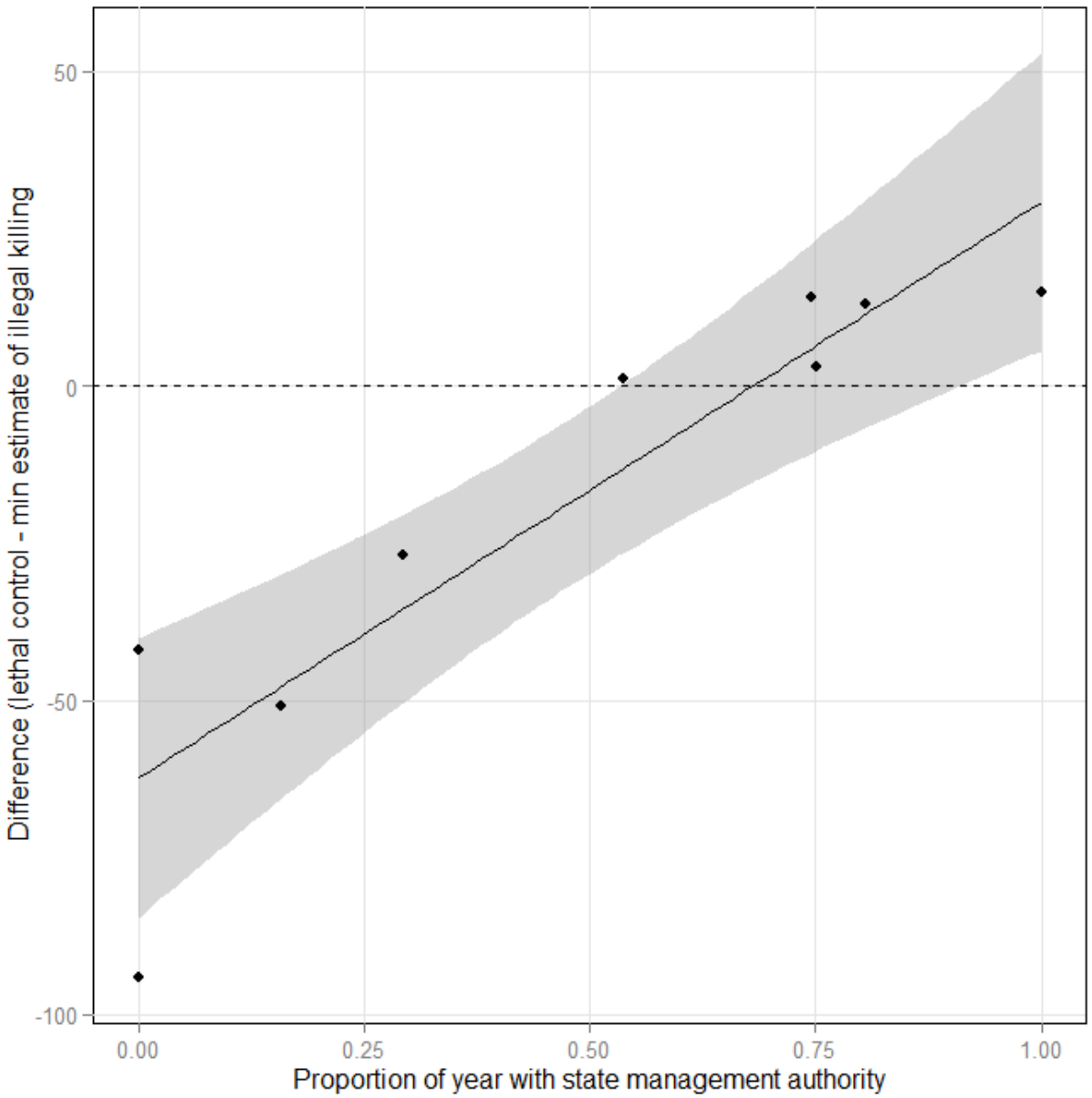
We also examined how the two types of mortality, illegal killing and lethal control, compared to one another in terms of the number of wolves killed. Due to biases associated with wolf mortality data we compared the total number of wolves killed from lethal control each year to the proportion of radio-collared wolves illegally killed that year multiplied by the minimum winter wolf count for that year. Undoubtedly the proportion of radio-collared wolves illegally killed is biased low because: 1) poachers may avoid killing animals fitted with radio-collars (Jacques et al. 2011), and because illegal kill rates among collared wolves was most indicative of illegal kill rates of wolves 1+ years of age because few pups were collared. Researchers have also determined that additional unobserved mortality is needed to reconcile the observed mortality with population growth rates, and some of that unobserved mortality is likely illegal killing (Liberg 2012; Stenglein 2014). Thus, our estimate is a minimum estimate. Throughout the study period (2003-2011) 222 wolves were legally killed while a *minimum* of 390 wolves are *estimated* to have been illegally killed (Supplemental Material Table 2). Because we were interested how the two types of mortality related to one another over time, we plotted the *difference* between the two types of mortality (lethal control minus min estimate of illegally killed wolves) against proportion of the year with state management authority for lethal control (Supplemental Material Fig. 4). The *difference* was significantly correlated to proportion of the year with state management authority (n=9, P<0.0007, Adjusted R^2=0.80). While fewer years fall below the horizontal line (years were more wolves died from illegal killing than lethal control), the difference, in terms of the number of wolves killed, was stark for those above and those below the line. When the state had management authority for less than half of the year more wolves died from illegal killing than lethal control (*difference* ranged from -27 to -94; mean= -53.5). However, when the state had management authority for at least half a year the *difference* was

less (*difference* ranged from 1 to 15; mean of 9.2; Supplemental Material Table 2; Supplemental Material Fig. 4).

Supplemental Material Table 2. Comparison of two types of mortality: 1) wolves killed for wildlife conflict management purposes (lethal control) and 2) a minimum estimate of illegal kills based on the proportion of radio-collared wolves illegally killed multiplied by the winter minimum wolf count for that year given year.

Year	Lethal control	Minimum estimate of illegal kill*	Difference**
2003	17	14	3
2004	29	14	15
2005	35	34	1
2006	18	45	-27
2007	42	29	13
2008	47	33	14
2009	11	62	-51
2010	18	60	-42
2011	5	99	-94
sum	222	390	-168
mean	24.66667	43.33333	-18.6667

* Minimum estimate of illegal kill = proportion of radio-collared wolves illegally killed * winter minimum wolf count. Poachers may avoid wolves with collars, illegal kill rates are not representative of pup illegal kill rates, and additional unobserved mortality is required to reconcile observed mortality with population growth rates – thus, a minimum estimate.
**Difference = Lethal control – Min. est. of illegal kill, negative values indicate more wolves dying from illegal killing.



Supplemental Material Figure 4. Difference between the numbers of wolves killed by lethal control minus those that died of illegal killing* plotted against the proportion of the year with state management authority. Points below the dashed horizontal line are years where more wolves died of illegal killing than lethal control. *Minimum estimate of illegal kill = proportion of radio-collared wolves illegally killed multiplied by the winter minimum wolf count for a given year. Poachers may avoid wolves with collars, illegal kill rates are not representative of pup illegal kill rates, and additional unobserved mortality is required to reconcile observed mortality with population growth rates – thus, a minimum estimate.

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